Court of Appeal File No.: C65807

COURT OF APPEAL FOR ONTARIO

IN THE MATTER OF A REFERENCE to the Court of Appeal pursuant to section 8 of the *Courts of Justice Act*, RSO 1990, c. C.34, by Order-in-Council 1014/2018 respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act, 2018, No. 1*, SC 2018, c. 12

RECORD OF THE ATTORNEY GENERAL OF CANADA
Volume 1 of 4

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RECORD OF THE ATTORNEY GENERAL OF CANADA

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AFFIDAVIT OF JOHN MOFFET
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FILED ON BEHALF OF THE ATTORNEY GENERAL OF CANADA

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IN THE MATTER OF A REFERENCE to the Court of Appeal pursuant to section 8 of the *Courts of Justice Act*, RSO 1990, c. C.34, by Order-in-Council 1014/2018 respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act, 2018, No. 1*, SC 2018, c. 12

AFFIDAVIT OF JOHN MOFFET

I, John Moffet, of the City of Ottawa, in the Province of Ontario, MAKE OATH AND SAY THAT:

1. I am the Assistant Deputy Minister (ADM) with Environment and Climate Change Canada (ECCC), responsible for the Environmental Protection Branch of ECCC. I have been employed with ECCC since 2006. I was appointed as ADM in July 2018. In this position, I oversee the development and implementation of many of ECCC's environmental protection measures. This includes carbon pricing[1] and the complementary greenhouse gas (GHG) mitigation regulations identified in the *Pan-Canadian Framework on Clean Growth and Climate Change* ("*Pan-Canadian Framework*") for which ECCC is responsible.

2. Immediately prior to my appointment as ADM, I was the Associate ADM of the Environmental Protection Branch of ECCC from March 2017, and the Director General of the Legislative and Regulatory Affairs Directorate, in the Environmental Protection Branch of ECCC from March 2007. In these positions, I was ECCC's lead on many of the Government of Canada's GHG mitigation initiatives, including carbon pricing. In 2016, I was the federal representative on the Federal-Provincial-Territorial Working Group on Carbon Pricing Mechanisms, and I led both the development of the *Pan-Canadian approach to pricing carbon pollution* and the development of the chapter on carbon pricing in the *Pan-Canadian Framework*, all of which is described in detail later in my affidavit. After the development of

[1] Pricing for greenhouse gas (GHG) emissions is typically referred to as "carbon pricing" even though pricing applies to a range of GHG emissions. This nomenclature reflects the dominant role of carbon dioxide (CO_2) in total GHG effects and the practice of equating emissions of various GHGs on a CO_2 equivalent basis. These concepts are explained in my affidavit.

the *Pan-Canadian Framework*, I led the development of the federal GHG emissions pricing system, including development of the *Greenhouse Gas Pollution Pricing Act*. I also led the work by the Government of Canada to help provinces and territories understand the pan-Canadian approach to pricing carbon and to develop their own pricing systems.

3. In addition to my work on carbon pricing in support of the *Pan-Canadian Framework*, as Associate ADM and ADM I lead the development and implementation of all of ECCC's other GHG emissions regulations, which are described later in my affidavit. Prior to my work in support of the *Pan-Canadian Framework*, I led the development of various past Government of Canada initiatives related to carbon pricing, including cap and trade and other mechanisms under various proposed GHG emissions mitigation policies between 2008 and 2015.

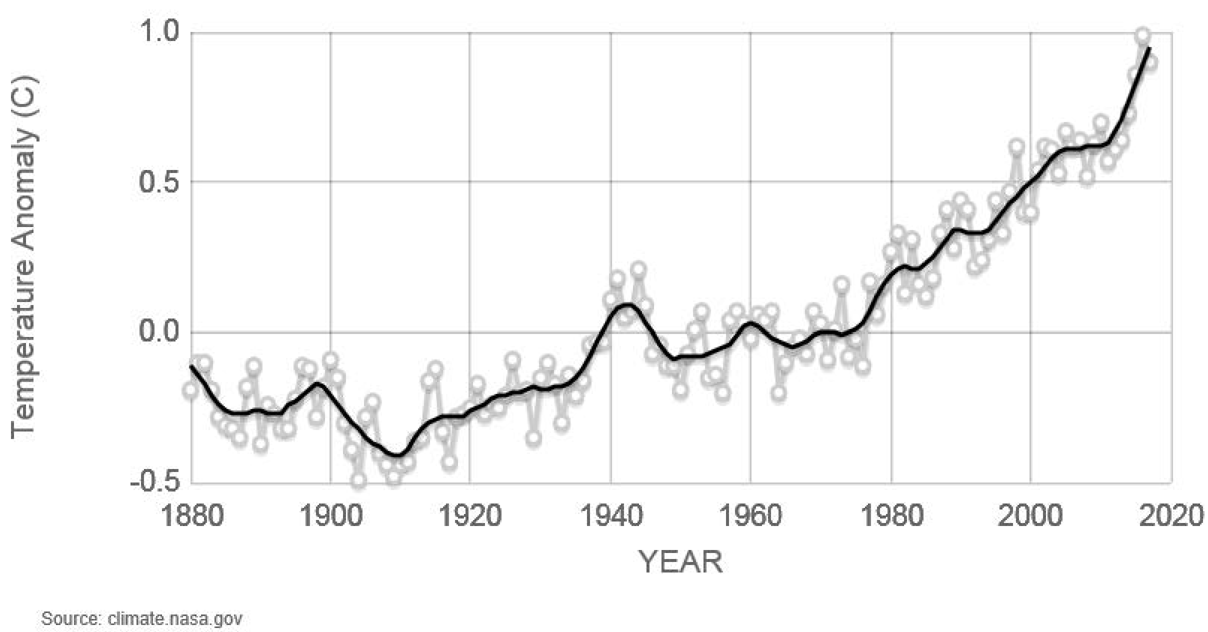
4. Beyond my direct involvement in developing federal carbon pricing systems and other GHG emissions mitigation efforts, as a result of my various positions with ECCC, I also have knowledge of scientific, technical, and socio-economic research related to climate change and its impacts, including its impacts in Canada.

5. Prior to my employment with ECCC, I worked as a consultant focusing on environmental law and policy issues from 1993 to 2005. As a consultant, much of my work focused on developing understanding of and support for the use of economic instruments for environmental protection, of which GHG emissions pricing is an example. I earned a Bachelor of Arts degree in English and Philosophy from the Royal Military College in 1982 and a Bachelor of Laws degree from the University of Toronto in 1985. I then earned a Masters of Public Policy from the University of California, Berkeley Campus in 1991. I also completed the comprehensive examinations towards earning a Doctor of Philosophy in Public Policy at Carleton University, School of Public Administration in 1993, but did not complete the dissertation necessary to earn a PhD. My graduate work focused on environmental policy.

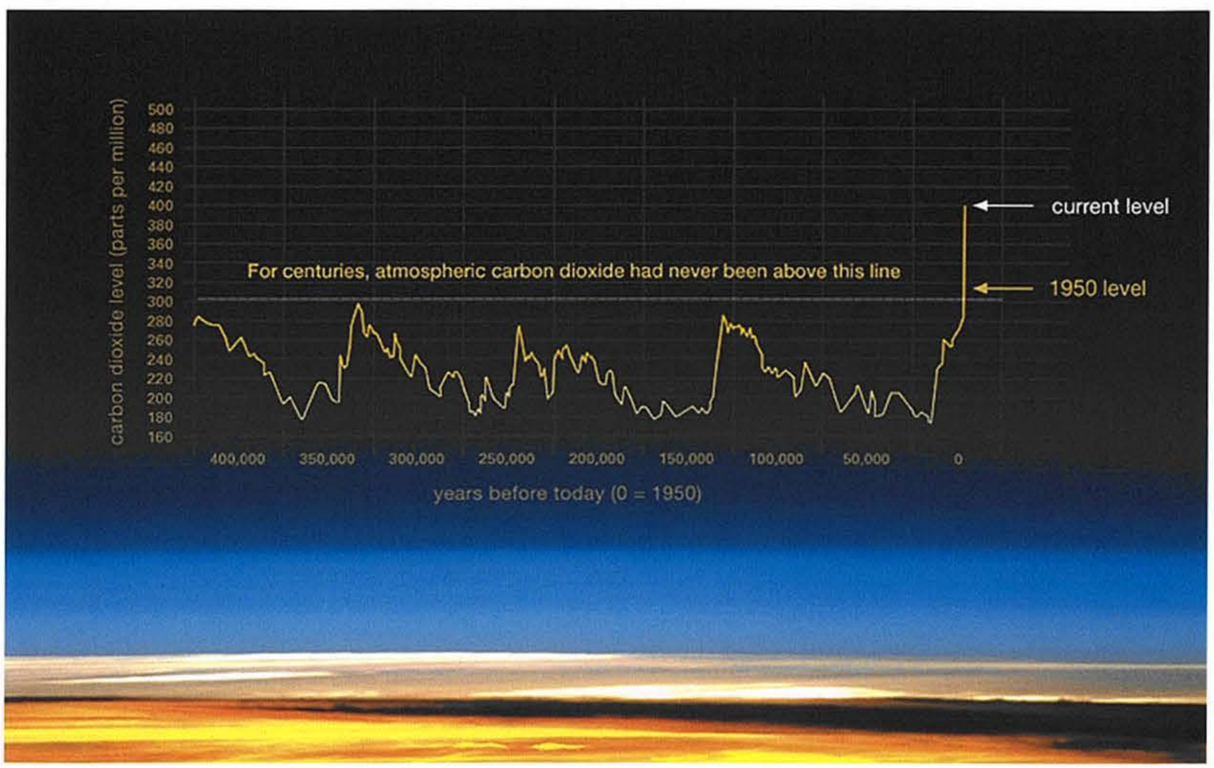
Climate change and its impacts

6. Global climate change is real, measured, and documented. Climate change is not a far-off problem. It is happening now and is having very real consequences on people's lives. Its impacts will get more significant over time.

7. Climate records reviewed by the National Aeronautics and Space Administration (NASA) show that 2017 marked the 41st consecutive year with global temperatures at least marginally above the 1951-1980 average temperatures (being the baseline comparator used by NASA). Seventeen of the 18 warmest years in the 136-year record have all occurred since 2001, with the 18th being in 1998. The past four years (2014-2017) are the hottest four years on record, with 2016 being the hottest. Preliminary data released by the Copernicus Climate Change Service, a service of the European Union's Earth observation program, shows that 2018 was the fourth warmest year on record. If this data is confirmed, then the past five years (2014-2018) will be the hottest 5 years on record. The following graph, prepared by NASA and retrieved from https://climate.nasa.gov/vital-signs/global-temperature/, illustrates the change in global surface temperature relative to 1951-1980 average temperatures.



8. The combustion of fossil fuels emits GHGs into the atmosphere, which enables global climate change. The scientific properties of GHGs, of which carbon dioxide (CO_2) is the most prevalent, and the role they play in global climate change are well established. Simply stated, when the sun's rays reflect off the surface of the earth, GHGs trap some of this reflected solar energy in the atmosphere instead of letting it escape outward. Given their role in global climate change, GHG emissions create a risk of harm to both human health and the environment upon which life depends. The impacts are global, and throughout Canada, and are not correlated to the location of the GHG emission source. GHG emissions circulate in the atmosphere, so emissions anywhere raise atmospheric concentration everywhere. Atmospheric GHG concentrations are fairly uniform around the globe and are higher than they have been at any time in the past 400,000 years. As NASA has graphed, prior to 1950, atmospheric concentrations of CO_2 had never been above 300 parts per million (ppm). Current concentrations have reached 400 ppm, and are still climbing. The following graph, prepared by NASA and retrieved from https://climate.nasa.gov/climate_resources/24/graphic-the-relentless-rise-of-carbon-dioxide/, illustrates historic and current levels of atmospheric CO_2.



9. The World Meteorological Organization ("WMO") publishes an annual Statement on the State of the Global Climate. The WMO is a specialized agency of the United Nations whose mandate covers weather, climate, and water resources. The most recent *WMO Statement on the State of the Global Climate in 2017* is an authoritative statement of the scientific information on the current state of key climate indicators and their changes over time. Among other things, it reports that, in 2017 "global ocean heat content change" and "global mean sea-level change since 1993" were the highest on record. The *WMO Statement on the State of the Global Climate in 2017* is attached as Exhibit "A" to my affidavit.

10. The existing and anticipated global impacts of climate change are well documented. For example, the introduction in the *United Nations Framework Convention on Climate Change* ("*UNFCCC*") secretariat's 2007 publication *Climate Change: Impacts, Vulnerabilities, and Adaptation in Developing Countries* notes that, "[o]ver the next decades, it is predicted that billions of people, particularly those in developing countries, face shortages of water and food and greater risks to health and life as a result of climate change." *Climate Change: Impacts, Vulnerabilities, and Adaptation in Developing Countries* is attached as Exhibit "B" to my affidavit.

11. Climate change impacts are most comprehensively and authoritatively documented by the Intergovernmental Panel on Climate Change (IPCC). The IPCC was established in 1988 by the United Nations Environment Programme and the WMO to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. The IPCC is the leading world body for assessing the most recent scientific, technical, and socio-economic information produced worldwide relevant to understanding climate change, its impacts and potential future risks, and possible response options.

12. Until October 2018, the IPCC's most recent publication was its 2014 *Fifth Assessment Report*. As the final part of the IPCC's *Fifth Assessment Report*, the *Synthesis Report* provides an integrated view of climate change. The IPCC also prepared a *Summary for Policy Makers* of the *Synthesis Report*. In the *Summary for Policy Makers*, the IPCC notes that human influence on the climate system is clear. It states that "the evidence for human influence on the

climate system has grown since the IPCC Fourth Assessment Report (AR4). It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by anthropogenic increase in GHG concentrations and other anthropogenic forcings" (p. 5). The *Summary for Policy Makers* of the IPCC's *Synthesis Report* is attached as Exhibit "C" to my affidavit.

13. On October 8, 2018, the IPCC released its *Special Report on Global Warming of 1.5°C*. The *Special Report* emphasized the growing urgency of action to reduce GHG emissions and the importance of action in all sectors. With over 6,000 scientific references and the input of thousands of expert reviewers worldwide, the *Special Report* presents the results of a broad-based scientific consensus.

14. The *Special Report* explains that global human-induced warming has already reached about 1°C and, if the current warming rate continues, the world would reach human-induced global warming of 1.5°C around 2040. It also explains that the world is already experiencing the consequences of 1°C warming through more extreme weather, rising sea levels, and diminishing Arctic sea ice and identifies the numerous climate change impacts that could be avoided by limiting global warming to 1.5°C compared to 2°C, or more. For instance, by 2100, global sea level rise would be 0.1 meter (10 cm) lower with global warming of 1.5°C compared with 2°C. A 10 cm reduction in sea level rise could prevent risks to about 10 million people globally. The likelihood of an Arctic Ocean free of sea ice in summer would be once per century with global warming of 1.5°C compared with at least once per decade with 2°C. Coral reefs would decline by 70-90% with global warming of 1.5°C, whereas virtually all (> 99 %) would be lost with 2°C. Similarly, limiting global warming to 1.5°C compared to 2°C could prevent the thawing of up to 2.5 million km^2 of permafrost, which provides habitat for numerous species and services such as solid foundations for housing and winter roads. Any increase in global warming is also projected to affect human health, including increased heat-related and ozone-related morbidity and mortality. Limiting global warming would also give people and ecosystems more room to adapt. Notably, Arctic areas, including in northern Canada, are among the regions facing disproportionately higher risk from global warming. With these clear benefits to people and ecosystems, the *Special Report* concludes that limiting global warming

to 1.5°C compared to 2°C could go hand in hand with ensuring a more sustainable and equitable society.

15. The *Special Report* also emphasizes both the urgency and the breadth of action needed. It finds that limiting global warming to 1.5°C would require "rapid and far-reaching" transitions in land, energy, industry, buildings, transport, and cities. Global net human-caused emissions of CO_2 would need to fall by about 45% from 2010 levels by 2030, and reach 'net zero' around 2050. Actions to reduce other GHG emissions are also needed. To achieve those goals, the decisions we make today are critical to ensure a safe and sustainable world for everyone, both now and in the future. At the Press Conference held for the release of the *Special Report*, Debra Roberts, Co-Chair of IPCC Working Group II, said "[t]he next few years are probably the most important in our history". The *Summary for Policy Makers* of the IPCC's *Special Report on Global Warming of 1.5˚C* is attached as Exhibit "D" to my affidavit and the IPCC's "Frequently Ask Questions" document that was released concurrently is attached as Exhibit "E" to my affidavit. The entire report is available online at http://www.ipcc.ch/report/sr15/.

16. The North Atlantic Treaty Organization ("NATO") Economics and Security Committee has also published a recent report, entitled *Assessing and Mitigating the Cost of Climate Change*. NATO, also called the North Atlantic Alliance, is an intergovernmental military alliance between 29 North American and European countries. In addition to reviewing a range of climate change impacts, NATO's report discusses climate change and security, starting at page 7 of the report. In this section, NATO's report states that climate change could "be a factor in triggering violent conflicts linked to declining food production, water shortages or economic crises linked to the phenomena" then elaborates on this risk. A copy of NATO's *Assessing and Mitigating the Cost of Climate Change* report is attached as Exhibit "F" to my affidavit.

17. Climate change impacts in Canada are discussed in the context of Canada's reporting requirements under the *UNFCCC*. In 2017, the Minister of ECCC submitted *Canada's 7th National Communication on Climate Change* and *3rd Biennial Report* to meet Canada's reporting requirements. These documents were prepared by ECCC officials with significant input from experts across Canada and from provinces and territories. Chapter 6 of *Canada's 7th National Communication*, entitled "Vulnerability Assessment, Climate Change Impacts and

Adaptation Measures" includes detailed climate modelling, projections, and scenarios, and an assessment of risk and vulnerability to climate change impacts for Canada. Chapter 6 of *Canada's 7th National Communication* is attached as Exhibit "G" to my affidavit.

18. Climate change is having a particularly significant impact in Canada. Some of these existing and anticipated impacts of climate change include changes in extreme weather events, degradation of soil and water resources, increased frequency and severity of heat waves, which may lead to an increase in illness and death, and expansion of the ranges of potentially life-threatening vector-borne diseases, like Lyme disease and West-Nile virus.

19. Canada will also face impacts from increased global unrest caused by climate change. Sea level rise will lead to inundation of coasts worldwide, with some small island States possibly facing complete inundation. The impacts of inundation in low elevation countries in southerly locations (i.e. Bangladesh, Pakistan, Indonesia, etc.), as well as drought, desertification, and food shortages in other places, will lead to increasing regional tensions that are likely to trigger increased migration pressures on countries like Canada.

20. While climate change encapsulates far more than warming temperatures, it is significant that temperatures in Canada have been increasing at roughly double the average global rate, with average temperatures in Canada having already increased by 1.7°C since 1948. Warming has been observed across most of Canada, with stronger trends in the North and West, and in winter and spring. In the Canadian Arctic, average temperature has increased at a rate of nearly three times the global average. Annual average precipitation has also changed in Canada with most of the country (particularly the North) having experienced an increase in precipitation since the mid-20th century. See Exhibit G (p 178) for additional details.

21. Predictions show that Canada's temperature will continue to warm at a faster rate than the world as a whole. The strongest warming is projected for winter and for northerly latitudes. Precipitation levels are also expected to rise overall, with strong regional and seasonal variability. Relative precipitation increases are predicted to be larger in the North and in the winter. Associated with these trends in average temperature and precipitation are projected

increases in daily hot extremes and heavy rainfall events, and declines in snow and ice cover. See Exhibit G (pp 178-181) for additional details.

22. Warming temperatures are causing a changing, less predictable, and more volatile climate system. This is reflected in extreme weather events. Climate change impacts are already being felt across Canada, with some of the most vulnerable communities among the most affected. Extreme weather events such as the forest fires experienced in 2016 in Fort McMurray, Alberta, in 2017 in British Columbia, and again in 2018 in British Columbia and Ontario are expected to become increasingly frequent. Changes in temperature and precipitation patterns have made the wildfire season longer. Major flooding events such as those experienced in Ontario and Quebec in 2017 and in British Columbia, Ontario, Quebec, and New Brunswick in 2018 are also expected to become increasingly frequent. See Exhibit G (pp 183-184) for additional details.

23. While Canada's temperature increases are outpacing the global average, temperatures are rising even faster in Canada's North. This is leading to significant reductions in the extent of sea ice, accelerated permafrost thaw and loss of glaciers, and other ecosystem impacts. See Exhibit G (pp 184-185) for additional details.

24. Canada has the longest coastline in the world. Changes in relative sea level, rising water temperatures, increased ocean acidity, and loss of sea ice and permafrost are posing considerable challenges for Canada's coastal areas. See Exhibit G (pp 185-186) for additional details.

25. Indigenous Peoples are among the most vulnerable to climate change and experience unique challenges. Indigenous Peoples have a strong cultural connection to the land, water, and air. This increases their exposure and sensitivity to climate change impacts. Although Indigenous Peoples are among the most vulnerable to a changing climate, they are not passive recipients of climate change impacts and contribute vital knowledge, experience, and leadership to adaptation efforts across Canada. See Exhibit G (p 186) for additional details.

26. Climate change poses risks to health and well-being, both directly and indirectly. More frequent and severe extreme weather events increases the risk of physical injury, illness, and death. Heat waves can cause heat-related illness and death, as well as exacerbating existing health conditions. Higher temperatures also contribute to increased air pollution and pollen production, worsening allergies and asthma. Smoke from wild fires impacts air quality, as has been directly experienced throughout Western Canada this summer due to British Columbia's extreme wild-fire season. Other risks to health and well-being result from risks to food security and water safety, and the likely increasing prevalence and spread of potentially life-threatening diseases. See Exhibit G (pp 186-188) for additional details.

International agreements and actions to address climate change fueled by GHG emissions

27. International concern about the risks associated with climate change caused by GHG emissions has resulted in the implementation of international agreements and actions.

28. Canada has been internationally committed to combating climate change since signing and ratifying the *UNFCCC*. The *UNFCCC* was ratified by Canada in December 1992, and entered into force both internationally and in Canada on March 21, 1994. The *UNFCCC* is attached as Exhibit "H" to my affidavit.

29. The preamble indicates that parties to the *UNFCCC* are "concerned that human activities have been substantially increasing the atmospheric concentrations of greenhouse gases, that these increases enhance the natural greenhouse effect, and that this will result on average in an additional warming of the Earth's surface and atmosphere and may adversely affect natural ecosystems and humankind". The preamble also provides that "the global nature of climate change calls for the widest possible cooperation by all countries and their participation in an effective and appropriate international response".

30. The *UNFCCC* defines "greenhouse gases" as "those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and re-emit infrared radiation." The *UNFCCC*'s ultimate objective is the "stabilization of greenhouse gas concentrations in the

atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (Art 2).

31. Carbon dioxide, which has the molecular formula CO_2, is the gas most commonly understood by the general public to be a GHG. However, scientists have identified other GHGs, which are mostly, but not always, carbon containing gases. The *UNFCCC* requires reporting on emissions of seven GHGs: CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3).

32. Canada made a number of commitments in the *UNFCCC*. Significantly, Canada, as a "developed country party", committed to "adopt national policies and take corresponding measures on the mitigation of climate change, by limiting its anthropogenic emissions of greenhouse gases" (Art 4, para 2(a)) with "the aim of returning individually or jointly [GHG emissions] to their 1990 levels" (Art 4, para 2(b)). Among other things, Canada's commitments also include reporting on national inventories of anthropogenic emissions.

33. Article 7 of the *UNFCCC* established a "Conference of the Parties", which convenes annually. The Conference of the Parties ("COP") is the "supreme" decision-making body of the *UNFCCC*. It makes the decisions necessary to promote the effective implementation of the Convention. All States that are parties to the *UNFCCC* are represented at the COP, at which they review the implementation of the *UNFCCC* and any other legal instruments that the COP adopts, and take decisions necessary to promote the effective implementation of the *UNFCCC*. To that end, the COP periodically examines the obligations of the parties, in light of the objective of the *UNFCCC*, the experience gained in its implementation, and the evolution of scientific and technological knowledge. The outcomes of a few key COP meetings are discussed below.

34. The third session of the COP ("COP 3") took place in December 1997 in Kyoto, Japan. Negotiations at COP 3 led to the *Kyoto Protocol*, which the COP adopted in December 1997. In adopting the *Kyoto Protocol*, the COP noted that it reviewed Article 4, paragraphs 2(a) and (b) of the *UNFCCC* at its first session and concluded that they are not adequate. The *Kyoto Protocol* established binding reduction commitments for developed country Parties. Canada

ratified the *Kyoto Protocol* on December 17, 2002 and committed to reduce its GHG emissions for the years 2008-2012 to an average of 6% below 1990 levels. Canada submitted its notification of withdrawal from the Protocol in December 2011, which took effect one year later. Ultimately, Canada's GHG emissions during the 2008–2012 period were higher than the levels it committed to meet.

35. In the last decade, the international community has recognized that tackling climate change has become an increasingly urgent priority.

36. COP 15 took place in December 2009 in Copenhagen, Denmark. I was the Deputy Head of the Canadian delegation to COP 15. At COP 15, the COP took note of the *Copenhagen Accord*, a non-legally binding instrument. The final terms of the *Copenhagen Accord* where negotiated during the Climate Summit in Copenhagen and agreed to by 114 out of the 194 Parties to the *UNFCCC*. In the *Copenhagen Accord*, the endorsing Parties underlined that "climate change is one of the greatest challenges of our time." The *Copenhagen Accord* expressed the will to "urgently combat climate change" and recognized the scientific view that the increase in global temperature should be below 2 degrees Celsius (2°C) to achieve the ultimate objective of the *UNFCCC*. Canada joined the *Copenhagen Accord* at COP 15 in 2009 and pledged to reduce its GHG emissions by 17% from its 2005 levels by 2020. According to the most recent emissions projections, Canada is not on track to meet its Copenhagen target.

37. COP 21 took place in December 2015 in Paris, France, during which Canada and 194 other countries committed to strengthen the global response to the threat of climate change through the implementation of the *Paris Agreement*. The adoption of the *Paris Agreement* was the culmination of years of negotiations under the *UNFCCC*. The *Paris Agreement* is a commitment to accelerate and intensify the actions and investments needed for a sustainable low-carbon future. The Report of COP 21 on the adoption of the *Paris Agreement*, including the *Paris Agreement* (pp 21-36), is attached as Exhibit "I" to my affidavit.

38. The language used in the preamble to the adoption of the *Paris Agreement* in the Report of COP 21 reflects the COP's view on the urgency of taking action to address climate change. The preamble includes the following:

Recognizing that climate change represents an urgent and potentially irreversible threat to human societies and the planet and thus requires the widest possible cooperation by all countries, and their participation in an effective and appropriate international response, with a view to accelerating the reduction of global emissions,

Also recognizing that deep reductions in global emissions will be required in order to achieve the ultimate objective of the Convention and *emphasizing* the need for urgency in addressing climate change,

...

Emphasizing with serious concern the urgent need to address the significant gap between the aggregate effect of Parties' mitigation pledges in terms of global annual emissions of greenhouse gases by 2020 and aggregate emission pathways consistent with holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels,

...

Emphasizing the enduring benefits of ambitious and early action, including major reductions in the cost of future mitigation and adaption efforts,

39. In relation to non-Party stakeholders, the Report of COP 21 notes that the COP "*[a]lso recognizes* the important role of providing incentives for emission reduction activities, including tools such as domestic policies and carbon pricing" (Exhibit I, p 20, para 136).

40. The *Paris Agreement*, in enhancing the implementation of the *UNFCCC*, "aims to strengthen the global response to the threat of climate change" (Art 2). One of the ways it aims to do so is by "holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change" (Art 1, para 1(a)). In order to achieve this long-term temperature goal, "Parties aim to reach global peaking of GHG emissions as soon as possible" and "to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (Art 4, para 1).

41. The *Paris Agreement* recognizes the importance of carbon pricing and market mechanisms to combat climate change. Article 6 provides a framework for international cooperation in implementing a market mechanism.

42. On October 5, 2016, after extensive consultations with the provinces (described below), Canada ratified the *Paris Agreement*. The *Paris Agreement* entered into force in November 2016, after ratification by at least 55 States, including Canada. Currently, the *Paris Agreement* has been ratified by 179 States and by the European Union.

43. Under the *Paris Agreement*, Canada is bound to report and account for the progress made towards achieving Canada's "nationally determined contribution". A nationally determined contribution is a GHG emissions target or other mitigation goal, communicated by a Party under the *Paris Agreement*, which the Party intends to achieve. The *Paris Agreement* also expects all Parties, including Canada, to show a progression in ambition through successive nationally determined contribution over time.

44. At the Warsaw Climate Conference (COP 19) in December 2013, as part of the negotiations leading up to the *Paris Agreement*, Parties were invited to develop and then communicate "intended nationally determined contribution". On May 15, 2015, under Canada's previous government, Canada communicated that its intended nationally determined contribution was an economy-wide target to reduce GHG emissions by 30% below 2005 levels by 2030. When Canada became a Party to the *Paris Agreement*, Canada's intended nationally determined contribution became Canada's first nationally determined contribution (Exhibit I, p 4, para 22).

45. In May 2017, Canada voluntarily re-communicated its first nationally determined contribution in a new written submission, which contains an updated narrative and some additional technical information. The revised submission did not modify the nationally determined contribution itself, which remains an economy-wide target to reduce its national GHG emissions by 30% below 2005 levels by 2030. By 2025, Canada is obligated to communicate its next nationally determined contribution, showing a progression in ambition and a revised submission is required every five years thereafter. Canada may adjust its existing

contribution at any time with a view to enhancing its level of ambition. Canada's 2017 Nationally Determined Contribution Submission to the UNFCCC is attached as Exhibit "J" to my affidavit.

International support for and trend towards widespread carbon pricing

46. Many expert international bodies regard carbon pricing as a necessary policy tool for efficiently reducing GHG emissions, including the World Bank, the Organisation for Economic Cooperation and Development, and the International Monetary Fund (IMF). There is widespread international consensus that carbon pricing is a necessary measure, though not a sufficient measure, to achieve the global reductions in GHG emissions needed to meet the *Paris Agreement* targets.

47. At the September 2014 United Nations Climate Summit, 74 countries and 22 sub-national governments signed a statement entitled "Putting a Price on Carbon". Following this, in December 2015 in Paris, the World Bank officially launched the Carbon Pricing Leadership Coalition ("CPLC"), which has the mandate to study and share best carbon pricing practices. The CPLC brings together leaders from national and subnational governments, from businesses, and from civil society to work together towards advocating for a price on carbon as a way of contributing to climate change action. The CPLC members include Canada, the provinces of British Columbia, Alberta, and Quebec, and over two dozen major Canadian companies in a wide range of sectors, including banking, consumer products, mining, oil and gas, and manufacturing.

48. In 2016, at COP 22, the Co-Chairs of the CPLC invited Joseph Stiglitz, Nobel Laureate in Economics, and Lord Nicholas Stern, former Chief Economist at the World Bank, to chair a High-Level Commission on Carbon Prices comprised of economists and climate change and energy specialists from all over the world. On May 20, 2017, the *Report of the High-Level Commission on Carbon Prices* was published. Among other things, the Commission concludes that "a well-designed carbon price is an indispensable part of a strategy for reducing emissions in an efficient way" (p. 1). Additionally, the Commission concludes that although carbon pricing is indispensable (*i.e.* necessary), carbon pricing alone may not be sufficient.

Complementing carbon pricing with other well-designed policies can mean that a given emissions reduction level may be induced with lower carbon prices than if those policies were absent. The *Report of the High-Level Commission on Carbon Prices* is attached as Exhibit "K" to my affidavit.

49. There is a widespread trend in favour of carbon pricing throughout the world's economies. The World Bank publication "State and Trend of Carbon Pricing 2017" states that, "[s]ince 2016, eight new [carbon pricing] initiatives have been launched and two more initiatives are scheduled for implementation in 2018. This brings the total number of carbon pricing initiatives implemented or scheduled for implementation to 47. Overall, 67 jurisdictions – representing about half of the global economy and more than a quarter of global GHG emissions – are putting a price on carbon". A year later, the World Bank publication "State and Trend of Carbon Pricing 2018" reports that 51 carbon pricing initiatives have been implemented or are scheduled for implementation. A copy of Figure 1, being a summary map of carbon pricing initiatives, and Figure 2, being a graph depicting the share of global annual GHG emissions covered by carbon pricing, from the Executive Summary of "State and Trend of Carbon Pricing 2018" are attached as Exhibits "L" and "M" respectively to my affidavit.

50. The IMF strongly supports the trend in favour of carbon pricing throughout the world's economies. In their January 2016 publication entitled *After Paris: Fiscal, Macroeconomic, and Financial Implications of Climate Change*, the IMF affirmed that carbon pricing is necessary and should be at the forefront of all plans aimed at reducing GHG emissions. The IMF reports that carbon pricing mechanisms are potentially the most effective mitigation instruments as they establish the price signals that are central for redirecting technological changes towards low-emission investments (p. 5). The IMF emphasizes the need to cover emissions comprehensively and provides design principle recommendations for an effective carbon pricing mechanism. *After Paris: Fiscal, Macroeconomic, and Financial Implications of Climate Change* is attached as Exhibit "N" to my affidavit.

Domestic support for carbon pricing from expert, non-governmental organization

51. Nationally, Canada's Ecofiscal Commission published a comprehensive carbon pricing study in April 2015 entitled *The Way Forward – A Practical Approach to Reducing Canada's Greenhouse Gas Emissions*. In *The Way Forward*, Ecofiscal concludes that carbon pricing is the most cost-effective way to reduce GHG emissions and stimulate clean innovation. The Ecofiscal Commission is an independent non-partisan panel of respected economists from across the country, which conducts analysis and issues reports on market-based approaches to address environmental problems. The analysis in the report was presented as a starting point for Ecofiscal's regional engagement on carbon pricing policy through 2015, explaining the important role that carbon pricing could play within a comprehensive climate policy for Canada (p. 2). The report primarily emphasized provincial carbon pricing systems, but noted the desirability of a comprehensive and coordinated system (p. 21) and a role for the federal government in establishing a minimum standard (p. 23). This report helped generate the national discussion on carbon pricing. The *Way Forward* is attached as Exhibit "O" to my affidavit.

52. Three years later, in April 2018, Ecofiscal Commission published a second comprehensive report on carbon pricing, entitled *Clearing the Air: How Carbon Pricing Helps Canada Fight Climate Change*. In *Clearing the Air*, Ecofiscal's stated objective was to provide facts and evidence to support the ongoing policy debate. *Clearing the Air* is attached as Exhibit "P" to my affidavit.

Post-*Paris Agreement* Canadian efforts to address climate change and reduce GHG emissions

Vancouver Declaration

53. On March 3, 2016, less than 90 days after the Paris Climate Change Conference (COP 21) and before Canada became a signatory to the *Paris Agreement*, the Prime Minister of Canada met with all provincial and territorial Premiers (collectively referred to as First Ministers) to discuss the economy and actions to address climate change. At that meeting, the

First Ministers adopted the *Vancouver Declaration on Clean Growth and Climate Change.* In the *Vancouver Declaration*, First Ministers agreed to work together to develop a concrete plan to achieve Canada's international commitments.

54. In particular, the First Ministers recognized the level of ambition set by the *Paris Agreement* and agreed to increase the level of ambition of environmental policies in Canada over time to drive greater GHG emissions reductions. The First Ministers committed to implement GHG mitigation policies in support of meeting or exceeding Canada's nationally determined contribution of reducing GHG emissions by 30% below 2005 levels by 2030.

55. Among other things, in the *Vancouver Declaration* the First Ministers recognized "that the cost of inaction is greater than the cost of action with regard to GHG emissions mitigation and adaptation to the impacts of climate change". First Ministers agreed to work together to develop a pan-Canadian framework on clean growth and climate change. One of the specific actions agreed to towards this end was the establishment of Federal-Provincial-Territorial working groups to identify options for actions in four areas: clean technology, innovation, and jobs; carbon pricing mechanisms; specific mitigation opportunities; and adaptation and climate resilience. Each of these groups were to include Indigenous peoples in their work, and were encouraged to commission expert analysis and reports as necessary to support their work and engage stakeholders. A process was also outlined, which directed that the working groups submit reports to the Ministerial tables charged with overseeing their work by September 2016 and that the Ministers review these reports and provide their recommendations to the First Ministers by October 2016. The First Ministers agreed to meet again in fall 2016 to finalize a pan-Canadian framework on clean growth and climate change. A copy of the *Vancouver Declaration on Clean Growth and Climate Change* is attached as Exhibit "Q" to my affidavit.

Working Group on Carbon Pricing Mechanisms

56. The Federal-Provincial-Territorial Working Group on Carbon Pricing Mechanisms was jointly overseen by Ministers of Finance and the Canadian Council of Ministers of the Environment. All provinces and territories, including Saskatchewan, had at least one senior official on the Working Group. It was co-chaired by an official from Finance Canada and an

ADM from Quebec. As noted above, I was the Government of Canada's representative. The Working Group's work occurred over a nine-month process, with approximately monthly full-day meetings, as well as stakeholder consultation sessions. The Working Group's work was supported by extensive modelling and other analysis. The Working Group's *Final Report* was prepared on a consensus basis. A copy of the Working Group on Carbon Pricing Mechanisms *Final Report* is attached as Exhibit "R" to my affidavit.

57. The Working Group's mandate, as established by the *Vancouver Declaration*, was to "provide a report with options on the role of carbon pricing mechanisms in meeting Canada's emission reduction targets, including different design options taking into consideration existing and planned provincial and territorial systems."

58. As outlined in the introduction in its *Final Report*, the Working Group:

> considered various elements of carbon pricing policy, including coverage, comparability and stringency, as well as market transactions related to mitigation technologies and international trends in carbon pricing and markets.
>
> The Working Group's report also considered the effectiveness of various carbon pricing mechanisms in contributing to the certainty of emission reductions and their efficiency at achieving this objective at the lowest possible costs, and take account of particular challenges, such as those facing Northern, remote and Indigenous communities. Finally, it addressed issues that are particularly important to industry and investors, such as predictability, and approaches to address interprovincial and international competitiveness, including carbon leakage.

59. In its *Final Report*, which was supported by all provinces, the Working Group reported that many experts regard carbon pricing as a necessary tool for efficiently reducing GHG emissions. Specifically, carbon pricing is generally considered to be one of the "most efficient policy approaches to reduce GHG emissions because it provides flexibility to industry and consumers to identify the least-cost way to reduce their own emissions, and spurs innovation to find new opportunities for emissions reduction" (Exhibit R, p 1).

60. Section 2 of the *Final Report* explains how carbon pricing results in GHG emissions reductions. Carbon pricing works by sending a price signal to the economy as a whole and to

various economic actors in particular to reduce GHG emissions, notably by increasing energy efficiency, and replacing carbon-intensive goods (such as fossil fuels) and services, with goods and services that have a lower or no carbon content. The clearer, more consistent, stronger, and more predictable the price signal is in the medium and long term, the more efficient it will be as a driver of the behavioural and technological changes needed to transition to a low-carbon economy. This section then discusses various mechanisms and systems that impose a price on carbon and reduce GHG emissions.

61. Section 3 of the *Final Report* reviews the main design parameters for broad-based pricing mechanisms, and section 4 evaluates how carbon pricing can help Canada meet its GHG reduction targets. Section 4 begins with an overview of Canada's emissions profile. GHG emissions are measured based on their CO_2 equivalent (CO_2e). While CO_2 is the most commonly emitted GHG, as noted above, there are other GHGs. The concept of "global warming potential" allows for a comparison of the ability of each GHG to trap heat in the atmosphere relative to CO_2, which has a nominal global warming potential of 1. For example, methane, which has the molecular formula CH_4, has a global warming potential of 25. A global warming potential of 25 means that CH_4 will trap heat in the atmosphere at 25 times the level of CO_2 over a 100-year period. In Canada's *National Inventory Report: Greenhouse Gas Sources and Sinks in Canada 1990-2013* submitted to the *UNFCCC* in 2015, Canada's total GHG emissions for 2013 were estimated to be 726 Mt of CO_2e. The emissions profile overview in Section 4 of the *Final Report* is based this report. Dr. Dominique Blain Provides an explanation of the processes by which Canada measures and reports on its inventories of GHG emissions, and more detailed information regarding Canada's GHG emissions, in her affidavit.

62. Returning to the overview of Canada's emissions profile, when the *Final Report* was prepared, Canada's 2030 *Paris Agreement* target was calculated to be 524 Mt of CO_2e. Based on policies in place prior to September 2015, Canada's emissions were projected to increase from 726 Mt of CO_2e in 2013 to 815 Mt in 2030, which is 9% above 2005 levels, or 291 Mt above Canada's reduction target. In section 4 of the Working Group's *Final Report*, this projected emissions profile is used as the baseline to illustrate the potential GHG emissions reductions of three carbon pricing scenarios at different levels of ambition.

63. Section 4 of the *Final Report* then examines the implications that additional carbon pricing could have in Canada using ECCC's "EC-Pro model", which is described at page 21 of the *Final Report* and elaborated on in the Affidavit of Warren Goodlet. Three carbon price scenarios were modelled and the economic and GHG emissions impacts are reported. All three scenarios result in GHG emissions reductions at the national level, with the largest reductions (95 Mt below the baseline scenario) resulting from the higher carbon price scenario. A discussion of the economic and emissions impacts is provided at pages 21-26 of the *Final Report* and the process followed in developing these projected impacts is elaborated on in Mr. Goodlet's affidavit.

64. With respect to Canada's GHG emissions reduction targets, the numerical targets set out in the *Final Report* have since been updated. The Affidavit of Dr. Dominque Blain, which I have reviewed, describes how GHG inventories are calculated, discusses Canada's most recent National Inventory Report made to the *UNFCCC* in April 2018, and explains recalculations of national inventories. Because Canada's *Copenhagen Accord* and *Paris Agreement* targets are set out as a percentage reduction compared to the emissions in a specified base year, as Canada's GHG emissions in that base year are recalculated, Canada's numerical GHG emissions reductions targets are also recalculated. Based on Canada's most recent National Inventory Report (2018), Canada's recalculated 2020 target under the *Copenhagen Accord* is 608 Mt CO_2e and Canada's 2030 target under the *Paris Agreement* is 513 Mt CO_2e.

65. Section 5 of the *Final Report* discusses considerations relevant to the implementation of carbon pricing in Canada, such as equity, competitiveness impacts, and carbon leakage created by a carbon price and policy tools for offsetting these impacts. Carbon leakage is a term to describe an increase in carbon emissions in one country or jurisdiction as a result of a reduction in emissions in another country or jurisdiction with a stricter climate change policy. This may occur if, for reasons of costs, emitting industries transfer production from a jurisdiction with a carbon price to a jurisdiction that does not price carbon. The equity considerations discussed included the impact of carbon pricing on Northern and remote communities. They also summarized some of the considerations raised by Indigenous representatives who emphasized that climate change is likely to have particularly significant

impacts on their lands and traditional activities, and that they would like carbon pricing systems to be designed in ways that provide economic opportunities for Indigenous people.

66. Section 6 of the *Final Report* discusses evaluating carbon pricing in Canada. When the Working Group was doing its work, carbon pricing mechanisms were already implemented or planned in some provinces. Chapter 6 reviews these carbon pricing mechanisms and considers issues such as ways to compare the stringency of carbon pricing mechanisms.

67. Section 7 of the *Final Report* recalls that the First Ministers recognized all governments' important role in the global effort to reduce GHG emissions and commitment to transition to a low-carbon economy by adopting a broad range of domestic measures, including carbon pricing mechanisms. Chapter 7 then sets out the principles that were used in guiding the development of options by the Working Group. Flexibility in the way in which carbon pricing is implemented is an important aspect of those principles, including recognizing and supporting existing carbon pricing policies already implemented or in development by provinces and territories. It was also noted that:

> Carbon pricing policies should minimize competitiveness impacts and carbon leakage. In this regard, carbon pricing policies in Canada, including explicit and implicit pricing mechanisms, should be reasonably comparable in price or stringency across the country to mitigate such impacts between provinces and territories. Those carbon pricing policies should also be designed to mitigate international competitiveness and carbon leakage pressures.

68. Section 8 of the *Final Report* describes three broad groups of options for implementing carbon pricing in Canada and includes a brief assessment of each in relation to the principles discussed in the previous section. The first option identified was a single form of broad-based carbon pricing mechanism that would apply across Canada. Among other points, it was noted that this option would not be consistent with the principle of flexibility and support for existing or planned carbon pricing policies. The second option identified was broad-based carbon pricing in all jurisdictions with flexibility on instrument choice. It was noted that this option would recognize and support existing or planned carbon pricing policies and ensure that carbon pricing is used throughout Canada (this is the option that was ultimately chosen). The third option identified was broad-based carbon pricing or reductions targets. It was noted that this

option would recognize and support existing carbon pricing mechanisms, but it would not lead to consistent pricing and coverage across provinces and territories. Emitters would face different carbon costs across jurisdictions, thereby potentially limiting the efficiencies of carbon pricing systems for Canada as a whole.

69. The Working Group invited a number of experts to meet with it to discuss issues and considerations related to the role that carbon pricing should play in the pan-Canadian framework. Annex 3 of the *Final Report* includes summary of the consultations with these experts. The experts generally agreed that, among all policy instruments, carbon pricing should play an important role in Canadian efforts to reduce GHG emissions. The experts also generally agreed that pricing should be consistent and GHG emissions coverage should be as broad as possible. The other points on which the experts provided input are also set out in Annex 3.

70. The Working Group's *Final Report* was submitted to the federal, provincial, and territorial Ministers of Finance and the Canadian Council of Ministers of the Environment.

Pan-Canadian Approach to Pricing Carbon Pollution

71. Following up on the work done by the Working Group on Carbon Pricing Mechanisms, I led the work to develop the pan-Canadian approach to pricing carbon pollution, which the Prime Minister of Canada announced in Parliament on October 3, 2016.

72. The corresponding *Pan-Canadian Approach to Pricing Carbon Pollution* document published by the Government of Canada on the same day noted that "economy-wide carbon pricing is the most efficient way to reduce emissions, and by pricing pollution, will drive innovation solutions to provide low-carbon choices for consumers and businesses." Both the Prime Minister's announcement and the Government of Canada document presented the pan-Canadian benchmark for carbon pricing (Benchmark). The Benchmark emphasizes that carbon pricing must be a foundational element of Canada's overall approach to fighting climate change. It expresses the policy objective of ensuring "that carbon pricing applies to a broad set of emission sources throughout Canada with increasing stringency over time to reduce GHG

emissions at lowest cost to business and consumers and to support innovation and clean growth."

73. The Benchmark was expressly designed to attain this policy goal in the least intrusive manner. When the government developed its commitment to pan-Canadian carbon pollution pricing, British Columbia, Alberta, and Quebec already had carbon pricing and Ontario had announced its intention to join the Quebec-California cap-and-trade system. The government decided not to impose a single carbon pricing system on Canada that would have applied in the four provinces with existing systems. Instead, the government decided to move in a stepwise fashion, where the first step was to articulate a commitment to ensure that there was a consistent approach to carbon pricing across Canada that respected the existing systems and provided flexibility to the remaining provinces to develop their own systems, provided those systems aligned with a core set of criteria.

74. The Benchmark was based on eight principles, which reflected the *Vancouver Declaration* and the principles proposed by the Working Group on Carbon Pricing Mechanisms. These underlying principles were set out in the Government of Canada document, as follows:

i. Carbon pricing should be a central component of the Pan-Canadian Framework.

ii. The approach should be flexible and recognize carbon pricing policies already implemented or in development by provinces and territories.

iii. Carbon pricing should be applied to a broad set of emission sources across the economy.

iv. Carbon pricing policies should be introduced in a timely manner to minimize investment into assets that could become stranded and maximize cumulative emission reductions.

v. Carbon price increases should occur in a predictable and gradual way to limit economic impacts.

vi. Reporting on carbon pricing policies should be consistent, regular, transparent and verifiable.

vii. Carbon pricing policies should minimize competitiveness impacts and carbon leakage, particularly for trade-exposed sectors.

viii. Carbon pricing policies should include revenue recycling to avoid a disproportionate burden on vulnerable groups and Indigenous peoples.

75. The Benchmark expressly recognizes that British Columbia, Alberta and Quebec already had carbon pricing systems in place and that carbon pricing can take the different forms reflected in those provinces' systems – (i) an explicit price-based system as in British Columbia and Alberta, or (ii) a cap-and-trade system as in Quebec.

76. In order to achieve the goal of having carbon pricing apply throughout Canada, while giving provinces and territories the flexibility to maintain or develop a carbon pricing system that suits their own circumstances, the Benchmark outlines basic criteria for carbon pricing systems. The Benchmark explains that either an explicit price-based system or a cap-and-trade system for carbon pricing would be acceptable. The Benchmark provides guidance on the scope of GHG emissions to be covered by carbon pricing, and provides criteria, including minimum stringency requirements, for each type of carbon pricing system. Finally, the Benchmark provides that the Government of Canada will implement a backstop carbon pricing system that will only be applied in jurisdictions that do not develop a system that aligns with the Benchmark, or where a province or territory requests the backstop. A copy of the *Pan-Canadian Approach to Pricing Carbon Pollution* document published by the Government of Canada on October 3, 2016 is attached as Exhibit "S" to my affidavit.

Pan-Canadian Framework on Clean Growth and Climate Change

77. The *Vancouver Declaration* and the reports from the working groups established as a result of the *Vancouver Declaration* set the path toward the adoption of the *Pan-Canadian Framework on Clean Growth and Climate Change* on December 9, 2016. A copy of the *Pan-Canadian Framework on Clean Growth and Climate Change* is attached as Exhibit "T" to my affidavit.

78. The *Pan-Canadian Framework* is Canada's first climate change plan to include commitments by federal, provincial, and territorial governments, and is the country's overarching framework to reduce GHG emissions across all sectors of the economy, stimulate clean economic growth, and build resilience to the impacts of climate change. Eight provinces and all three territories adopted the *Pan-Canadian Framework* on December 9, 2016. Subsequently, the province of Manitoba adopted it on February 23, 2018. The province of Saskatchewan has not yet adopted the *Pan-Canadian Framework.*

79. Since then, on July 3, 2018, Ontario revoked its cap and trade regulation and prohibited all trading of emissions allowances effective that day. On July 25, 2018, the Government of Ontario introduced Bill 4, *The Cap-and-Trade Cancellation Act*, to repeal the province's carbon pricing program. Bill 4 received Royal Assent on October 31, 2018. The Government of Ontario also notified ECCC that it has cancelled all of the seven programs that the federal government had agreed to co-fund through the Low Carbon Economy Fund (described later in my affidavit). On November 29, 2018, Ontario released a new environment plan for consultation. Discussions between ECCC officials and Ontario officials regarding Ontario's new plan are currently ongoing, particularly with respect to the proposed Industry Performance Standards (which appears to propose an output-based pricing system allowing for discretionary exemptions of entire industries).

80. On August 31, 2018, Premier Notley announced that the province of Alberta is withdrawing from the "federal climate change plan" in response to a judicial decision overturning the National Energy Board's approval of the Trans Mountain oil and gas pipeline expansion project. However, Premier Notley also stated that Alberta will still keep its provincial climate plan, including its carbon levy. Alberta has not followed Premier Notley's statement with any formal communication regarding its status under the *Pan-Canadian Framework*, and as such the federal government assumes that Alberta remains a signatory to the *Pan-Canadian Framework.*

81. On October 3, 2018, Manitoba announced that it no longer plans to implement carbon pricing.

82. The *Pan-Canadian Framework* is designed to achieve the behavioural and structural changes needed to transition to a low-carbon economy, and was developed collaboratively by Canada's federal, provincial, and territorial governments, with input from Indigenous Peoples as well as from businesses, non-governmental organizations, and Canadians across the country. The *Pan-Canadian Framework* builds on the diverse array of policies and measures already in place across Canada to reduce GHG emissions in all sectors of the economy. It includes over fifty concrete measures under four key pillars: pricing carbon pollution; complementary actions to further reduce emissions across the economy; measures to adapt to the impacts of climate change and build resilience; and actions to accelerate innovation, support clean technology, and create jobs. This multi-faceted approach is consistent with the approach recommended by international organizations described above in paragraphs 36-40.

83. Pricing carbon pollution is central to the *Pan-Canadian Framework*. The *Pan-Canadian Framework* notes that carbon pricing is broadly recognized as one of the most effective, transparent, and efficient policy approaches to reduce GHG emissions at the lowest cost to consumers and business and to support innovation and clean growth.

84. Shortly before the *Pan-Canadian Framework* was completed, Sustainable Prosperity (now known as Smart Prosperity) posted a letter to the Prime Minister and Premiers on their website strongly supporting carbon pricing and then emailed various federal Ministers and government officials, including me, to alert us to the letter. Smart Prosperity is a research network and policy think tank based at the University of Ottawa. This letter was significant because it was endorsed by a range of business and civil society leaders. This letter was relevant in last-minute discussions with provinces and territories around the content of the *Pan-Canadian Framework* to help demonstrate broad-based support for carbon pricing. A copy of this letter is attached as Exhibit "U" to my affidavit.

85. The *Pan-Canadian Framework* rearticulated the eight principles underlying the pan-Canadian approach to pricing carbon pollution announced on October 3, 2016, including the need to minimize competitiveness impacts and "carbon leakage", particularly for emissions-intensive, trade-exposed sectors.

86. The federal carbon pollution pricing Benchmark announced on October 3, 2016 was included in Annex 1 of the *Pan-Canadian Framework.* As noted above, the Benchmark outlined the criteria that provincial carbon pricing systems must meet in order to ensure they are effective. The goal of the Benchmark is to ensure that carbon pricing applies to a broad set of emission sources throughout Canada, with increases in stringency over time, to reduce GHG emissions. This goal is supported by a federal "backstop" that will apply in all jurisdictions that do not have a carbon pollution pricing system in place that meets the elements of the Benchmark, or where a province or territory requests the backstop.

87. Pricing carbon pollution will not, on its own, allow Canada to meet its *Paris Agreement* targets, but carbon pricing is recognized as an essential measure to reduce Canada's GHG emissions towards meeting these targets. In other words, carbon pricing is necessary, but not sufficient. Extensive complementary actions are outlined the *Pan-Canadian Framework.* Chapter 3 outlines actions in relation to electricity generation, construction practices, transportation, industry, forestry, agriculture, and waste management. Chapter 5 describes financing support for clean technology research, innovation, and jobs. Carbon pricing will work in combination with these complementary actions.

Government of Canada Policy Development Following Adoption of the Pan-Canadian Framework

88. Following up on Canada's *Pan-Canadian Framework* undertaking to introduce a carbon pollution pricing system as a "backstop", in May 2017, the Government of Canada released a document entitled *Technical Paper: Federal Carbon Pricing Backstop.* This discussion paper outlined the elements and operation of the proposed federal carbon pricing system. It also sought feedback from Canadian stakeholders, businesses, and the public, to be provided by June 30, 2017. A copy of the *Technical Paper: Federal Carbon Pricing Backstop* is attached as Exhibit "V" to my affidavit.

89. In August 2017, the Government of Canada published *Guidance on the Pan-Canadian Carbon Pollution Pricing Benchmark.* This document provided further guidance on the federal Benchmark published on October 3, 2016 to support all governments' efforts to have carbon

pollution pricing in place throughout Canada in 2018. The October 3, 2016 Benchmark text is set out in bold followed by further guidance, where applicable, including further guidance on the scope of GHG emissions to which carbon pricing should apply and on the minimum legislated increases in stringency. A copy of the *Guidance on the Pan-Canadian Carbon Pollution Pricing Benchmark* is attached as Exhibit "W" to my affidavit.

90. On December 20, 2017, the Government of Canada published *Supplemental Benchmark Guidance* to supplement the two federal Benchmark documents already published. This document provides additional guidance on the carbon pollution pricing Benchmark. A copy of the *Supplemental Benchmark Guidance* is attached as Exhibit "X" to my affidavit.

91. Together, the Benchmark document, the *Guidance on the Pan-Canadian Carbon Pollution Pricing Benchmark*, and the *Supplemental Benchmark Guidance* attempt to provide jurisdictions with the flexibility to design their own system, while setting out some common, basic requirements.

92. On that same day, Canada's Minister of Environment and Climate Change and Minister of Finance wrote to their provincial and territorial Ministerial counterparts. The letter noted that the *Pan-Canadian Framework* commitment to pricing carbon pollution across the country in 2018 was reaffirmed at the meeting of Canada's Finance Ministers held in Ottawa on December 11, 2017. It recalled that the pan-Canadian carbon pricing approach commits the federal government to implement a backstop to ensure progress on this national challenge, which can apply in jurisdictions that request it, or in those that do not have a carbon pricing system in place that meets the Benchmark in 2018. The letter then outlined the next steps in the federal government's process to price carbon, which included the following timeline:

> **In early January 2018**, Canada would release draft legislative proposals for the federal backstop, with an opportunity to review the draft and provide comments.
>
> **By March 30, 2018**, any province or territory choosing the federal backstop, in whole or in part, was asked to confirm this *via* written reply to this letter.
>
> **By September 1, 2018**, any province or territory opting to establish or maintain a provincial or territorial carbon pricing system that meets the Benchmark, was asked to

outline how the province or territory is implementing carbon pricing. Based on the information provided, as well as follow-up information as needed, Canada will work with the provinces and territories to confirm whether their carbon pricing system meets the Benchmark.

On January 1, 2019, Canada intends to implement the federal backstop, in whole or in part, in any province and territory that does not have a carbon pricing system that meets the Benchmark.

From 2019 onwards, there will be an annual verification process to ensure carbon pricing systems continue to meet the Benchmark and major changes to provincial and territorial systems will be monitored on an ongoing basis.

93. On January 15, 2018, the Minister of Environment and Climate Change and the Minister of Finance released a draft legislative proposal of the *Greenhouse Gas Pollution Pricing Act*, with explanatory notes, for public comment. As described in more detail later in my affidavit, the backstop has two complementary components: a fuel charge; and an Output-Based Pricing System (OBPS).

94. On the same day, the Government of Canada published a document called *Carbon Pricing: Regulatory Framework for the Output-based Pricing System*. It explains that the aim of the OBPS is to minimize competitiveness impacts and carbon leakage for emissions-intensive, trade-exposed industrial facilities, while retaining the carbon price signal and incentive to reduce GHG emissions. This paper provided additional information on the proposed design of the OBPS to be implemented under Part 2 of the *Greenhouse Gas Pollution Pricing Act*.

95. The paper explained that, in most cases, output-based standards for individual sectors will be set as a percentage of the production-weighted national average of emission intensity for that sector. At that time, the proposed starting percentage for all output-based standards was 70% of the production-weighted national average of emission intensity. However, it was noted that the percentage may be adjusted based on various considerations, such as the emissions intensity of the best in class performer, the distribution of emissions intensities among facilities in the sector, and potential impacts on intensity. The paper further noted that output-based standards would initially be developed for twelve identified industrial sectors.

The paper indicated that ECCC would undertake structured engagement on the development of OBPS and invited further input from the public and stakeholders on key technical issues to inform its development. A copy of the *Carbon Pricing: Regulatory Framework for the Output-based Pricing System* document is attached as Exhibit "Y" to my affidavit.

96. The *Greenhouse Gas Pollution Pricing Act* ("*Act*") was introduced in the House of Commons on March 27, 2018, as Part 5 of the *Budget Implementation Act, 2018 No. 1* (Bill C-74).

97. On April 30, 2018, the Government of Canada published a document called *Estimated Results of the Federal Carbon Pollution Pricing System.* This estimate was based on a scenario in which the fuel charge and the OBPS in the *Act* were applied in the nine provinces and territories that did not have a pricing system in place and on the existing systems remaining in place in British Columbia, Alberta, Quebec, and Ontario. That analysis found that carbon pricing will make a significant contribution towards meeting Canada's GHG emissions reduction targets. The analysis estimated that collectively carbon pricing in all provinces and territories across Canada (i.e. the collective effect of the provincial and federal systems) would achieve an 80 to 90 Mt reduction in GHG emissions by 2022.

98. The *Estimated Results* analysis also put "pricing pollution in perspective". It explained that carbon pricing is a critical element of Canada's clean growth and climate plan, however, it was never intended to be the only policy measure in the plan to reduce GHG emissions. Complementary measures were broadly described and the estimated additional emissions reductions contribution of three additional federal policy measures was provided. Among other things, *Estimated Results* also looked at the projected GDP impacts of carbon pricing. Again based on the information then available, it was estimated that application of the federal backstop in the nine jurisdictions that did not have their own regimes in place at that time would affect average annual real GDP growth rates for Canada by less than one tenth of one percentage point between 2018 and 2022.

99. I described and provided a copy of this study to the House of Commons Standing Committee on Finance on May 1, 2018, when I appeared as a witness during the hearings

considering Bill C-74. During another appearance as a witness on May 8, 2018, I explained that the *Estimated Results* GHG reductions projection did not break out the contribution that would be made by the *Act* alone, because it was not yet known how many other provinces would implement their own systems, so it was not yet known in which provinces and territories the federal backstop would ultimately apply. I also described and provided a copy of this study to the Senate standing committees considering Bill C-74. A copy of the *Estimated Results of the Federal Carbon Pollution Pricing System* is attached as Exhibit "Z" to my affidavit.

100. On May 28, 2018, the Government of Canada published a document called *Carbon Pricing: Compliance Options under the Federal Output-Based Pricing System.* Industrial facilities that are registered under the OBPS will have a compliance obligation for the portion of their emissions that exceeds an annual output-based emissions limit. A facility's ability to bank credits or trade credits with another facility when it emits GHGs below its limit maintains the full carbon price incentive on overall GHG emissions. This paper provided additional details regarding compliance units and their use in the OBPS. Further, the paper sought input from Indigenous Peoples, stakeholders, and the public on key technical issues related to the criteria and considerations for the OBPS system, to ensure that this system provides opportunities for emission trading while maintaining environmental integrity. A copy of the *Carbon Pricing: Compliance Options under the Federal Output-Based Pricing System* is attached as Exhibit "AA" to my affidavit.

Enactment and Operation of the Greenhouse Gas Pollution Pricing Act

101. The *Act to mitigate climate change through the pan-Canadian application of pricing mechanisms to a broad set of greenhouse gas emission sources and to make consequential amendments to other Acts*, the short title being the *Greenhouse Gas Pollution Pricing Act* (*Act*), received Royal Assent on June 21, 2018. The key purpose of the *Act* is to help reduce GHG emissions by ensuring that a carbon price applies broadly throughout Canada, with increasing stringency over time.

102. Part 1 of the *Act* implements the fuel charge (sections 3-168) and Part 2 provides the framework for implementing the OBPS for large industrial emitters (sections 169-261).

Together, Parts 1 and 2 of the *Act* provide a system for pricing GHG emissions from a broad set of emissions sources. Parts 1 and 2 of the *Act* operate in provinces or areas that are listed in parts 1 and 2 of Schedule 1, respectively. The Governor in Council may list provinces or areas in part 1 or part 2 of Schedule 1 under ss. 166(2) and 189(1) of the *Act*, respectively. The *Act* links the Governor in Council's decision to list provinces or areas on Schedule 1 to "the purpose of ensuring that pricing of greenhouse gas emissions is applied broadly in Canada". Under ss. 166(3) and 189(2) the Governor in Council is required to "take into account, as the primary factor, the stringency of provincial pricing mechanisms for greenhouse gas emissions" in making an order to list a province or area.

103. For provinces, territories, or areas listed in Schedule 1, the *Act* requires the Minister of National Revenue to return all direct revenue to the jurisdiction of origin (ss. 165(2) and 188(1)). The *Act* provides discretion as to how this will be done. The revenue may be returned to the province or territory of origin, or to designated persons within the province or territory of origin, or to a combination of both.

104. The fuel charge under Part 1 applies to 22 fuels, each of which are GHG emitting fuels. This list includes common fuels like gasoline, light fuel-oil (diesel), and natural gas, as well as less common fuels like methanol and coke oven gas. The specific fuels and their charge rates are set out in Schedule 2 of the *Act*. The charge rate for each fuel represents $10 per tonne of CO_2e emitted from each fuel in 2018, rising to $50 per tonne of CO_2e in 2022. The rates in Schedule 2 of the *Act* were established based on the average CO_2e emission factor for each fuel. This factor was relied on to determine the quantity of the fuel that is necessary to emit one tonne of CO_2e. Following this determination, the charge was converted using normal commercial units to facilitate compliance and administration. In the case of gasoline, for example, the charge of 4.42 ¢/L will apply in 2019, representing a charge of $20 for each tonne of CO_2e emitted from gasoline.

105. The fuel charge under Part 1 will apply to fuels that are produced, delivered, or used in a listed province, brought to a listed province from another place in Canada, or imported into Canada at a place in a listed province. Generally, a distributor, who is required to be registered under s. 55 of the *Act* will pay the fuel charge. Registered distributors are, most commonly,

fuel producers or persons who distribute fuels at the wholesale level. Typically these distributors will be large corporations. Registered distributors are responsible for paying the charge in respect of the fuel that they delivered to another person, and also in respect of the fuel that they may use themselves.

106. Part 1 provides for specific circumstances in which no charge is applicable to certain fuels that are delivered to certain persons if an exemption certificate is provided. In this case, when a registered distributor delivers fuel to certain types of persons, the registered distributor does not have to pay the fuel charge in respect of that delivery of fuel, so the fuel charge is not embedded in the selling price of the distributor. The types of persons who can use exemption certificates are set out in s. 36 of the *Act*. Examples include, other registered distributors of the same fuel (s. 36(1)(b)(i)), persons subject to the OBPS under Part 2 of the *Act*, where the fuel is for use at a covered facility (s. 36(1)(b)(v)), or farmers in respect of certain fuels in certain circumstances (s. 36(1)(b)(vii)).

107. An exemption certificate is a certification that the fuel purchaser provides to the vendor—generally the registered distributor—that relieves the distributor of the obligation to pay the charge in respect of the fuel that the distributor provides to the fuel purchaser. For example, a farmer will be exempt from paying the fuel charge if they certify that: they are a farmer, that the fuel is delivered to a farm, that the fuel will be used exclusively in the operation of farming machinery, and that it is being used for eligible farming activities (s. 36(1)(b)(vii)). Gasoline and diesel used by farmers for farming is entirely exempted from carbon pricing. As another example, the operators of a covered facility under the OBPS would be required to certify, first, that they are registered with the Canada Revenue Agency as an emitter under the OBPS, and that the fuel is for use at a covered facility under the OBPS (s. 36(1)(b)(v)). In this case, this means that the GHG emissions from the burning of that fuel will be priced under Part 2 of the *Act*, so they are still subject to a carbon price, but they are not priced under Part 1.

108. Part 1 also provides specific rules for determining the fuel charge applicable to certain interjurisdictional air, marine, rail, and road carriers (ss. 28-35). Some of these carriers will be entitled to receive fuel from a registered distributor, with no charge applying up front, when they present a valid exemption certificate. In this case they will be, instead, required to self-

assess and pay the charge directly based on their fuel use. For example, air and marine carriers are generally required to pay the charge only on fuel used in intra-jurisdictional journeys, which means a journey that begins and ends in the same listed province. There are specific reasons for these various exemptions. The case of international aviation is demonstrative. Starting in 2021, international aviation will be subject to carbon pricing under an international regime to which Canada is a party, negotiated at the International Civil Aviation Organization. Currently, States representing slightly over 75% of international aviation activity have signaled their intent to participate in the system from its outset, with other significant international aviation States to be phased in by 2027. An international system was essential because it would be difficult for one jurisdiction alone to put a price on international aviation fuels.

109. The Minister of National Revenue acting through the Canada Revenue Agency will administer the fuel charge under Part 1 of the *Act* (ss. 93-94). Part 1 sets out administrative rules, such as rules on filing periods (ss. 68-69), the obligation to file a form (s. 70), and the obligation to pay the fuel charge to the Receiver General (s. 71). Part 1 also includes administration and enforcement regulations meant to ensure compliance with the rules in Part 1 by those who must pay the charge (ss. 84-164). This includes provisions containing penalties, offences and means of recovery. Those provisions are similar to enforcement measures found in other acts administered through the Canada Revenue Agency. This similarity is intentional so that the implementation and enforcement of Part 1 will be based on rules that are familiar both to the regulated parties and to Canada Revenue Agency officials.

110. Part 2 of the *Act* sets out the main powers and authorities for the OBPS for GHG emissions by large industrial facilities. The additional objective of Part 2 is to reduce to a minimum competiveness impacts and the risk of carbon leakage from industries that engage in trade, while imposing a price signal that encourages those industries to reduce their of GHG emissions.

111. Part 2 of the *Act* applies to "covered facilities", which is a defined term under s. 169 of the *Act*, located in a listed province. To qualify, an industrial facility's emissions must be over a given threshold and the facility must perform certain activities. The OBPS will complement the fuel charge. Covered facilities subject to the OBPS are exempt from the Part 1 fuel charge.

Instead, they will pay a price on the portion of their emissions that exceeds the emissions limit that will be prescribed by forthcoming regulations.

112. Part 2 of the *Act* sets out registration requirements, GHG emissions reporting requirements, and requires covered facilities to determine their emissions output against a GHG emissions limit. The specific GHGs to which Part 2 of the *Act* applies, and their global warming potential, are listed in Schedule 3 of the *Act*.

113. The annual limit for covered facilities will use an output-based (i.e. emissions intensity) standard for the industrial activity of the facility, which will be defined by forthcoming regulations. The output-based standard for an industry will be prescribed as a percentage of the quantity of GHGs emitted on average by the facilities in the sector for a given unit of product. To determine its limit, a facility will multiply the quantity of product it produces during the annual compliance period by the output-based standard, which will result in a quantity of CO2e. The limit for a single product facility will be determined by multiplying the applicable output-based standard and the facility's total annual production. For a facility to which more than one output-based standard applies, the annual facility emissions limit will be based on the sum of the limits for each product.

114. Section 174 of Part 2 requires that covered facilities provide compensation for the portion of their emissions that exceeds its annual limit. However, facilities that emit less than their annual limit will receive surplus credits from the Government of Canada under s. 175, which they can bank and use for future compliance obligations, or sell to other regulated facilities. In this way the system creates an incentive for continuous improvement.

115. Facilities that must remit compensation for excess emissions under s. 174 may do so in one of the following three ways. First, the facilities may submit surplus credits they have earned in the past or that they have acquired from other facilities. Second, the facilities may submit offset credits they may acquire from approved projects that prevent or eliminate GHG emissions. Third, the facilities may pay an excess emissions charge, which is set out in Schedule 4 of the *Act*. The charge is set at the same level as the fuel charge in Part 1 of the *Act*,

i.e. \$10 per tonne of CO_2e in 2018, increasing by \$10 a year until it reaches \$50 a tonne in 2022. Section 185 of the *Act* provides for a system for tracking compliance units.

116. Much of the remainder of Part 2 (ss. 197-252) sets out provisions related to the enforcement or application of the *Act*. Those provisions are designed to ensure the integrity and proper operation of the pricing system. They are largely inspired by the application and enforcement provisions that are found in other federal environmental acts such as the *Canadian Environmental Protection Act, 1999* (*CEPA, 1999*).

Policy Updates and Implementation of the Greenhouse Gas Pollution Pricing Act

117. On July 27, 2018 the Government of Canada published a document called *Update on the Output-Based Pricing System: Technical Backgrounder*. This document updated the *Carbon Pricing: Regulatory Framework for the Output-based Pricing System* released on January 15, 2018, based on extensive consultation on the initial proposal and completion of the first two phases of ECCC's three-phase approach for assessing the impact of carbon pricing on the competitiveness of different industrial sectors. The update provided that four sectors assessed to be in a high competitive risk category will have their output-based standard adjusted to 90% of the sector's average GHG emissions intensity. It further provided that the starting point for all remaining industrial sectors would be revised from the 70% initially proposed to 80% of the sector's average GHG emissions intensity. The document also explained that the government will continue to refine the output-based standards and related rules for the next few months. The aim in publishing this update was to seek further feedback from stakeholders on ECCC's preliminary assessment.

118. In addition to refining the output-based standards for the sectors initially expected to be covered by the OBPS, from July through December, ECCC undertook extensive additional work to develop output-based standards for numerous additional industrial sectors as a result of Ontario's cancellation of their cap and trade carbon pricing system. There were thirty industrial activities in Ontario not covered by the output-based standards initially developed, and for which new standards needed to be developed.

119. On October 23, 2018, the Government of Canada announced the provinces and areas that would be listed in Schedule 1 of the *Act*, being the jurisdictions in which Part 1 and Part 2 of the *Act* will apply (*i.e.* the backstop jurisdictions). They announced that the fuel charge under Part 1 will apply in Saskatchewan, Ontario, Manitoba, and New Brunswick starting in April 2019 because the governments in these provinces have not developed a system to price carbon pollution that meets the Benchmark stringency requirements. They also announced that the OBPS under Part 2 would start applying in Ontario, Manitoba, New Brunswick, Prince Edward Island, and partially in Saskatchewan in January 2019. The Government of Prince Edward Island asked to have Part 2 apply, and the New Brunswick Government in place before the fall 2018 election had also asked for the federal OBPS. For the territories, the Government of the Northwest Territories is planning to implement a system that meets the Benchmark stringency requirements on July 1, 2019. The fuel charge and the OBPS will apply in Yukon and Nunavut starting on July 1, 2019, to ensure alignment across the territories. The Governments of Yukon and Nunavut agreed to have Part 1 and Part 2 of the *Act* apply. The Order in Council amending Part 2 of Schedule 1 was adopted on October 31, 2018.

120. The OBPS only applies partially in Saskatchewan, because the Government of Saskatchewan is implementing its own output-based performance standards system. Their standards and compliance system applies to large industrial facilities that emit 25,000 tonnes or more of CO_2e per year, with the exception of electricity generation and natural gas transmission pipelines. Saskatchewan estimates it will cover approximately 11% of the province's GHG emissions.

121. Saskatchewan's output based pricing system was assessed as being on track to partially meet the Benchmark stringency requirements, based on the information they provided for this purpose. Saskatchewan has since made the necessary legislative amendments and regulations to implement their carbon pricing system. The rate for compliance payments into a provincial technology fund is established as $20 per tonne of CO_2e in 2019. To fill in the gaps, the fuel charge under Part 1 of the *Act* will apply starting in April 2019 and, as of January 1, 2019, the OBPS under Part 2 of the *Act* applies to the emission sources not covered by Saskatchewan's system, namely electricity generation and natural gas transmission pipelines. Part 2 of the *Act*

applies to facilities in Saskatchewan from those sectors that emit 50,000 tonnes of CO_2e per year or more, with the ability for smaller facilities that emit 10,000 tonnes of CO_2e per year or more to voluntarily opt-in to the system over time. The federal fuel charge will cover about 24% of Saskatchewan's emissions, and the federal OBPS applies to the two largest industrial sources, responsible for about 23% of emissions. Together, the federal pollution pricing system and the province's OBPS on other industrial sources will have the effect of imposing a price on about 58% of the province's total GHG emissions. This is a lower proportion of overall emissions than for most other provinces, largely because of the very high proportion of emissions in Saskatchewan from agriculture, waste, and fugitive emissions (*i.e.* unintentional methane leaks from various types of equipment) in the oil and gas sector.

122. On October 23, 2018, the Government of Canada also announced how it proposes to return the proceeds from the fuel charge to the jurisdiction of origin, as is required under the *Act*. Jurisdictions that voluntarily adopted the federal system will receive these proceeds directly from the federal government and it is up to those governments to decide how to use them. For Saskatchewan, Ontario, Manitoba, and New Brunswick the federal government will return approximately 90% of the proceeds from the fuel charge directly to residents in the province of origin in the form of Climate Action Incentive payments. Most households in those provinces will receive more in Climate Action Incentive payments than the increased costs they incur from carbon pollution pricing. The direct proceeds from the fuel charge that are not returned through Climate Action Incentive payments, will be used to provide support to schools, hospitals, small and medium-sized businesses, colleges and universities, municipalities, not-for-profits, and Indigenous communities in the province of origin. The proceeds from the OBPS will also be reinvested in the province of origin to support carbon-pollution reduction. Further details on how this support will be delivered will be outlined in 2019.

123. Concurrent with the announcements made on October 23, 2018, a series of "backgrounders" and other supporting documents were released, including the following documents that are attached as Exhibits to my affidavit as indicated:

i. "How we're putting a price on carbon pollution" attached as Exhibit "BB" to my affidavit;

ii. "Fall 2018 update: Estimated impacts of the federal pollution pricing system" attached as Exhibit "CC" to my affidavit;

iii. "Saskatchewan and Pollution Pricing" attached as Exhibit "DD" to my affidavit;

iv. "Manitoba and Pollution Pricing" attached as Exhibit "EE" to my affidavit;

v. "Ontario and Pollution Pricing" attached as Exhibit "FF" to my affidavit;

vi. "New Brunswick and Pollution Pricing" attached as Exhibit "GG" to my affidavit;

vii. "Prince Edward Island and Pollution Pricing" attached as Exhibit "HH" to my affidavit;

viii. "Yukon and Pollution Pricing" attached as Exhibit "II" to my affidavit;

ix. "Nunavut and Pollution Pricing" attached as Exhibit "JJ" to my affidavit;

x. "Fuel Charge Rates in Listed Provinces and Territories" attached as Exhibit "KK" to my affidavit;

xi. "Ensuring Transparency" as Exhibit "LL" to my affidavit;

xii. "Targeted Relief for Farmers and Fishers, and Residents of Rural and Remote Communities" attached as Exhibit "MM" to my affidavit;

xiii. "Support for Municipalities, Universities, Schools and Colleges, Hospitals, Non-Profits, and Indigenous Communities" attached as Exhibit "NN" to my affidavit;

xiv. "Support for Small and Medium-Sized Businesses" attached as Exhibit "OO" to my affidavit;

xv. "Climate Action and Indigenous Peoples" attached as Exhibit "PP" to my affidavit;

124. The Government of Canada's decision to return the majority of the proceeds directly to individuals in the provinces listed in Schedule 1 of the *Act* over the provincial governments' objections is intended to avoid the risk that governments opposed to carbon pollution pricing could use the proceeds to undermine the effectiveness of pricing. Government representatives in Ontario and Saskatchewan have threatened to do so. Additionally, in delivering the Government of Ontario's Throne Speech on July 12, 2018, the Lieutenant Governor for Ontario stated that the government "will use every tool at its disposal to fight" the federal carbon pricing scheme. Undermining the effectiveness of carbon pricing could be accomplished, for example, by rebating funds from the fuel charge to the facilities that must pay the charge –fuel distributors and importers. This would allow them to avoid passing on any increased prices to fuel users, thereby eliminating any price signal and the resulting incentive for energy efficiency, energy switching, and other actions to reduce GHG emissions.

125. By contrast, the federal government's approach will retain the "price signal" that energy users will see in the cost of the carbon-based energy they consume while minimizing the "income effect" of those increased prices. This distinction between "price signal" and "income effect" is important in understanding how carbon pricing can influence behavior without making people worse off. Dr. Nicholas Rivers provides a detailed explanation of the impact of the Climate Action Incentive in the report attached as Exhibit "C" to his affidavit. In summary, the federal carbon pricing system will impose costs on suppliers of energy (*via* the fuel charge) and on the producers of goods (*via* the OBPS). In turn, these payers of the pollution price will pass on that cost to commercial and individual consumers through increased prices for fuel whose use emits GHGs and for products whose production generated high emissions. Those price changes will make carbon-intensive fuel and products relatively more expensive than lower carbon alternatives, creating incentives for changed consumption decisions, regardless of how the proceeds are returned. Returning the proceeds to individuals in amounts that correspond to (or exceed) the direct costs of carbon pricing to the average person in that province or territory should not change those incentives. Indeed, individuals and families would receive the Climate Action Incentive payment regardless of their purchasing decisions. It will, however, ensure that individuals have roughly the same overall income or purchasing power. As described by the EcoFiscal Commission, "[a] carbon dividend maintains incentives

to switch to lower-carbon goods because there's a separation between what the carbon price costs you and the value of the dividends. How much the carbon price costs is tied to your carbon consumption, whereas the dividend's value is fixed." EcoFiscal's complete explanation is available at https://ecofiscal.ca/2018/09/26/how-carbon-dividends-affect-incentives.

126. Regulatory instruments for the OBPS have been adopted and more will be forthcoming. The regulatory instruments already adopted include: *Order Amending Part 2 of Schedule 1 to the Greenhouse Gas Pollution Pricing Act*, SOR/2018-212; *Notice Establishing Criteria Respecting Facilities and Persons and Publishing Measures*, SOR/2018-213; *Greenhouse Gas Emissions Information Production Order*, SOR/2018-214; *Order Amending the Greenhouse Gas Emissions Information Production Order*, SOR/2018-277. These instruments provide information on which industrial facilities are required to register in the OBPS. They will set out quantification, reporting and verification requirements for facilities covered by the OBPS. The owner and operator of a facility subject to the OBPS must register that facility with ECCC. Registration opened on November 1, 2018. Initially, the OBPS will apply primarily to facilities that annually emit 50 kt CO_2e or more, with the ability for smaller facilities that emit 10,000 tonnes of CO2e per year or more to voluntarily opt-in to the system over time.

127. On December 19, 2018, ECCC published a Proposal for the OBPS Regulations, setting out the proposed output-based standards and rules. This proposal is currently open for comments from the public and interested stakeholders to inform the regulatory process, after which the regulations will be finalized. Under the proposed regulations:

i. The vast majority of the 38 industrial activities across 23 sectors with 74 output-based standards included in the system will face a standard set at 80% of their sector's weighted average emissions intensity. The standard includes emissions from combustion and those generated from industrial or chemical processes;

ii. As a result of further analysis and specific data received over the fall, the standards for the cement and lime sectors were adjusted from 90% to 95% given the higher risks of competitiveness impacts and leakage from carbon pollution pricing;

iii. The standard for coal-fired electricity phases down so that it reaches the level of natural gas electricity by 2030;

iv. Limits are proposed on the use of offsets and other credits to ensure the market functions well.

128. On December 19, 2018, ECCC also released a *Policy Regarding Voluntary Participation in the Output-Based Pricing System*. Under s. 172 of the *Act*, a person responsible for a facility may request that the facility be designated as a covered facility. The policy outlines the considerations that the Minister will take into account when making this designation. The aims of the policy are to minimize competitiveness and carbon leakage risks from the exposure of a sector to the fuel charge under Part 1, while maintaining the carbon pricing incentive for smaller facilities to reduce their emissions. A copy of the *Policy Regarding Voluntary Participation in the Output-Based Pricing System* is attached as Exhibit "QQ" to my affidavit.

Federal Financing for Complementary GHG Emissions Reduction Measures – The Low Carbon Economy Fund

129. As experts such as the High-Level Commission on Carbon Prices (described above at paragraph 48) above have emphasized, the *Pan-Canadian Framework* provides for carbon pricing as a foundational element of the country's approach to reducing GHG emissions, while also complementing carbon pricing with both government spending programs and additional regulations. This suite of measures reflects the reality that while carbon pricing is essential, and generally a cost-effective way of reducing GHG emissions, carbon pricing may not be sufficient on its own and there are some issues for which carbon pricing may not work.

130. With respect to government spending, the *Pan-Canadian Framework* includes commitments for public investments in research and development and infrastructure, deployment of market-ready GHG reducing technologies and practices, as well as in information programs, in order to support transformative low-carbon innovations and enhance the effectiveness of carbon pricing. Valued at approximately $2 billion, the Government of Canada's Low Carbon Economy Fund supports the *Pan-Canadian Framework* by providing

investments in projects that will generate clean growth, reduce GHG emissions, and help Canada meet its *Paris Agreement* commitments. The Low Carbon Economy Fund is split into two parts.

131. The first part is the Low Carbon Economy Leadership Fund, which was launched on June 15, 2017, with up to $1.4 billion in funding allocated over five years to provinces and territories that have adopted the *Pan-Canadian Framework* to help them deliver on their commitments to reduce GHG emissions. The Low Carbon Economy Leadership Fund recognizes the key role provinces and territories play in addressing climate change by reducing GHG emissions. Each province and territory whose project proposals have been approved for funding has focused on the best ways to reduce emissions given their unique climate and circumstances.

132. For example, British Columbia will access up to $162 million through the Low Carbon Economy Leadership Fund to invest in projects such as the reforestation of public forests, which absorb carbon from the atmosphere and store it, and the improvement of energy efficiency of buildings.

133. New Brunswick and Nova Scotia are focused on energy efficiency. New Brunswick will invest its approximately $51-million allocation, in collaboration with NB Power, to help New Brunswickers improve the energy efficiency of their homes and businesses. Nova Scotia will invest its approximately $56-million allocation to expand a home retrofit program delivered by Efficiency Nova Scotia. The new funding will contribute to the expansion of Efficiency Nova Scotia's retrofit programs to allow more Nova Scotian homes to be eligible for funding to reduce their energy bills, regardless of how they heat their homes. This will help reduce emissions and will improve comfort in households across the province.

134. In May of 2018, a funding agreement was concluded between Canada and Ontario whereby Canada committed $385 million in funding to support seven priority projects proposed by Ontario. These projects were to be funded using resources from Ontario's $420 million Low Carbon Economy Leadership Fund allocation and Ontario committed an additional $1.5 billion for these projects. The estimated GHG emission reductions to be achieved by the seven projects

in 2030 exceeded one megatonne. Following the election of the new government in Ontario in June 2018, in addition to cancelling its cap-and-trade system, Ontario cancelled all seven approved projects without notification or approval by Canada, as required by the funding agreement. In September 2018, Dr. Dianne Saxe, the Environmental Commissioner of Ontario released a report entitled *Climate Action in Ontario: What's Next?* criticizing the Ontario Government's decision to cancel cap-and-trade, the low-carbon programs that it funded, and "752 renewable energy projects" with nothing in their place. The summary of the *Climate Action in Ontario: What's Next?* is attached as Exhibit "RR" to my affidavit.

135. The second part of the Low Carbon Economy Fund is the Low Carbon Economy Challenge. Valued at over $500 million, it will support projects selected from applications that can be submitted by a wide range of potential applicants, including provinces and territories, municipalities, Indigenous communities and organizations, businesses, and not-for-profit organizations. Projects will be selected on merit and primarily based on their ability to reduce GHG emissions in a cost effective way and contribute to clean growth objectives in support of the *Pan-Canadian Framework*. The Low Carbon Economy Challenge is divided into two streams: Champions Streams and Partnership Streams for smaller applicants (*i.e.* municipalities under 100,000 population, small and medium enterprises with less than the equivalent of 500 full time employees, not for profit organizations, and Indigenous organizations).

136. In addition to the Low Economy Carbon Fund under the *Pan-Canadian Framework*, the federal government has other spending programs that support GHG emissions reductions. Some of these programs are described in Canada's 2017 Nationally Determined Contribution Submission to the UNFCCC (Exhibit "J") and some are described in Exhibits "DD" through "JJ" referred to above.

Other GHG Emissions Reduction Measures under the Canadian Environmental Protection Act, 1999

137. As experts recommend, and as the *Pan-Canadian Framework* provides for, other measures are needed to address GHG emissions for which carbon pricing may not work. As a result, in addition to carbon pricing, a number of federal GHG emissions reduction measures

are in place or planned under *CEPA, 1999*. In the electricity sector, the Government of Canada finalized regulations in December 2018 to phase out coal-fired electricity generation by 2030 and establish GHG emissions limits for natural gas-fired electricity generation (to provide regulatory certainty for investments in natural gas electricity and to ensure that all new natural gas electricity is efficient). In the oil and gas sector, the federal regulations require actions that will significantly reduce fugitive and other methane emissions. These emissions cannot be measured easily and are therefore not subject to federal carbon pollution pricing. In the transportation sector, the federal government is regulating emissions standards for light and heavy-duty vehicles. Regulations are also in place to limit GHG emissions from fuels by prescribing a minimum content of renewable fuels. Finally, steps are being taken to reduce hydroflorocarbon (HFCs) emissions. HFCs are potent GHGs that were introduced on the market as a replacement for ozone depleting substances. The steps being taken to reduce HFC emissions are described in the final section of my affidavit, which briefly explains the *Montreal Protocol on Substances that Deplete the Ozone Layer* (*Montreal Protocol*).

138. Coal-fired electricity generation is a major contributor to Canada's GHG emissions and an example of an area where carbon pricing alone is insufficient. The *Reduction of Carbon Dioxide Emissions from Coal-fired Generation of Electricity Regulations*, SOR/2012-167, adopted under *CEPA, 1999*, establish a regime for the reduction of CO_2 emissions resulting from coal-fired electricity generation. Among other measures, these regulations prescribe a GHG emissions intensity limit for coal-fired electricity generation. These regulations were recently amended to have the effect of phasing out units producing electricity with coal by 2030. This is needed to provide certainty around investments in capital stock that can have a long life. The federal regulations to phase-out coal-fired electricity generation should prevent new investments in new coal-fired electricity, regardless of other market considerations. This regulatory certainty is needed in addition to carbon pricing because electricity generation facilities typically have a lifespan of decades, and new investments in coal-fired electricity generation could lock-in sub-optimal technology, or result in costly stranded assets.

139. Significant investments in the electricity sector will be required as the use of coal-fired electricity facilities is phased out. Some of that investment will involve developing natural gas-

fired electricity generation capacity. Anticipating new or re-tooled infrastructure, on December 12, 2018, the Government of Canada published the *Regulations Limiting Carbon Dioxide Emissions from Natural Gas-fired Generation of Electricity*. These regulations were adopted under *CEPA, 1999* to ensure that all new and significantly modified natural gas-fired electricity generation units in Canada are efficient.

140. After CO_2 from the combustion of fossil fuels, methane is Canada's second most emitted GHG, accounting for 14% of Canada's total GHG emissions. As noted above, methane has a global warming potential of 25, meaning that it will trap heat in the atmosphere at 25 times the rate of CO_2 over a 100-year period. The oil and gas sector is the largest industrial emitter of methane in Canada. The *Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector)*, SOR 2018-66 (not yet in force), adopted under *CEPA, 1999*, will result in a significant reduction in methane emissions. When these regulations come into force in 2020, they will impose requirements on the oil and gas sector to reduce methane emissions, notably by introducing limits to venting, imposing operating standards, and restricting methane emissions from equipment. The operating standards address an example of a situation in which carbon pricing is inefficient. It is only possible to price activities whose emissions can be measured or modeled. These regulations are needed to ensure that oil and gas facilities take appropriate action to prevent leaks of methane from various types of equipment. By their nature, leaks are not planned and are inherently difficult to monitor – and therefore to price.

141. The transportation sector is a significant source of GHG emissions in Canada, accounting for approximately 25% of Canada's total GHG emissions, with passenger automobiles and light trucks accounting for almost half of the transportation GHG emissions. The transportation sector is an area in which it would likely take time for carbon pricing on its own to have a substantial impact on the overall composition of the vehicle fleet on the road and on the design of new vehicles. So, a series of regulations have been adopted under *CEPA, 1999* to reduce emissions from vehicles and engines in the transportation sector. Two of these regulations have the primary objective of reducing GHG emissions, notably the *Passenger Automobile and Light Truck Greenhouse Gas Emission Regulations*, SOR/2010-201 and the

Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations, SOR/2013-24. In general these regulations apply to companies that manufacture and import new vehicles or engines for the purpose of sale in Canada. These regulations, and the fuel regulations described next ensure that vehicle designs and changes to fuel start reducing GHG emissions in a predictable manner.

142. To limit GHG emissions from fuels the *Renewable Fuels Regulations,* SOR/2010-189 were adopted under to CEPA *1999.* The objective of this regulation is to reduce GHG emissions by requiring fuel producers and importers to have an average renewable content of at least 5% based on the volume of gasoline. The regulations also require an average 2% renewable fuel content in diesel fuel and heating distillate oil based on annual volumes.

143. On December 19, 2018, ECCC also released a backgrounder and a regulatory design paper setting out the main design elements of Clean Fuel Standard regulations for liquid fuels. The Clean Fuel Standard is an important complementary emissions-reduction policy in Canada's climate and clean growth plan. The regulations will be developed in two phases, starting with liquid fuels. Once finalized, the Clean Fuel Standard will apply to liquid, gaseous, and solid fuels used in Canada, and is expected to reduce GHG emissions by 30 Mt annually by 2030.

The Montreal Protocol and Regulation of Ozone Depleting Substances under the Canadian Environmental Protection Act, 1999

144. The *Montreal Protocol* is occasionally cross-referenced in materials relating to the *UNFCCC* and is part of the broader context for GHG emissions reductions. The *Montreal Protocol* is an example of a successful international environmental agreement. Canada and 23 other nations signed the *Montreal Protocol*, on September 16, 1987, which is an agreement aimed at protecting the earth's ozone layer by eliminating the use of ozone depleting substances in order to prevent the global environmental and health problems associated with increased ultra-violet radiation from reaching a crisis stage. Since then, the *Montreal Protocol* has achieved wide participation, with 197 parties having ratified the agreement.

145. Since its entry into force in 1989, the Parties to the *Montreal Protocol* have continued to adapt the regime in response to scientific evidence and technological developments. By 2016, the *Montreal Protocol* had enabled reductions of over 97% of all global consumption of controlled ozone–depleting substances.

146. In Canada, Parliament used its criminal law jurisdiction to pursue the elimination of ozone-depleting substances through successive regulations enacted under the former *Canadian Environmental Protection Act*, 1985, c. 16 (4th Supp.) and the current *CEPA, 1999*. The current *Ozone-depleting Substances and Halocarbon Alternatives Regulations*, SOR/2016-137, were adopted under *CEPA, 1999*. The purpose of these regulations is to implement Canada's current obligations under the *Montreal Protocol*. Controls in Canada have resulted in an overall phase-out of over 99% of ozone-depleting substances from baseline levels. These regulations introduced permitting and reporting requirements for HFCs, which are also GHGs, and set out rules concerning halocarbon alternatives.

147. In October 2016, the Parties to the Montreal Protocol adopted the *Kigali Amendment*, which requires all Parties to phase down the consumption and production of HFCs. The *Kigali Amendment* will came into force on January 1, 2019. To date, 43 Parties, including Canada, have ratified the *Kigali Amendment*. An amendment to the *Ozone-depleting Substances and Halocarbon Alternatives Regulations* came into force in 2018 to allow Canada to meet its obligations under the *Kigali Amendment* by establishing a phase-down of HFC consumption starting on January 1, 2019, and introducing restrictions and prohibitions on certain products containing or designed to contain HFCs.

AFFIRMED BEFORE ME in the City of Ottawa, in the Province of Ontario, this 29th day of January, 2019. I certify that Mr. Moffet has satisfied me that he is a person entitled to affirm. [signature] Commissioner for Taking Affidavits. My commission expires on: 05/10/21 #Q24458	))))))))	[signature] John Moffet

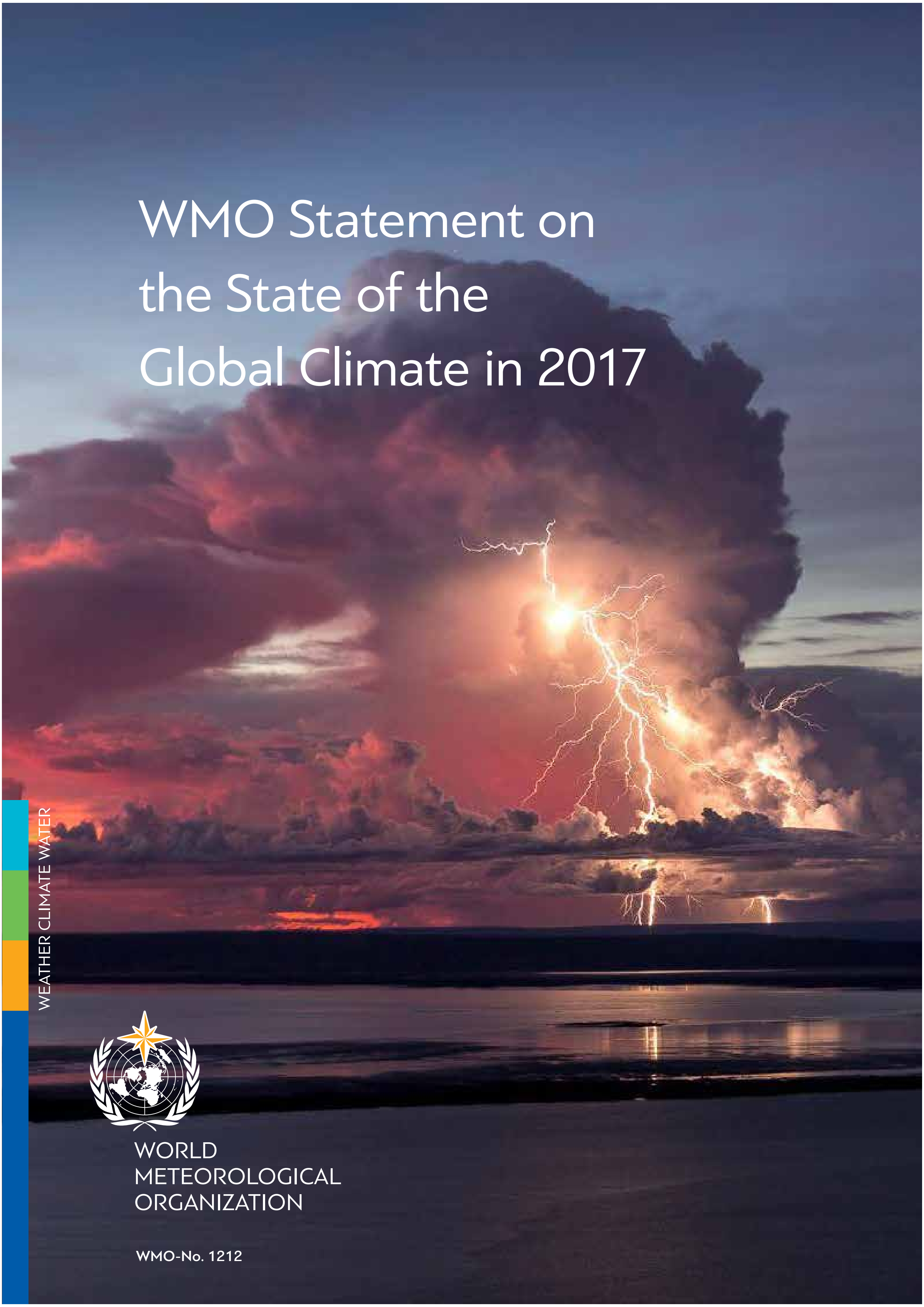
This is **Exhibit A** referred to in the

affidavit of **John Moffet**

affirmed before me on **January** 29, **2019**

Commissioner for Oaths for Québec

#224458



WMO Statement on the State of the Global Climate in 2017

WEATHER CLIMATE WATER

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ORGANIZATION

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DESTRUCTIVE WILDFIRES AROUND THE WORLD

Foreword

For the past 25 years, the World Meteorological Organization (WMO) has published an annual Statement on the State of the Global Climate in order to provide authoritative scientific information about the global climate and significant weather and climate events occurring around the world. As we mark the 25th anniversary, and following the entry into force of the Paris Agreement, the importance of the information contained in the WMO Statement is greater than ever. WMO will continue working to increase the relevance of the information it provides to the Parties to the United Nations Framework Convention on Climate Change through this Statement and the annual WMO Greenhouse Gas Bulletin. These publications complement the assessment reports that the Intergovernmental Panel on Climate Change (IPCC) produces every six to seven years.

Since the inaugural Statement on the State of the Global Climate, in 1993, scientific understanding of our complex climate system has progressed rapidly. This is particularly true with respect to our understanding of mankind's contribution to climate change, and the nature and degree of such change. This includes our ability to document the occurrence of extreme weather and climate events and the degree to which they can be attributed to human influences on the climate.

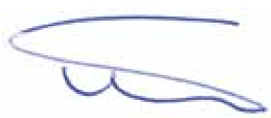
In the past quarter of a century, atmospheric concentrations of carbon dioxide – whose rising emissions, along with those of other greenhouse gases, are driving anthropogenic climate change – have risen from 360 parts per million (ppm) to more than 400 ppm. They will remain above that level for generations to come, committing our planet to a warmer future, with more weather, climate and water extremes. Climate change is also increasingly manifested in sea level rise, ocean acidification and heat, melting sea ice and other climate indicators.

The global mean temperature in 2017 was approximately 1.1 °C above the pre-industrial era, more than half way towards the maximum limit of temperature increase of 2 °C sought through the Paris Agreement, which further strives to limit the increase to 1.5 °C above pre-industrial levels. The year 2017 was the warmest on record without an El Niño event, and one of the three warmest years behind the record-setting 2016. The world's nine warmest years have all occurred since 2005, and the five warmest since 2010.

Extreme weather claimed lives and destroyed livelihoods in many countries in 2017. Fuelled by warm sea-surface temperatures, the North Atlantic hurricane season was the costliest ever for the United States, and eradicated decades of development gains in small islands in the Caribbean such as Dominica. Floods uprooted millions of people on the Indian subcontinent, whilst drought is exacerbating poverty and increasing migration pressures in the Horn of Africa. It is no surprise that extreme weather events are identified as the most prominent risk facing humanity in the World Economic Forum's *Global Risks Report 2018*.

Because the societal and economic impacts of climate change have become so severe, WMO has partnered with other United Nations organizations to include information in the Statement on how climate has affected migration patterns, food security, health and other sectors. Such impacts disproportionately affect vulnerable nations, as evidenced in a recent study by the International Monetary Fund, which warned that a 1 °C increase in temperature would cut significantly economic growth rates in many low-income countries.

I would like to take this opportunity to express my gratitude to the National Meteorological and Hydrological Services of WMO Members, international and regional data centres and agencies, and climate experts from around the world for their contributions, and to United Nations sister agencies for their valuable input on societal and economic impacts. They have greatly assisted in ensuring that this annual Statement achieves the highest scientific standards and societal relevance and informs action on the Paris Agreement, the Sendai Framework for Disaster Risk Reduction and the United Nations Sustainable Development Goals.



(P. Taalas)
Secretary-General

Executive summary

Global mean temperatures in 2017 were 1.1 °C ± 0.1 °C above pre-industrial levels. Whilst 2017 was a cooler year than the record-setting 2016, it was still one of the three warmest years on record, and the warmest not influenced by an El Niño event. The average global temperature for 2013–2017 is close to 1 °C above that for 1850–1900 and is also the highest five-year average on record. The world also continued to see rising sea levels, with some acceleration, and increasing concentrations of greenhouse gases. The cryosphere continued its contraction, with Arctic and Antarctic sea ice shrinking.

The overall risk of heat-related illness or death has climbed steadily since 1980, with around 30% of the world's population now living in climatic conditions that deliver deadly temperatures at least 20 days a year.

There were many significant weather and climate events in 2017, including a very active North Atlantic hurricane season, major monsoon floods in the Indian subcontinent, and continuing severe drought in parts of east Africa. This contributed to 2017 being the year with the highest documented economic losses associated with severe weather and climate events. Extreme weather events continue to be rated by the World Economic Forum as amongst the most significant risks facing humanity, both in terms of likelihood and impact.[1]

Massive internal displacement in the context of drought and food insecurity continues across Somalia. From November 2016 to December 2017, 892 000 drought-related displacements were recorded by the United Nations High Commissioner for Refugees (UNHCR).

In August and September 2017, the three major and devastating hurricanes that made landfall in the southern United States and in several Caribbean islands in rapid succession broke modern records for such weather extremes and for loss and damage.

The information used in this report is sourced from a large number of National Meteorological and Hydrological Services (NMHSs) and associated institutions, as well as Regional Climate Centres, the World Climate Research Programme (WCRP), the Global Atmosphere Watch (GAW) and Global Cryosphere Watch (GCW). Information has also been supplied by a number of other international organizations, including the Food and Agriculture Organization of the United Nations (FAO), the World Food Programme (WFP), the World Health Organization (WHO), the United Nations High Commissioner for Refugees (UNHCR), the International Organization for Migration (IOM), the International Monetary Fund (IMF), the United Nations International Strategy for Disaster Reduction (UNISDR) and the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (IOC-UNESCO).

Values of key climate indicators

Indicator	*Time period*	*Value*	*Ranking*
Global mean surface-temperature anomaly (1981–2010 baseline)	2017, annual mean	+0.46°C	Second-highest on record
Global ocean heat content change, 0–700 metre layer	2017, annual mean	1.581 x 1023 J	Highest on record
Global mean CO_2 surface mole fraction	2016, annual mean	403.3 parts per million	Highest on record
Global mean sea-level change since 1993	2017, December	8.0 cm	Highest on record
Arctic sea-ice extent summer minimum	2017, September	4.64 million km^2	Eighth-lowest on record

1 World Economic Forum, 2018: *The Global Risks Report 2018*.

Key climate indicators

TEMPERATURE

The year 2017 was one of the world's three warmest years on record. A combination of five datasets, three of them using conventional surface observations and two of them reanalyses,[2] shows that global mean temperatures were 0.46 °C ± 0.1 °C above the 1981–2010 average,[3] and about 1.1 °C ± 0.1 °C above pre-industrial levels.[4] By this measure, 2017 and 2015 were effectively indistinguishable as the world's second and third warmest years on record, ranking only behind 2016, which was 0.56 °C above the 1981–2010 average. The years 2015, 2016 and 2017 were clearly warmer than any year prior to 2015, with all pre-2015 years being at least 0.15 °C cooler than 2015, 2016 or 2017.

The world's nine warmest years have all occurred since 2005, and the five warmest since 2010, whilst even the coolest year of the 21st century – 2008, 0.09 °C above the 1981–2010 average – would have ranked as the second-warmest year of the 20th century.

The five-year mean temperature for 2013–2017, 0.4 °C above the 1981–2010 average (and 1.0 °C above pre-industrial values), is also the highest on record. A five-year average gives a longer-term perspective on recent global temperatures whilst being less influenced than annual temperatures by year-to-year fluctuations such as those associated with the El Niño/Southern Oscillation (ENSO).

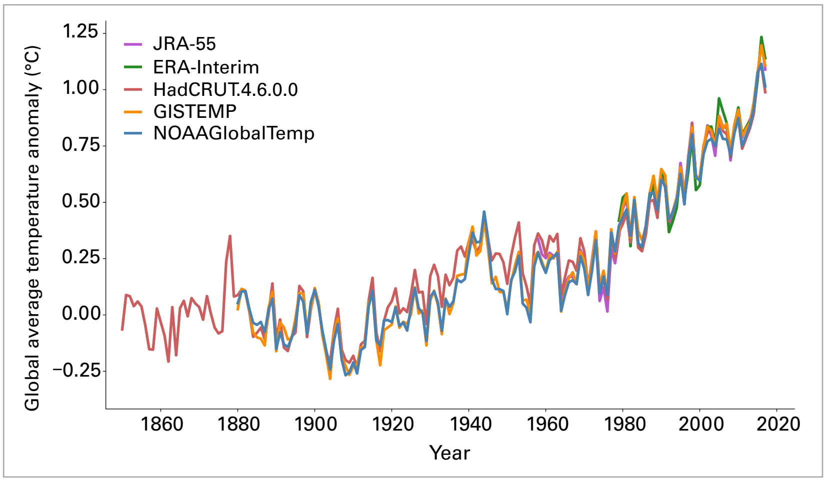


Figure 1. Global mean temperature anomalies, with respect to the 1850–1900 baseline, for the five global datasets *(Source: UK Met Office Hadley Centre)*

In the individual datasets, 2017 was second-warmest in the two reanalysis datasets (ERA-Interim and JRA-55) and in the dataset from the US National Aeronautics and Space Administration (NASA), and third-warmest in the datasets from the US National Oceanic and Atmospheric Administration (NOAA) and the UK Met Office Hadley Centre/Climatic Research Unit (CRU). Differences between individual datasets primarily relate to different ways in which they analyse data-sparse areas, especially in the Arctic which has experienced some of the world's strongest warming in recent years.

Global temperatures were well above average throughout the year. The strongest anomalies were early in the year, with each of the months from January to March being at least 0.5 °C above the 1981–2010 average, and March 0.64 °C above. For the remainder of the

The world's warmest years on record

Year	Anomaly in respect of the 1981–2010 average (°C)
2016	+0.56
2017	+0.46
2015	+0.45
2014	+0.30
2010	+0.28
2005	+0.27
2013	+0.24
2006	+0.22
2009	+0.21
1998	+0.21

[2] The conventional datasets used are those produced by the US National Oceanic and Atmospheric Administration (NOAA); the US National Aeronautics and Space Administration (NASA); and the Met Office, Hadley Centre/Climatic Research Unit (CRU), University of East Anglia (United Kingdom). The two reanalysis datasets used are the ERA-Interim dataset, produced by the European Centre for Medium-Range Weather Forecasts (ECMWF), and the JRA-55 dataset, produced by the Japan Meteorological Agency (JMA).

[3] For purposes other than comparison of temperatures with pre-industrial levels, this report uses 1981–2010 as a standard baseline period, as this is the period for which the widest range of datasets (especially satellite-based datasets) is available.

[4] For the purposes of this report, 1850–1900 is used as the baseline for pre-industrial temperatures. There is no appreciable difference between the temperature change derived from this baseline and that derived from other baselines used historically, such as 1880–1900.

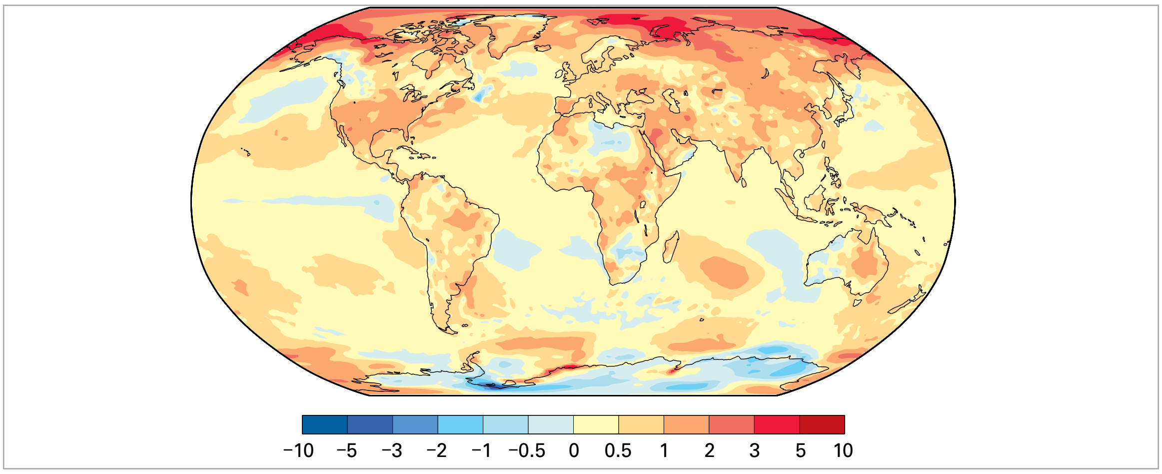


Figure 2. Surface-air temperature anomaly for 2017, with respect to the 1981-2010 average *(Source: ERA-Interim data, European Centre for Medium-range Weather Forecasts (ECMWF) Copernicus Climate Change Service)*

year, monthly global temperature anomalies were between 0.3 °C and 0.5 °C, the smallest monthly anomaly being 0.34 °C in June.

The year 2017 was clearly the warmest on record not influenced by an El Niño. Strong El Niño events, such as the one that occurred in 2015/2016, typically increase global mean temperatures by 0.1 °C to 0.2 °C in the year in which the event finishes, with a smaller increase in the event's first year. In the case of the 2015/2016 event, global temperatures were strongly boosted from October 2015 to April 2016, having a substantial influence on both the 2015 and 2016 annual values. Neutral ENSO conditions prevailed for most of 2017, with a weak La Niña developing late in the year.

Warmth in 2017 was notable for its spatial extent. The only land area of any size outside Antarctica that had annual mean temperatures in 2017 below the 1981–2010 average in conventional surface analyses was a section of western Canada centred on the interior of British Columbia. Reanalysis data also indicated some areas of below-average temperatures in parts of Africa where conventional data are sparse, including Libya and parts of the interior of southern Africa. Temperatures were 1 °C or more above average over most of the higher latitudes of Asia, including the Asian part of Russia, Mongolia and northern China. Other regions where 2017 temperatures were at least 1 °C above average included north-west Canada and Alaska, the southern half of the United States and parts of northern Mexico, and parts of eastern Australia. The largest anomalies, above 2 °C, were found at high northern latitudes, particularly in eastern Russia and north-west North America. Some coastal locations experiencing feedback from reduced sea-ice presence (such as Svalbard) were as much as 4 °C above average.

Despite the widespread high temperatures, only limited regions had their warmest year on record in 2017. Of 47 countries reporting mean temperatures at the national scale, only Argentina, Mauritius, Mexico, Spain and

Continental temperature anomalies

Region	Anomaly in respect of the 1981–2010 average (°C)	2017 rank	Existing record
North America	+0.84	6	+1.32 (2016)
South America	+0.54	2	+0.69 (2015)
Europe	+0.73	5	+1.18 (2014)
Africa	+0.54	4	+0.83 (2010)
Asia	+0.88	3	+0.92 (2015)
Oceania	+0.51	6	+0.73 (2013)

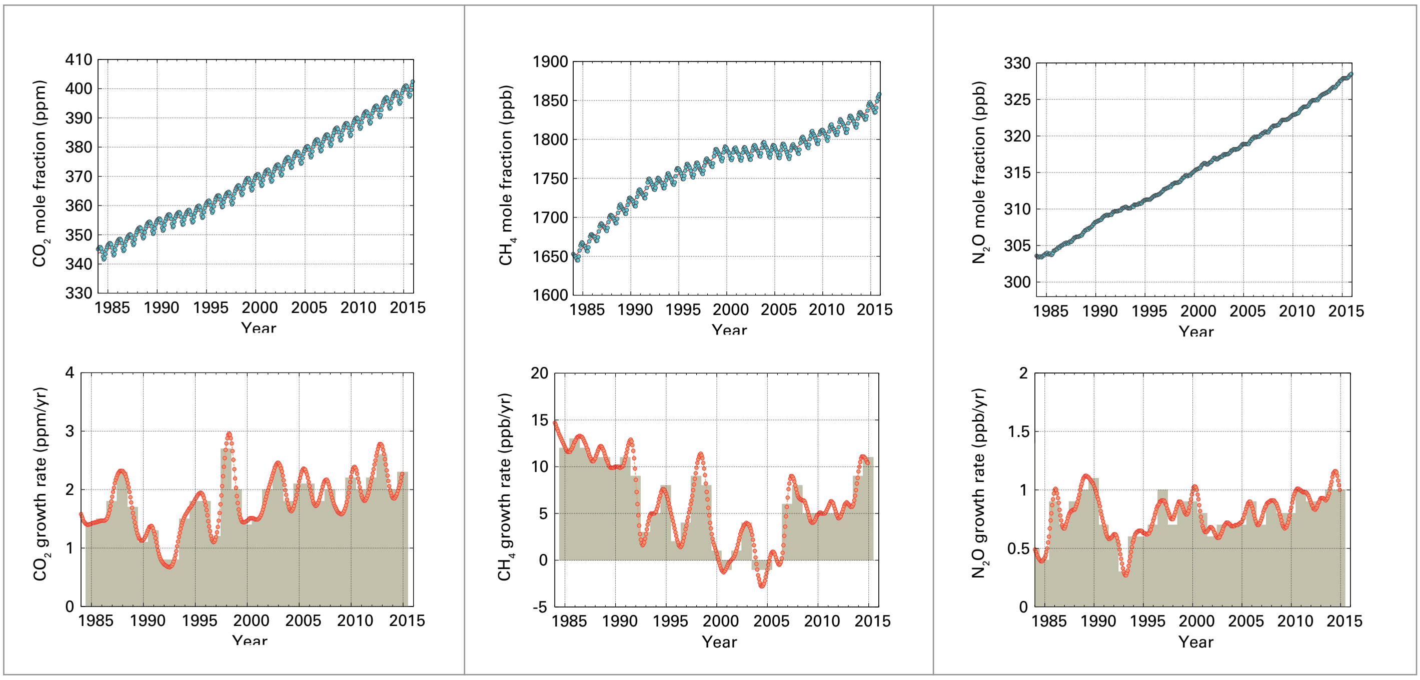


Figure 3. Top row: Globally averaged mole fraction (measure of concentration), from 1984 to 2016, of CO_2 in parts per million (left), CH_4 in parts per billion (middle) and N_2O in parts per billion (right). The red line is the monthly mean mole fraction with the seasonal variations removed; the blue dots and line depict the monthly averages. Bottom row: The growth rates representing increases in successive annual means of mole fractions for CO_2 in parts per million per year (left), CH_4 in parts per billion per year (middle) and N_2O in part per billion per year (right). *(Source: WMO Global Atmosphere Watch)*

Uruguay had their warmest year on record. The Asian part of Russia also had its warmest year on record (the Russian Federation as a whole ranked fourth), as did five states in the southern half of the United States, and the eastern Australian states of New South Wales and Queensland.

All continents had one of their six warmest years on record in 2017, with South America ranking second, Asia third, Africa fourth, Europe fifth, and North America and Oceania sixth[5]. Temperatures in Africa were at record levels through mid-year, with monthly records set in May, June, July and September, but it cooled considerably from October onwards. South America had its second-warmest summer and second-warmest winter on record, whilst Oceania had its warmest July.

GREENHOUSE GASES

Increasing levels of greenhouse gases (GHGs) in the atmosphere are key drivers of climate change. Atmospheric concentrations are formed as a balance between emissions due to human activities and the net uptake from the biosphere and oceans. They are expressed in terms of dry mole fractions calculated from a global in-situ observational network for carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Global average figures for 2017 will not be available until late 2018. Real-time data from a number of specific locations, including Mauna Loa (Hawaii) and Cape Grim (Tasmania) indicate that levels of CO_2, CH_4 and N_2O continued to increase in 2017, but it is not yet clear how the rate of increase compares with that in 2016 or in previous years.

In 2016, GHG concentrations reached new highs with CO_2 at 403.3±0.1 parts per million (ppm), CH_4 at 1853±2 parts per billion (ppb) and N_2O at 328.9±0.1 ppb. These values constitute, respectively, 145%, 257% and 122% of pre-industrial (before 1750) levels.

The increase in CO_2 from 2015 to 2016 was larger than the increase observed from 2014 to 2015 and the average over the last decade, and it was the largest annual increase observed in the post-1984 period. The El Niño event contributed to the increased growth rate in 2016, both through higher emissions from terrestrial sources (e.g. forest fires) and decreased uptake of CO_2 by vegetation in drought-affected areas. The El Niño event in 2015/2016 contributed to the increased growth rate through complex two-way interactions between climate change and the carbon cycle.

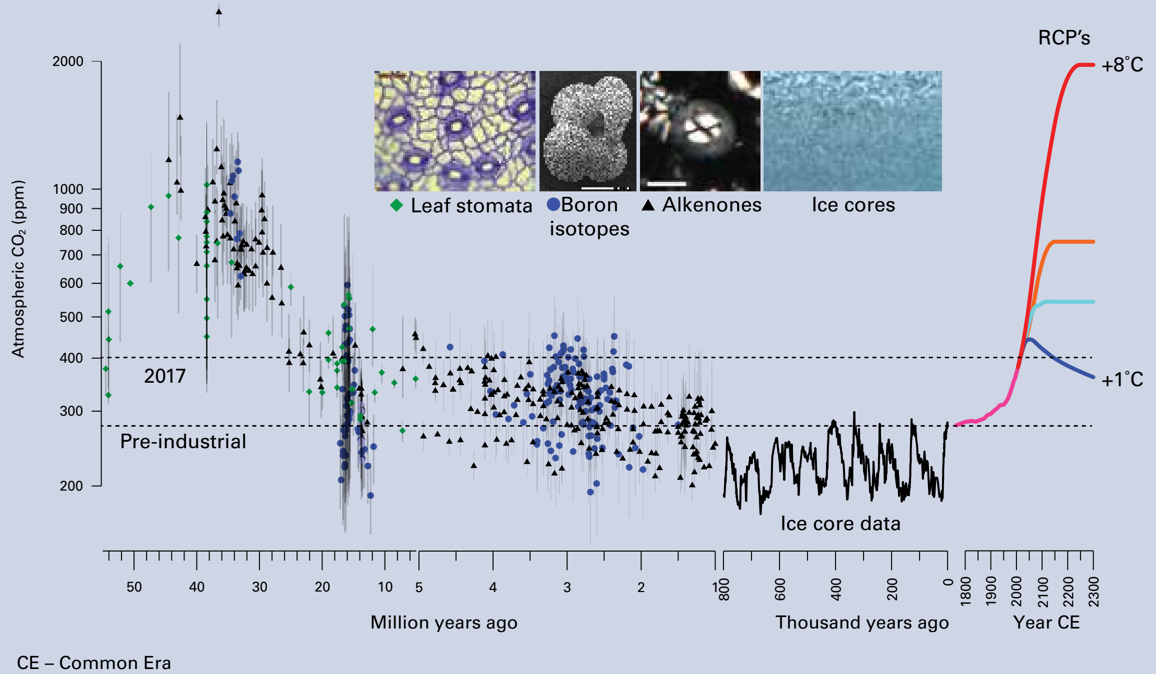
[5] Continental temperatures are as reported by NOAA, and are available at https://www.ncdc.noaa.gov/sotc/global-regions/201801.

PALEO AND CURRENT CONCENTRATIONS OF CO_2

The reconstruction of past climate provides an opportunity to learn how the Earth system responded to high concentrations of atmospheric carbon dioxide (CO_2). To obtain information about the state of the atmosphere before instrumental records began, combinations of proxies are used in which physical characteristics of past environmental conditions are preserved. Tiny bubbles of ancient air captured in ice cores when new snow accumulating at the top solidified into ice, can be directly measured and give some insight into the composition of the atmosphere in the past.

Direct measurements of atmospheric CO_2 over the past 800 000 years (see figure) provide proof that over the past eight swings between ice ages (glacials) and warm periods similar to today (interglacials) atmospheric CO_2 varied between 180 and 280 parts per million (ppm), demonstrating that today's CO_2 concentration of 400 ppm exceeds the natural variability seen over hundreds of thousands of years. Over the past decade, new high-resolution ice core records have been used to investigate how fast atmospheric CO_2 changed in the past. After the last ice age, some 23 000 years ago, CO_2 concentrations and temperature began to rise. During the period recorded in the West Antarctica ice core, fastest CO_2 increases (16 000, 15 000 and 12 000 years ago) ranged between 10 and 15 ppm over 100–200 years. In comparison, CO_2 has increased by 120 ppm in the last 150 years due to combustion of fossil fuel.

Periods of the past with a CO_2 concentration similar to the current one can provide estimates for the associated "equilibrium" climate. In the mid-Pliocene, 3–5 million years ago, the last time that the Earth's atmosphere contained 400 ppm of CO_2, global mean surface temperature was 2–3 °C warmer than today, the Greenland and West Antarctic ice sheets melted and even some of the East Antarctic ice was lost, leading to sea levels that were 10–20 m higher than they are today. During the mid-Miocene (15–17 million years ago), atmospheric CO_2 reached 400–650 ppm and global mean surface temperature was 3–4 °C warmer than today.



Reconstructions of atmospheric CO_2 over the past 55 million years are generated from proxy data that include boron isotopes (blue circles), alkenones (black triangles) and leaf stomata (green diamonds). Direct measurements from the past 800 000 years are acquired from Antarctic ice cores and modern instruments (pink). Future estimates include representative concentration pathways (RCPs) 8.5 (red), 6 (orange), 4.5 (light blue), and 2.6 (blue). References for all data shown in this plot are listed in the extended online version (http://www.wmo.int/pages/prog/arep/gaw/ghg/ghg-bulletin13).

For CH_4, the increase from 2015 to 2016 was slightly smaller than that observed from 2014 to 2015 but larger than the average over the past decade. For N_2O, the increase from 2015 to 2016 was also slightly smaller than that observed from 2014 to 2015 and lower than the average growth rate over the past 10 years.

OZONE

The 2017 Antarctic ozone hole was relatively small by the standards of recent decades. This largely reflects local atmospheric conditions in 2017 and is not, in itself, indicative of a more sustained downward trend. Most ozone hole indicators show weak, non-significant downward trends over the last 20 years.

The daily ozone hole area reached a maximum for the season of 19.6 million km^2 on 11 September. The first part of the season, up to the second week of September, saw the size of the Antarctic ozone hole at levels close to the 1979–2016 average. However, the polar vortex became unstable and elliptical in the third week of September, with temperatures at the polar cap (60–90°S) rising 5–7 °C above the long-term mean. This resulted in a rapid decrease in the size of the ozone hole before a small increase around the end of September.

The average area of the ozone hole through the peak of the season (from 7 September to 13 October) was 17.4 million km^2. This is the smallest value since 2002 (12.0 million km^2) and also smaller than in 2012, the lowest value in the 2003–2016 period (17.8 million km^2). The average ozone hole area over the 30 worst consecutive days was 17.5 million km^2. This is also the lowest value observed since 2002 (15.5 million km^2) and again somewhat smaller than in 2012 (18.9 million km^2).

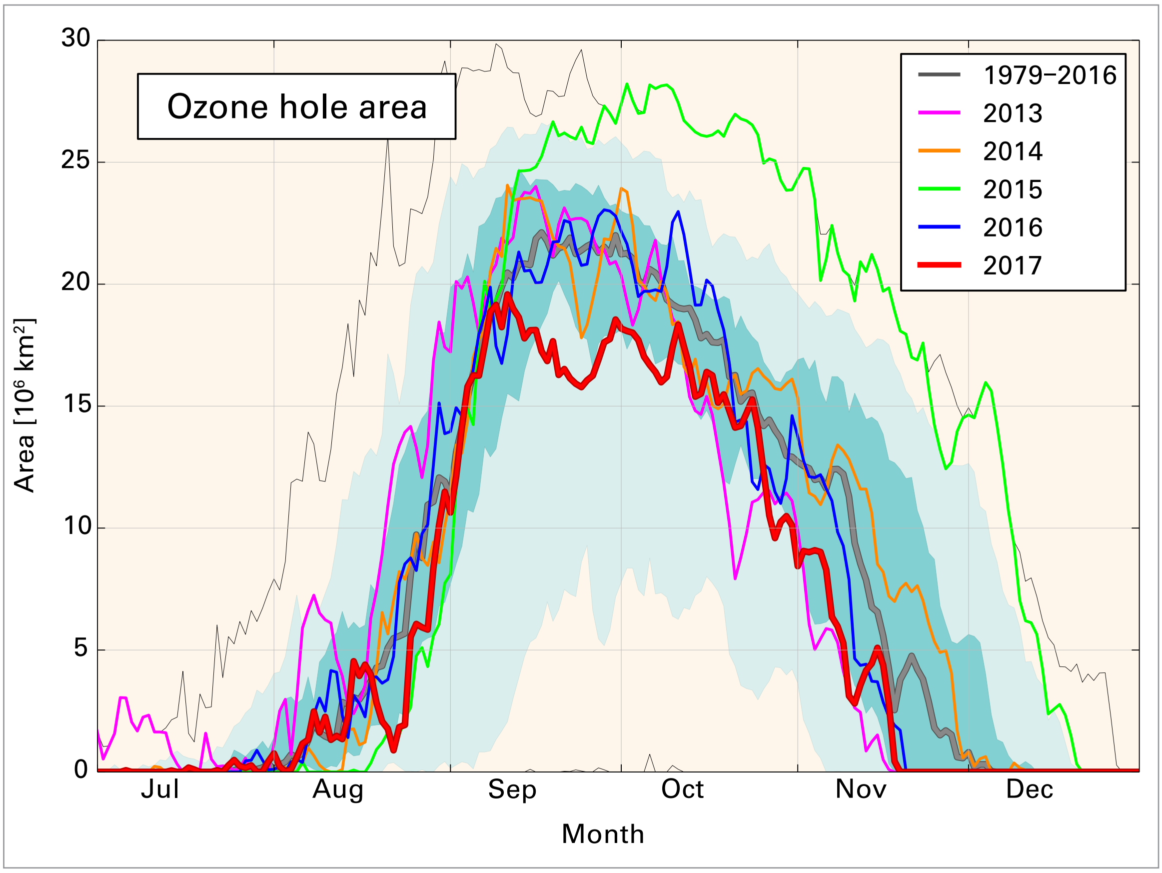


Figure 4. Area (millions of km^2) where the total ozone column is less than 220 Dobson units. The year 2017 is shown in red. The most recent years are shown for comparison as indicated by the legend. The smooth, thick grey line is the 1979–2016 average. The dark green-blue shaded area represents the 30th to 70th percentiles and the light green-blue shaded area represents the 10th and 90th percentiles for the time period 1979–2016. The thin black lines show the maximum and minimum values for each day during the 1979–2016 period. The plot is made at WMO on the basis of data downloaded from the Ozone Watch website at the US National Aeronautics and Space Administration (NASA). The NASA data are based on satellite observations from the Ozone Mapping and Profiler Suite (OMPS), Ozone Monitoring Instruments (OMI) and the Total Ozone Mapping Spectrometer (TOMS).

The Global Carbon Budget

Josep G. Canadell,[1] Corinne Le Quéré,[2] Glen Peters,[3] Robbie Andrew,[3] Pierre Fridlingstein,[4] Robert B. Jackson,[5] Tatiana Ilyina[6]

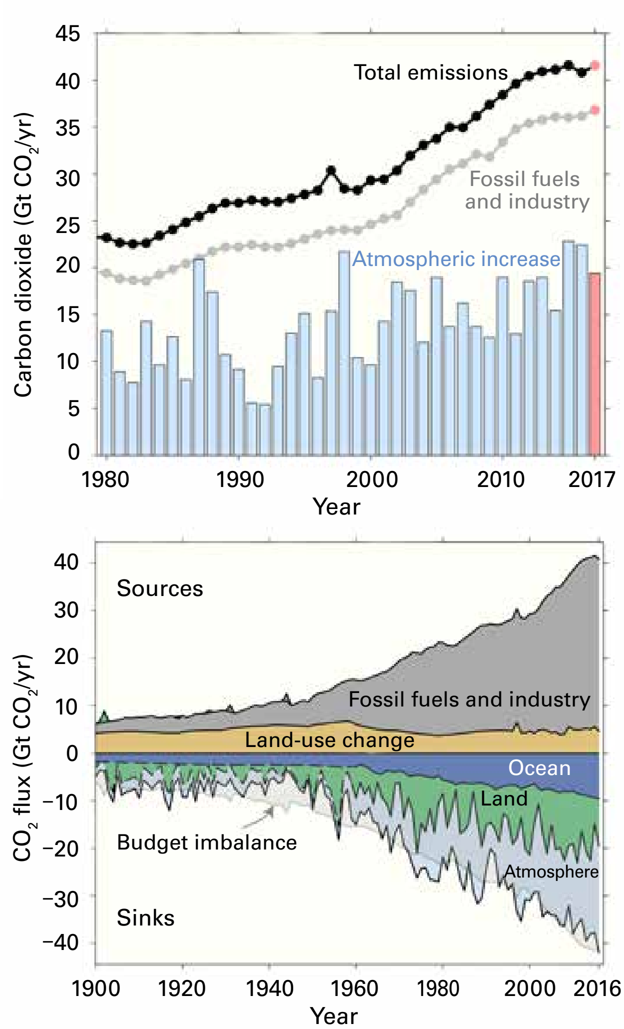
Accurately assessing carbon dioxide (CO_2) emissions and redistribution within the atmosphere, oceans, and land – the "global carbon budget" – helps us capture how humans are changing the Earth's climate, supports the development of climate policies, and improves projections of future climate change.

Carbon dioxide emissions from fossil fuels and industry have been growing for decades with pauses only during global economic downturns. For the first time, emissions stalled from 2014 to 2016 while the global economy continued to expand. Nonetheless, CO_2 accumulated in the atmosphere at unprecedented rates close to 3 parts per million (ppm) per year in 2015 and 2016, despite stable fossil fuel emissions (figure, top). This surprising dynamic was caused by strong El Niño warming in 2015 and 2016, when the land CO_2 sink was less efficient in removing atmospheric CO_2, and emissions from fires were above average (in 2015). Preliminary data for 2017 show that emissions from fossil fuels and industry resumed growing at about 1.5% (0.7%–2.4%, leap year adjusted), from 36.2±2.0 billion tonnes of CO_2 in 2016 to a record high of 36.6±2.0 billion tonnes in 2017 – 65% higher than in 1990.

Carbon dioxide emissions from change in land use were 4.8±2.6 billion tonnes in 2016, accounting for 12% of all anthropogenic CO_2 emissions, and are expected to remain stable or slightly lower for 2017 on the basis of initial observations using satellite data. Together, land use change and fossil fuel emissions reached an estimated 41.5±4.4 billion tonnes of CO_2 in 2017.

Of all anthropogenic CO_2 emissions, only about 45% remained in the atmosphere on an annual average over the past decade: 25% were removed by the oceans and 30% were removed by the terrestrial biosphere (figure, bottom). However, due to the strong El Niño conditions, the increase from 2015 to 2016 in atmospheric CO_2 concentration was 22.1±0.7 billion tonnes (54% of total emissions; 2.85 ppm) which is larger than the average for 2007–2016. Ocean and terrestrial ecosystems removed 9.5±1.8 billion tonnes of CO_2 (23%) and 9.9±3.7 billion tonnes of CO_2 (24%), respectively.

There are substantial uncertainties in the quantification of the land and ocean carbon sinks on sub-decadal and decadal time scales, and in the reconstruction of cumulative emissions across centuries of the industrial era, particularly historical emissions from changes in land use.



Trends in anthropogenic CO_2 emissions and growth of atmospheric CO_2, 1980–2017. Total emissions minus fossil fuel emissions equals emissions from change in land use (top). The historical global carbon budget, 1900–2016 (bottom) *(Source: Global Carbon Project, http://www.globalcarbonproject.org/carbonbudget; Le Quéré, C. et al., 2018: The Global Carbon Budget 2017.* Earth System Science Data, *10, 405–448); and March 2018 updates).*

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THE OCEANS IN 2017

TEMPERATURE

Global sea-surface temperatures in 2017 were somewhat below the levels of 2015 and 2016, but still ranked as the third warmest on record. The most significant sea-surface temperature anomalies were in the western tropical Pacific and the western and central subtropical South Indian Ocean. In both regions, sea-surface temperatures were widely 0.5 °C to 1.0 °C above the 1981–2010 average, locally exceeding 1.0 °C above average in the Indian Ocean, and were generally at record-high levels. In contrast, temperatures were slightly below average over most of the eastern Indian Ocean and over the central and eastern equatorial Pacific, the latter being consistent with weak La Niña conditions which developed late in the year. They were also slightly below average in parts of the far southern Atlantic. The area of cool waters in the north-east Atlantic south of Iceland was less prominent than in most recent years.

For the second successive year, above-average sea-surface temperatures off the east coast of Australia resulted in significant coral bleaching in the Great Barrier Reef, this time focused on central areas of the Reef rather than the northern areas affected in 2016.[6] Significant bleaching was also reported in other parts of the western tropical Pacific,[7] including Micronesia and Guam, although global bleaching was less extensive than it had been in 2016. Later in the year, exceptionally warm sea-surface temperatures (generally 2 °C or more above average, and 0.5 °C or more above previous records for the time of year) affected the southern Tasman Sea, coinciding with record high monthly temperatures in New Zealand (especially the South Island) and Tasmania. Whilst marine impacts of this event are still becoming apparent, there has already been a shift in the distribution of fish species, with snapper being caught off Fiordland (far south-west New Zealand) for the first time.

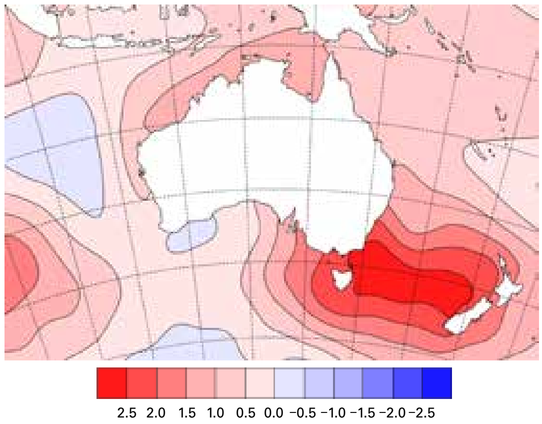
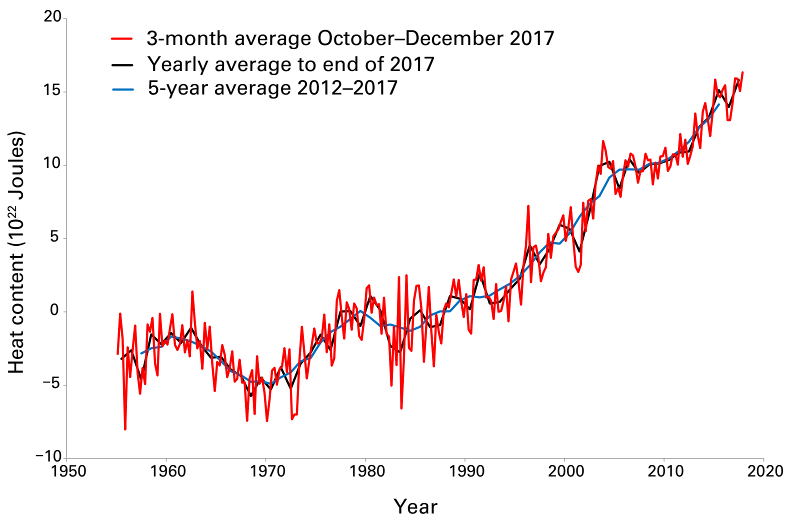


Figure 5. 5 December 2017 monthly sea-surface temperature anomalies (°C), showing temperatures 2.5°C or more above average in the southern Tasman Sea.
(Source: Australian Bureau of Meteorology)

Ocean heat content, a measure of the heat in the oceans through their upper layers, reached new record highs in 2017. Mean ocean heat content for 2017 for the 0–700 metre layer was 158.1 ZJ,[8] 6.9 ZJ higher than the previous annual mean record set in 2015. The mean for the October–December 2017 quarter, 163.4 ZJ, was also the highest quarterly value on record. The ocean heat content for the 0–2000 metre layer (233.5 ZJ) was also the highest on record, although records for this layer only extend back to 2005. Annual records for the 0–700 metre layer were also set for the northern hemisphere and for the Atlantic and Pacific Oceans, although the Indian Ocean had its lowest value since 2009.

Figure 6. Global ocean heat content change (x 10^{22} J) for the 0–700 metre layer: three-monthly means (red), and annual (black) and 5-year (blue) running means, from the US National Oceanic and Atmospheric Administration (NOAA) dataset.
(Source: prepared by WMO using data from NOAA National Centers for Environmental Information)



6 Australian Research Council (ARC) Centre of Excellence, Coral Reef Studies, https://www.coralcoe.org.au/.

7 NOAA Coral Reef Watch, coralreefwatch.noaa.gov.

8 Data sourced from NOAA; 1 ZJ (zetajoule) = 10^{21} J, a standard unit of energy.

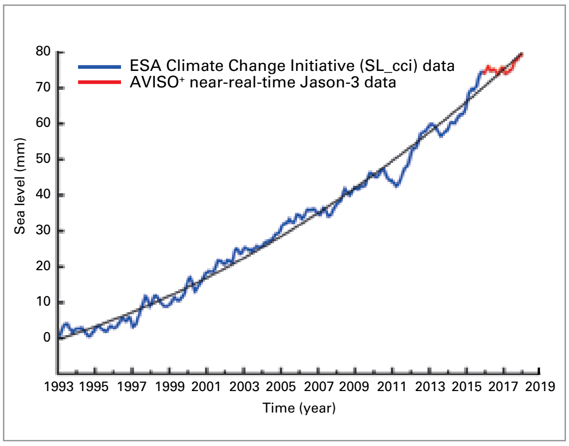


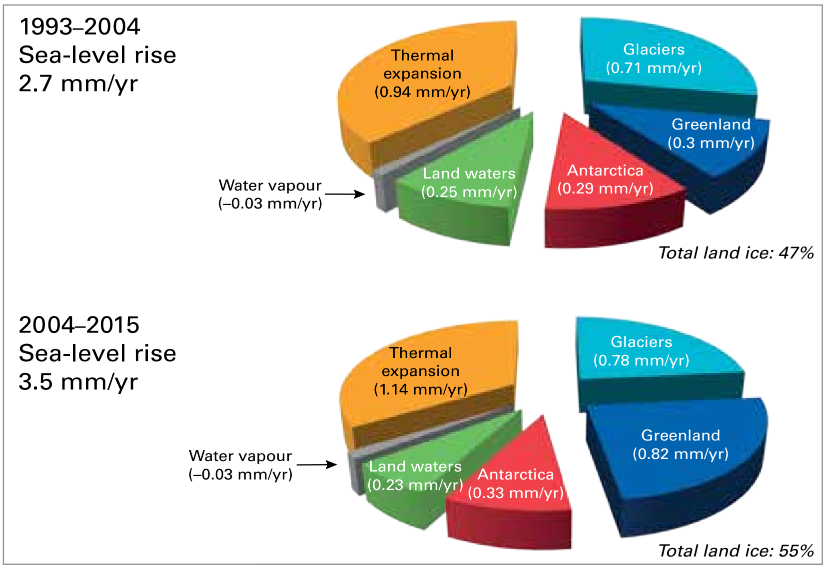
Figure 7. Global mean sea-level time series (with seasonal cycle removed), January 1993–January 2018, from satellite altimetry multi-missions. Data from AVISO *(Source: Collecte-Localisation-Satellite (CLS) – Laboratoire d'Etudes en Géophysique et Océanographie Spatiales (LEGOS))*

SEA LEVEL

The global mean sea level (GMSL) was relatively stable in 2016 and early 2017. This is because the temporary influence of the 2015/2016 El Niño (during which the GMSL peaked in early 2016 at around 10 millimetres above the 2004–2015 trend) continued to diminish and the GMSL reverted to values closer to the long-term trend. However, most recent sea-level data indicate that the GMSL has been rising again since mid-2017.

The pie charts show the contributions of individual components of the sea-level budget (expressed in percentage of the observed global mean sea level) for two periods, 1993–2004 and 2004–2015.[9] It clearly shows that the magnitude of almost all components has increased in recent years, particularly melting of the polar ice sheets, mostly in Greenland and to a lesser extent in Antarctica. Accelerated ice-mass loss from the ice sheets is the main cause of acceleration of the global mean sea-level rise, as revealed by satellite altimetry. This is even clearer when year-to-year fluctuations due to El Niño and La Niña as well as temporary cooling from the 1991 Mt Pinatubo eruption are removed.[10]

The bar chart (bottom) shows annual mean altimetry-based sea level (blue bars) and sum of thermal expansion and ocean mass component (red bars) for the years 2005 to 2016. Black vertical bars are associated uncertainties. Thermal expansion is based on Argo data[11] and ocean mass is derived from the Gravity Recovery and Climate Experiment (GRACE) (updates from Johnson and Chambers, 2013,[12] Lutchke et al., 2013,[13]



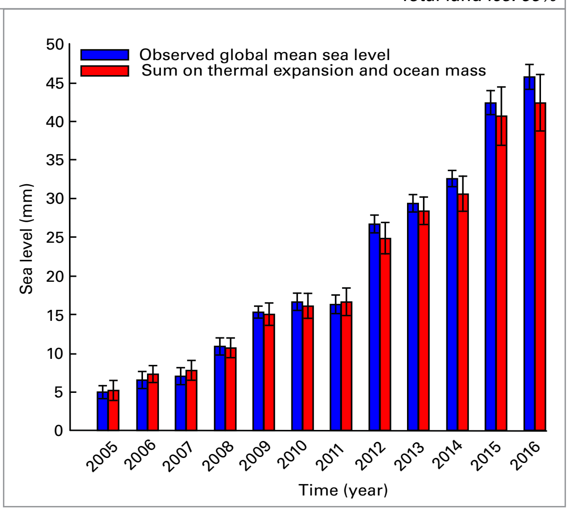


Figure 8. Percentage of individual contributions to global mean sea-level rise in 1993–2004 and 2004–2015 (top); annual sea-level budget (2005–2016) (bottom) *(Source: Dieng, H. et al., 2017: New estimate of the current rate of sea level rise from a sea level budget approach.* Geophysical Research Letters*, 44)*

[9] Dieng, H. et al., 2017: New estimate of the current rate of sea level rise from a sea level budget approach. *Geophysical Research Letters*, 44, doi:10.1002/2017GL073308.

[10] Nerem, R.S. et al., 2018: Climate-change-driven accelerated sea-level rise detected in the altimeter era. *Proceedings of the National Academy of Sciences of the United States of America*, published on line on 13 February 2018.

[11] Ibid.

[12] Johnson, G. C. and D. P. Chambers, 2013: Ocean bottom pressure seasonal cycles and decadal trends from GRACE Release-05: Ocean circulation implications. *Journal of Geophysical Research*, Oceans, Vol.118, 9:4228–4240, doi: 10.1002/jgrc.20307.

[13] Luthcke, S. B. et al., 2013: Antarctica, Greenland and Gulf of Alaska land-ice evolution from an iterated GRACE global mascon solution. *Journal of Glaciology*, 59:613–631, doi:10.3189/2013JoG12J147.

Watkins et al., 2015[14]). The sea-level budget is almost closed (i.e. the observed change can be almost fully accounted for by the known changes in the contributing components) within respective error bars, although since 2012 the sum of contributions from thermal expansion and changes in ocean mass is generally slightly lower than the observed change in annual sea level. The plot also shows a clear increase of the mean sea level from one year to another.

OCEAN ACIDIFICATION

The ocean absorbs up to 30% of the annual emissions of anthropogenic CO_2 into the atmosphere, helping to alleviate the impacts of climate change on the planet. However, this comes at a steep ecological cost, as the absorbed CO_2 reacts in seawater and changes acidity levels in the ocean. More precisely, this involves a decrease in seawater pH together with closely linked shifts in the carbonate chemistry of the waters, including the saturation state of aragonite, which is the main form of calcium carbonate used by key species to form shells and skeletal material (e.g. reef-building corals and shelled molluscs). Observations of marine acidity in open ocean and coastal locations have revealed that present-day conditions are often outside pre-industrial bounds. In some regions, the changes are amplified by natural processes such as upwelling (where cold water that is rich in CO_2 and nutrients rises from the deep toward the sea surface), resulting in conditions outside biologically relevant thresholds.

Projections of future ocean conditions show that ocean acidification affects all areas of the ocean, while consequences for marine species, ecosystems and their functioning vary. Over the past 10 years, various studies have confirmed that ocean acidification is directly influencing the health of coral reefs; the success, quality and taste of aquaculture-raised fish and seafood; and the survival and calcification of several key organisms. These alterations often affect species at lower trophic levels and have cascading effects within the food web, which are expected to result in increasing impacts on coastal economies.

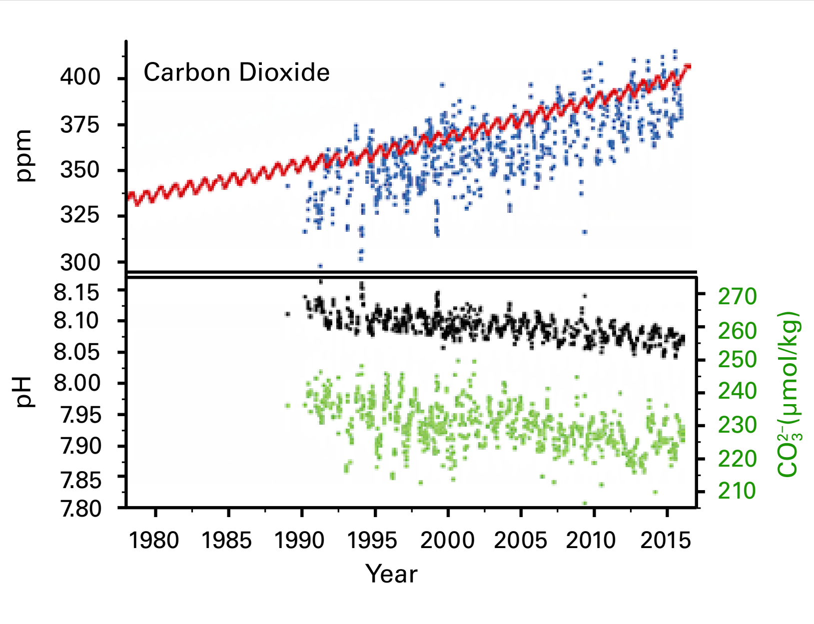


Figure 9. Trends in surface (< 50 m) ocean carbonate chemistry calculated from observations obtained at the Hawaii Ocean Time-series (HOT) Program in the North Pacific over 1988–2015. The upper panel shows the linked increase in atmospheric (red points) and seawater (blue points) CO_2 concentrations. The bottom panel shows a decline in seawater pH (black points, primary y-axis) and carbonate ion concentration (green points, secondary y-axis). Ocean chemistry data were obtained from the Hawaii Ocean Time-series Data Organization & Graphical System (HOT-DOGS). *(Source: US National Oceanic and Atmospheric Administration (NOAA), Jewett and Romanou, 2017)*

Further, ocean acidification does not impact marine ecosystems in isolation. Multiple other environmental stressors can interact with ocean acidification, such as ocean warming and stratification, de-oxygenation and extreme events, as well as other anthropogenic perturbations such as overfishing and pollution.

There has been a consistent trend in ocean acidification over time. Since records at Aloha station (north of Hawaii) began in the late 1980s, seawater pH has progressively fallen, from values above 8.10 in the early 1980s to between 8.04 and 8.09 in the last five years.

THE CRYOSPHERE IN 2017

Sea-ice extent was well below the 1981–2010 average throughout 2017 in both the Arctic and Antarctic. The winter maximum of Arctic sea ice of 14.42 million square kilometres, reached on 7 March, was the lowest winter maximum in the satellite record, 0.10 million square kilometres below the previous record low set in 2015. However, melting during the spring and summer was slower than in some recent years. The summer minimum of 4.64 million square kilometres on 13 September was the eighth-lowest on record, 1.25 million square kilometres above the 2012 record low. A slow

[14] Watkins, M. et al., 2015: Improved methods for observing Earth's time variable mass distribution with GRACE using spherical cap mascons. *Journal of Geophysical Research*, Solid Earth, 120:2648–2671, doi:10.1002/2014JB011547.

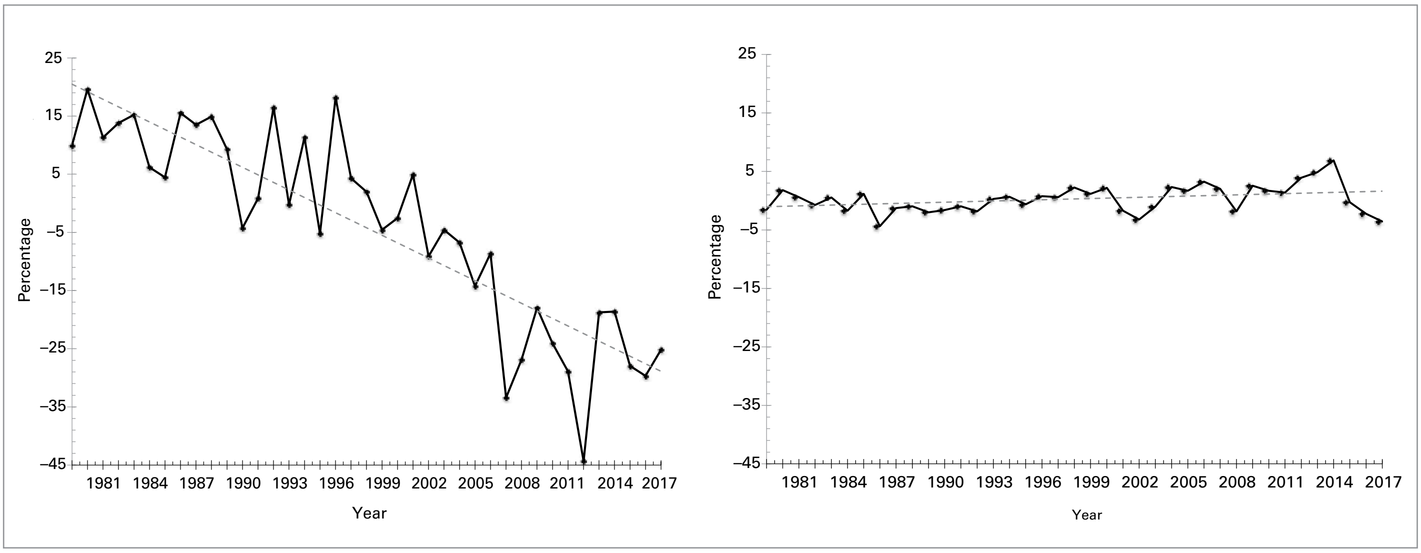


Figure 10. (left) September sea-ice extent for the Arctic, and (right) September sea-ice extent for the Antarctic. Percentage of long-term average of the reference period 1981–2010 *(Source: prepared by WMO using data from the US National Snow and Ice Data Center)*

freeze-up during the autumn saw Arctic sea-ice extent once again at near record low levels for the time of year by the end of December.

Antarctic sea-ice extent was at or near record low levels throughout the year. The summer minimum of 2.11 million square kilometres, recorded on 3 March, was 0.18 million square kilometres below the previous record set in 1997, whilst the winter maximum of 18.03 million square kilometres, recorded on 12 October (the equal-latest maximum date on record), was second behind 1986.

The mass balance change (the estimated change of the mass of ice from one year to the next) of the Greenland ice sheet in the year from September 2016 to August 2017 was well above the 1981–2010 average, due mainly to unusually heavy precipitation during autumn 2016. The mass balance change from September to December 2017 was close to average. Although the overall ice mass increased, this was only a small departure from the trend over the past two decades, with the Greenland ice sheet having lost approximately 3 600 billion tons of ice mass since 2002.

Mass balance change data for 2017 for glaciers outside major continental ice sheets are not yet available. For 2016, mass balance change, averaged across a set of 26 reference glaciers with data available at the time of writing, was approximately −900 mm water equivalent. This was a smaller decrease than in 2015, but close to the 2011–2016 mean. The glacial mass balance change has been negative in every year since 1988.

The northern hemisphere snow cover extent was near or slightly above the 1981–2010 average for most of the year, most significantly in May (9% above average, 12th highest on record). May snow cover extent was the highest since 1996, and the highest in Eurasia since 1985, with particularly strong anomalies in north-western Russia and northern Scandinavia, where May temperatures were well below average. Summer snow cover extent, which has been showing a strong downward trend, was close to the long-term average in 2017 for the first time in more than a decade, giving June, July and August the highest values since 2004, 2006 and 1998 respectively. Similar to most recent years, autumn snow cover extent was above average, although not to the same extent as in 2016, with October and November both ranking 9th highest. Snow cover extent returned to slightly below average in December. Contrasting precipitation anomalies during the 2016/2017 winter saw alpine snow cover well below average in most of the European Alps, but at or near record high levels in Corsica.

In the southern hemisphere, an extensive snow event in southern South America from 14 to 21 June saw continental snow cover extent reach 750 000 square kilometres, the highest since satellite monitoring began in 2005, whilst the alpine snowpack at high elevations in south-eastern Australia was the deepest since 2000.

MAJOR DRIVERS OF INTERANNUAL CLIMATE VARIABILITY IN 2017

There are several large-scale modes of variability in the world's climate that influence conditions over large parts of the world on seasonal to interannual timescales. The El Niño/Southern Oscillation (ENSO) is probably the best-known of the major drivers of interannual climate variability. The equatorial Indian Ocean is also subject to fluctuations in sea-surface temperatures, although on a less regular basis than the Pacific. The Indian Ocean Dipole (IOD) describes a mode of variability that affects the western and eastern parts of the ocean. The Arctic Oscillation (AO) and North Atlantic Oscillation (NAO) are two closely related modes of variability in the atmospheric circulation at middle and higher latitudes of the northern hemisphere. In positive mode, the subtropical high-pressure ridge is stronger than normal, as are areas of low pressure at higher latitudes, such as the "Icelandic" and "Aleutian" lows, resulting in enhanced westerly circulation through mid-latitudes. In negative mode, the reverse is true, with a weakened subtropical ridge, weakened higher-latitude low pressure areas and an anomalous easterly flow through mid-latitudes. The Southern Annular Mode (SAM), also known as the Antarctic Oscillation (AAO), is the southern hemisphere analogue of the AO.

In contrast with 2016, which saw the later part of one of the strongest El Niño events of the last 50 years, a neutral phase of ENSO prevailed for most of 2017. The year began with conditions slightly cooler than average in the central and eastern equatorial Pacific, consistent with the borderline cool neutral/weak La Niña conditions which had existed in the last part of 2016. These cool anomalies had weakened by February, before becoming re-established later in 2017. By November, conditions had cooled to the point where a weak La Niña event had been declared by most agencies.

Whilst there was no basin-wide El Niño in 2017, there was a sharp warming near the South American coast early in the year, of a type more often seen during El Niño events. Temperatures near the coast of Ecuador and Peru were more than 2 °C above average in February and March, before declining in the following months. These warm coastal temperatures were associated with significant flooding, particularly in Peru (something which had been largely absent during the previous year's El Niño), whilst there were also heavy rains and flooding in California to an extent which far exceeded that of the 2015/2016 El Niño.

The Indian Ocean Dipole was generally on the positive side of neutral for most of 2017, although the strength of the signal varied considerably between different datasets (the strongest cool signal in the eastern Indian Ocean was also south of the 10°S southern boundary of the area used to define IOD indices). The IOD state was associated with dry conditions in much of Australia between May and September, and with a return to average to above-average rains in the Horn of Africa late in the year after an extended period of drought.

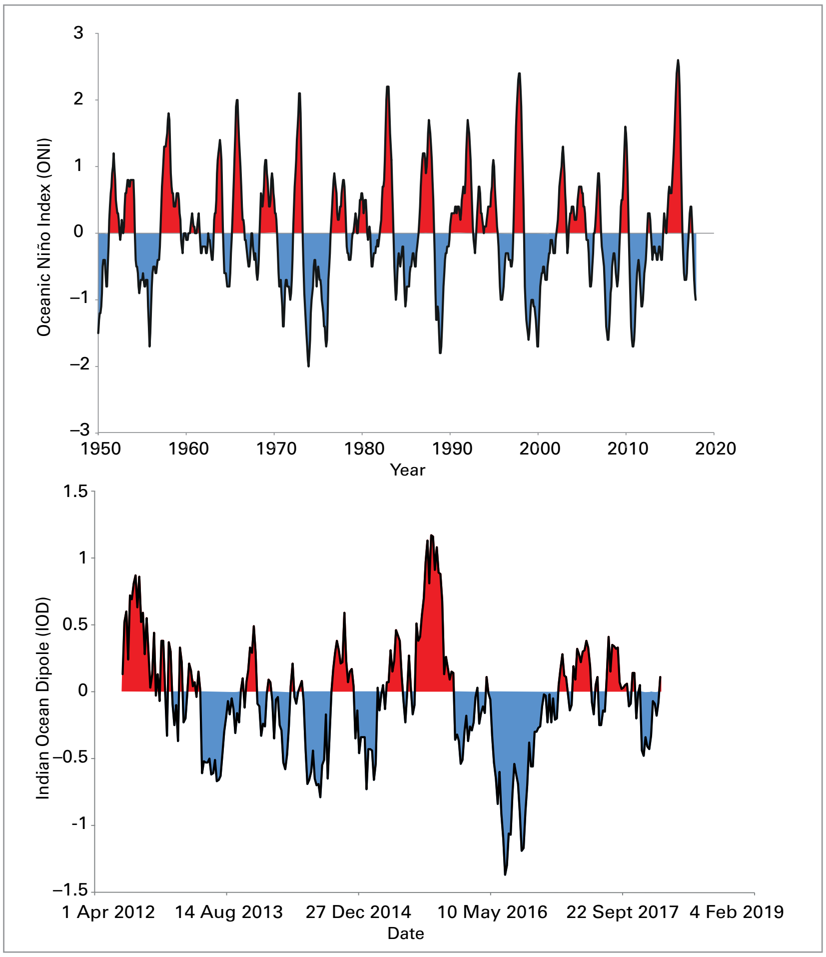


Figure 11. The Oceanic Niño Index (ONI) (top) and Indian Ocean Dipole (IOD) index (bottom). *(Source: prepared by WMO using data from the US National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (ONI) and the Australian Bureau of Meteorology (IOD))*

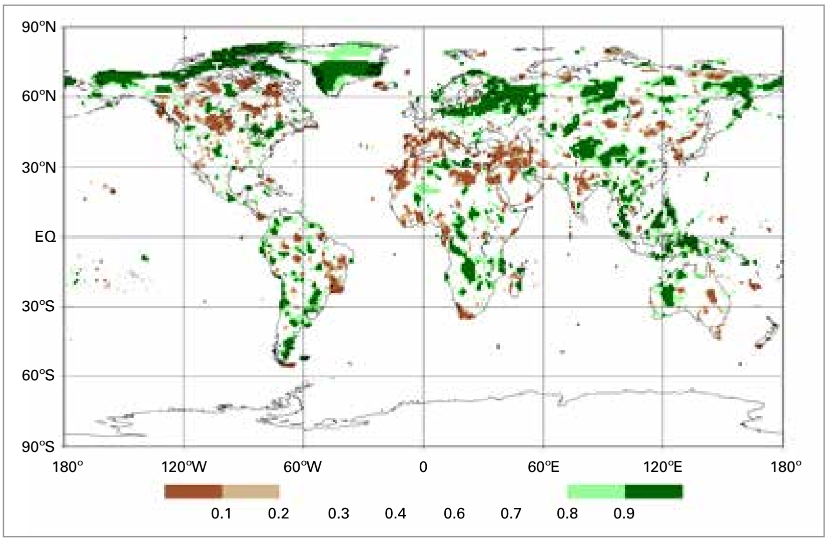


Figure 12. Annual total precipitation expressed as a percentile of the 1951–2010 reference period for areas that would have been in the driest 20% (brown) and wettest 20% (green) of years during the reference period, with darker shades of brown and green indicating the driest and wettest 10%, respectively *(Source: Global Precipitation Climatology Centre, Deutscher Wetterdienst, Germany)*

The Arctic Oscillation and North Atlantic Oscillation were both generally positive in their season of peak influence, January to March, with index values of +0.88 and +0.74 respectively, although in both cases these values were less strongly positive than in the equivalent period of 2016. These positive index values were associated with generally above-average temperatures in the 2016/2017 winter in most of Europe (despite a cold January) and eastern North America, and with dry winter conditions in the Mediterranean. Arctic Oscillation index values at the start of the 2017/2018 winter were near zero.

The Southern Annular Mode had its first period of sustained negative values for over two years in late 2016 and early 2017, with the three-month SAM index for November 2016 to January 2017 reaching –1.07, the strongest negative value since late 2013. Positive values then resumed for most of the remainder of 2017, although they were not as strong as those that prevailed for most of 2015 and 2016.

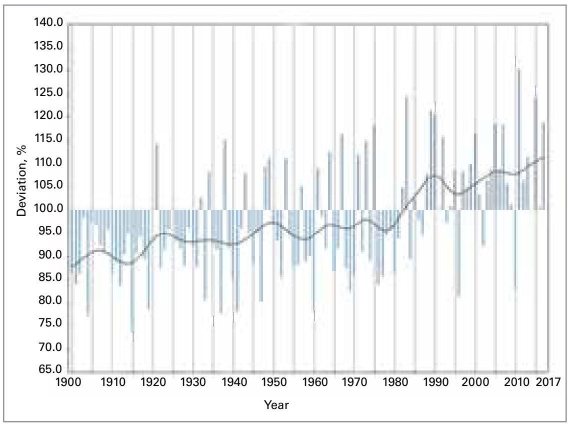


Figure 13. Annual precipitation for Norway in percentage of normal *(Source: Norwegian Meteorological Institute (Met.no))*

PRECIPITATION IN 2017

There were fewer areas with large precipitation anomalies in 2017 than there had been in 2015 or 2016, as the influence of the strong El Niño event of 2015/2016 ended.

The most extensive area with annual rainfall above the 90th percentile in 2017 was in north-east Europe, extending from northern European Russia as far west as northern Germany and southern Norway. European Russia had its second-wettest year on record (as did Russia as a whole) and Norway its sixth-wettest. Autumn was especially wet in the Baltic region, with Estonia and Lithuania both having their wettest autumn on record and Latvia its second-wettest.

Thailand had its wettest year on record, with national rainfall 27% above average. The south was especially wet with the east coast region 56% above average. However, the high rainfall was more evenly distributed through the year than it was in the previous record wet year of 2011. Even though that year's extreme flooding was not repeated, there were significant local floods from time to time, particularly in the south of the country early in the year. Rainfall above the 90th percentile also occurred in the Philippines, parts of eastern Indonesia and the interior of Western Australia.

Other areas with annual rainfall above the 90th percentile included parts of inland southern Africa, scattered areas in the southern half of South America east of the Andes, and around the Great Lakes in North America. Michigan had its wettest year on record, with very wet conditions also in the Great Lakes and St Lawrence region of Canada. Rainfall significantly above average also affected many parts of Central America and the Caribbean islands, with the largest anomalies in those parts of the Eastern Caribbean that were most affected by hurricanes.

Dry conditions with rainfall below the 10th percentile were most widespread around the Mediterranean, extending east as far as the Islamic Republic of Iran. They were especially prominent in southern Europe, from Italy westwards to Portugal, in north-western Africa and in south-west Asia, from eastern Turkey and the western Islamic Republic of Iran south to Israel. A small but significant area with rainfall below the 10th percentile affected the far south-west of South Africa. Other major areas with rainfall below the 10th percentile in 2017 included parts of central India and eastern Brazil, and the North American Prairies on both sides of the United States-Canada border.

Monsoon season rainfall was generally fairly close to average in the Indian subcontinent (where all-India rainfall for June to September was 5% below average), although with local variations, including significantly above-average totals in much of Bangladesh and parts of far eastern India. Monsoon season rainfall was also fairly close to average in the Sahel of west and central Africa, although flooding in late August from local heavy rains caused significant losses in Niger. Rainfall in 2017 was also close to average over most of the more heavily populated parts of western and central Indonesia, in Singapore, in most of Japan (where an exceptionally wet October offset a dry first half of the year) and in north-western South America.

EXTREME EVENTS

Extreme events have many significant impacts in terms of casualties, other health effects, economic losses and population displacement.[15] They are also a major driver of interannual variability in agricultural production.

A DESTRUCTIVE NORTH ATLANTIC HURRICANE SEASON, BUT NEAR AVERAGE GLOBALLY

There were 84 tropical cyclones around the globe in 2017,[16] very close to the long-term average. A very active North Atlantic season was offset by near- or below-average seasons elsewhere. The North Atlantic had 17 named storms, and the seventh-highest value of Accumulated Cyclone Energy (ACE) on record, including a record monthly value for September. The Northeast and Northwest Pacific basins both had a near-average number of cyclones but relatively few severe cyclones, leading to below-average ACE values in both basins.

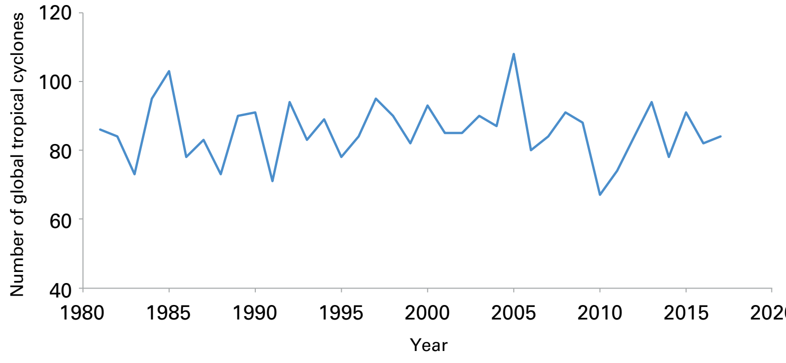


Figure 14. Total number of tropical cyclones globally, by year
(Source: WMO)

The 2016/2017 southern hemisphere season was below average on all measures, particularly in the first half of the season. Whilst the Australian region had a near-average number of cyclones, the south-west Indian Ocean and south-west Pacific (east of 160°E) were both well below average. The total hemispheric ACE was the lowest recorded since regular satellite coverage began in 1970.

Three exceptionally destructive hurricanes occurred in rapid succession in the North Atlantic in late August and September. *Harvey* made landfall in south Texas as a category 4 system, then remained near-stationary in the Houston area for several days, producing exceptionally prolonged extreme rainfall and severe flooding. An exceptional 1 539 mm of rain fell from 25 August to 1 September at a gauge near Nederland, Texas — the largest amount of rain ever recorded in a tropical cyclone in the United States — whilst the storm total rainfall was in the 900–1 200 mm range in much of metropolitan Houston.[17] One

[15] World Bank, 2017: A 360 degree look at Dominica post Hurricane *Maria*, 28 November, www.worldbank.org/en/news/feature/2017/11/28/a-360-degree-look-at-dominica-post-hurricane-maria

[16] Consistent with standard practice, the 2017 value quoted here is the sum of the values from January to December 2017 for northern hemisphere basins, and July 2016–June 2017 for southern hemisphere basins.

[17] National Hurricane Center, 2018: *National Hurricane Center Tropical Cyclone Report –Hurricane Harvey,* https://www.nhc.noaa.gov/data/tcr/AL092017_Harvey.pdf.

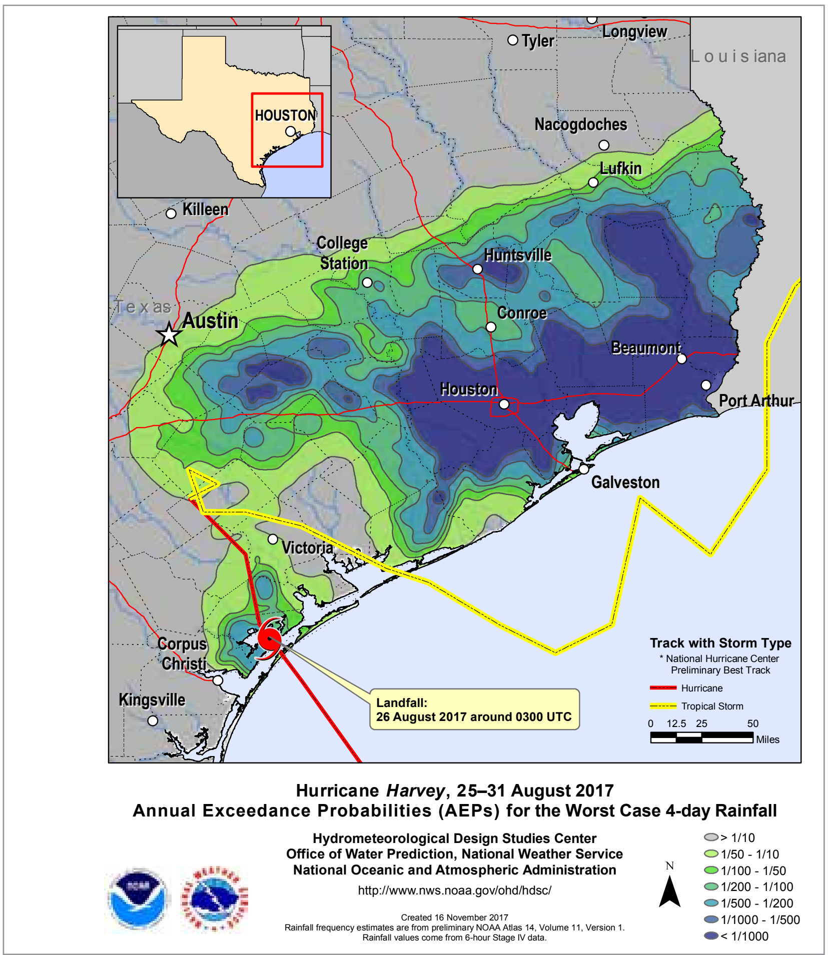


Figure 15. Annual exceedance probabilities for the peak 4-day rainfall during Hurricane *Harvey*, showing that much of the area from east Houston to the Texas-Louisiana border had 4-day rainfalls with an annual exceedance probability less than 1 in 1000. *(Source: US National Oceanic and Atmospheric Administration (NOAA)*

study[18] found that the maximum three-day rainfalls during Hurricane *Harvey* were made three times more likely by anthropogenic climate change.

Harvey was followed by Hurricane *Irma,* in early September, and by *Maria* in mid-September. Both hurricanes peaked at category 5 intensity, with *Irma* maintaining that intensity for 60 hours, which is longer than in any North Atlantic hurricane in the satellite era. *Irma*'s initial landfall, at near-peak intensity, led to extreme damage across numerous Caribbean islands, most significantly on Barbuda, which experienced near-total destruction, with only a few inhabitants having returned as of early 2018. Other islands to experience major damage included Saint Martin/Sint Maarten, Anguilla, St Kitts and Nevis, the Turks and Caicos Islands, the Virgin Islands and the southern Bahamas. *Irma* went on to track along the northern coast of Cuba, leading to extensive damage there, before making landfall in south-west Florida at category 4 intensity.

Hurricane *Maria* made initial landfall on Dominica at near-peak intensity, making it the first category 5 hurricane to strike the island, and leading to major destruction there. The World Bank estimates Dominica's total damages and losses from the hurricane at US$ 1.3 billion or 224% of its Gross Domestic Product (GDP). The storm weakened slightly but was still a category 4 hurricane when it reached Puerto Rico. *Maria* triggered widespread and severe damage on Puerto Rico from wind, flooding and landslides. Power was lost to the entire island, and had only been restored to just over half the population three months after the hurricane, whilst water supplies and communications were also severely affected.

All three of these hurricanes were assessed by the National Centers for Environmental Information (NCEI) as ranking in the top five for hurricane-related economic losses in the United States (alongside *Katrina* in 2005 and *Sandy* in 2012), with estimated costs of US$ 125 billion for *Harvey*, US$ 90 billion for *Maria* and US$ 50 billion for *Irma*.[19] *Irma* and *Maria* also led to substantial losses outside the United States. At least 251 deaths were attributed to the three hurricanes in the United States (including Puerto Rico and the US Virgin Islands) and 73 elsewhere.[20]

Other significant hurricanes during the 2017 North Atlantic season, both in October, were Hurricane *Nate*, which was associated with significant flooding in Central America

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[18] Van Oldenborgh, G.J. et al., 2017: Attribution of extreme rainfall from Hurricane *Harvey*, August 2017. *Environmental Research Letters*, 12, 124009.

[19] The total losses reported by NCEI for these three hurricanes (central estimate US$265 billion) are higher than the assessment by Munich Re (US$215 billion, including losses outside the United States), but this difference is within the margin of uncertainty. It may also reflect differences in accounting for indirect economic losses.

[20] Unless otherwise stated, casualty and economic loss data reported in this statement are sourced from the EM-DAT database, Centre for Research on the Epidemiology of Disasters, Université catholique de Louvain, Belgium, www.emdat.be. For the 2017 North Atlantic hurricane season, casualties and economic losses for the United States and its territories were as reported by NCEI.

NORTH ATLANTIC HURRICANE SEASON 2017: INDUCED LOSS AND DAMAGE

When Hurricane *Irma* made landfall, it hit Barbuda with maximum sustained winds of 295 km/h, record rainfall and a storm surge of nearly three metres. Deaths were limited to one but an estimated 90% of properties were damaged. This prompted the Prime Minister to order the complete evacuation of all residents as Hurricane *Jose* approached. It was three weeks before residents were permitted to return, and three months later only an estimated 20% of the population had returned. The long-term impact remains to be seen, with damage and loss estimated at US$ 155 million, and recovery and reconstruction needs estimated at US$ 222.2 million[1] – together accounting for approximately 9% of the gross domestic product of Antigua and Barbuda.

Hurricane *Maria* proved still more devastating for Dominica. Total damages and losses were estimated at US$ 1.3 billion or 224% of GDP, with significant parts of the island's rainforest damaged and destroyed. This has implications for the whole of society: the losses incurred by the tourist sector alone are estimated at 19%, and 38% of housing was damaged.[2] *Maria* caused the longest blackout in the history of the United States in Puerto Rico, which affected 35% of the island's population for at least three months – continued problems following the hurricane may see the privatization of the Puerto Rico Electric Power Authority (PREPA), the largest publicly owned corporation in the United States.[3] The disaster prompted the Federal Emergency Management Agency to approve US$ 1.02 billion of assistance to the Individuals and Households Program and obligate US$ 555 million in Public Assistance grants.[4]

[1] Post-Disaster Needs Assessment (PDNA) carried out with the support of the European Union (EU), the United Nations Development Programme (UNDP), the World Bank and the Caribbean Disaster Emergency Management Agency (CDEMA).

[2] Government of the Commonwealth of Dominica, 2017: Post Disaster Needs Assessment – Hurricane *Maria*, September 18, 2017, https://reliefweb.int/sites/reliefweb.int/files/resources/dominica-pdna-maria.pdf

[3] Attributed to the Governor of Puerto Rico.

[4] Government of the United States of America, Department of Homeland Security, Federal Emergency Management Agency.

(especially Costa Rica and Nicaragua), and Hurricane *Ophelia*, which became the easternmost hurricane on record to reach major (category 3) intensity, before crossing Ireland as a transitioning extratropical storm and leading to widespread damage. *Ophelia*'s broader wind field also contributed to destructive wildfires in Portugal.

Whilst the number of severe cyclones in the Northwest Pacific in 2017 was low, a number of systems still brought widespread destruction and heavy casualties, mostly from flooding. The largest loss of life from a tropical cyclone in 2017 was in late December, when Typhoon *Tembin* (*Vinta*) crossed the island of Mindanao with a peak 10-minute wind speed of 36 m s^{-1} (70 kt), resulting in at least 129 deaths,[21] mostly from flooding. Two separate events in Vietnam, an unnamed tropical depression in October and Typhoon *Damrey* (*Ramil*) in early November, were both associated with over 100 deaths from flooding. The heaviest economic losses were from Typhoon *Hato* (*Isang*) in August, which hit Hong Kong, Macau and neighbouring areas of China on 23 August, with an estimated US$ 6 billion in losses and at least 32 deaths.[22] It was the strongest impact in Macau for more than 50 years.

The two most significant cyclones of the year in the North Indian Ocean were Cyclone *Mora* in late May, and Cyclone *Ockhi* in early December, both of which caused substantial casualties. The major impact of both cyclones was severe flooding and landslides associated with their respective precursor lows. Sri Lanka

[21] Philippines Office of Civil Defense, Situation Report 25, 7 February 2018.

[22] Reports from the China Meteorological Administration and the government of the Macao SAR.

Chris B. Pye

ST THOMAS, US VIRGIN ISLANDS
Hurricane *Irma* destruction

was badly affected by both cyclones, whilst *Ockhi* also had major impacts in southern India, including a great number of fishermen going missing at sea. The largest impacts from Northeast Pacific systems in 2017 were from flooding, with Tropical Storm *Lidia* leading to significant flooding in Mexico in August, and Tropical Storm *Selma* (the first recorded tropical cyclone to make landfall in El Salvador) doing likewise in El Salvador, Nicaragua and Honduras.

Although the number of tropical cyclones in the south-west Indian Ocean was below average, there were two which had major impacts. *Dineo*, with maximum 10-minute winds of 39 m s^{-1} (75 kt), was the first to make landfall in Mozambique since 2008 when it hit in early February. In addition to its effects in Mozambique, the subsequent overland low resulted in severe flooding in Zimbabwe and northern South Africa, and was the main contributor to the 246 flood-related deaths reported in Zimbabwe during the 2016/2017 rainy season.[23] *Enawo*, in early March, hit the east coast of Madagascar at near its peak intensity (10-minute winds of 57 m s^{-1} (110 kt)). *Enawo* had major impacts on Madagascar,[24] with at least 81 associated deaths reported and extensive damage to houses, infrastructure and crops. Agricultural losses were estimated by the World Bank at US$ 207 million, mostly from the destruction of vanilla plantations.

In the Southwest Pacific, Cyclone *Debbie* hit the east coast of Australia in late March, making landfall in the Whitsunday region with maximum 10-minute winds of 43 m s^{-1} (80 kt) after earlier peaking at 49 m s^{-1} (95 kt), leading to extensive wind and flood damage. The system then tracked south and south-east as a tropical low, with widespread major flooding, especially on the east coast near the Queensland-New South Wales border. The remnant system then went on to be largely responsible for major flooding in much of the North Island of New Zealand in early April. Insured losses for *Debbie* in Australia were approximately US$ 1.3 billion,[25] the second-highest on record for an Australian tropical cyclone. Cyclone *Donna* was the strongest May cyclone on record in the Southwest Pacific region, with peak 10-minute winds

[23] United Nations Office for the Coordination of Humanitarian Affairs (OCHA), 2017: Zimbabwe Flood Snapshot, https://reliefweb.int/sites/reliefweb.int/files/resources/zimbabwe_flood_snapshot_3march2017.pdf.

[24] World Bank, 2017: Estimation of Economic Losses from Tropical Cyclone Enawo, https://reliefweb.int/sites/reliefweb.int/files/resources/MG-Report-on-the-Estimation-of-Economic-Losses.pdf.

[25] Insurance Council of Australia, media release 6 November 2017.

reaching 57 m s^{-1} (111 kt) on 8 May, with some damage reported, especially in Vanuatu.

HIGH WINDS AND SEVERE LOCAL STORMS

There were a number of destructive severe thunderstorms in 2017, with central and eastern Europe particularly affected during the spring and early summer. Winds, exceeding 100 km/h during a thunderstorm resulted in widespread damage and at least 11 deaths in Moscow on 29 May. Other noteworthy storms included a severe hailstorm and tornado that affected the southern suburbs of Vienna on 10 July, a 165 km/h wind gust at Innsbruck on 30 July, a hailstorm with hailstones up to 9 cm in diameter in Istanbul on 27 July, and widespread thunderstorms that left 50 000 households without power in southern Finland on 12 August. Severe flash flooding affected parts of the Croatian coast on 11 September, with 283 mm of rain recorded in 12 hours at Zadar.

For the first time since 2011, the United States had an above-average tornado season, with a preliminary annual total of 1 406 tornadoes, 12% above the 1991–2010 average. However, the number of fatalities during the season (34) was below the long-term average. The most destructive storm of the season was a hailstorm that hit Denver on 8 May, with hailstones exceeding 5 cm in diameter. Insured losses from this event exceeded US$ 2.2 billion.

A severe windstorm (known locally as *Zeus*) affected France on 6–7 March. Peak gusts reached 193 km/h at Camaret-sur-Mer in Brittany, and the storm was rated by Météo-France as the most significant windstorm in France since 2010. Later in the year, a storm in late October produced wind gusts exceeding 170 km/h at high elevations and 140 km/h in the lowlands in Austria and Czechia, with 11 deaths reported in total.

FLOODING (NON-TROPICAL CYCLONE) AND ASSOCIATED PHENOMENA

One of the most significant weather-related disasters of 2017, in terms of casualties, was a landslide in Freetown, Sierra Leone, on 14 August, in which at least 500 deaths occurred.[26] Exceptionally heavy rain was a major contributor to this disaster; Freetown received 1 459.2 mm in the period from 1 to 14 August, about four times the average rainfall for this period. Another major landslide associated with heavy rainfall occurred in Mocoa, in southern Colombia, on 1 April, with at least 273 deaths reported.

Many parts of the Indian subcontinent were affected by flooding during the monsoon season between June and September, despite overall seasonal rainfall being near average over the region. The most serious flooding occurred in mid-August, after extremely heavy rainfall over a region centred on eastern Nepal, northern Bangladesh and adjacent areas of northern and north-eastern India. Mawsynram (India), near the Bangladesh border, received 1 479 mm in the four days from 9 to 12 August. Daily totals in excess of 400 mm also occurred near the India-Nepal border, and the Rangpur region of northern Bangladesh received 360 mm, approximately the average monthly total, on 11–12 August. Across the period as a whole, more than 1 200 deaths were reported in India, Bangladesh and Nepal,[27] whilst more than 40 million people were affected. The World Health Organization (WHO) noted that in Bangladesh alone more than 13 000 cases of waterborne diseases and respiratory infections were reported over three weeks in August,[28] whilst extensive damage was reported to public health facilities in Nepal.[29]

Earlier in the season, 292 deaths were reported in Sri Lanka in late May, principally in southern

[26] International Organization for Migration (IOM), 2017 : Sierra Leone Flood Response. Situation Report, 28 August 2017, https://reliefweb.int/sites/reliefweb.int/files/resources/SL%20Floods%20Sitrep%201.pdf.

[27] World Meteorological Organization, 2017: Rainfall extremes cause widespread socio-economic impacts, https://public.wmo.int/en/media/news/rainfall-extremes-cause-widespread-socio-economic-impacts.

[28] International Federation of Red Cross and Red Crescent Societies (IFRC), 2017: South Asia flood crisis: Disease outbreaks, funding shortages compound suffering of flood survivors, https://media.ifrc.org/ifrc/press-release/south-asia-flood-crisis-disease-outbreaks-funding-shortages-compound-suffering-flood-survivors/.

[29] World Health Organization (WHO), 2017: Nepal. Situation Report #5, https://reliefweb.int/sites/reliefweb.int/files/resources/who_sitrep-06sept2017.pdf.

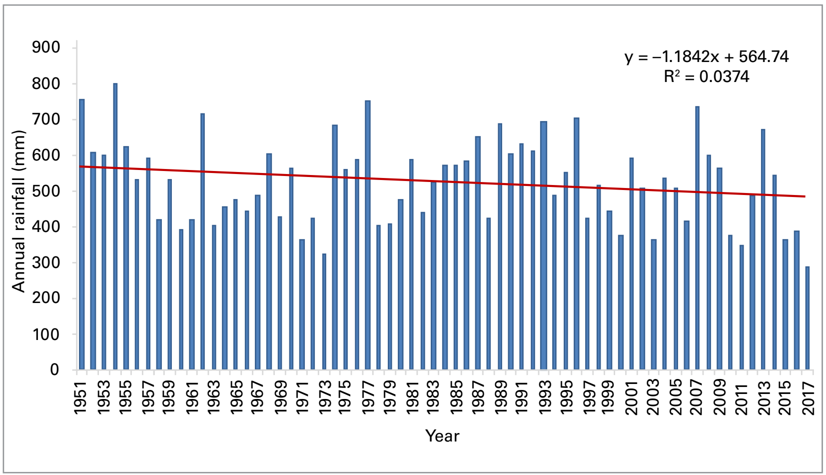


Figure 16. Annual rainfall for Cape Town, South Africa, 1951–2017. *(Source: South African Weather Service)*

and western parts of the country, due to heavy rains from the precursor low to Cyclone *Mora*. Ratnapura received 384 mm of rain in 24 hours on 25/26 May. Some 650 000 people were affected in some way by the floods, but the rains did little to alleviate significant drought in northern and eastern parts of Sri Lanka.[30] Cyclone *Mora* also had significant impacts in Bangladesh and Myanmar.[31] Heavy rains flooded thousands of hectares of crop and damaged poultry sheds, fishing nets and boats, severely eroding the livelihoods of communities that depend on agriculture and fisheries in the affected rural districts.

Flooding affected many parts of Peru in March, after sustained heavy rains. At least 75 deaths[32] were reported, and over 625 000 people were affected, including more than 70 000 who lost their homes. The Food and Agriculture Organization of the United Nations reported that there were significant crop production losses,[33] particularly maize, in the main producing regions of Lambayeque, Piura and Ica. Flooding of this type typically affects Peru during the late phase of El Niño events. Whilst there was no Pacific-wide El Niño during 2017, sea-surface temperatures near the Peruvian coast in March were 2 °C or more above average, values which would be more typical of an El Niño year than of a neutral year such as 2017. Major flooding occurred mid-year in parts of southern China, especially within the Yangtze River basin. The heaviest rain fell in the provinces of Hunan, Jiangxi, Guizhou and Guangxi. Peak totals during the period from 29 June to 2 July were in excess of 250 mm. Fifty-six deaths were reported and economic losses were estimated at more than US$ 5 billion.[34]

DROUGHT

The drought that affected significant parts of east Africa during 2016 continued into 2017. In the March to May rainy season, seasonal rainfall was at least 20% below average over most of Somalia, Kenya and southern Ethiopia, and more than 50% below average over most of the northern half of Kenya and parts of Somalia. There was some easing of conditions late in the year, with near- to above-average rainfall over most of the region in the October–December period. Reports for Somalia indicated that 6.7 million people were experiencing food insecurity as of October, this declined to 5.4 million by the end of December as crop and pasture conditions improved.[35]

Drought worsened significantly during 2017 in the Cape Province of South Africa. Following below-average rainfall in 2015 and 2016, Cape Town had its driest year on record in 2017 with a total of 285 mm (47% below the 1981–2010 average). The three-year period 2015–2017 was also the driest on record (36% below average). The dry conditions led to local water supplies becoming severely depleted, with no significant recovery as of early 2018. However, generally average to above-average rainfall further north in southern Africa during the 2016/2017 rainy season led to an improvement

[30] Food and Agriculture Organization of the United Nations (FAO) and World Food Programme (WFP), 2017: *Special Report. FAO/WFP Crop and Food Security Assessment Mission to Sri Lanka*, http://www.fao.org/3/a-i7450e.pdf.

[31] International Federation of Red Cross and Red Crescent Societies (IFRC), 2017: Emergency appeal revision. Bangladesh: Cyclone Mora, http://reliefweb.int/sites/reliefweb.int/files/resources/MDRBD019_RevEA.pdf.

[32] From information supplied by the United Nations Office for Disaster Risk Reduction (UNISDR).

[33] Food and Agriculture Organization of the United Nations (FAO), 2017: GIEWS – Global Information and Early Warning System. Country Brief: Peru, http://www.fao.org/giews/countrybrief/country.jsp?code=PER.

[34] From information supplied by the China Meteorological Administration.

[35] Food and Agriculture Organization of the United Nations (FAO), 2018: FSNAU-FEWS NET Technical Release, 29 January 2018, http://www.fsnau.org/in-focus/fsnau-fews-net-technical-release-january-29-2018.

in conditions there, with the total number of people experiencing food insecurity declining from 40 million at the peak of the 2014–2016 drought to 26 million in late 2017.[36]

Many parts of the Mediterranean region experienced significant drought in 2017, as did parts of central Europe. In the first part of 2017, the most severe anomalies were in Italy, which had its driest January to August on record (and went on to have its driest year, with annual rainfall 26% below the 1961–1990 average). Further north, Bratislava (Slovakia) had its driest December to August on record and southern Moravia (Czechia) its second-driest January to August. Later in the year the focus of the dry conditions was on south-west Europe. Spain had its driest autumn on record, the Provence-Haute Alpes-Côte d'Azur region in south-east France had its driest May to November, whilst Portugal had its driest April to December and its third-driest year (its four driest having all occurred since 2004). Autumn was also very dry in Morocco. The eastern Mediterranean was also badly affected by drought, including the eastern half of Turkey, Cyprus and most of Israel. The coastal plain of Israel had its driest year on record.

Drought also affected a region of central North America on both sides of the United States-Canada border. Particularly affected were the states of North Dakota and Montana, and the Prairie provinces of Canada, with areas of severe drought identified on both sides of the border.[37] After a period of prolonged drought, the 2016/2017 winter rainfall season brought heavy rains to much of California, and the Sierra Nevada snowpack was 66% above average, the heaviest since 1998. Large-scale evacuations were required in the state's north in February because of the risk of failure of the Oroville Dam. However, dry conditions resumed in the second half of the year, contributing to numerous major wildfires.

[36] World Food Programme (WFP), 2018: Poor Rains and Crop Infestation Threaten Deeper Hunger Across Southern Africa. Media release, 9 February 2018.

[37] National Oceanic and Atmospheric Administration (NOAA), 2017: North American Drought Monitor, December 2017.

Although rainfall deficit was not particularly extreme during 2017, near-average to below-average rainfall resulted in a continuation of multi-year drought in many parts of Brazil north of 20°S, and in central Chile (where 2017 was the wettest year since 2008, but still drier than the long-term average). In the Asia-Pacific region, abnormally dry conditions were reported in the Korean Peninsula in the first half of 2017, whilst New Caledonia experienced significant drought, especially later in the year.

HEATWAVES, A REGULAR FEATURE OF 2017

There were numerous significant heatwaves around the world during 2017, in both the southern and northern hemisphere summers.

Southern South America experienced extreme heat on several occasions during the 2016/2017 summer. The heat peaked in late January, when numerous Chilean stations had their hottest days on record, including Santiago (37.4 °C) and Curico (37.3 °C) on the 25th, and Chillan (41.5 °C) and Concepcion (34.1 °C) on the 26th. The heat extended eastwards into Argentine Patagonia where Puerto Madryn reached 43.4 °C on 27 January, the highest temperature ever recorded so far south. It was also a notably hot summer in much of eastern Australia, where Moree had 54 consecutive days of 35 °C or above from 28 December 2016 to 19 February 2017, the longest such sequence on record in New South Wales. Numerous locations, including Moree (47.3 °C), Dubbo (46.1 °C), Scone (46.5 °C), Bathurst (41.5 °C) and Williamtown (45.5 °C) had their highest recorded temperature on 11–12 February.

Extreme heat affected south-west Asia at the end of May. The temperature at Turbat, in the far south-west of Pakistan, reached 54.0 °C on 28 May, a national record for Pakistan and (if confirmed)[38] an equal record for Asia. During this event, sites in the Islamic Republic of Iran, Oman and the United Arab Emirates also exceeded 50 °C.

[38] This observation, and another of 54.0 °C at Mitribah (Kuwait), are currently being reviewed by a WMO evaluation committee.

SNOW IN THE ALGERIAN SAHARA (AIN SEFRA REGION)

NASA

There were numerous heatwaves during the European summer, particularly in the Mediterranean region. The most significant affected Turkey and Cyprus in late June and early July, the western Mediterranean (especially Spain and Morocco) in mid-July, and Italy and the Balkans in early August. All-time records were set in all three events, including Antalya, Turkey (45.4 °C on 1 July); Cordoba (46.9 °C on 13 July), Granada (45.7 °C on 12 July) and Badajoz (45.4 °C on 13 July) in Spain; and Pescara (41.0 °C on 4 August), Campobasso (38.4 °C on 5 August) and Trieste (38.0 °C on 5 August) in Italy.

The south-western United States had a very hot summer. Death Valley had the highest monthly mean temperature (41.9 °C) on record for an American station in July. Later in the season, record-high temperatures occurred in coastal California in early September, including San Francisco (41.1 °C on 1 September). Eastern China was another area to experience extreme summer heat, with records set at Shanghai (40.9 °C on 21 July) and at the Hong Kong Observatory (36.6 °C on 22 August, associated with offshore flow during Typhoon *Hato*).

SIGNIFICANT COLD PERIODS IN 2017

Whilst 2017 saw above-average annual mean temperatures over almost all inhabited land areas, there were still some noteworthy cold events during the year.

January was a cold month over much of central and south-east Europe. Several countries experienced their coldest January since 1987, with monthly mean temperatures more than 5 °C below average in places. The cold also extended to parts of northern Africa with snowfalls in some elevated parts of the Algerian Sahara.

A major late-season storm then affected the region on 20–21 April. Moldova was the hardest hit, with heavy falls of snow and freezing rain – exceptional for the time of year – causing extensive forest and agricultural damage. Following the storm, severe late-season frosts contributed to significant agricultural losses, estimated by Munich Re at EUR 3.3 billion,[39] across many countries, including Switzerland, Austria, Ukraine, Romania, and Slovenia. The losses were exacerbated in many areas by unusually early development of crops due to an unusually warm March.

Extreme cold affected parts of Argentina in July. Bariloche fell to –25.4 °C on 16 July, 4.3 °C below its previous record. Very low overnight temperatures also occurred in parts of south-eastern Australia in the first few days of July, with record lows set at locations including Sale, Deniliquin and West Wyalong.

[39] Munich Re, 2018: Spring frost losses and climate change – not a contradiction in terms, 29 January 2018, https://www.munichre.com/topics-online/en/2018/01/spring-frost?ref=social&ref=Facebook&tid=NatCat2017%20Review.

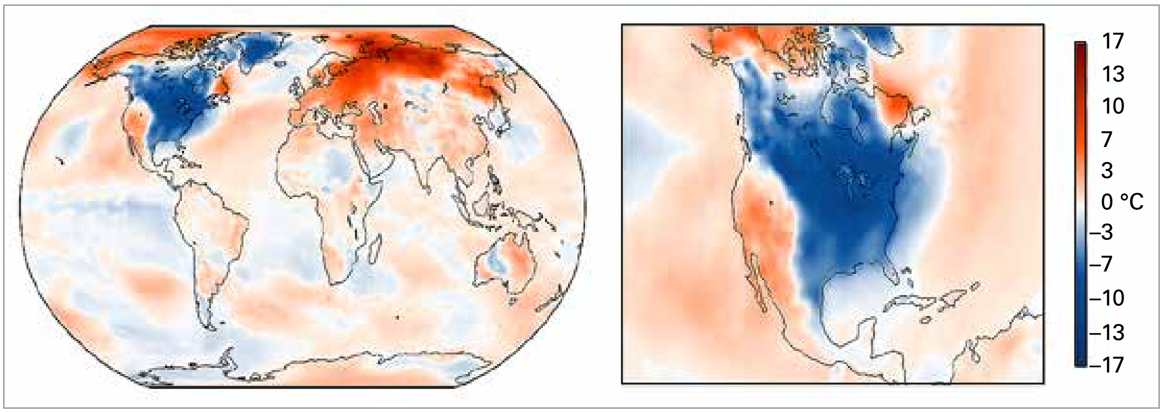


Figure 17. Temperature anomalies for the period 26 December 2017–5 January 2018 (relative to 1981–2010) showing the intense cold wave in eastern North America. *(Source: European Centre for Medium-range Weather Forecasts (ECMWF) Copernicus Climate Change Service)*

At the end of the year, a significant cold spell affected the north-eastern United States and eastern Canada, with temperatures remaining significantly below average for two weeks or more. The cold spell was more notable for its persistence than its intensity, with a number of locations setting or approaching records for the longest continuous period below certain thresholds: one example was Boston, which had a record seven consecutive days with maximum temperatures of 20 °F (–6.7 °C) or below from 27 December to 2 January.

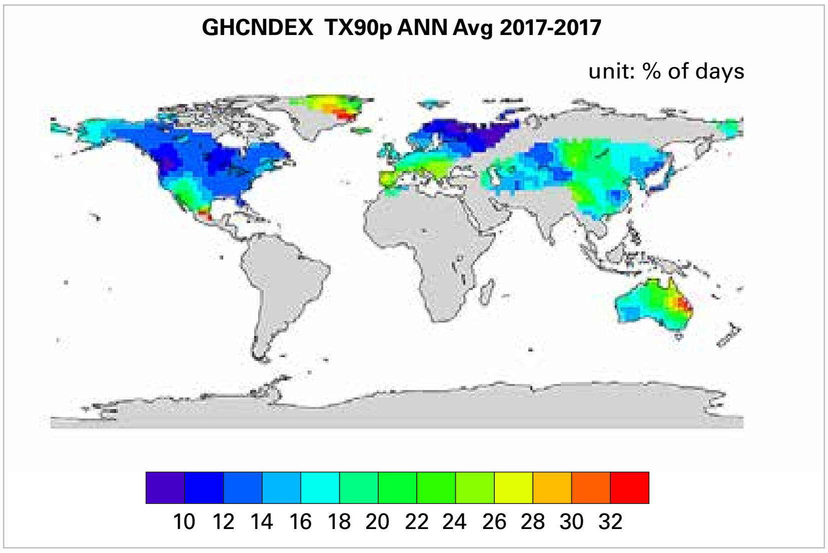
GLOBAL ASSESSMENT OF TEMPERATURE EXTREMES

Whilst a fully global assessment of temperature extremes for 2017 is not yet possible, the GHCNDEX dataset[40] of extreme temperature indices can be used to assess values over those parts of the world for which there is coverage. For minimum temperatures, the main areas of coverage are Europe, North America, Australia and parts of Russia; for maximum temperatures, coverage also extends to much of Asia (except the south and south-west) and South Africa. There is little or no coverage in South or Central America, or in Africa outside South Africa.

Over the areas that do have coverage, maximum temperatures above the 90th percentile occurred on an average of 16.7% of days, the third-highest value on record after 2015 (18.5%) and 2016 (17.8%). They occurred locally on 25% or more of days in parts of southern Queensland (Australia) and the Iberian Peninsula, and on 20% or more of days in much of eastern Australia, central Asia and southern Europe. Only western Canada and parts of north-west Russia had values below 10%. Warm nights were not as prevalent as warm days, with the average global frequency (15.7%) below the average of the last 10 years.

Cold days, with maximum temperatures below the 10th percentile, occurred on 6.2% of days, the third-lowest value on record, whilst cold nights, with minimum temperatures below the 10th percentile, had the fifth-lowest value (5.7%). Cold extremes, both by day and night, were particularly uncommon in 2017 in north-western Europe, with values in a region stretching from the United Kingdom to Germany below 3% for cold days and 4% for cold nights. Values above 10% were found only in parts of Australia for cold nights, and in central Canada for cold days, although

Figure 18. Percentage of days in 2017 with daily maximum temperatures above the 90th percentile, from the GHCNDEX dataset *(Source: University of New South Wales Climate Change Research Centre, Australia)*



[40] Donat, M.G. et al., 2013: Global Land-Based Datasets for Monitoring Climatic Extremes. *Bulletin of the American Meteorological Society*, 94:997–1006. This dataset uses a 1961–1990 baseline for the calculation of percentile thresholds.

much of the northern United States and southern Canada had a frequency of cold days between 8% and 10%.

HEAT AND DROUGHT CONTRIBUTE TO NUMEROUS DESTRUCTIVE WILDFIRES

Extreme heat and drought contributed to many destructive wildfires in various parts of the world in 2017. Whilst a return to near- or above-average rainfall contributed to reduced fire activity (compared with recent years) in various tropical regions, numerous mid-latitude regions had severe fire seasons.

Chile had the most significant forest fires in its history during the 2016/2017 summer, when exceptionally dry conditions during 2016 were followed by extreme heat in December and January. Eleven deaths were reported, and a total of 614 000 hectares of forest were burnt – the highest seasonal total on record and eight times the long-term average.[41] There were also significant fires during the 2016/2017 southern hemisphere summer in various parts of eastern Australia (especially eastern New South Wales) and in the Christchurch region of New Zealand, whilst the southern South African town of Knysna was badly affected by fire in June.

It was a very active fire season in the Mediterranean region. The worst single incident took place in central Portugal in June, where 64 people died in a fire near Pedrogao Grande. There were further major fire outbreaks in Portugal and north-western Spain in mid-October (exacerbated by strong winds associated with the circulation of Hurricane *Ophelia*), with a further 45 deaths reported. The area burned in Portugal in the period from January to October[42] was more than five times the 2007–2016 median. Other significant fires were reported, including in Croatia, France and Italy.

It was also an active fire season in western North America, both in the United States and Canada. A wet winter, which allowed the heavy growth of ground fuels, followed by a dry and hot summer, provided ideal conditions for high-intensity fires, the worst of which occurred north of San Francisco in early October. At least 44 people died, the worst loss of life in a wildfire in the United States since 1918. Insured losses from the fire were assessed as at least US$ 9.4 billion,[43] the worst for a wildfire anywhere in the world, even surpassing the 2016 Fort McMurray fires in Canada. Total economic losses for the 2017 California fire season were assessed at US$ 18 billion. A further fire north-west of Los Angeles in December became California's largest fire in modern history, and indirectly resulted in 21 deaths in flash floods and debris flows when heavy rains fell on the burnt area in early January.[44]

The total area burned in the contiguous United States in 2017 was 53% above the 2007–2016 average,[45] just short of the record set in 2015, whilst the area burned in the western provinces of Canada was also far above average, with over 1.2 million hectares burned in British Columbia, about eight times the 2006–2015 seasonal average.[46] Long-lived fires in British Columbia and the north-west United States also contributed to heavy smoke pollution across the region.

A significant tundra fire occurred in August in the Disko Bay area, on the central west coast of Greenland.

THE INFLUENCE OF ANTHROPOGENIC CLIMATE CHANGE ON EXTREME EVENTS

Determining the extent, if any, to which anthropogenic climate change has influenced the occurrence of extreme events has been an active area of research in recent years.

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41 From information supplied by the Chilean Directorate of Meteorology.

42 Portuguese Institute for Nature Conservation and Forests, http://www.icnf.pt/portal/florestas/dfci/Resource/doc/rel/2017/8-rel-prov-1jan-30set-2017.pdf.

43 California Department of Insurance, media release of 6 December 2017, http://www.insurance.ca.gov/0400-news/0100-press-releases/2017/release135-17.cfm.

44 National Centers for Environmental Information (NCEI), National Climate Reports for December 2017 and January 2018.

45 National Interagency Coordination Center, Wildland Fire Summary and Statistics – Annual Report 2017 https://www.predictiveservices.nifc.gov/intelligence/2017_statssumm/intro_summary17.pdf.

46 British Columbia Wildfire Service, http://bcfireinfo.for.gov.bc.ca/hprScripts/WildfireNews/Statistics.asp.

NASA

Such analyses are now routinely published in the peer-reviewed literature, many of them as part of an annual report prepared as a supplement to the *Bulletin of the American Meteorological Society* (BAMS).

The most-recently published BAMS report included 27 analyses of extreme events that occurred in 2016 (some of them multiple analyses of the same event), and found that anthropogenic climate change was a significant driver of the frequency of the event concerned in 21 of the 27 cases. In particular, of 15 analyses that assessed extreme temperature events (either on land or in the ocean), 13 found that their probability had been significantly influenced by anthropogenic climate change in the "expected" direction (that is, that a warm event had become more likely or a cold event less likely). One counter-example of interest was a frost event in south-western Australia in September 2016, where it was found that anthropogenic climate change had significantly increased the chance of the circulation anomalies which were the primary driver for the event (notwithstanding the background warming signal). As in previous years, anthropogenic signals were found less consistently for extreme precipitation events, with such signals being found (in three different analyses) for extremely high rainfall in eastern China during the summer of 2016, but not for extreme precipitation events in other parts of the world.

Given the timeframes involved, few studies of 2017 events have yet been published in the peer-reviewed literature. One exception is an assessment of the extremely high rainfall associated with Hurricane *Harvey*. The WMO Expert Team on Climate Impacts on Tropical Cyclones also found[47] that, whilst there is no clear evidence that climate change is making the occurrence of slow-moving, land-falling hurricanes more or less likely, it is probable that anthropogenic climate change made rainfall rates more intense, and that ongoing sea-level rise exacerbated storm surge impacts. Assessments of recent events – most of which use methods that have been documented in the peer-reviewed literature, although the assessments themselves are not – are regularly published shortly after the event through a variety of channels, and it is likely that many of these events will be documented in the peer-reviewed literature in due course.

[47] WMO expert team statement on Hurricane *Harvey*, https://public.wmo.int/en/media/news/wmo-expert-team-statement-hurricane-harvey.

ATTRIBUTION OF EXTREME CLIMATE EVENTS

A common question when an extreme climate event happens is “was this event caused by climate change?”. Scientists address this question in a different way: “Was the chance of this event happening affected by human influences on the climate, and if it was, by how much?”.

Answering this question has become a very active area of research in the last few years. Whilst a range of approaches has been used, the most common is to use climate models. The approach consists in running these models with all known climate forcings, both anthropogenic and natural, and with natural forcings only. Comparing the probability of the event in question using the two sets of model runs allows the attribution of the event to anthropogenic versus natural factors. This is often expressed as the Fraction of Attributable Risk (FAR), which is the probability that the event was the result of anthropogenic influence on climate as opposed to natural variability.

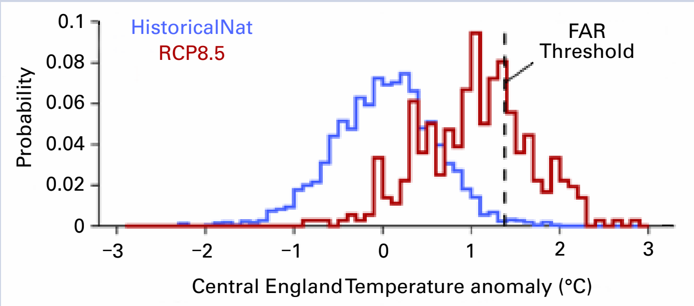
Many of these studies have found that the probability of the extreme event has been influenced by human activity, either directly, or indirectly through, for example, affecting the likelihood of occurrence of an unusual circulation anomaly which triggered the extreme event; sometimes in conjunction with other influences such as the El Niño/Southern Oscillation (ENSO). Of a set of 131 studies published between 2011 and 2016 in the *Bulletin of the American Meteorological Society*, 65% found that the event’s probability was significantly affected by anthropogenic activities.

The strongest anthropogenic influence has been found on temperature extremes: the likelihood of warm extremes increases and that of cold extremes decreases. This is especially true for events considered over large areas and over a long period of time, such as a season or a year. As an example, it was found that the 2016 record-breaking global mean temperature would have been almost impossible without human activity.[1] Because there is a higher level of “natural” variability at individual locations and over shorter timescales, it is more difficult to find a significant human signal in the occurrence of short-term extremes at specific places, although studies of that type are also starting to emerge.

It has been more difficult to identify anthropogenic influence in the attribution of precipitation extremes. Whilst some studies have found that the probability of some extreme precipitation events was increased, most often indirectly, by climate change, for many other studies the results have been inconclusive. This is because the underlying long-term climate signal in extreme precipitation is less clear than it is for temperature and, because extreme precipitation events typically occur on shorter spatial scales than extreme temperature events.

At present, attribution studies are mostly carried out in research mode and the most common platform for publishing these studies is through the traditional peer-reviewed literature. This is mostly done through an annual supplement to the State of the Climate report published in the *Bulletin of the American Meteorological Society*. Such studies usually appear several months following the occurrence of the event under consideration.

For some types of extremes, especially extremes defined using standard indices, such as national mean monthly temperature, methods have been developed which allow an assessment of the FAR for the event in close to real time. At present, most such reports are published through other channels than the National Meteorological and Hydrological Services (NMHSs) such as blogs, university or NGO websites, or the media. Operational attribution services under the auspices of NMHSs or Regional Climate Centres are in their infancy, although many individual NMHS scientists have contributed to the studies that are currently being published. Nevertheless, it is expected that there will be substantial progress in this area in the next few years due to the increased demand from governments, the public and the media for these services on quasi-real time.



Probability distribution of annual mean Central England Temperature under natural (blue) and RCP 8.5 (brown) model simulations as of 2006, with the 2006 value (the highest on record) shown as a black dashed line (*Source: Andrew King, University of Melbourne, Australia)*

[1] Knutson, T.R. et al., 2017 : CMIP5 model-based assessment of anthropogenic influence on record global warmth during 2016. *Bulletin of the American Meteorological Society*, 99:S11-S15.

Climate risks and related impacts

Climate-related extreme events and disasters take a heavy toll on human well-being and on various sectors of national economies. The year 2017 was particularly severe for disasters with high economic impacts. Munich Re assessed total disaster losses from weather and climate-related events in 2017 at US$ 320 billion,[48] the largest annual total on record (after adjustment for inflation).

AGRICULTURE AND FOOD SECURITY

Exposure and vulnerability to extreme events can destroy agricultural assets and infrastructure, causing serious damage to the livelihoods and food security of millions of people. A concern for the World Food Programme (WFP) is that more than 80% of the world's food-insecure people live in countries with degraded environments prone to natural hazards. When climate-related events occur, the situation of already-vulnerable people can quickly deteriorate into food and nutrition crises. Problems of acute food insecurity and malnutrition tend to be magnified where natural hazards such as droughts and floods compound the consequences of conflicts.[49]

The disruption of agricultural production in rural areas of developing countries affects the already fragile livelihoods of the poorest and most vulnerable people in particular. A review carried out by FAO found that agriculture (crops, livestock, fisheries, aquaculture and forestry) accounted for 26% of all the damage and loss associated with medium to large-scale climate-related disasters. [50]

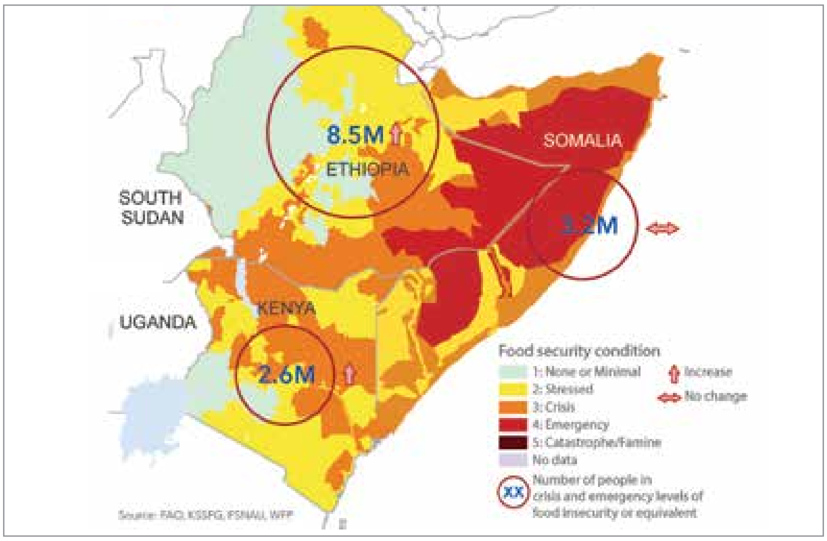


Figure 19. Number of severely food-insecure people in Kenya, Somalia and Ethiopia (*Source: Horn of Africa: Humanitarian Impacts of Drought – Issue 9, 20 August 2017 (OCHA)*)

In the Horn of Africa, rainfall deficits led to the failure of the 2016 rainy season, followed by a harsh January–February 2017 dry season, and a poor March–May rainy season. As a result, the number of food-insecure people rose significantly in Eastern Africa.[51] The most affected areas include southern and south-eastern Ethiopia, northern and coastal Kenya, almost all of Somalia, south-eastern areas of South Sudan and north-eastern areas of Uganda. In Somalia, as of June 2017, more than half of the cropland was affected by drought, and herds had reduced by 40 to 60% since December 2016 due to increased mortality and distress sales.

In Ethiopia, prolonged drought jeopardized crop production and caused a reduction in the availability of pasture, severely constraining the purchasing power of pastoral households. In drought-affected areas of Kenya, according to the Vegetation Condition Index (VCI), as of May 2017 drought was associated with a sharp increase in staple crop prices coupled with declining livestock prices and consequent erosion of livelihoods and threat to food security.[52]

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48 Munich Re, 2018: Hurricanes cause record losses in 2017 – The year in figures. Release of 4 January 2018. The losses quoted by Munich Re include both insured and non-insured losses, but may calculate indirect economic losses (e.g. business interruption) in a different way than some other sources.

49 Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development (IFAD), United Nations Children's Fund (UNICEF), World Food Programme (WFP) and World Health Organization (WHO), 2017: *The State of Food Security and Nutrition in the World 2017 – Building resilience for peace and food security.* FAO, Rome, http://www.fao.org/3/a-I7695e.pdf.

50 Food and Agriculture Organization of the United Nations (FAO), 2017: *The Impact of Disasters on Agriculture – Assessing the information gap*, http://www.fao.org/3/a-i7279e.pdf.

51 United Nations Office for the Coordination of Humanitarian Affairs (OCHA), 2017: Horn of Africa: Humanitarian Impacts of Drought, 9 (10 August 2017), https://reliefweb.int/report/somalia/horn-africa-humanitarian-impacts-drought-issue-9-10-aug-2017.

52 Food and Agriculture Organization of the United Nations (FAO), 2017: Global Information and Early Warning System on Food and Agriculture (GIEWS). Special Alert No. 339. Region: East Africa, http://www.fao.org/3/a-i7537e.pdf.

DATA FOR MONITORING IMPACTS OF CLIMATE-RELATED EXTREME EVENTS AND DISASTERS

At the Seventy-first Session of the United Nations General Assembly[1] and the Forty-eighth Session of the United Nations Statistical Commission,[2] the data and indicators for the measurement of progress in achieving the global targets of the Sendai Framework for Disaster Risk Reduction 2015–2030 and of the 2030 Agenda for Sustainable Development were adopted. This enabled integrated monitoring and reporting by countries of progress in managing disaster and climate risk and the corollary impacts, using multi-purpose datasets and common indicators.

Data are currently available in most countries to allow some degree of measurement of the impact of climate-related extreme events and disasters – including via the growing number of national disaster loss accounting systems – as detailed in the Sendai Framework Data Readiness Review 2017.[3] However, considerable work is required if countries are to be able to monitor the agreed indicators in the manner anticipated by the two intergovernmental working groups – the Open-ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction (OIEWG) and the Inter-agency and Expert Group on Sustainable Development Goal Indicators (IAEG-SDGs). Many countries are confronted with challenges related to data availability, accessibility and quality, which will need to be addressed if data are to be sufficiently consistent and comparable to allow meaningful measurement of progress and impact.

Work is ongoing with the international statistical community to address some of these challenges. The outcomes of the Expert Group on Disaster-related Statistics will be presented at the Seventy-fourth Session of the Economic and Social Commission for Asia and the Pacific. They include the development of the disaster-related statistical framework (DRSF) to monitor the achievement of the global targets of the Sendai Framework and the Sustainable Development Goals.

Established by the Conference of European Statisticians of the United Nations Economic Commission for Europe, the Task Force on Measuring Extreme Events and Disasters is clarifying the role of official statistics in providing data related to extreme events and disasters, as well as possible support of national statistical offices to the implementation of the Sendai Framework and the 2030 Agenda.

Countries are supported in systematic data entry and reporting by the Sendai Framework Monitoring system, an online monitoring facility which became available on 1 March 2018, and which is supported by detailed guidance on metadata and computational methodologies. The integration of monitoring and reporting with The Paris Agreement will be discussed at the Thirteenth Meeting of the United Nations Framework Convention on Climate Change (UNFCCC) Adaptation Committee.

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1 Resolution (A/RES/71/276) approving the Report of the Open-ended Intergovernmental Expert Working Group on Indicators and Terminology relating to Disaster Risk Reduction (A/71/644).

2 Report of the Inter-agency and Expert Group on Sustainable Development Goal Indicators – Note by the Secretary-General (E/CN.3/2017/2).

3 United Nations Office for Disaster Risk Reduction (UNISDR): Sendai Framework data readiness review 2017 – Global summary report, https://www.preventionweb.net/publications/view/53080.

In the Philippines, over the last two decades, 15 times more infants have died in the 24 months after typhoons than in the typhoons themselves. Of those infants, 80% were girls.[53] In Ethiopia, children born in an area affected by disasters are 35.5% more likely to be malnourished and 41% more likely to be stunted.[54]

Over the last three years, agricultural production and related livelihoods were heavily compromised by recurrent and intense floods in many countries. In Malawi, the 2015 floods resulted in more than US$ 60 million in damage and losses to crops, livestock, fisheries and forestry assets, and production flows. More than 37% of the total economic impact of the 2015 floods in Myanmar occurred in the agricultural sector.[55]

In 2017, several flood events affected the agricultural sector, especially in Asian countries. Heavy rains in May 2017 triggered severe flooding and landslides in south-western areas of Sri Lanka. The adverse impact of floods on crop production further aggravated the food security conditions in the country already stricken by drought.[56] In July 2017, localized floods in south and central Myanmar contributed to losses in paddy crop, stored food and livestock, and affected at least 200 000 people in the Magway, Sagaing, Bago and Ayeyarwady regions and Mon State. It was the third consecutive year in which severe floods affected Myanmar during the monsoon season.

Population affected (in millions) due to floods in Bangladesh, India and Nepal, as of 24 August 2017

Country	Total number of people affected
Bangladesh	6.9
India	32.1
Nepal	1.7

Source: United Nations Office for the Coordination of Humanitarian Affairs (OCHA)

Excess precipitation in late March and early April 2017 triggered floods in north-eastern agricultural areas of Bangladesh, affecting crop production in the Sylhet, Dhaka and Mymensingh divisions in particular.[57] The monsoon season in South Asia brought the worst flooding in the region for years. Between June and August 2017, flooding in Nepal, Bangladesh and northern India affected millions of people and caused death and displacement across the three countries.

The end of the climate anomalies associated with the 2015/2016 El Niño, both on land and in the ocean, resulted in improved agricultural and fisheries production in some areas.[58] More normal rainfall patterns have contributed to two successive record-breaking global cereal harvests since 2015. World wheat production hit an all-time high in 2016 and is expected to remain at near-record levels in 2017, mainly due to larger crops in India and the Russian Federation. More abundant rains since mid-2016 in India, Thailand and the Philippines have increased rice output to a level that marked recoveries in these countries. As a result, world rice production reached a fresh peak in 2016 and was expected to expand further in the 2017 season. As to annual oilcrops, global production recovered swiftly in 2016/2017, actually posting a new record, and is anticipated to grow modestly

[53] Anttila-Hughes, J. and S. Hsiang, 2013: Destruction, Disinvestment, and Death: Economic and Human Losses Following Environmental Disaster. Available at SSRN: http://ssrn.com/abstract=2220501.

[54] Intergovernmental Panel on Climate Change (IPCC), 2007: Fourth Assessment Report, https://www.ipcc.ch/report/ar4/.

[55] Government of Myanmar. (2015). Myanmar. Post-disaster needs assessment of floods and landslides, July–September 2015, http://documents.worldbank.org/curated/en/646661467990966084/Myanmar-Post-disaster-needs-assessment-of-floods-and-landslides-July-September-2015.

[56] Food and Agriculture Organization of the United nations (FAO) and World Food Programme (WFP), 2017: *Special Report. FAO/WFP Crop and Food Security Assessment Mission to Sri Lanka*, http://www.fao.org/3/a-i7450e.pdf.

[57] Food and Agriculture Organization of the United nations (FAO), 2017: GIEWS – Global Information and Early Warning System. Country Brief: Bangladesh, http://www.fao.org/giews/countrybrief/country.jsp?code=BGD.

[58] Food and Agriculture Organization of the United Nations (FAO), 2017: *Food Outlook – Biannual Report on Global Food Markets*, November 2017, http://www.fao.org/3/a-I8080e.pdf.

in 2017/2018. Conversely, the recovery in palm oil production was more gradual and is expected to revert to its usual growth rate only in 2018. There was also a strong recovery in the Anchoveta fishery off the Pacific coast of South America as sea-surface temperatures in the region reverted to near average.

HEALTH

The global health impacts of heatwaves depend not only on the overall warming trend, but also on how heatwaves are distributed across the area where people live. Recent research shows that the overall risk of heat-related illness or death has climbed steadily since 1980, with around 30% of the world's population now living in climatic conditions that deliver potentially deadly temperatures at least 20 days a year.[59] Between 2000 and 2016, the number of vulnerable people exposed to heatwave events has increased by approximately 125 million.[60]

In cholera-endemic countries, an estimated 1.3 billion people are at risk, while in Africa alone about 40 million people live in cholera "hotspots".[61] These cholera "hotspots" have been identified across most endemic countries facing recurrent and predictable cholera outbreaks, often coinciding with the rainy season. The World Health Organization has recognized that large cholera outbreaks in eastern and central, and later southern Africa were likely aided by El Niño-driven weather conditions that accelerated transmission across the region starting in mid-2015, with control efforts still underway in several countries in 2017. Flood events are also often associated with outbreaks of water-borne diseases or those linked to poor sanitation, as was reported in Bangladesh during the August 2017 floods.

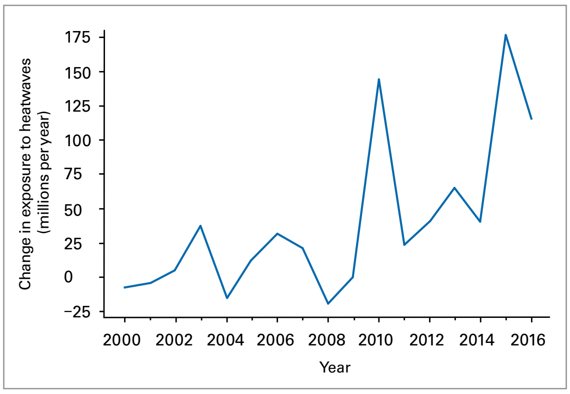

Figure 20. The change in exposure (in people aged over 65 years) to heatwaves from 2000 to 2016 relative to the heatwave exposure average from 1986 to 2008 *(Source: World Health Organization (WHO))*

POPULATION DISPLACEMENT

One of the adverse consequences of climate variability and change is population displacement. Most such displacement is internal and linked to sudden onset of extreme weather events. However, slow onset phenomena, such as droughts, desertification, coastal erosion and sea-level rise, can also lead to internal and cross-border displacement. These slow-onset events can act as a threat multiplier by, for example, exacerbating conflict which, in turn, can contribute to population displacement.

In 2016, weather-related disasters displaced 23.5 million people.[62] As in previous years, the majority of those internal displacements were associated with floods or storms and occurred in the Asia-Pacific region. The most striking example of displacement due to major climate events is from Somalia, where it was reported that 892 000 people were displaced internally, mostly in the first half of 2017.[63] Of the displaced people who were surveyed, approximately 90% indicated that drought was the primary reason for displacement, while the remaining 10% gave reasons closely related to drought or cited drought as a contributing factor, such as food or livelihood insecurity.[64]

59 Mora C. et al., 2017: Global risk of deadly heat. *Nature Climate Change*, 7. DOI:10.1038/nclimate3322.

60 Watts N. et al., 2017: The Lancet Countdown on Health and climate change: From 25 years of inaction to a global transformation for public health. *Lancet*, 30 October 2017.

61 World Health Organization (WHO), 2017: Weekly epidemiological record, No. 22, 2 June 2017, http://apps.who.int/iris/bitstream/10665/255611/1/WER9222.pdf?ua=1.

62 Internal Displacement Monitoring Centre (IDMC), 2017: Global Report on Internal Displacement 2017, http://www.internal-displacement.org/global-report/grid2017/pdfs/2017-GRID.pdf.

63 Office of the United Nations High Commissioner for Refugees (UNHCR), 2018: Somalia. UNHCR Emergency Response at 31 December 2017, https://reliefweb.int/report/somalia/somalia-unhcr-emergency-response-31-december-2017.

64 As of 23 June, 687 906 Somali IDPs interviewed by the UNHCR-led Protection & Return Monitoring Network (PRMN) indicated that drought was the primary reason for displacement, while 72 688 IDPs indicated that drought was a contributing factor, https://data2.unhcr.org/en/documents/download/58290.

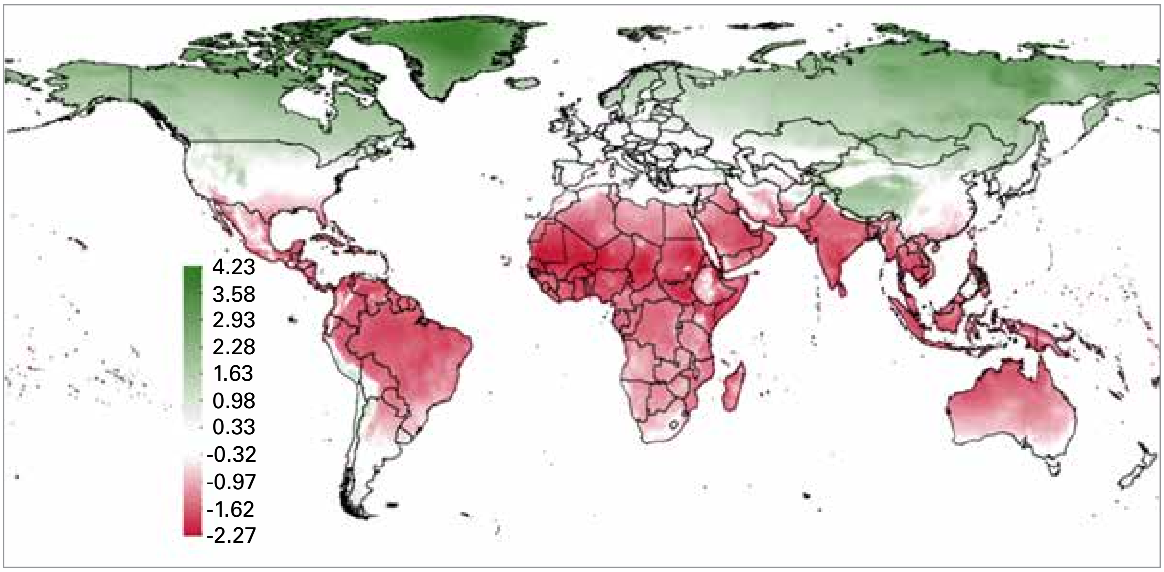

Figure 21. The effect of a 1 °C increase in temperature on real per capita output at the grid level.
(Sources: Natural Earth; ScapeToad; United Nations World Population Prospects: The 2015 Revision; World Bank Group Cartography Unit; and IMF staff calculations)

ECONOMIC IMPACTS

The International Monetary Fund (IMF) World Economic Outlook published in October 2017[65] indicates that increases in temperature have uneven macroeconomic effects. Adverse consequences are concentrated in regions with relatively hot climates, where a disproportionately large number of low-income countries are located. In these countries, a rise in temperature lowers per capita output, in both the short and medium term, by reducing agricultural output, suppressing the productivity of workers exposed to heat, slowing investment and damaging health.

The analysis confirms the existence of a statistically significant nonlinear effect of temperature on per capita economic growth. In countries with high average temperatures, an increase in temperature dampens economic activity, whereas it has the opposite effect in much colder climates.

For the median emerging market economy, a 1 °C increase from an average annual temperature of 22 °C lowers growth in the same year by 0.9%. For a median low-income developing country, with an annual average temperature of 25 °C, the effect of a 1 °C increase in temperature is even larger: growth falls by 1.2%. Countries whose economies are projected to be significantly adversely affected by an increase in temperature produced only about 20% of global GDP in 2016; however, they are currently home to nearly 60% of the global population and are projected to be home to more than 75% by the end of the century.

[65] International Monetary Fund, 2017: *World Economic Outlook, October 2017. Seeking Sustainable Growth: Short-Term Recovery, Long-Term Challenges*, https://www.imf.org/en/Publications/WEO/Issues/2017/09/19/world-economic-outlook-october-2017.

Vector-borne diseases: Zika in the Americas

Ángel G. Muñoz,[1] Rachel Lowe,[2] Anna M Stewart-Ibarra,[3] Joy Shumake-Guillemot,[4] Madeleine Thomson[1]

Vector-borne diseases are highly climate sensitive and favourable climate conditions can trigger and amplify disease transmission. Warm temperatures increase virus replication rates and drive the development of juvenile mosquitoes, adult feeding and egg laying behaviour. Rainfall excess and deficit have similar outcomes in terms of mosquito proliferation, as containers such as domestic pots, tires, drums and tanks tend to create suitable breeding sites in both cases.

The emergence of the Zika virus (ZIKV) epidemic, mainly carried by the *Aedes* mosquito in Latin America and the Caribbean in 2014–2016, occurred during a period of severe drought and unusually high temperatures developed since at least 2013 (see top and middle panels of the figure). These conditions have been shown to be associated with a cross-timescale combination of signals including the 2015/2016 El Niño event, decadal variability and climate change (Muñoz et al., 2016*a*,*b*).

A common approach to assess the potential risk of transmission of *Aedes*-borne epidemics is via the estimation of the basic reproduction number, R_0, which is in general a function of environmental variables, such as air temperature, and ento-epidemiological parameters (Mordecai et al, 2017). Using an R_0 model which considers the two most common *Aedes* mosquitoes in Latin America and the Caribbean, a recent study (Muñoz et al., 2017) showed that high temperatures enhanced the risk of transmission during the 2014–2016 ZIKV epidemic, and that neither El Niño nor climate change can be independently blamed for this event. While the potential risk of transmission signal (black curve in the bottom panel of the figure) is consistent with long-term temperature increase due to global warming and with inter-annual climate variability modes (filled red/blue curve shown in bottom panel of the figure) such as El Niño, other non-climatic factors come into play to explain the 2014–2016 ZIKV epidemic.

In fact, in addition to suitable climate conditions, the rapid transmission that occurred in the initial Brazilian outbreak appears to have been aided by a combination of factors including a massive susceptible population, alternative non-vector transmission, and a highly mobile population (Lowe et al., 2018). Furthermore, the occurrence of shocks such as natural disasters can also exacerbate population vulnerability. This was observed following the major earthquake in coastal Ecuador in April 2016, which seemingly enhanced the ZIKV transmission in that region where suitable hot and dry local climate conditions were already present (Sorensen et al., 2017).

Currently, local ZIKV transmission and the associated and resulting fetal malformations and neurological disorders continue to be monitored and recorded in the region and worldwide. Predictions of the timing and magnitude of outbreaks of multiple arboviruses, including ZIKV, can be improved using a combination of climate forecasts and sero-prevalence survey data (Lowe et al., 2017). For example, real-time seasonal climate forecasts have been used to produce dengue early warnings for Brazil (Lowe et al., 2014, 2016), and the use of the R_0 model mentioned above and state-of-the-art climate forecasts provided by the North American Multi-Model Ensemble (NMME) project could have successfully predicted the recent epidemic at least 1–3 months in advance for several high-risk ZIKV zones, including its epicenter in Northeast Brazil (Muñoz et al., 2017, Epstein et al., 2017).

[1] International Research Institute for Climate and Society, Earth Institute, Columbia University, New York.

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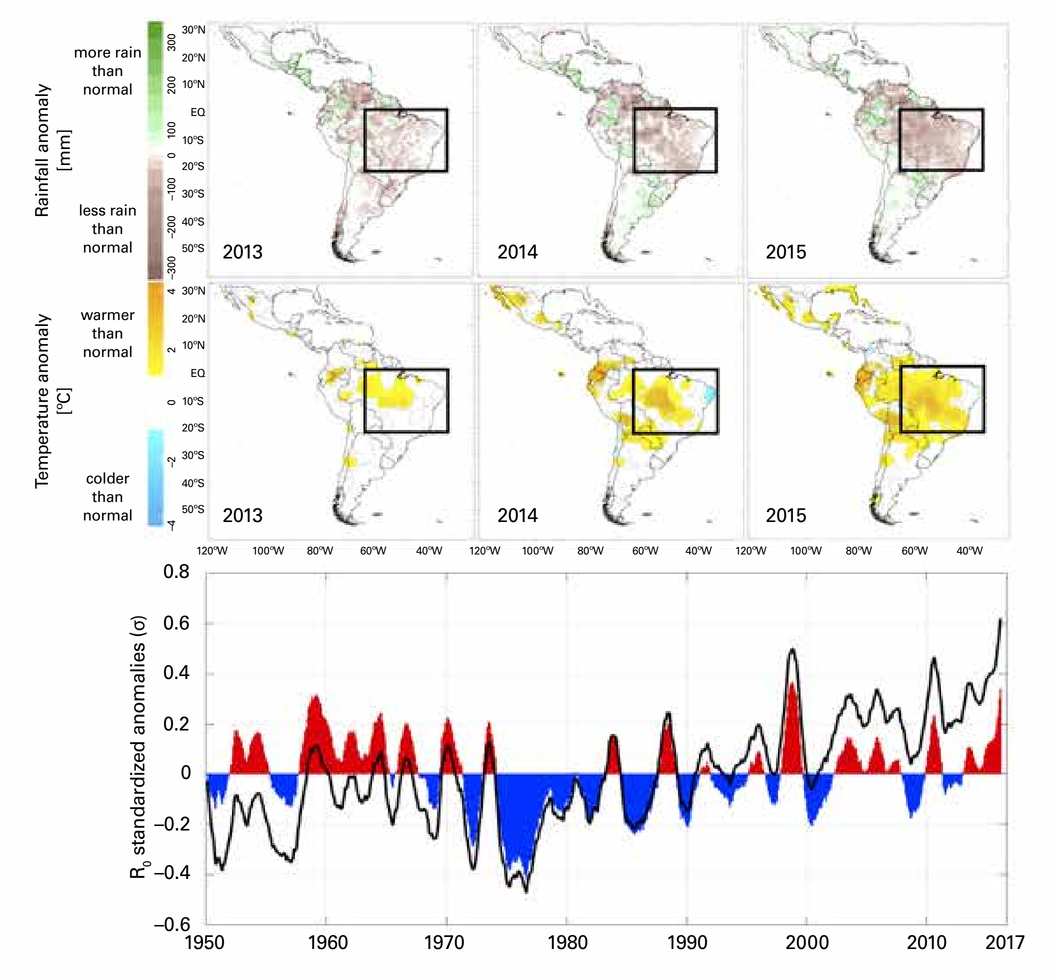

Annual rainfall anomalies (top panel) and temperature anomalies (middle panel) in 2013, 2014 and 2015; anomalies are computed with respect to the climatological period 1981–2010. Standardized anomalies of R_0 (bottom panel; units in standard deviations). The total potential risk of transmission (black curve) shows an upward trend consistent with climate warming and cannot be explained only by the contribution of El Niño and other year-to-year climate modes (filled curve): a combination of climate signals has been driving the risk of transmission in the region. Black boxes indicate the sector of analysis (After Muñoz et al., 2016*b*, 2017).

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JN 18331

This is **Exhibit B** referred to in the

affidavit of **John Moffet**

affirmed before me on **January 29, 2019**

Commissioner for Oaths for Québec

#224458

United Nations Framework Convention on Climate Change

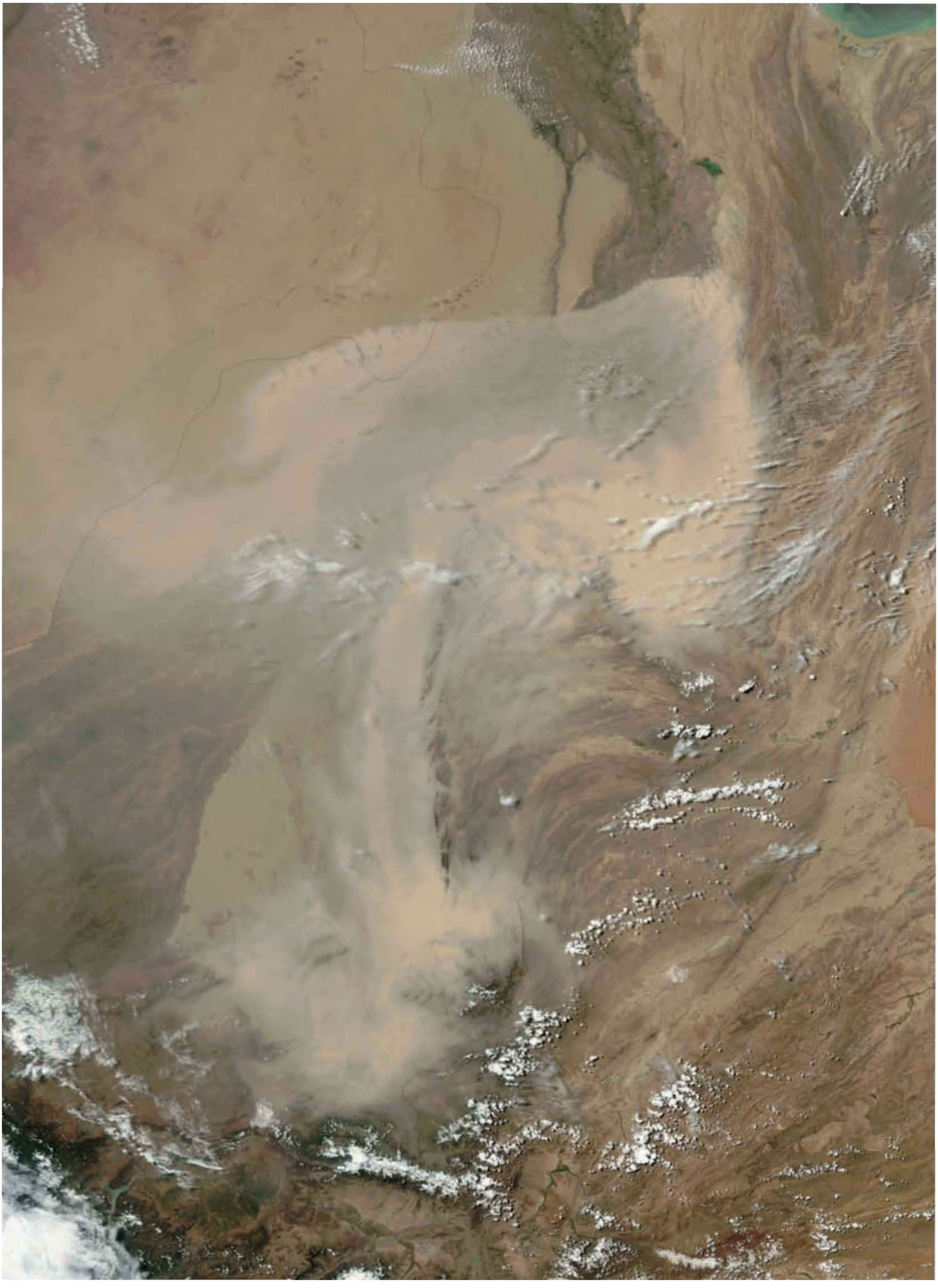
CLIMATE CHANGE:

IMPACTS, VULNERABILITIES AND ADAPTATION IN DEVELOPING COUNTRIES

UNFCCC

UNFCCC
United Nations Framework Convention on Climate Change

CLIMATE CHANGE: IMPACTS, VULNERABILITIES AND ADAPTATION IN DEVELOPING COUNTRIES



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I. INTRODUCTION

The United Nations Framework Convention on Climate Change (UNFCCC) secretariat has produced this book to highlight the concerns and needs of developing countries in adapting to the effects of climate change. This book outlines the impact of climate change in four developing country regions: Africa, Asia, Latin America and small island developing States; the vulnerability of these regions to future climate change; current adaptation plans, strategies and actions; and future adaptation options and needs.

The book draws heavily on information provided by Parties to the UNFCCC, particularly that provided at three regional workshops held in Africa, Asia and Latin America and one expert meeting held in small island developing States during 2006 – 2007[1], as mandated by the Buenos Aires programme of work on adaptation and response measures (decision 1/CP.10 of the Conference of the Parties to the UNFCCC)[2], as well as information in national communications[3] and national adaptation programmes of action[4] submitted to the UNFCCC, reports from the Intergovernmental Panel on Climate Change (IPCC 2007) and other sources, as referenced.

Over the next decades, it is predicted that billions of people, particularly those in developing countries, face shortages of water and food and greater risks to health and life as a result of climate change Concerted global action is needed to enable developing countries to adapt to the effects of climate change that are happening now and will worsen in the future.

The urgency for adaptation is highlighted by projections from the three reports produced by the IPCC in 2007 (IPCC 2007). Under a business as usual scenario, greenhouse gas emissions could rise by 25 – 90 per cent by 2030 relative to 2000 and the Earth could warm by 3°C this century. Even with a temperature rise of 1 – 2.5°C the IPCC predict serious effects including reduced crop yields in tropical areas leading to increased risk of hunger, spread of climate sensitive diseases such as malaria, and an increased risk of extinction of 20 – 30 per cent of all plant and animal species. By 2020, up to 250 million people in Africa could be exposed to greater risk of water stress. Over the course of this century, millions of people living in the catchment areas of the Himalayas and Andes face increased risk of floods as glaciers retreat followed by drought and water scarcity as the once extensive glaciers on these mountain ranges disappear. Sea level rise will lead to inundation of coasts worldwide with some small island States possibly facing complete inundation and people living with the constant threat of tropical cyclones now face increased severity and possibly increased frequency of these events with all associated risks to life and livelihoods.

The UNFCCC secretariat, using current information available on existing and projected investment flows and financing relevant to the development of an effective and appropriate international response to climate change, has estimated that by 2030 developing countries will require USD 28 – 67 billion in funds to enable adaptation to climate change.[5] This corresponds to 0.2 – 0.8 per cent of global investment flows, or just 0.06 – 0.21 per cent of projected global GDP, in 2030. Current global funding for adaptation is a fraction of this figure and access to these funds for developing countries is often lengthy and complex.

Developing countries are the most vulnerable to climate change impacts because they have fewer resources to adapt: socially, technologically and financially. Climate change is anticipated to have far reaching effects on the sustainable development of developing countries including their ability to attain the United Nations Millennium Development Goals by 2015 (UN 2007). Many developing countries' governments have given adaptation action a high, even urgent, priority.

1 <http://unfccc.int/3582.php>
2 <http://unfccc.int/resource/docs/cop10/10a01.pdf#page=2>
3 <http://unfccc.int/2979.php>
4 <http://unfccc.int/2719.php>
5 <http://unfccc.int/4053.php>

Developing countries need international assistance to support adaptation in the context of national planning for sustainable development, more capacity-building and transfer of technology and funds. Systematic planning and capacity-building are also needed to reduce the risk of disasters and raise the resilience of communities to increasing extreme events such as droughts, floods and tropical cyclones. Funding for adaptation in developing countries must be sufficient and sustained. Least developed countries (LDCs) and small island developing States (SIDS) in particular need special consideration due to their extreme vulnerability.

In this book, background information on climate change and why adaptation is needed in developing countries is provided in CHAPTER II. The chapter also explains how the UNFCCC, which provides the basis for international action on climate change, is helping adaptation efforts in developing countries.

A large amount of work has already been carried out by many countries on assessing impacts and vulnerabilities to climate change, as well as considering possible adaptation options. CHAPTER III covers how assessments on climate change are made by countries, including the gaps and needs of developing countries in information collection and analysis. Although there is still much work to be done, it was emphasised at all the UNFCCC-organized workshops and expert meeting that this should not be an obstacle to progress being made on implementing adaptation.

Developing countries have very different individual circumstances and the specific impacts of climate change on a country depend on the climate it experiences as well as its geographical, social, cultural, economic and political situations. As a result, countries require a diversity of adaptation measures very much depending on individual circumstances. However there are cross cutting issues which apply across countries and regions. The same sectors are affected by climate change, albeit to differing degrees. These main sectors include: agriculture, water resources, human health, terrestrial ecosystems and biodiversity and coastal zones. CHAPTER IV looks at the current and future impacts and vulnerabilities across these sectors in developing countries.

Although knowledge of how best to do adaptation is still in its infancy, the Parties of the UNFCCC are increasing their support for action on adaptation. This includes the development of national adaptation programmes by some developing countries including least developed countries, and their integration into national strategies. Climate change solutions need to identify and exploit synergy, as well as seek to balance trade-offs, among the multiple objectives of sustainable development, disaster risk reduction and adaptation policies. Such initiatives also require new and sustained funding sources. CHAPTER V highlights the adaptation needs and responses of developing countries to climate change and how the work of the UNFCCC can help catalyse more work on adaptation in these countries. This chapter also highlights the need to plan and implement adaptation in the context of sustainable development and integrate adaptation into policy at all levels. Recommendations from the workshops and meeting on how to cross the gap between planning and implementing adaptation options are highlighted.

Finally, CHAPTER VI looks forward to give an indication of possible next steps for the UNFCCC, including within a future climate regime beyond 2012, in addressing adaptation options for the threats posed by climate change.

II. CLIMATE CHANGE AND ADAPTATION

Human beings have been adapting to the variable climate around them for centuries. Worldwide local climate variability can influence peoples' decisions with consequences for their social, economic, political and personal conditions, and effects on their lives and livelihoods. The effects of climate change imply that the local climate variability that people have previously experienced and have adapted to is changing and changing at relatively great speed.

Rising fossil fuel burning and land use changes have emitted, and are continuing to emit, increasing quantities of greenhouse gases into the Earth's atmosphere. These greenhouse gases include carbon dioxide (CO_2), methane (CH_4) and nitrogen dioxide (N_2O), and a rise in these gases has caused a rise in the amount of heat from the sun withheld in the Earth's atmosphere, heat that would normally be radiated back into space. This increase in heat has led to the greenhouse effect, resulting in climate change. The main characteristics of climate change are increases in average global temperature (global warming); changes in cloud cover and precipitation particularly over land; melting of ice caps and glaciers and reduced snow cover; and increases in ocean temperatures and ocean acidity – due to seawater absorbing heat and carbon dioxide from the atmosphere (Figure II-1).

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) dispelled many uncertainties about climate change. Warming of the climate system is now unequivocal. It is now clear that global warming is mostly due to man-made emissions of greenhouse gases (mostly CO_2). Over the last century, atmospheric concentrations of carbon dioxide increased from a pre-industrial value of 278 parts per million to 379 parts per million in 2005, and the average global temperature rose by 0.74° C. According to scientists, this is the largest and fastest warming trend that they have been able to discern in the history of the Earth. An increasing rate of warming has particularly taken place over the last 25 years, and 11 of the 12 warmest years on record have occurred in the past 12 years. The IPCC Report gives detailed projections for the 21st century and these show that global warming will continue and accelerate. The best estimates indicate that the Earth could warm by 3° C by 2100. Even if countries reduce their greenhouse gas emissions, the Earth will continue to warm. Predictions by 2100 range from a minimum of 1.8° C to as much as 4° C rise in global average temperatures.

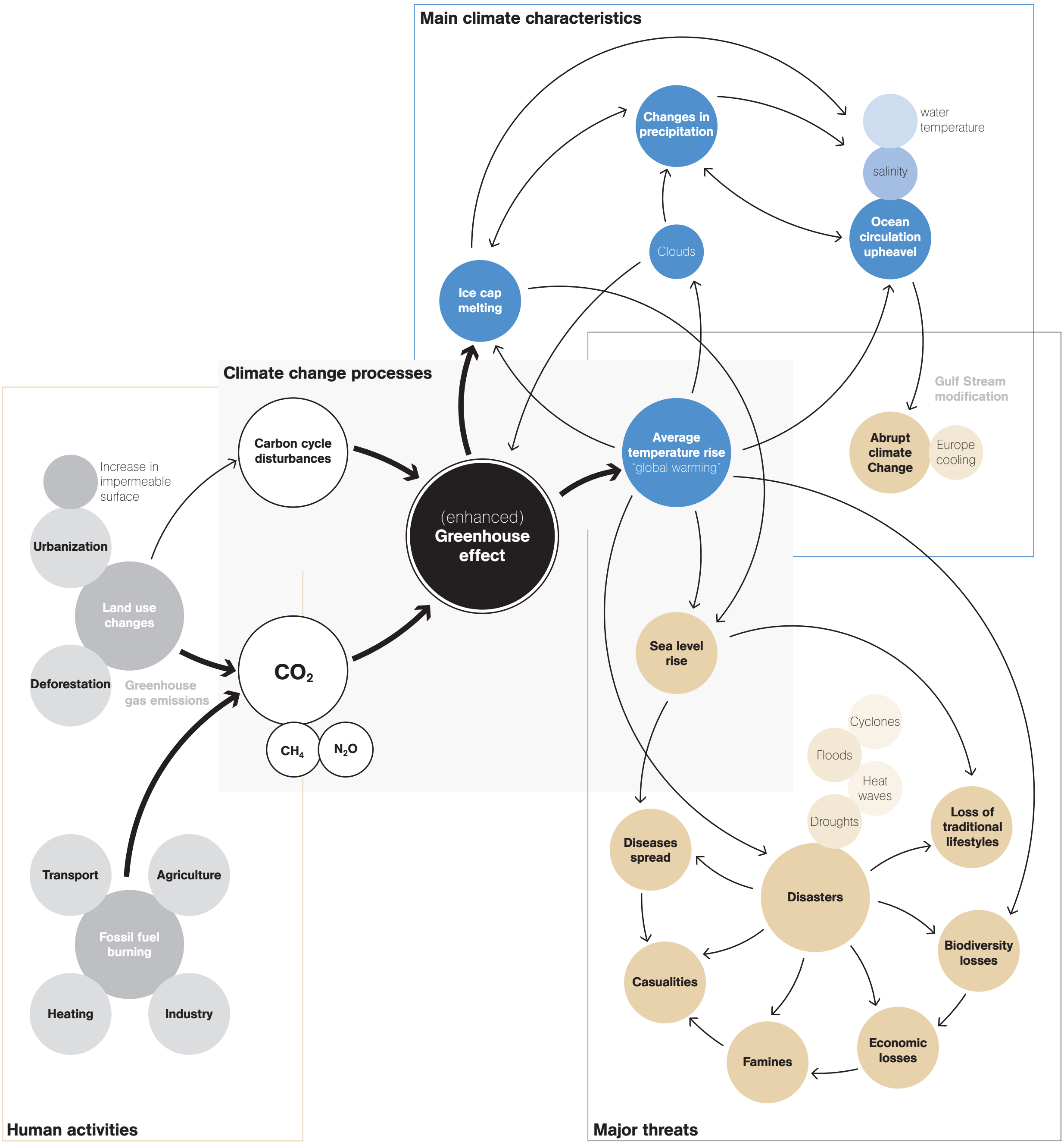
2.1 THE NEED FOR ADAPTATION

The major impacts and threats of global warming are widespread (Figure II-1). Increasing ocean temperatures cause thermal expansion of the oceans and in combination with meltwater from land-based ice this is causing sea level rise. Sea levels rose during the 20th century by 0.17 metres. By 2100, sea level is expected to rise between 0.18 and 0.59 metres. There are uncertainties in this estimate mostly due to uncertainty about how much water will be lost from ice sheets (Bindoff *et al*. 2007), for example Greenland is showing rising loss of mass in recent years (UNEP 2007). Increased melting of sea ice and freshwater influx from melting glaciers and ice sheets also has the potential to influence global patterns of ocean circulation.

As a result of global warming, the type, frequency and intensity of extreme events, such as tropical cyclones (including hurricanes and typhoons), floods, droughts and heavy precipitation events, are expected to rise even with relatively small average temperature increases. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events (Meehl *et al*. 2007).

Climate change will have wide-ranging effects on the environment, and on socio-economic and related sectors, including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity and coastal zones. Changes in rainfall pattern are likely to lead to severe water shortages and/or flooding. Melting of glaciers can cause flooding and soil erosion. Rising temperatures will cause shifts in crop growing seasons which affects food security and changes in the distribution of disease vectors putting more people at risk from diseases such as malaria and dengue fever. Temperature increases will potentially severely increase rates of extinction for many habitats and species (up to 30 per cent with a 2° C rise in temperature). Particularly affected will be coral reefs, boreal

Figure II-1. **Climate change: processes, characteristics and threats**



Source: UNEP/GRID–Arendal, 'Climate change: processes, characteristics and threats', designed by Philippe Rekacewicz, UNEP/GRID–Arendal Maps and Graphics Library, 2005, <http://maps.grida.no/go/graphic/climate_change_processes_characteristics_and_threats> (Last accessed 10 October 2007) forests, Mediterranean and mountain habitats. Increasing sea levels mean greater risk of storm surge, inundation and wave damage to coastlines, particularly in small island States and countries with low lying deltas. A rise in extreme events will have effects on health and lives as well as associated environmental and economic impacts.

Adaptation is a process through which societies make themselves better able to cope with an uncertain future. Adapting to climate change entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes. There are many options and opportunities to adapt. These range from technological options such as increased sea defenses or flood-proof houses on stilts, to behaviour change at the individual level, such as reducing water use in times of drought and using insecticide-sprayed mosquito nets. Other strategies include early warning systems for extreme events, better water management, improved risk management, various insurance options and biodiversity conservation.

Because of the speed at which change is happening due to global temperature rise, it is urgent that the vulnerability of developing countries to climate change is reduced and their capacity to adapt is increased and national adaptation plans are implemented. Future vulnerability depends not only on climate change but also on the type of development path that is pursued. Thus adaptation should be implemented in the context of national and global sustainable development efforts. The international community is identifying resources, tools and approaches to support this effort.

2.2 ADAPTATION AND THE UNFCCC

At the centre of efforts to address climate change on the international stage is the United Nations Framework Convention on Climate Change (UNFCCC). "The UNFCCC provides the basis for concerted international action to mitigate climate change and to adapt to its impacts. Its provisions are far-sighted, innovative and firmly embedded in the concept of sustainable development" (UNFCCC 2006a). The UNFCCC entered into force on 21st March 1994 and there are now 191 Parties (member countries) to the Convention, an almost global membership.[6] These members are committed to: launch national strategies for adapting to expected impacts, including the provision of financial and technological support to developing countries, and to cooperate in preparing for adaptation to the impacts of climate change.

The Convention refers to adaptation in several of its articles (Box II-1), and the Conference of the Parties to the UNFCCC has made several decisions in regards to adaptation to climate change. The Convention's Subsidiary Body for Implementation addresses agenda items on vulnerability and adaptation in the context of climate change negotiations. Particular attention has so far been given to issues relating to Article 4.8 and 4.9. Through the Subsidiary Body for Implementation, decisions have been made related to support and funding by Parties to assist developing countries with impact, vulnerability and adaptation assessment; capacity-building, training, education and public awareness; implementing concrete adaptation activities; promoting technology transfer; and exchanging experience through regional workshops. Attention has also been given to the scientific and technical aspects of adaptation and technology transfer, by the Convention's Subsidiary Body for Scientific and Technological Advice. This includes the Nairobi work programme on impacts, vulnerability and adaptation to climate change (Nairobi work programme).[7] The Programme was adopted by the Conference of the Parties to the UNFCCC in 2005 and renamed in 2006 and its objective is twofold: to assist countries, in particular developing countries, including the least developed countries and small island developing States, to improve their understanding and assessment of impacts, vulnerability and adaptation; and to assist countries to make informed decisions on practical adaptation actions and measures to respond to climate change on a sound, scientific, technical and socio-economic basis, taking into account current and future climate change and variability.

By its decision 1/CP.10, paragraph 8, the Conference of the Parties requested the UNFCCC secretariat to organize three regional workshops for Africa, Asia and Latin America and one expert meeting for small island developing States (SIDS).[8] These workshops and meetings were mandated in order to enable Parties and other experts from these four regions to reflect on their regional priorities; to facilitate information exchange and integrated assessments within and between regions; and to help identify specific adaptation needs and concerns.

Part of the mandate from the Conference of the Parties was for the UNFCCC secretariat to prepare reports, including a synthesis report, on the outcome of these workshops in order for the Subsidiary Body for Implementation to consider what further actions may be required on the international stage to promote adaptation in developing countries.

Box II-1. **Convention articles referring to adaptation**

All Parties are to "formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to … facilitate adequate adaptation to climate change". Article 4.1(b)

All Parties shall "Cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods". Article 4.1(e)

All Parties shall "Take climate change considerations into account, to the extent feasible, in their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessments, formulated and determined nationally, with a view to minimizing adverse effects on the economy, on public health and on the quality of the environment, of projects or measures undertaken by them to mitigate or adapt to climate change". Article 4.1(f)

"The developed country Parties … shall also assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to those adverse effects". Article 4.4

"The Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing country Parties arising from the adverse effects of climate change and/or the impact of the implentation of response measures". Article 4.8

"The Parties shall take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology". Article 4.9

The UNFCCC secretariat produced background papers for each of the workshops: Africa (UNFCCC 2006c), Asia (UNFCCC 2007b), Latin America (UNFCCC 2006b) and the SIDS expert meeting (UNFCCC 2007a). Following the workshops and meetings, summary reports were produced: Africa (UNFCCC 2007c), Asia (UNFCCC2007e), Latin America (UNFCCC 2006d) and SIDS (UNFCCC 2007d). The synthesis report of these workshops and meeting summarizes the identified adaptation needs and concerns, particularly those for which there was common interest across the regions (UNFCCC 2007f). The report includes recommendations by the Chair of the Subsidiary Body for Implementation on possible next steps by Parties. This publication draws upon the proceedings and outcomes of these workshops and meeting. The work of the regional workshops, mandated by the Subsidiary Body for Implementation, is complemented by ongoing work on the Nairobi work programme organized under the Subsidiary Body for Scientific and Technological Advice.

[6] <http://unfccc.int/2631.php>
[7] <http://unfccc.int/3633.php>
[8] Decision 1.CP/10, see <http://unfccc.int/resource/docs/cop10/10a01.pdf#page=2>

III. ASSESSING THE IMPACTS OF, AND VULNERABILITY AND ADAPTATION TO, CLIMATE CHANGE

Assessing the impacts of and vulnerability to climate change and subsequently working out adaptation needs requires good quality information. This information includes climate data, such as temperature, rainfall and the frequency of extreme events, and non-climatic data, such as the current situation on the ground for different sectors including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity, and coastal zones (see CHAPTER IV).

This chapter describes what information is collected to assess climate variability and change, and the tools used for assessing the impacts and vulnerability of developing countries to climate change. If the capacity for assessing climate change is not there, countries are limited in their ability to plan adaptation measures and adapt effectively.

3.1 INFORMATION GATHERING – DATA, SYSTEMATIC OBSERVATION AND MONITORING

For countries to understand their local climate better and thus be able to predict local climate change, they must have adequate operational national systematic observing networks, and access to the data available from other global and regional networks. Systematic observations of the climate system are usually carried out by national meteorological centres and other specialised centres. They take observations at standard preset times and places, and monitor atmosphere, ocean and terrestrial systems. The major climate variables measured include temperature, rainfall, sea surface temperature, sea level rise, wind speeds, tropical cyclones (including hurricanes and typhoons), snow and ice cover.

A sure knowledge base from systematic observation and forecasting services is essential to monitor climate; detect and attribute climatic change; improve the understanding of the dynamics of the climate system and its natural variability; provide input for climate models; and thus plan adaptation options. For example, monitoring trends of sea surface temperature and sea level are essential in order to assess their impacts on the increased intensity of tropical cyclones and storm surge; monitoring events relating to the phenomenon of El Niño Southern Oscillation (ENSO) is important in helping determining its effects on reducing or increasing precipitation in different regions leading to both floods and drought.

Article 5 of the UNFCCC refers to the need for the international community to support and further develop climate research and systematic observation systems, taking into account the concerns and needs of developing countries. As part of this recognition, the COP invited the Global Climate Observing System (GCOS)[9] to launch a regional workshop programme in 2000 to identify the priority capacity-building needs and identify gaps in regional systematic observation (see FCCC/SBSTA/2006/MISC.13, UNFCCC 2006f). Action Plans were subsequently developed and are now being implemented for developing country regions including Eastern and Southern Africa, Western and Central Africa, East and Southeast Asia, Central Asia, South and Southwest Asia, South America, Central America and the Caribbean, and the Pacific Islands. The plans highlight the need for a better knowledge base, better forecasting and climate services and a need to improve observations at all levels to enhance countries' ability to adapt. They emphasise that effective adaptation planning requires improved observations; improved regional, national and global data, as well as denser networks; the recovery of historical data; building of support among the user communities that have a demand for climate information; and promoting greater collaboration between the providers and users of climate information.

At all the UNFCCC workshops and meeting, participants reported that observations and data availability still need to be improved in all regions. At the Africa workshop, participants agreed that systematic observation networks in Africa are inadequate because there is a lack of stations and lack of maintenance. Participants reiterated that missing and scattered observational climate data in Africa is a constraint to understanding current and future climate variability. If data exist, there are difficulties in obtaining it. Participants underlined the importance of implementing the GCOS Action Plan for Africa, the "Climate Information for Development Needs: An Action Plan for Africa", to improve the situation. Launched in 2007, the plan aims to improve the inadequate and deteriorating observing systems through an integrated programme that includes not only observations, but also climate services and climate risk management and policy.

9 <http://www.wmo.ch/pages/prog/gcos/index.php>

In most countries of Asia, the meteorological or hydro-meteorological department of the government is responsible for collecting, processing and supplying data as well as maintaining infrastructure of the systematic observation system. Participants at the Asia workshop highlighted the need to improve observations and data availability, including in islands, mountainous, and coastal ecosystems, at the national, regional and global levels. Efforts regarding the harmonization and consistency of data should be enhanced through improved coordination between data providers from different sectors. For example, China reported at the workshop on the improvements it is making to its systematic observation network under the framework of the China GCOS programme. China is monitoring atmospheric composition, energy balance, water and carbon cycles, ecosystems, land use, ice and snow, and regularly submits real-time observation data of China GCOS stations and historical data records from national stations to the World Data Center for Meteorology. The country has an operational system of short-term climatic monitoring, prediction and assessment, established in the Beijing Climate Centre, and has some regional cooperative climate programmes with other Asian developing countries such as the Islamic Republic of Iran, Nepal, Sri Lanka and Uzbekistan.

In Latin America, workshop participants reported that climate information is either unavailable or sparse, and it is difficult to use it for modelling and scenario development. According to the GCOS February 2005 report, another reason for large gaps in observational coverage lies in the fact that the network of national correspondents works only on a voluntary basis. Retirements, political instability, economic problems and over-tasking of staff are a few of the issues that endanger the continuity of climate data series (GCOS 2005). The workshop reported a significant gap in observational coverage and that the problem is more acute for some regions, mainly the higher elevations along the Andean Mountain Range. This range constitutes a major determinant of the climate systems of the continent and high-elevation data is important for the detection and assessment of climate change and its impacts on glaciers, snow cover, and run-off. It was reported that the websites of national meteorological services, in general, do not make datasets available to allow studies of detection and attribution of climate change and there are just a few countries in Latin America which, at present, have active climate change programs. It was emphasised as urgent to implement plans for investments in meteorological information and to improve Latin American countries' capabilities and knowledge to undertake and maintain systematic, long-term, climate observational programs, along with the capacity to undertake analyses of climatic information.

In small island developing States the national meteorological and hydrological services are the responsible agency for climate observations. However, it was reported at the expert meeting that many networks are not working efficiently due to: limited assigned satellite windows for data transmission; low frequency of recordings; delays in maintenance and replacement and incorrect calibration of equipment; and limited access to products and services. Following 10 GCOS regional workshops between 2000–2006, elements of the regional action plans are now being implemented. The Pacific Islands Global Climate Observing System is addressing capacity-building needs, improving observing stations, climate prediction, telecommunication and data rescue. The Regional Action Plan for Central America and the Caribbean is partly being implemented through the Mainstreaming Adaptation to Climate Change project. This includes upgrades of observation networks, data rescue, and assessment of surface and groundwater monitoring networks.

In summary, the UNFCCC-organized workshops and meeting in 2006–2007 highlighted that there is still a need to take stock of available climate information in developing countries so that it is clear where the systematic observation needs are most pressing. Follow-up actions include improving and sustaining operational observing networks, such as the GCOS observational networks. Collaboration between national and international providers of climate information and the users, in all sectors, of such information for adaptation to climate change is vital as well as generating awareness among different user communities of the usefulness of climate information and services and improving national and regional coordination. Data needs to be carefully packaged so that it can be used effectively. Rescuing historical meteorological data is important. Education and training and improved national planning and reporting would also help build capacity.

At the workshops and meeting, it was highlighted that it is not just climate data that is needed for effective vulnerability and adaptation assessments to climate change in developing countries. Equally as important, and very much lacking at present, is the need for accurate socio-economic data. This data needs to come from across sectors and is an important complement to existing assessments, particularly given that poverty has been recognized as a major factor in vulnerability.

3.2 INFORMATION ANALYSIS – REPORTING OF IMPACTS, VULNERABILITY AND ADAPTATION

Reliable, systematic climate data helps countries determine their current climate variabilities, and model future changes. Countries use a number of assessment models, tools and methodologies as well as various scenarios, including those provided by the IPCC (IPCC 2000), to help provide an assessment of the future impacts of climate change. Climate change impacts, vulnerability and adaptation assessments need to generate outputs that are policy relevant. To do this, climate change data including future impacts and vulnerabilities needs to be integrated with socioeconomic data and analyses across a range of sectors, and the results must be tailored for policymakers and stakeholders.

All Parties to the UNFCCC are committed to submit national communications in which they outline the implementation of the UNFCCC and the impacts from climate change that they are facing. In their national communications, countries provide an assessment of vulnerabilities and adaptation options. Water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity, and coastal zones are common sectors for which impacts and vulnerability assessment have been carried out by developing countries.

At the workshops and expert meeting, vulnerability and adaptation assessments were identified as vital tools for developing countries to evaluate and implement responses to climate change. A major problem in all regions was the limited capacity at regional and national level due to deficiencies in data collection and the lack of technical expertise. It was highlighted as important to make the models, tools and methodologies that are appropriate for assessments in developing countries more widely available. Exchanging information on tools used for vulnerability and adaptation assessments, together with the outcomes of these assessments, would help countries improve capacity in this area. This could be done through workshops and symposia, regional science journals, websites to facilitate information exchange and by making better use of existing channels of information.

The resolution of models used to determine climate change in developing countries is too course and often relies on data from sources in other countries. Along with the disparity in outputs from different models, this makes the use of results as a basis for adaptation action very difficult. A major problem encountered when using models to get national results is the need for readjustment and downscaling to suit a country's individual needs. Participants highlighted the need for enabling training on the use of models and tools in all regions and providing technical support, such as through the training of trainers on modelling tools, and follow-up through regional centres of excellence, to address gaps in expertise in the application of methods and tools and in using climate information and geographical information systems. At the SIDS meeting special mechanisms for vulnerability and adaptation assessment training, including short courses and longer-term professional training incorporating capacity-building for participatory approaches, were mentioned as a follow-up action.

The development of higher resolution regional models for developing countries is important as well as analysing the disparity between the model outcomes. This would help enhance capacity for reaching informed decision making. For example, at the Africa workshop, participants emphasised the need to develop regional climate models to provide fine-scale climate information for long-term impact studies and forecasting, as well as facilitate information exchange between African institutions. Some efforts are being undertaken in this regard in developing countries, and regional models are being developed that are capable of providing more useful information needed by planners and policy makers. For example, the Hadley Centre's model PRECIS (Providing REgional Climates for Impacts Studies)[10] has been designed for use by local meteorological offices or research institutes. Training on this model has been undertaken in several developing countries, including Cuba, Brazil, Argentina, South Africa and India, and Jamaica, Cuba and Barbados mentioned at the expert meeting that results from the model have been used in vulnerability assessments.

At the SIDS meeting it was further highlighted that establishing a group of experts to facilitate assessments for specific circumstances of SIDS would be useful. Establishing a roster of experts with specialized skills, in all regions at centres of excellence, would help to maintain experts working in the regions. This would also help continuity in impact and vulnerability assessment, a problem highlighted at the Africa meeting where participants emphasized that the impact and vulnerability assessment undertaken in the initial national communication process was disjoined from that of the second national communication.

Participants at all workshops and at the expert meeting emphasised the lack of socio-economic data, or indeed development indicators and relevant tools for enhancing

[10] <http://precis.metoffice.com>

the use of socio-economic assessment in a way that would be relevant to policy makers and other stakeholders, including ministries of finance and economy. It is important to link climate vulnerability to socio-economic studies and long-term periodic and socio-economic assessments. Preserving indigenous knowledge that is relevant to community level responses, studies on coping strategies, and gender specific vulnerability assessments were all highlighted as important elements to determining adaptation options.

Useful methodologies for assessing adaptation options include both top-down and bottom-up approaches. Both methodologies need to be linked to promote integrated adaptation assessments. Top-down methodologies include the use of modelling and scenario analysis. This can provide useful background to decision making and is strong in terms of the biophysical aspects of impacts. However the models do not perform well in representing human interactions and local abilities to adapt. This is highlighted by an example from the Cook Islands (Box III- 2).

As a complement to the top-down approach is a vulnerability-based, bottom-up, approach, which recognizes and builds upon local coping strategies and indigenous knowledge and technologies, and the capacity and coping range of communities, local institutions and sectors in responding to current climate variability. This approach helps to incorporate human and economic dimensions of the local communities, particularly livelihood aspects and inter-sectoral relationships. It is useful in developing specific strategies and policy implementation. However, it exhibits a weaker attribution to future climate change.

An example of this approach is the UNFCCC's National Adaptation Programmes of Action (NAPAs) for use by least developed countries to prioritize their urgent adaptation needs.[12] The rationale for NAPAs rests on the limited ability of least developed countries to assess their vulnerability and adapt to climate change. A new approach was needed that would focus on enhancing adaptive capacity to climate variability and thus help these countries directly address their urgent needs arising from the adverse effects of climate change. The NAPAs use and build upon existing coping strategies at the grassroots level, rather than focusing on scenario-based modelling, to assess future vulnerability and adaptive responses at local and state level. Involvement of different stakeholders (national, sectoral, local) and including existing coping strategies are an integral part in the assessment process.

[11] Adapted from a presentation given by Ms. Pasha Carruthers on this topic at the UNFCCC CGE Regional Hands-on Training Workshop on Vulnerability and Adaptation Assessments for the Asia and the Pacific Region, held in Jakarta, Indonesia on 20 to 24 March 2006.
[12] <http://unfccc.int/2719.php>

Box III-2. **Experience of the Cook Islands in applying impacts assessments methodologies**[11]

As part of the Pacific Island Climate Change Assistance Programme which aims to help Pacific islands meet their reporting obligations to the UNFCCC, the Cook Islands applied the prototype integrated assessment model PACCLIM (PACific CLimate Impacts Model). This model was developed by the International Global Change Institute in New Zealand and involved the integration of a global climate model with climate data and a regional climate scenario generator.

Economic activity in the Cook Islands includes tourism, pearls, commercial and subsistence fisheries and coastal floodplain agriculture. The Cook Islands faced numerous challenges when carrying out the assessment, including gaining trust for the project, the limited time to carry out the project, the presentation of complex material, gathering the relevant input, recording feedback, verifying anecdotal evidence and quantifying observations and uncertainties. The conclusion was that the tool had limited applicability for the Cook Islands and was rather complicated, and that it would be better to focus on refining data collection and on improving results by using simpler methods. The tool could be better used for training in identifying cross-sectoral considerations.

IV. REGIONAL IMPACTS OF AND VULNERABILITIES TO CLIMATE CHANGE

This chapter highlights the impacts of and the vulnerabilities to climate change in the four regions: Africa, Asia, Latin America and small island developing States. Impacts and vulnerabilities vary by region and were reported in the background papers to the workshops and meeting held in these regions by the UNFCCC (UNFCCC 2006b, 2006c, 2007a, 2007b) and in presentations during the workshops and meeting themselves.[13] Additional sources, including information for the IPCC Fourth Assessment Report (IPCC 2007), are used here to complement the information provided at the workshops and meeting and are referenced where used.

4.1 AFRICA

Africa is already a continent under pressure from climate stresses and is highly vulnerable to the impacts of climate change. Many areas in Africa are recognized as having climates that are among the most variable in the world on seasonal and decadal time scales. Floods and droughts can occur in the same area within months of each other. These events can lead to famine and widespread disruption of socio-economic well-being. For example, estimates reported at the workshop indicate that one third of African people already live in drought- prone areas and 220 million are exposed to drought each year.

Many factors contribute and compound the impacts of current climate variability in Africa and will have negative effects on the continent's ability to cope with climate change. These include poverty, illiteracy and lack of skills, weak institutions, limited infrastructure, lack of technology and information, low levels of primary education and health care, poor access to resources, low management capabilities and armed conflicts. The overexploitation of land resources including forests, increases in population, desertification and land degradation pose additional threats (UNDP 2006). In the Sahara and Sahel, dust and sand storms have negative impacts on agriculture, infrastructure and health.[14]

Table IV-1 highlights some impacts of climate change in Africa on key sectors and gives an indication of the adaptive capacity of this continent to climate change. As a result of global warming, the climate in Africa is predicted to become more variable, and extreme weather events are expected to be more frequent and severe, with increasing risk to health and life. This includes increasing risk of drought and flooding in new areas (Few *et al*. 2004, Christensen *et al*. 2007) and inundation due to sea-level rise in the continent's coastal areas (Nicholls 2004; McMichael *et al*. 2006).

Africa will face increasing water scarcity and stress with a subsequent potential increase of water conflicts as almost all of the 50 river basins in Africa are transboundary (Ashton 2002, De Wit and Jacek 2006). Agricultural production relies mainly on rainfall for irrigation and will be severely compromised in many African countries, particularly for subsistence farmers and in sub-Saharan Africa. Under climate change much agricultural land will be lost, with shorter growing seasons and lower yields. National communications report that climate change will cause a general decline in most of the subsistence crops, e.g. sorghum in Sudan, Ethiopia, Eritrea and Zambia; maize in Ghana; Millet in Sudan; and groundnuts in Gambia. Of the total additional people at risk of hunger due to climate change, although already a large proportion, Africa may well account for the majority by the 2080s (Fischer *et al*. 2002).

Africa is vulnerable to a number of climate sensitive diseases including malaria, tuberculosis and diarrhoea (Guernier *et al*. 2004). Under climate change, rising temperatures are changing the geographical distribution of disease vectors which are migrating to new areas and higher altitudes, for example, migration of the malaria mosquito to higher altitudes will expose large numbers of previously unexposed people to infection in the densely populated east African highlands (Boko *et al*. 2007). Future climate variability will also interact with other stresses and vulnerabilities such as HIV/AIDS (which is already reducing life expectancy in many African countries) and conflict and war (Harrus and Baneth 2005), resulting in increased susceptibility and risk to infectious diseases (e.g. cholera and diahrrhoea) and malnutrition for adults and children (WHO 2004).

Climate change is an added stress to already threatened habitats, ecosystems and species in Africa, and is likely to trigger species migration and lead to habitat reduction. Up to 50 per cent of Africa's total biodiversity is at risk due to reduced habitat and other human-induced pressures (Boko *et al*. 2007). The latter include land-use conversion due to agricultural expansion and subsequent destruction

Table IV-1. **Regional Impacts and Vulnerabilities to Climate Change in Africa**

Impacts	Sectoral vulnerabilities	Adaptive Capacity
Temperature – Higher warming (x1.5) throughout the continent and in all seasons compared with global average. – Drier subtropical regions may become warmer than the moister tropics. Precipitation – Decrease in annual rainfall in much of Mediterranean Africa and the northern Sahara, with a greater likelihood of decreasing rainfall as the Mediterranean coast is approached. – Decrease in rainfall in southern Africa in much of the winter rainfall region and western margins. – Increase in annual mean rainfall in East Africa. – Increase in rainfall in the dry Sahel may be counteracted through evaporation. Extreme Events – Increase in frequency and intensity of extreme events, including droughts and floods, as well as events occurring in new areas.	Water – Increasing water stress for many countries. – 75–220 million people face more severe water shortages by 2020. Agriculture and food security – Agricultural production severely compromised due to loss of land, shorter growing seasons, more uncertainty about what and when to plant. – Worsening of food insecurity and increase in the number of people at risk from hunger. – Yields from rain-fed crops could be halved by 2020 in some countries. Net revenues from crops could fall by 90% by 2100. – Already compromised fish stocks depleted further by rising water temperatures. Health – Alteration of spatial and temporal transmission of disease vectors, including malaria, dengue fever, meningitis, cholera, etc. Terrestrial Ecosystems – Drying and desertification in many areas particularly the Sahel and Southern Africa. – Deforestation and forest fires. – Degradation of grasslands. – 25–40% of animal species in national parks in sub-Saharan Africa expected to become endangered. Coastal Zones – Threat of inundation along coasts in eastern Africa and coastal deltas, such as the Nile delta and in many major cities due to sea level rise, coastal erosion and extreme events. – Degradation of marine ecosystems including coral reefs off the East African coast. – Cost of adaptation to sea level rise could amount to at least 5–10% GDP.	Africa has a low adaptive capacity to both climate variability and climate change exacerbated by existing developmental challenges including: – low GDP per capita – widespread, endemic poverty – weak institutions – low levels of education – low levels of primary health care – little consideration of women and gender balance in policy planning – limited access to capital, including markets, infrastructure and technology – ecosystems degradation – complex disasters – conflicts

Source: Boko *et al*. (2007), Christensen *et al*. (2007).

[13] <http://unfccc.int/3582.php>
[14] Presentation from Ms. Balgis Osman Elasha, UNFCCC African Regional Workshop on Adaptation, Accra, Ghana, 21 to 23 September 2006. <http://unfccc.int/3743.php>

of habitat; pollution; poaching; civil war; high rates of land use change; population growth and the introduction of exotic species. For example, the habitat of the great apes, including the western lowland Gorilla – identified as critically endangered on the World Conservation Union's (IUCN) red list of threatened species, is likely to seriously decline between 2002 and 2032.[15]

Future sea level rise has the potential to cause huge impacts on the African coastlines including the already degraded coral reefs on the Eastern coast. National communications indicate that the coastal infrastructure in 30 percent of Africa's coastal countries, including the Gulf of Guinea, Senegal, Gambia, Egypt, and along the East-Southern African coast, is at risk of partial or complete inundation due to accelerated sea level rise.[16] In Tanzania, a sea level rise of 50 cm would inundate over 2,000 km2 of land, costing around USD 51 million (UNEP 2002a). Future sea level rise also threatens lagoons and mangrove forests of both eastern and western Africa, and is likely to impact urban centres and ports, such as Cape Town, Maputo, and Dar Es-Salaam.

4.2 ASIA

Asia is the largest continent on Earth and spreads over four climatic zones (boreal, arid and semi-arid, tropical and temperate). The region faces formidable environmental and socio-economic challenges in its effort to protect valuable natural resources. Land and ecosystems are being degraded, threatening to undermine food security. In addition, water and air quality are deteriorating while continued increases in consumption and associated waste have contributed to the exponential growth in the region's existing environmental problems. Furthermore, the region is highly subject to natural hazards, such as the 2004 Indian Ocean Tsunami, the 2005 Pakistan Earthquake, and the 2006 landslides in the Philippines. There is evidence of prominent increases in the intensity and/or frequency of many extreme weather events such as heat waves, tropical cyclones, prolonged dry spells, intense rainfall, tornadoes, snow avalanches, thunderstorms, and severe dust storms in the region (Cruz *et al*. 2007). Impacts of such disasters range from hunger and susceptibility to disease, to loss of income and livelihoods, affecting human survival and well-being. For example the extreme weather events in China during 2006 included major storms and flooding in the east and south, as well as heat and drought in central, western and northeastern regions, killing more that 2700 people and causing USD 20 billion in damages.

Climate change will affect many sectors, including water resources, agriculture and food security, ecosystems and biodiversity, human health and coastal zones (TABLE IV-2). Many environmental and developmental problems in Asia will be exacerbated by climate change.

Under climate change, predicted rainfall increases over most of Asia, particularly during the summer monsoon, could increase flood-prone areas in East Asia, South Asia and Southeast Asia. In Central and South Asia, crop yields are predicted to fall by up to 30 per cent, creating a very high risk of hunger in several countries.

Global warming is causing the melting of glaciers in the Himalayas. In the short term, this means increased risk of flooding, erosion, mudslides and GLOF in Nepal, Bangladesh, Pakistan, and north India during the wet season. Because the melting of snow coincides with the summer monsoon season, any intensification of the monsoon and/or increase in melting is likely to contribute to flood disasters in Himalayan catchments. In the longer term, global warming could lead to a rise in the snowline and disappearance of many glaciers causing serious impacts on the populations relying on the 7 main rivers in Asia fed by melt water from the Himalayas. Throughout Asia one billion people could face water shortage leading to drought and land degradation by the 2050s (Christensen *et al*. 2007, Cruz *et al*. 2007).

In Asia, the principal impacts of climate change on health will be on epidemics of malaria, dengue, and other vector-borne diseases (Martens *et al*. 1999). The global burden of climate change-attributable diarrhoea and malnutrition are already the largest in the world in Southeast Asian countries including Bangladesh, Bhutan, India, Maldives, Myanmar and Nepal in 2000. Illness and death are expected to increase from diarrhoeal diseases due to drought and flooding, and are also expected from increased amounts of cholera bacteria in coastal waters. An increase in the frequency and duration of severe heat waves and humid conditions during the summer is likely to increase the risk of mortality and morbidity, principally in the old and urban poor populations of temperate and tropical Asia (Epstein *et al*. 1995) and high temperatures and poor urban air quality, such as in Chongqing, China and in Jakarta, Indonesia, could contribute to widespread heat stress and smog induced illnesses in urban populations (Cruz *et al*. 2007).

Table IV-2. **Regional Impacts and Vulnerabilities to Climate Change in Asia**

Impacts	**Sectoral vulnerabilities**	**Adaptive Capacity**
Temperature – Warming above the global mean in central Asia, the Tibetan Plateau, northern, eastern and southern Asia. Warming similar to the global mean in Southeast Asia. – Fewer very cold days in East Asia and South Asia. Precipitation, snow and ice – Increase in precipitation in most of Asia. Decrease in precipitation in central Asia in Summer. – Increase in the frequency of intense precipitation events in parts of South Asia, and in East Asia. – Increasing reduction in snow and ice in Himalayan and Tibetan Plateau glaciers Extreme Events Increasing frequency and intensity of extreme events particularly: – droughts during the summer months and El Niño events; – increase in extreme rainfall and winds associated with tropical cyclones in East Asia, Southeast Asia and South Asia; – intense rainfall events causing landslides and severe floods; – heat waves/hot spells in summer of longer duration, more intense and more frequent, particularly in East Asia.	Water – Increasing water stress to over a hundred million people due to decrease of freshwater availability in Central, South, East and Southeast Asia, particularly in large river basins such as Changjiang. – Increase in the number and severity of glacial melt-related floods, slope destabilization followed by decrease in river flows as glaciers disappear. Agriculture and food security – Decreases in crop yield for many parts of Asia putting many millions of people at risk from hunger. – Reduced soil moisture and evapotranspiration may increase land degradation and desertification. – Agriculture may expand in productivity in northern areas. Health – Heat stress and changing patterns in the occurrence of disease vectors affecting health. – Increases in endemic morbidity and mortality due to diarrhoeal disease in south and Southeast Asia. – Increase in the abundance and/or toxicity of cholera in south Asia. Terrestrial Ecosystems – Increased risk of extinction for many species due to the synergistic effects of climate change and habitat fragmentation. – Northward shift in the extent of boreal forest in north Asia, although likely increase in frequency and extent of forest fires could limit forest expansion. Coastal Zones – Tens of millions of people in low-lying coastal areas of south and Southeast Asia affected by sea level rise and an increase in the intensity of tropical cyclones. – Coastal inundation is likely to seriously affect the aquaculture industry and infrastructure particularly in heavily-populated megadeltas. – Stability of wetlands, mangroves, and coral reefs increasingly threatened.	Adaptive capacity varies between countries depending on social structure, culture, economic capacity, geography and level of environmental degradation. Capacity is increasing in some parts of Asia, for example the success of early warning systems for extreme weather events in Bangladesh and the Philippines. However, capacity is still constrained due to poor resource bases, inequalities in income, weak institutions and limited technology.

Source: Christensen *et al*. (2007), Cruz *et al*. (2007).

[15] <http://maps.grida.no/go/graphic/loss_of_great_ape_habitat_2002_2032_africa>
[16] <http://unfccc.int/national_reports/non-annex_i_natcom/items/2979.php>

In recent years, enormous pressures have been put on Asia's ecosystems to support the ever growing demand for natural resources. The most affected areas are coastal and marine ecosystems, forests and mountainous regions and the flora and fauna within them. Climate change will have a profound effect on the future distribution, productivity, and health of forests throughout Asia, for example northeast China may become deprived of conifer forest.[17] Grassland productivity is expected to decline by as much as 40 – 90 per cent for an increase in temperature of 2 – 3° C, combined with reduced precipitation, in the semi-arid and arid regions of Asia.

Fisheries in both fresh water and sea water could be affected. Fisheries at higher elevations are likely to be adversely affected by lower availability of oxygen due to a rise in surface air temperatures. In the plains, the timing and amount of precipitation could also affect the migration of fish species from the river to the floodplains for spawning, dispersal, and growth (FAO 2003). Sea level rise and changes in sea water temperature, salinity, wind speed and direction, strength of upwelling, mixing layer thickness and predator response to climate change have the potential to substantially alter fish breeding habitats and food supply for fish and ultimately the abundance of fish populations in Asian waters with associated effects on coastal economies (Cruz *et al*. 2007).

Projected sea level rise could flood the residence of millions of people living in the low lying areas of South, Southeast and East Asia such as in Viet Nam, Bangladesh, India and China (Wassmann *et al*. 2004, Stern 2006, Cruz *et al*. 2007) and 30 percent of coral reefs could be lost in the next 10 years (Cruz *et al*. 2007). The loss may be as high as 88 per cent (59 per cent of global) in the next 30 years (Sheppard 2003; Wilkinson 2004).

4.3 LATIN AMERICA

Latin America includes much of the world's biological diversity, as well as a wide variety of ecosystems, climatic regions, topographies and land-use patterns. Particularly vulnerable to climate change are the water, agriculture and health sectors, the Andean glaciers, the Amazon region and regions vulnerable to extreme climatic events (UNFCCC 2006d). The impacts of climate change in this region and its adaptation potential are highlighted in Table IV-3. The region has already been experiencing climate-related changes with the frequency and intensity of extreme events, particularly those associated with the ENSO phenomenon. Torrential rains and resulting floods, including those associated with tropical cyclones, have result in tens of thousand of deaths and severe economic losses and social disruption in the region in recent years[18], for example in 1998 hurricane Mitch caused 10,000 deaths and severe damage to infrastructure, with Honduras and Nicaragua the worst hit. Northeast Brazil, on the other hand, is particularly affected by drought and its associated socio-economic impacts (Charvériat 2000).

Under climate change, as Andean glaciers disappear this century, there is likely to be serious effects on peoples lives and livelihoods and on ecosystems. Currently people in Bolivia, Chile, Ecuador and Peru, along the Andean Cordillera, depend on glacial seasonal discharge for their water supply as well as for hydro-energy. Higher rates of economic recession correspond with greater flows of water, which cause erosion, flooding and mudslides in lowland areas. However, as the glaciers disappear – such as the Chacaltaya Glacier in Bolivia, predicted to disappear within the next 15 years – flows will tail off dramatically leading to serious water shortages, reduced hydropower, greater risks of drought, as well as flooding, and serious environmental degradation (nef 2006, Magrin *et al*. 2007, UNEP 2007).

There are uncertainties over the effects of climate change on rainfall in Latin America. However it is predicted that arid and semi-arid areas will receive even less rain under climate change leading to degradation of agricultural land and impacting food security. Except for mid-latitude areas, where CO_2 fertilization effects may balance out the negative effects of climate change, agricultural yields are expected to decrease throughout Latin America by the end of the Century.

As well as through extreme events, the main risks of climate change on health and life are from heat stress – particularly due to urban heat island effects in megacities, and transmissible diseases including malaria, dengue and cholera (Githeko and Woodward, 2003, Patz 2005). Rodent-borne infections can also increase after floods and droughts such as leptospirosis and Hantavirus Pulmonary Syndrome (Ahern *et al*. 2005). Expected increases in forest fires due to warmer, drier climate and increased deforestation and forest fragmentation are likely to heighten the vulnerability of the population to the health impacts of biomass burning smoke, the effects of which have already been observed in Brazil (Haines and Patz 2004; Patz 2004).

Table IV-3. **Regional Impacts and Vulnerabilities to Climate Change in Latin America**

Impacts	Sectoral vulnerabilities	Adaptive Capacity
Temperature – Warming above the global mean is predicted in most of Latin America. – In southern South America warming similar to global mean. Precipitation, snow and ice – Decrease in annual precipitation in most of Central America and in the southern Andes, although large local variability in mountainous areas. – Increase in winter precipitation in Tierra del Fuego. – Increase in summer precipitation in south-eastern South America. – Uncertain rainfall changes over northern South America, including the Amazon forest. – Increasing reduction and disappearance of Andean glaciers. Extreme events Increasing frequency and intensity of extreme events, many related to ENSO, particularly: – intense rainfall events causing landslides and severe floods; – dry spells and drought, such as in northeast Brazil; – heat waves, with particularly major effects in megacities due to heat island effects; – Increase in intensity of tropical cyclones in the Caribbean basin.	Water – Increase in the number of people experiencing water stress – likely to be 7–77 million by the 2020s. – Runoff and water supply in many areas compromised due to loss and retreat of glaciers. – Reduction in water quality in some areas due to an increase in floods and droughts. Agriculture and food security – Reductions of crop yields in some areas, although other areas may see increases in yields. – By the 2050s, 50% of agricultural lands are very likely to be subjected to desertification and salinization in some areas. – Food security a problem in dry areas where agricultural land subject to salinization and erosion reducing crop yields and livestock productivity. Health – Risks to life due to increases in the intensity of tropical cyclones. – Heat stress and changing patterns in the occurrence of disease vectors risk to health. Terrestrial Ecosystems – Significant habitat loss and species extinctions in many areas of tropical Latin America, including tropical forests, due to higher temperatures and loss of groundwater with effects on indigenous communities. Coastal Zones – Impacts on low lying areas, such as the La Plata estuary, coastal cities and coastal morphology, coral reefs and mangroves, location of fish stocks, availability of drinking water and tourism due to sea level rise and extreme events.	The lack of modern observation equipment and climate monitoring hinders the quality of forecasts lowering public trust in climate records and applied meteorological services. This has a negative impact on the quality of the early warning and alert advisory services. Some social indicators have improved in recent decades including life expectancy, adult literacy and freshwater access. However, adaptive capacity is limited by high infant mortality, low secondary school enrolment and high levels of inequality both in income and in access to fresh water and health care as well as gender inequalities.

Source: Christensen *et al*. (2007), Magrin *et al*. (2007).

[17] Presentation by Mr. Mozaharul Alam, UNFCCC Asian Regional Workshop on Adaptation, 11-13 April, Beijing, China. <http://unfccc.int/3955.php>

[18] Presentation from Mr. Carlos Nobre, UNFCCC Latin American regional workshop on adaptation, Lima, Peru, 18 to 20 April 2006. <http://unfccc.int/3719.php>

The Amazon Basin is home to some 40 per cent of the world's remaining tropical forest and contains one of the Earth's richest assortments of biodiversity; thousands of species of plants, over a million insect species, more than 700 fish species, 1,000 bird species, and over 300 mammalian species. The reduction of tropical forest area, especially in the tropical rainforests, will probably entail the loss of many species (Scholze *et al*. 2005). Climate change threatens to substantially affect the Amazon region, which in turn is expected to alter global climate and increase the risk of biodiversity loss (WWF 2006). By 2050 for a projected increase of 2° C surface temperature, severe species loss is predicted over central Brazil, Mexico and in dry areas of Argentina, Bolivia and Chile (Thomas *et al*. 2004; Siqueira and Peterson 2003; Miles *et al*. 2004). The central-eastern Amazon is predicted to undergo an irreversible process of 'savannization' (Nobre *et al*. 2004).

Low-lying coasts in several countries (Argentina, Belize, Colombia, Costa Rica, Ecuador, Guyana, Mexico, Panama, El Salvador, Uruguay, Venezuela) and large cities (Buenos Aires, Rio de Janeiro, Recife, etc.) are among the most vulnerable to extreme weather events such as rain, windstorms and hurricanes with their associated storm surges and sea level rise.

National communications report that sea level rise is likely to have adverse impacts on: buildings and tourism, (e.g. in Mexico, Uruguay); coastal morphology (e.g. in Peru); mangroves (e.g. in Brazil, Ecuador, Colombia, Venezuela); and availability of drinking water in the Pacific coast of Costa Rica, Ecuador and the River Plate estuary. Mesoamerican coral reefs (e.g. Mexico, Belize, Panama); and the location of fish stocks in the south-east Pacific (e.g. Peru, Chile) are also likely to be affected.

Mangrove forests located in low-lying coastal areas are particularly vulnerable to sea level rise, increased mean temperatures, and hurricane frequency and intensity, especially in Mexico, Central America and Caribbean continental regions (Magrin *et al*. 2007) and could disappear unless they are better managed (Medina *et al*. 2001, McLeod and Salm 2006). Fish stocks are also affected by warmer sea waters with resulting negative consequences for fishing in the region.

Salinization of drinking water could become an increasingly serious problem in coastal areas due to sea level rise. Sea-level rise in some areas may lead to a reduction in the salinity of hypersaline lagoons negatively affecting biodiversity (Quammen and Onuf 1993).

4.4 SMALL ISLAND DEVELOPING STATES

The small island developing States comprise 51 States and Territories spread over the Pacific, Indian and Atlantic Oceans and Caribbean Sea, and are highly vulnerable to the effects of climate change and already feeling its impacts. The climate of SIDS is influenced by large ocean-atmosphere interactions such as trade winds, El Niño and the monsoons. Small island developing States are characterised by the concentration of large settlements with associated economic and social activities at or near the coast. In SIDS, arable land, water resources and biodiversity are already under pressure from sea level rise. Increases in population and the unsustainable use of available natural resources add further problems. Tropical storms and cyclones cause storm surges, coral bleaching, inundation of land, and coastal and soil erosion with resulting high-cost damages to socio-economic and cultural infrastructure. For example, in the Pacific islands region, cyclones accounted for 76 per cent of the reported disasters between 1950 and 2004, with the average costs relating to damage caused per cyclone standing at USD 75.7 million in 2004 value (World Bank 2006a). In the Caribbean region, the 2004 hurricane season alone caused damages estimated at USD 2.2 billion in four countries: the Bahamas, Grenada, Jamaica and the Dominican Republic.[19]

The projected impacts of climate change cross all sectors and the vulnerability and low adaptive capacity of SIDS is inextricably linked to the socio-cultural and economic context of these island States (TABLE IV-4). Vulnerabilities include low availability of resources, a small but rapidly growing population, remoteness, susceptibility to natural disasters, excessive dependence on international trade, and vulnerability to global developments.

Water supply in SIDS is likely to be exacerbated by future climate change. Freshwater lenses are predicted to reduce in size due to increased demand and reduced rainfall. It has been estimated that a 10 per cent reduction in average rainfall by 2050 could produce a 20 per cent reduction in the size of the freshwater lens on the Tarawa Atoll, Kiribati, and reduce the thickness of the freshwater lens on atolls by as much as 29 percent. Freshwater supplies are also threatened by saltwater intrusion due to storm surge and sea level rise (Mimura *et al*. 2007).

The projected impacts of climate change on agriculture include extended periods of drought, loss of soil fertility and shortening of the growing season which will lead to major economic losses and seriously affect food security.

Table IV-4. **Regional Impacts and Vulnerabilities to Climate Change in small island developing States**

Impacts	Sectoral vulnerabilities	Adaptive Capacity
Temperature – All Caribbean, Indian Ocean and North and South Pacific small island States will experience warming. Warming will be lower than the global average. Precipitation – Decrease in summer rainfall in the Caribbean in the vicinity of the Greater Antilles. – Increase in annual rainfall in the equatorial Pacific and in the northern Indian Ocean, in the Seychelles and the Maldives. – Decrease in rainfall in the vicinity of Mauritius, in the Indian Ocean, and east of French Polynesia, in the Pacific. Extreme Events – Increasing intensity of tropical cyclones, storm surge, coral bleaching and land inundation.	Water – Water sources seriously compromised due to rising sea level, changes in rainfall and increased evapotranspiration, e.g. in the Pacific, a ten percent reduction in average rainfall (by 2050) would lead to a twenty percent reduction in the size of the freshwater lens on the Tarawa Atoll, Kiribati. Agriculture and food security – Agricultural land and thus food security affected by sea-level rise, inundation, soil salinization, seawater intrusion into freshwater lenses, and decline in freshwater supply. – All agricultural production affected by extreme events. – Fisheries affected by increasing sea surface temperature, rising sea level and damage from tropical cyclones. Health – Increases in the intensity of tropical cyclones increase risks to life. – Heat stress and changing patterns in the occurrence of disease vectors and climate sensitive diseases affect health. Terrestrial Ecosystems – Replacement of local species and colonization by non-indigenous species. – Forests affected by extreme events are slow to regenerate. Forest cover may increase on some high latitude islands. Coastal Zones – Most infrastructure, settlements and facilities located on or near the shore and will be affected by sea-level rise, coastal erosion and other coastal hazards, compromising the socio-economic well-being of island communities and states. – Accelerated beach erosion, degradation of coral reefs and bleaching will all have impacts on incomes from fishing and tourism. – Habitability and thus sovereignty of some states threatened due to reduction in island size or complete inundation.	Small islands, whether located in the tropics or higher latitudes are especially vulnerable to the effects of climate change, sea level rise and extreme events. Characteristics such as limited size, proneness to natural hazards and external shocks enhance the vulnerability of islands to climate change. In most cases they have low adaptive capacity, and adaptation costs are high relative to GDP.

Source: Christensen *et al*. (2007), Mimura *et al*. (2007).

[19] United Nations Economic Commission for Latin America and the Caribbean press release. <http://www.reliefweb.int/rw/rwb.nsf/db900SID/JCDR-677LG5?OpenDocument>

On many islands, prime agricultural land is located on the coastal plains which are already threatened by sea-level rise. The relative magnitude of economic losses due to climate change is likely to differ among islands. For example, in the absence of adaptive measures on a high island such as Viti Levu in Fiji, the cost of damages could be in the range of USD 23 – 52 million per year (2 – 3 per cent of GDP) by 2050 whereas in a low island such as Tarawa, Kiribati, the annual average cost of damages would be in the order of USD 8 – 16 million (17 – 18 per cent of GDP) by 2050 (World Bank 2000).

In SIDS, increasing extreme events such as tropical cyclones are predicted to have huge impacts on forest cover and biodiversity, particularly as adaptation responses on small islands are expected to be slow, and impacts of storms may be cumulative (Mimura *et al*. 2007). Changes in temperature are likely to particularly affect high elevation SIDS, and biological invasions are predicted to drive several species, including many endemic birds, to extinction (Wormworth and Mallon 2006).

Increasing temperatures and decreasing water availability due to climate change may also increase the burden of diarrhoeal and other infectious diseases in some small island States. Increases in tropical cyclones, storm surges, flooding, and drought are likely to have both short- and long-term effects on human health, including drowning, injuries, increased disease transmission, decreases in agricultural productivity and subsequent malnutrition.

Coastlines will almost certainly suffer from accelerated coastal erosion as well as inundation of settlements and arable land with associated social and economic consequences. For example, in Grenada, a 50 cm rise in sea level could lead to serious inundation with 60 per cent of beaches in some areas being lost (UNFCCC 2007a). A one-metre rise in sea level is expected to cost Jamaica USD 462 million, 19 per cent of its GDP (Jamaica 2000); while for the Maldives a one-meter rise in sea level would mean the complete disappearance of the nation (Maldives 2001).

Sea level rise, increasing sea surface temperatures and acidification of the oceans will entail a loss of mangrove forests and coral reefs and reduced fish stocks throughout this region. For example, studies have projected that 3 per cent of Cuba's mangrove forests may be lost with a one meter rise in sea level. For the same rise in sea level a complete collapse of the Port mangrove wetland in Jamaica is predicted, since this system has shown little capacity to migrate over the last 300 years (Nurse *et al*. 2001).

Climate change is also likely to have a negative effect on tourism in SIDS, seriously affecting the economy of many small islands. The increasing frequency and severity of extreme weather, sea-level rise and accelerated beach erosion, degradation of coral reefs (including bleaching), and the loss of cultural heritage on the coasts through inundation and flooding are likely to reduce the attractiveness of small island States to tourists. For example, in Barbados 70 per cent of the hotels are located within 250 m of the high water mark. This suggests that many hotels are almost exclusively within the 1 in 500 and 1 in 100 inundation zones, placing them at risk of major structural damage.[20]

[20] "Preliminary review of the economic impact of climate change on Caribbean Tourism: what is at risk and adapting for sustainable tourism development", presentation given by Ms. Marlene Attzs at the Organization of American States Meeting on Adaptation to Climate Change in the Caribbean, Tourism Sector Workshop held in Grenada, in May 2002.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V. ADAPTATION TO CLIMATE CHANGE

Adaptation to climate change in developing countries is vital and has been highlighted by them as having a high or urgent priority. Although uncertainty remains about the extent of climate change impacts, in many developing countries there is sufficient information and knowledge available on strategies and plans to implement adaptation activities now.

However, developing countries have limitations in capacity making adaptation difficult. Limitations include both human capacity and financial resources. Outputs from the UNFCCC workshops and meeting highlighted that the most effective adaptation approaches for developing countries are those addressing a range of environmental stresses and factors. Strategies and programmes that are more likely to succeed need to link with coordinated efforts aimed at poverty alleviation, enhancing food security and water availability, combating land degradation and reducing loss of biological diversity and ecosystem services, as well as improving adaptive capacity. Sustainable development and the Millennium Development Goals are a necessary backdrop to integrating adaptation into development policy. ,reduction policies are also important elements of adaptation.

This chapter explores adaptation in developing countries. The lack of funding available in various forms, as well as difficulties in accessing the funds which are available, represents a major barrier for adaptation, particularly for local community action. International financial mechanisms, including possible novel mechanisms for adaptation are explored. It is recognised that research and training to enable adaptation is needed in developing countries in order to help understand climate change impacts and vulnerabilities and facilitate better policy decisions and management. Many developing countries face difficulties in integrating climate change concerns into national policies due to a lack of resources and institutional capacities. Capacity-building, for example to integrate climate change and socio-economic assessments into vulnerability and adaptation assessments, helps to better identify effective adaptation options and their associated costs. The chapter looks at adaptation in the light of sustainable development, the integration of adaptation into policy and development planning, and the need for further capacity-building and training. Given that many countries may experience similar effects from climate change, sharing experience can broaden knowledge on how to address the adaptation challenges. In this regard South-South and North-South cooperation on adaptation is an effective way of promoting the implementation of adaptation measures. A number of current collaborations are discussed which are helping to pave the way for cooperation on climate change adaptation.

A final section on implementing adaptation looks at suggestions from the UNFCCC workshops and meeting in 2006 – 2007 on a number of ways forward for the Conference of the Parties to the UNFCCC and the international community to consider in implementing adaptation action.

5.1 ADAPTATION STRATEGIES, PLANS AND PROGRAMMES

Adapting to climate change will entail adjustments and changes at every level – from community to national and international. Communities must build their resilience, including adopting appropriate technologies while making the most of traditional knowledge, and diversifying their livelihoods to cope with current and future climate stress. Local coping strategies and traditional knowledge need to be used in synergy with government and local interventions. The choice of adaptation interventions depends on national circumstances. To enable workable and effective adaptation measures, ministries and governments, as well as institutions and non-government organizations, must consider integrating climate change in their planning and budgeting in all levels of decision making.

In CHAPTER IV the impacts and vulnerabilities of developing countries to climate change were highlighted in terms of the sectors affected. One way of grouping adaptation options is to identify whether they are sectoral, cross-sectoral or multi-sectoral.

Sectoral adaptation measures look at actions for individual sectors that could be affected by climate change. For example, in agriculture, reduced rainfall and higher evaporation may call for the extension of irrigation; and for coastal zones, sea level rise may necessitate improved coastal protection such as reforestation. Often adaptation measures in one sector will involve a strengthening of the policy that already exists, emphasizing the importance of including long term climate change considerations along with existing local coping mechanisms and integrating them into national development plans.

Multi-sectoral adaptation options relate to the management of natural resources which span sectors, for example, integrated management of water, river basins or coastal zones. Linking management measures for adaptation to climate change with management measures identified as necessary from the other Rio Conventions: the Convention on Biological Diversity and the United Nations Convention to Combat Desertification; could be a useful multi-sectoral approach which addresses a range of environmental stresses.

Cross-sectoral measures also span several sectors and can include: improvements to systematic observation and communication systems; science, research and development and technological innovations such as the development of drought-resistant crop varieties or new technologies to combat saltwater intrusion; education and training to help build capacity among stakeholders; public awareness campaigns to improve stakeholder and public understanding on climate change and adaptation; strengthening or making changes in the fiscal sector such as new insurance options; and risk/disaster management measures such as emergency plans. For example, Bhutan's NAPA provides an example of a cross-sectoral adaptation project. It identifies the need for a forecasting and early warning system to provide seasonal forecasts for supporting agricultural production decisions and provide an early warning system and disaster management strategy for food security and emergency medicine to vulnerable communities in the case of extreme events (Bhutan 2006).

Adaptation to climate change must also occur through the prevention and removal of maladaptive practices. Maladaptation refers to adaptation measures that do not succeed in reducing vulnerability but increase it instead. Examples of measures that prevent or avoid maladaptation include: better management of irrigation systems; and removal of laws that can inadvertently increase vulnerability such as destruction of mangroves and relaxation of building regulations on coasts and in floodplains.

Parties to the UNFCCC have all agreed to undertake national adaptation measures and cooperate in preparing for the impacts of climate change. The UNFCCC plays an important catalytic role in promoting the development of adaptation strategies and plans. The UNFCCC secretariat developed a compendium on methodologies for assessing vulnerability and adaptation,[21] and a database on existing local coping strategies to climate variability and hazards, which can be replicated in countries which are now facing similar threats as these but due to climate change.[22] The Nairobi work programme[23] is fostering knowledge exchange among the research and stakeholder communities to help countries make informed decisions on practical adaptation options. The initial activities of the Nairobi work programme during 2007 – 2008 involve workshops and reports on nine key areas of work: methods and tools; data and observations; climate modelling, scenarios and downscaling; climate related risks and extreme events; socio-economic information; adaptation planning and practices; research; technologies for adaptation; and economic diversification. Outcomes of the Nairobi work programme are expected to lead to enhanced knowledge on adaptation options at all levels and integration of actions into planning and sustainable development.

In their national communications to the UNFCCC, developing countries provided information on their vulnerabilities to climate change for a wide range of sectors. The main sectoral adaptation options and responses highlighted by developing countries to adapt to climate change in these different sectors are provided in Table V-5. These include both reactive and anticipatory responses to climate change. Reactive responses are those which are implemented as a response to an already observed climate impact whereas anticipatory responses are those that aim to reduce exposure to future risks posed by climate change.

As shown by the national communications, the range of practices that can be used to adapt to climate change is diverse. The effectiveness of a practice tends to depend on location and socio-economic situation, but that does not prevent practices from being shared, replicated and improved. Work on adaptation planning and practices under the Nairobi work programme has highlighted a number of adaptation approaches, strategies, practices and technologies at the regional, national, and local levels in different sectors (UNFCCC 2007h). Two examples from Indonesia as provided by submissions by the ISDR secretariat and the International Research Institute for Climate and Society (IRI) highlight: building a monitoring system for food security and livelihood through Community Based Disaster Risk Management to prevent food shortage in the eastern part of Nusa Tenggara; and a fire early response system in Central Kalimatan to include analysis of links between climate and fires, identify policy links and develop and test tools to support fire management.

Table V-5. **Adaptation measures in key vulnerable sectors highlighted in national communications of developing countries**

Vulnerable sectors	Reactive adaptation	Anticipatory adaptation
Water Resources	– Protection of groundwater resources – Improved management and maintenance of existing water supply systems – Protection of water catchment areas – Improved water supply – Groundwater and rainwater harvesting and desalination	– Better use of recycled water – Conservation of water catchment areas – Improved system of water management – Water policy reform including pricing and irrigation policies – Development of flood controls and drought monitoring
Agriculture and food security	– Erosion control – Dam construction for irrigation – Changes in fertilizer use and application – Introduction of new crops – Soil fertility maintenance – Changes in planting and harvesting times – Switch to different cultivars – Educational and outreach programmes on conservation and management of soil and water	– Development of tolerant/resistant crops (to drought, salt, insect/pests) – Research and development – Soil-water management – Diversification and intensification of food and plantation crops – Policy measures, tax incentives/subsidies, free market – Development of early warning systems
Human health	– Public health management reform – Improved housing and living conditions – Improved emergency response	– Development of early warning system – Better and/or improved disease/vector surveillance and monitoring – Improvement of environmental quality – Changes in urban and housing design
Terrestrial ecosystems	– Improvement of management systems including control of deforestation, reforestation and afforestation – Promoting agroforestry to improve forest goods and services – Development/improvement of national forest fire management plans – Improvement of carbon storage in forests	– Creation of parks/reserves, protected areas and biodiversity corridors – Identification/development of species resistant to climate change – Better assessment of the vulnerability of ecosystems – Monitoring of species – Development and maintenance of seed banks – Including socioeconomic factors in management policy
Coastal zones and marine ecosystems	– Protection of economic infrastructure – Public awareness to enhance protection of coastal and marine ecosystems – Building sea walls and beach reinforcement – Protection and conservation of coral reefs, mangroves, sea grass and littoral vegetation	– Integrated coastal zone management – Better coastal planning and zoning – Development of legislation for coastal protection – Research and monitoring of coasts and coastal ecosystems

Source: National communications of non-Annex I Parties[24] and UNFCCC Sixth compilation and synthesis of initial national communications from Parties not included in Annex I to the Convention. Note by the secretariat. Addendum 5. Climate change impacts, adaptation measures and response strategies[25]

[21] <http://unfccc.int/2674.php>
[22] <http://maindb.unfccc.int/public/adaptation>
[23] <http://unfccc.int/3633.php>
[24] <http://unfccc.int/2979.php>
[25] <http://unfccc.int/resource/docs/2005/sbi/eng/18a05.pdf>

Planning for climate change must involve consideration of climate related risks including those which have a slow onset, such as changes in temperature and precipitation leading to agricultural losses and drought and biodiversity losses, and those which happen more suddenly such as tropical storms and floods. It is now recognized that climate-related risks are already happening and past and current experiences in dealing with climate variability and extreme events provide valuable information for reducing vulnerability and enhancing resilience to future climate-related adverse impacts. The disaster risk reduction community already has a strong body of experience in dealing with climate-related risks. The global disaster management community, as well as sectoral communities, are increasingly focusing their efforts on building resilience into investments and development. Where necessary risk reduction needs to be built into adaptation plans to help plan for and cope with future climate variability and extreme events. Work under the Nairobi work programme in this area has already started (UNFCCC 2007m).

For all regions, as highlighted at the workshops, there is a need to enhance technical capacity to assess, plan and integrate adaptation needs into sectoral development plans; and to support integration of adaptation into sectoral policy, particularly in the areas of water, agriculture, coastal zones and managing natural ecosystems. Needs-based regional technology transfer is an important area in helping countries to adapt (UNFCCC 2007g). Technology transfer can include "hard" forms of technology, such as new irrigation systems or drought-resistant seeds, or "soft" technologies, such as insurance schemes or crop rotation patterns; or they can involve a combination of hard and soft, as with early warning systems that combine hard measuring devices with soft knowledge and skills that can raise awareness and stimulate appropriate action. Submissions to the UNFCCC secretariat by Parties and relevant organizations through the Nairobi Work Programme reported a number of technologies for adaptation (UNFCCC 2007k) including hard technologies such as sea walls in Male Island, in the Maldives; soft technologies such as low-cost irrigation, embankment cropping, floating gardens and integrated farming systems in Bangladesh. Mexico also commends combining soft and hard technologies in the development of risk atlases and early warning systems, which have resulted in greater attention and resource allocation to risk prevention.

Another important adaptation strategy is economic diversification within sectors to reduce dependence on climate-sensitive resources, particularly for countries that rely on narrow ranges of climate-sensitive economic activities, such as the export of a climate-sensitive crop. For example coffee in Uganda, a vital source of income for the country, will suffer drastic reduction in suitable growing areas under climate change (UNFCCC 2007b). Economic diversification is being discussed within the context of UNFCCC negotiations (see document FCCC/SBI/2007/15, UNFCCC 2007i), and through the Nairobi Work Programme (UNFCCC 2007l).

A significant move by the UNFCCC process was to enable least developed countries to identify their immediate priorities for adaptation options via the National Adaptation Programmes of Action[26] which identify their urgent and immediate adaptation needs – those for which further delay could increase vulnerability or lead to increased costs at a later stage. Over 40 least developed countries have received funding under the Convention to prepare their NAPAs which draw on existing information and community-level input to prioritize adaptation plans. Many countries have already submitted their NAPAs to the UNFCCC secretariat.[27]

Priority adaptation projects identified by NAPAs include:

- improved forecasting for farming, extreme events and disaster management;
- improved water management for drinking and agriculture through understanding water flows and water quality, improved rainwater harvesting and water storage and diversification of irrigation techniques;
- improved food security through crop diversification, developing and introducing drought, flood and saline-tolerant crops, improving livestock and fisheries breeding and farming techniques, developing local food banks for people and livestock, and improving local food preservation;
- better land and land use management through erosion control and soil conservation measures, agroforestry and forestry techniques, forest fire management and finding alternative energy sources to wood and charcoal, as well as better town planning;
- coastal zone management including coral monitoring and restoration and improving coastal defences through afforestation, reforestation, set-back areas and vegetation buffers;
- improved health care through flood shelters and assistance shelters as part of community emergency preparedness programmes, better health education, better access to primary health care such as distribution of treated mosquito nets and better malaria surveillance programmes and habitat clearance;
- capacity-building to integrate climate change into sectoral development plans, involving local communities in adaptation activities, raising public awareness and

education on climate change, and enabling representation at international meetings;
- and promotion of sustainable tourism.

Given the good experiences so far with NAPA preparation, it was suggested at the workshops and meeting to extend NAPAs to more developing countries in order to help them identify their priority needs and plans for adaptation.

As well as projects planned via the NAPA process, a number of other adaptation projects have also been planned, and some implemented, by and in developing countries at a number of levels. Adaptation projects have been funded by the UNFCCC process through the Global Environment Facility (GEF), via governments, and from national and international bilateral and multilateral agencies and organizations.

Bilaterally funded projects are already providing capacity-building for adaptation. At the workshops and expert meeting, several of these projects were highlighted. These include work by developing country governments, bilateral and multilateral agencies to assess local vulnerability and adaptation as well as, in some cases, integrate work on adaptation into development and policy planning.

In the Africa workshop, a representative from the Food and Agriculture Organization (FAO) reported that FAO has produced CD ROMs on tools and models relevant to adaptation in the agriculture sector, and has also made this information available on the Internet.[28] In addition, FAO conducts training workshops to build related capacity. The background paper to the workshop (UNFCCC 2006c) reports on a number of capacity-building projects including a series of GEF funded projects to assist African communities to assess risks and options to adopt to drought, coastal flooding and health risks, such as Coping with Drought and Climate Change (in Mozambique, Zimbabwe and Ethiopia) and Adaptation to Climate and Coastal Change in West Africa (ACCC) (in Senegal, Cape Verde, Guinea Bissau, Gambia and Mauritania).

Mentioned in the Asia workshop was a study by the United Nations Environment Programme (UNEP) and the International Centre for Integrated Mountain Development in the Himalayan region, which aims to establish an inventory of glacial lakes, a monitoring and early warning system and adaptation measures for this region. Mongolia mentioned its National Action Programme on climate change, which includes evaluating concrete and practical adaptations that could possibly decrease the livestock sector's vulnerability to climate change. The Asia background paper (UNFCCC 2007b) highlights a number of capacity-building projects funded by the GEF and other sources including the Asia-Pacific Network for Global Change Research; Practical Action; SouthSouthNorth and the Netherlands, Canadian and UK governments. For example, a project by the Asia-Pacific Network for Global Change Research is helping to build adaptive capacity in southeast Asia by contributing to building better theories and models of resilience and adaptive capacity and develop improved awareness among decision makers in business, government and resource management agencies (Cambodia, China, India, Indonesia, Japan, Lao PDR, Malaysia, Philippines, Thailand, Viet Nam).

In Latin America the Capacity-Building Project for Stage II adaptation to climate change in Central America, Mexico and Cuba plans to help prepare adaptation plans and strategies in participating countries. Capacity-building and training for model development to help understand climate change has been provided by the UK Hadley Centre's PRECIS initiative which was highlighted by participants. Another initiative started by Brazil involves training on the regional model ETA developed by the Centro de Previsao de Tempo e Estudos Climaticos. An important issue in Latin America is that of glacial melt in the Andes, a project currently being funded by GEF will design and implement adaptation measures to address glacial melt in the central Andes, Bolivia, Ecuador and Peru (UNFCCC 2006b).

At the SIDS meeting, a representative of the Caribbean Community Climate Change Centre (CCCCC) gave two examples of projects dealing with adaptation. The Mainstreaming Adaptation to Climate Change project carries out vulnerability assessments for communities at risk, exploring their history and possible climate change impacts in order to design adaptation options with the aim of influencing adaptation policy. Assessments are being undertaken in the tourism sector in Barbados and in the agriculture sector in Guyana, and may also be undertaken in Jamaica and Belize in the water resources sector. The Special Pilot on Adaptation to Climate Change supported by the GEF, 2007 – 2011, is being undertaken in three SIDS (Dominica, St. Lucia, and St. Vincent and the Grenadines) to implement specific pilot adaptation measures addressing the impacts of climate change on biodiversity and land degradation. A representative from the Pacific Regional Environment

[26] <http://unfccc.int/2719.php>
[27] As of 1 September 2007, 21 countries had submitted their NAPAs to the UNFCCC
[28] <http://www.fao.org/nr/climpag>

Programme (SPREP) mentioned the Pacific Islands Framework for Action on Climate Change 2006 – 2015 endorsed by leaders. This establishes sets of priorities for action on climate change in the region and involves local, national, regional and international levels. Adaptation is focused on: multi-stakeholder engagement, risk management, no regrets, and improving safe secure livelihoods; with a particular focus on the most vulnerable areas and on integration into national strategies. Kiribati is one of the world's most vulnerable countries, spread over 33 low-lying atolls in the central and western Pacific region. The Kiribati adaptation programme, funded by GEF, is providing vulnerable communities with the information and means to enhance adaptive capacity, including improved management, conservation, restoration and sustainable use of biodiversity, improved protection and management of mangroves and coral reefs, and integrating adaptation into government economic planning.

Representatives at the workshops and meeting also highlighted global and inter-regional capacity-building projects. These include a WHO/UNDP/GEF pilot project on adaptation policies and programmes for developing countries to design and implement measures to protect health[29] (Barbados, Fiji, Uzbekistan, Jordan, Bhutan, Kenya, China) and the Community-based Adaptation (CBA) Programme, which is funded by GEF and provides capacity-building for adaptation planning through community level consultations in a number of countries (Bangladesh, Bolivia, Niger, Samoa, Guatemala, Jamaica, Kazakhstan, Morocco, Namibia, Viet Nam). The Assessments of Impacts and Adaptations to Climate Change (AIACC) global initiative is implemented by the United Nations Environment Programme and executed jointly by the global change SysTem for Analysis, Research and Training (START) and the Third World Academy of Sciences, and funded by the GEF.[30] This project involving 46 developing countries aims to advance scientific understanding of climate change vulnerabilities and adaptation options in developing countries and has carried out regional assessments in Africa, Asia, Latin America and SIDS, identifying nine key messages for adaptation: adapt now, create conditions to enable adaptation, integrate adaptation with development, increase awareness and knowledge, strengthen institutions, protect natural resources, provide financial assistance, involve those at risk, and use place specific strategies (AIACC 2007).

Also given at the workshops and meeting were specific examples of adaptation projects that go beyond capacity-building to implement actual adaptation activities on the ground. These include a number of community-based adaptation plans and projects. These bottom-up initiatives include community-based water harvesting or allocation systems, supplying mosquito nets, and community-based disaster risk reduction. Participants noted that, from a country perspective, community based approaches provide the most effective capacity-building for practical adaptation actions through implementation and a 'learning by doing' process. Community-based adaptation is an important tool for developing adaptation options and it is important to share the knowledge gained from these experiences. The community based adaptation exchange (CBA-X)[31] run by the Eldis Programme, UK, in collaboration with the International Institute for Environment and Development is a shared resource supporting the exchange of up-to-date and relevant information about community-based climate adaptation.

Further specific adaptation examples from the Africa workshop include that reported by Benin on soft technology adaptation techniques where seedling transplantation is being used to adapt to floods: before the rainy season, fields are prepared and, in cases of predicted flooding, seedlings are transplanted to the nursery. In Tanzania increased drought has forced farmers to avoid the risk of planting a single crop and they now plant a number of crop varieties and species on the same land. The Sustainable Land Use and Forestry/USAID programs in Africa (UNFCCC 2006c) help mitigate climate change by absorbing and storing carbon dioxide from the atmosphere, promoting biodiversity conservation and improving forest management, and sustainable agriculture.

At the Asia workshop, a representative from the Philippines reported on the national Community Based Flood Early Warning System which aims at helping local communities prevent losses from increasing floods. Policy measures employed include coordination with the local government, organizing training, sharing information, monitoring rain and water levels, mapping and providing legislative support to local communities. The lessons learned from the CBFEWS that can be replicated for many community-based adaptation activities include the importance of involving grassroots organizations, transferring decision-making power to local communities; and combining advanced technologies with indigenous knowledge. The project also identified needs in relation to scientific, technological and policy aspects, including improved climate and water modelling of climate change impacts on the water cycle, environmental impact assessments and flood management; better communication between the scientific community and various stakeholders, and enhanced regional collaboration using a common flood management protocol.

In Latin America, examples of adaption activities include a GEF funded project in Ecuador which collaborates with the Waorani and Timpoca communities to create a sustainable management plan of raising palms and frogs to earn income. In Brazil, SouthSouthNorth have a number of adaptation projects which are helping agricultural productivity, reforestation and recovery of degraded land.

In SIDS, adaptation has mostly been taking place through individual, ad-hoc actions on a local scale. For example, placing concrete blocks on the top of zinc roofs to prevent the roofs from being blown away during hurricanes has become common practice in Jamaica since Hurricane Ivan. In Vanuatu, SPREP, with funding from the Canadian government, has moved 100 villagers living in the Lateu settlement to higher ground 600 m from the coast and 15 m above current sea level (UNFCCC 2007a).

A recent analysis of completed, ongoing or planned adaptation projects that have adaptation as a stated objective, and for which information is publicly available, was undertaken by the UNFCCC secretariat. This list is relatively short, only about 180 identified projects have been identified so far.

Despite all positive efforts in the assessment of vulnerability and adaptation, the movement from adaptation assessment and planning to implementation is not well developed. At the regional workshops and expert meeting on adaptation, it was pointed out that, whereas a number of countries have well-developed adaptation plans or are in the process of finalising them, many more resources are needed for implementation. The Andean Community of Nations, for example, developed an adaptation plan in 2004, but no concrete actions have been taken so far towards its implementation (UNFCCC 2006d). A lot of projects being implemented at the moment deal with capacity-building for adaptation. The lessons learnt from these need to be communicated at every level. The national communications and NAPAs highlight a large number of priority adaptation options. It is important now to enable and fund the implementation of these plans and projects.

5.2 LOCAL COPING STRATEGIES

There is a large body of knowledge and experience within local communities on coping with climatic variability and extreme weather events. Local communities have always aimed to adapt to variations in their climate. To do so, they have made preparations based on their resources and their knowledge accumulated through experience of past weather patterns. This includes times when they have also been forced to react to and recover from extreme events, such as floods, drought and hurricanes.

Local coping strategies are an important element of planning for adaptation. Climate change is leading communities to experience climatic extremes more frequently, as well as new climate conditions and extremes. Traditional knowledge can help to provide efficient, appropriate and time-tested ways of advising and enabling adaptation to climate change in communities who are feeling the effects of climate changes due to global warming. Several examples of local coping strategies are mentioned in the background papers to the workshops (UNFCCC 2006b, 2006c, 2007a, 2007b).

In Africa rural farmers have been practicing a range of agricultural techniques as coping strategies and tactics to enable sustainable food production and deal with extreme events. These include intercropping and crop diversification; use of home gardens, diversification of herds and incomes, such as the introduction of sheep in place of goats in the Bara province in Western Sudan, pruning and fertilizing to double tree densities and prevent soil erosion in semi-arid areas, e.g. Senegal, Burkina Faso, Madagascar and Zimbabwe; manipulation of land use leading to land use conversion, e.g. a shift from livestock farming to game farming in Southern Africa; water conservation techniques to cope with arid conditions such as the Zaï technique in Burkina Faso: farmers dig pits in the soil to collect organic material carried by the wind during the dry season, at the start of the rainy season farmers add organic matter from animals which attracts termite activity resulting in termite tunnels that can collect rain deep enough that it doesn't evaporate, and thus increasing soil fertility. In many locations tribal and individual movements and migration are also identified as adaptation options.

In Asia, farmers have traditionally observed a number of practices to adapt to climate variability, for example intercropping, mixed cropping, agro-forestry, animal husbandry, and developing new seed varieties to cope with local climate. Various water use and conservation strategies include terracing, surface water and groundwater irrigation; and diversification in agriculture to deal with drought. Structural and non-structural measures are used

[29] <http://www.who.int/globalchange/climate/gefsummary.pdf>
[30] <http://www.aiaccproject.org/aiacc.html>
[31] <http://www.cba-exchange.org>

to deal with flood and coastal inundation. For example, in the Philippines, after Typhoon Sisang in 1987, which completely destroyed over 200,000 homes, the Department of Social Welfare and Development decided to instigate a programme of providing typhoon-resistant housing designed to withstand wind speeds of 180 km/h for those living in the most typhoon prone areas. In Bangladesh, the Cyclone Preparedness Program has been set up over 11 coastal area districts by the Bangladesh Red Crescent Society, and is partly funded by the government. Volunteers have been trained to help in cyclone warning, evacuation, rescue, first aid emergency relief and the use of radio communication equipment.

In Latin America, local coping strategies include a variety of agricultural practices, ecosystem protection and methods to adapt to extreme events. Farmers in Peru have been using an ancient irrigation and drainage system "waru waru", or raised field agriculture, which makes it possible to bring into production the low-lying, flood-prone, poorly drained lands found all over the Altiplano. The shallow canals provide moisture during droughts and drainage during the rainy season. When filled with water they also create a microclimate that acts as a buffer against night time frosts. The waru waru system provides farmers with greater harvest security and reduces the risks associated with frosts and drought. In Mexico, the Cajete Terrace agroecosystems have been in place for three thousand years in hillside regions in Tlaxcala. In these rainfed Corn–Bean–Squash agroecosystems, food is grown on steep erosion-prone slopes. Rainfall is concentrated between May and September and often occurs in sudden downpours. Sloping terraces feed excess water into tanks (cajetes). The water, which would otherwise not be absorbed into the soil, is collected inside the cajetes and slowly percolates into the surrounding soils after the rain has ended. Eroded soils are also trapped inside the cajetes, preventing soil loss down the slope. Nutrient rich soils inside of the cajetes are later gathered and distributed into the fields. The Aymaran indigenous people of Bolivia have been coping with droughts through the construction of small dams "qhuthañas". These dams collect and store rainwater from 50 to 10,000 cubic meters.
In El Salvador communities employ a number of soil conservation measures to cope with recurrent droughts, for example building barriers consisting of stone and pine suckers, which provide edible fruits and additional income. In Costa Rica and Ecuador local communities have improved their housing design to better cope with floods and droughts. Houses are either elevated or have a reinforced concrete strip as a foundation so that the bamboo walls do not touch the ground and are protected from fungal deterioration. These houses are cost-efficient and last longer than regular houses.

In SIDS, coping strategies include agricultural techniques, coral reef protection and coping with climate extremes. For example, on Timor Island farmers have developed their own varieties of major staple crops to adapt to erratic rainfall and cyclones and to ensure food security. Practices for coping with coastal erosion include community relocation. For example at Playa Rosaria, Havana Province, Cuba, the community has been relocated five kilometres inland because of coastal erosion. Other less disruptive activities such as reconstructing groynes, building sand dune fences, and planting trees along the coast can also reduce the impact of coastal erosion on communities.

The UNFCCC database on local coping strategies is a tool that enables sharing of information to help community based adaptation. It provides a collection of long-standing coping strategies, mechanisms, knowledge and experience from communities in developing countries that have had to adapt to specific hazards or climatic conditions. This database is available on the internet <http://maindb.unfccc.int/public/adaptation> and can be searched by climate hazard, impact or coping strategy. This knowledge can be used by communities that may just be starting to experience such conditions as a result of climate change. For example, searching for information on the climate hazard drought, provides a list of corresponding adaptation actions and associated case studies. Accessing adaptation action on Integrated agriculture-aquaculture will provide a case study on rice-fish farming on West Java. Clicking on the link provides a short summary on the coping practice, details on resource requirements, non-climate benefits and potential maladaptation, as well as contact information and links to relevant files and web sites.

5.3 FUNDING FOR ADAPTATION

Funding is vital in order for developing countries to plan for and implement adaptation plans and projects. A basic conclusion of the Stern Review is that the costs of strong and urgent action on climate change will be less than the costs thereby avoided of the impacts of climate change under business as usual (Stern 2006). All countries, rich and poor, need to adapt to climate change, and this will be costly. Developing countries, already the hardest hit by climate change, have little capacity (both in terms of human capacity and financial resources) to adapt. Financial ways and means must be found to enable developing countries to enhance their efforts to adapt.
At the workshops and meeting the lack of funding available for adaptation was highlighted as a large impediment to implementing adaptation plans. Accessing the funds which

are available at present was identified as complex and lengthy. Even if this process were to be streamlined, a lot more funding would still be required for adaptation. New international financial mechanisms to provide a sustained and sufficient response to adaptation are needed.

At the workshops and meeting, participants emphasised the need for sustained financing for adaptation. Without sustained funding, adaptation runs the risk of not being effectively addressed, and largely limited to “reactive” funding, such as short-term emergency relief. This would be unsupportive of sustainable development and ultimately prove to be very costly. Funding is required for all developing countries to develop national adaptation strategies or action plans. These plans should exist at all levels: local, provincial and national.

Article 4 of the Convention highlights that developed country Parties shall provide financial resources to assist developing country Parties adapt to climate change. To facilitate this, the Convention assigned to the GEF the responsibility of operating its financial mechanism.[32] The GEF enables a transfer of financial resources from developed to developing countries by establishing operational programmes, providing programming documents and allocating resources. Based on guidance from the UNFCCC, the GEF operates three funds.[33] These are the GEF Trust Fund; the Least Developed Countries Fund (LDCF) and the Special Climate Change Fund (SCCF). Further funding opportunities currently available for developing countries to fund adaptation projects include: the future Adaptation Fund under the Kyoto Protocol, funds from other multilateral environmental agreements (MEAs), and bilateral and multilateral funding from governments, national and international organizations and agencies.

The GEF Trust Fund and its Strategic Priority on Adaptation (SPA) support enabling activities and pilot and demonstration projects that address adaptation and at the same time generate global environmental benefits. COP guidance on GEF support for adaptation identified three stages. Stage I provided support for the national communications process, a portion of which is the vulnerability and adaptation assessment. Stage II provides further assistance for other capacity-building efforts for adaptation. Stage III refers to support for actual adaptation activities, including insurance. In 2001, the GEF established the Strategic Priority on Adaptation (SPA). The GEF has allocated USD 50 million under SPA of which USD 5 million has been devoted to piloting community adaptation initiatives through the Small Grants Programme (SGP). For example, the Special Program on Adaptation to Climate Change in coastal areas aims to support participating countries (Dominica, St. Lucia and St. Vincent and the Grenadines) in implementing pilot adaptation measures, where climate change mainstreaming activities have already occurred. Activities will specifically address the impacts of climate change on biodiversity and land degradation at the coast. The Community based adaptation programme is aimed at developing a framework that spans all levels from local to intergovernmental to respond to unique community-based adaptation needs; identify and finance diverse community-based adaptation projects in a number of selected countries (Bangladesh, Bolivia, Niger, Samoa, Guatemala, Jamaica, Kazakhstan, Morocco, Namibia, Viet Nam); and disseminate lessons learned at the community level to all stakeholders, including governments.

The Special Climate Change Fund (SCCF) is partly designed to finance adaptation activities that increase resilience to the impacts of climate change, through a focus on adaptation responses particularly in water resources, land, agriculture, health, infrastructure development, disaster preparedness, and in fragile ecosystems and coastal zones. Funding will be available for establishing pilot or demonstration projects to show how adaptation planning and assessment can be practically translated into projects that will provide real benefits, and may be integrated into national policy and sustainable development planning, on the basis of information provided in the national communications, or of in-depth national studies, including NAPAs. For example, an SCCF project in Tanzania is aimed at incorporating Climate Change into integrated Water Resources Management in the Pangani River Basin; and in Ecuador an SCCF project is enabling adaptation to climate change through effective water governance.

The Least Developed Countries Fund (LDCF) was partly established to support projects addressing urgent and immediate adaptation needs in the least developed countries as identified by their National Adaptation Programmes of Action (NAPAs). The LDCF supports a learning-by-doing approach to adaptation. Projects proposed in the NAPAs which are being considered for LDCF funding include a coastal afforestation community based adaptation project in Bangladesh; a project to integrate climate change risks into community-based livestock management in the northwest lowlands of Eritrea; and a project to reduce climate change-induced risks and vulnerabilities from glacial lake outburst floods in the Punakha-Wangdi and Chamkhar Valleys in Bhutan.

[32] <http://www.thegef.org>
[33] <http://www.gefweb.org/projects/focal_areas/climate/documents/GEF_Support_for_Adaptation_to_Climate_Change.pdf>

At the workshops and expert meeting developing country representatives expressed their concern with the complexity of current arrangements for accessing funds from the GEF. It was highlighted that procedures for accessing existing financial resources for adaptation remain complex and lengthy. Participants at the UNFCCC workshops and meeting emphasised the need for capacity-building and information on the financial mechanisms available to improve access to funding and to facilitate project preparation. Improving the access of developing countries to financial resources, including through streamlining guidelines for application and by assisting countries in the preparation of project proposals was thought important at all workshops and meeting.

Within the context of the UNFCCC, the international carbon market has emerged as a result of the Clean Development Mechanism established under the Kyoto Protocol. The Clean Development Mechanism allows industrialized countries to help generate funding for adaptation in developing countries in the context of sustainable development while providing them a cost-effective means of offsetting their greenhouse gas emissions. The mechanism enables approved emission-reducing projects in developing countries to earn certified emission reduction units, each equivalent to one tonne of carbon dioxide, which the project participants in the developing country can then sell to buyers in industrialized countries. These sustainable development projects range from wind farms to hydroelectric power stations and also include energy efficiency projects.

The Adaptation Fund under the Kyoto Protocol is intended to fund concrete adaptation projects and programmes in developing countries that are particularly vulnerable to the adverse effects of climate change. The source of this funding is intended to be from a 2 per cent levy on proceeds from Clean Development Mechanism projects (excluding those undertaken in least developed countries), as well as from other voluntary sources. The Adaptation Fund is yet to be operationalized. The actual amount of money that will be available from this fund is uncertain as it depends on the extent of use of the Clean Development Mechanism and on the price of carbon. The World Bank estimates that the Adaptation Fund is likely to total USD 100 – 500 million by 2012.

Multilateral Environmental Agreements (MEAs) whose areas of work could be synergetic with adaptation may also provide further funding for adaptation. These MEAs include the Convention on Biological Diversity, UN Convention to Combat Desertification and the Ramsar Convention on Wetlands. For example, the Central African Regional Program for the Environment funded by USAID aims to help mitigate climate change by absorbing and storing carbon dioxide from the atmosphere, promoting biodiversity conservation and improving forest management, and sustainable agriculture, and help reduce the vulnerability of ecosystems.

Bilateral and Multilateral Funding includes funding of adaptation projects directly via inter-governmental organizations, national and local governments, institutions and non-governmental organizations. Examples include many community-based projects by non-governmental organizations aimed at improving agricultural practices, water resource supply and use, primary health care and energy supply in developing countries.

In 2007 the UNFCCC secretariat launched a project to review and analyze investment and financial flows relevant to the development of an effective and appropriate international response to climate change, with particular focus on developing country's needs, including their medium-to long-term requirements for investment and finance.[34] As part of this project, the secretariat assessed the investment flows needed in 2030 that will be necessary to meet adaptation requirements in several sectors. The global cost of adaptation to climate change is difficult to estimate as climate change adaptation measures will be widespread and heterogeneous. However, for all of the sectors examined, there is a substantial deficit in current investment and financial flows.

In 2030 the adaptation funds required were estimated at: USD 14 million for agriculture, forestry and fisheries; USD 11 billion for water resources; USD 5 billion for human health; USD 11 billion for coastal zones; and USD 8 – 130 billion for infrastructure. In summary, the UNFCCC secretariat estimated that the investment and financial flows needed for adaptation are likely to be tens of billions of dollars per year several decades from now and could be more than USD 100 billion per year. Other studies (World Bank 2006b, Oxfam 2007) also estimate adaptation costs at tens of billions of dollars per year.

The funds that are currently available under the Convention and the Kyoto Protocol are small compared to the magnitude of the needs identified by the UNFCCC. The financial resources available for adaptation in the funds currently operated by the GEF (Trust Fund, LDCF and SCCF) amounted to about USD 275 million as of August 2007. The Adaptation Fund could receive USD 80 – 300 million per year for the period 2008 – 2012. Assuming a share of proceeds for adaptation of 2 per cent continues to apply post 2012, the level of funding could be: USD 100 – 500 million per year for a low demand for the CDM; and USD 1 – 5 billion per year for a high demand. However, there is still a deficit in funding that needs to be filled.

5.4 INSURANCE

Climate change is a catalyst for rising costs for human health, the global economy and the Earth's life support system. Disaster losses could reach over USD 1 trillion in a single year by 2040. Climate change presents challenges and even opportunities for the finance sector. Businesses will be affected by climate change and by policies to address it. From the perspective of sustainable development, insurance measures can be beneficial for many developing countries by transferring risk from climate change. At the workshops and expert meeting, one part of the finance sector, that of insurance, emerged as a high priority for developing countries in adapting to climate change. The SIDS expert meeting focussed particularly on insurance options.

According to the Convention (Article 4.8), insurance-related actions constitute one of the three main means of response to the adverse effects of climate change, alongside funding and technology transfer. They can enhance financial resilience to external shocks and provide a unique opportunity to spread and transfer risk. They may provide incentives for risk reduction and prevention while engaging the private sector in climate change response action.

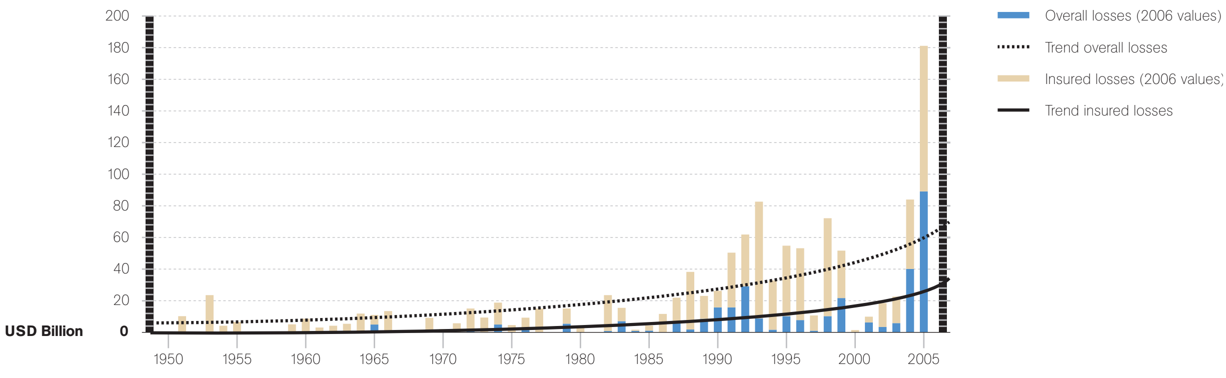
One of the benefits of promoting insurance-related actions is that it may help advance efforts on quantifying risks and potential losses due to climate change. Minimizing risk can result in a reduction of the rates for insurance, which thereby become more affordable. Rates could also reflect mitigation measures, such as implementation of hazard plans, forecasting and warning systems, undertaken by a community, individuals, governments, and other stakeholders.

As a result of climate change, there are both major challenges and opportunities for the insurance industry. The financial sector is already incurring additional costs from adverse climatic conditions, for example economic losses from extreme events are scaling new records (FIGURE V-2). The Insurance Working Group of the UNEP Finance Initiative[35] (UNEP FI) is a strategic and successful public-private partnership between UNEP and 16 leaders of the global financial sector. UNEP FI believe that the critical questions are "How can insurance assist developing countries grow more sustainably?" and "What are the principles for sustainable insurance?". Their recent report explores the growing area of sustainable insurance (UNEP FI 2007).

Currently, the insurance market is very limited in developing countries, although it is a vital instrument for these countries, particularly for coastal communities and sectors such as tourism. Current limitations are, in part, due to limited economic assets and limited private sector interest in insurance. In SIDS this is compounded by their geographical size, relative isolation, and high risk of extreme weather events.

[34] <http://unfccc.int/4053.php>, <http://unfccc.int/files/cooperation_and_support/financial_mechanism/financial_mechanism_gef/application/pdf/dialogue_working_paper_8.pdf>
[35] <http://www.unepfi.org>

Figure V-2. **Economic losses from great weather disasters 1950 – 2006, overall and insured losses**



Source: © NatCatSERVICE, Geo RiskResearch, Munich Re <http://www.munichre.com/app_resources/pdf/ts/geo_risks/natcatservice/long-term_statistics_since_1950/MRNatCatSERVICE_1950-2006_Great_weather_disasters_Overall_insured_losses_en.pdf> [Last accessed 10 October 2007]

Participants at the workshops and SIDS expert meeting highlighted the need for the implementation of insurance schemes and finance services for risk sharing at different levels. Possible cost-effective insurance initiatives are highlighted in (Box V-3). A well-coordinated dialogue between the private sector and representatives from Parties would assess cooperative actions that could be carried out to increase the insurance coverage of populations affected by climate change. The banking sector must also be involved in the work relating to climate change insurance and mainstreaming adaptation, on the basis that many loans could be at risk because of the absence of climate-proofing in projects.

In response to the growing realization that insurance solutions can play a role in adaptation, as suggested in the UNFCCC and the Kyoto Protocol, the Munich Climate Insurance Initiative was initiated by Munich Re in April 2005.[36] This initiative, formed by insurers, climate change and adaptation experts, NGOs, and policy researchers aims to develop insurance-related solutions to climate change, including identifying and promoting loss reduction measures, in cooperation with other organizations and initiatives and conduct pilot projects.

Examples of insurance schemes in developing countries from which lessons could be learned includes a microinsurance scheme by the United Insurance Company Limited Hurricane Mitigation Programme,[37] which operates in 14 Caribbean countries. This Programme aims to reduce the vulnerability of Caribbean property to hurricanes by providing financial incentives for insurance holders to put preventative measures in place. Microfinancing is also an option for hedging risk. In Bangladesh the microfinancing institutions, Proshika and Grameen, with their long acquaintance with the impacts of disasters on the poor, have started to promote loans to reduce vulnerability to climate change. Loans are available for safer housing, diversifying incomes, from agriculture and sharecropping to more disaster-proof activities and mobile assets, and for rapid credit to promote fast recovery immediately after a disaster. Loan officers and borrowers are also increasingly taking a role in community preparedness projects.

The case of the Caribbean Catastrophe Risk Insurance Facility (CCRIF) could be extrapolated and localized to the circumstances of other regions. It uses a portion of donor-funded capital reserves to assist in the establishment of a facility that assists countries in pooling their risk and reducing insurance costs. The CCRIF uses parametric cover which enables immediate claims payments to the country because payouts are linked to triggers, such as wind speed. Insurance premiums are tied to the risk profiles of individual countries. The advantages of this scheme include efficient risk transfer mechanisms, optimal pricing from reinsurance through risk-pooling and economies of scale, and sharing of administrative and operational costs of the insurance business. However, as risk profiles increase due to the impacts of climate change, premiums will also rise which will mean that small island States will need to bear the costs of additional risks associated with climate change.

Box V-3. **Possible cost-effective insurance initiatives for developing countries to help adaptation to climate change**

- Innovative risk transfer mechanisms such as multi-state risk pooling mechanisms;
- Regional reinsurance facilities, either through the private market or from the state, whereby the re-insurer assumes responsibility for covering a portion of the risk, especially for rare but extreme event losses;
- Catastrophe funds linked to international financial markets – that pay out on a trigger condition, such as temperatures over a certain value for a certain length of time, rather than on proof of loss;
- National/regional disaster funds supported financially by the international community;
- Micro-finance and micro-insurance;
- Public-private partnerships, such as the UNEP FI;
- Generation of carbon credits in exchange for support for insurance;
- Weather derivatives which provide payouts in response to weather triggers rather than in response to demonstrated losses;
- An international insurance pool – proposed by the Alliance of Small Island States in 1992, it was suggested that payments into an insurance pool would be a form of compensation linked to responsibility or liability for the impacts of climate change.

For many insurance options, national governments will need to support local governments through transfer of resources based on risk assessments by subregion. Public-private partnerships with financial institutions, that help promote preparedness and mitigation and short-term training programmes for community-based organizations, could be of great assistance in building capacity at a local level.

At the SIDS meeting, suggested ways forward include identifying specific issues and constraints relating to insurance, and engaging the insurance industry and finance experts on novel and innovative approaches to address insurance and relief funding in the context of risks relating to climate change. This could be done through expert meetings and/or workshops, perhaps bringing together actual practitioners and providers of insurance services with climate change stakeholders to devise appropriate responses to enhance the role of insurance as an adaptation tool for SIDS. This will require the involvement of non-SIDS countries to ensure practical risk distribution. Participants at the workshops and expert meeting suggested that the UNFCCC process could provide support to help identify possible insurance options and increase the resilience of countries to climate change. More information and assessment, including the expansion of early warning systems and information dissemination systems, and improvement in forecasting and disaster related decision-making would help to evaluate insurance options. The Nairobi work programme can also provide a valuable opportunity for furthering methodological efforts relating to insurance in the context of climate change adaptation. The international community could provide support in the context of insurance in a number of ways (Box V-4).

[36] <http://www.climate-insurance.org>
[37] <http://www.unitedinsure.com/united.cfm?LID=helpful%20info&SID=Hurricane%20Retrofitting>

Box V-4. **Opportunities for the international community to support insurance-related solutions to climate change in developing countries**

The international community could contribute to identify actions aimed at:

Supporting public private partnership: by transferring (or arranging the transfer of) the risks of national or regional public-private insurance systems in the capacity of re-insurer or consider subsidizing the costs of alternative hedging instruments.

Supporting relief and reconstruction: by assisting governments in transferring their risks of public infrastructure damage either through private insurers or directly to the capital markets through alternative risk-transfer instruments.

Supporting micro insurers: by playing a possible role in supporting and transferring the risks of micro-insurers, for example those offering weather hedges, possibly by acting as reinsurer or assuming the interest payments of catastrophe bonds.

Supporting data collection and analytical capacity-building: by providing support to developing countries in collecting the requisite data and in building analytical capacity as any insurance or insurance-related system requires knowledge of these risks.

Supporting new risk hedging instruments: by creating national-level market incentives, for example tax reductions to individuals or institutions for purchasing developing country catastrophe bonds at lower interest.

5.5 SUSTAINABLE DEVELOPMENT PLANNING AND PRACTICES

Climate change has the potential to undermine sustainable development, increase poverty, and delay or prevent the realization of the Millennium Development Goals. An effective way to address the impacts of climate change is by integrating adaptation measures into sustainable development strategies so as to reduce the pressure on natural resources, improve environmental risk management, and increase the social well-being of the poor. Climate change can influence humans directly, through impacts on health and the risk of extreme events on lives, livelihoods and human settlements, and indirectly, through impacts on food security and the viability of natural resource-based economic activity. The workshops and meeting discussed the impacts of climate change on achievement of the Millennium Goals in the different regions (TABLE V-6).

Competition for scarce resources, such as fresh water, land or fishing grounds, brought about by changes in climate, has the added potential to cause conflict over resources with impacts on the achievement of the Millennium Development Goals, and on human migration. For example, in Africa increased pressure on resources related to food and water insecurity can deepen tensions between communities and ethnic groups resulting in violence and war (Oxfam 2006, Sachs 2007).

As the incidence and magnitude of events such as droughts, floods and island inundation increase, there could be large-scale demographic responses, such as increased migration and threats to the sovereignty of some small island States. The United Nations University Institute for Environment and Human Security (UNU–EHS) reported in 2005 that there were at least 20 million “environmental refugees” worldwide, more than those displaced by war and political repression combined. UNU–EHS predicts that by 2010 the number of environmental refugees could grow to 50 million and, according to further estimates, there could be as many as 150 million by 2050 (Myers 2005).

Considering that the adverse effects of climate change pose an additional burden to development goals, integrating adaptation into sustainable development is necessary, and is already being considered and implemented by some developing countries, although it is still in its early stages. Sustainable development in the context of climate change is a particular challenge for SIDS, particularly as they have been among the first to experience the direct effects of climate change. The Mauritius Strategy for the Further Implementation of the Programme of Action for the Sustainable Development of Small Island Developing States (Mauritius Strategy) outlines actions for the international community to help SIDS in addressing the threats posed by climate change. This includes actions for the development, transfer and dissemination of appropriate technologies and practices to address climate change; building and enhancing scientific and technological capabilities and enhancing the implementation of national, regional and international global atmospheric observing systems.

In the tourism sector, sustainable practices must be established, developed or promoted in synergy with adaptation activities and work to protect biodiversity. Links and synergy must also be encouraged between the programmes of work on biodiversity and climate change under the two Conventions, in particular with regard to island biodiversity. Although many developing countries have ratified the Conventions, support is still needed from their development partners to ensure effective implementation of their emerging strategies and plans, as well as to fully exploit the opportunities that could be achieved.

At the adaptation workshops and expert meeting, synergy between the UNFCCC and the other two Rio Conventions, the Convention on Biological Diversity, and the UN Convention to Combat Desertification, was highlighted as important for implementing adaptation projects, sharing data collection and information networking. This would help integrate the Conventions into national development programmes, a problem encountered by many countries at present, and help establish synergies and linkages among the Conventions.

The Stern Review highlighted that the costs of strong and urgent action on climate change will be less than the costs thereby avoided of the impacts of climate change under business as usual (Stern 2006). All countries, rich and poor, need to adapt to climate change and this will be costly. Developing countries, already the hardest hit by climate change, have little capacity (both in human capacity and financial resources) to adapt. Spending to adapt to climate change will undermine funding for sustainable development, putting strong pressure on developing country budgets and overseas development assistance. It is therefore vital that ways and means are found to enable developing countries to enhance their efforts to adapt in the context of sustainable development and sustainable development must incorporate adaptation plans.

Table V-6. **Impacts of Climate Change on the Millennium Development Goals**

Millennium Development Goal	Potential impacts of climate change
Goal 1 Eradicate extreme poverty and hunger	– Damage to livelihood assets, including homes, water supply, health, and infrastructure, can undermine peoples' ability to earn a living; – Reduction of crop yields affects food security; – Changes in natural systems and resources, infrastructure and labour productivity may reduce income opportunities and affect economic growth; – Social tensions over resource use can lead to conflict, destabilising lives and livelihoods and forcing communities to migrate.
Goal 2 Achieve universal primary education	– Loss of livelihood assets and natural disasters reduce opportunities for full time education, more children (especially girls) are likely to be taken out of school to help fetch water, earn an income or care for ill family members; – Malnourishment and illness reduces school attendance and the ability of children to learn when they are in class; – Displacement and migration can reduce access to education.
Goal 3 Promote gender equality and empower women	– Exacerbation of gender inequality as women depend more on the natural environment for their livelihoods, including agricultural production. This may lead to increasingly poor health and less time to engage in decision making and earning additional income; – Women and girls are typically the ones to care for the home and fetch water, fodder, firewood, and often food. During times of climate stress, they must cope with fewer resources and a greater workload; – Female headed households with few assets are particularly affected by climate related disasters.
Goal 4 Reduce child mortality **Goal 5** Improve Maternal Health	– Deaths and illness due to heat-waves, floods, droughts and hurricanes; – Children and pregnant women are particularly susceptible to vector-borne diseases (e.g. malaria and dengue fever) and water-borne diseases (e.g. cholera and dysentery) which may increase and/or spread to new areas – e.g. anaemia resulting from malaria is currently responsible for one quarter of maternal mortality; – Reduction in the quality and quantity of drinking water exacerbates malnutrition especially among children; – Natural disasters affect food security leading to increased malnutrition and famine, particularly in sub-Saharan Africa.
Goal 6 Combat HIV/AIDS, malaria and other diseases	– Water stress and warmer conditions encourage disease; – Households affected by AIDS have lower livelihood assets, and malnutrition accelerates the negative effects of the disease.
Goal 7 Ensure environmental sustainability	– Alterations and possible irreversible damage in the quality and productivity of ecosystems and natural resources; – Decrease in biodiversity and worsening of existing environmental degradation; – Alterations in ecosystem-human interfaces and interactions lead to loss of biodiversity and loss of basic support systems for the livelihood of many people, particularly in Africa.
Goal 8 Develop a global partnership for development	– Climate change is a global issue and a global challenge: responses require global cooperation, especially to help developing countries adapt to the adverse effects of climate change; – International relations may be strained by climate impacts.

Source: Source: National communications of non-Annex I Parties and UNFCCC Sixth compilation and synthesis of initial national communications from Parties not included in Annex I to the Convention. Note by the secretariat. Addendum 5. Climate change impacts, adaptation measures and response strategies

There is a need to develop integrated, well planned and coordinated adaptation actions and adaptation projects, and to improve financial flows into adaptation-related activities through existing and new international, official development assistance and private sector mechanisms thus providing a firm basis for sustainable development.

5.6 ADAPTATION INTEGRATION INTO POLICY AND PLANNING

Incorporating or integrating adaptation to climate change into planning processes is a necessary strategy for sustainable development over the long term. Climate change impacts do not happen in isolation; impacts in one sector can adversely or positively affect another; sectors can be affected directly and/or indirectly by climate change and indeed sometimes a change in one sector can offset the effects of climate change in another sector. In many developing countries there are difficulties in integrating adaptation concerns into national policy due to low staff capacity for planning, monitoring and evaluation; poor data on adaptation options and lack of mechanisms for information sharing and management across sectors; and limited awareness of adaptation among stakeholders and the population. The Africa workshop identified several further factors that exacerbate the overall level of vulnerability in this region including political instability, widespread illiteracy and poverty of the rural population.

Lack of cooperation among ministries was highlighted as a major barrier to progress on adaptation. In order that real progress can be made, key governmental departments (such as ministries of finance) need to be involved in the development of adaptation strategies. In the same way, national and local development planning agencies need to be informed by the relevant outputs of impact and vulnerability assessments, and environmental and sectoral institutions need to be strengthened in order to be able to address the complexities of addressing and coordinating the implementation of adaptation action. There are a number of actions that can help facilitate adaptation and integration of adaptation into policy, including actions at the local level (e.g. strengthening coping strategies and feedback to national policies), the national level (e.g. inter-agency coordination in the water sector and legal provisions for mainstreaming) and the regional level (e.g. incorporating climate change risks in projects of regional development agencies and the creation of intersectoral committees to be engaged in the formulation of adaptation plans). At the international level it was noted that the UNFCCC, other Conventions and other international organizations can play a catalytic role in exchange of experiences, and in facilitating the development of region-wide and sector-wide approaches.

Policy and development planners require effective tools and frameworks for developing, disseminating and building capacity for adaptation and integrating it into policy at all levels (e.g. UNDP 2004). This is a particular priority for SIDS for whom international relocation is not an option. In addition to the socio-economic consequences, relocation would mean an infringement on the sovereignty of these islands. Participants at the workshops and meeting highlighted the importance of building on existing collaboration frameworks such as those of the Congo Basin Forest Partnership (CBFP), the Forum of Ministers of Environment of Latin America and the Caribbean, the Economic Commission for Latin America and the Caribbean (ECLAC), the Organization of Eastern Caribbean States (OECS), the Caribbean Community Climate Change Centre (CCCCC), the Pacific Islands Forum (PIF), the Secretariat of the Pacific Community (SPC), and the Pacific Regional Environment Programme (SPREP). Small island developing States were among the first to start work on integrating adaptation. Some examples of integrating adaptation into research, policy and development in SIDS are given in Box V-5.

As climate change increases the potential for climate related risk, it is also important that risk management and risk reduction is incorporated into adaptation planning at all levels, and that climate change is incorporated into disaster and risk management activities. The ISDR secretariat has highlighted the necessity for integrating disaster reduction management into development and adaptation strategies. The Hyogo framework was adopted at the World Conference on Disaster Reduction in Kobe, Japan, in January 2005, and gives prominence to disaster risk reduction in the context of climate change. Considerations include promoting the integration of risk reduction associated with existing climate variability and future climate change into strategies for the reduction of disaster risk and adaptation to climate change; and mainstreaming disaster risk reduction measures appropriately into development assistance programmes, including those relating to, inter alia, adaptation to climate change. The ISDR secretariat is establishing national platforms on disaster risk reduction where participation of practitioners in the area of adaptation is highly encouraged. Meetings of these national platforms will be held annually at regional level to exchange information, experiences and lessons learned.

A number of examples of integrating adaptation and policy planning by institutions and governments were highlighted at the workshops and meeting. The Caribbean Development Bank was one of the first to integrate climate change into its project planning process. The Inter-American Development Bank[40] has a disaster risk management policy which was developed in the context of an increase in the number and gravity of natural hazards resulting in disasters in Latin America. The policy, which emphasizes risk reduction, is intended to improve the institutional and policy framework of the bank's support to disaster risk management in order to help protect the socio-economic development of member countries and improve the effectiveness of the bank's assistance. The Asian Development Bank (ADB) is increasingly integrating adaptation considerations into its strategic planning processes at the country level and taking measures to reconfigure sector development plans so that they are more resilient to climate change. More directly, they are organizing to provide greater support for national climate change adaptation planning and programming efforts.[41] On the other hand, the World Bank found a quarter of its portfolio subject to climate risk but only two percent consider it in the project design documents (World Bank 2006b). The World Bank is now aiming to earmark specific funds and create new financial instruments for adaptation.

In April 2006 OECD Member Countries adopted the Declaration on Integrating Climate Change Adaptation into Development Cooperation.[42] They declare that they will aim to work to better integrate climate change adaptation in development planning and assistance, both within their own governments and in activities undertaken with partner countries. In addition they encourage regional initiatives that include common actions on impacts and vulnerability assessment and adaptation options, in order to promote transboundary initiatives, encourage

[38] The advisory body to the integrated agriculture and forestry programme being implemented by the Land Resources Division of the Secretariat of the Pacific Community.
[39] The Jamaica Observer, online article, posted 25 July 2006.
[40] <http://www.iadb.org>
[41] From the Asian Development Bank submission to the UNFCCC's Nairobi Work Programme "ADB's Clean Energy and Environment Program" <http://unfccc.int/files/adaptation/sbsta_agenda_item_adaptation/application/pdf/adb_ccadaptation.pdf>
[42] <http://www.oecd.org/dataoecd/44/29/36426943.pdf >
[43] <http://www.aiaccproject.org/aiacc.html>

Box V-5. **Integrating adaption activities into national planning**

Some examples of cooperation on adaptation, and its integration into research, policy and development in SIDS

Research: In July 2006, the University of the West Indies held a conference entitled "Global Change and Caribbean Vulnerability: Environment, Economy and Society at Risk?" where researchers took a multi-disciplinary view of climate change in the Caribbean, linking changes in climate with other environmental and socio-economic changes that are occurring.

Policy: The Climate Change Adaptation Program for the Pacific, funded by the Asian Development Bank, has produced a set of guidelines on mainstreaming adaptation, focusing on its integration into disaster risk reduction strategies (ADB 2005).

National and international meetings: In 2006, the Regional Meeting of the Heads of Agriculture and Forestry[38] structured their discussions around the theme "Managing Change". Change was considered in the context of biodiversity, health and nutrition, agriculture and forestry commodity trade, atoll agriculture and forestry and climate change and food security.

National partnerships: In Jamaica, the Jamaican Red Cross is joining forces with the National Meteorological Service, the Office of Disaster Preparedness and Emergency Management and the University of the West Indies to disseminate information on climate change impacts and inform those communities that are most at risk.[39]

International Partnerships: Through the UNEP–Grid Arendal Many Strong Voices consortium, SIDS from both the Caribbean and Pacific regions are cooperating with Arctic communities to build capacity, enhance awareness, assess needs and implement adaptation measures. These regions, although geographically and climatically very different, share a high vulnerability to climate change because of their dependence on the natural resource base and geographical and socio-economic isolation. The consortium focuses on the links between the regions and on encouraging education, training and public awareness among their inhabitants so that they take a more active role in the climate change debate. It also aims to increase understanding of needs and solutions and take practical measures on adaptation.

South-South cooperation and avoid duplicated efforts. In 2003, the European Commission produced a communication entitled "Climate Change in the context of development co-operation", in which it proposed an EU action plan aimed at integrating climate change concerns into EU development cooperation activities. The World Bank's progress report on its investment framework for clean energy and development asserts that "it is essential that the Bank Group, along with other International Financial Institutions, play a leading role in ensuring that maximum impact is obtained from UNFCCC funds by mainstreaming appropriate investment and appropriate risk in the global development portfolio" (World Bank 2006b).

5.7 CAPACITY-BUILDING, EDUCATION AND TRAINING AND PUBLIC AWARENESS

Capacity-building at local, national and regional levels is vital to enable developing countries to adapt to climate change. It is important for stakeholders and funders to recognize the role of universities, tertiary centres and centres of excellence. Enhanced support is needed for institutional capacity-building, including establishing and strengthening centres of excellence and building up hydrometeorological networks. Training for stakeholders in all sectors would help the development of specialized tools for planning and implementing adaptation activities and thus promote action by local and national governments.

Participants at the workshops and expert meeting emphasized the need for capacity-building, training and increased public awareness as well as international support to build and strengthen environmental and sectoral institutions so that they can address the complexities of addressing and coordinating the planning and implementation of adaptation action. Internationally-coordinated capacity-building and training through the Convention and appropriate regional agencies was recognized as extremely important for advancing climate change adaptation in all regions. Support for institutional strengthening can be enhanced through multilateral and bilateral channels. For example, the Assessments of Impacts and Adaptations to Climate Change project, 2001 – 2006, involved enhancing the scientific and technical capacity among researchers within developing countries to help understand climate change adaptation and vulnerability.[43]

5.7.1 CAPACITY-BUILDING

The need for capacity-building to assist Parties, especially developing countries, to respond to climate change has long been recognized by the UNFCCC. Work in this area by the Convention includes the elaboration of the capacity-building frameworks under decisions 2/CP.7[44] and 3/CP.7[45], providing guidance on national communications and NAPA preparation, and capacity-building for adaptation research under the Nairobi work programme.

Governments, national and international agencies also provide capacity-building for adaptation. These include other United Nations organizations, for example the UNEP funded Caribbean Environment Programme[46], represented at the SIDS meeting, promotes regional cooperation for the protection and development of the marine environment of the Wider Caribbean Region. At the Africa workshop, the World Conservation Union (IUCN) detailed their work on capacity-building for adaptation including their Community-based Risk Screening Tool-Adaptation and Livelihoods (CRISTAL). This tool can reduce impacts of climate change on community livelihoods. It was first tested in an IUCN project in Mali (Inner Delta of the Niger River) and is to be made widely available after further tests (e.g. in Tanzania).

Non-governmental agencies and organizations involved in capacity-building for adaptation include the Red Cross/Red Crescent Centre of Climate Change and Disaster Preparedness[47] and SouthSouthNorth[48] – a network of organizations, research institutions and consultants operating in Brazil, South Africa, Tanzania, Mozambique, Bangladesh and Indonesia whose projects are aimed at driving the sustainable development agenda and building capacity for adaptation to climate change at the local level.

Some developing countries have already included adaptation measures in their national action plans and/or national environmental action plans as a first step towards implementation of adaptation. For example the NAPAs of least developed countries have helped build capacity for adaptation at the local and community level by building on and enhancing existing coping strategies. Expanding the NAPA process to other developing countries has been proposed to help these countries also build capacity for adaptation planning and implementation.

Representatives at the workshops and expert meetings reported that some legislative changes and recognition by all government ministries would help facilitate incorporation of climate change adaptation into future policy. It was suggested that intersectoral committees can help in integrating adaptation into policy. Examples of these include the Caribbean Planning for Adaptation to Climate Change project, which developed climate change scenarios for the Caribbean and calculated potential losses. Following on from this project, a comprehensive adaptation programme is now underway in the Caribbean which includes the Mainstreaming Adaptation to Climate Change project bringing together climate change and disaster management communities, and the Special Program on Adaptation to Climate Change.

One of the challenges for capacity-building mentioned at the workshops is that external support of adaptation activities, including developing national communications, are short-term and project-based, often using a single task approach rather than a long-term programme approach. This means that expertise is lost between projects, and often it is difficult to retain experts once they reach a high level of expertise. Working groups created under projects, that show significant potential for providing technical and scientific support need to realize their potential by disseminating information better and building up best practices. For example, the Linking Climate Adaptation (LCA) Network was set up to help communities, policy-makers, practitioners and academics share experiences and knowledge about adaptation to climate change.[49]

5.7.2 EDUCATION AND TRAINING

Education and training of stakeholders, including policy-level decision makers, are important catalysts for the success of assessing vulnerabilities and planning adaptation activities, as well as implementing adaptation plans. It is important to communicate both successful and unsuccessful efforts at planning and implementation to avoid future mistakes. Short policy cycles are a major challenge in keeping decision makers up to date.

Effective training and capacity-building needs support and funding, often from external agencies and donors. Within the UNFCCC, regional teams have helped deliver training, such as in the case of the Least Developed Countries Expert Group which provides advice to least developed countries on the preparation and implementation of national adaptation programmes of action, and the Consultative Group of Experts on National Communications from Parties not included in Annex I to the Convention which has conducted hands-on training workshops for the Africa region, the Asia and the Pacific region, and the Latin America and the Caribbean region (FCCC/SBI/ 2006/ 17, UNFCCC 2006g) and for SIDS(FCCC/SBI/2007/17, UNFCCC 2007j).

Training is also needed for models to be effectively applied and used for assessments at the national or regional level. For example the PRECIS initiative helps build capacity by training on how to use the climate model to generate high resolution climate change scenarios for developing countries.[50]

Collaboration between educational, training and research institutions would help to enable the formal exchange of experience and lessons learned among different institutions of the respective regions. Universities, tertiary centres and research centres have a special role to play in educating and building the capacity of stakeholders in key sectors, and climate change and adaptation issues should be integrated into education curricula. For example the Global Change SysTem for Analysis, Research and Training (START) fosters regional networks of collaborating scientists and institutions and provides a wide variety of training and career development opportunities for young scientists. The START regional networks in Southeast Asia, South Asia, East Asia, SIDS and Africa help to mobilize scientific capacity and resources to address region specific issues of global change and to assist in creating working links between science and policy communities.

Effective international collaboration also helps to enable training on, and structured dissemination of, international and national activities on adaptation with a view to retaining experts working in their region, and promoting the exchange of information between experts from key sensitive sectors. It is also important to assess, systematize and disseminate knowledge about adaptation measures taken, including indigenous ones. The UNFCCC database on local coping strategies is one example of this effort as well as the workshops organised under the Nairobi work programme.

43 <http://www.aiaccproject.org/aiacc.html>
44 <http://unfccc.int/resource/docs/cop7/13a01.pdf#page=5>
45 <http://unfccc.int/resource/docs/cop7/13a01.pdf#page=15>
46 <http://www.unep.org/regionalseas>
47 <http://www.climatecentre.org>
48 <http://www.southsouthnorth.org>
49 <http://www.linkingclimateadaptation.org>
50 <http://precis.metoffice.com>

It is important to recognise the language needs of particular regions. Often, the tools and material available to experts on adaptation planning and implementation is mainly in English. For Africa, the availability of technical documentation in French and possibly African languages needs to be enhanced for experts in the region to fully participate in the adaptation process. In Latin America, there is a need for the documentation to be available in Spanish.

5.7.3 PUBLIC AWARENESS

Participants at the workshops and meeting noted that awareness on climate change risks and the need for adaptation should be raised among key sectors and mass media, including by using current events, such as economic, weather and health crises, as a basis to promote adaptation measures with co-benefits. Improving public awareness and developing overall communications strategies makes climate change science accessible to the average citizen and can reduce their vulnerability. Besides awareness-raising at local levels, it is also important to involve high-level policymakers to ensure integration of climate change risks into national development policies. For example, in Cuba, hurricane and disaster risk reduction is taught in schools and training is carried out for the entire population every year (Cuba 2001). Important public awareness activities include linking research to policy-making, with an emphasis on getting research messages to appropriate target groups and building credibility of forecasts and improving their dissemination and use.

A communication strategy is an effective way of elaborating and communicating between knowledge providers and stakeholders on climate change risks and adaptation needs, targeting actors ranging from those at the grassroots level to national and regional policymakers, using appropriate language. This communication strategy could include the preparation of a global awareness campaign on climate change, including video messages in different languages.

5.8 COOPERATION AND SYNERGIES

Given that many countries may experience similar effects from climate change, sharing experience can broaden knowledge on how to address the adaptation challenges. In this regard South-South and North-South cooperation on adaptation is an effective tool for promoting the implementation of adaptation measures. There is still considerable scope and opportunity for regional and international collaboration.

The workshops and meeting highlighted the need for all stakeholders including governments, institutions and the private sector in the North and South to be fully engaged in adaptation planning and implementation. Climate change should be integrated into the work of different regional organizations and networks, and in particular though partnerships of sectors such as water and agriculture in order to share experiences and lessons learned by communities facing similar problems. New funding and improved access to funding, including through existing GEF funds, is needed to effectively provide technical and financial support and capacity-building capabilities.

Existing mechanisms for regional (South-South) cooperation on vulnerability assessment and adaptation include forums of ministers, economic commissions, bilateral cooperation initiatives and initiatives to share information and data. Collaboration between Southern institutions helps to share experiences and lessons learned by communities facing similar problems; develop joint projects; carry out research and development on downscaling of climate scenarios; and conduct workshops and training activities.

The regional workshops and expert meeting emphasized a need to enhance coordination of activities between different organizations, networks and initiatives to promote South-South collaboration. Inadequate capacity and resources, including such fundamental problems as poor communication and transport infrastructure, were seen as hindrances to such collaboration. Fostering cooperation among researchers and institutions also lays a good foundation. Additional regional workshops focusing on specific areas of priority for different regions were suggested in order to enhance such exchange of experience by the groups already working on collaboration in the regions.

The activities considered most effective for regional collaboration identified at the workshops were projects helping to identify common problems and solutions such as developing national climate change scenarios, solving transboundary adaptation issues such as with water resources, and developing 'sister' projects between countries facing similar challenges. Example projects include the GEF-funded project to design and implement adaptation measures to address glacial melt in the central Andes, and the Pacific Island Adaptation Initiative designed to catalyze action and strengthen partnerships at all levels to enable the Pacific Island's region to understand and respond to climate change, climate variability and sea level rise.

Mechanisms for current international (North – South) collaboration involve a wide-range of initiatives and funding by inter-governmental agencies, governments, institutions and non-government agencies. Collaboration includes the assessment of vulnerability and risks associated with climate change such as funding for national communications and NAPAs, public education and outreach, data and observations, decision support, adaptation planning and implementation, and integration of climate change into development.

Participants at the workshops and meeting proposed a number of options to further facilitate North-South cooperation. Promoting better access to funding and synergy with sources of funding external to the climate change process is vital and has been referred to in the previous section on funding. Effective collaboration with government and non-government organizations, including through global fora on adaptation, would improve stakeholder awareness to enable adaptation on a sustainable and long term basis. Integrating climate change considerations in the work of regional and international financial bodies and organizations would also provide a basis for work in the long term. It is important to engage fully the private sector from the North and South in adaptation planning and implementation on a sectoral basis and use a programme based, rather than a project based approach to adaptation, to ensure a long-term and sustainable approach to adaptation.

The UNFCCC process needs to play a more active role in enhancing North – South collaboration, as well as in disseminating information and enhancing the dialogue on climate change adaptation with other United Nations agencies, and the sectoral and disaster reduction communities, attempts to do so include through the Nairobi work programme. Synergy with other multilateral environment agreements in future adaptation activities and projects is paramount for advancing collaboration. There is a critical need to ensure continuity (a programme-based rather than project-based approach) and adherence to the strategic direction for support identified by the COP, in particular by its decisions 5/CP.7[51] and 1/CP.10,[52] and, in the case of SIDS, the Mauritius Strategy.

North – South collaboration could also be instrumental in facilitating South–South collaboration, for example the Ibero-American Network of Climate Change Offices (RIOCC). This network, created as a result of a decision taken by Ministers at the IV Ibero-American Ministers of Environment Forum in 2004, is now active in the 21 Ibero-American Nations. Its work programme focusses on different topics related to climate change, including adaptation.[53] The UNEP – UNDP partnership for mainstreaming climate change was established during the twelfth session of the COP, and is working on operational issues for adaptation and its integration into national planning for sustainable development.

5.9 IMPLEMENTING ADAPTATION

Implementing adaptation plans and strategies is a vital next step for developing countries. As highlighted in this chapter, many plans and strategies have been made and a number of capacity-building projects have been undertaken. Now, it is important to bridge the gap between adaption assessment and planning and adaption implementation, and to build on knowledge from capacity-building projects. Adaptation options need to be matched to priority needs both in the context of community-based action and in national and sectoral planning as well as disaster risk reduction. Adaptation plans must be integrated into top-down and bottom-up approaches for planning to enable sustainable development and the efficient use of resources for adaptation. In order to avoid maladaptation, mechanisms should be introduced to validate adaptation options. Participants from developing countries at the workshops and meeting discussed and suggested a number of ways forward to help implement adaptation in developing countries.

[51] <http://unfccc.int/resource/docs/cop7/13a01.pdf#page=32>
[52] <http://unfccc.int/resource/docs/cop10/10a01.pdf#page=2>
[53] <http://www.mma.es/portal/secciones/cambio_climatico/areas_tematicas/cooperacion_cc/menu_coop_iber.htm>

Implementing identified adaptation projects including those proposed through the NAPA process would be an important start for developing countries. Given the good experience so far identified with NAPAs, the methodology could be extended to other developing countries beyond the least developed. Expanding knowledge on local coping strategies would also help implement community based action on adaptation, for example through enhancing the UNFCCC's local coping strategies database.

National governments were identified as having the responsibility to scale up lessons learned and products from adaptation projects for use nationally. In order to do so, creating awareness on adaptation among planners and political decision makers beyond the environment sectors, and training of stakeholders within these areas, is a useful start. Operational guidelines could be prepared to help integrate adaptation into various sectors from national to local level and from local to national level, and to encourage countries in the regions to implement more pilot projects and facilitate funding for such projects.

It is clear that enhanced funding is required for adaptation projects in developing countries and needs to be increased in national budgets as well as in multilateral funds. All regions requested improvements in the access to the financial resources currently available, including through streamlining guidelines for application, and by assisting countries in the preparation of project proposals. Novel mechanisms for funding could include adaptation funds designed for specific regions as well as a variety of insurance options including those which include public-private and sectoral partnerships.

Capacity must be built at all stages of the adaptation process in developing countries. Climate change focal points could be trained. Inventories of successful experiences and expertise available could be developed. Links with the disaster risk reduction community, especially with regard to disaster preparedness rather than relief, could be reinforced. Enhancing synergies between the Rio Conventions would help share information and knowledge on assessment processes. Capacity-building and training of stakeholders would help the necessary integration of adaptation into sectoral policies and environmental impact assessments. International climate change committees could be created to help feed relevant information into regional committees. Collaboration among institutions active on climate change in all developing country regions and with institutions in the North would help knowledge exchange and build capacity. National forums could help exchange information on vulnerability assessments, and adaptation planning and implementation at regional level.

VI. LOOKING FORWARD

Developing countries are already suffering from the impacts of climate change and are the most vulnerable to future change. A number of developing countries have developed adaptation plans or are in the process of finalizing them. This includes the National Adaptation Programmes of Action of least developed countries. There is now an urgency for developing countries to find ways to implement these plans. Against a backdrop of low human and financial capacity, developing countries lack many of the resources to do this on their own.

Adaptation is already considered a vital part of any future climate change regime. Within the UNFCCC and the international community, deliberations are building to find an effective means to tackle climate change, which is described by UN Secretary General Ban Ki-moon as the ”defining issue of our era“. Future decisions within the UNFCCC negotiating process must assist developing countries in a streamlined, innovative and transparent way, with transfer of knowledge, technology and financial resources to adapt and to adapt at all levels and in all sectors.

At a series of workshops for Africa, Asia and Latin America and an expert meeting for small island developing States during 2006–2007, these regions identified areas for future action in adapting to climate change. To be most effective, adaptation plans and strategies need to be integrated into sustainable development planning and risk reduction planning at community, local, national and international levels. Crucially there has been little work to integrate adaptation into development plans or within existing poverty alleviation frameworks. Taking stock of and promoting good practice by the international community in the integration of climate change related issues would help promote adaptation strategies with multiple benefits.

Capacity is still needed to enable developing countries to develop adaptation programmes and strategies. The Nairobi work programme is building capacity to understand and assess impacts, vulnerability and adaptation and to make informed decisions on practical adaptation actions and measures. The NAPAs have proved an important way to prioritise adaptation actions for least developed countries. Initiating a process for extending the positive experience of NAPAs for developing countries that are not least developed countries, and that wish to develop national adaptation programmes or strategies, could vitally help adaptation option prioritisation. This would take into account lessons learned from the NAPA preparation process and its successful experience at policy integration, as well as relevant outcomes from the Nairobi work programme. Using local coping strategies can assist community-based adaptation and can be facilitated by knowledge exchange within different communities facing similar problems, such as via the UNFCCC local coping strategies database. Finding synergies between the Rio Conventions could also help share information and knowledge on assessment processes.

If there are delays to implementing adaptation in developing countries, including delays in financing adaptation projects, this will lead ultimately to increased costs. Delays in implementing adaptation will also lead to greater dangers to more people. For example, extreme events including droughts, floods and loss of glacial meltwater could trigger large-scale population movements and large-scale conflict due to competition over scarcer resources such as water, food and energy.

There are already mechanisms for financial assistance for developing countries available. Application procedures need to be streamlined, including enhancing the capacity for the development of project proposals as well as capacity-building to identify the different requirements and modalities of different sources of current support.

It is also clear that current funding is not enough to support adaptation needs. Recent studies by the UNFCCC secretariat showed that an incremental level of annual investment and financial flows of about USD 50 billion is needed for adaptation in 2030. In the context of any discussion on future international cooperation on climate change, future financial resources need to be sufficient, predictable and sustainable in order to facilitate adaptation to the adverse impacts of climate change by developing countries. As well as via funding envisioned through the operationalization of the Adaptation Fund under the Kyoto Protocol, innovative financing options are needed to close the gap between costs of adaptation and available resources.

Insurance is an area that has been identified as an important component of future action on adaptation. Innovative risk sharing mechanisms are needed to respond to the new challenges posed, including increasing frequency of extreme events, land degradation and loss of biodiversity.

Collaboration and cooperation between South-South and North-South can directly engage multiple stakeholders in dealing with climate change and coordinate planning and actions. This could be facilitated by international fora with the participation of Parties and relevant stakeholders involved in South–South and North–South collaboration, multilateral environmental agreements and with the disaster risk reduction community. Awareness raising among the key sectors and mass media, including using current events such as economic, weather and health crisis can also help promote adaptation measures with co-benefits.

Climate change requires a global framework for international cooperation. Adaptation action is a vital part of this framework. Actions to enable adaptation to climate change pose opportunities to promote sustainable development. Developing countries require resources in order to promote these actions. A successful framework must directly involve assistance for adaptation in developing countries, particularly small island developing States and least developed countries, given that they will disproportionately bear the brunt of climate change impacts.

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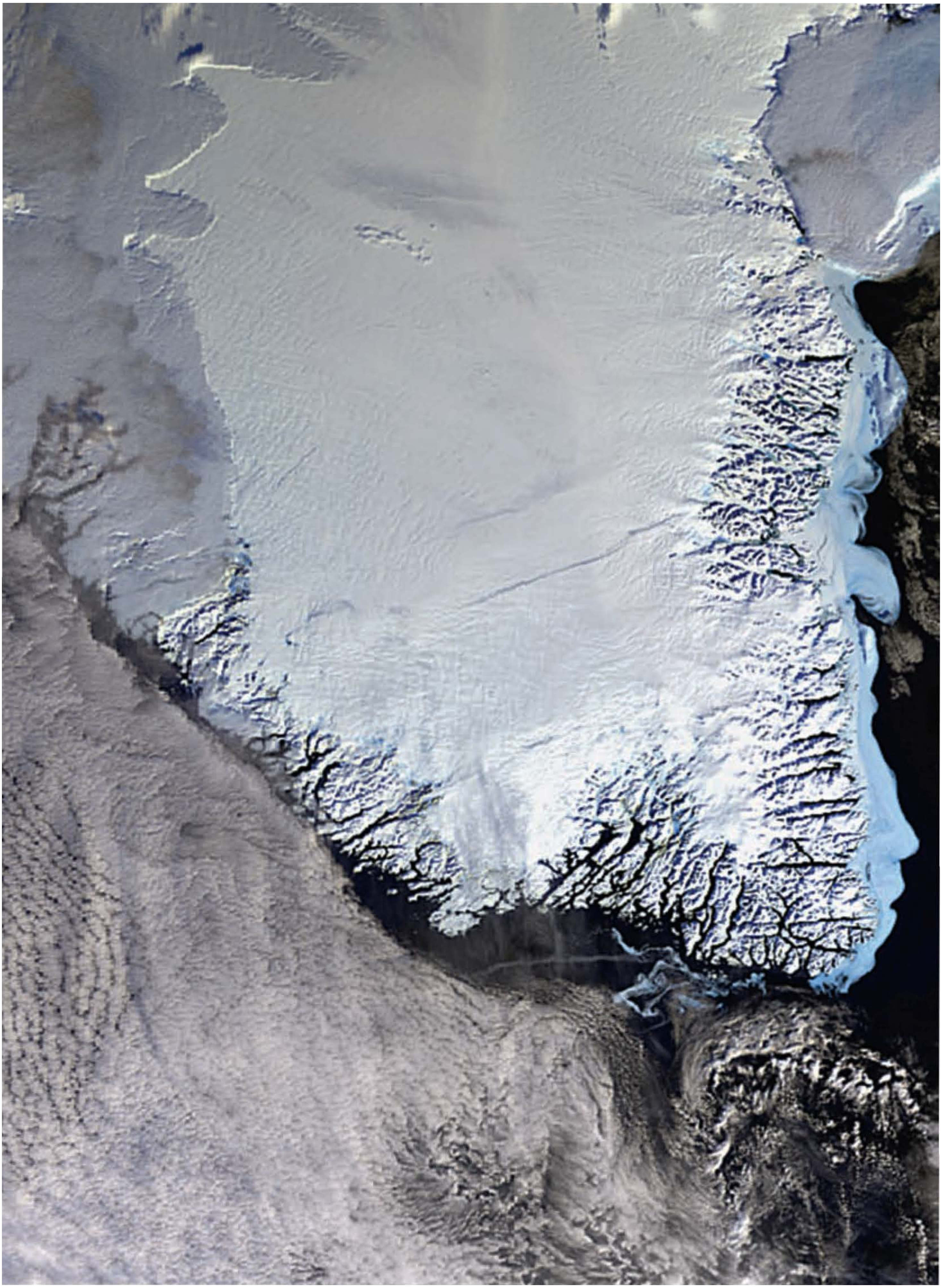
ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
AIACC	Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors
CBA	Community based adaptation
CBA-X	Community based adaptation exchange
CCCCC	Caribbean Community Climate Change Centre
CCRIF	Caribbean Catastrophe Risk Insurance Facility
CH4	methane
CO_2	carbon dioxide
CRISTAL	Community-based Risk Screening Tool-Adaptation and Livelihoods
ECLAC	Economic Commission for Latin America and the Caribbean
ENSO	El Niño Southern Oscillation
FAO	Food and Agriculture Organization
GCOS	Global Climate Observing System
GEF	Global Environment Facility
GTZ	German Agency for Technical Cooperation
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
ISDR	International Strategy for Disaster Reduction
IUCN	World Conservation Union
LCA	Linking Climate Adaptation
LDC	Least Developed Country
LDCF	Least Developed Countries Fund
MACC	Mainstreaming Adaptation to Climate Change
Mauritius Strategy	Mauritius Strategy for the Further Implementation of the Programme of Action for the Sustainable Development of Small Island Developing States
MEA	multilateral environmental agreement
Nairobi work programme	Nairobi work programme on impacts, vulnerability and adaptation to climate change
N_2O	nitrogen dioxide
NAPA	National adaptation programme of action
PACCLIM	PACific CLimate Impacts Model
PIF	Pacific Islands Forum
PRECIS	Providing REgional Climates for Impacts Studies Model
OECS	Organization of Eastern Caribbean States
OSS	Sahara and Sahel Observatory
RIOCC	Ibero-American Network of Climate Change Offices
SCCF	Special Climate Change Fund
SIDS	Small island developing States
SGP	Small Grants Programme
SPA	Strategic Priority on Adaptation
SPC	Secretariat of the Pacific Community
SPREP	Pacific Regional Environment Programme
START	SysTem for Analysis, Research and Training
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP FI	United Nations Environment Programme Finance Initiative
UNFCCC	United Nations Framework Convention on Climate Change
UNU-EHS	United Nations University Institute for Environment and Human Security



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CLIMATE CHANGE:

IMPACTS, VULNERABILITIES AND ADAPTATION IN DEVELOPING COUNTRIES

UNFCCC

United Nations Framework Convention on Climate Change

This is **Exhibit C** referred to in the
affidavit of **John Moffet**
affirmed before me on **January 29, 2019**

Commissioner for Oaths for Québec

#224458

Climate Change 2014
Synthesis Report
Summary for Policymakers

SPM

Introduction

This Synthesis Report is based on the reports of the three Working Groups of the Intergovernmental Panel on Climate Change (IPCC), including relevant Special Reports. It provides an integrated view of climate change as the final part of the IPCC's Fifth Assessment Report (AR5).

This summary follows the structure of the longer report which addresses the following topics: Observed changes and their causes; Future climate change, risks and impacts; Future pathways for adaptation, mitigation and sustainable development; Adaptation and mitigation.

In the Synthesis Report, the certainty in key assessment findings is communicated as in the Working Group Reports and Special Reports. It is based on the author teams' evaluations of underlying scientific understanding and is expressed as a qualitative level of confidence (from *very low* to *very high*) and, when possible, probabilistically with a quantified likelihood (from *exceptionally unlikely* to *virtually certain*)[1]. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers.

This report includes information relevant to Article 2 of the United Nations Framework Convention on Climate Change (UNFCCC).

SPM 1. Observed Changes and their Causes

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. *{1}*

SPM 1.1 Observed changes in the climate system

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. *{1.1}*

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. The period from 1983 to 2012 was *likely* the warmest 30-year period of the last 1400 years in the Northern Hemisphere, where such assessment is possible (*medium confidence*). The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C[2] over the period 1880 to 2012, when multiple independently produced datasets exist (Figure SPM.1a). *{1.1.1, Figure 1.1}*

In addition to robust multi-decadal warming, the globally averaged surface temperature exhibits substantial decadal and interannual variability (Figure SPM.1a). Due to this natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over

[1] Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence. The summary terms for evidence are: limited, medium or robust. For agreement, they are low, medium or high. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., *very likely*. See for more details: Mastrandrea, M.D., C.B. Field, T.F. Stocker, O. Edenhofer, K.L. Ebi, D.J. Frame, H. Held, E. Kriegler, K.J. Mach, P.R. Matschoss, G.-K. Plattner, G.W. Yohe and F.W. Zwiers, 2010: Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties, Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, 4 pp.

[2] Ranges in square brackets or following '±' are expected to have a 90% likelihood of including the value that is being estimated, unless otherwise stated.

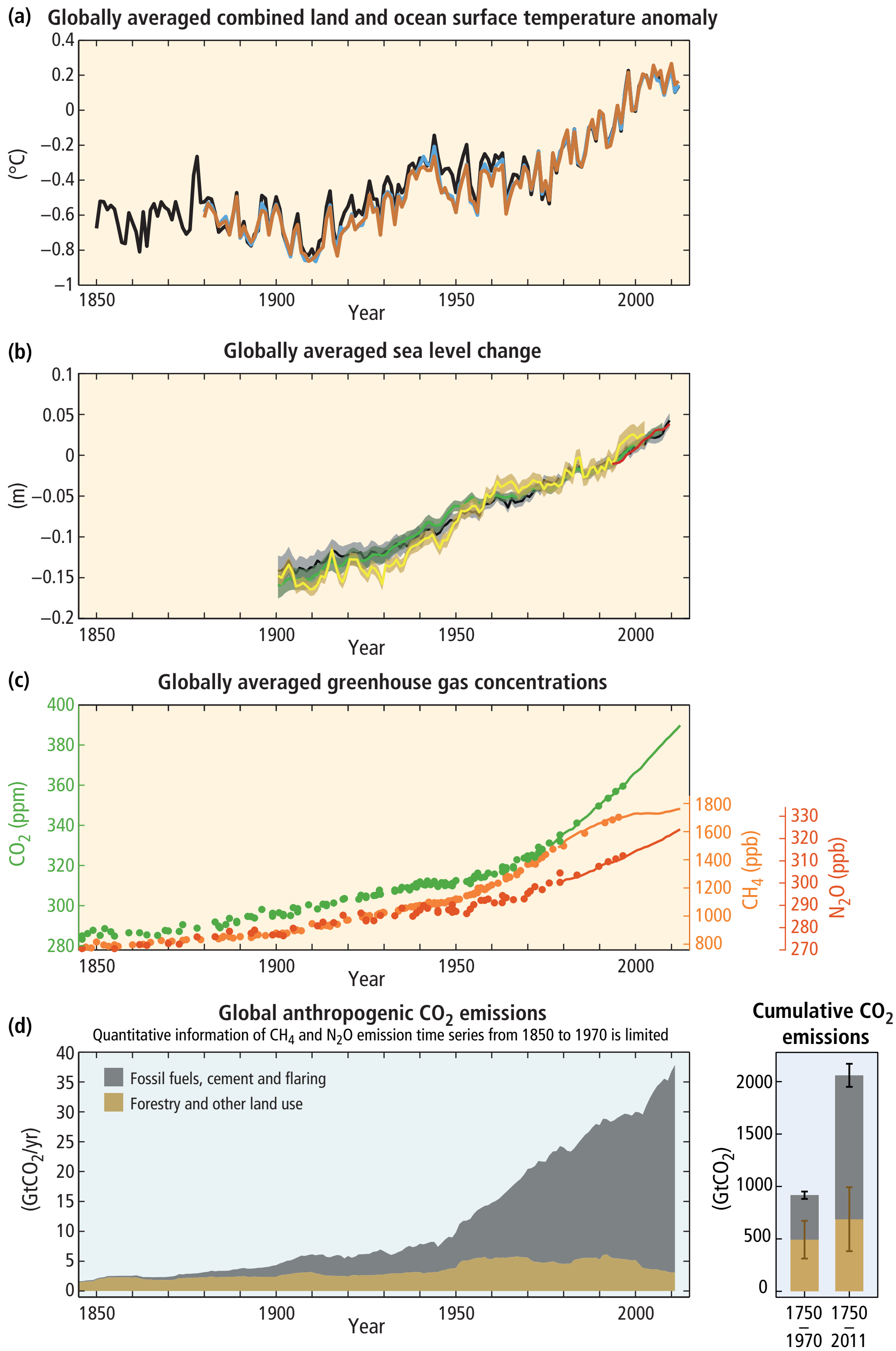

Figure SPM.1 | The complex relationship between the observations (panels a, b, c, yellow background) and the emissions (panel d, light blue background) is addressed in Section 1.2 and Topic 1. Observations and other indicators of a changing global climate system. Observations: **(a)** Annually and globally averaged combined land and ocean surface temperature anomalies relative to the average over the period 1986 to 2005. Colours indicate different data sets. **(b)** Annually and globally averaged sea level change relative to the average over the period 1986 to 2005 in the longest-running dataset. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading. **(c)** Atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2, green), methane (CH_4, orange) and nitrous oxide (N_2O, red) determined from ice core data (dots) and from direct atmospheric measurements (lines). Indicators: **(d)** Global anthropogenic CO_2 emissions from forestry and other land use as well as from burning of fossil fuel, cement production and flaring. Cumulative emissions of CO_2 from these sources and their uncertainties are shown as bars and whiskers, respectively, on the right hand side. The global effects of the accumulation of CH_4 and N_2O emissions are shown in panel c. Greenhouse gas emission data from 1970 to 2010 are shown in Figure SPM.2. *{Figures 1.1, 1.3, 1.5}* the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade). *{1.1.1, Box 1.1}*

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*), with only about 1% stored in the atmosphere. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010, and it *likely* warmed between the 1870s and 1971. *{1.1.2, Figure 1.2}*

Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (*medium confidence* before and *high confidence* after 1951). For other latitudes, area-averaged long-term positive or negative trends have *low confidence*. Observations of changes in ocean surface salinity also provide indirect evidence for changes in the global water cycle over the ocean (*medium confidence*). It is *very likely* that regions of high salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s. *{1.1.1, 1.1.2}*

Since the beginning of the industrial era, oceanic uptake of CO_2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 (*high confidence*), corresponding to a 26% increase in acidity, measured as hydrogen ion concentration. *{1.1.2}*

Over the period 1992 to 2011, the Greenland and Antarctic ice sheets have been losing mass (*high confidence*), *likely* at a larger rate over 2002 to 2011. Glaciers have continued to shrink almost worldwide (*high confidence*). Northern Hemisphere spring snow cover has continued to decrease in extent (*high confidence*). There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s in response to increased surface temperature and changing snow cover. *{1.1.3}*

The annual mean Arctic sea-ice extent decreased over the period 1979 to 2012, with a rate that was *very likely* in the range 3.5 to 4.1% per decade. Arctic sea-ice extent has decreased in every season and in every successive decade since 1979, with the most rapid decrease in decadal mean extent in summer (*high confidence*). It is *very likely* that the annual mean Antarctic sea-ice extent increased in the range of 1.2 to 1.8% per decade between 1979 and 2012. However, there is *high confidence* that there are strong regional differences in Antarctica, with extent increasing in some regions and decreasing in others. *{1.1.3, Figure 1.1}*

Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure SPM.1b). The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). *{1.1.4, Figure 1.1}*

SPM 1.2 Causes of climate change

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century. *{1.2, 1.3.1}*

Anthropogenic greenhouse gas (GHG) emissions since the pre-industrial era have driven large increases in the atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Figure SPM.1c). Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 $GtCO_2$. About 40% of these emissions have remained in the atmosphere (880 ± 35 $GtCO_2$); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification. About half of the anthropogenic CO_2 emissions between 1750 and 2011 have occurred in the last 40 years (*high confidence*) (Figure SPM.1d). *{1.2.1, 1.2.2}*

SPM

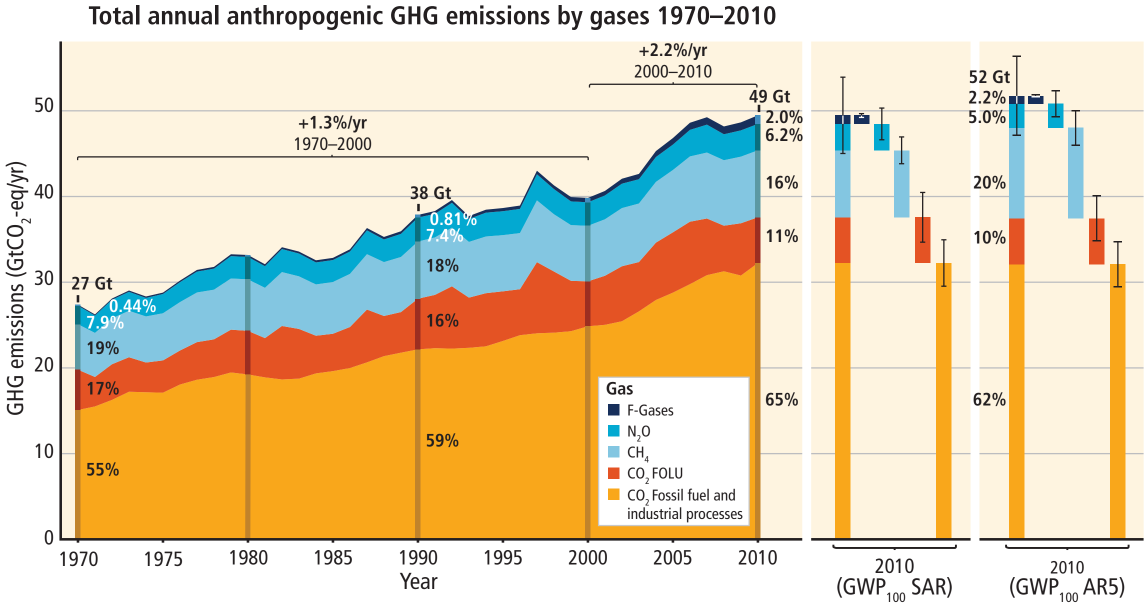

Figure SPM.2 | Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) for the period 1970 to 2010 by gases: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). Right hand side shows 2010 emissions, using alternatively CO_2-equivalent emission weightings based on IPCC Second Assessment Report (SAR) and AR5 values. Unless otherwise stated, CO_2-equivalent emissions in this report include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values from the SAR (see Glossary). Using the most recent GWP_{100} values from the AR5 (right-hand bars) would result in higher total annual GHG emissions (52 $GtCO_2$-eq/yr) from an increased contribution of methane, but does not change the long-term trend significantly. *{Figure 1.6, Box 3.2}*

Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010, despite a growing number of climate change mitigation policies. Anthropogenic GHG emissions in 2010 have reached 49 ± 4.5 $GtCO_2$-eq/yr [3]. Emissions of CO_2 from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution for the increase during the period 2000 to 2010 (*high confidence*) (Figure SPM.2). Globally, economic and population growth continued to be the most important drivers of increases in CO_2 emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, while the contribution of economic growth has risen sharply. Increased use of coal has reversed the long-standing trend of gradual decarbonization (i.e., reducing the carbon intensity of energy) of the world's energy supply (*high confidence*). *{1.2.2}*

The evidence for human influence on the climate system has grown since the IPCC Fourth Assessment Report (AR4). It is *extremely likely* that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together. The best estimate of the human-induced contribution to warming is similar to the observed warming over this period (Figure SPM.3). Anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century over every continental region except Antarctica[4]. Anthropogenic influences have *likely* affected the global water cycle since 1960 and contributed to the retreat of glaciers since the 1960s and to the increased surface melting of the Greenland ice sheet since 1993. Anthropogenic influences have *very likely* contributed to Arctic sea-ice loss since 1979 and have *very likely* made a substantial contribution to increases in global upper ocean heat content (0–700 m) and to global mean sea level rise observed since the 1970s. *{1.3, Figure 1.10}*

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[3] Greenhouse gas emissions are quantified as CO_2-equivalent ($GtCO_2$-eq) emissions using weightings based on the 100-year Global Warming Potentials, using IPCC Second Assessment Report values unless otherwise stated. *{Box 3.2}*

[4] For Antarctica, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations.

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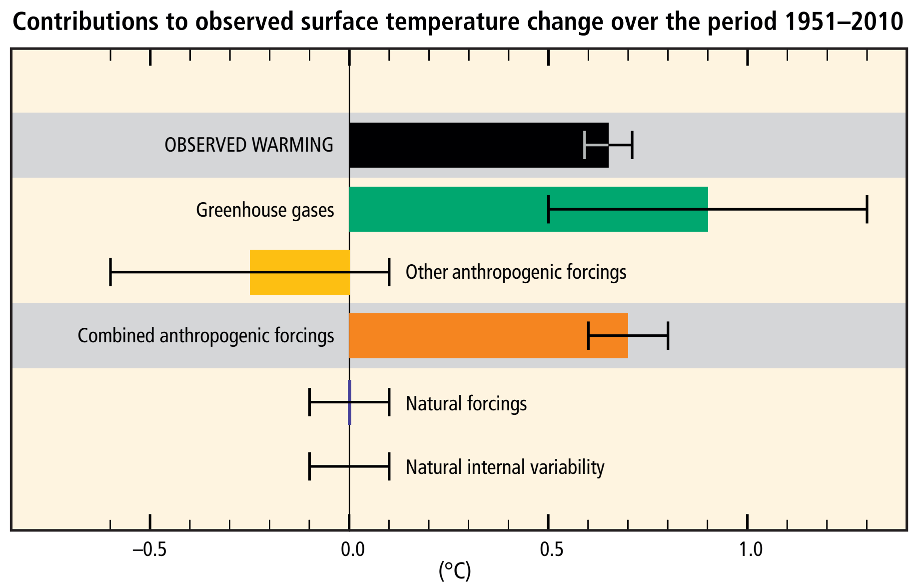

Figure SPM.3 | Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings (including the cooling effect of aerosols and the effect of land use change), combined anthropogenic forcings, natural forcings and natural internal climate variability (which is the element of climate variability that arises spontaneously within the climate system even in the absence of forcings). The observed surface temperature change is shown in black, with the 5 to 95% uncertainty range due to observational uncertainty. The attributed warming ranges (colours) are based on observations combined with climate model simulations, in order to estimate the contribution of an individual external forcing to the observed warming. The contribution from the combined anthropogenic forcings can be estimated with less uncertainty than the contributions from greenhouse gases and from other anthropogenic forcings separately. This is because these two contributions partially compensate, resulting in a combined signal that is better constrained by observations. *{Figure 1.9}*

SPM 1.3 Impacts of climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. *{1.3.2}*

Evidence of observed climate change impacts is strongest and most comprehensive for natural systems. In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (*medium confidence*). Many terrestrial, freshwater and marine species have shifted their geographic ranges, seasonal activities, migration patterns, abundances and species interactions in response to ongoing climate change (*high confidence*). Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguishable from other influences (Figure SPM.4). Assessment of many studies covering a wide range of regions and crops shows that negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*). Some impacts of ocean acidification on marine organisms have been attributed to human influence (*medium confidence*). *{1.3.2}*

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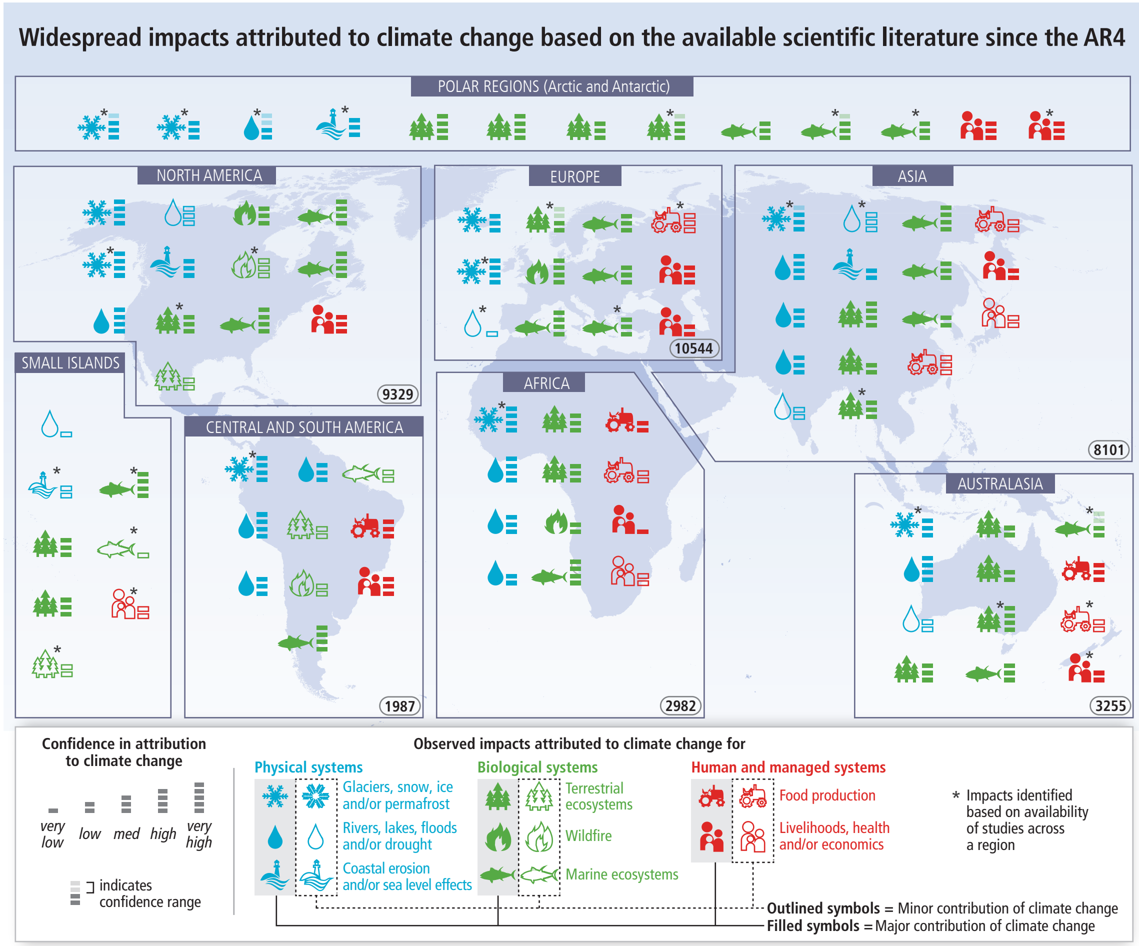

Figure SPM.4 | Based on the available scientific literature since the IPCC Fourth Assessment Report (AR4), there are substantially more impacts in recent decades now attributed to climate change. Attribution requires defined scientific evidence on the role of climate change. Absence from the map of additional impacts attributed to climate change does not imply that such impacts have not occurred. The publications supporting attributed impacts reflect a growing knowledge base, but publications are still limited for many regions, systems and processes, highlighting gaps in data and studies. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact and confidence in attribution. Each symbol refers to one or more entries in WGII Table SPM.A1, grouping related regional-scale impacts. Numbers in ovals indicate regional totals of climate change publications from 2001 to 2010, based on the Scopus bibliographic database for publications in English with individual countries mentioned in title, abstract or key words (as of July 2011). These numbers provide an overall measure of the available scientific literature on climate change across regions; they do not indicate the number of publications supporting attribution of climate change impacts in each region. Studies for polar regions and small islands are grouped with neighbouring continental regions. The inclusion of publications for assessment of attribution followed IPCC scientific evidence criteria defined in WGII Chapter 18. Publications considered in the attribution analyses come from a broader range of literature assessed in the WGII AR5. See WGII Table SPM.A1 for descriptions of the attributed impacts. *{Figure 1.11}*

SPM 1.4 Extreme events

Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions. *{1.4}*

It is *very likely* that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale. It is *likely* that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. It is

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very likely that human influence has contributed to the observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century. It is *likely* that human influence has more than doubled the probability of occurrence of heat waves in some locations. There is *medium confidence* that the observed warming has increased heat-related human mortality and decreased cold-related human mortality in some regions. *{1.4}*

There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. Recent detection of increasing trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (*medium confidence*). It is *likely* that extreme sea levels (for example, as experienced in storm surges) have increased since 1970, being mainly a result of rising mean sea level. *{1.4}*

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones and wildfires, reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability (*very high confidence*). *{1.4}*

SPM 2. Future Climate Changes, Risks and Impacts

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks. *{2}*

SPM 2.1 Key drivers of future climate

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Projections of greenhouse gas emissions vary over a wide range, depending on both socio-economic development and climate policy. *{2.1}*

Anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy. The Representative Concentration Pathways (RCPs), which are used for making projections based on these factors, describe four different 21st century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use. The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5). Scenarios without additional efforts to constrain emissions ('baseline scenarios') lead to pathways ranging between RCP6.0 and RCP8.5 (Figure SPM.5a). RCP2.6 is representative of a scenario that aims to keep global warming *likely* below 2°C above pre-industrial temperatures. The RCPs are consistent with the wide range of scenarios in the literature as assessed by WGIII[5]. *{2.1, Box 2.2, 4.3}*

Multiple lines of evidence indicate a strong, consistent, almost linear relationship between cumulative CO_2 emissions and projected global temperature change to the year 2100 in both the RCPs and the wider set of mitigation scenarios analysed in WGIII (Figure SPM.5b). Any given level of warming is associated with a range of cumulative CO_2 emissions[6], and therefore, e.g., higher emissions in earlier decades imply lower emissions later. *{2.2.5, Table 2.2}*

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[5] Roughly 300 baseline scenarios and 900 mitigation scenarios are categorized by CO_2-equivalent concentration (CO_2-eq) by 2100. The CO_2-eq includes the forcing due to all GHGs (including halogenated gases and tropospheric ozone), aerosols and albedo change.

[6] Quantification of this range of CO_2 emissions requires taking into account non-CO_2 drivers.

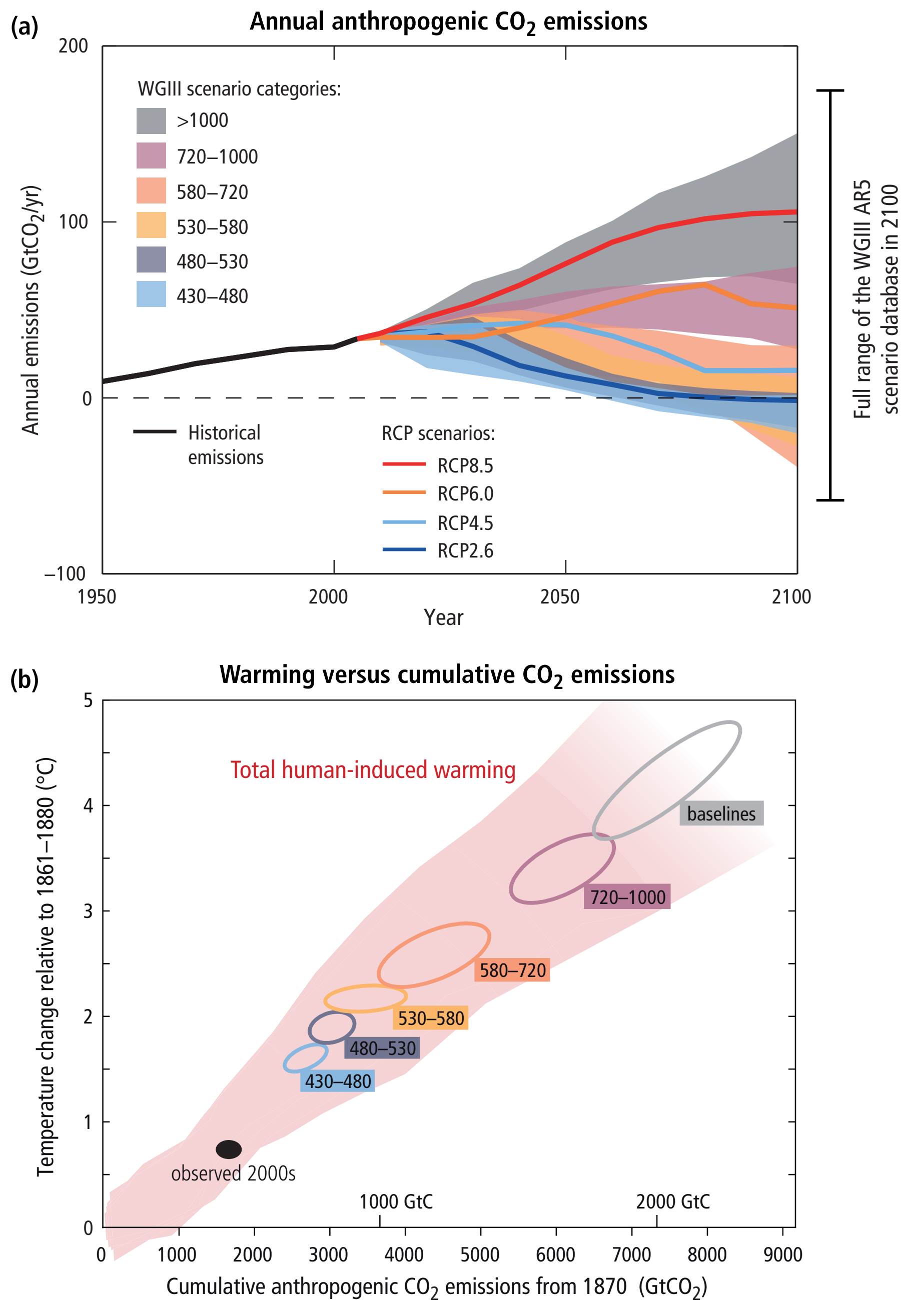

Figure SPM.5 | **(a)** Emissions of carbon dioxide (CO_2) alone in the Representative Concentration Pathways (RCPs) (lines) and the associated scenario categories used in WGIII (coloured areas show 5 to 95% range). The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined on the basis of CO_2-eq concentration levels (in ppm) in 2100. The time series of other greenhouse gas emissions are shown in Box 2.2, Figure 1. **(b)** Global mean surface temperature increase at the time global CO_2 emissions reach a given net cumulative total, plotted as a function of that total, from various lines of evidence. Coloured plume shows the spread of past and future projections from a hierarchy of climate-carbon cycle models driven by historical emissions and the four RCPs over all times out to 2100, and fades with the decreasing number of available models. Ellipses show total anthropogenic warming in 2100 versus cumulative CO_2 emissions from 1870 to 2100 from a simple climate model (median climate response) under the scenario categories used in WGIII. The width of the ellipses in terms of temperature is caused by the impact of different scenarios for non-CO_2 climate drivers. The filled black ellipse shows observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties. *{Box 2.2, Figure 1; Figure 2.3}*

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Multi-model results show that limiting total human-induced warming to less than 2°C relative to the period 1861–1880 with a probability of >66%[7] would require cumulative CO_2 emissions from all anthropogenic sources since 1870 to remain below about 2900 $GtCO_2$ (with a range of 2550 to 3150 $GtCO_2$ depending on non-CO_2 drivers). About 1900 $GtCO_2$[8] had already been emitted by 2011. For additional context see Table 2.2. *{2.2.5}*

SPM 2.2 Projected changes in the climate system

Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is *very likely* that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise. *{2.2}*

The projected changes in Section SPM 2.2 are for 2081–2100 relative to 1986–2005, unless otherwise indicated.

Future climate will depend on committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability. The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four RCPs and will *likely* be in the range 0.3°C to 0.7°C (*medium confidence*). This assumes that there will be no major volcanic eruptions or changes in some natural sources (e.g., CH_4 and N_2O), or unexpected changes in total solar irradiance. By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario. *{2.2.1, Table 2.1}*

Relative to 1850–1900, global surface temperature change for the end of the 21st century (2081–2100) is projected to *likely* exceed 1.5°C for RCP4.5, RCP6.0 and RCP8.5 (*high confidence*). Warming is *likely* to exceed 2°C for RCP6.0 and RCP8.5 (*high confidence*), *more likely than not* to exceed 2°C for RCP4.5 (*medium confidence*), but *unlikely* to exceed 2°C for RCP2.6 (*medium confidence*). *{2.2.1}*

The increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is *likely* to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.5[9]. The Arctic region will continue to warm more rapidly than the global mean (Figure SPM.6a, Figure SPM.7a). *{2.2.1, Figure 2.1, Figure 2.2, Table 2.1}*

It is *virtually certain* that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is *very likely* that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur. *{2.2.1}*

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[7] Corresponding figures for limiting warming to 2°C with a probability of >50% and >33% are 3000 $GtCO_2$ (range of 2900 to 3200 $GtCO_2$) and 3300 $GtCO_2$ (range of 2950 to 3800 $GtCO_2$) respectively. Higher or lower temperature limits would imply larger or lower cumulative emissions respectively.

[8] This corresponds to about two thirds of the 2900 $GtCO_2$ that would limit warming to less than 2°C with a probability of >66%; to about 63% of the total amount of 3000 $GtCO_2$ that would limit warming to less than 2°C with a probability of >50%; and to about 58% of the total amount of 3300 $GtCO_2$ that would limit warming to less than 2°C with a probability of >33%.

[9] The period 1986–2005 is approximately 0.61 [0.55 to 0.67] °C warmer than 1850–1900. *{2.2.1}*

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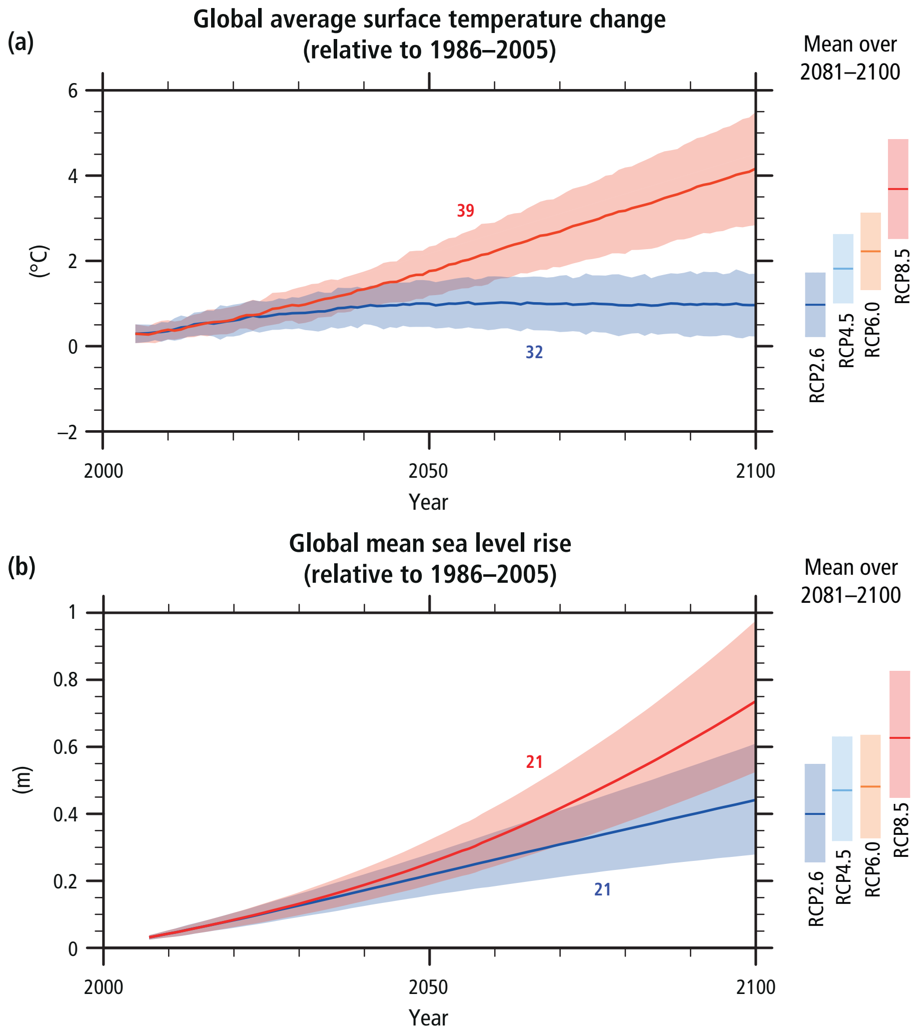

Figure SPM.6 | Global average surface temperature change **(a)** and global mean sea level rise[10] **(b)** from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as coloured vertical bars at the right hand side of each panel. The number of Coupled Model Intercomparison Project Phase 5 (CMIP5) models used to calculate the multi-model mean is indicated. *{2.2, Figure 2.1}*

Changes in precipitation will not be uniform. The high latitudes and the equatorial Pacific are *likely* to experience an increase in annual mean precipitation under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase under the RCP8.5 scenario (Figure SPM.7b). Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent. *{2.2.2, Figure 2.2}*

The global ocean will continue to warm during the 21st century, with the strongest warming projected for the surface in tropical and Northern Hemisphere subtropical regions (Figure SPM.7a). *{2.2.3, Figure 2.2}*

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[10] Based on current understanding (from observations, physical understanding and modelling), only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the *likely* range during the 21st century. There is *medium confidence* that this additional contribution would not exceed several tenths of a meter of sea level rise during the 21st century.

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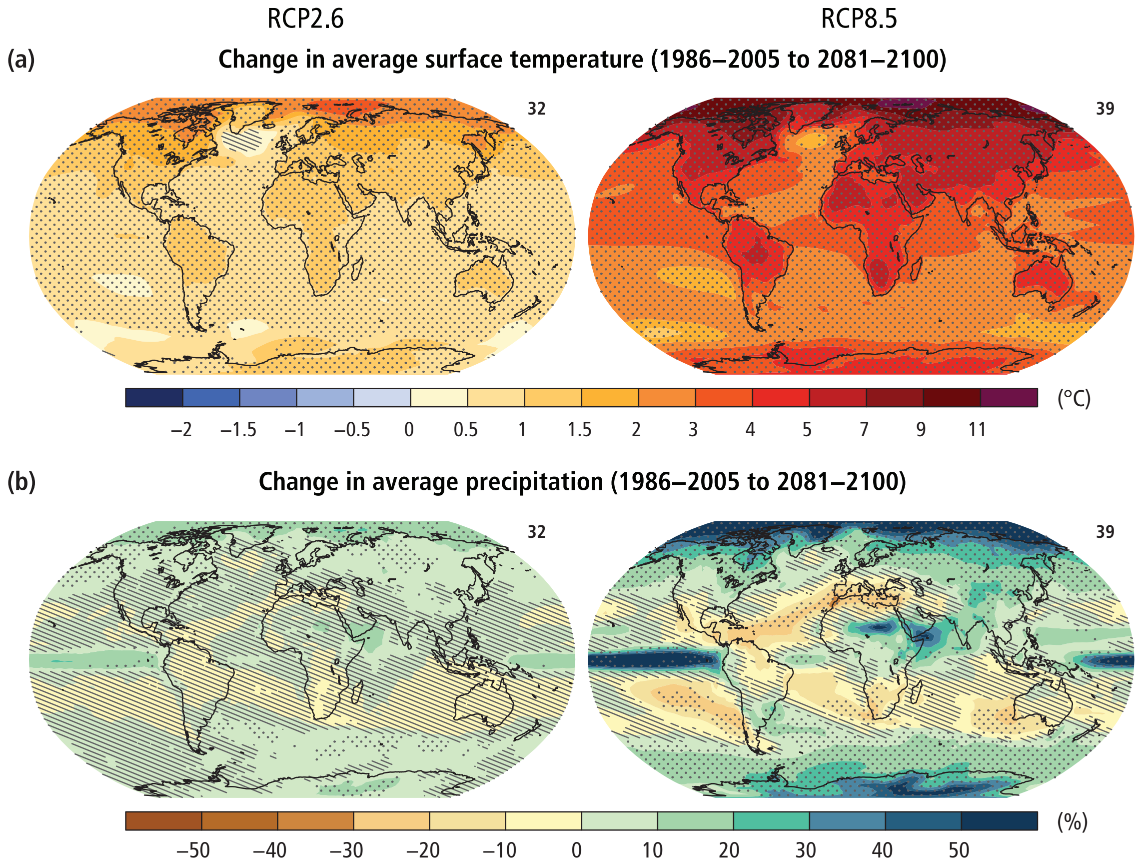

Figure SPM.7 | Change in average surface temperature **(a)** and change in average precipitation **(b)** based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios. The number of models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling (i.e., dots) shows regions where the projected change is large compared to natural internal variability and where at least 90% of models agree on the sign of change. Hatching (i.e., diagonal lines) shows regions where the projected change is less than one standard deviation of the natural internal variability. *{2.2, Figure 2.2}*

Earth System Models project a global increase in ocean acidification for all RCP scenarios by the end of the 21st century, with a slow recovery after mid-century under RCP2.6. The decrease in surface ocean pH is in the range of 0.06 to 0.07 (15 to 17% increase in acidity) for RCP2.6, 0.14 to 0.15 (38 to 41%) for RCP4.5, 0.20 to 0.21 (58 to 62%) for RCP6.0 and 0.30 to 0.32 (100 to 109%) for RCP8.5. *{2.2.4, Figure 2.1}*

Year-round reductions in Arctic sea ice are projected for all RCP scenarios. A nearly ice-free[11] Arctic Ocean in the summer sea-ice minimum in September before mid-century is *likely* for RCP8.5[12] (*medium confidence*). *{2.2.3, Figure 2.1}*

It is *virtually certain* that near-surface permafrost extent at high northern latitudes will be reduced as global mean surface temperature increases, with the area of permafrost near the surface (upper 3.5 m) projected to decrease by 37% (RCP2.6) to 81% (RCP8.5) for the multi-model average (*medium confidence*). *{2.2.3}*

The global glacier volume, excluding glaciers on the periphery of Antarctica (and excluding the Greenland and Antarctic ice sheets), is projected to decrease by 15 to 55% for RCP2.6 and by 35 to 85% for RCP8.5 (*medium confidence*). *{2.2.3}*

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11 When sea-ice extent is less than one million km^2 for at least five consecutive years.

12 Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979–2012 trend of the Arctic sea-ice extent.

There has been significant improvement in understanding and projection of sea level change since the AR4. Global mean sea level rise will continue during the 21st century, *very likely* at a faster rate than observed from 1971 to 2010. For the period 2081–2100 relative to 1986–2005, the rise will *likely* be in the ranges of 0.26 to 0.55 m for RCP2.6, and of 0.45 to 0.82 m for RCP8.5 (*medium confidence*)[10] (Figure SPM.6b). Sea level rise will not be uniform across regions. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area. About 70% of the coastlines worldwide are projected to experience a sea level change within ±20% of the global mean. *{2.2.3}*

SPM 2.3 Future risks and impacts caused by a changing climate

Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development. *{2.3}*

Risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems, including their ability to adapt. Rising rates and magnitudes of warming and other changes in the climate system, accompanied by ocean acidification, increase the risk of severe, pervasive and in some cases irreversible detrimental impacts. Some risks are particularly relevant for individual regions (Figure SPM.8), while others are global. The overall risks of future climate change impacts can be reduced by limiting the rate and magnitude of climate change, including ocean acidification. The precise levels of climate change sufficient to trigger abrupt and irreversible change remain uncertain, but the risk associated with crossing such thresholds increases with rising temperature (*medium confidence*). For risk assessment, it is important to evaluate the widest possible range of impacts, including low-probability outcomes with large consequences. *{1.5, 2.3, 2.4, 3.3, Box Introduction.1, Box 2.3, Box 2.4}*

A large fraction of species faces increased extinction risk due to climate change during and beyond the 21st century, especially as climate change interacts with other stressors (*high confidence*). Most plant species cannot naturally shift their geographical ranges sufficiently fast to keep up with current and high projected rates of climate change in most landscapes; most small mammals and freshwater molluscs will not be able to keep up at the rates projected under RCP4.5 and above in flat landscapes in this century (*high confidence*). Future risk is indicated to be high by the observation that natural global climate change at rates lower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years. Marine organisms will face progressively lower oxygen levels and high rates and magnitudes of ocean acidification (*high confidence*), with associated risks exacerbated by rising ocean temperature extremes (*medium confidence*). Coral reefs and polar ecosystems are highly vulnerable. Coastal systems and low-lying areas are at risk from sea level rise, which will continue for centuries even if the global mean temperature is stabilized (*high confidence*). *{2.3, 2.4, Figure 2.5}*

Climate change is projected to undermine food security (Figure SPM.9). Due to projected climate change by the mid-21st century and beyond, global marine species redistribution and marine biodiversity reduction in sensitive regions will challenge the sustained provision of fisheries productivity and other ecosystem services (*high confidence*). For wheat, rice and maize in tropical and temperate regions, climate change without adaptation is projected to negatively impact production for local temperature increases of 2°C or more above late 20th century levels, although individual locations may benefit (*medium confidence*). Global temperature increases of ~4°C or more[13] above late 20th century levels, combined with increasing food demand, would pose large risks to food security globally (*high confidence*). Climate change is projected to reduce renewable surface water and groundwater resources in most dry subtropical regions (*robust evidence*, *high agreement*), intensifying competition for water among sectors (*limited evidence*, *medium agreement*). *{2.3.1, 2.3.2}*

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[13] Projected warming averaged over land is larger than global average warming for all RCP scenarios for the period 2081–2100 relative to 1986–2005. For regional projections, see Figure SPM.7. *{2.2}*

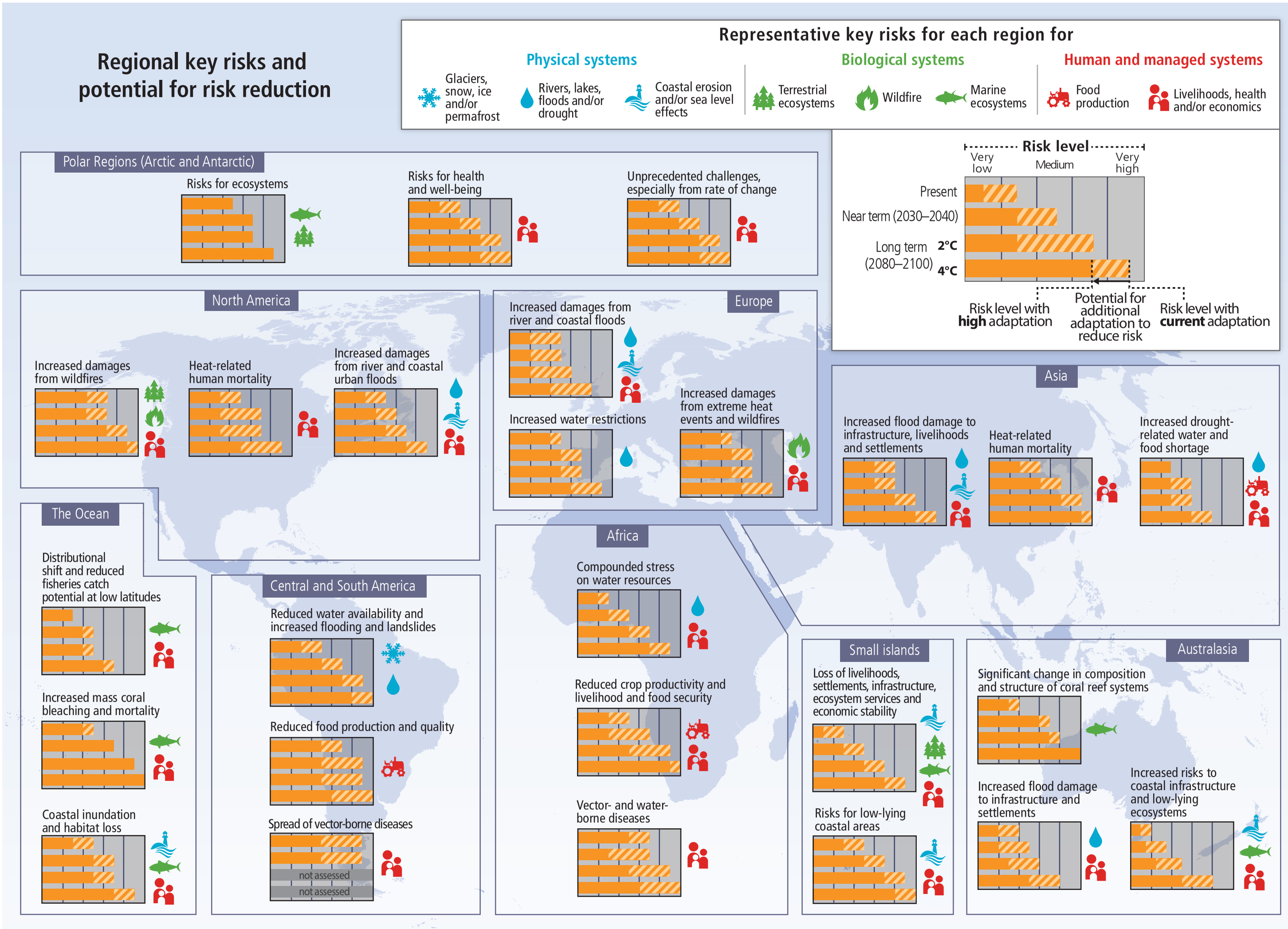

Figure SPM.8 | Representative key risks[14] for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high or very high. Risk levels are presented for three time frames: present, near term (here, for 2030–2040) and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2°C and 4°C global mean temperature increase above pre-industrial levels). For each timeframe, risk levels are indicated for a continuation of current adaptation and assuming high levels of current or future adaptation. Risk levels are not necessarily comparable, especially across regions. *{Figure 2.4}*

[14] Identification of key risks was based on expert judgment using the following specific criteria: large magnitude, high probability or irreversibility of impacts; timing of impacts; persistent vulnerability or exposure contributing to risks; or limited potential to reduce risks through adaptation or mitigation.

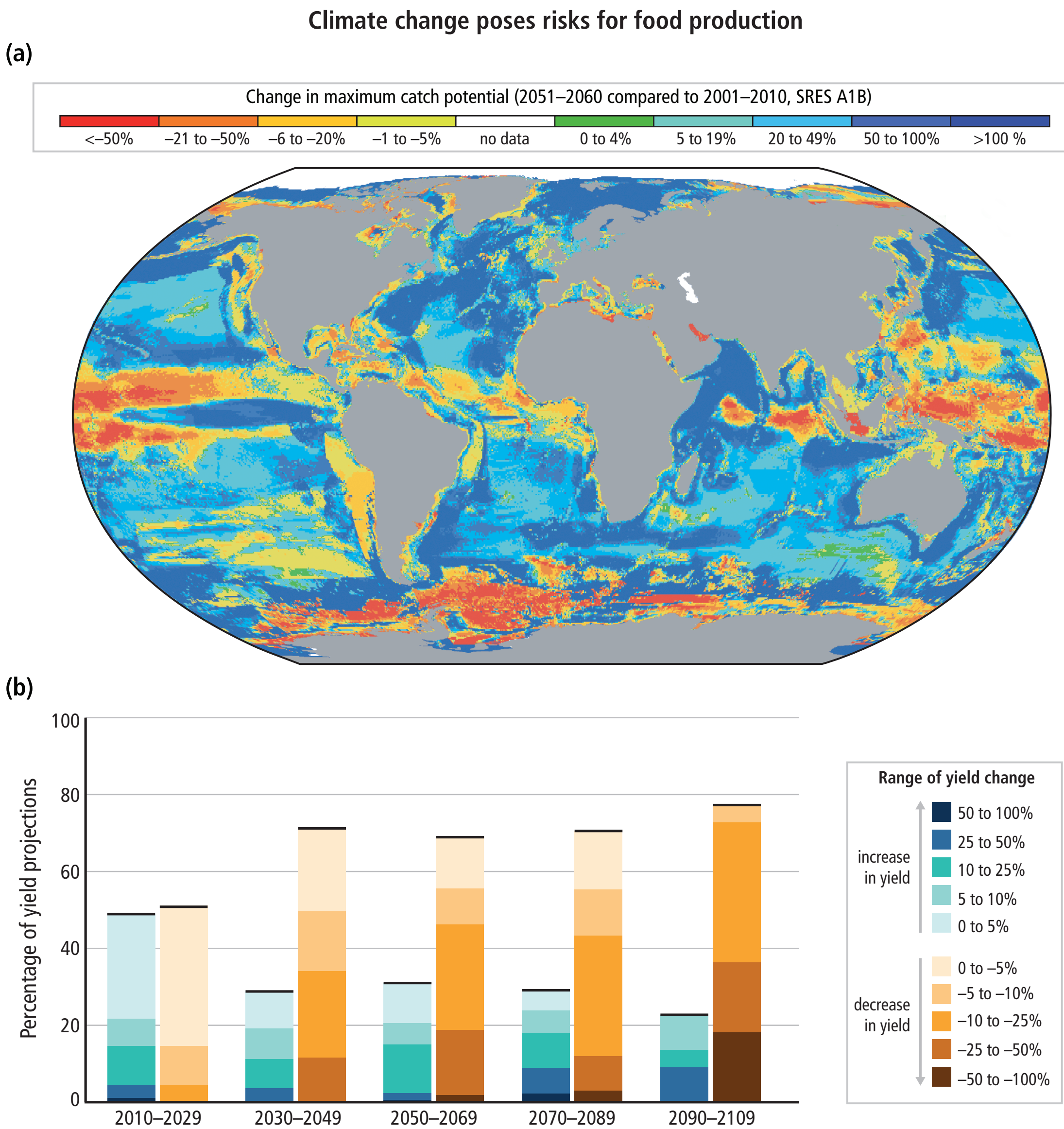

Figure SPM.9 | **(a)** Projected global redistribution of maximum catch potential of ~1000 exploited marine fish and invertebrate species. Projections compare the 10-year averages 2001–2010 and 2051–2060 using ocean conditions based on a single climate model under a moderate to high warming scenario, without analysis of potential impacts of overfishing or ocean acidification. **(b)** Summary of projected changes in crop yields (mostly wheat, maize, rice and soy), due to climate change over the 21st century. Data for each timeframe sum to 100%, indicating the percentage of projections showing yield increases versus decreases. The figure includes projections (based on 1090 data points) for different emission scenarios, for tropical and temperate regions and for adaptation and no-adaptation cases combined. Changes in crop yields are relative to late 20th century levels. *{Figure 2.6a, Figure 2.7}*

Until mid-century, projected climate change will impact human health mainly by exacerbating health problems that already exist (*very high confidence*). Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries with low income, as compared to a baseline without climate change (*high confidence*). By 2100 for RCP8.5, the combination of high temperature and humidity in some areas for parts of the year is expected to compromise common human activities, including growing food and working outdoors (*high confidence*). *{2.3.2}*

In urban areas climate change is projected to increase risks for people, assets, economies and ecosystems, including risks from heat stress, storms and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea level rise and storm surges (*very high confidence*). These risks are amplified for those lacking essential infrastructure and services or living in exposed areas. *{2.3.2}*

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Rural areas are expected to experience major impacts on water availability and supply, food security, infrastructure and agricultural incomes, including shifts in the production areas of food and non-food crops around the world (*high confidence*). *{2.3.2}*

Aggregate economic losses accelerate with increasing temperature (*limited evidence, high agreement*), but global economic impacts from climate change are currently difficult to estimate. From a poverty perspective, climate change impacts are projected to slow down economic growth, make poverty reduction more difficult, further erode food security and prolong existing and create new poverty traps, the latter particularly in urban areas and emerging hotspots of hunger (*medium confidence*). International dimensions such as trade and relations among states are also important for understanding the risks of climate change at regional scales. *{2.3.2}*

Climate change is projected to increase displacement of people (*medium evidence, high agreement*). Populations that lack the resources for planned migration experience higher exposure to extreme weather events, particularly in developing countries with low income. Climate change can indirectly increase risks of violent conflicts by amplifying well-documented drivers of these conflicts such as poverty and economic shocks (*medium confidence*). *{2.3.2}*

SPM 2.4 Climate change beyond 2100, irreversibility and abrupt changes

Many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gases are stopped. The risks of abrupt or irreversible changes increase as the magnitude of the warming increases. *{2.4}*

Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO_2 emissions. A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial timescale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period. *{2.4, Figure 2.8}*

Stabilization of global average surface temperature does not imply stabilization for all aspects of the climate system. Shifting biomes, soil carbon, ice sheets, ocean temperatures and associated sea level rise all have their own intrinsic long timescales which will result in changes lasting hundreds to thousands of years after global surface temperature is stabilized. *{2.1, 2.4}*

There is *high confidence* that ocean acidification will increase for centuries if CO_2 emissions continue, and will strongly affect marine ecosystems. *{2.4}*

It is *virtually certain* that global mean sea level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions. The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated sea level rise of up to 7 m, is greater than about 1°C (*low confidence*) but less than about 4°C (*medium confidence*) of global warming with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment. *{2.4}*

Magnitudes and rates of climate change associated with medium- to high-emission scenarios pose an increased risk of abrupt and irreversible regional-scale change in the composition, structure and function of marine, terrestrial and freshwater ecosystems, including wetlands (*medium confidence*). A reduction in permafrost extent is *virtually certain* with continued rise in global temperatures. *{2.4}*

SPM 3. Future Pathways for Adaptation, Mitigation and Sustainable Development

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development. *{3.2, 3.3, 3.4}*

SPM 3.1 Foundations of decision-making about climate change

Effective decision-making to limit climate change and its effects can be informed by a wide range of analytical approaches for evaluating expected risks and benefits, recognizing the importance of governance, ethical dimensions, equity, value judgments, economic assessments and diverse perceptions and responses to risk and uncertainty. *{3.1}*

Sustainable development and equity provide a basis for assessing climate policies. Limiting the effects of climate change is necessary to achieve sustainable development and equity, including poverty eradication. Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries also face varying challenges and circumstances and have different capacities to address mitigation and adaptation. Mitigation and adaptation raise issues of equity, justice and fairness. Many of those most vulnerable to climate change have contributed and contribute little to GHG emissions. Delaying mitigation shifts burdens from the present to the future, and insufficient adaptation responses to emerging impacts are already eroding the basis for sustainable development. Comprehensive strategies in response to climate change that are consistent with sustainable development take into account the co-benefits, adverse side effects and risks that may arise from both adaptation and mitigation options. *{3.1, 3.5, Box 3.4}*

The design of climate policy is influenced by how individuals and organizations perceive risks and uncertainties and take them into account. Methods of valuation from economic, social and ethical analysis are available to assist decision-making. These methods can take account of a wide range of possible impacts, including low-probability outcomes with large consequences. But they cannot identify a single best balance between mitigation, adaptation and residual climate impacts. *{3.1}*

Climate change has the characteristics of a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g., individual, community, company, country) affect other agents. Effective mitigation will not be achieved if individual agents advance their own interests independently. Cooperative responses, including international cooperation, are therefore required to effectively mitigate GHG emissions and address other climate change issues. The effectiveness of adaptation can be enhanced through complementary actions across levels, including international cooperation. The evidence suggests that outcomes seen as equitable can lead to more effective cooperation. *{3.1}*

SPM 3.2 Climate change risks reduced by mitigation and adaptation

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts. *{3.2, 3.4}*

Mitigation and adaptation are complementary approaches for reducing risks of climate change impacts over different timescales (*high confidence*). Mitigation, in the near term and through the century, can substantially reduce climate change

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impacts in the latter decades of the 21st century and beyond. Benefits from adaptation can already be realized in addressing current risks, and can be realized in the future for addressing emerging risks. *{3.2, 4.5}*

Five Reasons For Concern (RFCs) aggregate climate change risks and illustrate the implications of warming and of adaptation limits for people, economies and ecosystems across sectors and regions. The five RFCs are associated with: (1) Unique and threatened systems, (2) Extreme weather events, (3) Distribution of impacts, (4) Global aggregate impacts, and (5) Large-scale singular events. In this report, the RFCs provide information relevant to Article 2 of UNFCCC. *{Box 2.4}*

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (*high confidence*) (Figure SPM.10). In most scenarios without additional mitigation efforts (those with 2100 atmospheric concentrations

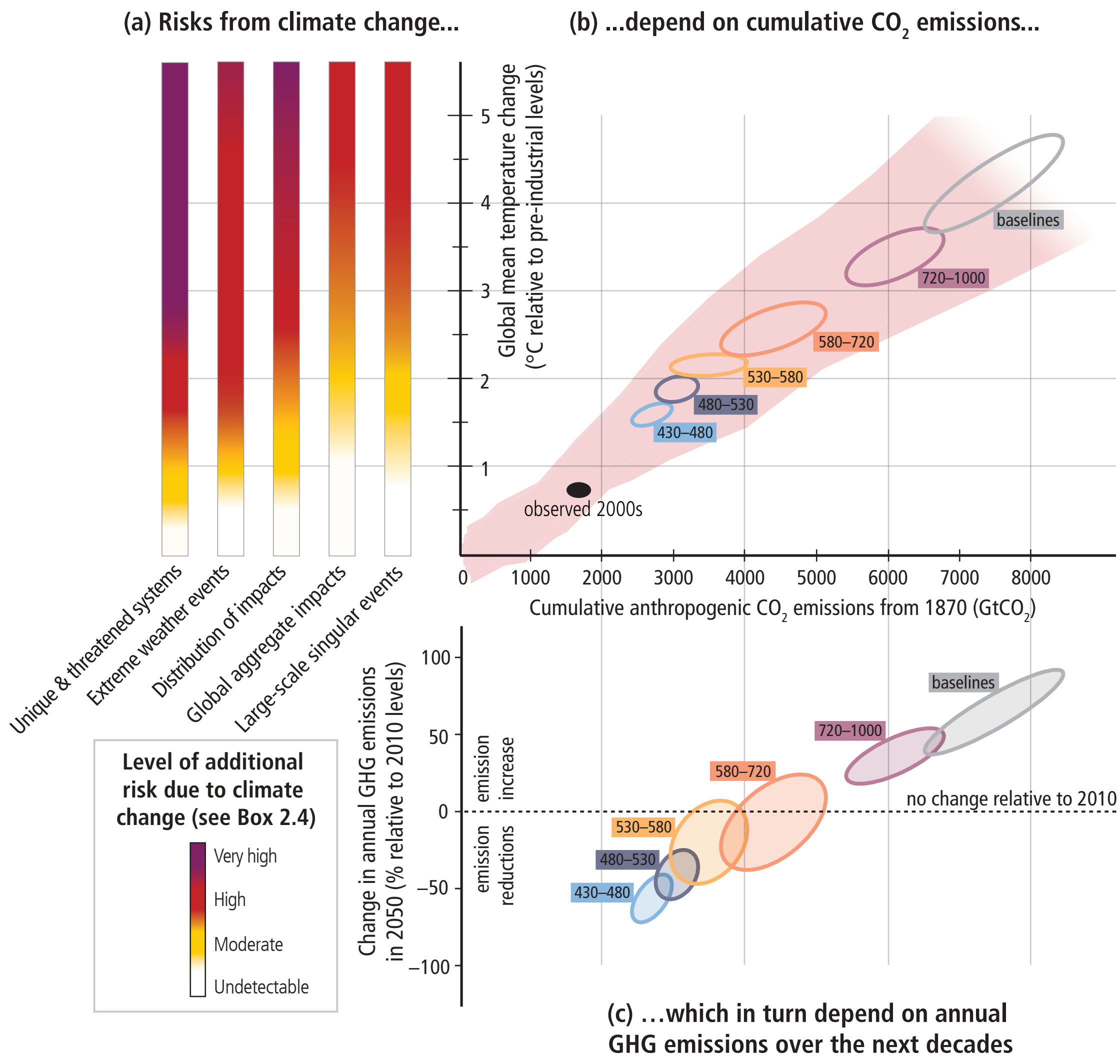

Figure SPM.10 | The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO_2) emissions and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across Reasons For Concern **(a)** would imply a limit for cumulative emissions of CO_2 **(b)** which would constrain annual GHG emissions over the next few decades **(c)**. **Panel a** reproduces the five Reasons For Concern *{Box 2.4}*. **Panel b** links temperature changes to cumulative CO_2 emissions (in $GtCO_2$) from 1870. They are based on Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations (pink plume) and on a simple climate model (median climate response in 2100), for the baselines and five mitigation scenario categories (six ellipses). Details are provided in Figure SPM.5. **Panel c** shows the relationship between the cumulative CO_2 emissions (in $GtCO_2$) of the scenario categories and their associated change in annual GHG emissions by 2050, expressed in percentage change (in percent $GtCO_2$-eq per year) relative to 2010. The ellipses correspond to the same scenario categories as in Panel b, and are built with a similar method (see details in Figure SPM.5). *{Figure 3.1}*

>1000 ppm CO_2-eq), warming is *more likely than not* to exceed 4°C above pre-industrial levels by 2100 (Table SPM.1). The risks associated with temperatures at or above 4°C include substantial species extinction, global and regional food insecurity, consequential constraints on common human activities and limited potential for adaptation in some cases (*high confidence*). Some risks of climate change, such as risks to unique and threatened systems and risks associated with extreme weather events, are moderate to high at temperatures 1°C to 2°C above pre-industrial levels. *{2.3, Figure 2.5, 3.2, 3.4, Box 2.4, Table SPM.1}*

Substantial cuts in GHG emissions over the next few decades can substantially reduce risks of climate change by limiting warming in the second half of the 21st century and beyond. Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond. Limiting risks across RFCs would imply a limit for cumulative emissions of CO_2. Such a limit would require that global net emissions of CO_2 eventually decrease to zero and would constrain annual emissions over the next few decades (Figure SPM.10) (*high confidence*). But some risks from climate damages are unavoidable, even with mitigation and adaptation. *{2.2.5, 3.2, 3.4}*

Mitigation involves some level of co-benefits and risks, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change. Inertia in the economic and climate system and the possibility of irreversible impacts from climate change increase the benefits from near-term mitigation efforts (*high confidence*). Delays in additional mitigation or constraints on technological options increase the longer-term mitigation costs to hold climate change risks at a given level (Table SPM.2). *{3.2, 3.4}*

SPM 3.3 Characteristics of adaptation pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness. *{3.3}*

Adaptation can contribute to the well-being of populations, the security of assets and the maintenance of ecosystem goods, functions and services now and in the future. Adaptation is place- and context-specific (*high confidence*). A first step towards adaptation to future climate change is reducing vulnerability and exposure to present climate variability (*high confidence*). Integration of adaptation into planning, including policy design, and decision-making can promote synergies with development and disaster risk reduction. Building adaptive capacity is crucial for effective selection and implementation of adaptation options (*robust evidence, high agreement*). *{3.3}*

Adaptation planning and implementation can be enhanced through complementary actions across levels, from individuals to governments (*high confidence*). National governments can coordinate adaptation efforts of local and sub-national governments, for example by protecting vulnerable groups, by supporting economic diversification and by providing information, policy and legal frameworks and financial support (*robust evidence*, *high agreement*). Local government and the private sector are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence*, *high agreement*). *{3.3}*

Adaptation planning and implementation at all levels of governance are contingent on societal values, objectives and risk perceptions (*high confidence*). Recognition of diverse interests, circumstances, social-cultural contexts and expectations can benefit decision-making processes. Indigenous, local and traditional knowledge systems and practices, including indigenous peoples' holistic view of community and environment, are a major resource for adapting to climate change, but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge with existing practices increases the effectiveness of adaptation. *{3.3}*

Constraints can interact to impede adaptation planning and implementation (*high confidence*). Common constraints on implementation arise from the following: limited financial and human resources; limited integration or coordination of governance; uncertainties about projected impacts; different perceptions of risks; competing values; absence of key adaptation leaders and advocates; and limited tools to monitor adaptation effectiveness. Another constraint includes insufficient research, monitoring, and observation and the finance to maintain them. *{3.3}*

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Greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*). Limits to adaptation emerge from the interaction among climate change and biophysical and/or socio-economic constraints. Further, poor planning or implementation, overemphasizing short-term outcomes or failing to sufficiently anticipate consequences can result in maladaptation, increasing the vulnerability or exposure of the target group in the future or the vulnerability of other people, places or sectors (*medium evidence, high agreement*). Underestimating the complexity of adaptation as a social process can create unrealistic expectations about achieving intended adaptation outcomes. *{3.3}*

Significant co-benefits, synergies and trade-offs exist between mitigation and adaptation and among different adaptation responses; interactions occur both within and across regions (*very high confidence*). Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, particularly at the intersections among water, energy, land use and biodiversity, but tools to understand and manage these interactions remain limited. Examples of actions with co-benefits include (i) improved energy efficiency and cleaner energy sources, leading to reduced emissions of health-damaging, climate-altering air pollutants; (ii) reduced energy and water consumption in urban areas through greening cities and recycling water; (iii) sustainable agriculture and forestry; and (iv) protection of ecosystems for carbon storage and other ecosystem services. *{3.3}*

Transformations in economic, social, technological and political decisions and actions can enhance adaptation and promote sustainable development (*high confidence*). At the national level, transformation is considered most effective when it reflects a country's own visions and approaches to achieving sustainable development in accordance with its national circumstances and priorities. Restricting adaptation responses to incremental changes to existing systems and structures, without considering transformational change, may increase costs and losses and miss opportunities. Planning and implementation of transformational adaptation could reflect strengthened, altered or aligned paradigms and may place new and increased demands on governance structures to reconcile different goals and visions for the future and to address possible equity and ethical implications. Adaptation pathways are enhanced by iterative learning, deliberative processes and innovation. *{3.3}*

SPM 3.4 Characteristics of mitigation pathways

There are multiple mitigation pathways that are *likely* to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO_2 and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales. *{3.4}*

Without additional efforts to reduce GHG emissions beyond those in place today, global emissions growth is expected to persist, driven by growth in global population and economic activities. Global mean surface temperature increases in 2100 in baseline scenarios—those without additional mitigation—range from 3.7°C to 4.8°C above the average for 1850–1900 for a median climate response. They range from 2.5°C to 7.8°C when including climate uncertainty (5th to 95th percentile range) (*high confidence*). *{3.4}*

Emissions scenarios leading to CO_2-equivalent concentrations in 2100 of about 450 ppm or lower are *likely* to maintain warming below 2°C over the 21st century relative to pre-industrial levels[15]. These scenarios are characterized by 40 to 70% global anthropogenic GHG emissions reductions by 2050 compared to 2010[16], and emissions levels near zero or below in 2100. Mitigation scenarios reaching concentration levels of about 500 ppm CO_2-eq by 2100 are *more likely than not* to limit temperature change to less than 2°C, unless they temporarily overshoot concentration levels of roughly 530 ppm CO_2-eq

[15] For comparison, the CO_2-eq concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm)

[16] This range differs from the range provided for a similar concentration category in the AR4 (50 to 85% lower than 2000 for CO_2 only). Reasons for this difference include that this report has assessed a substantially larger number of scenarios than in the AR4 and looks at all GHGs. In addition, a large proportion of the new scenarios include Carbon Dioxide Removal (CDR) technologies (see below). Other factors include the use of 2100 concentration levels instead of stabilization levels and the shift in reference year from 2000 to 2010.

before 2100, in which case they are *about as likely as not* to achieve that goal. In these 500 ppm CO_2-eq scenarios, global 2050 emissions levels are 25 to 55% lower than in 2010. Scenarios with higher emissions in 2050 are characterized by a greater reliance on Carbon Dioxide Removal (CDR) technologies beyond mid-century (and vice versa). Trajectories that are *likely* to limit warming to 3°C relative to pre-industrial levels reduce emissions less rapidly than those limiting warming to 2°C. A limited number of studies provide scenarios that are *more likely than not* to limit warming to 1.5°C by 2100; these scenarios are characterized by concentrations below 430 ppm CO_2-eq by 2100 and 2050 emission reduction between 70% and 95% below 2010. For a comprehensive overview of the characteristics of emissions scenarios, their CO_2-equivalent concentrations and their likelihood to keep warming to below a range of temperature levels, see Figure SPM.11 and Table SPM.1. *{3.4}*

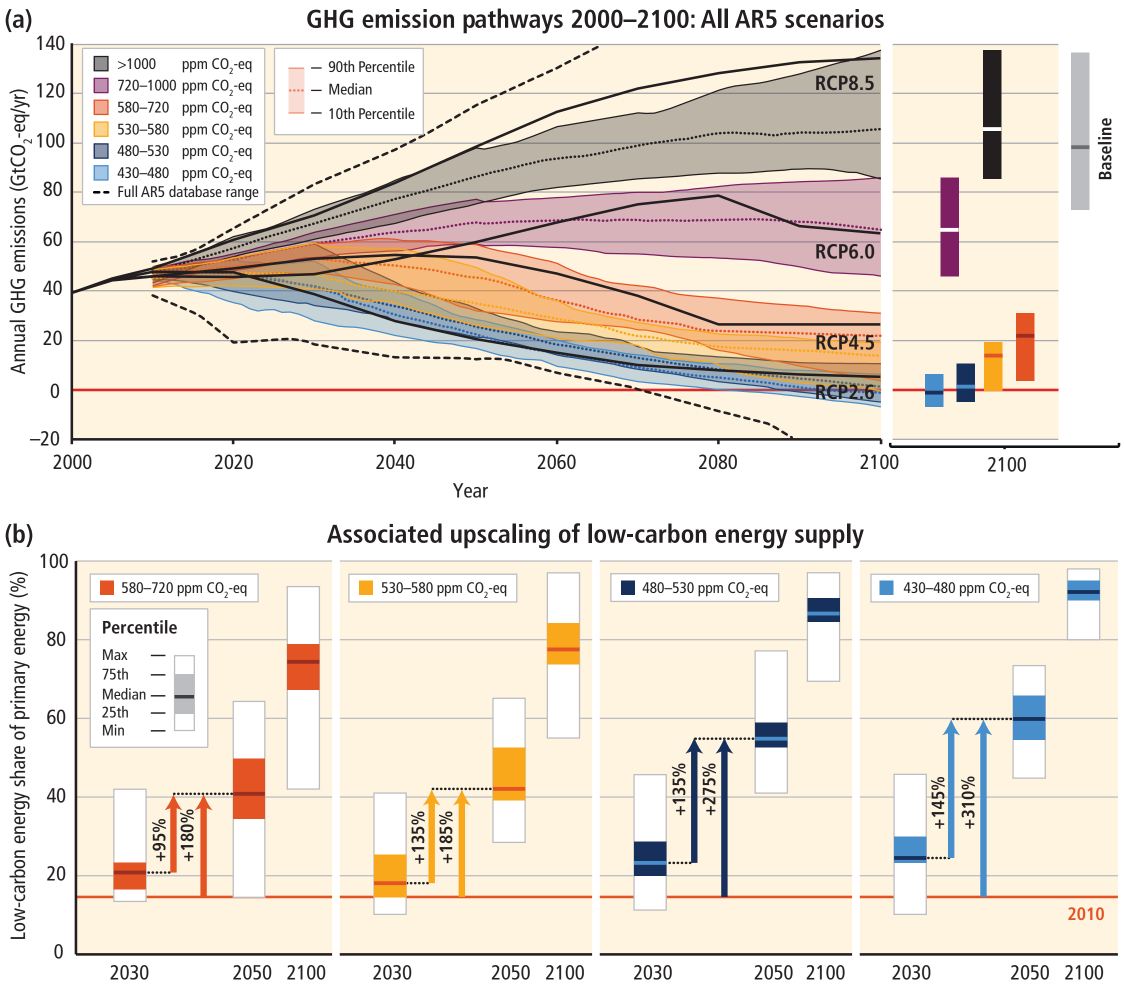

Figure SPM.11 | Global greenhouse gas emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) in baseline and mitigation scenarios for different long-term concentration levels **(a)** and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared to 2010 levels in mitigation scenarios **(b)**. *{Figure 3.2}*

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Table SPM.1 | Key characteristics of the scenarios collected and assessed for WGIII AR5. For all parameters the 10th to 90th percentile of the scenarios is shown [a]. *{Table 3.1}*

<table>
<tr><th rowspan="2">CO_2-eq Concentrations in 2100 (ppm CO_2-eq) [f]

Category label (conc. range)</th><th rowspan="2">Subcategories</th><th rowspan="2">Relative position of the RCPs [d]</th><th colspan="2">Change in CO_2-eq emissions compared to 2010 (in %) [c]</th><th colspan="4">Likelihood of staying below a specific temperature level over the 21st century (relative to 1850–1900) [d, e]</th></tr>
<tr><th>2050</th><th>2100</th><th>1.5°C</th><th>2°C</th><th>3°C</th><th>4°C</th></tr>
<tr><td><430</td><td colspan="8">Only a limited number of individual model studies have explored levels below 430 ppm CO_2-eq [j]</td></tr>
<tr><td>450
(430 to 480)</td><td>Total range [a, g]</td><td>RCP2.6</td><td>−72 to −41</td><td>−118 to −78</td><td>More unlikely than likely</td><td>Likely</td><td rowspan="6">Likely</td><td rowspan="8">Likely</td></tr>
<tr><td rowspan="2">500
(480 to 530)</td><td>No overshoot of 530 ppm CO_2-eq</td><td></td><td>−57 to −42</td><td>−107 to −73</td><td rowspan="6">Unlikely</td><td>More likely than not</td></tr>
<tr><td>Overshoot of 530 ppm CO_2-eq</td><td></td><td>−55 to −25</td><td>−114 to −90</td><td>About as likely as not</td></tr>
<tr><td rowspan="2">550
(530 to 580)</td><td>No overshoot of 580 ppm CO_2-eq</td><td></td><td>−47 to −19</td><td>−81 to −59</td><td rowspan="3">More unlikely than likely [i]</td></tr>
<tr><td>Overshoot of 580 ppm CO_2-eq</td><td></td><td>−16 to 7</td><td>−183 to −86</td></tr>
<tr><td>(580 to 650)</td><td>Total range</td><td rowspan="2">RCP4.5</td><td>−38 to 24</td><td>−134 to −50</td></tr>
<tr><td>(650 to 720)</td><td>Total range</td><td>−11 to 17</td><td>−54 to −21</td><td rowspan="2">Unlikely</td><td>More likely than not</td></tr>
<tr><td>(720 to 1000) [b]</td><td>Total range</td><td>RCP6.0</td><td>18 to 54</td><td>−7 to 72</td><td rowspan="2">Unlikely [h]</td><td>More unlikely than likely</td></tr>
<tr><td>>1000 [b]</td><td>Total range</td><td>RCP8.5</td><td>52 to 95</td><td>74 to 178</td><td>Unlikely [h]</td><td>Unlikely</td><td>More unlikely than likely</td></tr>
</table>

Notes:

[a] The 'total range' for the 430 to 480 ppm CO_2-eq concentrations scenarios corresponds to the range of the 10th to 90th percentile of the subcategory of these scenarios shown in Table 6.3 of the Working Group III Report.

[b] Baseline scenarios fall into the >1000 and 720 to 1000 ppm CO_2-eq categories. The latter category also includes mitigation scenarios. The baseline scenarios in the latter category reach a temperature change of 2.5°C to 5.8°C above the average for 1850–1900 in 2100. Together with the baseline scenarios in the >1000 ppm CO_2-eq category, this leads to an overall 2100 temperature range of 2.5°C to 7.8°C (range based on median climate response: 3.7°C to 4.8°C) for baseline scenarios across both concentration categories.

[c] The global 2010 emissions are 31% above the 1990 emissions (consistent with the historic greenhouse gas emission estimates presented in this report). CO_2-eq emissions include the basket of Kyoto gases (carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) as well as fluorinated gases).

[d] The assessment here involves a large number of scenarios published in the scientific literature and is thus not limited to the Representative Concentration Pathways (RCPs). To evaluate the CO_2-eq concentration and climate implications of these scenarios, the Model for the Assessment of Greenhouse Gas Induced Climate Change (MAGICC) was used in a probabilistic mode. For a comparison between MAGICC model results and the outcomes of the models used in WGI, see WGI 12.4.1.2, 12.4.8 and WGIII 6.3.2.6.

[e] The assessment in this table is based on the probabilities calculated for the full ensemble of scenarios in WGIII AR5 using MAGICC and the assessment in WGI of the uncertainty of the temperature projections not covered by climate models. The statements are therefore consistent with the statements in WGI, which are based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) runs of the RCPs and the assessed uncertainties. Hence, the likelihood statements reflect different lines of evidence from both WGs. This WGI method was also applied for scenarios with intermediate concentration levels where no CMIP5 runs are available. The likelihood statements are indicative only *{WGIII 6.3}* and follow broadly the terms used by the WGI SPM for temperature projections: likely 66–100%, more likely than not >50–100%, about as likely as not 33–66%, and unlikely 0–33%. In addition the term more unlikely than likely 0–<50% is used.

[f] The CO_2-equivalent concentration (see Glossary) is calculated on the basis of the total forcing from a simple carbon cycle/climate model, MAGICC. The CO_2-equivalent concentration in 2011 is estimated to be 430 ppm (uncertainty range 340 to 520 ppm). This is based on the assessment of total anthropogenic radiative forcing for 2011 relative to 1750 in WGI, i.e., 2.3 W/m^2, uncertainty range 1.1 to 3.3 W/m^2.

[g] The vast majority of scenarios in this category overshoot the category boundary of 480 ppm CO_2-eq concentration.

[h] For scenarios in this category, no CMIP5 run or MAGICC realization stays below the respective temperature level. Still, an *unlikely* assignment is given to reflect uncertainties that may not be reflected by the current climate models.

[i] Scenarios in the 580 to 650 ppm CO_2-eq category include both overshoot scenarios and scenarios that do not exceed the concentration level at the high end of the category (e.g., RCP4.5). The latter type of scenarios, in general, have an assessed probability of *more unlikely than likely* to stay below the 2°C temperature level, while the former are mostly assessed to have an *unlikely* probability of staying below this level.

[j] In these scenarios, global CO_2-eq emissions in 2050 are between 70 to 95% below 2010 emissions, and they are between 110 to 120% below 2010 emissions in 2100.

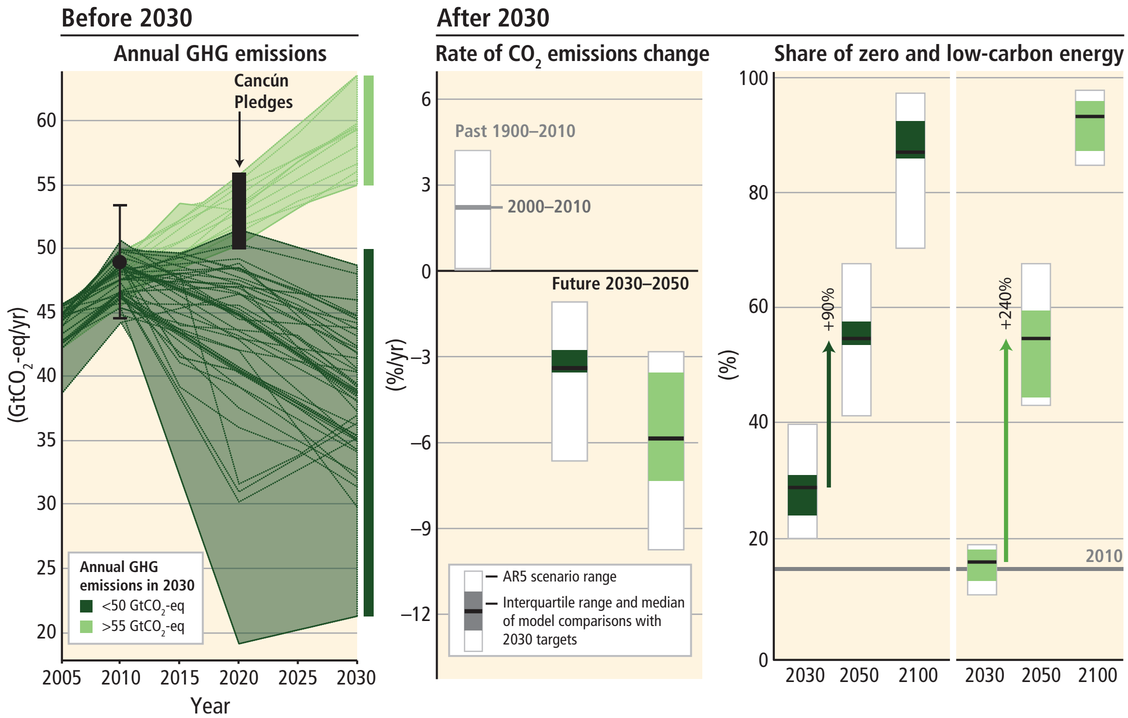

Figure SPM.12 | The implications of different 2030 greenhouse gas (GHG) emissions levels for the rate of carbon dioxide (CO_2) emissions reductions and low-carbon energy upscaling in mitigation scenarios that are at least *about as likely as not* to keep warming throughout the 21st century below 2°C relative to pre-industrial levels (2100 CO_2-equivalent concentrations of 430 to 530 ppm). The scenarios are grouped according to different emissions levels by 2030 (coloured in different shades of green). The left panel shows the pathways of GHG emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) leading to these 2030 levels. The black dot with whiskers gives historic GHG emission levels and associated uncertainties in 2010 as reported in Figure SPM.2. The black bar shows the estimated uncertainty range of GHG emissions implied by the Cancún Pledges. The middle panel denotes the average annual CO_2 emissions reduction rates for the period 2030–2050. It compares the median and interquartile range across scenarios from recent inter-model comparisons with explicit 2030 interim goals to the range of scenarios in the Scenario Database for WGIII AR5. Annual rates of historical emissions change (sustained over a period of 20 years) and the average annual CO_2 emission change between 2000 and 2010 are shown as well. The arrows in the right panel show the magnitude of zero and low-carbon energy supply upscaling from 2030 to 2050 subject to different 2030 GHG emissions levels. Zero- and low-carbon energy supply includes renewables, nuclear energy and fossil energy with carbon dioxide capture and storage (CCS) or bioenergy with CCS (BECCS). [Note: Only scenarios that apply the full, unconstrained mitigation technology portfolio of the underlying models (default technology assumption) are shown. Scenarios with large net negative global emissions (>20 $GtCO_2$-eq/yr), scenarios with exogenous carbon price assumptions and scenarios with 2010 emissions significantly outside the historical range are excluded.] *{Figure 3.3}*

Mitigation scenarios reaching about 450 ppm CO_2-eq in 2100 (consistent with a *likely* chance to keep warming below 2°C relative to pre-industrial levels) typically involve temporary overshoot[17] of atmospheric concentrations, as do many scenarios reaching about 500 ppm CO_2-eq to about 550 ppm CO_2-eq in 2100 (Table SPM.1). Depending on the level of overshoot, overshoot scenarios typically rely on the availability and widespread deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century. The availability and scale of these and other CDR technologies and methods are uncertain and CDR technologies are, to varying degrees, associated with challenges and risks[18]. CDR is also prevalent in many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive (*high confidence*). *{3.4, Box 3.3}*

Reducing emissions of non-CO_2 agents can be an important element of mitigation strategies. All current GHG emissions and other forcing agents affect the rate and magnitude of climate change over the next few decades, although long-term warming is mainly driven by CO_2 emissions. Emissions of non-CO_2 forcers are often expressed as 'CO_2-equivalent emissions', but the choice of metric to calculate these emissions, and the implications for the emphasis and timing of abatement of the various climate forcers, depends on application and policy context and contains value judgments. *{3.4, Box 3.2}*

[17] In concentration 'overshoot' scenarios, concentrations peak during the century and then decline.

[18] CDR methods have biogeochemical and technological limitations to their potential on the global scale. There is insufficient knowledge to quantify how much CO_2 emissions could be partially offset by CDR on a century timescale. CDR methods may carry side effects and long-term consequences on a global scale.

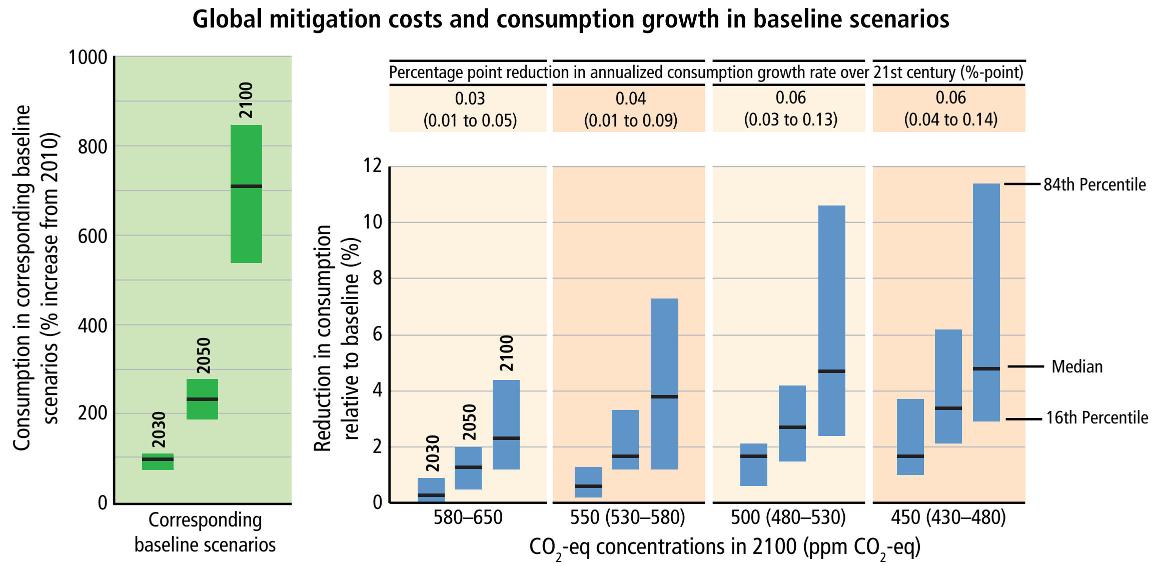

Figure SPM.13 | Global mitigation costs in cost-effective scenarios at different atmospheric concentrations levels in 2100. Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions. Consumption losses are shown relative to a baseline development without climate policy (left panel). The table at the top shows percentage points of annualized consumption growth reductions relative to consumption growth in the baseline of 1.6 to 3% per year (e.g., if the reduction is 0.06 percentage points per year due to mitigation, and baseline growth is 2.0% per year, then the growth rate with mitigation would be 1.94% per year). Cost estimates shown in this table do not consider the benefits of reduced climate change or co-benefits and adverse side effects of mitigation. Estimates at the high end of these cost ranges are from models that are relatively inflexible to achieve the deep emissions reductions required in the long run to meet these goals and/or include assumptions about market imperfections that would raise costs. *{Figure 3.4}*

Delaying additional mitigation to 2030 will substantially increase the challenges associated with limiting warming over the 21st century to below 2°C relative to pre-industrial levels. It will require substantially higher rates of emissions reductions from 2030 to 2050; a much more rapid scale-up of low-carbon energy over this period; a larger reliance on CDR in the long term; and higher transitional and long-term economic impacts. Estimated global emissions levels in 2020 based on the Cancún Pledges are not consistent with cost-effective mitigation trajectories that are at least *about as likely as not* to limit warming to below 2°C relative to pre-industrial levels, but they do not preclude the option to meet this goal (*high confidence*) (Figure SPM.12, Table SPM.2). *{3.4}*

Estimates of the aggregate economic costs of mitigation vary widely depending on methodologies and assumptions, but increase with the stringency of mitigation. Scenarios in which all countries of the world begin mitigation immediately, in which there is a single global carbon price, and in which all key technologies are available have been used as a cost-effective benchmark for estimating macro-economic mitigation costs (Figure SPM.13). Under these assumptions mitigation scenarios that are *likely* to limit warming to below 2°C through the 21st century relative to pre-industrial levels entail losses in global consumption—not including benefits of reduced climate change as well as co-benefits and adverse side effects of mitigation—of 1 to 4% (median: 1.7%) in 2030, 2 to 6% (median: 3.4%) in 2050 and 3 to 11% (median: 4.8%) in 2100 relative to consumption in baseline scenarios that grows anywhere from 300% to more than 900% over the century (Figure SPM.13). These numbers correspond to an annualized reduction of consumption growth by 0.04 to 0.14 (median: 0.06) percentage points over the century relative to annualized consumption growth in the baseline that is between 1.6 and 3% per year (*high confidence*). *{3.4}*

In the absence or under limited availability of mitigation technologies (such as bioenergy, CCS and their combination BECCS, nuclear, wind/solar), mitigation costs can increase substantially depending on the technology considered. Delaying additional mitigation increases mitigation costs in the medium to long term. Many models could not limit *likely* warming to below 2°C over the 21st century relative to pre-industrial levels if additional mitigation is considerably delayed. Many models could not limit *likely* warming to below 2°C if bioenergy, CCS and their combination (BECCS) are limited (*high confidence*) (Table SPM.2). *{3.4}*

Table SPM.2 | Increase in global mitigation costs due to either limited availability of specific technologies or delays in additional mitigation [a] relative to cost-effective scenarios [b]. The increase in costs is given for the median estimate and the 16th to 84th percentile range of the scenarios (in parentheses) [c]. In addition, the sample size of each scenario set is provided in the coloured symbols. The colours of the symbols indicate the fraction of models from systematic model comparison exercises that could successfully reach the targeted concentration level. *{Table 3.2}*

Mitigation cost increases in scenarios with limited availability of technologies [d] *[% increase in total discounted* [e] *mitigation costs (2015–2100) relative to default technology assumptions]*					**Mitigation cost increases due to delayed additional mitigation until 2030** *[% increase in mitigation costs relative to immediate mitigation]*	
2100 concentrations (ppm CO_2-eq)	no CCS	nuclear phase out	limited solar/wind	limited bioenergy	medium term costs (2030–2050)	long term costs (2050–2100)
450 (430 to 480)	138% (29 to 297%) [4]	7% (4 to 18%) [8]	6% (2 to 29%) [8]	64% (44 to 78%) [8]	} 44% (2 to 78%) [29]	37% (16 to 82%) [29]
500 (480 to 530)	not available (n.a.)	n.a.	n.a.	n.a.		
550 (530 to 580)	39% (18 to 78%) [11]	13% (2 to 23%) [10]	8% (5 to 15%) [10]	18% (4 to 66%) [12]	} 15% (3 to 32%)	16% (5 to 24%)
580 to 650	n.a.	n.a.	n.a.	n.a.		

Symbol legend—fraction of models successful in producing scenarios (numbers indicate the number of successful models)

green: all models successful	orange: between 50 and 80% of models successful
tan: between 80 and 100% of models successful	red: less than 50% of models successful

Notes:

[a] Delayed mitigation scenarios are associated with greenhouse gas emission of more than 55 $GtCO_2$-eq in 2030, and the increase in mitigation costs is measured relative to cost-effective mitigation scenarios for the same long-term concentration level.

[b] Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' default technology assumptions.

[c] The range is determined by the central scenarios encompassing the 16th to 84th percentile range of the scenario set. Only scenarios with a time horizon until 2100 are included. Some models that are included in the cost ranges for concentration levels above 530 ppm CO_2-eq in 2100 could not produce associated scenarios for concentration levels below 530 ppm CO_2-eq in 2100 with assumptions about limited availability of technologies and/or delayed additional mitigation.

[d] No CCS: carbon dioxide capture and storage is not included in these scenarios. Nuclear phase out: no addition of nuclear power plants beyond those under construction, and operation of existing plants until the end of their lifetime. Limited Solar/Wind: a maximum of 20% global electricity generation from solar and wind power in any year of these scenarios. Limited Bioenergy: a maximum of 100 EJ/yr modern bioenergy supply globally (modern bioenergy used for heat, power, combinations and industry was around 18 EJ/yr in 2008). EJ = Exajoule = 10^{18} Joule.

[e] Percentage increase of net present value of consumption losses in percent of baseline consumption (for scenarios from general equilibrium models) and abatement costs in percent of baseline gross domestic product (GDP, for scenarios from partial equilibrium models) for the period 2015–2100, discounted at 5% per year.

Mitigation scenarios reaching about 450 or 500 ppm CO_2-eq by 2100 show reduced costs for achieving air quality and energy security objectives, with significant co-benefits for human health, ecosystem impacts and sufficiency of resources and resilience of the energy system. *{4.4.2.2}*

Mitigation policy could devalue fossil fuel assets and reduce revenues for fossil fuel exporters, but differences between regions and fuels exist (*high confidence*). Most mitigation scenarios are associated with reduced revenues from coal and oil trade for major exporters (*high confidence*). The availability of CCS would reduce the adverse effects of mitigation on the value of fossil fuel assets (*medium confidence*). *{4.4.2.2}*

Solar Radiation Management (SRM) involves large-scale methods that seek to reduce the amount of absorbed solar energy in the climate system. SRM is untested and is not included in any of the mitigation scenarios. If it were deployed, SRM would entail numerous uncertainties, side effects, risks and shortcomings and has particular governance and ethical implications. SRM would not reduce ocean acidification. If it were terminated, there is *high confidence* that surface temperatures would rise very rapidly impacting ecosystems susceptible to rapid rates of change. *{Box 3.3}*

SPM 4. Adaptation and Mitigation

Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives. *{4}*

SPM 4.1 Common enabling factors and constraints for adaptation and mitigation responses

Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioural and lifestyle choices. *{4.1}*

Inertia in many aspects of the socio-economic system constrains adaptation and mitigation options (*medium evidence, high agreement*). Innovation and investments in environmentally sound infrastructure and technologies can reduce GHG emissions and enhance resilience to climate change (*very high confidence*). *{4.1}*

Vulnerability to climate change, GHG emissions and the capacity for adaptation and mitigation are strongly influenced by livelihoods, lifestyles, behaviour and culture (*medium evidence, medium agreement*). Also, the social acceptability and/or effectiveness of climate policies are influenced by the extent to which they incentivize or depend on regionally appropriate changes in lifestyles or behaviours. *{4.1}*

For many regions and sectors, enhanced capacities to mitigate and adapt are part of the foundation essential for managing climate change risks (*high confidence*). Improving institutions as well as coordination and cooperation in governance can help overcome regional constraints associated with mitigation, adaptation and disaster risk reduction (*very high confidence*). *{4.1}*

SPM 4.2 Response options for adaptation

Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Some adaptation responses involve significant co-benefits, synergies and trade-offs. Increasing climate change will increase challenges for many adaptation options. *{4.2}*

Adaptation experience is accumulating across regions in the public and private sectors and within communities. There is increasing recognition of the value of social (including local and indigenous), institutional, and ecosystem-based measures and of the extent of constraints to adaptation. Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). *{1.6, 4.2, 4.4.2.1}*

The need for adaptation along with associated challenges is expected to increase with climate change (*very high confidence*). Adaptation options exist in all sectors and regions, with diverse potential and approaches depending on their context in vulnerability reduction, disaster risk management or proactive adaptation planning (Table SPM.3). Effective strategies and actions consider the potential for co-benefits and opportunities within wider strategic goals and development plans. *{4.2}*

Table SPM.3 | Approaches for managing the risks of climate change through adaptation. These approaches should be considered overlapping rather than discrete, and they are often pursued simultaneously. Examples are presented in no specific order and can be relevant to more than one category. *{Table 4.2}*

Overlapping Approaches	Category	Examples
Vulnerability & Exposure Reduction through development, planning & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
	Livelihood security	Income, asset & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
Adaptation including incremental & transformational adjustments	Structural/physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
		Technological options: New crop & animal varieties; Indigenous, traditional & local knowledge, technologies & methods; Efficient irrigation; Water-saving technologies; Desalinisation; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer & diffusion.
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks & other *ex situ* conservation; Community-based natural resource management.
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
	Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
	Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
		Behavioural options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
Transformation	Spheres of change	***Practical***: Social & technical innovations, behavioural shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
		Political: Political, social, cultural & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values & worldviews influencing climate-change responses.

SPM 4.3 Response options for mitigation

Mitigation options are available in every major sector. Mitigation can be more cost-effective if using an integrated approach that combines measures to reduce energy use and the greenhouse gas intensity of end-use sectors, decarbonize energy supply, reduce net emissions and enhance carbon sinks in land-based sectors. *{4.3}*

Well-designed systemic and cross-sectoral mitigation strategies are more cost-effective in cutting emissions than a focus on individual technologies and sectors, with efforts in one sector affecting the need for mitigation in others (*medium confidence*). Mitigation measures intersect with other societal goals, creating the possibility of co-benefits or adverse side effects. These intersections, if well-managed, can strengthen the basis for undertaking climate action. *{4.3}*

Emissions ranges for baseline scenarios and mitigation scenarios that limit CO_2-equivalent concentrations to low levels (about 450 ppm CO_2-eq, *likely* to limit warming to 2°C above pre-industrial levels) are shown for different sectors and gases in Figure SPM.14. Key measures to achieve such mitigation goals include decarbonizing (i.e., reducing the carbon intensity of) electricity generation (*medium evidence, high agreement*) as well as efficiency enhancements and behavioural changes, in order to reduce energy demand compared to baseline scenarios without compromising development (*robust evidence, high agreement*). In scenarios reaching 450 ppm CO_2-eq concentrations by 2100, global CO_2 emissions from the energy supply sector are projected to decline over the next decade and are characterized by reductions of 90% or more below 2010 levels between 2040 and 2070. In the majority of low-concentration stabilization scenarios (about 450 to about 500 ppm CO_2-eq, at least *about as likely as not* to limit warming to 2°C above pre-industrial levels), the share of low-carbon electricity supply (comprising renewable energy (RE), nuclear and carbon dioxide capture and storage (CCS) including bioenergy with carbon dioxide capture and storage (BECCS)) increases from the current share of approximately 30% to more than 80% by 2050, and fossil fuel power generation without CCS is phased out almost entirely by 2100. *{4.3}*

Direct CO_2 emissions by major sectors, and non-CO_2 emissions, for baseline and mitigation scenarios

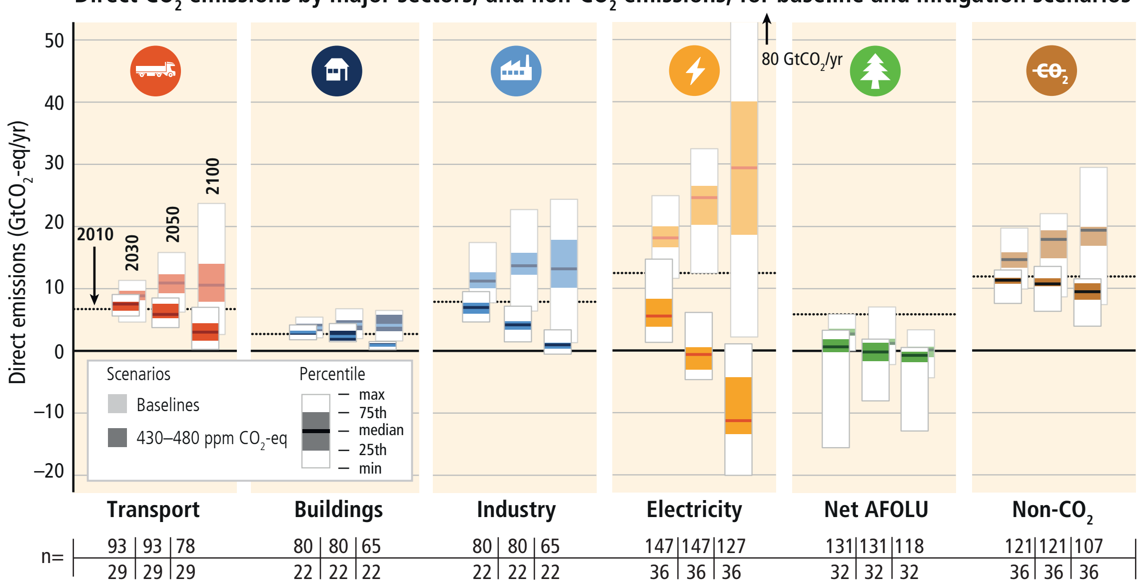

Figure SPM.14 | Carbon dioxide (CO_2) emissions by sector and total non-CO_2 greenhouse gases (Kyoto gases) across sectors in baseline (faded bars) and mitigation scenarios (solid colour bars) that reach about 450 (430 to 480) ppm CO_2-eq concentrations in 2100 (*likely* to limit warming to 2°C above pre-industrial levels). Mitigation in the end-use sectors leads also to indirect emissions reductions in the upstream energy supply sector. Direct emissions of the end-use sectors thus do not include the emission reduction potential at the supply-side due to, for example, reduced electricity demand. The numbers at the bottom of the graphs refer to the number of scenarios included in the range (upper row: baseline scenarios; lower row: mitigation scenarios), which differs across sectors and time due to different sectoral resolution and time horizon of models. Emissions ranges for mitigation scenarios include the full portfolio of mitigation options; many models cannot reach 450 ppm CO_2-eq concentration by 2100 in the absence of carbon dioxide capture and storage (CCS). Negative emissions in the electricity sector are due to the application of bioenergy with carbon dioxide capture and storage (BECCS). 'Net' agriculture, forestry and other land use (AFOLU) emissions consider afforestation, reforestation as well as deforestation activities. *{4.3, Figure 4.1}*

Near-term reductions in energy demand are an important element of cost-effective mitigation strategies, provide more flexibility for reducing carbon intensity in the energy supply sector, hedge against related supply-side risks, avoid lock-in to carbon-intensive infrastructures, and are associated with important co-benefits. The most cost-effective mitigation options in forestry are afforestation, sustainable forest management and reducing deforestation, with large differences in their relative importance across regions; and in agriculture, cropland management, grazing land management and restoration of organic soils (*medium evidence, high agreement*). *{4.3, Figures 4.1, 4.2, Table 4.3}*

Behaviour, lifestyle and culture have a considerable influence on energy use and associated emissions, with high mitigation potential in some sectors, in particular when complementing technological and structural change (*medium evidence, medium agreement*). Emissions can be substantially lowered through changes in consumption patterns, adoption of energy savings measures, dietary change and reduction in food wastes. *{4.1, 4.3}*

SPM 4.4 Policy approaches for adaptation and mitigation, technology and finance

Effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation. *{4.4}*

International cooperation is critical for effective mitigation, even though mitigation can also have local co-benefits. Adaptation focuses primarily on local to national scale outcomes, but its effectiveness can be enhanced through coordination across governance scales, including international cooperation: *{3.1, 4.4.1}*

- The United Nations Framework Convention on Climate Change (UNFCCC) is the main multilateral forum focused on addressing climate change, with nearly universal participation. Other institutions organized at different levels of governance have resulted in diversifying international climate change cooperation. *{4.4.1}*

- The Kyoto Protocol offers lessons towards achieving the ultimate objective of the UNFCCC, particularly with respect to participation, implementation, flexibility mechanisms and environmental effectiveness (*medium evidence, low agreement*). *{4.4.1}*

- Policy linkages among regional, national and sub-national climate policies offer potential climate change mitigation benefits (*medium evidence, medium agreement*). Potential advantages include lower mitigation costs, decreased emission leakage and increased market liquidity. *{4.4.1}*

- International cooperation for supporting adaptation planning and implementation has received less attention historically than mitigation but is increasing and has assisted in the creation of adaptation strategies, plans and actions at the national, sub-national and local level (*high confidence*). *{4.4.1}*

There has been a considerable increase in national and sub-national plans and strategies on both adaptation and mitigation since the AR4, with an increased focus on policies designed to integrate multiple objectives, increase co-benefits and reduce adverse side effects (*high confidence*): *{4.4.2.1, 4.4.2.2}*

- National governments play key roles in adaptation planning and implementation (*robust evidence, high agreement*) through coordinating actions and providing frameworks and support. While local government and the private sector have different functions, which vary regionally, they are increasingly recognized as critical to progress in adaptation, given their roles in scaling up adaptation of communities, households and civil society and in managing risk information and financing (*medium evidence, high agreement*). *{4.4.2.1}*

- Institutional dimensions of adaptation governance, including the integration of adaptation into planning and decision-making, play a key role in promoting the transition from planning to implementation of adaptation (*robust evidence,* *high agreement*). Examples of institutional approaches to adaptation involving multiple actors include economic options (e.g., insurance, public-private partnerships), laws and regulations (e.g., land-zoning laws) and national and government policies and programmes (e.g., economic diversification). *{4.2, 4.4.2.1, Table SPM.3}*

- In principle, mechanisms that set a carbon price, including cap and trade systems and carbon taxes, can achieve mitigation in a cost-effective way but have been implemented with diverse effects due in part to national circumstances as well as policy design. The short-run effects of cap and trade systems have been limited as a result of loose caps or caps that have not proved to be constraining (*limited evidence, medium agreement*). In some countries, tax-based policies specifically aimed at reducing GHG emissions—alongside technology and other policies—have helped to weaken the link between GHG emissions and GDP (*high confidence*). In addition, in a large group of countries, fuel taxes (although not necessarily designed for the purpose of mitigation) have had effects that are akin to sectoral carbon taxes. *{4.4.2.2}*

- Regulatory approaches and information measures are widely used and are often environmentally effective (*medium evidence, medium agreement*). Examples of regulatory approaches include energy efficiency standards; examples of information programmes include labelling programmes that can help consumers make better-informed decisions. *{4.4.2.2}*

- Sector-specific mitigation policies have been more widely used than economy-wide policies (*medium evidence, high agreement*). Sector-specific policies may be better suited to address sector-specific barriers or market failures and may be bundled in packages of complementary policies. Although theoretically more cost-effective, administrative and political barriers may make economy-wide policies harder to implement. Interactions between or among mitigation policies may be synergistic or may have no additive effect on reducing emissions. *{4.4.2.2}*

- Economic instruments in the form of subsidies may be applied across sectors, and include a variety of policy designs, such as tax rebates or exemptions, grants, loans and credit lines. An increasing number and variety of renewable energy (RE) policies including subsidies—motivated by many factors—have driven escalated growth of RE technologies in recent years. At the same time, reducing subsidies for GHG-related activities in various sectors can achieve emission reductions, depending on the social and economic context (*high confidence*). *{4.4.2.2}*

Co-benefits and adverse side effects of mitigation could affect achievement of other objectives such as those related to human health, food security, biodiversity, local environmental quality, energy access, livelihoods and equitable sustainable development. The potential for co-benefits for energy end-use measures outweighs the potential for adverse side effects whereas the evidence suggests this may not be the case for all energy supply and agriculture, forestry and other land use (AFOLU) measures. Some mitigation policies raise the prices for some energy services and could hamper the ability of societies to expand access to modern energy services to underserved populations (*low confidence*). These potential adverse side effects on energy access can be avoided with the adoption of complementary policies such as income tax rebates or other benefit transfer mechanisms (*medium confidence*). Whether or not side effects materialize, and to what extent side effects materialize, will be case- and site-specific, and depend on local circumstances and the scale, scope and pace of implementation. Many co-benefits and adverse side effects have not been well-quantified. *{4.3, 4.4.2.2, Box 3.4}*

Technology policy (development, diffusion and transfer) complements other mitigation policies across all scales, from international to sub-national; many adaptation efforts also critically rely on diffusion and transfer of technologies and management practices (*high confidence*). Policies exist to address market failures in R&D, but the effective use of technologies can also depend on capacities to adopt technologies appropriate to local circumstances. *{4.4.3}*

Substantial reductions in emissions would require large changes in investment patterns (*high confidence*). For mitigation scenarios that stabilize concentrations (without overshoot) in the range of 430 to 530 ppm CO_2-eq by 2100[19], annual investments in low carbon electricity supply and energy efficiency in key sectors (transport, industry and buildings) are projected in the scenarios to rise by several hundred billion dollars per year before 2030. Within appropriate enabling environments, the private sector, along with the public sector, can play important roles in financing mitigation and adaptation (*medium evidence, high agreement*). *{4.4.4}*

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[19] This range comprises scenarios that reach 430 to 480 ppm CO_2-eq by 2100 (*likely* to limit warming to 2°C above pre-industrial levels) and scenarios that reach 480 to 530 ppm CO_2-eq by 2100 (without overshoot: *more likely than* not to limit warming to 2°C above pre-industrial levels).

Financial resources for adaptation have become available more slowly than for mitigation in both developed and developing countries. Limited evidence indicates that there is a gap between global adaptation needs and the funds available for adaptation (*medium confidence*). There is a need for better assessment of global adaptation costs, funding and investment. Potential synergies between international finance for disaster risk management and adaptation have not yet been fully realized (*high confidence*). *{4.4.4}*

SPM 4.5 Trade-offs, synergies and interactions with sustainable development

Climate change is a threat to sustainable development. Nonetheless, there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (*high confidence*). Successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond (*medium confidence*). *{3.5, 4.5}*

Climate change exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor (*high confidence*). Aligning climate policy with sustainable development requires attention to both adaptation and mitigation (*high confidence*). Delaying global mitigation actions may reduce options for climate-resilient pathways and adaptation in the future. Opportunities to take advantage of positive synergies between adaptation and mitigation may decrease with time, particularly if limits to adaptation are exceeded. Increasing efforts to mitigate and adapt to climate change imply an increasing complexity of interactions, encompassing connections among human health, water, energy, land use and biodiversity (*medium evidence, high agreement*). *{3.1, 3.5, 4.5}*

Strategies and actions can be pursued now which will move towards climate-resilient pathways for sustainable development, while at the same time helping to improve livelihoods, social and economic well-being and effective environmental management. In some cases, economic diversification can be an important element of such strategies. The effectiveness of integrated responses can be enhanced by relevant tools, suitable governance structures and adequate institutional and human capacity (*medium confidence*). Integrated responses are especially relevant to energy planning and implementation; interactions among water, food, energy and biological carbon sequestration; and urban planning, which provides substantial opportunities for enhanced resilience, reduced emissions and more sustainable development (*medium confidence*). *{3.5, 4.4, 4.5}*

This is **Exhibit D** referred to in the

affidavit of **John Moffet**

affirmed before me on **January 29, 2019**

Commissioner for Oaths for Québec

#224458

ipcc

INTERGOVERNMENTAL PANEL ON climate change

GLOBAL WARMING OF 1.5 °C

an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

Summary for Policymakers

This Summary for Policymakers was formally approved at the First Joint Session of Working Groups I, II and III of the IPCC and accepted by the 48th Session of the IPCC, Incheon, Republic of Korea, 6 October 2018.

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WMO UNEP

Summary for Policymakers

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Introduction

This report responds to the invitation for IPCC '... to provide a Special Report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways' contained in the Decision of the 21st Conference of Parties of the United Nations Framework Convention on Climate Change to adopt the Paris Agreement.[1]

The IPCC accepted the invitation in April 2016, deciding to prepare this Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

This Summary for Policy Makers (SPM) presents the key findings of the Special Report, based on the assessment of the available scientific, technical and socio-economic literature[2] relevant to global warming of 1.5°C and for the comparison between global warming of 1.5°C and 2°C above pre-industrial levels. The level of confidence associated with each key finding is reported using the IPCC calibrated language.[3] The underlying scientific basis of each key finding is indicated by references provided to chapter elements. In the SPM, knowledge gaps are identified associated with the underlying chapters of the report.

[1] Decision 1/CP.21, paragraph 21.

[2] The assessment covers literature accepted for publication by 15 May 2018.

[3] Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, for example, *medium confidence*. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, about as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Additional terms (extremely likely 95–100%, more likely than not >50–100%, more unlikely than likely 0–<50%, extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, for example, *very likely*. This is consistent with AR5.

A. Understanding Global Warming of 1.5°C[4]

A1. Human activities are estimated to have caused approximately 1.0°C of global warming[5] above pre-industrial levels, with a *likely* range of 0.8°C to 1.2°C. Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*) {1.2, Figure SPM.1}

A1.1. Reflecting the long-term warming trend since pre-industrial times, observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C (*likely* between 0.75°C and 0.99°C)[6] higher than the average over the 1850–1900 period (*very high confidence*). Estimated anthropogenic global warming matches the level of observed warming to within ±20% (*likely* range). Estimated anthropogenic global warming is currently increasing at 0.2°C (*likely* between 0.1°C and 0.3°C) per decade due to past and ongoing emissions (*high confidence*). {1.2.1, Table 1.1, 1.2.4}

A1.2. Warming greater than the global annual average is being experienced in many land regions and seasons, including two to three times higher in the Arctic. Warming is generally higher over land than over the ocean. (*high confidence*) {1.2.1, 1.2.2, Figure 1.1, Figure 1.3, 3.3.1, 3.3.2}

A1.3. Trends in intensity and frequency of some climate and weather extremes have been detected over time spans during which about 0.5°C of global warming occurred (*medium confidence*). This assessment is based on several lines of evidence, including attribution studies for changes in extremes since 1950. {3.3.1, 3.3.2, 3.3.3}

A.2. Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts (*high confidence*), but these emissions alone are *unlikely* to cause global warming of 1.5°C (*medium confidence*) {1.2, 3.3, Figure 1.5, Figure SPM.1}

A2.1. Anthropogenic emissions (including greenhouse gases, aerosols and their precursors) up to the present are *unlikely* to cause further warming of more than 0.5°C over the next two to three decades (*high confidence*) or on a century time scale (*medium confidence*). {1.2.4, Figure 1.5}

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[4] SPM BOX.1: Core Concepts

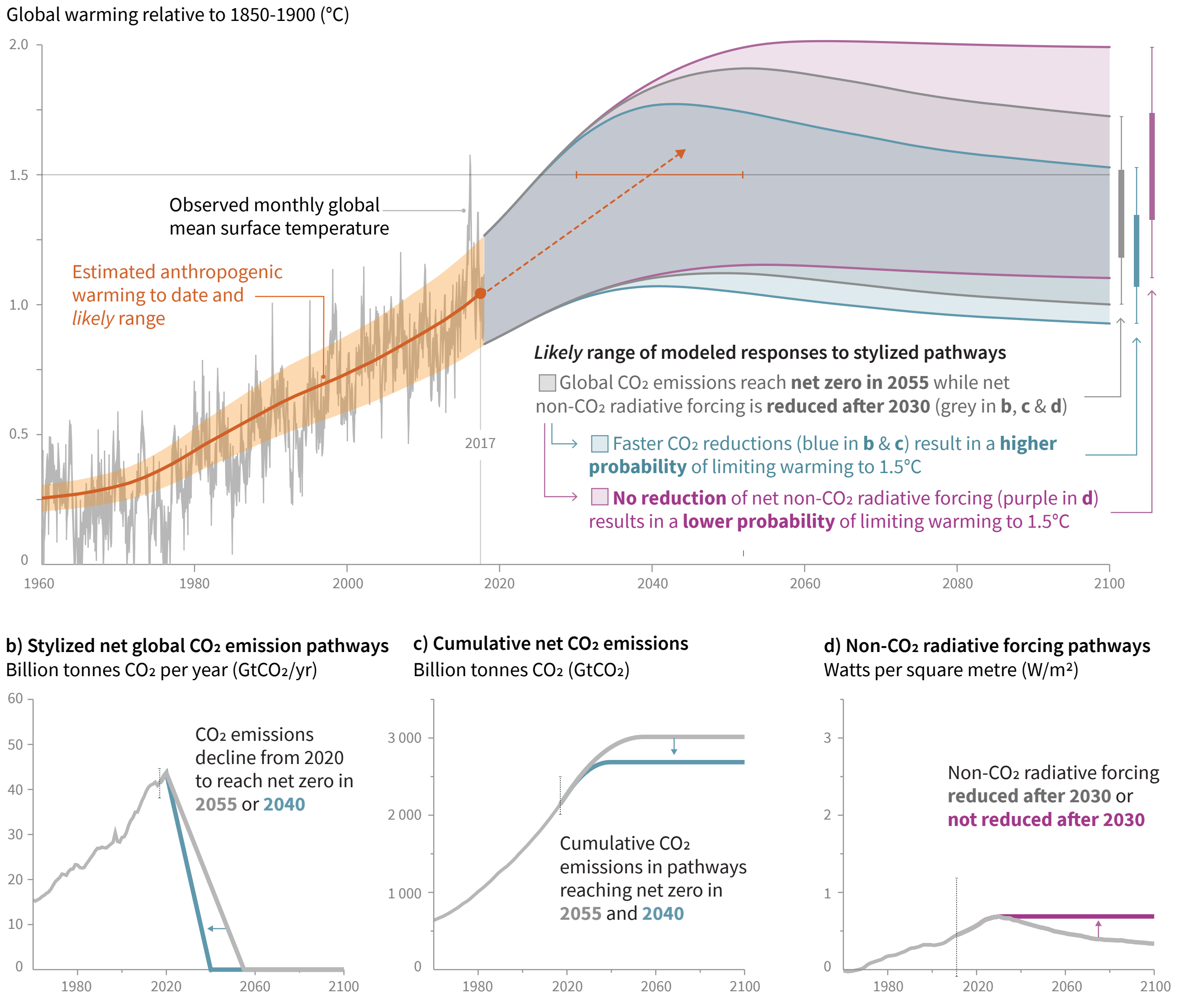
[5] Present level of global warming is defined as the average of a 30-year period centered on 2017 assuming the recent rate of warming continues.

[6] This range spans the four available peer-reviewed estimates of the observed GMST change and also accounts for additional uncertainty due to possible short-term natural variability. {1.2.1, Table 1.1}

A2.2. Reaching and sustaining net-zero global anthropogenic CO_2 emissions and declining net non-CO_2 radiative forcing would halt anthropogenic global warming on multi-decadal timescales (*high confidence*). The maximum temperature reached is then determined by cumulative net global anthropogenic CO_2 emissions up to the time of net zero CO_2 emissions (*high confidence*) and the level of non-CO_2 radiative forcing in the decades prior to the time that maximum temperatures are reached (*medium confidence*). On longer timescales, sustained net negative global anthropogenic CO_2 emissions and/or further reductions in non-CO_2 radiative forcing may still be required to prevent further warming due to Earth system feedbacks and reverse ocean acidification (*medium confidence*) and will be required to minimise sea level rise (*high confidence*). {Cross-Chapter Box 2 in Chapter 1, 1.2.3, 1.2.4, Figure 1.4, 2.2.1, 2.2.2, 3.4.4.8, 3.4.5.1, 3.6.3.2}

Cumulative emissions of CO_2 and future non-CO_2 radiative forcing determine the probability of limiting warming to 1.5°C

a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways



Faster immediate CO_2 emission reductions limit cumulative CO_2 emissions shown in panel **(c)**.

Maximum temperature rise is determined by cumulative net CO_2 emissions and net non-CO_2 radiative forcing due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents.

Figure SPM.1: Panel a: Observed monthly global mean surface temperature (GMST) change grey line up to 2017, from the HadCRUT4, GISTEMP, Cowtan–Way, and NOAA datasets) and estimated anthropogenic global warming (solid orange line up to 2017, with orange shading indicating assessed *likely* range). Orange dashed arrow and horizontal orange error bar show respectively central estimate and *likely* range of the time at which 1.5°C is reached if the current rate of warming continues. The grey plume on the right of Panel a) shows the *likely* range of warming responses, computed with a simple climate model, to a stylized pathway (hypothetical future) in which net CO_2 emissions (grey line in panels b and c) decline in a straight line from 2020 to reach net zero in 2055 and net non-CO_2 radiative forcing (grey line in panel d) increases to 2030 and then declines. The blue plume in panel a) shows the response to faster CO_2 emissions reductions (blue line in panel b), reaching net zero in 2040, reducing cumulative CO_2 emissions (panel c). The purple plume shows the response to net CO_2 emissions declining to zero in 2055, with net non-CO_2 forcing remaining constant after 2030. The vertical error bars on right of panel a) show the *likely* ranges (thin lines) and central terciles (33rd – 66th percentiles, thick lines) of the estimated distribution of warming in 2100 under these three stylized pathways. Vertical dotted error bars in panels b, c and d show the *likely* range of historical annual and cumulative global net CO_2 emissions in 2017 (data from the Global Carbon Project) and of net non-CO_2 radiative forcing in 2011 from AR5, respectively. Vertical axes in panels c and d are scaled to represent approximately equal effects on GMST. {1.2.1, 1.2.3, 1.2.4, 2.3, Chapter 1 Figure 1.2 & Chapter 1 Supplementary Material, Cross-Chapter Box 2}

A3. Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C (*high confidence*). These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (*high confidence*) (Figure SPM.2). {1.3, 3.3, 3.4, 5.6}

A3.1. Impacts on natural and human systems from global warming have already been observed (*high confidence*). Many land and ocean ecosystems and some of the services they provide have already changed due to global warming (*high confidence*). {1.4, 3.4, 3.5, Figure SPM.2}

A3.2. Future climate-related risks depend on the rate, peak and duration of warming. In the aggregate they are larger if global warming exceeds 1.5°C before returning to that level by 2100 than if global warming gradually stabilizes at 1.5°C, especially if the peak temperature is high (e.g., about 2°C) (*high confidence*). Some impacts may be long-lasting or irreversible, such as the loss of some ecosystems (*high confidence*). {3.2, 3.4.4, 3.6.3, Cross-Chapter Box 8}

A3.3. Adaptation and mitigation are already occurring (*high confidence*). Future climate-related risks would be reduced by the upscaling and acceleration of far-reaching, multi-level and cross-sectoral climate mitigation and by both incremental and transformational adaptation (*high confidence*). {1.2, 1.3, Table 3.5, 4.2.2, Cross-Chapter Box 9 in Chapter 4, Box 4.2, Box 4.3, Box 4.6, 4.3.1, 4.3.2, 4.3.3, 4.3.4, 4.3.5, 4.4.1, 4.4.4, 4.4.5, 4.5.3}

B. Projected Climate Change, Potential Impacts and Associated Risks

B1. Climate models project robust[7] differences in regional climate characteristics between present-day and global warming of 1.5°C,[8] and between 1.5°C and 2°C.[8] These differences include increases in: mean temperature in most land and ocean regions (*high confidence*), hot extremes in most inhabited regions (*high confidence*), heavy precipitation in several regions (*medium confidence*), and the probability of drought and precipitation deficits in some regions (*medium confidence*). {3.3}

B1.1. Evidence from attributed changes in some climate and weather extremes for a global warming of about 0.5°C supports the assessment that an additional 0.5°C of warming compared to present is associated with further detectable changes in these extremes (*medium confidence*). Several regional changes in climate are assessed to occur with global warming up to 1.5°C compared to pre-industrial levels, including warming of extreme temperatures in many regions (*high confidence*), increases in frequency, intensity, and/or amount of heavy precipitation in several regions (*high confidence*), and an increase in intensity or frequency of droughts in some regions (*medium confidence*). {3.2, 3.3.1, 3.3.2, 3.3.3, 3.3.4, Table 3.2}

B1.2. Temperature extremes on land are projected to warm more than GMST (*high confidence*): extreme hot days in mid-latitudes warm by up to about 3°C at global warming of 1.5°C and about

[7] Robust is here used to mean that at least two thirds of climate models show the same sign of changes at the grid point scale, and that differences in large regions are statistically significant.

[8] Projected changes in impacts between different levels of global warming are determined with respect to changes in global mean surface air temperature.

4°C at 2°C, and extreme cold nights in high latitudes warm by up to about 4.5°C at 1.5°C and about 6°C at 2°C (*high confidence*). The number of hot days is projected to increase in most land regions, with highest increases in the tropics (*high confidence*). {3.3.1, 3.3.2, Cross-Chapter Box 8 in Chapter 3}

B1.3. Risks from droughts and precipitation deficits are projected to be higher at 2°C compared to 1.5°C global warming in some regions (*medium confidence*). Risks from heavy precipitation events are projected to be higher at 2°C compared to 1.5°C global warming in several northern hemisphere high-latitude and/or high-elevation regions, eastern Asia and eastern North America (*medium confidence*). Heavy precipitation associated with tropical cyclones is projected to be higher at 2°C compared to 1.5°C global warming (*medium confidence*). There is generally *low confidence* in projected changes in heavy precipitation at 2°C compared to 1.5°C in other regions. Heavy precipitation when aggregated at global scale is projected to be higher at 2.0°C than at 1.5°C of global warming (*medium confidence*). As a consequence of heavy precipitation, the fraction of the global land area affected by flood hazards is projected to be larger at 2°C compared to 1.5°C of global warming (*medium confidence*). {3.3.1, 3.3.3, 3.3.4, 3.3.5, 3.3.6}

B2. By 2100, global mean sea level rise is projected to be around 0.1 metre lower with global warming of 1.5°C compared to 2°C (*medium confidence*). Sea level will continue to rise well beyond 2100 (*high confidence*), and the magnitude and rate of this rise depends on future emission pathways. A slower rate of sea level rise enables greater opportunities for adaptation in the human and ecological systems of small islands, low-lying coastal areas and deltas (*medium confidence*). {3.3, 3.4, 3.6 }

B2.1. Model-based projections of global mean sea level rise (relative to 1986-2005) suggest an indicative range of 0.26 to 0.77 m by 2100 for 1.5°C global warming, 0.1 m (0.04-0.16 m) less than for a global warming of 2°C (*medium confidence*). A reduction of 0.1 m in global sea level rise implies that up to 10 million fewer people would be exposed to related risks, based on population in the year 2010 and assuming no adaptation (*medium confidence*). {3.4.4, 3.4.5, 4.3.2}

B2.2. Sea level rise will continue beyond 2100 even if global warming is limited to 1.5°C in the 21st century (*high confidence*). Marine ice sheet instability in Antarctica and/or irreversible loss of the Greenland ice sheet could result in multi-metre rise in sea level over hundreds to thousands of years. These instabilities could be triggered around 1.5°C to 2°C of global warming (*medium confidence*). {3.3.9, 3.4.5, 3.5.2, 3.6.3, Box 3.3, Figure SPM.2}

B2.3. Increasing warming amplifies the exposure of small islands, low-lying coastal areas and deltas to the risks associated with sea level rise for many human and ecological systems, including increased saltwater intrusion, flooding and damage to infrastructure (*high confidence*). Risks associated with sea level rise are higher at 2°C compared to 1.5°C. The slower rate of sea level rise at global warming of 1.5°C reduces these risks enabling greater opportunities for adaptation including managing and restoring natural coastal ecosystems, and infrastructure reinforcement (*medium confidence*). {3.4.5, Figure SPM.2, Box 3.5}

B3. On land, impacts on biodiversity and ecosystems, including species loss and extinction, are projected to be lower at 1.5°C of global warming compared to 2°C. Limiting global warming to 1.5°C compared to 2°C is projected to lower the impacts on terrestrial, freshwater, and coastal ecosystems and to retain more of their services to humans (*high confidence*). (Figure SPM.2) {3.4, 3.5, Box 3.4, Box 4.2, Cross-Chapter Box 8 in Chapter 3}

B3.1. Of 105,000 species studied,[9] 6% of insects, 8% of plants and 4% of vertebrates are projected to lose over half of their climatically determined geographic range for global warming of 1.5°C, compared with 18% of insects, 16% of plants and 8% of vertebrates for global warming of 2°C (*medium confidence*). Impacts associated with other biodiversity-related risks such as forest fires, and the spread of invasive species, are lower at 1.5°C compared to 2°C of global warming (*high confidence*). {3.4.3, 3.5.2}

B3.2. Approximately 4% (interquartile range 2–7%) of the global terrestrial land area is projected to undergo a transformation of ecosystems from one type to another at 1ºC of global warming, compared with 13% (interquartile range 8–20%) at 2°C (*medium confidence*). This indicates that the area at risk is projected to be approximately 50% lower at 1.5°C compared to 2°C (*medium confidence*). {3.4.3.1, 3.4.3.5}

B3.3. High-latitude tundra and boreal forests are particularly at risk of climate change-induced degradation and loss, with woody shrubs already encroaching into the tundra (*high confidence*) and will proceed with further warming. Limiting global warming to 1.5°C rather than 2°C is projected to prevent the thawing over centuries of a permafrost area in the range of 1.5 to 2.5 million km^2 (*medium confidence*). {3.3.2, 3.4.3, 3.5.5}

B4. Limiting global warming to 1.5°C compared to 2ºC is projected to reduce increases in ocean temperature as well as associated increases in ocean acidity and decreases in ocean oxygen levels (*high confidence*). Consequently, limiting global warming to 1.5°C is projected to reduce risks to marine biodiversity, fisheries, and ecosystems, and their functions and services to humans, as illustrated by recent changes to Arctic sea ice and warm water coral reef ecosystems (*high confidence*). {3.3, 3.4, 3.5, Boxes 3.4, 3.5}

B4.1. There is *high confidence* that the probability of a sea-ice-free Arctic Ocean during summer is substantially lower at global warming of 1.5°C when compared to 2°C. With 1.5°C of global warming, one sea ice-free Arctic summer is projected per century. This likelihood is increased to at least one per decade with 2°C global warming. Effects of a temperature overshoot are reversible for Arctic sea ice cover on decadal time scales (*high confidence*). {3.3.8, 3.4.4.7}

B4.2. Global warming of 1.5°C is projected to shift the ranges of many marine species, to higher latitudes as well as increase the amount of damage to many ecosystems. It is also expected to drive the loss of coastal resources, and reduce the productivity of fisheries and aquaculture (especially at low latitudes). The risks of climate-induced impacts are projected to be higher at 2°C than those at global warming of 1.5°C (*high confidence*). Coral reefs, for example, are projected to decline by a further 70–90% at 1.5°C (*high confidence*) with larger losses (>99%) at 2ºC (*very high confidence*). The risk of irreversible loss of many marine and coastal ecosystems increases with global warming, especially at 2°C or more (*high confidence*). {3.4.4, Box 3.4}

B4.3. The level of ocean acidification due to increasing CO_2 concentrations associated with global warming of 1.5°C is projected to amplify the adverse effects of warming, and even further at 2°C,

[9] Consistent with earlier studies, illustrative numbers were adopted from one recent meta-study.

impacting the growth, development, calcification, survival, and thus abundance of a broad range of species, e.g., from algae to fish (*high confidence*). {3.3.10, 3.4.4}

B4.4. Impacts of climate change in the ocean are increasing risks to fisheries and aquaculture via impacts on the physiology, survivorship, habitat, reproduction, disease incidence, and risk of invasive species (*medium confidence)* but are projected to be less at 1.5ºC of global warming than at 2ºC. One global fishery model, for example, projected a decrease in global annual catch for marine fisheries of about 1.5 million tonnes for 1.5°C of global warming compared to a loss of more than 3 million tonnes for 2°C of global warming (*medium confidence*). {3.4.4, Box 3.4}

B5. Climate-related risks to health, livelihoods, food security, water supply, human security, and economic growth are projected to increase with global warming of 1.5°C and increase further with 2°C. (Figure SPM.2) {3.4, 3.5, 5.2, Box 3.2, Box 3.3, Box 3.5, Box 3.6, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 5.2}

B5.1. Populations at disproportionately higher risk of adverse consequences of global warming of 1.5°C and beyond include disadvantaged and vulnerable populations, some indigenous peoples, and local communities dependent on agricultural or coastal livelihoods (*high confidence*). Regions at disproportionately higher risk include Arctic ecosystems, dryland regions, small-island developing states, and least developed countries (*high confidence)*. Poverty and disadvantages are expected to increase in some populations as global warming increases; limiting global warming to 1.5°C, compared with 2°C, could reduce the number of people both exposed to climate-related risks and susceptible to poverty by up to several hundred million by 2050 (*medium confidence*). {3.4.10, 3.4.11, Box 3.5, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5, 4.2.2.2, 5.2.1, 5.2.2, 5.2.3, 5.6.3}

B5.2. Any increase in global warming is projected to affect human health, with primarily negative consequences (*high confidence*). Lower risks are projected at 1.5°C than at 2°C for heat-related morbidity and mortality (*very high confidence*) and for ozone-related mortality if emissions needed for ozone formation remain high (*high confidence)*. Urban heat islands often amplify the impacts of heatwaves in cities (*high confidence*). Risks from some vector-borne diseases, such as malaria and dengue fever, are projected to increase with warming from 1.5°C to 2°C, including potential shifts in their geographic range (*high confidence*). {3.4.7, 3.4.8, 3.5.5.8}

B5.3. Limiting warming to 1.5°C, compared with 2ºC, is projected to result in smaller net reductions in yields of maize, rice, wheat, and potentially other cereal crops, particularly in sub-Saharan Africa, Southeast Asia, and Central and South America; and in the CO_2 dependent, nutritional quality of rice and wheat (*high confidence*). Reductions in projected food availability are larger at 2ºC than at 1.5°C of global warming in the Sahel, southern Africa, the Mediterranean, central Europe, and the Amazon (*medium confidence*). Livestock are projected to be adversely affected with rising temperatures, depending on the extent of changes in feed quality, spread of diseases, and water resource availability (*high confidence*). {3.4.6, 3.5.4, 3.5.5, Box 3.1, Cross-Chapter Box 6 in Chapter 3, Cross-Chapter Box 9 in Chapter 4}

B5.4. Depending on future socioeconomic conditions, limiting global warming to 1.5°C, compared to 2°C, may reduce the proportion of the world population exposed to a climate-change induced increase in water stress by up to 50%, although there is considerable variability between regions (*medium confidence*). Many small island developing states would experience lower water stress as a result of projected changes in aridity when global warming is limited to 1.5°C, as compared to 2°C (*medium confidence*). {3.3.5, 3.4.2, 3.4.8, 3.5.5, Box 3.2, Box 3.5, Cross-Chapter Box 9 in Chapter 4}

B5.5. Risks to global aggregated economic growth due to climate change impacts are projected to be lower at 1.5°C than at 2°C by the end of this century[10] (*medium confidence*). This excludes the costs of mitigation, adaptation investments and the benefits of adaptation. Countries in the tropics and Southern Hemisphere subtropics are projected to experience the largest impacts on economic growth due to climate change should global warming increase from 1.5°C to 2 °C (*medium confidence*). {3.5.2, 3.5.3}

B5.6. Exposure to multiple and compound climate-related risks increases between 1.5°C and 2°C of global warming, with greater proportions of people both so exposed and susceptible to poverty in Africa and Asia (*high confidence*). For global warming from 1.5°C to 2°C, risks across energy, food, and water sectors could overlap spatially and temporally, creating new and exacerbating current hazards, exposures, and vulnerabilities that could affect increasing numbers of people and regions (*medium confidence*). {Box 3.5, 3.3.1, 3.4.5.3, 3.4.5.6, 3.4.11, 3.5.4.9}

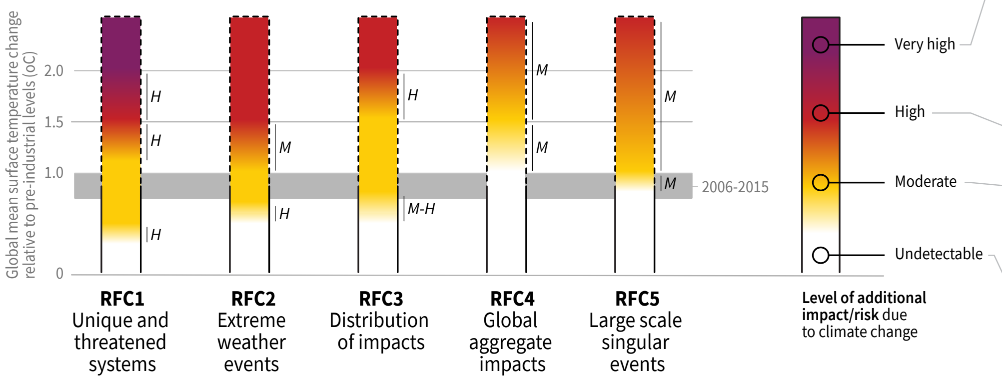
B5.7. There are multiple lines of evidence that since the AR5 the assessed levels of risk increased for four of the five Reasons for Concern (RFCs) for global warming to 2°C (*high confidence*). The risk transitions by degrees of global warming are now: from high to very high between 1.5°C and 2°C for RFC1 (Unique and threatened systems) (*high confidence*); from moderate to high risk between 1.0°C and 1.5°C for RFC2 (Extreme weather events) (*medium confidence*); from moderate to high risk between 1.5°C and 2°C for RFC3 (Distribution of impacts) (*high confidence*); from moderate to high risk between 1.5°C and 2.5°C for RFC4 (Global aggregate impacts) (*medium confidence*); and from moderate to high risk between 1°C and 2.5°C for RFC5 (Large-scale singular events) (*medium confidence*). (Figure SPM.2) {3.4.13; 3.5, 3.5.2}

[10] Here, impacts on economic growth refer to changes in GDP. Many impacts, such as loss of human lives, cultural heritage, and ecosystem services, are difficult to value and monetize.

How the level of global warming affects impacts and/or risks associated with the Reasons for Concern (RFCs) and selected natural, managed and human systems

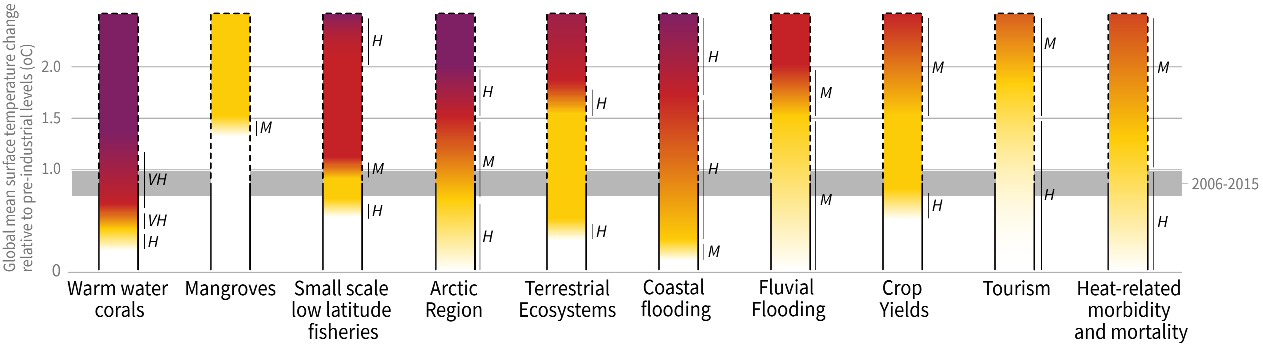
Five Reasons For Concern (RFCs) illustrate the impacts and risks of different levels of global warming for people, economies and ecosystems across sectors and regions.

Impacts and risks associated with the Reasons for Concern (RFCs)



Purple indicates very high risks of severe impacts/risks and the presence of significant irreversibility or the persistence of climate-related hazards, combined with limited ability to adapt due to the nature of the hazard or impacts/risks.
Red indicates severe and widespread impacts/risks.
Yellow indicates that impacts/risks are detectable and attributable to climate change with at least medium confidence.
White indicates that no impacts are detectable and attributable to climate change.

Impacts and risks for selected natural, managed and human systems



Confidence level for transition: *L*=Low, *M*=Medium, *H*=High and *VH*=Very high

Figure SPM.2: Five integrative reasons for concern (RFCs) provide a framework for summarizing key impacts and risks across sectors and regions, and were introduced in the IPCC Third Assessment Report. RFCs illustrate the implications of global warming for people, economies, and ecosystems. Impacts and/or risks for each RFC are based on assessment of the new literature that has appeared. As in the AR5, this literature was used to make expert judgments to assess the levels of global warming at which levels of impact and/or risk are undetectable, moderate, high or very high. The selection of impacts and risks to natural, managed and human systems in the lower panel is illustrative and is not intended to be fully comprehensive. **RFC1 Unique and threatened systems:** ecological and human systems that have restricted geographic ranges constrained by climate related conditions and have high endemism or other distinctive properties. Examples include coral reefs, the Arctic and its indigenous people, mountain glaciers, and biodiversity hotspots. **RFC2 Extreme weather events**: risks/impacts to human health, livelihoods, assets, and ecosystems from extreme weather events such as heat waves, heavy rain, drought and associated wildfires, and coastal flooding. **RFC3 Distribution of impacts:** risks/impacts that disproportionately affect particular groups due to uneven distribution of physical climate change hazards, exposure or vulnerability. **RFC4 Global aggregate impacts:** global monetary damage, global scale degradation and loss of ecosystems and biodiversity. **RFC5 Large-scale singular events:** are relatively large, abrupt and sometimes irreversible changes in systems that are caused by global warming. Examples include disintegration of the Greenland and Antarctic ice sheets. {3.4, 3.5, 3.5.2.1, 3.5.2.2, 3.5.2.3, 3.5.2.4, 3.5.2.5, 5.4.1 5.5.3, 5.6.1, Box 3.4}

B6. Most adaptation needs will be lower for global warming of 1.5°C compared to 2°C (*high confidence*). There are a wide range of adaptation options that can reduce the risks of climate change (*high confidence*). There are limits to adaptation and adaptive capacity for some human and natural systems at global warming of 1.5°C, with associated losses (*medium confidence*). The number and availability of adaptation options vary by sector (*medium confidence*). {Table 3.5, 4.3, 4.5, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 12 in Chapter 5}

B6.1. A wide range of adaptation options are available to reduce the risks to natural and managed ecosystems (e.g., ecosystem-based adaptation, ecosystem restoration and avoided degradation and deforestation, biodiversity management, sustainable aquaculture, and local knowledge and indigenous knowledge), the risks of sea level rise (e.g., coastal defence and hardening), and the risks to health, livelihoods, food, water, and economic growth, especially in rural landscapes (e.g., efficient irrigation, social safety nets, disaster risk management, risk spreading and sharing, community-based adaptation) and urban areas (e.g., green infrastructure, sustainable land use and planning, and sustainable water management) (*medium confidence*). {4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.5.3, 4.5.4, 5.3.2, Box 4.2, Box 4.3, Box 4.6, Cross-Chapter Box 9 in Chapter 4}.

B6.2. Adaptation is expected to be more challenging for ecosystems, food and health systems at 2°C of global warming than for 1.5°C (*medium confidence*). Some vulnerable regions, including small islands and Least Developed Countries, are projected to experience high multiple interrelated climate risks even at global warming of 1.5°C (*high confidence*). {3.3.1, 3.4.5, Box 3.5, Table 3.5, Cross-Chapter Box 9 in Chapter 4, 5.6, Cross-Chapter Box 12 in Chapter 5, Box 5.3}

B6.3. Limits to adaptive capacity exist at 1.5°C of global warming, become more pronounced at higher levels of warming and vary by sector, with site-specific implications for vulnerable regions, ecosystems, and human health (*medium confidence*) {Cross-Chapter Box 12 in Chapter 5, Box 3.5, Table 3.5}

C. Emission Pathways and System Transitions Consistent with 1.5°C Global Warming

C1. In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045–2055 interquartile range). For limiting global warming to below 2°C[11] CO_2 emissions are projected to decline by about 20% by 2030 in most pathways (10–30% interquartile range) and reach net zero around 2075 (2065–2080 interquartile range). Non-CO_2 emissions in pathways that limit global warming to 1.5°C show deep reductions that are similar to those in pathways limiting warming to 2°C. (*high confidence*) (Figure SPM.3a) {2.1, 2.3, Table 2.4}

C1.1. CO_2 emissions reductions that limit global warming to 1.5°C with no or limited overshoot can involve different portfolios of mitigation measures, striking different balances between lowering energy and resource intensity, rate of decarbonization, and the reliance on carbon dioxide removal. Different portfolios face different implementation challenges, and potential synergies and trade-offs with sustainable development. (*high confidence*). (Figure SPM.3b) {2.3.2, 2.3.4, 2.4, 2.5.3}

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[11] References to pathways limiting global warming to 2ºC are based on a 66% probability of staying below 2ºC.

C1.2. Modelled pathways that limit global warming to 1.5°C with no or limited overshoot involve deep reductions in emissions of methane and black carbon (35% or more of both by 2050 relative to 2010). These pathways also reduce most of the cooling aerosols, which partially offsets mitigation effects for two to three decades. Non-CO_2 emissions[12] can be reduced as a result of broad mitigation measures in the energy sector. In addition, targeted non-CO_2 mitigation measures can reduce nitrous oxide and methane from agriculture, methane from the waste sector, some sources of black carbon, and hydrofluorocarbons. High bioenergy demand can increase emissions of nitrous oxide in some 1.5°C pathways, highlighting the importance of appropriate management approaches. Improved air quality resulting from projected reductions in many non-CO_2 emissions provide direct and immediate population health benefits in all 1.5°C model pathways. (*high confidence*) (Figure SPM.3a) {2.2.1, 2.3.3, 2.4.4, 2.5.3, 4.3.6, 5.4.2}

C1.3. Limiting global warming requires limiting the total cumulative global anthropogenic emissions of CO_2 since the preindustrial period, i.e. staying within a total carbon budget (*high confidence*).[13] By the end of 2017, anthropogenic CO_2 emissions since the preindustrial period are estimated to have reduced the total carbon budget for 1.5°C by approximately 2200 ± 320 $GtCO_2$ (*medium confidence*). The associated remaining budget is being depleted by current emissions of 42 ± 3 $GtCO_2$ per year (*high confidence*). The choice of the measure of global temperature affects the estimated remaining carbon budget. Using global mean surface air temperature, as in AR5, gives an estimate of the remaining carbon budget of 580 $GtCO_2$ for a 50% probability of limiting warming to 1.5°C, and 420 $GtCO_2$ for a 66% probability (*medium confidence*).[14] Alternatively, using GMST gives estimates of 770 and 570 $GtCO_2$, for 50% and 66% probabilities,[15] respectively (*medium confidence*). Uncertainties in the size of these estimated remaining carbon budgets are substantial and depend on several factors. Uncertainties in the climate response to CO_2 and non-CO_2 emissions contribute ±400 $GtCO_2$ and the level of historic warming contributes ±250 $GtCO_2$ (*medium confidence*). Potential additional carbon release from future permafrost thawing and methane release from wetlands would reduce budgets by up to 100 $GtCO_2$ over the course of this century and more thereafter (*medium confidence*). In addition, the level of non-CO_2 mitigation in the future could alter the remaining carbon budget by 250 $GtCO_2$ in either direction (*medium confidence*). {1.2.4, 2.2.2, 2.6.1, Table 2.2, Chapter 2 Supplementary Material}

C1.4. Solar radiation modification (SRM) measures are not included in any of the available assessed pathways. Although some SRM measures may be theoretically effective in reducing an overshoot, they face large uncertainties and knowledge gaps as well as substantial risks,

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[12] Non-CO_2 emissions included in this report are all anthropogenic emissions other than CO_2 that result in radiative forcing. These include short-lived climate forcers, such as methane, some fluorinated gases, ozone precursors, aerosols or aerosol precursors, such as black carbon and sulphur dioxide, respectively, as well as long-lived greenhouse gases, such as nitrous oxide or some fluorinated gases. The radiative forcing associated with non-CO_2 emissions and changes in surface albedo is referred to as non-CO_2 radiative forcing. {x.y}

[13] There is a clear scientific basis for a total carbon budget consistent with limiting global warming to 1.5°C. However, neither this total carbon budget nor the fraction of this budget taken up by past emissions were assessed in this report.

[14] Irrespective of the measure of global temperature used, updated understanding and further advances in methods have led to an increase in the estimated remaining carbon budget of about 300 $GtCO_2$ compared to AR5. (*medium confidence*) {x.y}

[15] These estimates use observed GMST to 2006–2015 and estimate future temperature changes using near surface air temperatures.

institutional and social constraints to deployment related to governance, ethics, and impacts on sustainable development. They also do not mitigate ocean acidification. (*medium confidence*). {4.3.8, Cross-Chapter Box 10 in Chapter 4}

Global emissions pathway characteristics

General characteristics of the evolution of anthropogenic net emissions of CO_2, and total emissions of methane, black carbon, and nitrous oxide in model pathways that limit global warming to 1.5°C with no or limited overshoot. Net emissions are defined as anthropogenic emissions reduced by anthropogenic removals. Reductions in net emissions can be achieved through different portfolios of mitigation measures illustrated in Figure SPM3B.

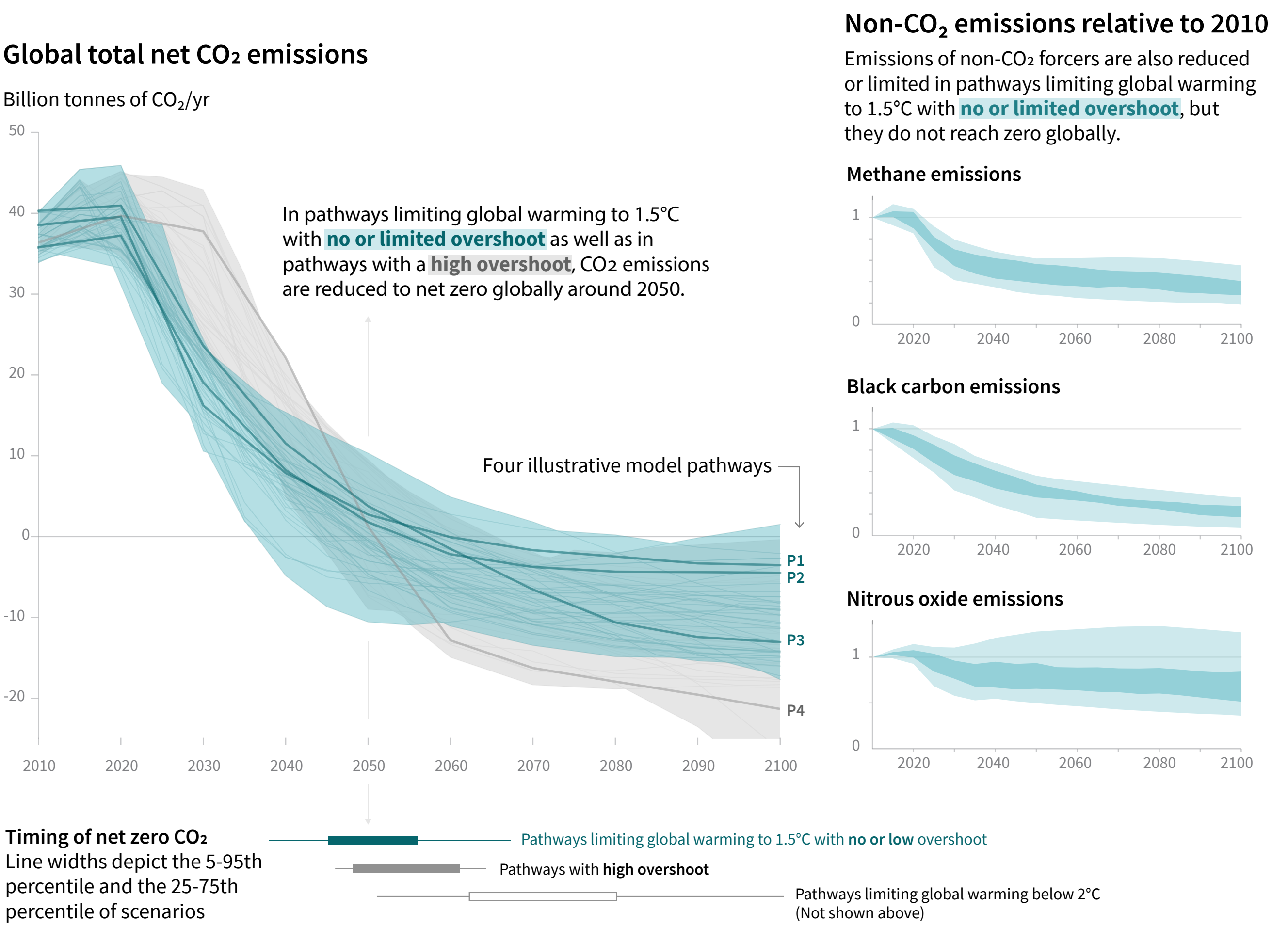
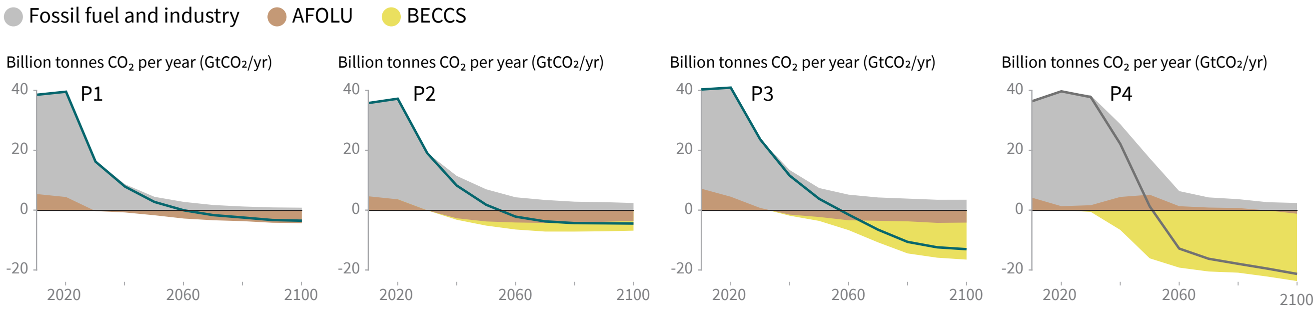


Figure SPM.3a: Global emissions pathway characteristics. The main panel shows global net anthropogenic CO_2 emissions in pathways limiting global warming to 1.5°C with no or limited (less than 0.1°C) overshoot and pathways with higher overshoot. The shaded area shows the full range for pathways analysed in this report. The panels on the right show non-CO_2 emissions ranges for three compounds with large historical forcing and a substantial portion of emissions coming from sources distinct from those central to CO_2 mitigation. Shaded areas in these panels show the 5–95% (light shading) and interquartile (dark shading) ranges of pathways limiting global warming to 1.5°C with no or limited overshoot. Box and whiskers at the bottom of the figure show the timing of pathways reaching global net zero CO_2 emission levels, and a comparison with pathways limiting global warming to 2°C with at least 66% probability. Four illustrative model pathways are highlighted in the main panel and are labelled P1, P2, P3 and P4, corresponding to the LED, S1, S2, and S5 pathways assessed in Chapter 2. Descriptions and characteristics of these pathways are available in Figure SPM3b. {2.1, 2.2, 2.3, Figure 2.5, Figure 2.10, Figure 2.11}

Characteristics of four illustrative model pathways

Different mitigation strategies can achieve the net emissions reductions that would be required to follow a pathway that limit global warming to 1.5°C with no or limited overshoot. All pathways use Carbon Dioxide Removal (CDR), but the amount varies across pathways, as do the relative contributions of Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector. This has implications for the emissions and several other pathway characteristics.

Breakdown of contributions to global net CO_2 emissions in four illustrative model pathways



P1: A scenario in which social, business, and technological innovations result in lower energy demand up to 2050 while living standards rise, especially in the global South. A down-sized energy system enables rapid decarbonisation of energy supply. Afforestation is the only CDR option considered; neither fossil fuels with CCS nor BECCS are used.

P2: A scenario with a broad focus on sustainability including energy intensity, human development, economic convergence and international cooperation, as well as shifts towards sustainable and healthy consumption patterns, low-carbon technology innovation, and well-managed land systems with limited societal acceptability for BECCS.

P3: A middle-of-the-road scenario in which societal as well as technological development follows historical patterns. Emissions reductions are mainly achieved by changing the way in which energy and products are produced, and to a lesser degree by reductions in demand.

P4: A resource and energy-intensive scenario in which economic growth and globalization lead to widespread adoption of greenhouse-gas intensive lifestyles, including high demand for transportation fuels and livestock products. Emissions reductions are mainly achieved through technological means, making strong use of CDR through the deployment of BECCS.

Global indicators	P1	P2	P3	P4	**Interquartile range**
Pathway classification	No or low overshoot	No or low overshoot	No or low overshoot	High overshoot	No or low overshoot
CO_2 emission change in 2030 (% rel to 2010)	-58	-47	-41	4	(-59,-40)
└ *in 2050 (% rel to 2010)*	-93	-95	-91	-97	(-104,-91)
Kyoto-GHG emissions in 2030 (% rel to 2010)*	-50	-49	-35	-2	(-55,-38)
└ *in 2050 (% rel to 2010)*	-82	-89	-78	-80	(-93,-81)
*Final energy demand** in 2030 (% rel to 2010)*	-15	-5	17	39	(-12, 7)
└ *in 2050 (% rel to 2010)*	-32	2	21	44	(-11, 22)
Renewable share in electricity in 2030 (%)	60	58	48	25	(47, 65)
└ *in 2050 (%)*	77	81	63	70	(69, 87)
Primary energy from coal in 2030 (% rel to 2010)	-78	-61	-75	-59	(-78, -59)
└ *in 2050 (% rel to 2010)*	-97	-77	-73	-97	(-95, -74)
from oil in 2030 (% rel to 2010)	-37	-13	-3	86	(-34,3)
└ *in 2050 (% rel to 2010)*	-87	-50	-81	-32	(-78,-31)
from gas in 2030 (% rel to 2010)	-25	-20	33	37	(-26,21)
└ *in 2050 (% rel to 2010)*	-74	-53	21	-48	(-56,6)
from nuclear in 2030 (% rel to 2010)	59	83	98	106	(44,102)
└ *in 2050 (% rel to 2010)*	150	98	501	468	(91,190)
from biomass in 2030 (% rel to 2010)	-11	0	36	-1	(29,80)
└ *in 2050 (% rel to 2010)*	-16	49	121	418	(123,261)
from non-biomass renewables in 2030 (% rel to 2010)	430	470	315	110	(243,438)
└ *in 2050 (% rel to 2010)*	832	1327	878	1137	(575,1300)
Cumulative CCS until 2100 ($GtCO_2$)	0	348	687	1218	(550, 1017)
└ *of which BECCS ($GtCO_2$)*	0	151	414	1191	(364, 662)
Land area of bioenergy crops in 2050 (million hectare)	22	93	283	724	(151, 320)
Agricultural CH_4 emissions in 2030 (% rel to 2010)	-24	-48	1	14	(-30,-11)
in 2050 (% rel to 2010)	-33	-69	-23	2	(-46,-23)
Agricultural N_2O emissions in 2030 (% rel to 2010)	5	-26	15	3	(-21,4)
in 2050 (% rel to 2010)	6	-26	0	39	(-26,1)

NOTE: Indicators have been selected to show global trends identified by the Chapter 2 assessment. National and sectoral characteristics can differ substantially from the global trends shown above.

** Kyoto-gas emissions are based on SAR GWP-100*
*** Changes in energy demand are associated with improvements in energy efficiency and behaviour change*

Figure SPM.3b: Characteristics of four illustrative model pathways in relation to global warming of 1.5°C introduced in Figure SPM3a. These pathways were selected to show a range of potential mitigation approaches and vary widely in their projected energy and land use, as well as their assumptions about future socioeconomic developments, including economic and population growth, equity and sustainability. A breakdown of the global net anthropogenic CO_2 emissions into the contributions in terms of CO_2 emissions from fossil fuel and industry, agriculture, forestry and other land use (AFOLU), and bioenergy with carbon capture and storage (BECCS) is shown. AFOLU estimates reported here are not necessarily comparable with countries' estimates. Further characteristics for each of these pathways are listed below each pathway. These pathways illustrate relative global differences in mitigation strategies, but do not represent central estimates, national strategies, and do not indicate requirements. For comparison, the right-most column shows the interquartile ranges across pathways with no or limited overshoot of 1.5°C. Pathways P1, P2, P3 and P4, correspond to the LED, S1, S2, and S5 pathways assessed in Chapter 2. (Figure SPM.3a) {2.2.1, 2.3.1, 2.3.2, 2.3.3, 2.3.4, 2.4.1, 2.4.2, 2.4.4, 2.5.3, Figure 2.5, Figure 2.6, Figure 2.9, Figure 2.10, Figure 2.11, Figure 2.14, Figure 2.15, Figure 2.16, Figure 2.17, Figure 2.24, Figure 2.25, Table 2.4, Table 2.6, Table 2.7, Table 2.9, Table 4.1}

C2. Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (*high confidence*). These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options (*medium confidence*). {2.3, 2.4, 2.5, 4.2, 4.3, 4.4, 4.5}

C2.1. Pathways that limit global warming to 1.5°C with no or limited overshoot show system changes that are more rapid and pronounced over the next two decades than in 2°C pathways (*high confidence*). The rates of system changes associated with limiting global warming to 1.5°C with no or limited overshoot have occurred in the past within specific sectors, technologies and spatial contexts, but there is no documented historic precedent for their scale (*medium confidence*). {2.3.3, 2.3.4, 2.4, 2.5, 4.2.1, 4.2.2, Cross-Chapter Box 11 in Chapter 4}

C2.2. In energy systems, modelled global pathways (considered in the literature) limiting global warming to 1.5°C with no or limited overshoot (for more details see Figure SPM.3b), generally meet energy service demand with lower energy use, including through enhanced energy efficiency, and show faster electrification of energy end use compared to 2°C (*high confidence*). In 1.5°C pathways with no or limited overshoot, low-emission energy sources are projected to have a higher share, compared with 2°C pathways, particularly before 2050 (*high confidence*). In 1.5°C pathways with no or limited overshoot, renewables are projected to supply 70–85% (interquartile range) of electricity in 2050 (*high confidence*). In electricity generation, shares of nuclear and fossil fuels with carbon dioxide capture and storage (CCS) are modelled to increase in most 1.5°C pathways with no or limited overshoot. In modelled 1.5°C pathways with limited or no overshoot, the use of CCS would allow the electricity generation share of gas to be approximately 8% (3–11% interquartile range) of global electricity in 2050, while the use of coal shows a steep reduction in all pathways and would be reduced to close to 0% (0–2%) of electricity (*high confidence*). While acknowledging the challenges, and differences between the options and national circumstances, political, economic, social and technical feasibility of solar energy, wind energy and electricity storage technologies have substantially improved over the past few years (*high confidence*). These improvements signal a potential system transition in electricity generation (Figure SPM.3b) {2.4.1, 2.4.2, Figure 2.1, Table 2.6, Table 2.7, Cross-Chapter Box 6 in Chapter 3, 4.2.1, 4.3.1, 4.3.3, 4.5.2}

C2.3. CO_2 emissions from industry in pathways limiting global warming to 1.5°C with no or limited overshoot are projected to be about 75–90% (interquartile range) lower in 2050 relative to 2010, as compared to 50–80% for global warming of 2ºC (*medium confidence*). Such reductions can be achieved through combinations of new and existing technologies and practices, including electrification, hydrogen, sustainable bio-based feedstocks, product substitution, and carbon capture, utilization and storage (CCUS). These options are technically proven at various scales but their large-scale deployment may be limited by economic, financial, human capacity and institutional constraints in specific contexts, and specific characteristics of large-scale industrial installations. In industry, emissions reductions by energy and process efficiency by themselves are insufficient for limiting warming to 1.5°C with no or limited overshoot (*high confidence*). {2.4.3, 4.2.1, Table 4.1, Table 4.3, 4.3.3, 4.3.4, 4.5.2}

C2.4. The urban and infrastructure system transition consistent with limiting global warming to 1.5°C with no or limited overshoot would imply, for example, changes in land and urban planning practices, as well as deeper emissions reductions in transport and buildings compared to pathways that limit global warming below 2°C (see 2.4.3; 4.3.3; 4.2.1) (*medium confidence*). Technical measures and practices enabling deep emissions reductions include various energy efficiency options. In pathways limiting global warming to 1.5°C with no or limited overshoot, the electricity share of energy demand in buildings would be about 55–75% in 2050 compared to 50–70% in 2050 for 2°C global warming (*medium confidence*). In the transport sector, the share of low-emission final energy would rise from less than 5% in 2020 to about 35–65% in 2050 compared to 25–45% for 2°C global warming (*medium confidence*). Economic, institutional and socio-cultural barriers may inhibit these urban and infrastructure system transitions, depending on national, regional and local circumstances, capabilities and the availability of capital (*high confidence*). {2.3.4, 2.4.3, 4.2.1, Table 4.1, 4.3.3, 4.5.2}.

C2.5. Transitions in global and regional land use are found in all pathways limiting global warming to 1.5°C with no or limited overshoot, but their scale depends on the pursued mitigation portfolio. Model pathways that limit global warming to 1.5°C with no or limited overshoot project the conversion of 0.5–8 million km^2 of pasture and 0–5 million km^2 of non-pasture agricultural land for food and feed crops into 1–7 million km^2 for energy crops and a 1 million km^2 reduction to 10 million km^2 increase in forests by 2050 relative to 2010 (*medium confidence*).[16] Land use transitions of similar magnitude can be observed in modelled 2°C pathways (*medium confidence*). Such large transitions pose profound challenges for sustainable management of the various demands on land for human settlements, food, livestock feed, fibre, bioenergy, carbon storage, biodiversity and other ecosystem services (*high confidence*). Mitigation options limiting the demand for land include sustainable intensification of land use practices, ecosystem restoration and changes towards less resource-intensive diets (*high confidence*). The implementation of land-based mitigation options would require overcoming socio-economic, institutional, technological, financing and environmental barriers that differ across regions (*high confidence*). {2.4.4, Figure 2.24, 4.3.2, 4.5.2, Cross-Chapter Box 7 in Chapter 3}

C2.6 Total annual average energy-related mitigation investment for the period 2015 to 2050 in pathways limiting warming to 1.5°C is estimated to be around 900 billion USD2015 (range of 180 billion to 1800 billion USD2015 across six models[17]). This corresponds to total annual average energy supply investments of 1600 to 3800 billion USD2015 and total annual average energy demand investments of 700 to 1000 billion USD2015 for the period 2015 to 2050, and an increase in total energy-related investments of about 12% (range of 3% to 23%) in 1.5°C pathways relative to 2°C pathways. Average annual investment in low-carbon energy technologies and energy efficiency are upscaled by roughly a factor of five (range of factor of 4 to 5) by 2050 compared to 2015 (*medium confidence*). {2.5.2, Box 4.8, Figure 2.27}

C2.7. Modelled pathways limiting global warming to 1.5°C with no or limited overshoot project a wide range of global average discounted marginal abatement costs over the 21st century. They are roughly 3-4 times higher than in pathways limiting global warming to below 2°C (*high confidence*). The economic literature distinguishes marginal abatement costs from total mitigation costs in the economy. The literature on total mitigation costs of 1.5°C mitigation pathways is limited and was not assessed in this report. Knowledge gaps remain in the integrated assessment of the economy wide costs and benefits of mitigation in line with pathways limiting warming to 1.5°C. {2.5.2; 2.6; Figure 2.26}

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[16] The projected land use changes presented are not deployed to their upper limits simultaneously in a single pathway.

[17] Including two pathways limiting warming to 1.5°C with no or limited overshoot and four pathways with high overshoot.

C3. All pathways that limit global warming to 1.5°C with limited or no overshoot project the use of carbon dioxide removal (CDR) on the order of 100–1000 $GtCO_2$ over the 21st century. CDR would be used to compensate for residual emissions and, in most cases, achieve net negative emissions to return global warming to 1.5°C following a peak (*high confidence*). CDR deployment of several hundreds of $GtCO_2$ is subject to multiple feasibility and sustainability constraints (*high confidence*). Significant near-term emissions reductions and measures to lower energy and land demand can limit CDR deployment to a few hundred $GtCO_2$ without reliance on bioenergy with carbon capture and storage (BECCS) (*high confidence*). {2.3, 2.4, 3.6.2, 4.3, 5.4}

C3.1. Existing and potential CDR measures include afforestation and reforestation, land restoration and soil carbon sequestration, BECCS, direct air carbon capture and storage (DACCS), enhanced weathering and ocean alkalinization. These differ widely in terms of maturity, potentials, costs, risks, co-benefits and trade-offs (*high confidence*). To date, only a few published pathways include CDR measures other than afforestation and BECCS. {2.3.4, 3.6.2, 4.3.2, 4.3.7}

C3.2. In pathways limiting global warming to 1.5°C with limited or no overshoot, BECCS deployment is projected to range from 0–1, 0–8, and 0–16 $GtCO_2\ yr^{-1}$ in 2030, 2050, and 2100, respectively, while agriculture, forestry and land-use (AFOLU) related CDR measures are projected to remove 0–5, 1–11, and 1–5 $GtCO_2\ yr^{-1}$ in these years (*medium confidence*). The upper end of these deployment ranges by mid-century exceeds the BECCS potential of up to 5 $GtCO_2\ yr^{-1}$ and afforestation potential of up to 3.6 $GtCO_2\ yr^{-1}$ assessed based on recent literature (*medium confidence*). Some pathways avoid BECCS deployment completely through demand-side measures and greater reliance on AFOLU-related CDR measures (*medium confidence*). The use of bioenergy can be as high or even higher when BECCS is excluded compared to when it is included due to its potential for replacing fossil fuels across sectors (*high confidence*). (Figure SPM.3b) {2.3.3, 2.3.4, 2.4.2, 3.6.2, 4.3.1, 4.2.3, 4.3.2, 4.3.7, 4.4.3, Table 2.4}

C3.3. Pathways that overshoot 1.5°C of global warming rely on CDR exceeding residual CO_2 emissions later in the century to return to below 1.5°C by 2100, with larger overshoots requiring greater amounts of CDR (Figure SPM.3b). (*high confidence*). Limitations on the speed, scale, and societal acceptability of CDR deployment hence determine the ability to return global warming to below 1.5°C following an overshoot. Carbon cycle and climate system understanding is still limited about the effectiveness of net negative emissions to reduce temperatures after they peak (*high confidence*). {2.2, 2.3.4, 2.3.5, 2.6, 4.3.7, 4.5.2, Table 4.11}

C3.4. Most current and potential CDR measures could have significant impacts on land, energy, water, or nutrients if deployed at large scale (*high confidence*). Afforestation and bioenergy may compete with other land uses and may have significant impacts on agricultural and food systems, biodiversity and other ecosystem functions and services (*high confidence*). Effective governance is needed to limit such trade-offs and ensure permanence of carbon removal in terrestrial, geological and ocean reservoirs (*high confidence*). Feasibility and sustainability of CDR use could be enhanced by a portfolio of options deployed at substantial, but lesser scales, rather than a single option at very large scale (*high confidence*). (Figure SPM.3b). {2.3.4, 2.4.4, 2.5.3, 2.6, 3.6.2, 4.3.2, 4.3.7, 4.5.2, 5.4.1, 5.4.2; Cross-Chapter Boxes 7 and 8 in Chapter 3, Table 4.11, Table 5.3, Figure 5.3}

C3.5. Some AFOLU-related CDR measures such as restoration of natural ecosystems and soil carbon sequestration could provide co-benefits such as improved biodiversity, soil quality, and local food security. If deployed at large scale, they would require governance systems enabling sustainable land management to conserve and protect land carbon stocks and other ecosystem functions and services (*medium confidence*). (Figure SPM.4) {2.3.3, 2.3.4, 2.4.2, 2.4.4, 3.6.2, 5.4.1, Cross-Chapter Boxes 3 in Chapter 1 and 7 in Chapter 3, 4.3.2, 4.3.7, 4.4.1, 4.5.2, Table 2.4}

D. Strengthening the Global Response in the Context of Sustainable Development and Efforts to Eradicate Poverty

D1. Estimates of the global emissions outcome of current nationally stated mitigation ambitions as submitted under the Paris Agreement would lead to global greenhouse gas emissions[18] in 2030 of 52–58 $GtCO_2eq\ yr^{-1}$ (*medium confidence)*. Pathways reflecting these ambitions would not limit global warming to 1.5°C, even if supplemented by very challenging increases in the scale and ambition of emissions reductions after 2030 (*high confidence*). Avoiding overshoot and reliance on future large-scale deployment of carbon dioxide removal (CDR) can only be achieved if global CO_2 emissions start to decline well before 2030 (*high confidence*). {1.2, 2.3, 3.3, 3.4, 4.2, 4.4, Cross-Chapter Box 11 in Chapter 4}

D1.1. Pathways that limit global warming to 1.5°C with no or limited overshoot show clear emission reductions by 2030 (*high confidence*). All but one show a decline in global greenhouse gas emissions to below 35 $GtCO_2eq\ yr^{-1}$ in 2030, and half of available pathways fall within the 25–30 $GtCO_2eq\ yr^{-1}$ range (interquartile range), a 40–50% reduction from 2010 levels (*high confidence*). Pathways reflecting current nationally stated mitigation ambition until 2030 are broadly consistent with cost-effective pathways that result in a global warming of about 3°C by 2100, with warming continuing afterwards (*medium confidence*). {2.3.3, 2.3.5, Cross-Chapter Box 11 in Chapter 4, 5.5.3.2}

D1.2. Overshoot trajectories result in higher impacts and associated challenges compared to pathways that limit global warming to 1.5°C with no or limited overshoot (*high confidence*). Reversing warming after an overshoot of 0.2°C or larger during this century would require upscaling and deployment of CDR at rates and volumes that might not be achievable given considerable implementation challenges (*medium confidence*). {1.3.3, 2.3.4, 2.3.5, 2.5.1, 3.3, 4.3.7, Cross-Chapter Box 8 in Chapter 3, Cross-Chapter Box 11 in Chapter 4}

D1.3. The lower the emissions in 2030, the lower the challenge in limiting global warming to 1.5°C after 2030 with no or limited overshoot (*high confidence*). The challenges from delayed actions to reduce greenhouse gas emissions include the risk of cost escalation, lock-in in carbon-emitting infrastructure, stranded assets, and reduced flexibility in future response options in the medium to long-term (*high confidence*). These may increase uneven distributional impacts between countries at different stages of development (*medium confidence*). {2.3.5, 4.4.5, 5.4.2}

D2. The avoided climate change impacts on sustainable development, eradication of poverty and reducing inequalities would be greater if global warming were limited to 1.5°C rather than 2°C, if mitigation and adaptation synergies are maximized while trade-offs are minimized (*high confidence*). {1.1, 1.4, 2.5, 3.3, 3.4, 5.2, Table 5.1}

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[18] GHG emissions have been aggregated with 100-year GWP values as introduced in the IPCC Second Assessment Report

D2.1. Climate change impacts and responses are closely linked to sustainable development which balances social well-being, economic prosperity and environmental protection. The United Nations Sustainable Development Goals (SDGs), adopted in 2015, provide an established framework for assessing the links between global warming of 1.5°C or 2°C and development goals that include poverty eradication, reducing inequalities, and climate action (*high confidence*) {Cross-Chapter Box 4 in Chapter 1, 1.4, 5.1}

D2.2. The consideration of ethics and equity can help address the uneven distribution of adverse impacts associated with 1.5°C and higher levels of global warming, as well as those from mitigation and adaptation, particularly for poor and disadvantaged populations, in all societies (*high confidence*). {1.1.1, 1.1.2, 1.4.3, 2.5.3, 3.4.10, 5.1, 5.2, 5.3. 5.4, Cross-Chapter Box 4 in Chapter 1, Cross-Chapter Boxes 6 and 8 in Chapter 3, and Cross-Chapter Box 12 in Chapter 5}

D2.3. Mitigation and adaptation consistent with limiting global warming to 1.5°C are underpinned by enabling conditions, assessed in SR1.5 across the geophysical, environmental-ecological, technological, economic, socio-cultural and institutional dimensions of feasibility. Strengthened multi-level governance, institutional capacity, policy instruments, technological innovation and transfer and mobilization of finance, and changes in human behaviour and lifestyles are enabling conditions that enhance the feasibility of mitigation and adaptation options for 1.5°C consistent systems transitions. *(high confidence*) {1.4, Cross-Chapter Box 3 in Chapter 1, 4.4, 4.5, 5.6}

D3. Adaptation options specific to national contexts, if carefully selected together with enabling conditions, will have benefits for sustainable development and poverty reduction with global warming of 1.5°C, although trade-offs are possible (*high confidence*). {1.4, 4.3, 4.5}

D3.1. Adaptation options that reduce the vulnerability of human and natural systems have many synergies with sustainable development, if well managed, such as ensuring food and water security, reducing disaster risks, improving health conditions, maintaining ecosystem services and reducing poverty and inequality (*high confidence*). Increasing investment in physical and social infrastructure is a key enabling condition to enhance the resilience and the adaptive capacities of societies. These benefits can occur in most regions with adaptation to 1.5°C of global warming (*high confidence*). {1.4.3, 4.2.2, 4.3.1, 4.3.2, 4.3.3, 4.3.5, 4.4.1, 4.4.3, 4.5.3, 5.3.1, 5.3.2}

D3.2. Adaptation to 1.5°C global warming can also result in trade–offs or maladaptations with adverse impacts for sustainable development. For example, if poorly designed or implemented, adaptation projects in a range of sectors can increase greenhouse gas emissions and water use, increase gender and social inequality, undermine health conditions, and encroach on natural ecosystems (*high confidence*). These trade-offs can be reduced by adaptations that include attention to poverty and sustainable development (*high confidence*). {4.3.2, 4.3.3, 4.5.4, 5.3.2; Cross-Chapter Boxes 6 and 7 in Chapter 3}

D3.3. A mix of adaptation and mitigation options to limit global warming to 1.5°C, implemented in a participatory and integrated manner, can enable rapid, systemic transitions in urban and rural areas (*high confidence*). These are most effective when aligned with economic and sustainable development, and when local and regional governments and decision makers are supported by national governments (*medium confidence*) {4.3.2, 4.3.3, 4.4.1, 4.4.2}

D3.4. Adaptation options that also mitigate emissions can provide synergies and cost savings in most sectors and system transitions, such as when land management reduces emissions and disaster risk, or when low carbon buildings are also designed for efficient cooling. Trade-offs between mitigation and adaptation, when limiting global warming to 1.5°C, such as when bioenergy crops, reforestation or afforestation encroach on land needed for agricultural adaptation, can undermine food security, livelihoods, ecosystem functions and services and other aspects of sustainable development. (*high confidence*) {3.4.3, 4.3.2, 4.3.4, 4.4.1, 4.5.2, 4.5.3, 4.5.4}

D4. Mitigation options consistent with 1.5°C pathways are associated with multiple synergies and trade-offs across the Sustainable Development Goals (SDGs). While the total number of possible synergies exceeds the number of trade-offs, their net effect will depend on the pace and magnitude of changes, the composition of the mitigation portfolio and the management of the transition. *(high confidence*) (Figure SPM.4) {2.5, 4.5, 5.4}

D4.1. 1.5°C pathways have robust synergies particularly for the SDGs 3 (health), 7 (clean energy), 11 (cities and communities), 12 (responsible consumption and production), and 14 (oceans) (*very high confidence*). Some 1.5°C pathways show potential trade-offs with mitigation for SDGs 1 (poverty), 2 (hunger), 6 (water), and 7 (energy access), if not carefully managed (*high confidence*) (Figure SPM.4). {5.4.2; Figure 5.4, Cross-Chapter Boxes 7 and 8 in Chapter 3}

D4.2. 1.5°C pathways that include low energy demand (e.g., see P1 in Figure SPM.3a and SPM.3b), low material consumption, and low GHG-intensive food consumption have the most pronounced synergies and the lowest number of trade-offs with respect to sustainable development and the SDGs (*high confidence*). Such pathways would reduce dependence on CDR. In modelled pathways sustainable development, eradicating poverty and reducing inequality can support limiting warming to 1.5◦C. (*high confidence*) (Figure SPM.3b, Figure SPM.4) {2.4.3, 2.5.1, 2.5.3, Figure 2.4, Figure 2.28, 5.4.1, 5.4.2, Figure 5.4}

D4.3. 1.5°C and 2°C modelled pathways often rely on the deployment of large-scale land-related measures like afforestation and bioenergy supply, which, if poorly managed, can compete with food production and hence raise food security concerns (*high confidence*). The impacts of carbon dioxide removal (CDR) options on SDGs depend on the type of options and the scale of deployment (*high confidence*). If poorly implemented, CDR options such as BECCS and AFOLU options would lead to trade-offs. Context-relevant design and implementation requires considering people's needs, biodiversity, and other sustainable development dimensions (*very high confidence*). {Figure SPM.4, 5.4.1.3, Cross-Chapter Box 7 in Chapter 3}

D4.4. Mitigation consistent with 1.5°C pathways creates risks for sustainable development in regions with high dependency on fossil fuels for revenue and employment generation (*high confidence*). Policies that promote diversification of the economy and the energy sector can address the associated challenges (*high confidence*). {5.4.1.2, Box 5.2}

D4.5. Redistributive policies across sectors and populations that shield the poor and vulnerable can resolve trade-offs for a range of SDGs, particularly hunger, poverty and energy access. Investment needs for such complementary policies are only a small fraction of the overall mitigation investments in 1.5°C pathways. (*high confidence*) {2.4.3, 5.4.2, Figure 5.5}

Indicative linkages between mitigation options and sustainable development using SDGs (The linkages do not show costs and benefits)

Mitigation options deployed in each sector can be associated with potential positive effects (synergies) or negative effects (trade-offs) with the Sustainable Development Goals (SDGs). The degree to which this potential is realized will depend on the selected portfolio of mitigation options, mitigation policy design, and local circumstances and context. Particularly in the energy-demand sector, the potential for synergies is larger than for trade-offs. The bars group individually assessed options by level of confidence and take into account the relative strength of the assessed mitigation-SDG connections.

Length shows strength of connection

The overall **size of the coloured bars** depict **the relative** for synergies and trade-offs between the sectoral mitigation options and the SDGs.

Shades show level of confidence

The shades depict **the level of confidence** of the assessed potential for **Trade-offs**/**Synergies**.

Very High *Low*

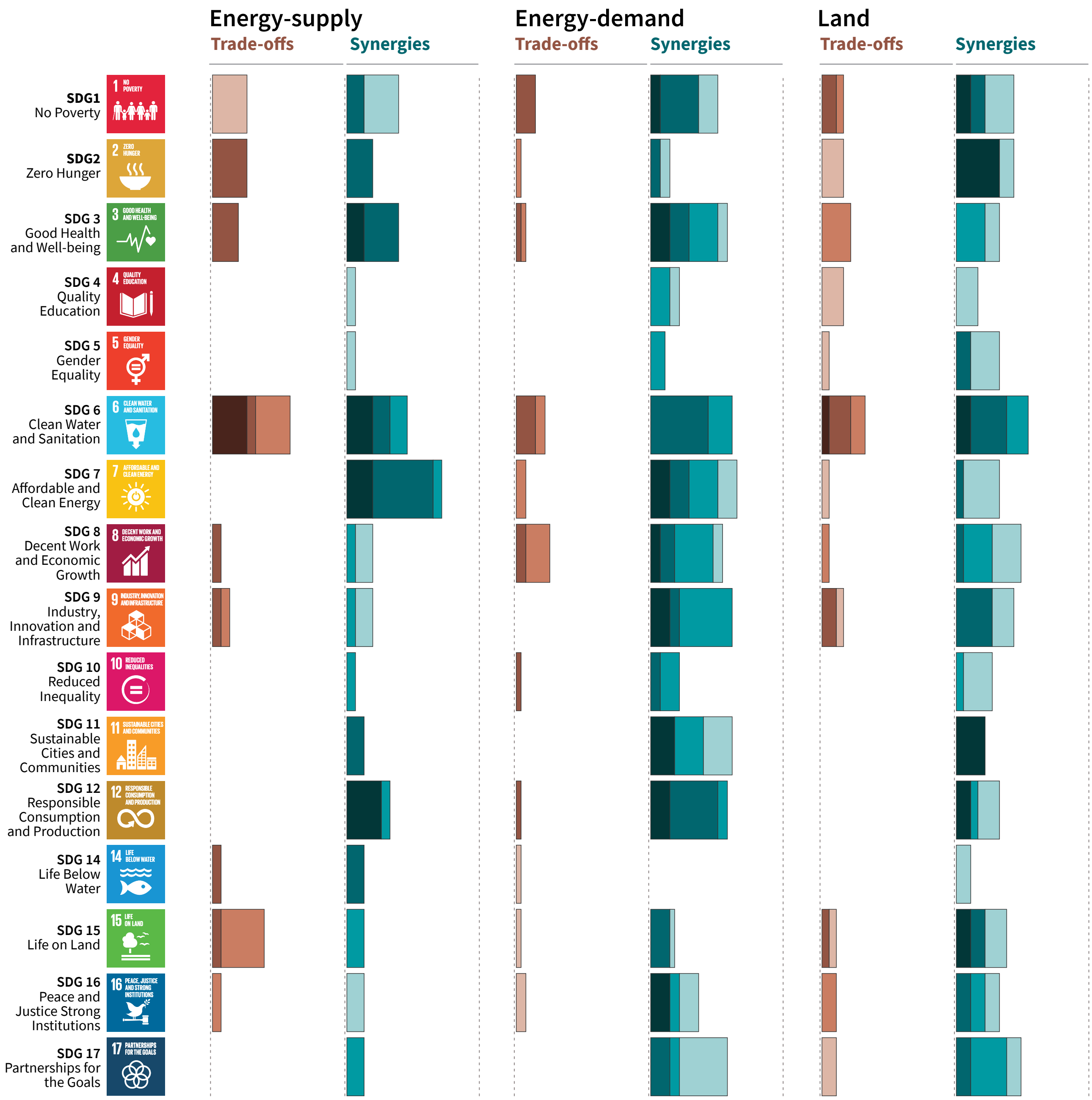

Figure SPM.4: Potential synergies and trade-offs between the sectoral portfolio of climate change mitigation options and the Sustainable Development Goals (SDGs). The SDGs serve as an analytical framework for the assessment of the different sustainable development dimensions, which extend beyond the time frame of the 2030 SDG targets. The assessment is based on literature on mitigation options that are considered relevant for 1.5ºC. The assessed strength of the SDG interactions is based on the qualitative and quantitative assessment of individual mitigation options listed in Table 5.2. For each mitigation option, the strength of the SDG-connection as well as the associated confidence of the underlying literature (shades of green and red) was assessed. The strength of positive connections (synergies) and negative connections (trade-offs) across all individual options within a sector (see Table 5.2) are aggregated into sectoral potentials for the whole mitigation portfolio. The (white) areas outside the bars, which indicate no interactions, have *low confidence* due to the uncertainty and limited number of studies exploring indirect effects. The strength of the connection considers only the effect of mitigation and does not include benefits of avoided impacts. SDG 13 (climate action) is not listed because mitigation is being considered in terms of interactions with SDGs and not vice versa. The bars denote the strength of the connection, and do not consider the strength of the impact on the SDGs. The energy demand sector comprises behavioural responses, fuel switching and efficiency options in the transport, industry and building sector as well as carbon capture options in the industry sector. Options assessed in the energy supply sector comprise biomass and non-biomass renewables, nuclear, CCS with bio-energy, and CCS with fossil fuels. Options in the land sector comprise agricultural and forest options, sustainable diets & reduced food waste, soil sequestration, livestock & manure management, reduced deforestation, afforestation & reforestation, responsible sourcing. In addition to this figure, options in the ocean sector are discussed in the underlying report. {5.4, Table 5.2, Figure 5.2}

Statement for knowledge gap:
Information about the net impacts of mitigation on sustainable development in 1.5°C pathways is available only for a limited number of SDGs and mitigation options. Only a limited number of studies have assessed the benefits of avoided climate change impacts of 1.5°C pathways for the SDGs, and the co-effects of adaptation for mitigation and the SDGs. The assessment of the indicative mitigation potentials in Figure SPM.4 is a step further from AR5 towards a more comprehensive and integrated assessment in the future.

D5. Limiting the risks from global warming of 1.5°C in the context of sustainable development and poverty eradication implies system transitions that can be enabled by an increase of adaptation and mitigation investments, policy instruments, the acceleration of technological innovation and behaviour changes (*high confidence*). {2.3, 2.4, 2.5, 3.2, 4.2, 4.4, 4.5, 5.2, 5.5, 5.6}

D5.1. Directing finance towards investment in infrastructure for mitigation and adaptation could provide additional resources. This could involve the mobilization of private funds by institutional investors, asset managers and development or investment banks, as well as the provision of public funds. Government policies that lower the risk of low-emission and adaptation investments can facilitate the mobilization of private funds and enhance the effectiveness of other public policies. Studies indicate a number of challenges including access to finance and mobilisation of funds (*high confidence*) {2.5.2, 4.4.5}

D5.2. Adaptation finance consistent with global warming of 1.5°C is difficult to quantify and compare with 2°C. Knowledge gaps include insufficient data to calculate specific climate resilience-enhancing investments, from the provision of currently underinvested basic infrastructure. Estimates of the costs of adaptation might be lower at global warming of 1.5°C than for 2°C. Adaptation needs have typically been supported by public sector sources such as national and subnational government budgets, and in developing countries together with support from development assistance, multilateral development banks, and UNFCCC channels (*medium confidence*). More recently there is a growing understanding of the scale and increase in NGO and private funding in some regions (*medium confidence*). Barriers include the scale of adaptation financing, limited capacity and access to adaptation finance (*medium confidence*).{4.4.5, 4.6}

D5.3. Global model pathways limiting global warming to 1.5°C are projected to involve the annual average investment needs in the energy system of around 2.4 trillion USD2010 between 2016 and 2035 representing about 2.5% of the world GDP (*medium confidence*). {2.5.2, 4.4.5, Box 4.8}

D5.4. Policy tools can help mobilise incremental resources, including through shifting global investments and savings and through market and non-market based instruments as well as accompanying measures to secure the equity of the transition, acknowledging the challenges related with implementation including those of energy costs, depreciation of assets and impacts on international competition, and utilizing the opportunities to maximize co-benefits (*high confidence*) {1.3.3, 2.3.4, 2.3.5, 2.5.1, 2.5.2, Cross-Chapter Box 8 in Chapter 3 and 11 in Chapter 4, 4.4.5, 5.5.2}

D5.5. The systems transitions consistent with adapting to and limiting global warming to 1.5°C include the widespread adoption of new and possibly disruptive technologies and practices and enhanced climate-driven innovation. These imply enhanced technological innovation capabilities, including in industry and finance. Both national innovation policies and international cooperation can contribute to the development, commercialization and widespread adoption of mitigation and adaptation technologies. Innovation policies may be more effective when they combine public support for research and development with policy mixes that provide incentives for technology diffusion. (*high confidence*) {4.4.4, 4.4.5}.

D5.6. Education, information, and community approaches, including those that are informed by Indigenous knowledge and local knowledge, can accelerate the wide scale behaviour changes consistent with adapting to and limiting global warming to 1.5°C. These approaches are more effective when combined with other policies and tailored to the motivations, capabilities, and resources of specific actors and contexts (*high confidence*). Public acceptability can enable or inhibit the implementation of policies and measures to limit global warming to 1.5°C and to adapt to the consequences. Public acceptability depends on the individual's evaluation of expected policy consequences, the perceived fairness of the distribution of these consequences, and perceived fairness of decision procedures (*high confidence*). {1.1, 1.5, 4.3.5, 4.4.1, 4.4.3, Box 4.3, 5.5.3, 5.6.5}

D6. Sustainable development supports, and often enables, the fundamental societal and systems transitions and transformations that help limit global warming to 1.5°C. Such changes facilitate the pursuit of climate-resilient development pathways that achieve ambitious mitigation and adaptation in conjunction with poverty eradication and efforts to reduce inequalities *(high confidence)*. {Box 1.1, 1.4.3, Figure 5.1, 5.5.3, Box 5.3}

D6.1. Social justice and equity are core aspects of climate-resilient development pathways that aim to limit global warming to 1.5°C as they address challenges and inevitable trade-offs, widen opportunities, and ensure that options, visions, and values are deliberated, between and within countries and communities, without making the poor and disadvantaged worse off (*high confidence*). {5.5.2, 5.5.3, Box 5.3, Figure 5.1, Figure 5.6, Cross-Chapter Boxes 12 and 13 in Chapter 5}

D6.2. The potential for climate-resilient development pathways differs between and within regions and nations, due to different development contexts and systemic vulnerabilities (*very high confidence*). Efforts along such pathways to date have been limited (*medium confidence*) and enhanced efforts would involve strengthened and timely action from all countries and non-state actors (*high confidence*). {5.5.1, 5.5.3, Figure 5.1}

D6.3. Pathways that are consistent with sustainable development show fewer mitigation and adaptation challenges and are associated with lower mitigation costs. The large majority of modelling studies could not construct pathways characterized by lack of international cooperation, inequality and poverty that were able to limit global warming to 1.5°C. (*high confidence*) {2.3.1, 2.5.3, 5.5.2}

D7. Strengthening the capacities for climate action of national and sub-national authorities, civil society, the private sector, indigenous peoples and local communities can support the implementation of ambitious actions implied by limiting global warming to 1.5°C (*high confidence*). International cooperation can provide an enabling environment for this to be achieved in all countries and for all people, in the context of sustainable development. International cooperation is a critical enabler for developing countries and vulnerable regions (*high confidence*). {1.4, 2.3, 2.5, 4.2, 4.4, 4.5, 5.3, 5.4, 5.5, 5.6, 5, Box 4.1, Box 4.2, Box 4.7, Box 5.3, Cross-Chapter Box 9 in Chapter 4, Cross-Chapter Box 13 in Chapter 5}

D7.1. Partnerships involving non-state public and private actors, institutional investors, the banking system, civil society and scientific institutions would facilitate actions and responses consistent with limiting global warming to 1.5°C (*very high confidence*). {1.4, 4.4.1, 4.2.2, 4.4.3, 4.4.5, 4.5.3, 5.4.1, 5.6.2, Box 5.3}.

D7.2. Cooperation on strengthened accountable multilevel governance that includes non-state actors such as industry, civil society and scientific institutions, coordinated sectoral and cross-sectoral policies at various governance levels, gender-sensitive policies, finance including innovative financing and cooperation on technology development and transfer can ensure participation, transparency, capacity building, and learning among different players (*high confidence*). {2.5.2, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.5.3, Cross-Chapter Box 9 in Chapter 4, 5.3.1, 4.4.5, 5.5.3, Cross-Chapter Box 13 in Chapter 5, 5.6.1, 5.6.3}

D7.3. International cooperation is a critical enabler for developing countries and vulnerable regions to strengthen their action for the implementation of 1.5°C-consistent climate responses, including through enhancing access to finance and technology and enhancing domestic capacities, taking into account national and local circumstances and needs (*high confidence*). {2.3.1, 4.4.1, 4.4.2, 4.4.4, 4.4.5, 5.4.1 5.5.3, 5.6.1, Box 4.1, Box 4.2, Box 4.7}.

D7.4. Collective efforts at all levels, in ways that reflect different circumstances and capabilities, in the pursuit of limiting global warming to 1.5ºC, taking into account equity as well as effectiveness, can facilitate strengthening the global response to climate change, achieving sustainable development and eradicating poverty (*high confidence*). {1.4.2, 2.3.1, 2.5.2, 4.2.2, 4.4.1, 4.4.2, 4.4.3, 4.4.4, 4.4.5, 4.5.3, 5.3.1, 5.4.1, 5.5.3, 5.6.1, 5.6.2, 5.6.3}

Box SPM 1: Core Concepts Central to this Special Report

Global mean surface temperature (GMST): Estimated global average of near-surface air temperatures over land and sea-ice, and sea surface temperatures over ice-free ocean regions, with changes normally expressed as departures from a value over a specified reference period. When estimating changes in GMST, near-surface air temperature over both land and oceans are also used.[19] {1.2.1.1}

Pre-industrial: The multi-century period prior to the onset of large-scale industrial activity around 1750. The reference period 1850–1900 is used to approximate pre-industrial GMST. {1.2.1.2}

Global warming: The estimated increase in GMST averaged over a 30-year period, or the 30-year period centered on a particular year or decade, expressed relative to pre-industrial levels unless otherwise specified. For 30-year periods that span past and future years, the current multi-decadal warming trend is assumed to continue. {1.2.1}

Net zero CO_2 emissions: Net-zero carbon dioxide (CO_2) emissions are achieved when anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals over a specified period.

Carbon dioxide removal (CDR): Anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical sinks and direct air capture and storage, but excludes natural CO_2 uptake not directly caused by human activities.

Total carbon budget: Estimated cumulative net global anthropogenic CO_2 emissions from the preindustrial period to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions. {2.2.2}

Remaining carbon budget: Estimated cumulative net global anthropogenic CO_2 emissions from a given start date to the time that anthropogenic CO_2 emissions reach net zero that would result, at some probability, in limiting global warming to a given level, accounting for the impact of other anthropogenic emissions. {2.2.2}

Temperature overshoot: The temporary exceedance of a specified level of global warming.

Emission pathways: In this Summary for Policymakers, the modelled trajectories of global anthropogenic emissions over the 21st century are termed emission pathways. Emission pathways are classified by their temperature trajectory over the 21st century: pathways giving at least 50% probability based on current knowledge of limiting global warming to below 1.5°C are classified as 'no overshoot'; those limiting warming to below 1.6°C and returning to 1.5°C by 2100 are classified as '1.5°C limited-overshoot'; while those exceeding 1.6°C but still returning to 1.5°C by 2100 are classified as 'higher-overshoot'.

[19] Past IPCC reports, reflecting the literature, have used a variety of approximately equivalent metrics of GMST change.

Impacts: Effects of climate change on human and natural systems. Impacts can have beneficial or adverse outcomes for livelihoods, health and well-being, ecosystems and species, services, infrastructure, and economic, social and cultural assets.

Risk: The potential for adverse consequences from a climate-related hazard for human and natural systems, resulting from the interactions between the hazard and the vulnerability and exposure of the affected system. Risk integrates the likelihood of exposure to a hazard and the magnitude of its impact. Risk also can describe the potential for adverse consequences of adaptation or mitigation responses to climate change.

Climate-resilient development pathways (CRDPs): Trajectories that strengthen sustainable development at multiple scales and efforts to eradicate poverty through equitable societal and systems transitions and transformations while reducing the threat of climate change through ambitious mitigation, adaptation, and climate resilience.

This is **Exhibit E** referred to in the

affidavit of **John Moffet**

affirmed before me on **January 29, 2019**

Commissioner for Oaths for Québec

#224458

IPCC Special Report on Global Warming of 1.5°C
Frequently Asked Questions

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Draft Note: *06/10/2018 - FAQs are subject to copy editing and trickle backs.*

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FAQ 1.1: Why Are We Talking about 1.5°C?

Summary: *Climate change represents an urgent and potentially irreversible threat to human societies and the planet. In recognition of this, the overwhelming majority of countries around the world adopted the Paris Agreement in December 2015, the central aim of which includes pursuing efforts to limit global temperature rise to 1.5°C. In doing so, these countries, through the United Nations Framework Convention on Climate Change (UNFCCC), also invited the IPCC to provide a Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emissions pathways.*

At the 21st Conference of the Parties (COP21) in December 2015, 195 nations adopted the Paris Agreement[1]. The first instrument of its kind, the landmark agreement includes the aim to strengthen the global response to the threat of climate change by 'holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels'.

The first UNFCCC document to mention a limit to global warming of 1.5°C was the Cancun Agreement, adopted at the sixteenth COP (COP16) in 2010. The Cancun Agreement established a process to periodically review the 'adequacy of the long-term global goal (LTGG) in the light of the ultimate objective of the Convention and the overall progress made towards achieving the LTGG, including a consideration of the implementation of the commitments under the Convention'. The definition of LTGG in the Cancun Agreement was 'to hold the increase in global average temperature below 2°C above pre-industrial levels'. The agreement also recognised the need to consider 'strengthening the long term global goal on the basis of the best available scientific knowledge…to a global average temperature rise of 1.5°C'.

Beginning in 2013 and ending at the COP21 in Paris in 2015, the first review period of the long-term global goal largely consisted of the Structured Expert Dialogue (SED). This was a fact-finding, face-to-face exchange of views between invited experts and UNFCCC delegates. The final report of the SED[2] concluded that 'in some regions and vulnerable ecosystems, high risks are projected even for warming above 1.5°C'. The SED report also suggested that Parties would profit from restating the temperature limit of the long-term global goal as a 'defence line' or 'buffer zone', instead of a 'guardrail' up to which all would be safe, adding that this new understanding would 'probably also favour emission pathways that will limit warming to a range of temperatures below 2°C'. Specifically on strengthening the temperature limit of 2°C, the SED's key message was: 'While science on the 1.5°C warming limit is less robust, efforts should be made to push the defence line as low as possible'. The findings of the SED, in turn, fed into the draft decision adopted at COP21.

With the adoption of the Paris Agreement, the UNFCCC invited the IPCC to provide a Special Report in 2018 on 'the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emissions pathways'. The request was that the report, known as SR1.5, should not only assess what a 1.5°C warmer world would look like but also the different pathways by which global temperature rise could be limited to 1.5°C. In 2016, the IPCC accepted the invitation, adding that the Special Report would also look at these issues in the context of strengthening the global response to the threat of climate change, sustainable development and efforts to eradicate poverty.

The combination of rising exposure to climate change and the fact that there is a limited capacity to adapt to its impacts amplifies the risks posed by warming of 1.5°C and 2°C. This is particularly true

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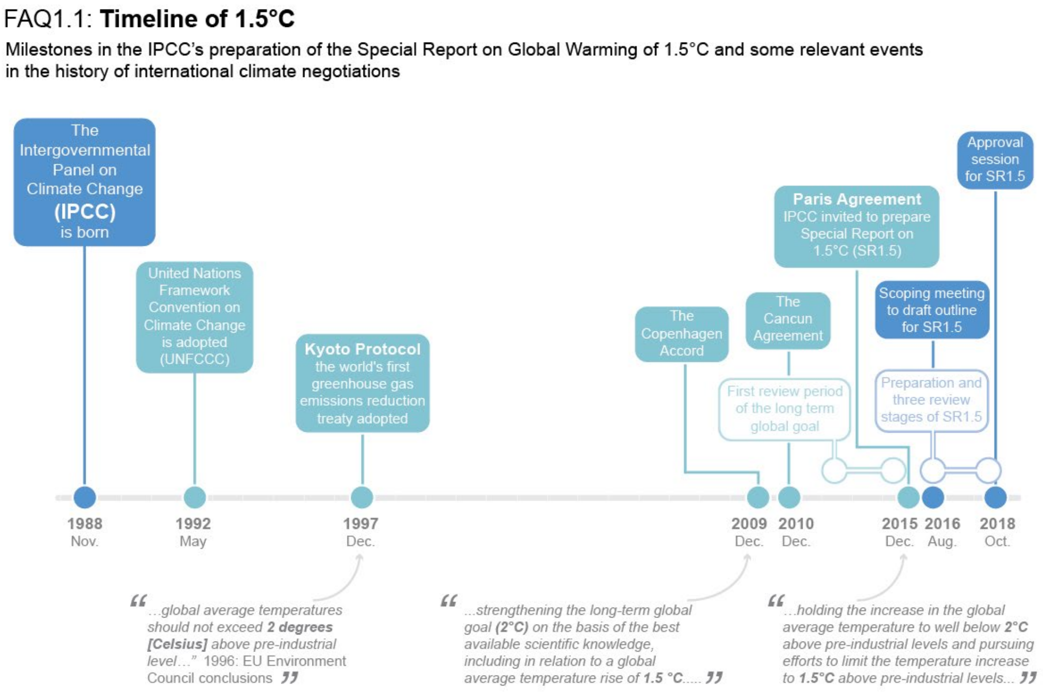
[1] Paris Agreement FCCC/CP/2015/10/Add.1 https://unfccc.int/documents/9097

[2] Structured Expert Dialogue (SED) final report FCCC/SB/2015/INF.1 https://unfccc.int/documents/8707

for developing and island countries in the tropics and other vulnerable countries and areas. The risks posed by global warming of 1.5°C are greater than for present-day conditions but lower than at 2°C.



FAQ1.1, Figure 1: A timeline of notable dates in preparing the IPCC Special Report on Global Warming of 1.5°C (blue) embedded within processes and milestones of the United Nations Framework Convention on Climate Change (UNFCCC; grey), including events that may be relevant for discussion of temperature limits.

FAQ 1.2: How Close Are We to 1.5°C?

Summary: *Human-induced warming has already reached about 1°C above pre-industrial levels at the time of writing of this Special Report. By the decade 2006–2015, human activity had warmed the world by 0.87°C (±0.12°C) compared pre-industrial times (1850–1900). If the current warming rate continues, the world would reach human-induced global warming of 1.5°C around 2040.*

Under the 2015 Paris Agreement, countries agreed to cut greenhouse gas emissions with a view to 'holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels'. While the overall intention of strengthening the global response to climate change is clear, the Paris Agreement does not specify precisely what is meant by 'global average temperature', or what period in history should be considered 'pre-industrial'. To answer the question of how close are we to 1.5°C of warming, we need to first be clear about how both terms are defined in this Special Report.

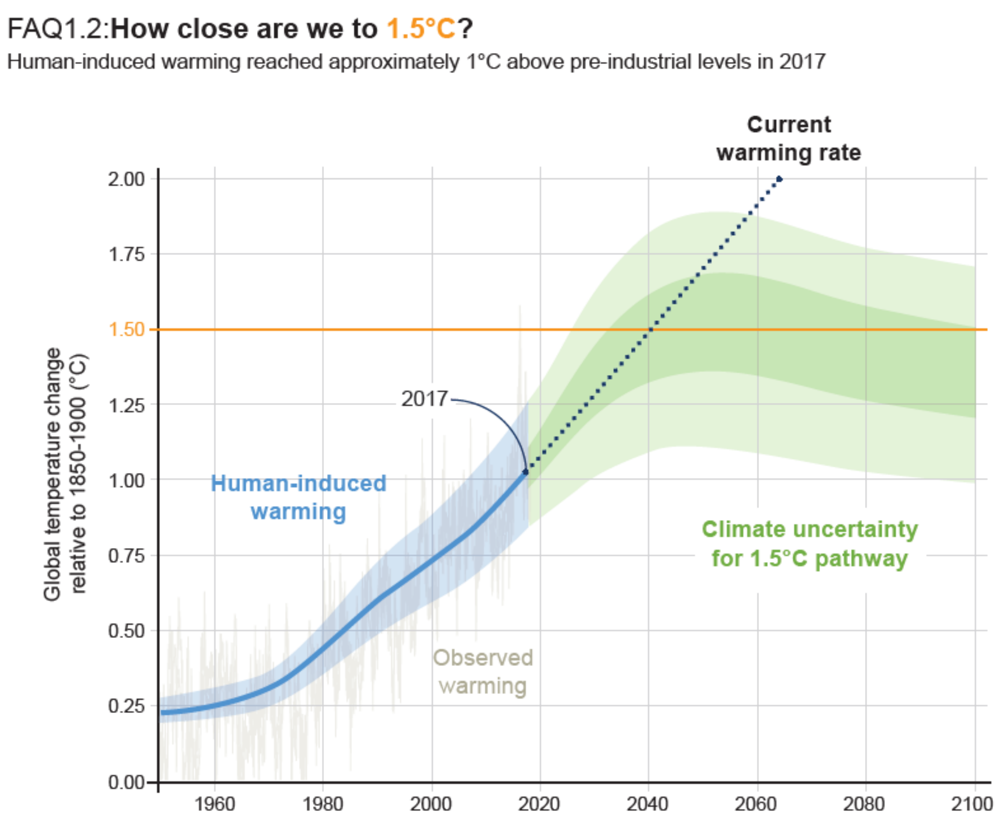
The choice of pre-industrial reference period, along with the method used to calculate global average temperature, can alter scientists' estimates of historical warming by a couple of tenths of a degree Celsius. Such differences become important in the context of a global temperature limit just half a degree above where we are now. But provided consistent definitions are used, they do not affect our understanding of how human activity is influencing the climate.

In principle, 'pre-industrial levels' could refer to any period of time before the start of the industrial revolution. But the number of direct temperature measurements decreases as we go back in time. Defining a 'pre-industrial' reference period is, therefore, a compromise between the reliability of the temperature information and how representative it is of truly pre-industrial conditions. Some pre-industrial periods are cooler than others for purely natural reasons. This could be because of spontaneous climate variability or the response of the climate to natural perturbations, such as volcanic eruptions and variations in the sun's activity. This IPCC Special Report on Global Warming of 1.5°C uses the reference period 1850–1900 to represent pre-industrial conditions. This is the earliest period with near-global observations and is the reference period used as an approximation of pre-industrial temperatures in the IPCC Fifth Assessment Report.

Once scientists have defined 'pre-industrial', the next step is to calculate the amount of warming at any given time relative to that reference period. In this report, warming is defined as the increase in the 30-year global average of combined temperature over land and at the ocean surface. The 30-year timespan accounts for the effect of natural variability, which can cause global temperatures to fluctuate from one year to the next. For example, 2015 and 2016 were both affected by a strong El Niño event, which amplified the underlying human-caused warming.

In the decade 2006–2015, warming reached 0.87°C (±0.12°C) relative to 1850–1900, predominantly due to human activity increasing the amount of greenhouse gases in the atmosphere. Given that global temperature is currently rising by 0.2°C (±0.1°C) per decade, human-induced warming reached 1°C above pre-industrial levels around 2017 and, if this pace of warming continues, would reach 1.5°C around 2040.

While the change in global average temperature tells researchers about how the planet as a whole is changing, looking more closely at specific regions, countries and seasons reveals important details. Since the 1970s, most land regions have been warming faster than the global average, for example. This means that warming in many regions has already exceeded 1.5°C above pre-industrial levels. Over a fifth of the global population live in regions that have already experienced warming in at least one season that is greater than 1.5°C above pre-industrial levels.



FAQ1.2, Figure 1: Human-induced warming reached approximately 1°C above pre-industrial levels in 2017. At the present rate, global temperatures would reach 1.5°C around 2040. Stylized 1.5°C pathway shown here involves emission reductions beginning immediately, and CO_2 emissions reaching zero by 2055.

FAQ 2.1: What Kind of Pathways Limit Warming to 1.5°C and Are We on Track?

***Summary**: There is no definitive way to limit global temperature rise to 1.5°C above pre-industrial levels. This Special Report identifies two main conceptual pathways to illustrate different interpretations. One stabilizes global temperature at, or just below, 1.5°C. Another sees global temperature temporarily exceed 1.5°C before coming back down. Countries' pledges to reduce their emissions are currently not in line with limiting global warming to 1.5°C.*

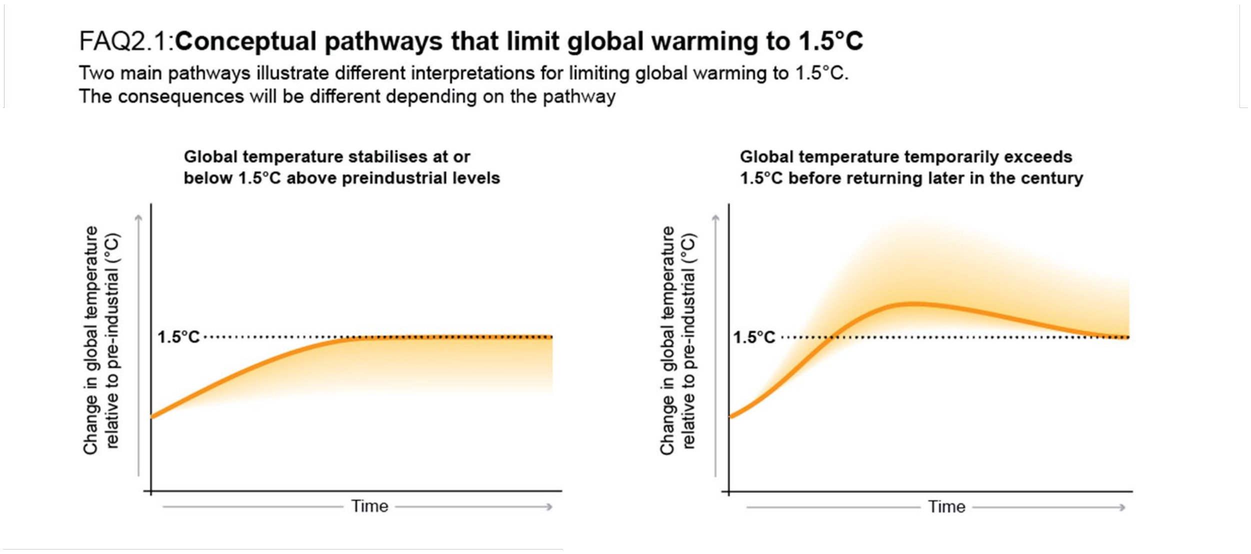
Scientists use computer models to simulate the emissions of greenhouse gases that would be consistent with different levels of warming. The different possibilities are often referred to as 'greenhouse gas emission pathways'. There is no single, definitive pathway to limiting warming to 1.5°C.

This IPCC special report identifies two main pathways that explore global warming of 1.5°C. The first involves global temperature stabilizing at or below before 1.5°C above pre-industrial levels. The second pathway sees warming exceed 1.5°C around mid-century, remain above 1.5°C for a maximum duration of a few decades, and return to below 1.5°C before 2100. The latter is often referred to as an 'overshoot' pathway. Any alternative situation in which global temperature continues to rise, exceeding 1.5°C permanently until the end of the 21st century, is not considered to be a 1.5°C pathway.

The two types of pathway have different implications for greenhouse gas emissions, as well as for climate change impacts and for achieving sustainable development. For example, the larger and longer an 'overshoot', the greater the reliance on practices or technologies that remove CO_2 from the atmosphere, on top of reducing the sources of emissions (mitigation). Such ideas for CO_2 removal have not been proven to work at scale and, therefore, run the risk of being less practical, effective or economical than assumed. There is also the risk that the use of CO_2 removal techniques ends up competing for land and water, and if these trade-offs are not appropriately managed, they can adversely affect sustainable development. Additionally, a larger and longer overshoot increases the risk for irreversible climate impacts, such as the onset of the collapse of polar ice shelves and accelerated sea level rise.

Countries that formally accept or 'ratify' the Paris Agreement submit pledges for how they intend to address climate change. Unique to each country, these pledges are known as Nationally Determined Contributions (NDCs). Different groups of researchers around the world have analysed the combined effect of adding up all the NDCs. Such analyses show that current pledges are not on track to limit global warming to 1.5°C above pre-industrial levels. If current pledges for 2030 are achieved but no more, researchers find very few (if any) ways to reduce emissions after 2030 sufficiently quickly to limit warming to 1.5°C. This, in turn, suggests that with the national pledges as they stand, warming would exceed 1.5°C, at least for a period of time, and practices and technologies that remove CO_2 from the atmosphere at a global scale would be required to return warming to 1.5°C at a later date.

A world that is consistent with holding warming to 1.5°C would see greenhouse gas emissions rapidly decline in the coming decade, with strong international cooperation and a scaling up of countries' combined ambition beyond current NDCs. In contrast, delayed action, limited international cooperation, and weak or fragmented policies that lead to stagnating or increasing greenhouse gas emissions would put the possibility of limiting global temperature rise to 1.5°C above pre-industrial levels out of reach.



FAQ2.1, Figure 1: Two main pathways for limiting global temperature rise to 1.5°C above pre-industrial levels are discussed in this Special Report. These are: stabilizing global temperature at, or just below, 1.5°C (left) and global temperature temporarily exceeding 1.5°C before coming back down later in the century (right). Temperatures shown are relative to pre-industrial but pathways are illustrative only, demonstrating conceptual not quantitative characteristics.

FAQ 2.2: What Do Energy Supply and Demand Have to do with Limiting Warming to 1.5°C?

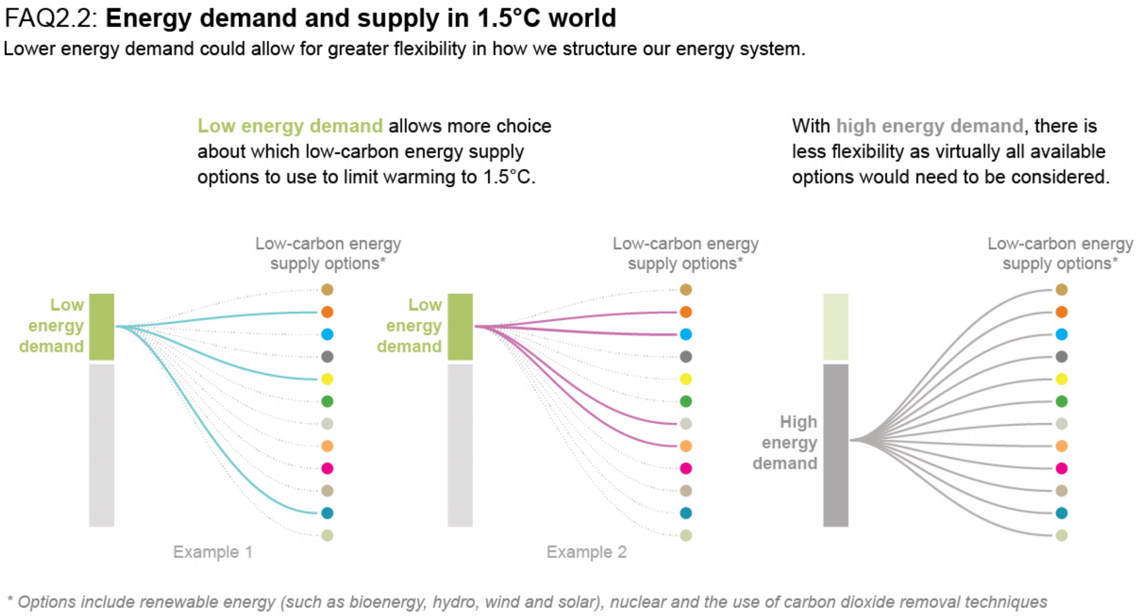
***Summary**: Limiting global warming to 1.5°C above pre-industrial levels would require major reductions in greenhouse gas emissions in all sectors. But different sectors are not independent of each other, and making changes in one can have implications for another. For example, if we as a society use a lot of energy, then this could mean we have less flexibility in the choice of mitigation options available to limit warming to 1.5°C. If we use less energy, the choice of possible actions is greater – for example, we could be less reliant on technologies that remove carbon dioxide (*CO_2*) from the atmosphere.*

To stabilize global temperature at any level, 'net' CO_2 emissions would need to be reduced to zero. This means the amount of CO_2 entering the atmosphere must equal the amount that is removed. Achieving a balance between CO_2 'sources' and 'sinks' is often referred to as 'net zero' emissions or 'carbon neutrality'. The implication of net zero emissions is that the concentration of CO_2 in the atmosphere would slowly decline over time until a new equilibrium is reached, as CO_2 emissions from human activity are redistributed and taken up by the oceans and the land biosphere. This would lead to a near-constant global temperature over many centuries.

Warming will not be limited to 1.5°C or 2°C unless transformations in a number of areas achieve the required greenhouse gas emissions reductions. Emissions would need to decline rapidly across all of society's main sectors, including buildings, industry, transport, energy, and agriculture, forestry and other land use (AFOLU). Actions that can reduce emissions include, for example, phasing out coal in the energy sector, increasing the amount of energy produced from renewable sources, electrifying transport, and reducing the 'carbon footprint' of the food we consume.

The above are examples of 'supply-side' actions. Broadly speaking, these are actions that can reduce greenhouse gas emissions through the use of low-carbon solutions. A different type of action can reduce how much energy human society uses, while still ensuring increasing levels of development and well-being. Known as 'demand-side' actions, this category includes improving energy efficiency in buildings and reducing consumption of energy- and greenhouse-gas intensive products through behavioural and lifestyle changes, for example. Demand- and supply-side measures are not an either-or question, they work in parallel with each other. But emphasis can be given to one or the other.

Making changes in one sector can have consequences for another, as they are not independent of each other. In other words, the choices that we make now as a society in one sector can either restrict or expand our options later on. For example, a high demand for energy could mean we would need to deploy almost all known options to reduce emissions in order to limit global temperature rise to 1.5°C above pre-industrial levels, with the potential for adverse side-effects. In particular, a pathway with high energy demand would increase our reliance on practices and technologies that remove CO_2 from the atmosphere. As of yet, such techniques have not been proven to work on a large scale and, depending on how they are implemented, could compete for land and water. By leading to lower overall energy demand, effective demand-side measures could allow for greater flexibility in how we structure our energy system. However, demand-side measures are not easy to implement and barriers have prevented the most efficient practices being used in the past.



FAQ2.2, Figure 1: Having a lower energy demand increases the flexibility in choosing options for supplying energy. A larger energy demand means many more low carbon energy supply options would need to be used.

FAQ 3.1: What are the Impacts of 1.5°C and 2°C of Warming?

***Summary**: The impacts of climate change are being felt in every inhabited continent and in the oceans. However, they are not spread uniformly across the globe, and different parts of the world experience impacts differently. An average warming of 1.5°C across the whole globe raises the risk of heatwaves and heavy rainfall events, amongst many other potential impacts. Limiting warming to 1.5°C rather than 2°C can help reduce these risks, but the impacts the world experiences will depend on the specific greenhouse gas emissions 'pathway' taken. The consequences of temporarily overshooting 1.5°C of warming and returning to this level later in the century, for example, could be larger than if temperature stabilizes below 1.5°C. The size and duration of an overshoot will also affect future impacts.*

Human activity has warmed the world by about 1°C since pre-industrial times, and the impacts of this warming have already been felt in many parts of the world. This estimate of the increase in global temperature is the average of many thousands of temperature measurements taken over the world's land and oceans. Temperatures are not changing at the same speed everywhere, however: warming is strongest on continents and is particularly strong in the Arctic in the cold season and in mid-latitude regions in the warm season. This is due to self-amplifying mechanisms, for instance due to snow and ice melt reducing the reflectivity of solar radiation at the surface, or soil drying leading to less evaporative cooling in the interior of continents. This means that some parts of the world have already experienced temperatures greater than 1.5°C above pre-industrial levels.

Extra warming on top of the approximately 1°C we have seen so far would amplify the risks and associated impacts, with implications for the world and its inhabitants. This would be the case even if the global warming is held at 1.5°C, just half a degree above where we are now, and would be further amplified at 2°C of global warming. Reaching 2°C instead of 1.5°C of global warming would lead to substantial warming of extreme hot days in all land regions. It would also lead to an increase in heavy rainfall events in some regions, particularly in the high latitudes of the Northern Hemisphere, potentially raising the risk of flooding. In addition, some regions, such as the Mediterranean, are projected to become drier at 2°C versus 1.5°C of global warming. The impacts of any additional warming would also include stronger melting of ice sheets and glaciers, as well as increased sea level rise, which would continue long after the stabilization of atmospheric CO_2 concentrations.

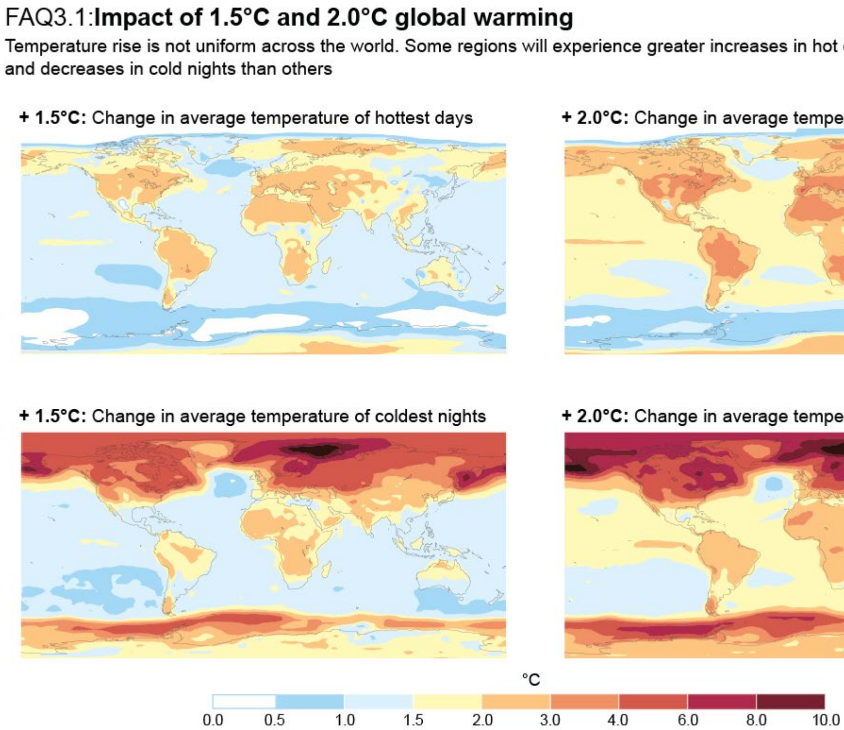
Change in climate means and extremes have knock-on effects for the societies and ecosystems living on the planet. Climate change is projected to be a poverty multiplier, which means that its impacts are expected to make the poor poorer and the total number of people living in poverty greater. The 0.5°C rise in global temperatures that we have experienced in the past 50 years has contributed to shifts in the distribution of plant and animal species, decreases in crop yields and more frequent wildfires. Similar changes can be expected with further rises in global temperature.

Essentially, the lower the rise in global temperature above pre-industrial levels, the lower the risks to human societies and natural ecosystems. Put another way, limiting warming to 1.5°C can be understood in terms of 'avoided impacts' compared to higher levels of warming. Many of the impacts of climate change assessed in this report have lower associated risks at 1.5°C compared to 2°C.

Thermal expansion of the oceans, resulting from delayed ocean mixing, means sea level will continue to rise even if global temperature is limited to 1.5°C, but this rise would be lower than in a 2°C warmer world. Ocean acidification, the process by which excess CO_2 dissolves into oceans and makes them more acidic, is expected to be less damaging in a world where CO_2 emissions are reduced and warming is stabilized at 1.5°C compared to 2°C. The persistence of coral reefs is greater in a 1.5°C world than that of a 2°C world, too.

The impacts of climate change that we experience in future will be affected by factors other than the change in temperature. The consequences of 1.5°C of warming will additionally depend on the specific greenhouse gas emissions 'pathway' that is followed and the extent to which adaptation can reduce vulnerability. This IPCC Special Report uses a number of 'pathways' to explore different possibilities for limiting global warming to 1.5°C above pre-industrial levels. One type of pathway sees global temperature stabilize at, or just below, 1.5°C. Another sees global temperature temporarily exceed 1.5°C before declining later in the century (known as an 'overshoot' pathway).

Such pathways would have different associated impacts, so it is important to distinguish between them for planning adaptation and mitigation strategies. For example, impacts from an overshoot pathway could be larger than impacts from a stabilization pathway. The size and duration of an overshoot would also have consequences for the impacts the world experiences. For instance, pathways that overshoot 1.5°C run a greater risk of passing through 'tipping points', thresholds beyond which certain impacts can no longer be avoided even if temperatures are brought back down later on. The collapse of the Greenland and Antarctic ice sheets on the timescale of centuries and millennia is one example of a tipping point.



FAQ 3.1, Figure 1: Temperature change is not uniform across the globe. Projected changes are shown for the average temperature of the annual hottest day (top) and the annual coldest night (bottom) with 1.5°C of global warming (left) and 2°C of global warming (right) compared to pre-industrial levels.

FAQ 4.1: What Transitions Could Enable Limiting Global Warming to 1.5°C?

Summary: *In order to limit warming to 1.5°C above pre-industrial levels, the world would need to transform in a number of complex and connected ways. While transitions towards lower greenhouse gas emissions are underway in some cities, regions, countries, businesses and communities, there are few that are currently consistent with limiting warming to 1.5°C. Meeting this challenge would require a rapid escalation in the current scale and pace of change, particularly in the coming decades. There are many factors that affect the feasibility of different adaptation and mitigation options that could help limit warming to 1.5°C and with adapting to the consequences.*

There are actions across all sectors that can substantially reduce greenhouse gas emissions. This Special Report assesses energy, land and ecosystems, urban and infrastructure, and industry in developed and developing nations to see how they would need to be transformed to limit warming to 1.5°C. Examples of actions include shifting to low- or zero-emission power generation, such as renewables; changing food systems, such as diet changes away from land-intensive animal products; electrifying transport and developing 'green infrastructure', such as building green roofs, or improving energy efficiency by smart urban planning, which will change the layout of many cities.

Because these different actions are connected, a 'whole systems' approach would be needed for the type of transformations that could limit warming to 1.5°C. This means that all relevant companies, industries and stakeholders would need to be involved to increase the support and chance of successful implementation. As an illustration, the deployment of low-emission technology (e.g., renewable energy projects or a bio-based chemical plants) would depend upon economic conditions (e.g., employment generation or capacity to mobilize investment), but also on social/cultural conditions (e.g., awareness and acceptability) and institutional conditions (e.g., political support and understanding).

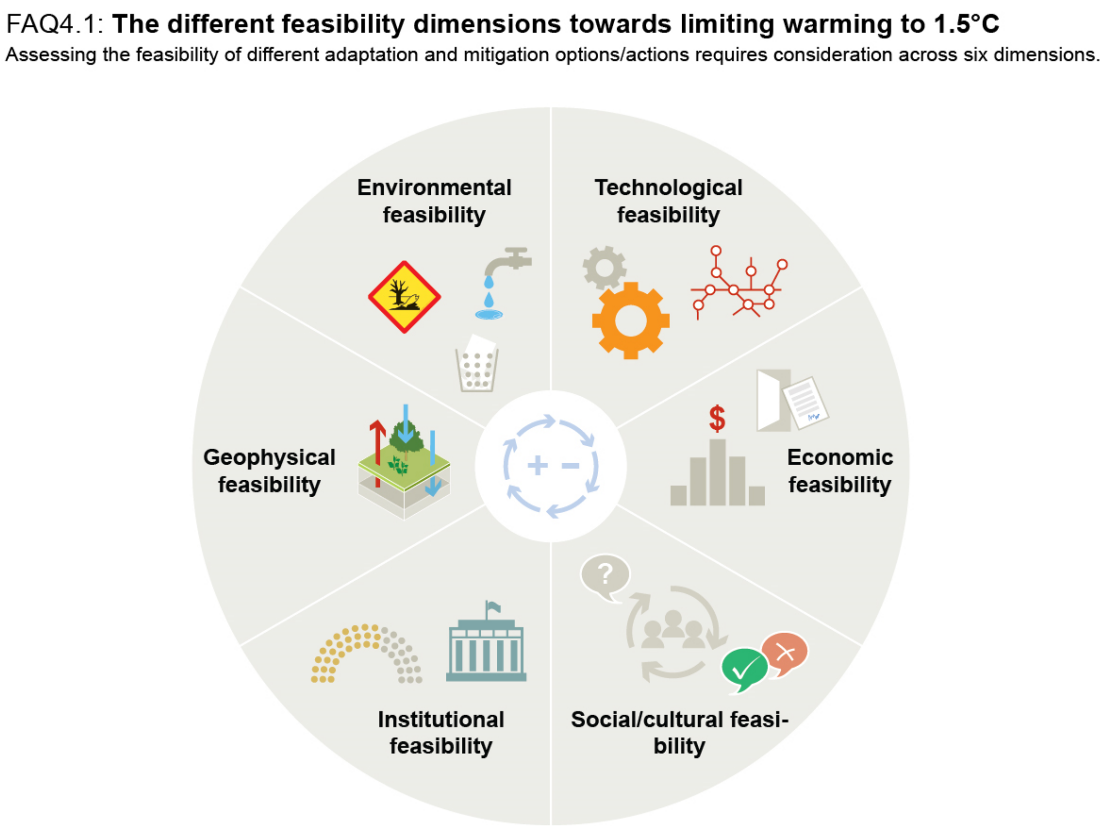
To limit warming to1.5°C, mitigation would have to be large-scale and rapid. Transitions can be transformative or incremental, and they often, but not always, go hand in hand. Transformative change can arise from growth in demand for a new product or market, such that it displaces an existing one. This is sometimes called 'disruptive innovation'. For example, high demand for LED lighting is now making more energy-intensive, incandescent lighting near-obsolete, with the support of policy action that spurred rapid industry innovation. Similarly, smart phones have become global in use within ten years. But electric cars, which were released around the same time, have not been adopted so quickly because the bigger, more connected transport and energy systems are harder to change. Renewable energy, especially solar and wind, is considered to be disruptive by some as it is rapidly being adopted and is transitioning faster than predicted. But its demand is not yet uniform. Urban systems that are moving towards transformation are coupling solar and wind with battery storage and electric vehicles in a more incremental transition, though this would still require changes in regulations, tax incentives, new standards, demonstration projects and education programmes to enable markets for this system to work.

Transitional changes are already underway in many systems, but limiting warming to 1.5°C would require a rapid escalation in the scale and pace of transition, particularly in the next 10–20 years. While limiting warming to 1.5°C would involve many of the same types of transitions as limiting warming to 2°C, the pace of change would need to be much faster. While the *pace* of change that would be required to limit warming to 1.5°C can be found in the past, there is no historical precedent for the *scale* of the necessary transitions, in particular in a socially and economically sustainable way. Resolving such speed and scale issues would require people's support, public-sector interventions and private-sector cooperation.

Different types of transitions carry with them different associated costs and requirements for institutional or governmental support. Some are also easier to scale up than others, and some need more government support than others. Transitions between, and within, these systems are connected and none would be sufficient on its own to limit warming to 1.5°C.

The 'feasibility' of adaptation and mitigation options or actions within each system that together can limit warming to 1.5°C within the context of sustainable development and efforts to eradicate poverty requires careful consideration of multiple different factors. These factors include: (i) whether sufficient natural systems and resources are available to support the various options for transitioning (known as *environmental feasibility*); (ii) the degree to which the required technologies are developed and available (known as *technological feasibility*); (iii) the economic conditions and implications (known as *economic feasibility*); (iv) what are the implications for human behaviour and health (known as *social/cultural feasibility*); and (v) what type of institutional support would be needed, such as governance, institutional capacity and political support (known as *institutional feasibility*). An additional factor (vi – known as the *geophysical feasibility*) addresses the capacity of physical systems to carry the option, for example, whether it is geophysically possible to implement large-scale afforestation consistent with 1.5°C.

Promoting enabling conditions, such as finance, innovation and behaviour change, would reduce barriers to the options, make the required speed and scale of the system transitions more likely, and therefore would increase the overall feasibility limiting warming to 1.5°C.



FAQ4.1, Figure 1: The different dimensions to consider when assessing the 'feasibility' of adaptation and mitigation options or actions within each system that can help to limit warming to 1.5°C. These

are: (i) the environmental feasibility; (ii) the technological feasibility; (iii) the economic feasibility; (iv) the social/cultural feasibility; (v) the institutional feasibility; and (vi) the geophysical feasibility.

FAQ 4.2: What are Carbon Dioxide Removal and Negative Emissions?

Summary: *Carbon dioxide removal (CDR) refers to the process of removing CO_2 from the atmosphere. Since this is the opposite of emissions, practices or technologies that remove CO_2 are often described as achieving 'negative emissions'. The process is sometimes referred to more broadly as greenhouse gas removal if it involves removing gases other than CO_2. There are two main types of CDR: either enhancing existing natural processes that remove carbon from the atmosphere (e.g., by increasing its uptake by trees, soil, or other 'carbon sinks') or using chemical processes to, for example, capture CO_2 directly from the ambient air and store it elsewhere (e.g., underground). All CDR methods are at different stages of development and some are more conceptual than others, as they have not been tested at scale.*

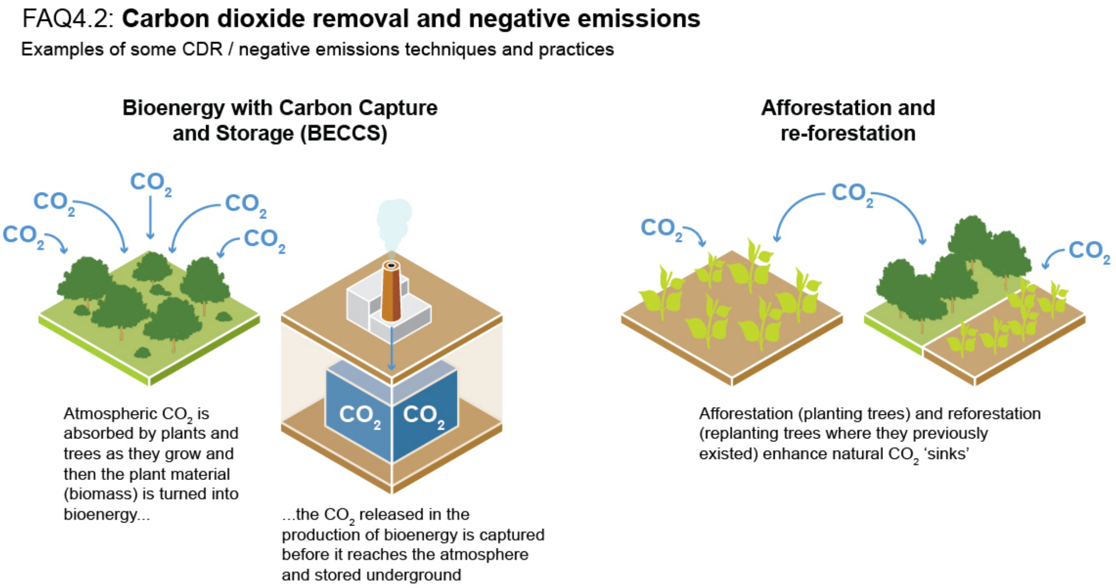
Limiting warming to 1.5°C above pre-industrial levels would require unprecedented rates of transformation in many areas, including in the energy and industrial sectors, for example. Conceptually, it is possible that techniques to draw CO_2 out of the atmosphere (known as carbon dioxide removal, or CDR) could contribute to limiting warming to 1.5°C. One use of CDR could be to compensate for greenhouse gas emissions from sectors that cannot completely decarbonize, or which may take a long time to do so.

If global temperature temporarily overshoots 1.5°C, CDR would be required to reduce the atmospheric concentration of CO_2 to bring global temperature back down. To achieve this temperature reduction, the amount of CO_2 drawn out of the atmosphere would need to be greater than the amount entering the atmosphere, resulting in 'net negative emissions'. This would involve a greater amount of CDR than stabilizing atmospheric CO_2 concentration – and, therefore, global temperature – at a certain level. The larger and longer an overshoot, the greater the reliance on practices that remove CO_2 from the atmosphere.

There are a number of CDR methods, each with different potentials for achieving negative emissions, as well as different associated costs and side effects. They are also at differing levels of development, with some more conceptual than others. One example of a CDR method in the demonstration phase is a process known as bioenergy with carbon capture and storage (BECCS), in which atmospheric CO_2 is absorbed by plants and trees as they grow, and then the plant material (biomass) is burned to produce bioenergy. The CO_2 released in the production of bioenergy is captured before it reaches the atmosphere and stored in geological formations deep underground on very long timescales. Since the plants absorb CO_2 as they grow and the process does not emit CO_2, the overall effect can be to reduce atmospheric CO_2.

Afforestation (planting new trees) and reforestation (replanting trees where they previously existed) are also considered forms of CDR because they enhance natural CO_2 'sinks'. Another category of CDR techniques uses chemical processes to capture CO_2 from the air and store it away on very long timescales. In a process known as direct air carbon capture and storage (DACCS), CO_2 is extracted directly from the air and stored in geological formations deep underground. Converting waste plant material into a charcoal-like substance called biochar and burying it in soil can also be used to store carbon away from the atmosphere for decades to centuries.

There can be beneficial side effects of some types of CDR, other than removing CO_2 from the atmosphere. For example, restoring forests or mangroves can enhance biodiversity and protect against flooding and storms. But there could also be risks involved with some CDR methods. For example, deploying BECCS at large scale would require a large amount of land to cultivate the biomass required for bioenergy. This could have consequences for sustainable development if the use of land competes with producing food to support a growing population, biodiversity conservation or land rights. There are also other considerations. For example, there are uncertainties about how much it would cost to deploy DACCS as a CDR technique, given that removing CO_2 from the air requires considerable energy.



FAQ4.2, Figure 1: Carbon dioxide removal (CDR) refers to the process of removing CO_2 from the atmosphere. There are a number of CDR techniques, each with different potential for achieving ‘negative emissions’, as well as different associated costs and side effects.

FAQ 4.3: Why is Adaptation Important in a 1.5°C-Warmer World?

Summary*: Adaptation is the process of adjusting to current or expected changes in climate and its effects. Even though climate change is a global problem, its impacts are experienced differently across the world. This means that responses are often specific to the local context, and so people in different regions are adapting in different ways. A rise in global temperature from the current 1°C above pre-industrial levels to 1.5°C, and beyond, increases the need for adaptation. Therefore, stabilizing global temperatures at 1.5°C above pre-industrial levels would require a smaller adaptation effort than at 2°C. Despite many successful examples around the world, progress in adaptation is, in many regions, in its infancy and unevenly distributed globally.*

Adaptation refers to the process of adjustment to actual or expected changes in climate and its effects. Since different parts of the world are experiencing the impacts of climate change differently, there is similar diversity in how people in a given region are adapting to those impacts.

The world is already experiencing the impacts from 1°C of global warming above pre-industrial levels, and there are many examples of adaptation to impacts associated with this warming. Examples of adaptation efforts taking place around the world include investing in flood defences such as building sea walls or restoring mangroves, efforts to guide development away from high risk areas, modifying crops to avoid yield reductions, and using social learning (social interactions that changes understanding on the community level) to modify agricultural practices, amongst many others. Adaptation also involves building capacity to respond better to climate change impacts, including making governance more flexible and strengthening financing mechanisms, such as by providing different types of insurance.

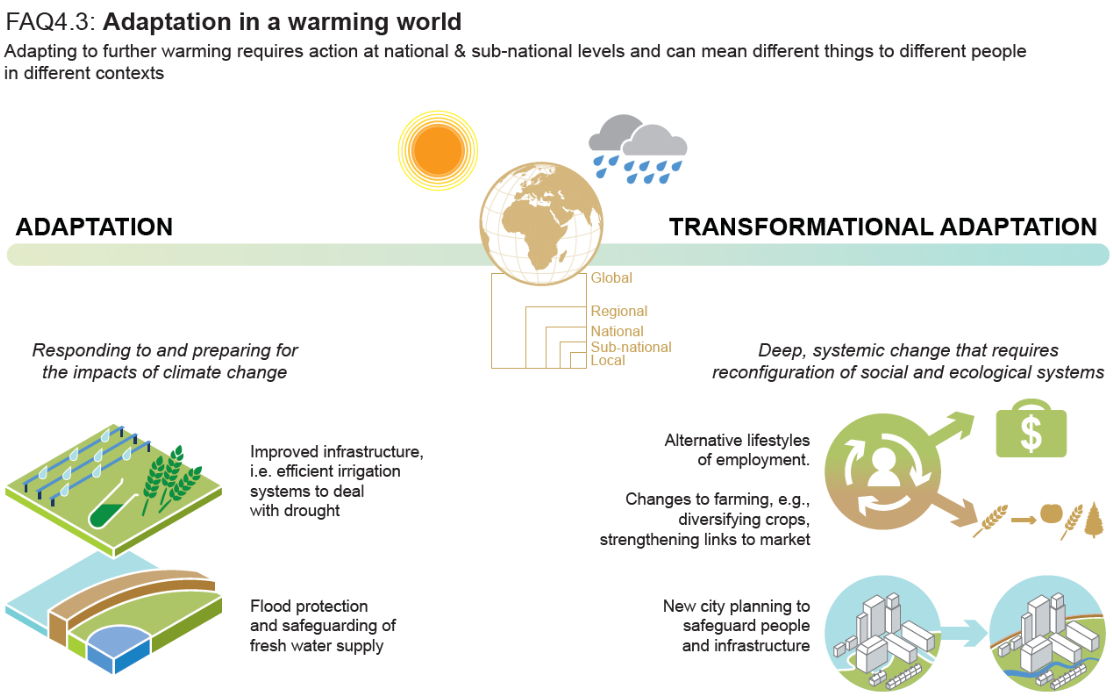
In general, an increase in global temperature from present day to 1.5°C or 2°C (or higher) above pre-industrial temperatures would increase the need for adaptation. Stabilising global temperature increase at 1.5°C would require a smaller adaptation effort than for 2°C.

Since adaptation is still in early stages in many regions, there are questions about the capacity of vulnerable communities to cope with any amount of further warming. Successful adaptation can be supported at the national and sub-national levels, with national governments playing an important role in coordination, planning, determining policy priorities, and distributing resources and support. However, given that the need for adaptation can be very different from one community to the next, the kinds of measures that can successfully reduce climate risks will also depend heavily on the local context.

When done successfully, adaptation can allow individuals to adjust to the impacts of climate change in ways that minimize negative consequences and to maintain their livelihoods. This could involve, for example, a farmer switching to drought-tolerant crops to deal with increasing occurrences of heatwaves. In some cases, however, the impacts of climate change could result in entire systems changing significantly, such as moving to an entirely new agricultural system in areas where the climate is no longer suitable for current practices. Constructing sea walls to stop flooding due to sea level rise from climate change is another example of adaptation, but developing city planning to change how flood water is managed throughout the city would be an example of transformational adaptation. These actions require significantly more institutional, structural, and financial support. While this kind of transformational adaptation would not be needed everywhere in a 1.5°C world, the scale of change needed would be challenging to implement, as it requires additional support, such as through financial assistance and behavioural change. Few empirical examples exist to date.

Examples from around the world show that adaptation is an iterative process. Adaptation pathways describe how communities can make decisions about adaptation in an ongoing and flexible way. Such pathways allow for pausing, evaluating the outcomes of specific adaptation actions, and modifying the strategy as appropriate. Due to their flexible nature, adaptation pathways can help to identify the most effective ways to minimise the impacts of present and future climate change for a given local context. This is important since adaptation can sometimes exacerbate vulnerabilities and existing inequalities if poorly designed. The unintended negative consequences of adaptation that can sometimes occur are known as 'maladaptation'. Maladaptation can be seen if a particular adaptation option has negative consequences for some (e.g., rainwater harvesting upstream might reduce water availability downstream) or if an adaptation intervention in the present has trade-offs in the future (e.g., desalination plants may improve water availability in the present but have large energy demands over time).

While adaptation is important to reduce the negative impacts from climate change, adaptation measures on their own are not enough to prevent climate change impacts entirely. The more global temperature rises, the more frequent, severe, and erratic the impacts will be, and adaptation may not protect against all risks. Examples of where limits may be reached include substantial loss of coral reefs, massive range losses for terrestrial species, more human deaths from extreme heat, and losses of coastal-dependent livelihoods in low lying islands and coasts.



FAQ4.3, Figure 1: Examples of adaptation and transformational adaptation. Adapting to further warming requires action at national and sub-national levels and can mean different things to different people in different contexts. While transformational adaptation would not be needed everywhere in a world limited to 1.5°C warming, the scale of change needed would be challenging to implement.

FAQ 5.1: What Are the Connections between Sustainable Development and Limiting Global Warming to 1.5°C above Pre-Industrial Levels?

Summary: *Sustainable development seeks to meet the needs of people living today without compromising the needs of future generations, while balancing social, economic and environmental considerations. The 17 UN Sustainable Development Goals (SDGs) include targets for eradicating poverty; ensuring health, energy and food security; reducing inequality; protecting ecosystems; pursuing sustainable cities and economies; and a goal for climate action (SDG13). Climate change affects the ability to achieve sustainable development goals, and limiting warming to 1.5°C will help meet some sustainable development targets. Pursuing sustainable development will influence emissions, impacts and vulnerabilities. Responses to climate change in the form of adaptation and mitigation will also interact with sustainable development with positive effects, known as synergies, or negative effects, known as trade-offs. Responses to climate change can be planned to maximize synergies and limit trade-offs with sustainable development.*

For more than 25 years, the United Nations (UN) and other international organizations have embraced the concept of sustainable development to promote well-being and meet the needs of today's population without compromising the needs of future generations. This concept spans economic, social and environmental objectives including poverty and hunger alleviation, equitable economic growth, access to resources, and the protection of water, air and ecosystems. Between 1990 and 2015, the UN monitored a set of eight Millennium Development Goals (MDGs). They reported progress in reducing poverty, easing hunger and child mortality, and improving access to clean water and sanitation. But with millions remaining in poor health, living in poverty and facing serious problems associated with climate change, pollution and land-use change, the UN decided that more needed to be done. In 2015, the UN Sustainable Development Goals (SDGs) were endorsed as part of the 2030 Agenda for Sustainable Development. The 17 SDGs (Figure FAQ 5.1) apply to all countries and have a timeline for success by 2030. The SDGs seek to eliminate extreme poverty and hunger; ensure health, education, peace, safe water and clean energy for all; promote inclusive and sustainable consumption, cities, infrastructure and economic growth; reduce inequality including gender inequality; combat climate change and protect oceans and terrestrial ecosystems.

Climate change and sustainable development are fundamentally connected. Previous IPCC reports found that climate change can undermine sustainable development, and that well-designed mitigation and adaptation responses can support poverty alleviation, food security, healthy ecosystems, equality and other dimensions of sustainable development. Limiting global warming to 1.5°C would require mitigation actions and adaptation measures to be taken at all levels. These adaptation and mitigation actions would include reducing emissions and increasing resilience through technology and infrastructure choices, as well as changing behaviour and policy. These actions can interact with sustainable development objectives in positive ways that strengthen sustainable development, known as synergies. Or they can interact in negative ways, where sustainable development is hindered or reversed, known as trade-offs.

An example of a synergy is sustainable forest management, which can prevent emissions from deforestation and take up carbon to reduce warming at reasonable cost. It can work synergistically with other dimensions of sustainable development by providing food (SDG 2) and clean water (SDG 6) and protecting ecosystems (SDG 15). Other examples of synergies are when climate adaptation measures, such as coastal or agricultural projects, empower women and benefit local incomes, health and ecosystems.

An example of a trade-off can occur if ambitious climate change mitigation compatible with 1.5°C changes land use in ways that have negative impacts on sustainable development. An example could be turning natural forests, agricultural areas, or land under indigenous or local ownership to plantations for bioenergy production. If not managed carefully, such changes could undermine dimensions of sustainable development by threatening food and water security, creating conflict over land rights and causing biodiversity loss. Another trade-off could occur for some countries, assets, workers and infrastructure already in place if a switch is made from fossil fuels to other energy sources without adequate planning for such a transition. Trade-offs can be minimized if effectively managed, as when care is taken to improve bioenergy crop yields to reduce harmful land-use change or where workers are retrained for employment in lower carbon sectors.

Limiting temperatures to 1.5°C can make it much easier to achieve the SDGs, but it is also possible that pursuing the SDGs could result in trade-offs with efforts to limit climate change. There are trade-offs when people escaping from poverty and hunger consume more energy or land and thus increase emissions, or if goals for economic growth and industrialization increase fossil fuel consumption and greenhouse gas emissions. Conversely, efforts to reduce poverty and gender inequalities and to enhance food, health and water security can reduce vulnerability to climate change. Other synergies can occur when coastal and ocean ecosystem protection reduces the impacts of climate change on these systems. The sustainable development goal of affordable and clean energy (SDG 7) specifically targets access to renewable energy and energy efficiency, which are important to ambitious mitigation and limiting warming to 1.5°C.

The link between sustainable development and limiting global warming to 1.5°C is recognized by the SDG for climate action (SDG 13), which seeks to combat climate change and its impacts while acknowledging that the United Nations Framework Convention on Climate Change (UNFCCC) is the primary international, intergovernmental forum for negotiating the global response to climate change.

The challenge is to put in place sustainable development policies and actions that reduce deprivation, alleviate poverty and ease ecosystem degradation while also lowering emissions, reducing climate change impacts and facilitating adaptation. It is important to strengthen synergies and minimize trade-offs when planning climate change adaptation and mitigation actions. Unfortunately, not all trade-offs can be avoided or minimized, but careful planning and implementation can build the enabling conditions for long-term sustainable development.

FAQ5.1: **The United Nations Sustainable Development Goals (SDGs)**

The link between sustainable development and limiting global warming to 1.5°C is recognised by the Sustainable Development Goal for climate action (SDG 13)

FAQ 5.1, Figure 1: Climate change action is one of the United Nations Sustainable Development Goals (SDGs) and is connected to sustainable development more broadly. Actions to reduce climate

risk can interact with other sustainable development objectives in positive ways (synergies) and negative ways (trade-offs).

FAQ 5.2: What are the Pathways to Achieving Poverty Reduction and Reducing Inequalities While Reaching the 1.5°C World?

Summary: *There are ways to limit global warming to 1.5°C above pre-industrial levels. Of the pathways that exist, some simultaneously achieve sustainable development. They entail a mix of measures that lower emissions and reduce the impacts of climate change, while contributing to poverty eradication and reducing inequalities. Which pathways are possible and desirable will differ between and within regions and nations. This is due to the fact that development progress to date has been uneven and climate-related risks are unevenly distributed. Flexible governance would be needed to ensure that such pathways are inclusive, fair and equitable to avoid poor and disadvantaged populations becoming worse off. Climate-resilient development pathways (CRDPs) offer possibilities to achieve both equitable and low-carbon futures.*

Issues of equity and fairness have long been central to climate change and sustainable development. Equity, like equality, aims to promote justness and fairness for all. This is not necessarily the same as treating everyone equally, since not everyone comes from the same starting point. Often used interchangeably with fairness and justice, equity implies implementing different actions in different places, all with a view to creating an equal world that is fair for all and where no one is left behind.

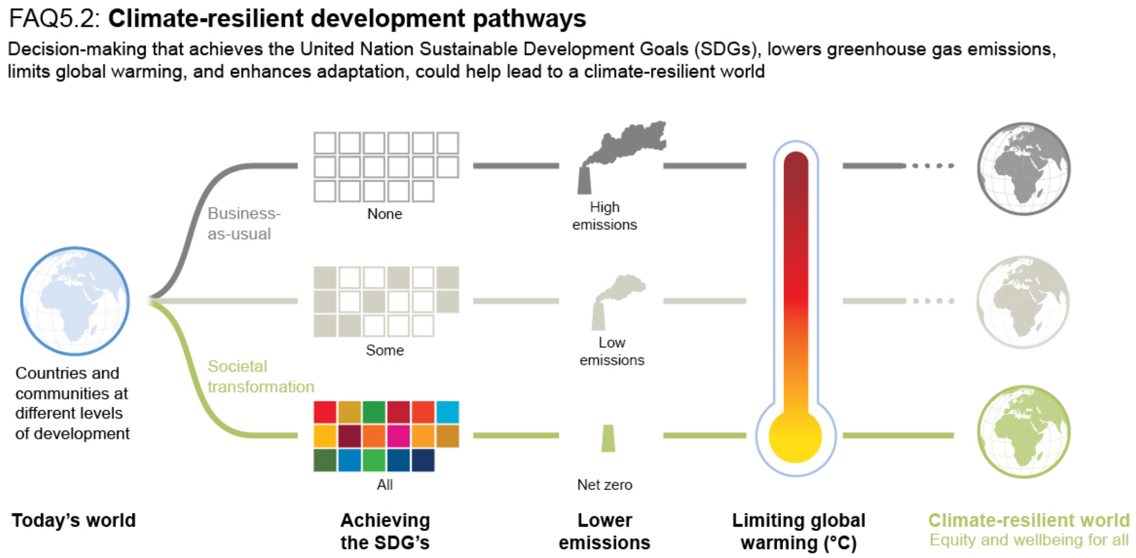
The Paris Agreement states that it 'will be implemented to reflect equity… in the light of different national circumstances' and calls for 'rapid reductions' of greenhouse gases to be achieved 'on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty'. Similarly, the UN SDGs include targets to reduce poverty and inequalities, and to ensure equitable and affordable access to health, water and energy for all.

The principles of equity and fairness are important for considering pathways that limit warming to 1.5°C in a way that is liveable for every person and species. They recognize the uneven development status between richer and poorer nations, the uneven distribution of climate impacts (including on future generations) and the uneven capacity of different nations and people to respond to climate risks. This is particularly true for those who are highly vulnerable to climate change, such as indigenous communities in the Arctic, people whose livelihoods depend on agriculture or coastal and marine ecosystems, and inhabitants of small island developing states. The poorest people will continue to experience climate change through the loss of income and livelihood opportunities, hunger, adverse health effects and displacement.

Well-planned adaptation and mitigation measures are essential to avoid exacerbating inequalities or creating new injustices. Pathways that are compatible with limiting warming to 1.5°C and aligned with the SDGs consider mitigation and adaptation options that reduce inequalities in terms of who benefits, who pays the costs and who is affected by possible negative consequences. Attention to equity ensures that disadvantaged people can secure their livelihoods and live in dignity, and that those who experience mitigation or adaptation costs have financial and technical support to enable fair transitions.

CRDPs describe trajectories that pursue the dual goal of limiting warming to 1.5°C while strengthening sustainable development. This includes eradicating poverty as well as reducing vulnerabilities and inequalities for regions, countries, communities, businesses and cities. These trajectories entail a mix of adaptation and mitigation measures consistent with profound societal and systems transformations. The goals are to meet the short-term SDGs, achieve longer-term sustainable development, reduce emissions towards net zero around the middle of the century, build resilience and enhance human capacities to adapt, all while paying close attention to equity and well-being for all.

The characteristics of CRDPs will differ across communities and nations, and will be based on deliberations with a diverse range of people, including those most affected by climate change and by possible routes towards transformation. For this reason, there are no standard methods for designing CRDPs or for monitoring their progress towards climate-resilient futures. However, examples from around the world demonstrate that flexible and inclusive governance structures and broad participation often help support iterative decision-making, continuous learning and experimentation. Such inclusive processes can also help to overcome weak institutional arrangements and power structures that may further exacerbate inequalities.



FAQ 5.2, Figure 1: Climate-resilient development pathways (CRDPs) describe trajectories that pursue the dual goals of limiting warming to 1.5°C while strengthening sustainable development. Decision-making that achieves the SDGs, lowers greenhouse gas emissions and limits global warming could help lead to a climate-resilient world, within the context of enhancing adaptation.

Ambitious actions already underway around the world can offer insight into CRDPs for limiting warming to 1.5°C. For example, some countries have adopted clean energy and sustainable transport while creating environmentally friendly jobs and supporting social welfare programmes to reduce domestic poverty. Other examples teach us about different ways to promote development through practices inspired by community values. For instance, *Buen Vivir*, a Latin American concept based on indigenous ideas of communities living in harmony with nature, is aligned with peace; diversity; solidarity; rights to education, health, and safe food, water, and energy; and well-being and justice for all. The Transition Movement, with origins in Europe, promotes equitable and resilient communities through low-carbon living, food self-sufficiency and citizen science. Such examples indicate that pathways that reduce poverty and inequalities while limiting warming to 1.5°C are possible and that they can provide guidance on pathways towards socially desirable, equitable and low-carbon futures.

This is **Exhibit F** referred to in the

affidavit of **John Moffet**

affirmed before me on **January 29, 2019**

Commissioner for Oaths for Québec

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ECONOMICS AND SECURITY COMMITTEE

ASSESSING AND MITIGATING THE COST OF CLIMATE CHANGE

REPORT

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Acting Rapporteur
Sub-Committee on Transatlantic Economic Relations

www.nato-pa.int 7 October 2017

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I. INTRODUCTION

1. This report explores a range of challenges linked to climate change and considers recent international efforts to cope with the problem. It seeks to take stock of some of the potential costs climate changes will induce and explores several of the important trade-offs the international community confronts as it grapples with this exceedingly complex and important set of environmental changes. It will do so by surveying some of the recent work environmental scientists and economists have undertaken to assess the potential costs to the global economy of climate change, the costs of undertaking efforts to mitigate that change and the possible price tag of failing to do so. The report will also look at new economic opportunities adaptation and mitigation create and suggests that first movers may derive outsized economic advantages. It finally explores the special challenges faced in the High North and explores several of the security implications of climate change and how this might shape the security environment in which NATO member countries operate.

2. Examples of the ways climate change are becoming apparent are myriad. To take one example, in the autumn of 2016, Danish and US researchers reported that warming air and sea surfaces were likely to trigger record lows of sea ice in the High North. Air temperatures in the High North in November 2016 were 20°C higher than what had been the “normal temperatures of -25 °C between 1981 and 2010, suddenly hovering near freezing - this at a time of year when the sun no longer shines above the horizon. Warmer waters naturally take longer to freeze and not surprisingly sea ice remained exceedingly thin in 2017 (Vidal). This shocking development, however, reflected a broader long range trend. The rate of warming in the Arctic from 1981 to 2001 was eight times greater than the rate of Arctic warming over the last 100 years. Not surprisingly, the Arctic’s sea ice maximum extent has fallen by an average of 2.8 % per decade since 1979. The summertime minimum extent losses are nearly five times larger: 13.5 % per decade. As the sea ice cap thins, it becomes more vulnerable to the action of ocean waters, winds and warmer temperatures (Earth Observatory).

3. The problems of Arctic warming and dramatically thinning Arctic ice illustrate the kind of tipping points of which environmental scientists have long warned. In other words, these phenomena demonstrate how global warming might accelerate to a point of no return once certain levels of warming have been breached; there is thus a risk that climate change could reach a point at which no concerted human action could reverse warming trends. What has recently transpired in the High North could well be the onset of one of these tipping points. If not, it at least illustrates the kind of complex and worrying linkages between climate phenomena that can be expected over coming decades if the international community is unable to move off the current path of greenhouse gas production.

4. Recent and dramatic changes in the High North also unambiguously illustrate the degree to which climate change has become a reality. Climate change is happening and human activity is the primarily driver of change in the current era. The US National Aeronautics and Space Agency (NASA) has pointed out that 97% or more of actively publishing climate scientists agree that climate warming trends over the past century are extremely likely due to human activities. In addition, most leading scientific organisations have issued public statements endorsing this position. The NASA webpage lists a selection of these including: the American Association for the Advancement of Science, The American Chemical Society, the American Geophyyscial Union, the American Meterological Society, the American Physical society etc. (NASA).

5. Forward looking and responsible governments need to acknowledge what is transpiring while understanding and preparing for its consequences, many of which have important economic dimensions. Indeed, the challenge confronting humanity is not simply scientific in nature. It is also social, political, and economic in nature and will thus require the international community to address climate change, mitigate its impacts, and manage its costs while constructing a more

environmentally sustainable economy out of this effort. This would be a daunting task in itself, but it is made all the more so given the elusiveness of political consensus regarding the nature of the threat and the apparent costs involved. Indeed, any political consensus on the nature of the challenge could well be eroded when the costs of climate mitigation enter the discussion. Oftentimes these costs are presented with little consideration either of the costs of failing to act or the economic opportunitites that moving to new forms of energy and energy saving might afford, and so voters rarely have an opportunity to consider trade-offs, opportunity costs and dynamic paradigm changes shaping the economy itself.

II. THE FRAMEWORK CONVENTION ON CLIMATE CHANGE: CONTENT AND PROSPECTS

6. In 2016 in Paris, it seemed that a global consensus around climate action had finally been achieved. After years of discussion, the international community agreed to directly address greenhouse gas emission mitigation, adaptation and finance. In so doing, they launched a global effort to deal with all three of these challenges. One hundred and ninety-five countries (out of 197) negotiated the language of the agreement. It was adopted by consensus in December 2015 and put into effect on 4 November 2016. As of December 2016, 194 countries had signed the Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC) and 127 had ratified it.

7. The goals of this first comprehensive climate agreement, are essentially:

- to hold the increase in the global average temperature to below 2°C above pre-industrial levels and to undertake efforts to limit temperature increases to 1.5°C above pre-industrial levels;
- to increase the international community’s ability to adapt to the adverse impacts of climate change and to foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production;
- to make financial flows consistent with a pathway towards lower greenhouse gas emissions and climate-resilient development (UNFCCC).

8. The exact contributions countries make to achieve the goals laid out in the Paris Agreement are set by nationally determined contributions (NDCs). These NDCs are submitted to the UNFCCC secretariat. They are not, however, enforceable by law and thus are ultimately dependent upon prevailing economic and political conditions among signatory countries. The signatories established a name and shame system to encourage all countries focused on following a path to emissions reduction.

9. In 2018, signatory countries will assess the degree to which the NDCs will move the world toward the goal both of halting the rise of global emissions and ultimately achieve zero net emissions by the second half of this century. At this point, the NDCs will be revalued. The structure of the Paris Agreement is thus bottom up, voluntary and seeks to build consensus broadly rather than impose highly specific obligations as did the Kyoto Protocol. While the agreement is ambitious, such ambition is necessary to cope with the challenge. The Paris Agreement also established a framework to govern the international transfer of mitigation outcomes (ITMOs) while allowing countries to use emissions reductions beyond their borders through a carbon accounting and trading system. The agreement then links up emissions trading schemes into a global accounting framework so that net global outcomes of emission reductions are registered.

10. Unlike the Kyoto Protocol, the Paris Agreement makes no formal distinction between developed and developing countries and accepts the notion that countries will do what they can to achieve the core goals of the agreement. It also establishes the principle of a Sustainable

Development Mechanism to assist parties on a voluntary basis to make their contributions to global emissions reduction while developing in an environmentally sustainable fashion.

11. Although the world's wealthier countries, many of which industrialised in the 19th century, have emitted most of the greenhouse gases driving climate change, it is the poorer countries that are likely to suffer the worst consequences. Many of the hotter and dryer countries in the global south will confront the challenge of sustaining life in ever more harsh climatic conditions. Small low-lying island nations will be the first to suffer catastrophic losses as a result of sea rise while arid countries could well see water levels fall. Countries in these conditions will undoubtedly see their economic growth affected by climate change. Many of these countries also lack the financial resources to counteract proactively the impacts of climate change. There is thus a serious responsibility on the primary generators of greenhouse gases to move now to counteract the impacts of the past and to help poorer countries cope with the challenge.

12. The concept of Common But Differentiated Responsibilities and Respective Capabilities, (CBDR-RC) recognises that while all countries share an interest in addressing climate change, their capacity to do so varies. International law recognises that the ability to finance contributions to mitigate climate change should factor into the expectations of developing countries to contribute to the effort. There is also a second principle of cost sharing suggesting that wealthier countries should support the efforts of developing countries to mitigate climate change. Finally there is a merit principle by which the greater the effort of a country to contribute to solving the problem, the more it should be rewarded. The challenge lies in squaring these three principles to find equitable and effective ways to lower carbon emissions (Bretschger).

13. A central question, of course, is how all of this is to be financed, particularly in the developing world which faces acute economic challenges. At the 2010 Cancun Climate Summit, leaders agreed a goal of mobilising USD100 billion in private and public funds to help developing countries finance both adaptation and mitigation in roughly equal measure. Without finance for the effort to limit climate change, the goals of the Paris Agreement will never be successfully reached. The International Energy Agency (IEA) recently estimated that the international community will need to spend USD16.5 trillion on climate action by 2030, which is the equivalent to approximately USD1.1 trillion a year. An important share of this will be invested in energy innovation (Geronimo and Wright) and this should be considered as much an economic as an environmental investment. Technology transfer remains key to empowering developing countries to lower greenhouse gas emissions, improve energy efficiency and mitigate the most adverse consequences of climate change. Beyond the daunting costs involved, an additional challenge is that developed countries continue to worry about intellectual property rights for green technologies and see the preservation of these rights as a way to ensure that those undertaking research in this field are properly incentivized to do so. Of course, this raises problems of affordability for developing countries. This is a classical policy dilemma which has emerged in many trade negotiations in recent years and which has required carefully balanced trade-offs and innovative solutions (Jayaraman).

14. In Paris, developed countries pledged to mobilise USD100 billion a year to help developing countries make progress in achieving both emissions reduction and adaption to climate change. A recently-produced roadmap projects that public climate finance could reach USD67 billion by 2020 so using public finance effectively to leverage increased private finance will be essential. The availability of financing for adaptation remains worryingly low even though the Paris Agreement calls for greater adaptation support for those countries most likely to suffer the consequences of climate change. These include the least developed countries and small island states that are highly vulnerable to sea rise.

15. The G7 has also announced a plan for a USD420 million Climate Risk Insurance Program. A UNFCCC Green Climate Fund targeted on low emission and climate resilient development has so far been funded to USD10 billion. Small and less developed countries have also pushed for a loss

and damage programme to help compensate for devastating losses linked, for example, to single catastrophic events or for phenomena such as land loss linked to sea rise. But developed countries have been reluctant to create a separate category for these types of events and so the focus remains on averting and minimising the impacts of climate change rather than compensating countries for losses incurred. The agreement also includes a Transparency Framework to ensure that progress in meeting targets is monitored and published. Countries are obliged to report on any headway that they have made in mitigating emissions, adaptation, finance, technology development and transfer and capacity building and they need to do so in a peer review framework.

16. The Obama Administration never put the Paris Agreement to a ratification vote in the US Senate. Because there are no legal action-related or financial obligations pertaining to the Paris Agreement and because the US Senate had ratified the 1992 UNFCCC Treaty, it legally fell under the guise of an executive agreement rather than a treaty. During the presidential campaign in the United States, Donald Trump announced that if he were elected, his administration would pull out of the Paris Agrement and withdraw all funding from the UN Framework Convention on Climate Change. This has now come to pass. The Administration has announced that terminate US payments into the Green Climate Fund, which had been created in advance of the Paris Agreement, to support climate change related projects in developing countries (Kotchen). These funds were to help fund infrastucture needed to develop and deploy clean energy or to encourage investment for the same ends. Because many of these projects were to pay returns that would then be plowed back into other projects, the impact could be extensive (Worland). The Trump Administration has also made it clear that it will not seek to fulfill the promises the Obama Administration had made to move toward an energy mix in which the importance of renewable energy would steadily increase. Indeed, the new administration has announced that in addition to pulling out of the Paris Accord, it also hopes to increase US oil and gas drilling and coal mining, reduce subsidies for renewable energy (Cohen) and even impose retroactive tariffs on imported solar panels which have helped make the industry competitive (Cardwell). A legal discussion is now underway as to whether the United States would still be obliged to submit to its legally binding procedural commitments under the Paris Agreement for a four-year period, although it could simply leave the UNFCCC altogether (Chemnick).

17. President Trump had previously suggested that he believed climate change is a “hoax” foisted on the world by the Chinese “in order to make US manufacturing non-competitive” (Jacobson). This view does not suggest a great deal of leeway for dialogue on the issue between Europe and the United States and indeed, in the wake of the Administration’s decision to withdraw from the Paris Agreement, the issue has unfortunately become a source of trans-Atlantic diplomatic and political tension. Indeed, the new US position has triggered concerns in European capitals and in Canada, where the science surrounding climate change is widely accepted and the Paris Agreement has been strongly embraced as a key step to coping with the challenge (Reuters). But there is no doubt that the effort to carry out that dialogue will continue as the issue is not going away and the current disagreement will not be allowed to undermine allied solidarity in the broader sense. For example,the issue came up in the 14 July meeting President Trump had with French President Macron in Paris.

III. THE EXPERT COMMUNITY COMES TO GRIPS WITH THE ECONOMIC CONSEQUENCES OF CLIMATE CHANGE

18. Climate science is obviously highly complex and dependent upon many variables. Although there is a near consensus among scientists, if not among politicians, that the global climate is changing rapidly and that human activity is the main driver of these changes, all the consequences of a warming planet are not fully understood. Scientists and economists, however, have developed a range of scenarios to facilitate climate and economic forecasting. Any attempt to come to grips

with the potential costs of climate change, the cost of moving the planet off the pathway to significant warming, the price tag of failing to do so and the cost of adjustment to a warmer planet is dependent on these climate change models.

19. A number of economists have begun to think through potential environmental outcomes and the stakes and costs of various policy options aiming to cope with these outcomes. It is essential that this work be done; societies need to make informed critical judgements about possible trade-offs in a setting of scarce resources. Although difficult to quantify, the impacts of climate change on the global economy are likely to be significant. Some of these costs will be direct, while others will be indirect. Some of the impacts will be one off – such as catastrophic incidents like super storms emerging over warmer oceans - while others, like desertification or sea rise, are likely to persist or even worsen over time. Some costs will be evident in the short run while others will only reveal themselves over the longer term. It is expected, for example, that the number of people exposed to episodes of extreme rainfall will quadruple over the next century while the number of those exposed to drought will triple. The exposure of older people to drought will rise 12 fold according one study led by Peter Cox at the University of Exeter (Tavernise). And of course, there could also be economic benefits, for example, from new possibilities to navigate Arctic waters, mining and agricultural opportunities arising from retreating ice, longer growing seasons in northern climes, and lower heating costs in regions where these costs have traditionally been daunting. It is interesting to note that most of the potential benefits accrue to developed countries in cooler northern locations.

20. More quantifiable economic consequences will likely include developments such as falling crop yields, loss of land due to sea rise, altered fisheries, storm related damages, increased energy required for cooling, and public health challenges requiring new health expenditures. There is substantial evidence that in global terms a warming planet will reduce yields of critical commodities like maize. The yield of African maize, for example, has fallen in direct correlation with rising temperatures on that continent as has US maize (Presentation by Marshall Burke, NATO PA Spring Session 2016, Tbilisi, Georgia). Severe weather events will become more frequent as ocean temperatures rise and these would likely become more lethal and destructive. The Intergovernmental Panel on Climate Change (IPCC) projections forecast a sea-level rise of 52-98 cm by 2100 if greenhouse emissions continue to grow, or of 28-61 cm if emissions are strongly curbed. The former would imply a sea level rise of 5-110 meters which would threaten the survival of coastal cities and island nations (“Climate Change 2013: The Physical Science Basis,” IPCC, Fifth Report, Chapter 13). This would threaten the lives of billions of people living along the world’s coast lines and would obviously have devastating impacts on urban infrastructure, energy, agriculture and tourism.

21. The OECD conducted one of the more comprehensive efforts to begin to assess potential costs of climate change (OECD) . The study looked at matters such as changes in crop yields, loss of land and capital due to sea level rise, changes in fish catches, capital damages from hurricanes, labor productive changes, alteration in health care expenditure arising from the spread of disease and heat stress, altered tourism patterns and shifting energy demand for heating and cooling. Other potential impacts were not considered including phenomena such as moving beyond irreversible tipping points at which point environmental impacts become far more dramatic than currently assumed. It also excludes consideration of non-market factors like the potential for political instability related to climate change, which itself could have substantial economic costs. These are important caveats, and they point to the sheer difficulty of coming to reasonable approximation of the likely economic impacts of climate change. The OECD study, however, importantly deduces that there is still time and policy space to affect positive changes.

22. The OECD forecasts that market damages across a selected set of impacts are likely to rise gradually over time, although these costs will increase more quickly than will global economic activity. The complex economic models employed by the OECD suggested that if no further climate

change action is taken and the world remains on its current warming trajectory, the impact will undermine global growth and could result in global economic damages ranging between 1% and 6% of GDP by the end of the century, even if emissions were to fall to zero in 2060. If temperatures, however, were to rise to 4°C above pre-industrial levels by 2100, GDP would fall between 2% and 10% by the end of the century relative to a no change baseline. Higher temperatures could lead to damages as high as 12% of GNP by 2100, with the largest negative impacts on crop yields and labor productivity. The OECD study suggests that over time, sea level rises will likely become an increasingly important generator of costs and damage to the world economy. The study also notes that 23 of 25 regions of the world modelled in the analysis would likely suffer negative effects because of climate change at the levels described above. Africa and Asia would be particularly vulnerable in this regard.

23. If the Paris Agreement is to reach its goal of holding the global average temperature increase to below 2°C, countries will need to further ramp up the ambition of their commitments. A much-discussed study in the scientific journal *Nature* (Rogelj et al.) suggests that the commitments so far made by signatories of the Paris Agreement are not sufficient to achieve the global temperature target and that much more has to be done, and done sooner rather than later. The Nature piece surveyed current national pledges and argued that even if these are fully implemented, the planet would temperature increases from 2.6°C to 3.1°C by 2100 and could even warm more than this with a 10% chance of an increase 4°C. This study argues that the goal of limiting temperature rise to 1.5% is well-nigh impossible given current and promised levels of climate action. For this reason, the 2018 facilitative dialogue to take stock of the collective efforts of the parties foreseen in the Paris Agreement could well request substantial course corrections (Rogelj, et al., and Mooney, 2017).

24. The Nature study notes that there are important bonuses to acting early and that the longer climate action is delayed, the greater the reliance will be on negative emissions—or technologies that actually remove CO_2 from the atmosphere like carbon capture and storage—a far more problematic and expensive approach to the problem.

25. Another challenge relates to the global distribution of burdens arising out of climate change. According to a second Nature study, if climate change is unmitigated, average income in the poorest 40% of the world's countries would fall by as much as 75% by 2100, while the richest 20% of the world might experience slight gains (Burke, Hsiang and Miguel). That study states that:

> "*Overall economic productivity is non-linear in temperature for all countries, with productivity peaking at an annual average temperature of 13°C and declining strongly at higher temperatures. The relationship is globally generalisable, unchanged since 1960, and apparent for agricultural and non-agricultural activity in both rich and poor countries. These results provide the first evidence that economic activity in all regions is coupled to the global climate and establish a new empirical foundation for modelling economic loss in response to climate change, with important implications. If future adaptation mimics past adaptation, unmitigated warming is expected to reshape the global economy by reducing average global incomes roughly 23% by 2100 and widening global income inequality, relative to scenarios without climate change*" (Burke, Hsiang and Miguel).

26. The projected per capita income fall is five to ten times greater than reported in most other models. Fourty-three percent of the world's countries would likely be poorer in 2100 than they are today as a result of climate change, even when standard projections of technological progress are incorporated in the model. This stunning result is based on hard data exploring the relationship between economic activity and temperature rise. It does not even consider other climatic impacts beyond temperature changes. The complex statistical analysis of historical economic data separated out temperature as it relates to growth and demonstrated strong shifts in growth when temperature changes.

27. Based on past data, very cold countries like Canada and Sweden tend to grow faster as they warm while warmer countries in Africa and South Asia tend to undergo slower growth as temperature rises (Burke). The study also found economies operate optimally at roughly 13°C - the average temperature for both New York City and Palo Alto in Silicon Valley. Above and below that figure, economic performance tails off. Twenty percent of the world's countries that are now cooler than this optimal average temperature could therefore theoretically benefit from climate change (discounting, of course, the negative shocks that might be transmitted from adversely affected countries, for example, through their declining demand for imports). But 80% of countries that are currently at the optimum temperature level or above it could find their economies harmed as a result of warming. This includes key global players like Japan and the United States. The statistical study found that even wealthy countries do not escape the consequences of this logic even though they have more resources than developing countries to mitigate the impacts. Climate change could therefore augur a continual redistribution of global income favoring cooler countries which tend already to be wealthier (Maclay).

IV. CLIMATE CHANGE AND SECURITY

28. Climate change could also be a factor in triggering violent conflicts linked to declining food production, water shortages or economic crises linked to these phenomena. Indeed, the potential for conflict between regions affected by climate change cannot be ruled out. The refugee crisis shaking political stability in the Middle East and posing serious challenges in Europe could be a harbinger of things to come. The huge economic and social costs linked to mass movements on this scale are self-evident. It is distinctly possible that global climate challenges could become a trigger of mass movements of people, particularly in arid regions where agriculture and food supplies are vulnerable to drought. The potential problems here are very much worth considering and could certainly emerge as a key element in the economic fallout of unmitigated climate change.

29. Another study by the above cited three academics unearthed statistical data that linked increased human conflict to rising temperatures. That study reviewed 60 rigorous quantitative studies and unearthed striking causal evidence linking climatic events to human conflict in different regions of the world and at different times. That statistically convincing study suggested that climate has a strong influence on the level of violence: “For each standard deviation (1σ) change in climate toward warmer temperatures or more extreme rainfall, median estimates indicate that the frequency of interpersonal violence rises 4% and the frequency of intergroup conflict rises 14%." The effect of temperature change is greater than the impact of rainfall change and the effect on intergroup violence like civil war is greater than the effect of interpersonal violence like assault. (Hsiang, Buke, and Miguel) In Africa, violent conflicts increase by between 5 and 20% during hot years. Not surprisingly the numbers also suggest that hotter temperatures also correlate with increased migration. Asylum applications to the EU rise when temperatures in source countries are high and a +1°C higher temperature increases applications by roughly 10% (Presentation by Marshall Burke, NATO PA Spring Session, Tbilisi, Georgia). Civil conflict, war and the mass movement of refugees also impose major costs, and countries caught in cycles of violence invariably suffer serious setbacks to economic growth and development.

30. The impact of climate change on water supplies alone could constitute a global emergency and could generate new cylces of instability. More than 30 countries in the Middle East are expected to experience serious water stress over the next 25 years, and this could exacerbate social and political tensions throughout the region[1]. Warming will also melt high mountain glaciers with a corresponding impact on Asian rivers and water supplies although similar impacts will also be apparent elsewhere in the world.

1 See the 2017 STC report on « Food and Water Security in the Middle East » [176 STC 17 F]

31. Climate change is thus a risk multiplier and poses a particular threat to fragile states. Along these lines, it is not surprising that terrorist groups like ISIS in the Middle East and Boko Haram in Nigeria have begun to use water and access to water as a weapon of war in vulnerable countries. It is worth considering that the breakdown of order and security in Syria was preceded by one of the worst water crisis in that country's history—an event that gravely effected food supplies and led to a sharp degradation of living conditions for millions of people. Drought and food shortages had already compelled thousands to flee their homes even prior to the beginning of the conflict and were likely an important factor in ratcheting up political tensions and possibly pushing the Syrian society over the edge. It is worth considering here that there is clear evidence that human civilization arose in a period of climate stability (NATO PA, Joint Special Seminar in Svalbard).

V. TRADE IMPACTS

32. There multifarious connections between international trade and climate change. The World Trade Organization (WTO) and UN Environnment Programme (UNEP) published a major survey of the literature in 2009, which explored many of the linkages established by experts studying the issue. Trade, of course, remains a key driver of the global economy and has been a critical factor of global economic growth. The volume of trade is also correlated to increased use of carbon-based energy. It is thus worth noting that the average share of exports and imports of goods and commercial services in global GDP rose from 20% in 1995 to 30% in 2014 (in value terms) (WTO). Trade has thus been a critical agent of economic development and growth and has also been a factor in climate change. It will undoubtedly be impacted both by global warming and the effort to mitigate it.

33. Trade has had three broad effects on global warming:

- a **scale effect** insofar as trade has increased energy intensive economic activity and, by extension, greenhouse gas emissions, for example through increased use of transport or by making affordable automobiles more accessible to more people;
- a **composition effect** or the way trade changes the composition of national production either to become more or less carbon energy intensive;
- a **technique effect** by which technologies are transmitted that might reduce the emission intensity of goods and service production (WTO-UNEP).

A potential fourth impact might be that because trade is wealth producing and because mitigating climate change is a costly endeavour, trade can help generate resources to fund adaptation and mitigation efforts.

34. Studying the precise relationship between trade and greenhouse gas emission levels is highly complex and tends to reveal variegated results depending, in part, upon assumption. For example, trade openness for OECD countries seems to correlate to reduced CO_2 emissions as it improves access to energy efficient technologies, whereas trade for non-OECD countries seems to correspond with higher emissions as both scale and composition factors predominate. In a globalised economy, there has also been a degree of industrial off-shoring so that emissions once produced by factories located in the West, are now offshored to developing countries. As a result, a degree of industrial pollution has also been offshored as developed countries become more service oriented.

35. Over the long term, there nevertheless seems to have been be a positive correlation of trade and CO_2 emissions (WTO-UNEP). Transport represents a primary reason why trade might be contributing to greater CO_2 generation. Goods can be transported by ship, road, rail, air and pipeline with maritime transport accounting for the largest volume and value of trade. Aviation is a highly polluting form of transport and the share of traded goods carried by air has been rising. Shipping is the most energy efficient mode of transport, but CO_2 emissions from shipping,

particularly from diesel based fuels, are slated to rise substantially. More generally, petroleum products power 95% of world trade transportation so the expansion of trade could weaken the effort to mitigate the emission of greenhouse gases unless this trade-energy relationship is not altered. Finally it is worth mentioning here that melting sea ice in the Arctic is likely to open new trade routes that will shorten the routes for trade between Europe and Asia. This could well confer certain commercial benefits and reduce energy use required, for example, to ship goods from Europe to Asia. It it difficult, however, to assert at this juncture that costs associated with the loss of Arctic sea ice would outweigh the benefits of shortened trade routes in the summer months.

36. On the other hand, trade helps diffuse energy saving technologies and energy efficient practices that reduce carbon fuel use. An example here might be the export of relatively inexpensive solar panels exported from China to the rest of the world — a development which has helped trigger the rapid transmission and use of a technology seen to be a key to a sustainable energy future. As these technologies develop and become cost effective, trade will play a critical role in their diffusion and will also help drive down their cost. These technologies, in turn, will likely further delink economic growth with carbon energy use — a critical step toward finding sustainable solutions to the carbon energy challenge.

37. It is also important to consider other factors such as the phenomenon that highly polluting industries operating in free trade regimes might tend to concentrate in those countries that have the least regulation. This, in turn, lends credence to the argument that a certain level of environmental regulation needs to be globalised to prevent “beggar thy neighbour” environmental policies or environmental dumping, which merely shift the locus of production without mitigating overall greenhouse gas emissions. But insofar as trade can generate growth and act as a catalyst to development, it can encourage countries that previously could not afford to undertake regulation to begin to do so. Thus a country like China which imposed few environmental restrictions on firms producing in the country during its initial industrialisation, has now begun to do so because it has generated so much national wealth through trade and thus has the means to begin to cope with the problem. Moreover, that country confronts a problem of general environmental degradation, and there is mounting domestic pressure to begin to address the problem in a systematic way. Finally, because China’s northern and western regions are suffering from very acute and ever worsening water shortages, the country is vulnerable to the effects of climate change and its leaders recognise that it must do its part to address the problems. In short, China has now both the means and the incentive to begin to address the problem.

38. As suggested earlier, trade is also a primary vehicle through which macro-economic shocks are transmitted internationally. In an open trading world, a contraction in demand in one or a number of countries can be transmitted to other countries through the trading system. Following this logic, an economic contraction linked to climate change in one country, could theoretically be transmitted abroad through a reduction of demand for imports in that country or even through a reduction of exports—both of which would impinge on the economies of its trading partners.

39. Climate adaption strategies will invariably have a trade dimension as well. If there are supply shocks in vulnerable countries that are directly or indirectly linked to climate change, trade offers one way to offset the impacts. Trade will be a critical tool of adaptation particularly in sectors like agriculture which are most sensitive to warming and drought. Not only can the trading system move food to where it is most needed, but it can also diffuse technologies and practices that help countries cope with drought conditions or rising waters.

40. Climate change could also trigger changes in national comparative advantages which, in turn, would generate new patterns of trade. This will be particularly true for countries specialising in climate sensitive products like food, but there could also be impacts on service exporters, particularly in areas like tourism. Of course, countries that master renewable energy technologies will particularly stand to benefit as the world’s economies looks to wean themselves off of carbon based energy. Societies that most successfully manage adaptation to climate change may also

gain certain advantages in global commercial markets as will those countries that develop technologies that mitigate the use of CO_2 because they will also benefit by exporting these technologies.

41. Finally one should also consider that climate change could also leave international supply chains vulnerable because of increased storms, sea level rise and the threat this poses to critical port and coastal infrastructure that represent critical nodes in the global trading system (WTO-UNEP).

VI. POTENTIAL ECONOMIC GAINS FROM MITIGATION

42. Beyond the apparent economic gains to be had simply by averting or at least minimising global climate change, there are other potential advantages that might be derived as countries begin to adjust. Since climate change has essentially been driven by the expanding use of fossil fuel and as governments are committed to move away from their use, the market for renewable energy sources is bound to grow. Indeed, this market is expanding rapidly, aided not only by increasing demand but also by technological innovation that is driving down costs, increasing supply and opening whole new vistas of economic opportunity. The Paris Agreement is often characterised simply as a large cost, but it is also an opportunity as those countries dedicated to adhering to its strictures are likely to move quickly to embrace new energy producing and saving technologies that could define new avenues to productivity increases and growth.

43. In 2015, the world invested $350 billion in renewable energy or more than double the amount invested in coal and gas fired power generation. The explosion of demand for renewables, the entrance of large companies enjoying scale economies and the flood of investment in relevant technology has driven down the costs of solar and wind power to the point where they are now competitive with fossil fuel power generation despite the limits of intermittency and their dependence on weather conditions. The march of technology will continue and the cost of renewables will invariably fall further. Better solutions to the intermittency problem, for example, are likely to emerge out of this research. All of this will eventually produce a paradigmatic shift that will drive future economic growth. Some countries will be better poised than others to establish leads in this future economy and most likely, they will be early movers both in adaptation and in technology development.

44. Indeed, markets now seem increasingly poised to move into high technology solutions to the carbon energy challenge including the development of renewable technologies but also energy saving technologies that lower energy/GDP ratios. Even though solar power currently accounts for only 1.3% of US electricity generation, it employs roughly 260,000 people in that country and this number is growing, with the industry accounting for one of every 50 new jobs in 2016. Most of these jobs are in the installation field and provide a median wage of nearly USD26 per hour. The solar energy industry currently employs slightly more workers than natural gas, twice as many people as coal, three times the number of people employed in wind energy and five times the number working in nuclear energy. The oil/petroleum sector, by comparison, still employs 38% more people than the solar industry in the United States. One reason that solar energy is employing so many people is that it is a new industry and much of the work involves installation of fixed capital projects. These numbers also suggest that solar remains relatively labor intensive and this is one of the reasons it is still more costly than gas and oil. But job creation has a certain political appeal and the solar lobby, which heretofore has not been terribly consequential, could begin to throw around its weight in US energy policy discussions. It has, after all, become something of a job creating machine (Plumer). As the industry matures, it will likely require significantly less labor, but over the medium term, it will continue to be a job creating engine.

45. China has become one of the global leaders in the renewable energy sector and in related technology development. Reducing pollution has become a top priority, and this has led to a significant slow down in coal plant construction and massive investments in renewable energy including very large investments in research and development. China has started to develop a lead in a sector that could eventually become one of the foundations of the global economy. According to Bloomberg New Energy Finance, China invested USD102 billion in renewable energy in 2015, which is twice as high as US investment in that sector that year.

46. It is also investing abroad globally. China Light and Power, for example, invested USD1.1 billion in Austria to purchase power from wind and solar farms. In Chile, Tianqi Lithium purchased 25% of a lithium mining and processing operation. Lithium is a key input in batteries used in electric cars and home energy storage systems. China currently owns five of the world's six largest solar module manufacturing firms, the largest wind turbine manufacturer, the largest lithium ion manufacturer and the largest electric utlity (Slezak). As a first mover that has mobilised signifant capital for these ventures and that enjoys the benefits of scale, China has put itself into a good position to reap long-term rewards in this renewable sector. A new industrial paradigm could well be emerging as a result of climate change and a near global consensus to work to mitigate its worst impacts. It is worth noting that India is also now getting into the game and has recently begun to move away from coal generated electricity precisely because of persistent pollution problems.

VII. OTHER IMPACTS

47. The World Health Organization has estimated that climate change linked to human activity is currently causing the deaths of 150,000 people each year. The Climate Vulnerability Monitor puts this figure at 400,000, which, based on the US Environmental Protection Agency (EPA)'s Value of Statistical Life, exacts a cost of USD3 trillion (Tago and Thom). The disparity between the two studies is revealing insofar as it illustrates the methodological challenges associated with this kind of estimate. They nonetheless point to the scale of the human costs of climate change which are linked to extreme weather, eco system changes and related shocks to human health and society. To make this tangible, it could be helpful to consider one event — the inordinately hot summer in Europe in 2003. That summer, over 19,000 people died in France due to the heat according to a range of public studies. That single event provides an indication of the kinds of shocks to human health and well being that can be expected as a result of global warming.

48. A second threat to human life arises out of related changes to biodiversity and changing conditions for flora and fauna. An obvious example here is represented by the rise of disease spread by mosquitoes like the Zika virus or by waterborne disease including malaria. A warming planet exposes previously sheltered regions to these types of diseases.

49. Climated induced phenomenon such as drought, desertification and land degradation, could also be a factor leading to socio-economic problems and even instability due to declining food production or water shortages. Desertification could be a factor in compelling people to leave their homes and livelihood and thus could be one of many factors triggering mass movements of migrants.

VIII. THE CHALLENGE TO THE ARCTIC

50. There are unique challenges confronted by the Arctic as a result of global warming. The Arctic is warming twice as fast as the rest of the planet. In Svalbard, Norway for example, the temperature has been rising for the past 37 years with the annual temperature at four meterological stations there increasing by 2.7–4.0°C, and winter temperature rising by 4.8–6.5°C over that period (Forland, Eirik J. et. Al.). The last two years have been the warmest ever registered in the Arctic and the past 73 months have registered higher than average temperatures. Winters are warming more than summers and this is consistent with current climate change models. The region's reflectivity has begun to dissipate as sea ice melts, and this is accelerating the warming trend. Antarctica is naturally much colder so the warming trend there, although well underway, is less apparent. Scientists working in Antarctica, for example, recently documented a massive melt event as well as unprecedented rainfall in the Western part of that continent. Green moss is also appearing on rocks for the first time according to scientists. Both of these phenomena could be a harbinger of more rapid change in a region of that continent that contains over 10 feet of potential sea level rise. One influential study published last year suggested that there could be a major ice loss on that continent in this century that alone could account for four feet of sea level rise. A British Antarctic Survey recently indicated that Antartica had warmed by 2.5° C since the 1940s. Ice shelves on both the eastern and western sides of the Peninsula have retreated since 1995 and the annual melt season has increase by 12 days over the last 20 years. The shelves are weakened by meltwater on the surface and thus become more susceptible to fracturing (Union of Concerned Scientists, "Early warning signs of global warming: Arctic and Antarctic Warming").

51. The equatorial regions of the world absorb far more energy than the polar reaches of the planet. This energy is partly transferred to the north through weather fronts and the Gulf Stream. Likewise, cold air and water from the north also moves southward, thereby acting as a natural air conditioner for the planet. The High North's cooling role, however, is now threatened as the region heats up. Other feedback loops could be accelerating climate change in ways that exceed expectations expressed in earlier climate change models. For example, permafrost is melting and as it does, it releases more carbon into the atmosphere, which, in turn, further accelerates warming thereby releasing even more carbon etc. These feedback loops help explain why the Arctic is changing so precipitously.

52. The retreat of sea ice is only the most apparent change in the region, but there are many more. Indeed ice retreat is having an amplified impact on global climate change. As white ice is replaced by dark water, the earth absorbs and retains more solar heat and this feedback loop could be accelerating climate change in ways that exceed expectations expressed in earlier climate change models. Climate change, however, is altering these weather bands, and far more heat appears to be moving northward. This is accelerating sea level rise as ice around Greenland and in Svalbard, among other High North locations, begins to melt. This is also opening new sea routes through the North East and North West passage. Fish stocks are shifting as many species are following water temperature trends and rapidly moving northward. Melting ice and warming water is thus having a significant impact on the fishing industry and is leading to a reassessment of economic opportunities in the High North in sectors such as shipping and mining.

53. The Arctic's natural heritage is now at grave risk. A significant migration of fish is underway from the North Atlantic to Arctic waters. Shrimp and Snow crab are now fished in far northern waters and cod and haddock are being caught north of Svalbard. This migration has unfolded very quickly, and has changed how littoral and more distant countries look at these waters. At the same time, polar bear hunting grounds are rapidly diminishing, permafrost is melting, and the glaciers are retreating rapidly. Perhaps most worrisome of all is that there is now little predictability as these changes have never been observed and their impacts are highly complex. It is, in essence, nearly impossible to fathom where all of this is leading although the general trend line is very worrying

(NATO PA-Joint Special Seminar in Svalbard , Comments by Kim Holmenan, Vidar Helgesen, and Sverre Engeness).

54. A report that the Arctic Council recently issued suggests that the Arctic as a whole is shifting into a new state that will have a profound impact on the rest of the world. The Arctic is currently heating up at a rate that is twice that of the rest of the world. Its temperature is on a pace to increase by 5-9 degrees Celsius by the end of the century and could rise possibly as high as 12 degrees. This would have a dramatic impact on sea level rise, which in turn, would gravely affect low lying coastal regions of the world such as Bangladesh. A 1.5 meter rise in the sea level would erase 16% of that country's territory and 17 million people would be displaced. It is important to recognise that in the last ice age, sea levels were 25 meters lower than today so the amount of ice on land profoundly impacts sea levels.

55. Warming temperatures in the Arctic, for example, could theoretically render an important swathe of the Middle East uninhabitable, trigger draught in parts of Europe and North America and cause flooding in other parts. The Director of the National Snow and Ice Date Center in Colorado, Mark Serreze, are predicting an ice-free Arctic summer by 2030 (Borenstein). Insofar as the Arctic is one of the world's primary cooling systems, the impact of this change would be dramatic, enduring, and global in nature. It would affect everything from sea level to storm patterns. Change in the Arctic is thus amplifying the impact of global warming, and if this transformation continues unabated, it could well produce extreme weather, effect bio diversity, trigger crop failures, wild fires, new and unexpected pandemics, infrastructure break downs, and mass migration among many other impacts.

56. There are important economic opportunities implicit in some of these changes. The melting of sea ice holds out the opportunity for navigation in the high Arctic and the shipping industry is poised to exploit this opportunity although with a modicum of caution. The melting of permafrost makes road transport across Arctic tundra increasingly problematic so the shipping industry will likely shoulder the burden of transporting goods across the region. The opening of the North-Eastern passage, for example, would cut the shipping distance between Europe and Asia by a third, although the industry believes that the use of this passage is many years down the road. The North West-passage is likely to remain a more difficult option as ice blockage there is more substantial.

57. It is also important to recognise that the High North is no longer an isolated and depopulated region. It is growing more dynamic and the population has been rising. For example, 10% of Norway's population lives above the Arctic circle, and the Arctic plays a critical role in the national economy as it does, for example, in Russia. The Arctic Council has become an important vehicle for member and observer countries to discuss how the changing climate is shaping economic opportunity and how this is to be managed. Sustainable development of the region will be essential, but this will only be possible if it is done in a cooperative international framework. The Law of the Sea plays a vital role in regulating how countries approach the region. Updated regulations will be needed to resolve outstanding disputes arising out of new opportunites linked to climate change that could threaten the broader comity that characterises relations in the region. Shifting fish populations is an example but there are many others. Although the Arctic Council began as a forum that was largely focused on the region's environment, the range of issues that it addresses has expanded substantially. One of the most important of these issues is how to manage economic development cooperatively in that fragile and environmentally changing region (NATO PA-Joint Special Seminar in Svalbard Seminar, Presentation by Marit Berer Rosland).

58. Shipping in the High North represents another particularly compelling challenge. Currently the support systems needed to sustain shipping in the Arctic simply are not present. New industrial standards are needed as well as critical support infrastructure. Responsible shipping requires accurate weather forecasts, proper navigation charts, search and rescue support, and resupply

centres. Presently there are gaps in all of these and this too operates against extensive commercial exploitation of Arctic passages.

IX. CARBON TAXATION

59. Decisions about how to mitigate the impact of global climate change require consideration of optimal economic policy responses, the burdens those responses impose and who exactly ought to shoulder which burdens. This becomes a process of considering trade-offs between equitable and efficient solutions. There is little doubt that both climate change and the response to it involve very important questions of income distribution. As suggested above, there is growing evidence that poorer and hotter countries will likely suffer harsher economic impacts as a result of global climate change which has largely been induced by the world’s more advanced economies. Many of the wealthier carbon fuel intensive countries recognise that they ought to foot a higher share of the overall bill to cope with the challenge. The Paris Agreement, however, has created an expectation that developing countries, particularly major emitters like China, will also have to do their share (Bretschger). The Kyoto Protocol had largely exempted developing countries from its most burdensome strictures. Paris makes it incumbent upon all carbon emitters to take action to bring down the level of carbon based energy to levels consistent with overall targets.

60. It is important to recognise that the costs of using carbon energy are often not reflected in the price of these commodities. The externality costs of using carbon based energy includes the costs to the environment, health and even national security costs that are not adequately captured in the market price of energy. This is a classic market failure. An externality, in this case, is the cost that affects the entire society linked to the use of a commodity by those who did not fully incur that cost. Economists often urge governments to adopt policies that "internalise" externalities so that the price actually paid reflects the total cost including the societal costs.

61. There is thus a sound economic efficiency justification for taxing carbon so that the price at the pump reflects the real opportunity costs of using that energy. These real costs need to be reflected in those prices so that business and consumers possess the full cost information needed to make efficient energy use decisions. In 2011, coal generated power plants charged only USD 3.2 cents per kilowatt/hour but the actual costs were estimated to be 170% higher as each kWh of coal generated electricity resulted in 5.6 cents of damage including 3.4 cents of adverse health impacts, and 2.2 cents in climate related damages (Greenstone and Looney). Externalities reflect market failures that states can correct through tax policies that actually render markets more efficient. These taxes, in turn, help moderate consumption behaviour so that demand is conditioned by real prices reflecting the full spectrum of opportunity costs.

62. This is the essential justification for taxing carbon based fuels. A number of countries have implemented carbon tax systems which invariably reduce the price differential between carbon and renewable energy sources. Carbon taxes, however, are not the only reason that carbon energy use has begun to fall. In the United States, the growing use of natural gas instead of coal in electricity generation has had a dramatic impact on carbon emissions. The Obama Administration’s efforts to boost fuel efficiency standards for automobiles and to impose higher efficiency standards on household appliances have helped reduce the energy intensity of the economy and, by extension, lowered the component of carbon based fuels used in it. All of this was accomplished without a tax on carbon although the results would likely have been even more dramatic had one been established in the United States (Komanoff). Carbon taxation represents a highly efficient and powerful tool to properly price carbon and encourage clean fuel use and for this reason, many free market advocates now embrace it including a group of influential US Republicans including former Secretary of State James A. Baker, former Secretary of State George P. Schultz and former Secretary of the Treasury Henry M. Paulson Jr. Major oil companies, including Exxon Mobil have also favored the idea (Schwartz).

X. THE US WITHDRAWAL FROM THE PARIS AGREEMENT

63. The Trump Administration's 1st June 2017 announcement to pull out of the Paris Agreement has been broadly understood as a serious blow to the international effort to cope with the climate change challenge and that it has become a source of discord between the United States and it Allies. But dialogue on this issue will have to continue as climate change will remain an enduring problem the consequences with which all countries will have to cope. Under the accord, the United States can only formally submit its intention to withdraw after November 2019 and the process of withdrawal would likely take a year to consummate. In any case, the international reaction to the decision has been decidedly negative and has a potential to weaken trans-Atlantic political solidarity. The initial reaction from a number of government leaders both within and beyond NATO, has also included an express determination to respect the terms of the agreement and a refusal to contemplate any renegotiations of its terms (Sengupta).

64. Although the United States, like many other countries, would have faced both technical challenges and costs to meet the goal of reducing its greenhouse gas emissions as laid out in the Agreement, it will not escape the kinds of costs associated with climate change outlined in this report. One study conducted in 2008 when cost estimates were far lower than current estimates, laid out only four impacts — hurricane damage, real estate losses, energy costs and water costs and suggested that just these alone could cost the United States 1.8% of GDP or roughly USD1.9 trillion annually in current dollars by 2100 (Ackerman and Stanton).

65. In a recent peer reviewed EPA study (*Climate Change in the United States: the Benefits of Collective Action*), experts estimated the various savings that would accrue to the United States if goals for greenhouse gas limits were achieved by 2100. These include: an estimated 57,000 fewer deaths from poor air quality in 2100; an averted increase in electricity demand of 1.1%-4.0% in 2050, an estimated USD10-USD34 billion in savings on power systems; in 49 major US cities, an estimated 12,000 fewer deaths from extreme temperature in 2100; an estimated 720-2,200 fewer bridges made structurally vulnerable in 2100; an estimated USD4.2-USD7.4 billion in avoided adaptation costs in 2100; approximately USD110 billion in avoided damages from lost labour due to extreme temperatures in 2100; an estimated USD2.6-USD3.0 billion in averted damages linked to poor water quality; in 50 US cities, an estimated USD50 million-USD6.4 billion saved in adaptation costs in 2100; approximately USD3.1 billion in averted damages and adaptation costs from sea level rise and storm surge in 2100; savings of as much as USD2.8 billion in damages averted from land flooding; an estimated USD6.6-USD11 billion in averted damages to agriculture in 2100; an estimated USD520 million to USD1.5 billion in averted damages to forestry in 2100; an estimated 40%-59% fewer severe and extreme droughts in 2100; an averted loss of approximately 34% of the US oyster supply, 37% of scallops, and 29% of clams in 2100; an estimated 6.0-7.9 million fewer acres burned by wildfires in 2100; an estimated USD11-USD180 billion in avoided damages from water shortages in key economic sectors in 2100; an avoided loss of approximately 35% of current Hawaiian coral by 2100, with a recreational value of USD1.1 billion; an estimated 230,000-360,000 acres of cold water fish habitat preserved in 2100; an estimated 1.0-26 million fewer tons of carbon stored in vegetation in 2100. A study conducted by Frank Ackerman and Elizabeth Stanton of Tufts University, predicted that in an inaction scenario, temperatures in most of the United States would rise by an average of 13 ° F and 18 °F in Alaska. High costs would also be inflicted through more frequent and severe heat waves, hurricanes, droughts and other abnormal weather events. It is worth noting that studies conducted since the publication of this particular study have grown decidedly more gloomy.

66. Climate change would thus strike many sectors including state budgets, tourism, agriculture and a range of other weather dependent industries. Households would see water bills rising due to water scarcity in dryer parts of the country. Higher sea surface temperatures would generate stronger hurricanes along the Atlantic coastline and these storms would interact with higher seas to trigger highly damaging storm surges, erosion and flooding. Hurricanes have recently generated an

average cost to the United States of USD12 billion and cause 120 deaths a year. If climate change is not slowed due to a lack of international action, this figure could rise to USD422 billion and 720 deaths per year according to the Tufts study. Sea rise would also cause very serious property destruction and damage and by 2100 could generate costs of USD360 billion per year. Energy costs in the United States would also likely rise as demand for air conditioning and refrigeration would soar. There would be some offset costs for reduced winter heating demands in the north. Cooling demand would generate an extra USD200 billion in electricity and air conditioning costs, while there would be an USD80 billion reduction in heating costs, netting out to an additional USD141 billion per year in costs. Finally, the study foresees an additional USD95 billion per year in water costs, as drought conditions worsen in many regions of the United States. Again, just within these four categories, the additional costs to the United States of remaining on the current climate change path is USD1.9 trillion per year according to this model, and this does not even factor in many other potential costs in areas like health and other environmental damages. These could raise the cost from 1.8% of GDP to 3.6% per year if the international community as a whole does fails to mitigate climate change.

67. As suggested above, some of the most interesting solutions to the challenge in the United States are now being offered by free market economists who both recognise the nature of the environmental threat but who are wary of traditional regulatory approaches. Martin Feldstein, Ted Halstead and Gregory Mankiw have played a particularly prominent role in this discussion. They lament that the two major political parties in the United States have sought to cope with the problem of reducing carbon emissions through executive orders which subsequent administrations abandon. This has fostered regulatory inconsistencies and created great uncertainty for businesses that need a degree of certainty to engage in long term planning. This is precisely the logic behind the carbon tax-carbon dividend proposed by former Secretary of State James A. Baker described above.

68. These free market advocates argue that carbon emissions reduction efforts should also seek to mitigate regulatory intrusion promote economic growth, benefit working class people and should be acceptable to a broad political spectrum of US voters. They have accordingly laid out a four pillar plan in which the federal government would gradually impose an increasing tax on carbon dioxide emissions, beginning at USD40 per ton but rising over time. This would send a powerful pricing decision that would encourage a reduction in CO2 emissions. They also maintain that the proceeds from this tax should be rebated to US voters through a quarterly dividend check. At USD40 per ton, this would mean a USD2,000 rebate to a family of four. The dividend payments would rise as the tax increases.

69. US companies exporting to countries without comparable carbon pricing would receive rebates on the carbon taxes they have paid producing these goods, while imports from such countries would be charged fees on the carbon content of their products. This would protect the competitiveness of domestic firms and discourage carbon free riding. Finally, because pricing signals are so powerful in shaping behaviours, the government would be able to eliminate a number of regulations currently shaping emissions policy, including the Clean Power Plan, which many conservatives have claimed is very inefficient and burdensome.

70. The plan is interesting not only in the context of US politics but in any society seeking to balance environmentally sound policies with liberal market solutions. It offers a way to forge a broad political agreement over an issue which has been heavily divisive in US politics. The authors suggest that the pricing approach would be far more effective than regulations, less burdensome, more efficient and would encourage long-term investments in cleaner technologies. There would also be a redistributive impact as the bottom 70% of Americans would come out ahead if all elements of this plan were implemented (Feldstein, Halstead and Mankiw). Were the US Administration and the Congress to move in this direction, they would together chart out an

innovative way to cope with a serious global environmental challenge while championing free market principles and competitiveness.

XI. CONCLUSIONS

71. Although the cost of mitigating global climate change will be substantial, the failure to act will exact even higher costs not only in terms of lost economic and agricultural assets, budgetary burdens, additional energy and water costs but also in terms of human lives lost, species and ecosystem damage, social conflict and political instability.

72. There is growing evidence that the adverse economic impacts of climate change could be far more substantial than originally envisioned. This suggests that the benefits of mitigation could far outweigh the costs of the measures needed to achieve mitigation. Put another way, the cost of inaction increasingly seems prohibitive. The problem is the gap between the evidence and the political will needed to act on that evidence - or even to accept the evidence. Democratic politics tends to focus on the short run and is biased against planning for longer term dynamic economic, social and environmental phenomena. Not surprisingly, on the environmental front there is a built-in bias against undertaking mitigation strategies. The costs are up front and short term while the benefits - or the pay back on the initial investment - are only made apparent over the long term.

73. Understanding longer term economic dynamics is critical here. It is essential to recognise that decisions made today will alter the very structure of future economies and the energy that powers them. As the international community leans toward renewable energy over carbon based fuels, investment in the former will continue to increase. This will drive down the costs of clean energy technology, make it increasingly competitive and an ever more important generator of new jobs. Insisting that there is no alternative to dirty coal use, for example, is belied by the fact that far cleaner natural gas has already begun to replace coal as has even cleaner solar and wind power. The world has not yet entered a post-carbon energy order, but it is moving in this direction. Governments now have a blue print to ensure that this effort is ramped up to such an extent that the worst impacts of climate change can be averted.

74. The benefits of a successful effort to achieve the goals laid out in the Paris Agreement would outweigh the substantial costs. This effort will likely involve a degree of creative destruction by which older and obsolete forms of energy production will invariably have to decline unless cleaner ways to employ these energies are found. Coal use is already in decline in many parts of the world including in China and India. Eventually other carbon fuels may be expected to face similar competitive pressures as the cost of cleaner energy sources falls. India recently abandoned a huge expansion of coal fired electricity plants in favor of solar panel arrays both because the cost of solar had become highly competititve and because India is suffering serious pollution problems from coal burning. Subsidising the use of carbon based energies is now understood as utterly regressive and will only postpone an inevitable transition while leaving societies poorly positioned for the emerging economic order.

75. Properly pricing carbon will make clean energies more attractive and accelerate their introduction into national energy mixes. Under-pricing carbon has distorted energy markets. The state has a corrective role to play to make those markets better reflect real cost conditions. Serious carbon pricing schemes are needed so that consumer decision making reflects the true price of the energy that they consume. Innovative market oriented schemes like those recently proposed by James Baker and George Schultz are welcome and demonstrate that the goal of carbon reduction and economic efficiency are not mutually exclusive. Carbon needs to be priced to reflect its real costs, including environmental and security costs (through carbon taxation), while cleaner technologies (e.g., carbon capture) and renewable energy should be subsidised so that the environmental and societal benefits are better reflected in those prices. Such policies might appear

costly, but they would help move energy prices to accurately reflect opportunity costs associated with their use.

76. Market economies advance, in part, through the discovery of interruptive technologies which literally shift the foundations of economies and define new patters of growth and development. In this manner, renewable energy “may become the greatest opportunity for wealth creation of the 21st century” (Stoiljkovic). Some industries and workers will lose in this process. That is the very nature of creative destruction. But it is hard to argue that it is worth holding the world economy hostage to the false notion that coal jobs are coming back. They are not and that is why China and India have decided to look for other ways to produce energy. On the demand side, investments in far more efficient appliances, cogeneration, and green buildings will also characterise this new economy and environmentally sensible regulatory standards will provide focus for these investments. Undoubtedly these new energy industries will create millions of jobs. The explosion of employment in the US solar industry is likely just the tip of the iceberg. Seen this way, climate targets can actually be understood as elements of long term growth strategies (Stoiljkovic).

77. To build this future economy, incentives will be needed to encourage far greater levels of energy efficiency in everything from building codes, appliance efficiency and mileage standards for automobiles. Enormous progress has been made on these fronts as well and continued technological advancements will create new economic opportunities. Governments and business need to work in partnership to ensure that higher efficiency standards are constantly pursued and made mandatory. These efficiency standards will lower costs and can foster tremendous growth opportunities for firms and for national economies. Indeed, first movers will be rewarded, and this is precisely why climate action should be seen as an investment in a dynamic growth opportunity and not simply, and misleadingly, as simply a deadweight cost. Building the support infrastructure essential to making renewable energy widely available remains a major challenge for governments, but it also offers a substantial opportunity for innovation, enhanced security and economic growth. Transmission capacity, which facilitates the integration of intermittent energy sources like solar and wind, is particularly important in this regard. There is a great deal of room for innovation here as well, and international cooperation will be essential to push out the technological frontier.

78. The Paris Agreement marks an important advance and suggests that the international community has begun to come to terms with the challenge and recognised that action must be undertaken by both the developed rich and developing poorer countries. The United States played a leading role in pushing for the Paris Agreement, but the Trump Adminstration has now announced its intention to leave that agreement. This undoubtedly represents a setback given the historic importance of US leadership on global envirionmental challenges. The international community, including NATO allied countries, must continue to engage the United States on the issue of climate change. US society itself remains deeply engaged in these issues and local and state governments, businesses and civil society as a whole will continue to work for positive change.

79. Generating and sustaining consensus on coping with this monumental set of challenges will thus be critical to coping with the problem and new ways of reaching out to sceptics will be essential. Although the Administration in Washington has expressed scepticism about climate change and the Paris Agreement, it might be fruitful to find new ways to conduct a dialogue on these matters. The future of world agricultural markets, food security, and the military-security implications of climate change represent a series of potential entry points. The risks of sea rise to property and insurance markets might be another way to talk about this issue with US leaders. The Governor of the Bank of England, for example, has warned that climate change could ultimately upend insurance markets as more and more property becomes uninsurable. This is already underway in the United States and the problem could lead to all manner of financial breakdowns while undermining existing business models and asset pricing (Haufler). These are real and

contemporary challenges that will be hard to ignore and they have implications for all allied countries regardless of their position on the Paris Agreement.

80. The hard security implications of climate change needs to considered by the defense and security establishments of all NATO countries and should be a subject more closely taken up within the Alliance. The challenges here are myriad and include everything from the future of coastal bases, to emergency response, to the prospects of long-term instability in the Middle East as a result of drought.

81. Finally, special attention needs to be paid to the Arctic, the importance of which seems to be on the rise. Some have argued, in fact, that climate change is essentially placing the Arctic at the centre of the world rather than on its periphery. The stake here are extraordinarily high as stability will not be possible in a world characterised by rising temperature, far more extensive drought, and unpredictable food supplies. A paradigmatic shift will be essential, and this will have broad cultural and political implications. A shared outlook on environmental matters in the Arctic has lain at the root of cooperation in the region and this will have to continue particularly as the international community comes to better appreciate how central the Arctic is to the planet’s delicate environmental balance and to critical security issues like future food supplies.

82. On the other hand, the Arctic is also increasingly seen as a zone of economic exploitation and international rivalry. There are signs of militarisation or perhaps remilitarisation in that delicate region, but this avenue should be resisted. Managing these challenges will only be possible in a cooperative framework, and this represents a critical challenge for the international community as a whole. This cooperation will have to be rooted in new understandings and a broader knowledge of how these various systems are interacting (NATO PA-Joint Special Seminar in Svalbard, Comments by Lassi Heininen).

83. For several centuries, the world has been in an Anthropocene era in which humankind is exercising tremendous influence over the natural world and its environment. The question today is whether the world will manage to exercise the kind of restraint needed to maintain critical planetary balances that make life itself possible. In the coming years, the Arctic states will move from the periphery to the very core of international discussions about security and sustainability simply because of their location in this rapidly changing and highly exceptional region and their own vital role in protecting it.

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This is **Exhibit G** referred to in the
affidavit of **John Moffet**
affirmed before me on **January 29, 2019**

Commissioner for Oaths for Québec

#224458

Government of Canada Gouvernement du Canada

Canada

CANADA'S 7TH NATIONAL COMMUNICATION AND 3RD BIENNIAL REPORT

Canada's Seventh National Communication on Climate Change and Third Biennial Report—Actions to meet commitments under the United Nations Framework Convention on Climate Change

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Minister's Message

As Canada's Environment and Climate Change Minister, I am pleased to submit Canada's *7th National Communication* and *3rd Biennial Report* to the United Nations Framework Convention on Climate Change (UNFCCC).

In the two years since our last Biennial Report to the UNFCCC, Canada has taken significant steps to advance action on climate change and clean growth, both at home and abroad.

In December 2016, the Prime Minister and Provincial and Territorial Premiers adopted Canada's clean growth and climate plan to take ambitious action to fight climate change, build resilience to the changing climate, and drive clean economic growth. A landmark achievement, the Pan-Canadian Framework on Clean Growth and Climate Change is the first climate change plan in Canada's history to include joint and individual commitments by federal, provincial and territorial governments and to have been developed with input from Indigenous Peoples. The Pan-Canadian Framework outlines more than 50 concrete measures to reduce carbon pollution, help the country adapt to the impacts of a changing climate, foster clean technology solutions, and create good jobs that contribute to a stronger economy.

We have covered considerable ground since launching Canada's clean growth and climate plan just over one year ago. Now, we're starting to see results. Our plan includes a pan-Canadian approach to pricing carbon pollution, as well as measures to reduce emissions across all sectors of the economy that put Canada on the path to meet our Paris Agreement target to reduce emissions 30 percent below 2005 levels by 2030. We are determined to meet or exceed that 2030 goal.

Based on our updated greenhouse gas projections included in this report, we have taken great strides towards our target. But of course, much work remains. We have laid out a comprehensive plan for ourselves, and are now implementing it, along with an ambitious suite of policies, programs, regulations, and funding initiatives. The country has taken steps towards pricing carbon pollution: our approach requires carbon pricing across Canada in 2018. We are also advancing a number of additional measures that will take us the rest of the way to our target, in continued partnership with provinces and territories, and in consultation with stakeholders across sectors.

Despite global action to reduce emissions, adapting to the impacts of climate change will also be critical. In the past year, governments across Canada have taken steps to support communities most affected by impacts of climate change, such as fires, floods and extreme weather. Governments have also invested in climate solutions and clean growth. Their investments will help Canadians save money through the use of smarter energy solutions.

Indigenous Peoples are important environmental leaders in Canada. They are often among the most vulnerable to the effects of a changing climate. The Government of Canada is committed to ensuring that Canada's Indigenous Peoples are real partners in the country's transition to a low-carbon, climate resilient economy. That is why the Government of Canada is working with National Indigenous Organizations to support the implementation of the Pan-Canadian Framework and to advance broader clean growth and climate change priorities.

These and other domestic actions represent Canada's commitment to implementing the Paris Agreement and, much like processes under the UNFCCC, the Pan-Canadian Framework includes accountability and reporting mechanisms that will allow us to revisit our climate change measures and enhance our ambition over time.

The Government of Canada is supporting these domestic actions with historic investments. In June 2017, we launched the Low Carbon Economy Fund to leverage investments in projects that will support clean growth and reduce greenhouse gas emissions from buildings, industries and forestry. The government is also investing billions in green infrastructure and public transit, and through the Canada Infrastructure Bank and green bonds from Export Development Canada, we are using innovative financing mechanisms to support climate investments and help new technologies become mainstream.

At the international level, Canada continues to demonstrate its strong commitment to global leadership on clean growth and climate change. Our country is working closely with its international partners on negotiations to implement the Paris Agreement under the UNFCCC. In advance of the 23rd Conference of the Parties (COP23), together with China and the European Union, Canada co-hosted a Ministerial on Climate Action, bringing together ministers and representatives from more than 30 major economies and other key players on international climate change.

In 2017, Canada also hosted a series of events on key issues under the UNFCCC. These included carbon markets, gender equality, and the engagement of Indigenous Peoples in international climate action. These complementary meetings informed the COP23 negotiations, where Canada was recognized for its leadership in helping to reach agreement on a UNFCCC Gender Action Plan and on the launch of the local communities and Indigenous Peoples' platform to enhance engagement of Indigenous Peoples on international climate action.

Canada remains committed to supporting countries that are most vulnerable to the impacts of climate change. We are delivering on a historic commitment to provide $2.65 billion in climate finance by 2020-21. Canada also recently doubled its funding to the UN Intergovernmental Panel on Climate Change (IPCC), and hosted hundreds of scientists supporting the IPCC at a Montréal conference in fall 2017.

We continue to work through other multilateral fora to advance action on climate change. For example, Canada has acted as a strong advocate for a global hydrofluorocarbon (HFC) phase-down under the Montreal Protocol. Canada also ratified the Kigali Amendment to the Protocol in November 2017, which commits countries to significantly reduce consumption and production of HFCs thereby minimizing their impact on climate change. We played a leadership role in encouraging the support of 21 other Parties to ratify the Kigali Amendment, helping bring it into force on January 1, 2019. Canada is also playing a lead role in Mission Innovation, a global initiative launched in 2015 by countries that have agreed to double national investment in clean energy innovation over five years while encouraging greater levels of private-sector investment in clean energy technologies.

In addition to multilateral work, Canada continues to advance climate action directly with its partners. For example, Canada worked in partnership with the United Kingdom recently to launch the Powering Past Coal Alliance, a global initiative to phase out traditional coal-fired electricity generation. In December 2017, Canada and five provinces joined with Mexico, Chile, Colombia, Costa Rica and two U.S. states to establish the Declaration on Carbon Markets in the Americas, which aims to enhance collaboration on carbon pricing systems and promote carbon markets throughout the Americas.

Canada understands that addressing climate change represents a significant economic opportunity. Those countries that pursue strong climate action will be best placed to compete in the clean growth century. Through reducing emissions and enhancing resilience, we can all work together to avoid the worst impacts of climate change and secure a safer, more prosperous future for our kids and grandkids.

I look forward to continued work with my domestic and international colleagues to make this future a reality.

Sincerely,
Catherine McKenna

CHAPTER 6

Vulnerability Assessment, Climate Change Impacts and Adaptation Measures

The impacts of climate change are being felt across Canada. Ongoing climate change poses significant risks to communities, public safety, health and well-being, the economy, and the natural environment. Mobilizing action on adaptation helps protect Canadians from climate change risks, build resilience, and ensure that society thrives in a changing climate.

Climate resilience is the ability to survive and prosper in the face of the new climate reality. Adaptation is key to achieving climate resilience, and is about making informed, forward looking decisions in response to climate change, in order to moderate harm or take advantage of new opportunities. Implementing effective adaptation measures saves lives, minimizes damage, and lowers costs over the long term for individuals, businesses, organizations, and governments.

Adapting to climate change impacts is a shared responsibility. Governments, communities, the private sector, academia, the non-profit sector, professional organizations, and individuals all have important roles to play in building resilience to climate change. In Canada, there is growing awareness of the impacts of climate change and the value of adaptation, and there are examples of initiatives being advanced across the country.

This chapter provides an overview of progress on adaptation in Canada since *Canada's 6th National Communication* (2014). It includes a brief overview of climate change impacts in Canada and outlines key programs, policies, strategies, and frameworks related to adaptation implemented domestically and internationally by federal, provincial, territorial, municipal, and Indigenous governments and Indigenous Peoples.

Key Developments since 2014

As described elsewhere in this report, Canada's First Ministers adopted the Vancouver Declaration on Clean Growth and Climate Change on March 3, 2016. Under the Vancouver Declaration, First Ministers committed to build on the momentum of the Paris Agreement by developing a concrete plan to achieve Canada's international commitments through a Pan-Canadian Framework on Clean Growth and Climate Change.

The Government of Canada became a signatory to the Paris Agreement on October 5, 2016, and committed to continuing to enhance its domestic adaptation activities and supporting international adaptation actions for developing countries.

The Pan-Canadian Framework on Clean Growth and Climate Change was adopted on December 9, 2016 by federal, provincial, and territorial governments.[a] The Pan-Canadian Framework sets out a collaborative plan for building resilience to climate change, encouraging clean economic growth, and reducing GHG emissions.

In 2016, the Government of Canada announced funding over five years (2016–2021) for seven federal departments and agencies to implement federal adaptation programming, and to integrate climate resilience into building design guides and codes.

Building on 2016 adaptation investments, in 2017 the Government of Canada announced funding over five years (2017–2022) for a suite of adaptation and climate resilience programs to protect communities and all Canadians from the risks associated with climate change. The Government of Canada also announced green infrastructure funding, a significant portion of which will help communities prepare for challenges that result from climate change. This includes significant investments in a Disaster Mitigation and Adaptation Fund to support large-scale national, provincial and municipal infrastructure projects that are resilient to the effects of a changing climate.

Provinces and territories have recognized the need to adapt either through stand-alone plans or strategies or as part of broader climate change plans or strategies and have made investments to support adaptation initiatives.

At the local level, cities and communities are actively planning for climate risks including, for example, through the development of adaptation strategies that inform city planning and infrastructure decisions and encourage action by homeowners and businesses.

Indigenous Peoples are also taking adaptation action, in the form of, for example, the development of community plans and hazard maps, and specific actions to maintain cultural practices and engage youth.

In the private sector, some companies are integrating climate considerations into their investment, planning, and operational decisions in order to improve their long-term resilience and competitiveness. Professional associations (e.g., engineers, planners, accountants, insurers, foresters) are working to inform and equip their members to be able to address a changing climate within their professional practice.

Banks are also beginning to engage in climate change risk reporting. Toronto-Dominion Bank and Royal Bank of Canada are among 14 of the world's leading banks to work with the United Nations Environment Programme Financial Initiative to develop better climate-risk assessments for financial institutions.

[a] Manitoba and Saskatchewan did not join the Pan-Canadian Framework at this time.

6.1 Climate Modelling, Projections, and Scenarios

Temperatures in Canada have been increasing at roughly double the average global rate, with average temperatures in Canada having already increased by 1.7°C since 1948.[1,2] Warming has been observed consistently across most of Canada, and across all seasons, but with stronger trends in the north and west, and in winter and spring.[3] Annual average precipitation has also changed in Canada with most of the country (particularly the North) having experienced an increase in precipitation since the mid-20th century. The strong regional and seasonal variability in precipitation is illustrated in Figure 6-1.

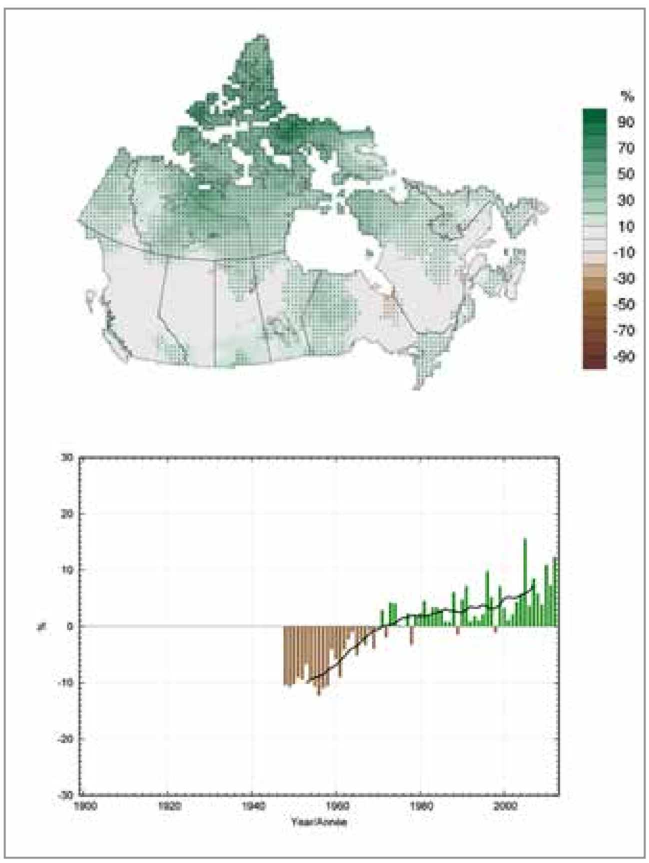

Figure 6-1: Annual total precipitation 1948–2012
The upper panel shows linear trends in annual total precipitation (expressed as per cent change relative to the local 1961–1990 climatology) for the period 1948–2012 for all of Canada. Grid squares with trends statistically significant at the 5% level are marked with a dot. Note that the distribution of observing stations over northern Canada is sparse. The bottom panel shows the time series and the 11-year moving average for Canada (Vincent et al., 2015[4]).

Future climate projections for Canada, fully consistent with those used in the IPCC Fifth Assessment Report (AR5), are developed by Environment and Climate Change Canada's Climate Research Division and made available to Canadians through the Climate Data and Scenarios website.

Continued amplification of warming at high latitudes compared to the global average is projected under all scenarios of future climate change; therefore, Canada's temperature will continue to warm at a faster rate than the world as a whole. Within Canada, climate change is not projected to be uniform, with both seasonal and geographic differences in rates of projected warming. The strongest warming is projected for winter and for northerly latitudes, a robust result consistent across all scenarios.

See Figure 6-2 for climate projections under a scenario based on a mid-range global GHG emissions scenario (e.g., Representative Concentration Pathway (RCP) 4.5).

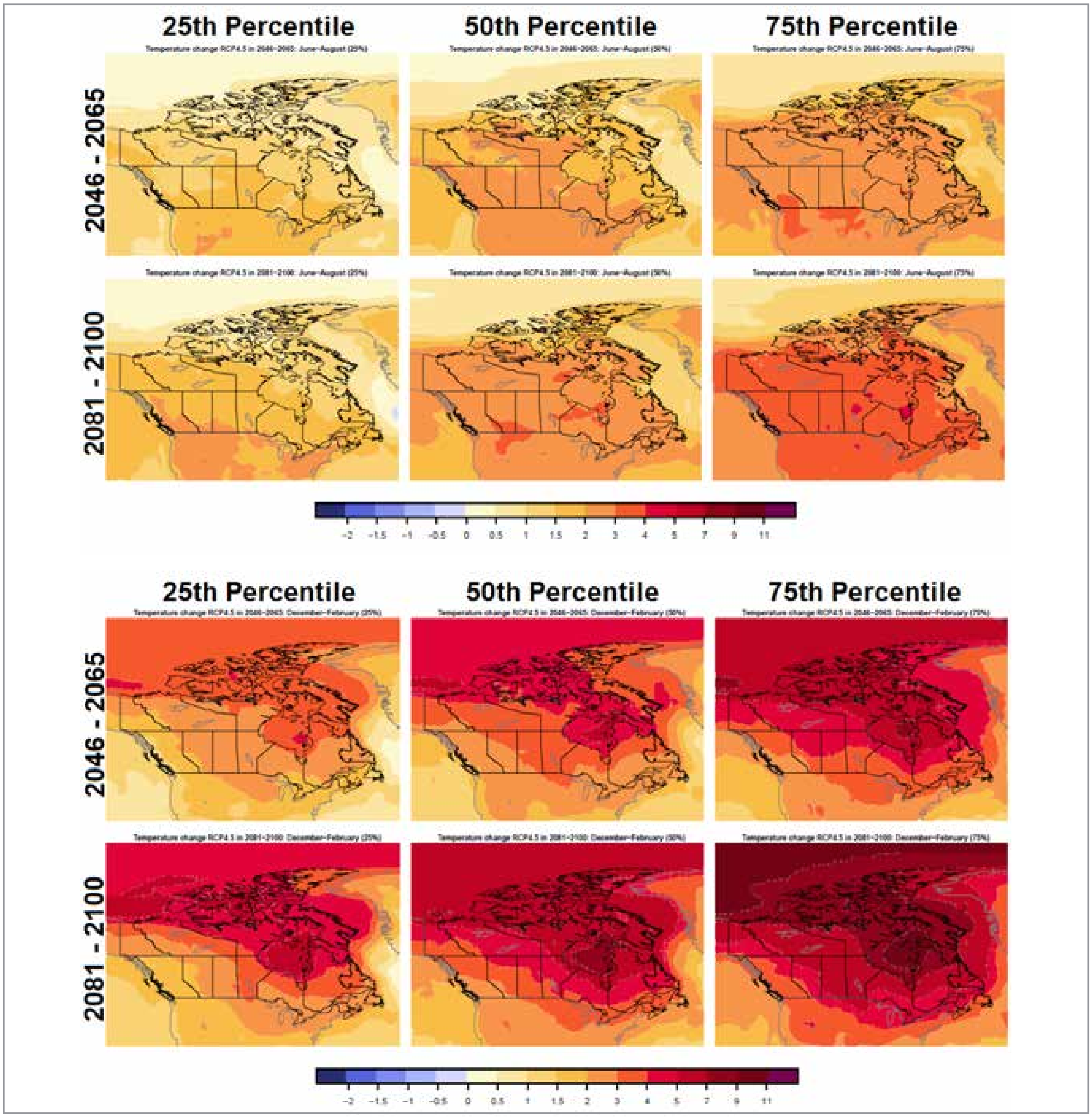

Figure 6-2: Temperature Change Projected by the CMIP5 Multi-Model Ensemble for the RCP4.5 Scenario; Summer and Winter

Maps of temperature change projected by the Coupled Model Intercomparison Project (CMIP5) multi-model ensemble for the RCP4.5 scenario, for summer (top frame, averaged over June–August) and winter (bottom frame, averaged over December-February). Change is computed relative to the 1986–2005 baseline period.[5] As in the IPCC Atlas (Annex 1, IPCC, 2013),[6] the top row shows results for the period 2046–2065, and the bottom row for 2081–2100. For each row the left panel shows the 25th percentile, the middle panel the 50th percentile (median), and the right panel the 75th percentile. The color scale indicates temperature change in °C with positive change (warming) indicated by yellow through red colors and cooling by blue colors, consistent with the color scale used in the IPCC AR5 Annex I.

Figure 6-3 below provides a projection of changes in summer and winter precipitation for Canada under a mid-range GHG emissions scenario (RCP4.5). Relative precipitation increases (% changes) are larger in the north and in winter versus summer.

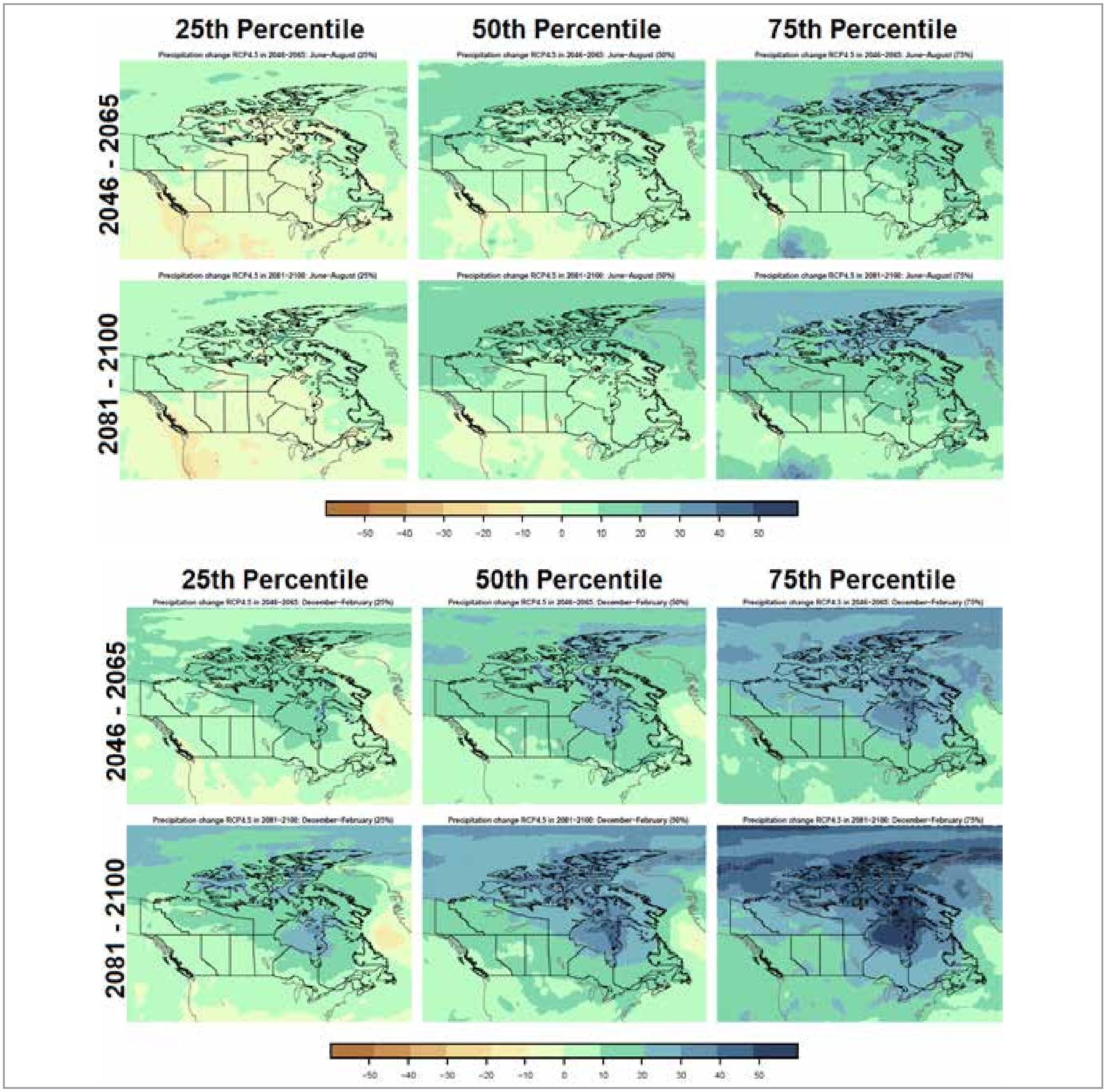

Figure 6-3: Precipitation Change Projected by the CMIP5 Multi-Model Ensemble for the RCP4.5 Scenario; Summer and Winter

Maps of precipitation change projected by the CMIP5 multi-model ensemble for the RCP4.5 scenario, for summer (top frame, averaged over June–August) and winter (top frame, averaged over December-February). Change is computed relative to the 1986–2005 baseline period.[7] As in the IPCC Atlas (Annex 1, IPCC, 2013),[8] the top row shows results for the period 2046–2065 and the bottom row for 2081–2100. For each row the left panel shows the 25th percentile, the middle panel the 50th percentile (median), and the right panel the 75th percentile. The colour scale indicates precipitation change in % with positive change (increased precipitation) indicated by green colours and decrease by yellow to brown colours, consistent with the colour scale used in the IPCC AR5 Annex I.

Overall, Canada can expect to continue to experience warmer temperatures and more rainfall across the country as a whole, although regional and seasonal variability will continue. Associated with these trends in average temperature and precipitation are projected increases in daily hot extremes and heavy rainfall events, and declines in snow and ice cover (see section 6.2.2.2 on Canada's North).[9] Sea level along many of Canada's coastlines will continue to rise, and this rise will be greatest in areas where the land is currently eroding, such as most of the Maritime Provinces. Warmer waters and ocean acidification are expected to become increasingly evident in most Canadian ocean waters over the next century.[10]

The impacts being observed are the result of historical emissions. Even with a successful transition to a carbon-neutral society, the impacts of changing temperature, precipitation, and the occurrence and severity of extreme events will continue to touch all regions, sectors, communities, and ecosystems for decades to come.

6.2 Assessment of Risk and Vulnerability to Climate Change Impacts

Knowledge of climate change impacts and the potential for associated risks is the foundation for organizations to protect assets and resources and to strengthen planning and decision-making. The development of programs, policies, and actions related to climate change impacts and adaptation are commonly informed by research and different types of assessments, including vulnerability, risk, and science assessments.

Since Canada's *6th National Communication*, more Canadian governments and communities have completed some form of climate change assessment focusing on their own organization or specific sector. These research and assessment activities have contributed to the development of decision-support tools and have revealed lessons learned that have supported the advancement of adaptation. While there has been no systematic attempt to conduct risk or vulnerability assessments across Canada, a number of individual initiatives employing a wide range of methodologies have been undertaken.

The consequences of climate change are evident across Canada, and include impacts to natural and built environments, as well as to the safety, health, socio-economic, and cultural well-being of Canadians. These impacts have high human and financial costs, and are already causing rapid and irreversible change in Canada's northern and coastal regions. These threats are often more acute for some Indigenous Peoples, who live closer to the land, with a strong socio-economic and spiritual connection to it. These changes have been well documented in several assessment reports (for example, *Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation, Canada's Marine Coasts in a Changing Climate, Climate Risks & Adaptation Practices for the Canadian Transportation Sector 2016)*.

This section outlines assessments conducted by federal, provincial, territorial, and municipal governments, and Indigenous Peoples and provides a brief summary of some impacts of concern identified by assessments, focusing on extreme events, northern and coastal regions, Indigenous Peoples, food and water security, health and well-being, and economic prosperity.

6.2.1 Assessments of Risk and Vulnerability to Climate Change

Assessments have been performed by the Government of Canada as a tool to further highlight the importance of understanding and addressing climate change impacts. These assessments are scientific reports that assess, critically analyze, and synthesize the growing knowledge base on the issue. Working with subject matter experts in government, universities, and non-government organizations, federal departments produce science assessments that are current, relevant, and accessible sources of information to help inform planning of policies, programs, and actions.

Fisheries and Oceans Canada completed four Large Aquatic Basin Risk Assessments covering the Pacific, Arctic, Atlantic Oceans and Canada's inland waters represented by the Lake Winnipeg and Great Lakes' drainage systems. Each large basin assessment included an analysis of climate trends and projections for the aquatic environment in order to help managers make strategic, climate-sensitive decisions about aquatic resource management activities and coastal infrastructure which are at risk to a changing climate.

Natural Resources Canada published a national-scale scientific assessment on the impacts of climate change in Canada in 2014, titled Canada in a Changing Climate: Sector Perspectives on Impacts and Adaptation. This report was an update to the 2008 report, titled *From Impacts to Adaptation: Canada in a Changing Climate*. The updated report took a sector-based approach, and focused on natural resources (e.g., forestry, mining, and energy), food production, industry, biodiversity and protected areas, human health, and water and transportation infrastructure. This assessment illustrated how Canada's climate is changing and will continue to change, and how adaptation has been accepted as a necessary response to climate change, complementing global measures to reduce GHG emissions.

Natural Resources Canada also published a sectoral assessment focused on marine coasts in 2016, titled *Canada's Marine Coasts in a Changing Climate*. This assessment emphasized the impacts of climate change on Canada's coasts, and presented both the challenges and potential opportunities for coastal communities, ecosystems, and the economy as a result of these changes. The assessment highlighted a variety of adaptation measures that are being adopted in different coastal regions, such as presenting enhanced use of natural infrastructure as an alternative to hard coastal protection measures to reduce climate risks, and emphasized the importance of adaptation in ensuring the sustainability and continued prosperity of Canada and its coastal regions.

Transport Canada released a national-level assessment of climate risks and adaptation practices for the Canadian transportation sector in 2017, titled *Climate Risks & Adaptation Practices for the Canadian Transportation Sector 2016*. The report represents the state of knowledge on climate risks to the sector and identifies existing or potential adaptation measures to mitigate risks. The report is structured regionally, with a synthesis chapter that brings together knowledge relevant to each main mode of transportation (e.g., rail, marine, aviation, road), as well as a chapter specifically dedicated to urban transportation. The information will help decision-makers across the sector better understand potential climate risks and the actions that can be taken to mitigate them.

The Government of Canada also supports sectors, provinces, territories, and communities in conducting their own assessments. For example, through the AgriRisk Initiatives program, Agriculture and Agri-Food Canada is supporting the agriculture sector in developing regional climate vulnerability and opportunity assessments to evaluate potential climate change impacts on local agricultural production.

Together with the governments of the Northwest Territories and of Nunavut, the Government of Canada assessed infrastructure engineering vulnerabilities of three northern airports (Churchill Airport, Inuvik Airport and Cambridge Bay Airport), using the Public Infrastructure Engineering Vulnerability Committee (PIEVC) Protocol. The knowledge gained through these assessments is intended to inform asset management plans, investment plans, and other decision-making relevant to these assets.

The Government of Yukon is developing better methodologies for assessing the financial impacts of permafrost thaw, and experimenting with new approaches to building and maintaining infrastructure on permafrost-affected terrain. The territory has also performed risk and/or vulnerability assessments, disaster resiliency planning, and is actively monitoring permafrost temperatures and identifying intervention opportunities to mitigate impacts with the help of the Yukon Permafrost Knowledge Network.

Assessments are often the first stage of municipal adaptation planning processes. For example, the municipality of Wawa, Ontario brought together varied stakeholders from across the community to come together and identify local climate change impacts. Using this information they then worked through a process of vulnerability and risk assessment and they will use the results to protect Wawa's community by integrating the identified climate risks into their broader *Emergency Preparedness Plan*.

Similarly, Calgary and Edmonton, Alberta, worked with the Prairie Climate Centre to create a series of publications for the public and government officials that explore how to build cities that are resilient to the impacts of climate change, drawing on lived experience and best practices. The reports touch on climate change and its local impacts on a number of sectors, including economics and finance, agriculture and food security, urban ecosystems, transportation, water supply, and electricity.

While important, assessments of adaptation planning in Indigenous and northern communities have occurred on a predominantly ad-hoc basis. Despite this the Government of Canada, as well as provincial, territorial and municipal governments, contribute to increasing northern and Indigenous Peoples' resilience to climate change by supporting them in the identification of high risk areas for climate change impacts. Indigenous and Northern Affairs Canada has provided financial support to communities to engage in a variety of planning activities including: gathering traditional knowledge, participating in regional planning activities, producing Indigenous-specific tools and guides and conducting vulnerability assessments and adaptation plans.

6.2.2 Climate Change Impacts

Assessments present the latest knowledge on climate change impacts and adaptation, and act as accessible sources of information to help inform planning of policies, programs, and actions.

6.2.2.1 Extreme Weather Events

Extreme weather events are a key concern for Canada and there is growing confidence that some types of extreme events will increase in frequency and/or intensity as the climate continues to warm.[11] Changes in temperature and precipitation patterns have made the wildfire season longer, while drought- and pest-stressed forests and rangelands are increasing the severity of wildland fires.[12] Sea level rise is increasing the extent of storm surge flooding.[13]

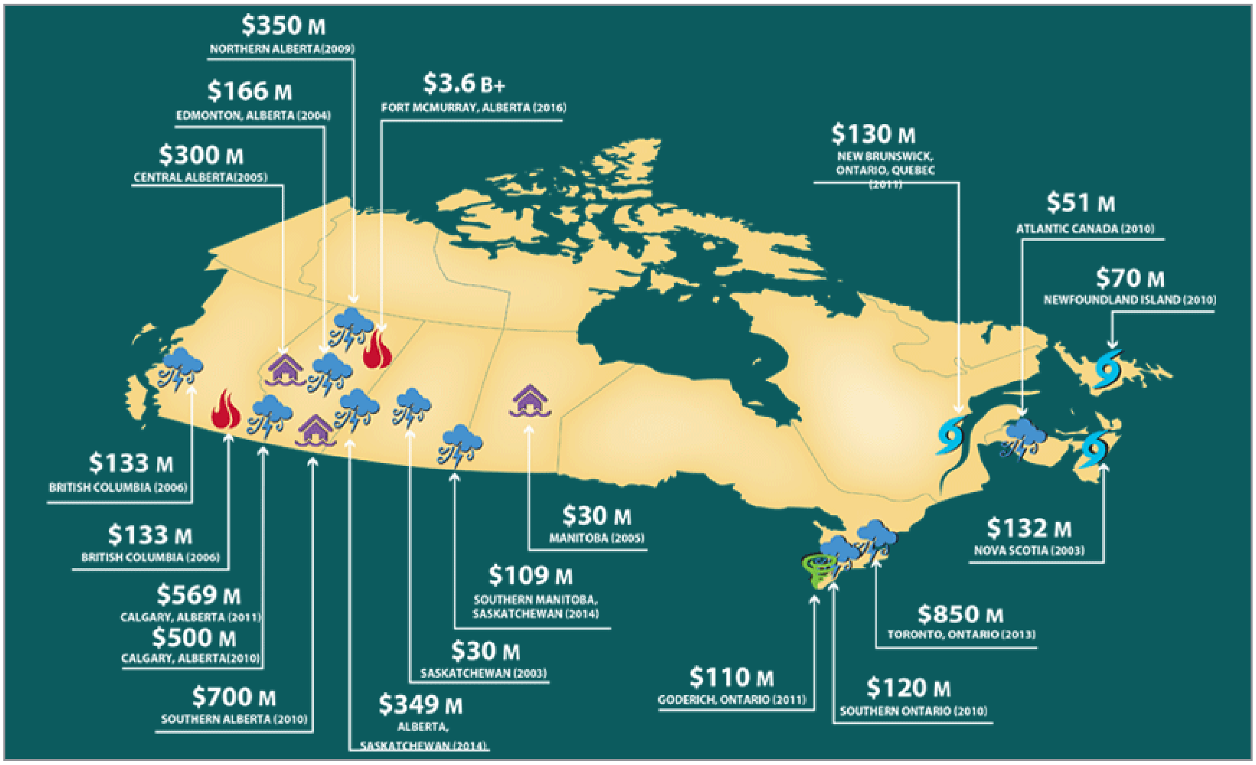

Figure 6-4: Insured Losses from Extreme Weather Events in Canada

Examples of insured losses from extreme weather events in Canada (Sources: Updated from Kovacs and Thistlethwaite, 2014[14])

Recent examples demonstrate the potentially devastating effects of these events and the vulnerability of communities to an increasing risk of climate-related extreme events. The 2016 Fort McMurray wildfire displaced 90,000 people, destroyed approximately 2,400 homes and other buildings, and caused disruptions in local economic activities. With insured losses in excess of $3.5 billion, this fire was the costliest insurable loss in Canada's history. In early May 2017, a strong and prolonged precipitation event caused historic floods in eastern Ontario and western Québec. The flooding caused thousands of people to evacuate their homes, and even more were affected by the flooding.[15] The response to the flooding required over 2,000 Canadian Armed Forces personnel to be deployed to assist in relief efforts.[16]

6.2.2.2 Canada's North

While Canada's temperature increases are outpacing the global average, temperatures are rising even faster in Canada's Arctic and northern areas. The rapid warming of Canada's North is leading to significant reductions in the extent of sea ice, accelerated permafrost thaw and loss of glaciers, and other ecosystem impacts.

The volume and coverage of sea ice have decreased significantly since observations began in 1979. A nearly-ice free summer is considered a strong possibility for the Arctic Ocean by the middle of the century although summer sea ice may persist longer in the Canadian Arctic Archipelago region, which will have wide ranging implications in Canada's North, as well as globally.[17] Northern Arctic ice shelves have undergone significant changes in the last 100 years, eroding from one large ice shelf that spanned the entire northwest coast of Ellesmere Island into three smaller ice shelves. Since 2005, the total remaining area of ice shelves has decreased by more than 50%.[18] Sea ice provides critical transportation in parts of the North, and its rapid loss is having a profound impact on communities that rely on ice to access hunting grounds and traditional sites, as well as on seasonal ice roads that provide access to food and supplies from the south. As Simeonie Amagoalik, an Elder from Nunavut, recalls: “I used to go egg hunting but now it is too dangerous to travel by ice so I cannot go to the places that I used to go to. I think it is mainly the ice on the sea that has affected me the most.”[19]

The loss of sea ice also alters animal ranges (e.g., seals, walruses, salmon, whales) and opens new pathways for disease (e.g., a seal-killing virus previously seen only in the Atlantic Ocean was found in a population of Pacific sea otters in Alaska). These impacts are especially felt by Indigenous Peoples that depend on these animals for sustenance and cultural survival. While reduced ice cover is increasing marine access to the North for resource development, shipping, and tourism, these activities bring with them new risks of accidents and spills, which put people and ecosystems at risk and place additional stress on limited search and rescue and disaster response capacity.

Warmer temperatures, along with other factors such as fire, increased rainfall, and erosion, are causing permafrost to degrade. The loss of permafrost is causing irreversible changes to the landscape, including slumping, erosion, ground instability, and forest mortality. Habitat is changing and, for some species, being lost altogether. Since permafrost impacts how far water can penetrate into the ground, permafrost degradation leads to changes in drainage patterns, expansion or drainage of ponds, lakes, and wetlands, changes in water quality, and shifts in the timing of peak and minimum flows in rivers and streams. For example, in the summer of 2015, a large permafrost thaw slump caused rapid drainage of a tundra lake near the Mackenzie Delta in the Northwest Territories. This event was driven, in part, by rising temperatures and increased rainfall. More information pertaining to permafrost impacts can be found in Chapter 8: Research and Systematic Observation of Climate Change.

Northern infrastructure, including roads, buildings, communications towers, energy systems and facilities, community landfills, sewage lagoons, and large-scale waste containment sites (including berms around tailings ponds), often depend on stable permafrost. Degradation causes costly damage and unsafe or unstable conditions.

Remote communities, Indigenous Peoples, and isolated economic sites often depend on a network of winter roads for critical shipments of medical supplies, food, fuel, and equipment. Climate change continues to affect the length of time that winter roads can be operational and whether they are viable at all, making these communities and sites more reliant on other transportation routes or modes. This significantly increases the cost of living and doing business in the North, affecting the ability to attract investment, the prosperity of local businesses, and the strength, health, and well-being of remote communities and Indigenous Peoples.

6.2.2.3 Canada's Coasts

Canada has the longest coastline in the world, and many coastal areas are of great economic, social, historical, and environmental significance. Through changes in relative sea level, rising water temperatures, increased ocean acidity, and loss of sea ice and permafrost, climate change is posing considerable challenges for Canada’s coastal areas.

Coastlines projected to experience the greatest relative sea level rise are the Atlantic Provinces, the Gulf of St. Lawrence, the Beaufort Sea, Haida Gwaii, parts of Vancouver Island, and other parts of the British Columbia coast.[20] Relative sea level rise will negatively impact some coastal ecosystems (including dunes, wetlands, tidal flats, and shallow coastal waters) and the services they provide. When combined with high winds, storms, and high tides, sea level rise causes storm surges to reach higher elevations, affecting both natural shorelines and human built coastal infrastructure.

Sea ice acts as natural protection against waves and storm surges. The loss of sea ice further increases storm surge risks and coastal erosion in the Beaufort Sea and Atlantic region. Along the northern coast, the additional challenges posed by the loss of permafrost are contributing to unprecedented rates of erosion.[21]

Coastal communities are experiencing challenges that include: unstable shorelines; flooding damage to property and agricultural lands; permanent loss of archaeological sites and cultural heritage landmarks; contamination of water supplies; increasing costs for protection, maintenance, and insurance; disrupted transportation and trade routes and infrastructure (e.g., small craft harbours); and impacts on human health (e.g., water-borne diseases). Increases in water temperatures and ocean acidity also impact fisheries, traditional foods, iconic species (e.g., salmon), and food and water safety (e.g., harmful algal blooms).[22]

In some cases, ensuring the continued safety of coastal communities will require considerable effort and resources, and in others it will be necessary to relocate. Given the strong ties to land and place, relocation is likely to have social, cultural, and mental health impacts.

6.2.2.4 Indigenous Peoples and Communities

Indigenous Peoples have a strong cultural connection to the land, water, and air. While this increases their exposure and sensitivity to climate change impacts, it is also a source of strength, understanding, and resilience.[23]

Indigenous Peoples are among the most vulnerable to climate change and experience unique challenges. A range of factors, largely related to historical legacies, contribute to this vulnerability.[24,25,26] Unprecedented changes to the environment and ecosystems challenge traditional ways of knowing and Indigenous Peoples' ability to maintain practices, languages, and culture. Indigenous Peoples also face challenges of access to climate change adaptation resources, programs, and tools.

Although Indigenous Peoples are among the most vulnerable to a changing climate due to their close relationship with the environment and its resources, they are not passive recipients of climate change impacts. Rather, they are active drivers of change who contribute vital knowledge, experience, and leadership to adaptation efforts across Canada. In the face of the challenges presented by climate change, Indigenous Peoples are changing the way they live and interact with the environment and each other, and are taking tangible steps to become agents of change.

Building resilience for Indigenous Peoples is fundamentally about food, water, and energy independence, where communities are self-sufficient in all means needed for survival and cultural expression.[27,28] Indigenous Peoples and their knowledge-holders have a long history of, and deep understanding about, adapting to changes in climate and the land.

6.2.2.5 Food and Water Security

Climate change is impacting agricultural productivity and access to traditional food sources. Risks are directly related to increased incidence of drought, floods, storms, and heat waves, as well as changes to plant lifecycles and productivity, shifting plant and animal ranges, the spread of invasive species, and the emergence and spread of pests and disease. Higher temperatures and potentially longer growing seasons present opportunities for agricultural production in certain areas.

In the North and for Indigenous Peoples, changes in seasonal weather and climate conditions impact the transportation of food and other supplies and have made some traditional travel and hunting routes unsafe, thereby deepening existing food security challenges. For example, climate change is affecting the timing of freeze- and break-up on rivers used for transportation and gathering food through hunting, trapping, and fishing. Reduced access to country foods is increasing reliance on expensive store-bought foods with negative effects on health (e.g., diabetes, obesity) and cultural identity. Costs for transporting food and other supplies have also increased, especially in areas that are increasingly dependent on shipments by air.

Water flows, availability, and quality are also changing due to temperature increases and precipitation changes. Rising temperatures are leading to a rapid loss of glaciers, impacting water flow and temperature in glacial-fed streams and rivers. More information pertaining to climate change impacts on glaciers can be found in Chapter 8: Research and Systemic Observations of Climate Change.

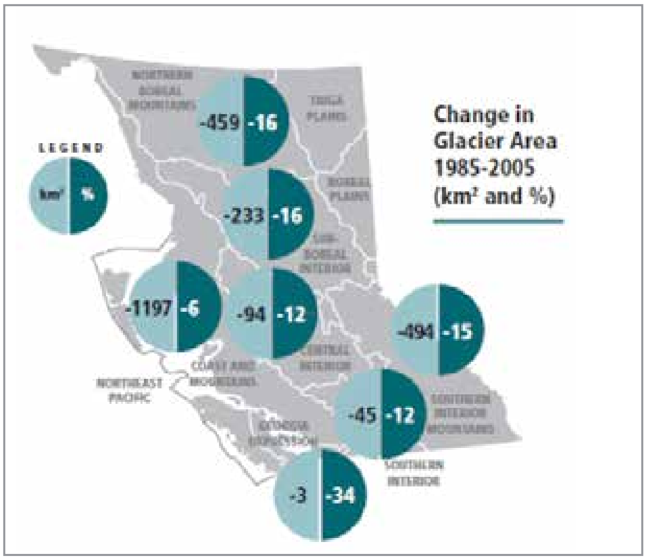

Figure 6-5: Change in Glacier Area 1985–2005 (km and %)
From 1985 to 2005 the glacier coverage in British Columbia decreased by 2,525 km^2 (Bolch et al, 2010).[29]

Water availability, in terms of both the amount of water and the times of minimum and peak flows, is also impacted by changes in spring precipitation and reduced snow accumulation. These changes in the timing and amount of water have consequences for agriculture, industrial activities, power generation, and ecological function.

Higher water temperatures (and less available oxygen) and higher acidity in the water threaten marine life and habitats, impacting commercial, recreational and subsistence fisheries and aquaculture activities. Shorter seasons of ice cover, higher water temperatures, and changing precipitation patterns can affect lake water levels, impacting shipping, tourism, and water quality. For example, observed water levels in the Great Lakes basin have been highly variable, making it difficult to predict the direction of long-term change. However, warming temperatures and changing precipitation patterns are expected to contribute to altered (increased or decreased) water levels, with implications for shipping capacity in the Great Lakes-St. Lawrence Seaway system.[30]

6.2.2.6 Health and Well-Being

Climate change impacts affect the health and well-being of Canadians in many ways, both directly and indirectly. More frequent and severe extreme weather events increase the risk of physical injury, illness, and death. Health systems are challenged and health care facilities can be impacted, with consequences for patient care, safety, and health care costs. In addition, the impact of natural disasters and changing landscapes, the loss of property and cultural heritage sites, and the inability to attend work or school have a negative impact on public health, including mental health, and can diminish individual and community resilience. This can have a significant impact on people, their families, communities, the economy, and the functioning of society as a whole.

Heat waves can cause heat-related illness and death, as well as exacerbate existing conditions, such as respiratory and cardiovascular diseases. Higher temperatures also contribute to increased air pollution and production of pollens, worsening allergies and asthma and exacerbating some existing health conditions. Smoke from wildland fires also impacts air quality. Increased contamination of drinking and recreational water by run-off from heavy rainfall can cause illness and disease outbreaks (e.g., acute gastrointestinal illness, E-coli).[31]

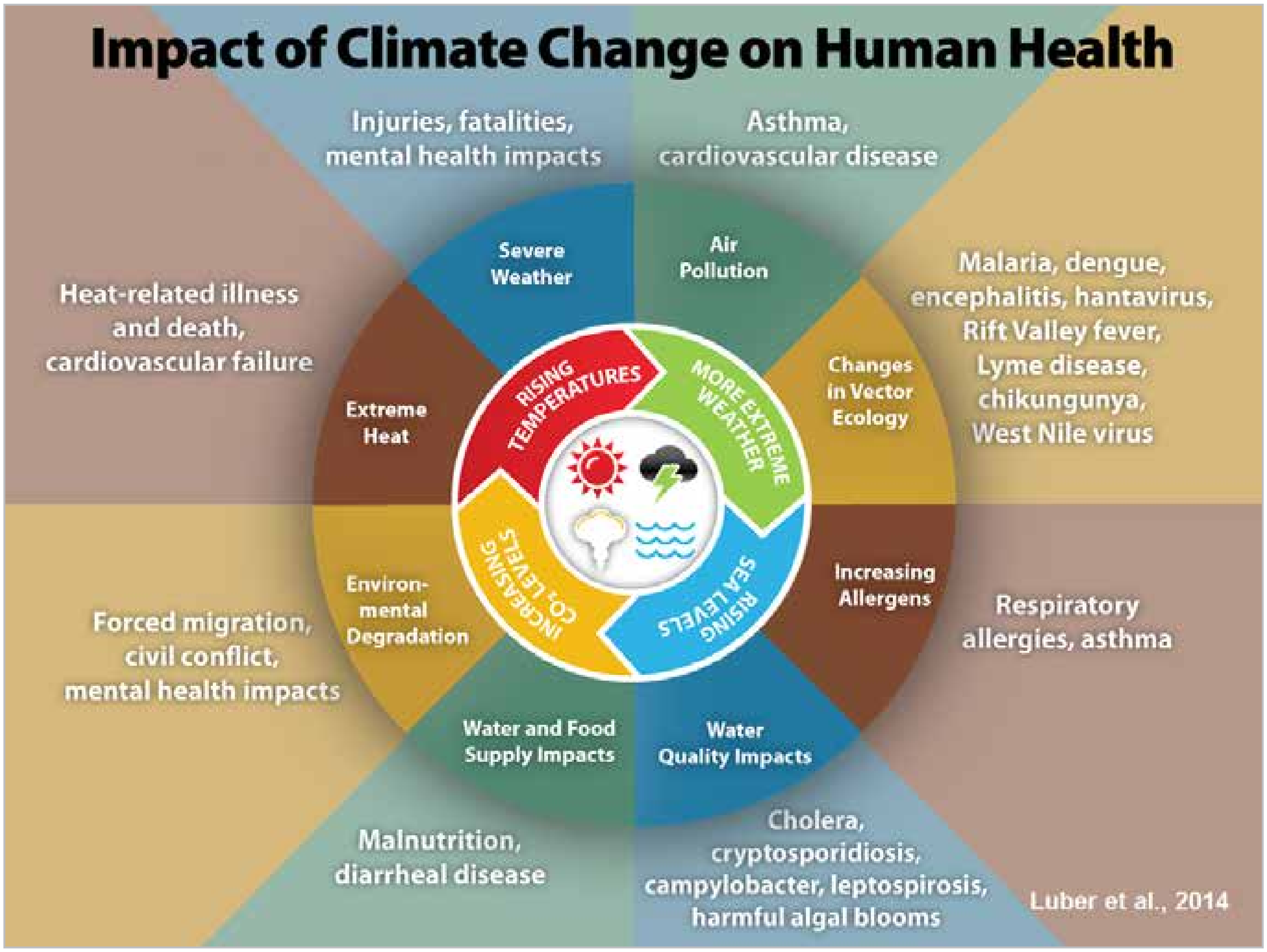

Figure 6-6: Climate Change Effects on Health and Well-Being
Overview of the ways in which climate change affects health and well-being.[32]

Climate change is also likely increasing the prevalence and spread of certain zoonotic, foodborne, or water-borne diseases. For example, Canada is already seeing increased prevalence and geographic range of vector-borne diseases, such as Lyme disease and West Nile virus, as higher temperatures and changes in precipitation can make the environment more hospitable for insects, such as ticks and mosquitoes. In addition, there may be an emergence or re-emergence of diseases that are currently considered to be rare or exotic to Canada (e.g., malaria, chikungunya, Zika virus).

More broadly, climate change affects the various social determinants of health (e.g., food security, availability of potable water, housing, working conditions, income) and reduces resilience. Household food insecurity has been associated with a range of poor physical and mental health outcomes, including multiple chronic conditions and depression.

6.2.2.7 Economic Prosperity

Canadian industries are affected by climate change in various ways. Impacts associated with climate change and extreme weather (for example, the loss of permafrost, coastal erosion, and changing precipitation patterns) are already affecting transportation systems, services and operations across all modes, in all regions of Canada. Associated disruptions in the movement of freight and people, represents risks to the economy and Canadians.

Disruptions in productivity, critical trade infrastructure, electricity generation, and supply chains have broad consequences for many economic sectors, services to consumers, and businesses. Climate change impacts in Canada and around the world affect global food and water security issues, commodity prices, trade, supply chains, conflict, and displaced people, which will have consequences for Canadian immigration, defense, and private sector prosperity. Tourism and recreation activities that rely on weather conditions are particularly sensitive to climate change.[33]

Canada's resource economy is vulnerable to the impacts of climate change. The forestry and agriculture sectors have been affected by increased incidence of drought, floods, storms, heat waves, wildfires, and pests and diseases (e.g., mountain pine beetle and spruce budworm), which has consequences for productivity, the quality of the harvest, and work opportunities.[34] Mining, oil and gas production, hydroelectric power generation, transportation, and agriculture are all affected by variable water levels. Increased temperatures, changing precipitation patterns, and increased frequency and intensity of extreme weather events are creating risks and operational challenges for agriculture and aquaculture production, though rising temperatures could also increase growing days and present opportunities for new crops or species in some regions.

Some of the most vulnerable components of Canada's transportation system are integral to the resource industry in the North. Climate change impacts, such as permafrost degradation, can cause infrastructure damage and deterioration, disruptions to transport operations, and unsafe conditions for the resource sector and for other local economies.

6.3 Climate Information and Services

Climate information can inform decision-making in key sectors such as health (e.g., air and water quality, heat, infectious diseases such as Lyme), agriculture (e.g., food production and security), infrastructure (buildings, roads, bridges and water assets), and natural resource management (e.g., energy, forestry, fisheries, and mining). It is also a foundation for developing appropriate adaptation and risk management strategies. Climate services include climate data, predictions, information, and tools to support adaptation decision-making. Climate services in Canada are a responsibility shared by federal, provincial, and territorial governments.

6.3.1 Federal Climate Information and Services

The Government of Canada undertakes science and monitoring activities related to past, present, and future states of the climate system and how it functions, as well as on the changing composition of the atmosphere and related impacts. These activities include foundational climate and climate change science as well as climate information and services provided by federal departments to inform effective adaptation planning and decision-making. Climate change science includes research related to the impacts of climate change on biodiversity and ecosystem services, as well as options and opportunities for using ecosystems to support climate change adaptation and mitigation. More information pertaining to climate modelling, projections, and scenarios can be found in Chapter 8: Research and Systematic Observation of Climate Change.

Environment and Climate Change Canada currently provides some climate information products and services including seasonal outlooks (e.g., bulletins and consultation process), historical climate data sets, trends analysis, and climate change scenarios. Environment and Climate Change Canada also provides some tailored climate information products and services. For example, the department provides long-term historical climate data sets for internal and external clients and users through its engineering climate services. This includes information about historical snow and ice conditions, which is incorporated into the development of rooftop snow load requirements for the National Building Code of Canada; wind pressure analysis that informs the telecommunications and renewable energy industries (e.g., siting communications towers and wind farms); and analysis on the intensity, duration, and frequency of extreme rainfall to support storm and waste water management.

Agriculture and Agri-Food Canada also provides a variety of climate data products, information, and services specifically for Canada's agriculture and agri-food sector. The Department translates highly technical research, applied research and resultant products for a broader agriculture and agri-food audience to use when making climate change adaptation decisions. Agriculture and Agri-Food Canada's National Agroclimate, Geomatics and Earth Observation Service is an authoritative source for a wide variety of agroclimate data, indices, information, tools, and models for use by the agricultural sector, such as monitoring and assessing climate-related risks to agricultural production, analyzing changing land suitability and forecasting crop production (see Drought Watch for current product offerings).

Through its Aquatic Climate Change Adaptation Program, Fisheries and Oceans Canada is monitoring and studying the effects that changing ocean conditions is having on Canada's fisheries, aquatic ecosystems, and coastlines. The department is also looking at the impacts of sea level rise and more frequent storms and storm surges on coasts and ocean infrastructure, such as wharfs and dams.

The Government of Canada created Polar Knowledge Canada through the *Canadian High Arctic Research Act*, which came to force on June 1, 2015. Polar Knowledge Canada reports to the Minister of Crown-Indigenous Relations and Northern Affairs and is led by a Board of Directors and a President. Polar Knowledge Canada is responsible for advancing knowledge of the Canadian Arctic and strengthening Canadian leadership in polar science and technology. Polar Knowledge Canada's pan-northern Science and Technology program priorities for 2014–2019 include: alternative and renewable energy; baseline information to prepare for northern sustainability; predicting the impacts of changing ice, permafrost, and snow on shipping; infrastructure and communities; and catalyzing improved design, construction, and maintenance of northern built infrastructure.

Efforts are underway to improve climate information products and services provided by Environment and Climate Change Canada and other federal departments, including investments in 2017 to support the establishment of a new Canadian Centre for Climate Services. The Canadian Centre for Climate Services will deliver trusted climate information, data, and tools that will support adaptation decision-making. Training, support, and user-driven products will ensure tools are used while partnerships with other organizations will shape and deliver services across the country.

Additionally, Indigenous and Northern Affairs Canada launched an Indigenous Community-Based Climate Monitoring program that will support Indigenous communities in developing climate impact monitoring projects and initiatives using both Indigenous Knowledge and western science while collaborating with researchers. The program will assist with the development of community-led initiatives and help build collaborative partnerships between communities, researchers and existing monitoring networks at regional, national and international levels when appropriate. It will help communities document their Indigenous Knowledge and integrate current technologies in monitoring community relevant indicators of climate change, and contribute to advancing climate research. The information resulting from projects and connections to research and monitoring networks will help communities access more comprehensive climate information and help communities take concrete actions to manage climate change risks associated with activities on the land.

6.3.2 Provincial and Territorial Climate Information and Services

Provinces and territories, private consultants, and research institutions provide climate information products and services. These are usually regionally, locally and/or sector specific. This section focuses on jurisdictions that provide climate information and services, such as data, information, and tools, to support climate change adaptation decision-making.

6.3.2.1 British Columbia

The Government of British Columbia's ministries and partners continue to operate and improve hydrological monitoring (climate, snow, surface water, and groundwater) in order to provide better data to support decision-making for drought, flood, infrastructure planning, environmental flow needs, and ecological modelling.

Additionally, the Pacific Climate Impacts Consortium, a regional climate service centre established in 2005, supports climate change adaptation in Canada's Pacific and Yukon regions by carrying out research and providing information and projections of future climate change impacts and conditions.

6.3.2.2 Manitoba

Manitoba's Prairie Climate Centre, a collaboration of the University of Winnipeg and the International Institute for Sustainable Development, enables governments, businesses, and community members across the Prairies to reduce their vulnerability to climate variability and change by providing access to an innovative, stakeholder-driven hub for data, guidance, research, knowledge exchange, training and capacity building. The Prairie Climate Centre has developed a Prairie Climate Atlas to provide information about how Canadian Prairie Provinces may change in the coming decades. The Prairie Climate Atlas is an interactive website that includes climate data, geo-visualizations, and multimedia tools to communicate climate change impacts to the general public and provide decision-makers and regional leaders with information to inform adaptation and mitigation decision-making.

6.3.2.3 Ontario

The Government of Ontario is working to establish a new independent climate change organization, which will serve as a one-window source for climate data and services in the province. This new organization will work with municipalities, Indigenous Peoples, and leaders to help both public and private sectors make informed and evidence-based decisions regarding adapting to climate change and increasing resilience. By offering a range of climate services, the organization will provide access to expertise to understand how climate change may affect different activities or lines of business, and help plan for and manage risks in areas such as agriculture, infrastructure, and public health.

In addition, the Ontario Centre for Climate Impacts and Adaptation Resources, operating out of Laurentian University, is a resource hub for researchers and stakeholders searching for information on climate change impacts and adaptation.

6.3.2.4 Québec

To better inform decision-making at all levels, the Government of Québec has a strong partnership with the Ouranos consortium, which it jointly created with Hydro-Québec, Environment and Climate Change Canada, and Valorisation-Recherche-Québec in 2001 to provide specialized information on regional climate science and adaptation. Ouranos is a network of approximately 450 researchers, experts, practitioners, and policy-makers from a variety of climatology-related disciplines that has implemented over 100 projects in collaboration with government, academia, and industry. Ouranos brings together researchers, practitioners, and policy-makers to promote and support adaptation, develops climate scenarios and services, and produces regional climate simulations. Ouranos also develops and implements climate projections to identify the potential impacts of climate change and inform adaptation decision-making across sectors.

6.3.2.5 Newfoundland and Labrador

In 2015, Newfoundland and Labrador undertook a detailed assessment of 19 rainfall monitoring locations to ensure that extreme precipitation events could be reviewed in the context of projected climate change conditions. At the same time, the province established 113 coastal erosion monitoring sites to inform planning and development decisions given the risk of more rapid coastal erosion in a province where 90% of the population lives along the coast. These products, which are available at a publicly available Climate Information Portal, have facilitated improvements in related adaptation tools and resources, such as flood risk mapping, and complement other data, such as coastal erosion monitoring, to provide stakeholders with a range of planning information to inform decision-making processes.

6.3.2.6 Yukon

The Government of Yukon has prioritized improving baseline climate science to support data-driven, targeted adaptation investments and actions. The territory has improved the accessibility of its flood risk data through a flood risk mapping project that uses light detection and ranging remote sensing and historic water-level data to identify flood risks for Yukon communities.

6.4 Domestic Adaptation Policies, Plans, and Programs

Governments across Canada are developing adaptation policies and plans to build Canada's resilience to climate change; working to ensure that Canadians understand how they may be affected by climate change; and helping Canadians make the best decisions to protect their homes, businesses, health, and communities.

Recognizing that adaptation is a long-term challenge, adaptation and climate resilience is one of the four pillars of the Pan-Canadian Framework on Clean Growth and Climate Change.

Under this pillar, federal, provincial and territorial governments made commitments to address the significant risks that climate change impacts pose to communities, the health and well-being of Canadians, the economy, and the natural environment—in particular in Canada's northern and coastal regions, and for Indigenous Peoples. It represents the first time that federal, provincial, and territorial governments have identified priority areas for collaboration to build resilience to a changing climate across the country. These priorities include:

- Ensuring Canadians have information and expertise to consider climate change in their planning and decision-making;
- Building climate resilience through infrastructure;
- Working to protect the health and well-being of Canadians;
- Supporting particularly vulnerable regions and Indigenous Peoples in addressing climate impacts; and,
- Reducing the risks to communities from climate-related hazards and disasters.

For each priority area, federal, provincial, and territorial governments identified new actions that would advance efforts towards a more resilient Canada. These actions range from measures to improve access to climate science and information that supports adaptation decision-making, to investments in built and natural infrastructure to increase climate resilience in communities, to efforts that help better understand and take action to address climate-related health risks such as extreme heat and infectious diseases. These actions are further outlined in the following section.

6.4.1 Federal Adaptation Policies, Plans and Programs

The federal government has a long history of working on adaptation. Research on the impacts of climate change has been underway for decades, and permanently funded federal adaptation work began in 1998. Since then, federal efforts have expanded from research and assessment to policy development and investments to enable action at the local level, with a key principle of current federal action being collaboration with provincial, territorial, and municipal governments, and Indigenous Peoples.

Through the Pan-Canadian Framework on Clean Growth and Climate Change, the federal government has committed to working with provinces and territories to complement and support their climate change actions. The federal government has further committed to working with provinces and territories, municipalities, and Indigenous Peoples to bring together partners to share and leverage knowledge, capacity, and resources.

Significant investments have been made in climate change adaptation since 2014. In 2016, the Government of Canada strengthened its approach to domestic climate change adaptation by funding seven federal departments and agencies for a suite of adaptation programs. These programs include those related to science, health, northern and Indigenous Peoples, and key economic sectors ($129.5 million), Canada's National Research Council to develop climate-resilient building design guides and codes ($40 million), and the Federation of Canadian Municipalities' Municipalities for Climate Innovation Program ($75 million), which helps municipalities prepare for, and adapt to, climate change, and to reduce GHG emissions.[35]

Building on 2016 adaptation and climate resilience investments, the Government of Canada announced further funding over five years in 2017 for a suite of federal adaptation programs related to information and capacity, climate-resilient infrastructure, human health and well-being, vulnerable regions, and climate-related hazards and disaster risks ($260 million). Climate change adaptation initiatives funded by the Government of Canada under Budget 2017 include:[36]

- Environment and Climate Change Canada's Canadian Centre for Climate Services.
- Natural Resources Canada's efforts to build regional adaptation capacity and expertise.
- Health Canada, the Public Health Agency of Canada, and the Canadian Institutes of Health Research work to respond to the broad range of health risks caused by climate change.
- Health Canada's implementation of a climate change and health adaptation program for First Nations and Inuit communities.
- Indigenous and Northern Affairs Canada's integration of Indigenous Knowledge to build a better understanding of climate change and to guide adaptation measures; enhance Indigenous community resilience through infrastructure planning and emergency management in those communities where flooding risks are increasing; and enhance resilience in northern communities by improving the design and construction of northern infrastructure.
- Fisheries and Oceans Canada's Aquatic Climate Change Adaptation Services Program.
- Transport Canada's Northern Transportation Adaptation Initiative.
- Transport Canada's risk assessments on federal transportation infrastructure assets.

Investments announced in 2017 also included further detail on green infrastructure investments ($21.9 billion) intended to boost economic growth and build resilient communities. These investments will include funding for bilateral agreements with provinces and territories ($9.2 billion), a portion of which will be invested in adaptation and climate resilience, and funding for a Disaster Mitigation and Adaptation Fund ($2 billion) to support infrastructure required to deal with the effects of a changing climate, the most significant commitment to invest in adaptation by the federal government to date. In addition, $5 billion will be made available through the Canada Infrastructure Bank for green infrastructure projects.

Investments in climate change adaptation made in 2017 were guided by the adaptation and climate resilience pillar of the Pan-Canadian Framework on Clean Growth and Climate Change (2016).

Specific examples of federal adaptation programming include Canada's Adaptation Platform, chaired by Natural Resources Canada, which brings together key groups from governments, industry, professional and Indigenous organizations to collaborate on adaptation priorities. The overarching goal of the Adaptation Platform is to create an enabling environment for adaptation, where decision-makers in regions and key industries are equipped with the tools and information they need to adapt to a changing climate.

The Standards Council of Canada's new program, Standards to Support Resilience in Infrastructure, supports the development of standardization guidance on weather data, climate information and climate change projections, in support of the Government of Canada's objective to adapt infrastructure to climate change impacts. This initiative also supports an update of a broad range of existing standards to ensure infrastructure across Canada is climate-ready, and invests in new standards that support northern infrastructure through the Northern Infrastructure Standardization Initiative.

Agriculture and Agri-Food Canada supports and leads research and collects agro-climate, soil, drought, and crop information to inform adaptation decision-making in Canada's agriculture sector. These efforts contribute to the development of decision-support tools and practices for farmers to adapt to climate change, including through the optimization of land use and production, pest and disease surveillance, variety selection, and breeding for new climatic conditions. The department also undertakes research on current and future weather trends, as well as efforts to improve regional weather forecasting and crop forecasting to help assess potential impacts on crop yields and changes to disease pressures from climate change.

Indigenous and Northern Affairs Canada is working collaboratively with territorial and northern governments and Indigenous Peoples to develop a *Northern Adaptation Strategy*. The purpose of the *Northern Adaptation Strategy* is to strengthen northern capacity for climate change adaptation and to establish partnerships and collaboration mechanisms to guide investments (from all partners including federal, territorial and provincial governments) across the territorial north as well as Inuit Nunangat.

The Government of Canada also collaborates with provinces and territories to implement adaptation actions. For example, the Canadian Parks Council, which is the federal, provincial, and territorial coordination body for parks and protected areas, re-established the Canadian Parks Council Climate Change Working Group in 2017. Parks Canada and the Northwest Territories co-chair the working group, which intends to: build on its previous work by promoting the concept of parks and protected areas as natural climate change solutions through new approaches, tools, and communication opportunities; provide a forum for cross-jurisdictional sharing tools, information and best practices for mainstreaming climate change decision-making into park and protected area management planning and operations, considering both mitigation and adaptation; identify key common issues, challenges, and opportunities for federal, provincial, and territorial coordination and collaboration on climate change and parks and protected areas dialogues and initiatives, such as the Pan-Canadian Framework on Clean Growth and Climate Change.

6.4.2 Provincial and Territorial Adaptation Policies, Plans and Programs

The Pan-Canadian Framework on Clean Growth and Climate Change recognizes the varying scope and scale of adaptation efforts across the country and that provinces and territories have been early leaders in this context. Provinces and territories have undertaken a variety of adaptation activities, including: implementing adaptation strategies; funding for research, pilot projects, and regional risk and vulnerability assessments to support adaptation planning and decision making; action to strengthen land-use planning processes, infrastructure investments, and building codes through the inclusion of climate change considerations; efforts to increase awareness about impacts and adaptation options for communities; and the development of tools to help integrate adaptation into all levels of decision-making.

6.4.2.1 Yukon

The Government of Yukon has undertaken adaptation actions to enhance the resilience of Yukon communities both directly and through partnerships with the federal government and non-government organizations. The territory has committed to enhancing the knowledge and capacity of communities and local decision-makers to respond to challenges to the territory's landscapes, natural resources, and traditional ways of life resulting from climate change. The territory is exploring opportunities to better understand the relationship between climate change and food security in Yukon, integrate Indigenous Knowledge into the understanding of climate change impacts, and target investments towards evidence-based adaptation actions.

Yukon released a *Climate Change Action Plan Progress Report* (2015), which reviewed the progress made since the implementation of its *Climate Change Action Plan* (2009). The report included the addition of four new actions to support climate change goals, including the addition of a specific adaptation goal.[37] The territory also released a Climate Change Indicators and Key Findings report in 2016 to provide an objective and accessible overview of the current state of Yukon's climate system, which will be regularly updated.

6.4.2.2 Northwest Territories

The Government of the Northwest Territories is developing a comprehensive Climate Change Strategic Framework, which will include both climate change adaptation and climate change mitigation. The framework will have three main themes: (1) reducing the territory's reliance on fossil fuels and the production of GHG emissions; (2) increasing knowledge of how a warming climate is impacting the territory's biophysical environment, economy, and peoples' health and safety; and (3) increasing the territory's resilience to climate change impacts and identifying ways to adapt to unavoidable impacts. The territorial government also supported building climate change adaptation capacity within communities by integrating climate change adaptation curriculum into their School of Community Government.

6.4.2.3 Nunavut

The Government of Nunavut has been developing programs, policies, and partnerships that assist Nunavummiut (the people of Nunavut) with increasing adaptive capacity and addressing the impacts of climate change that are being experienced in the North. The Government of Nunavut acknowledges that support for adaptation initiatives in the near-term will result in long-term benefits for all communities, such as decreased costs to infrastructure, increased safety and security, economic prosperity, and more sustainable communities. The Government of Nunavut is therefore committed to working nationally to address climate change impacts and supports the undertaking of a coordinated, strategic, Canadian approach that will lead to improved resiliency of the territory's communities.

Climate change impacts and adaptation initiatives in Nunavut are supported through both standard scientific methods and Inuit Qaujimajatuqangit, the system of Inuit Indigenous Knowledge and societal values. Inuit Qaujimajatuqangit is based upon a long and close relationship with the land that provides detailed insight into climate change in Canada's north. The Government of Nunavut places great weight and importance on Inuit Qaujimajatuqangit in its planning, program, and policy development on climate change.

The Government of Nunavut's Climate Change Secretariat has initiated a number of projects to support adaptation in Nunavut over the years. These include the Nunavut Climate Change Centre (NC[3]) website that provides Nunavummiut with current information on climate change, the Nunavut Permafrost Databank that improves access to open-source permafrost data from across the North, outreach initiatives like the Tukisigiaqta web-based risk tool that informs Nunavummiut about climate change risks in the home and on the land, and creating and delivering the Climate Change Adaptation Training Course for Nunavut Decision-Makers that instructs community and government staff on climate change impacts and adaptation and builds on both scientific and Inuit Qaujimajatuqangit.

6.4.2.4 British Columbia

Adaptation action in British Columbia is guided by the *Preparing for Climate Change: British Columbia's Climate Adaptation Strategy* (2010), a plan to increase knowledge about climate change and its impacts on key economic sectors, and government programs and services, and produce tools to help governments, businesses, and communities find out how climate change will affect them, and what they can do now to prepare.

In 2017, the Office of the Auditor General of British Columbia conducted a performance audit examining the provincial government's action to adapt to a changing climate, including the 2010 Adaptation Strategy, initiatives to assess risks and vulnerabilities and monitoring and reporting on performance and achievements. The audit also examined the efforts of specific ministries to adapt, including Environment; Forests, Lands and Natural Resource Operations; Agriculture; Transportation and Infrastructure/ Emergency Management BC; and, Ministry of Municipal Affairs and Housing.

6.4.2.5 Alberta

Alberta's approach to adaptation includes research on current or potential climate change impacts in specific sectors and developing capacity to better use science and Indigenous Knowledge to understand the implications of climate change and innovative adaptive measures. Alberta is also beginning to reinvest carbon emissions revenues to understand and implement innovative adaptive measures.

The Alberta Government currently allocates $15 million annually for the Alberta FireSmart program. FireSmart uses preventable measures to reduce wildfire threat to Albertans and their communities while balancing the benefits of wildfire on the landscape. For example, the FireSmart Forest Resource Improvement Association of Alberta program focuses on improving the protection of forest communities, resources, and values through operational and planning activities designed to prevent wildfire occurrence and to reduce fire hazard throughout Alberta.

The Government of Alberta is developing policy to enable and encourage water reuse and stormwater use, in an effort to mitigate flood and drought cycles in Alberta, and to offset fresh water withdrawals. The Government of Alberta has also made changes to the *Forest and Prairie Protection Act* and associated regulations to improve public safety as they relate to preventing human-caused wildfires and protecting Albertans, their communities, natural resources, and infrastructure from wildfire damage.

Alberta has worked with the universities of Alberta and British Columbia on projects such as "AdapTree": Assessing the Adaptive Portfolio of Reforestation Stocks for Future Climates. Through this project Alberta has gained additional knowledge on the ecological genetics of white spruce and lodgepole pine to support decision-making for climate change adaptation. Alberta is currently supporting new genomics research projects at the University of Alberta which are partly designed to address climate change adaptation in three specific pine and spruce tree breeding regions.

6.4.2.6 Saskatchewan

Saskatchewan is enhancing its Wildfire Management program to mitigate wildfire risks by improving wildfire response capacity, strengthening collaboration with international, national, and provincial jurisdictions, increasing government, community, and industry mitigation efforts, and adopting proactive wildfire legislation. The Government of Saskatchewan is also developing a drought strategy and a new water allocation policy and legislation that will provide flexibility to manage water shortages, and an irrigation strategy that will focus on long-term capacity building in the irrigation sector.

In partnership with the Crop Development Centre at the University of Saskatchewan, the province supports public sector plant breeding and several plant breeders who focus on developing crop varieties that can better withstand changing climatic conditions. In addition to the improvement of existing crop varieties, the province supports the development of new crops that will be suited to future climatic conditions in Saskatchewan. Saskatchewan also works with the federal government to support a strong suite of business risk management programs for the agriculture sector, including crops insurance that assist growers in managing risks associated with crop yield declines that can be the result of extreme climatic events. Further, the province has implemented an assisted migration project and associated scientific trial as part of its ongoing forest renewal activities to identify seed sources that are best adapted to projected climatic conditions. Lastly, Saskatchewan has increased monitoring of recreational water quality in the province and has an on-going surveillance for West Nile and Lyme disease.

The Government of Saskatchewan has also identified multiple areas for action. For instance, Saskatchewan is using technology in winter road maintenance to provide early warning of weather events and gather better road information and data, thereby improving response times and ensuring the plows are properly equipped for extreme weather events. Saskatchewan is also addressing increased severity and frequency of localized flooding from rainstorms and other extreme precipitation events through flood mapping and related infrastructure planning initiatives with municipal governments.

6.4.2.7 Manitoba

Manitoba has developed a Made in *Manitoba Climate and Green Plan* that includes carbon pricing and specific priorities for addressing climate change, jobs, nature, and water.

Manitoba has taken significant measures to reduce the impacts of flooding within the Red and Assiniboine River basins, as well as strategies to conserve polar bears, caribou, and moose populations, and address invasive species in Manitoba. Actions include enhancing infrastructure resiliency, provincial strategies on surface water management and drought preparedness, further initiatives in land use and watershed planning and working with municipalities and Indigenous Peoples across the province.

Manitoba is also working with partners to implement a province-wide program based on the Alternative Land Use Services model to help reduce flooding and improve water quality and nutrient management. It will also develop a framework to reconcile the needs of industry and rural and northern communities while continuing to enhance the network of protected areas in Manitoba. Collectively these measures support enhanced landscape resiliency to flood, drought, and other risks posed by a changing climate, thereby helping to ensure communities and economic sectors are better prepared and less vulnerable to these changes.

6.4.2.8 Ontario

Ontario announced its next steps to help ensure communities, the private sector, governments, and individual Ontarians have the information they need to identify climate change risks and vulnerabilities and to take action to prepare for these risks. Ontario will: launch a new organization for climate change data and services; undertake a province-wide risk assessment; raise public awareness of climate change impacts; and develop a new governance framework to help ensure that adaptation is considered in program and policy decisions across all departments.

Ontario's next steps build on actions Ontario is already taking to prepare for the effects of climate change, including in the areas of public health, natural environment and agriculture, the built environment, and Indigenous Peoples. These current and ongoing actions are outlined in Ontario's first adaptation strategy and plan *Climate Ready: Ontario's Adaptation Strategy and Action Plan (2011–2014)*.

On-going or already completed actions include the Ontario Climate Change and Health Toolkit released in 2016 to help raise community awareness of the health impacts of climate change, identify local vulnerabilities, and support a more resilient health system that can manage emerging health risks.

In 2014, Ontario updated its *Provincial Policy Statement* to require municipalities to consider the impacts of climate change in planning for resilient communities, including planning for new or expanded infrastructure, and to strengthen protection for natural features and areas including key hydrological features such as wetlands. In 2017, Ontario updated its four provincial land use plans to include revised requirements such as stormwater management planning and Low Impact Development and green infrastructure, as well as strengthened protection for natural areas and key hydrological areas and features.

6.4.2.9 Québec

Québec adopted its *Government Strategy for Climate Change Adaptation* and *2013–2020 Climate Change Action Plan* in 2012. The strategy and the plan bring together stakeholders and key players in implementing actions from the Québec government, municipalities, civil society, and research organizations. Through commitment and action, the strategy aims to reduce the impacts of climate change, to strengthen the resilience of Québec society and to seize new opportunities provided by climate change. The Plan is financed through the revenues of Québec's carbon market, which are entirely dedicated to addressing climate change. As such, in addition to investments in GHG reduction initiatives, more than $200 million is dedicated to a wide range of concrete actions that will strengthen Québec's collective capacity to adapt.

Examples of these initiatives include the Québec government's financing of a systematic evaluation of short-, medium-, and long-term vulnerabilities related to coastal erosion for municipalities along the estuary and Gulf of St. Lawrence. This work, in close collaboration with municipalities, will also focus on identifying priority areas for intervention and developing decision-making tools for choosing adaptation solutions. The Québec government also supports community initiatives to reduce urban heat island effect in urbanized areas of the province. Projects include planting trees and vegetation, and greening roofs, parking lots, and other surfaces that absorb and retain heat.

To ensure consistency and more efficient government action, Québec included adaptation and climate resilience in many of its government documents, such as the *Sustainable Development Strategy 2015–2020* and the *Québec Policy 2014–2024 on Civil Security*. In 2017, the government of Québec committed to amending the *Environment Quality Act* to modernize the environmental authorization scheme and other legislative provisions (e.g., Green Fund), to ensure that climate changes impacts, as well as greenhouse gas emissions, are better taken into account in the environmental evaluation and authorization of projects.

6.4.2.10 New Brunswick

New Brunswick released *Transitioning to a Low-Carbon Economy—New Brunswick's Climate Change Action Plan* in December of 2016. The Plan includes a comprehensive list of adaptation actions grouped into six themes: (1) understand climate change impacts; (2) build climate resilient infrastructure; (3) support community adaptation planning; (4) adapt natural resources and agriculture; (5) reduce climate related hazards; and (6) reduce climate change impacts on public health.

Adaptation actions that ensure the well-being and resilience of citizens, ecosystems, communities, and natural resources, as well as enhancing the Province's economic competitiveness are a priority in New Brunswick. Examples of adaptation efforts include vulnerability assessments that address flooding, erosion, and sea level rise, the adoption of adaptation plans in several municipalities, incorporating future climate conditions into infrastructure design, vegetation management to reduce potential power outages following storms, incorporating updated sea level rise and storm surge projections into land use planning and to inform infrastructure placement, and modelling tree species distribution under future climate conditions to help inform forest management decisions. An increasing availability of adaptation tools, guidance, improved projections, and science has also contributed to the attainment of these initiatives.

Communities and municipalities continue to be a strong focus of New Brunswick's adaptation efforts. The New Brunswick Climate Change Secretariat is focusing on facilitating adaptation efforts with municipalities, putting strong emphasis on conducting vulnerability assessment and adaptation planning across sectors, and disseminating climate change knowledge to inform decision makers and the general public. This reflects the Government of New Brunswick's resolve to deal with issues that are emerging and will be exacerbated by future climate conditions.

6.4.2.11 Nova Scotia

Nova Scotia is focusing its efforts on building the provincial government's capacity to mainstream climate adaptation into all department planning policies and operations, so that it becomes a normal, automatic part of how government does business. This is done through the delivery of an integrated program that strengthens the socio-cultural competencies of the public service to effectively communicate climate concerns, lead complex adaptation initiatives, work across department silos, and build strong public-private partnerships. Participating departments are undertaking the program and associated capacity building programs by creating teams that will design adaptation projects that move research into action. Qualitative and quantitative metrics are used to measure progress on the implementation and impact of the projects and mainstreaming strategies, as well as the ability of the program to enhance the government's capacity to anticipate, prepare for, and respond to projected and unforeseen climate risks.

Departmental adaptation projects underway in 2016–2017 include risk-proofing the Nova Scotia grape and wine industry, integrating climate risks into protected area management, re-aligning dykes and restoring salt marshes for flood risk reduction, and developing new climate smart standards for dyke construction and repair.

6.4.2.12 Prince Edward Island

Prince Edward Island is developing a climate change action plan that will include key climate change mitigation actions and key adaptation actions that will seek to minimize the impacts of climate change on Prince Edward Island. This climate change action plan will replace Prince Edward Island's previous climate change strategy, *Prince Edward Island and Climate Change: A Strategy for Reducing the Impacts of Global Warming* (2008).

Through its partnership in the Atlantic Climate Adaptation Solutions Association and with funding from Natural Resources Canada, Prince Edward Island co-led two regional projects, the development of a decision support tool for small coastal communities and an economic analysis of adaptation options for coastal infrastructure and property. Both projects included extensive stakeholder involvement across federal, provincial, and municipal governments. Future adaptation efforts on Prince Edward Island will continue to focus on assessments of coastal risk to infrastructure, buildings, and property and Prince Edward Island will expand this focus to include the dissemination of existing products that will assist provincial and local decision-makers as they seek to minimize climate change impacts.

6.4.2.13 Newfoundland and Labrador

The Government of Newfoundland and Labrador released *Charting Our Course: Climate Change Action Plan* in 2011, a five-year strategy that contained 18 commitments aimed at improving the province's resilience to the impacts of climate change. The action plan ended in 2016, and all 18 of the commitments were implemented. The commitments focus broadly on improving the understanding of climate change impacts in Newfoundland and Labrador and mechanisms to integrate that understanding into decision-making by individuals, businesses, communities, and governments. The Government of Newfoundland and Labrador is now in the process of developing a new five-year climate change action plan, to be released in 2017–2018, which will include adaptation as a key pillar.

Newfoundland and Labrador has collaborated with various stakeholders to develop provincial adaptation programs and actions, as well as build knowledge capacity and expertise. For example, capacity building and education is facilitated and maintained through workshops in cooperation with partners such as Engineers Canada to raise awareness of climate change impacts on infrastructure and available datasets among local private sector and provincial and municipal government decision-makers, engineers, and planners.

To increase collaboration on adaptation, the Government of Newfoundland and Labrador established an Adaptation Network that includes representatives from government departments, industry, and Memorial University. The network identifies research needs and shares best practices for integrating climate change adaptation into planning and decision-making. The work of the Adaptation Network has resulted in the impacts of climate change being more thoroughly integrated in the government's decision-making processes for environmental assessments and the granting of crown land.

6.4.3 Municipal Adaptation Policies, Plans and Programs

Canadian municipalities have been consistently taking action to build local capacity to identify the impacts from a changing climate, assess their local vulnerabilities and risks, develop and implement plans to address these risks, and ultimately to implement actions and monitor their results. Municipalities have responded to climate change impacts in Canada with stand-alone adaptation strategies, innovative communications strategies, practical projects to better manage stormwater absorption, and programs that provide emergency shelter during extreme weather events. Some specific examples of municipal leadership on climate change adaptation and resilience are presented below.

6.4.3.1 Municipal Adaptation Policies and Plans

In 2016, Durham Region, Ontario completed its *Community Climate Adaptation Plan*. The plan is a response to the risks posed by climate change to the municipality's infrastructure, health, welfare, and economy. It includes 18 proposed programs to improve Durham's resilience to climate change impacts, such as flooding and extreme heat. Durham's proposed programs are anticipated to begin implementation in 2018.

The City of Surrey, British Columbia began its adaptation efforts in late 2010 through the development of the *Climate Change Adaptation Strategy*. Since then it has taken many steps to become more prepared and resilient. Most recently, the City is exploring the timing and extent of changing flood hazards and using this to inform a *Coastal Flood Adaptation Strategy*. Through this effort the City has been engaging residents and stakeholders in public meetings to determine the best solutions for adaptation to sea level rise and flood risk within Surrey.

In some cases municipal regions have developed climate change adaptation plans that include a number of different municipalities. For example, the agglomeration of Montréal, Québec released its first climate change adaptation plan in 2015. The Plan is divided into two volumes. The first volume presents a diagnosis of the adaptation challenges faced by the agglomeration of Montréal, and presents a vulnerability analysis of six climactic hazards: increased temperature, heavy rainfalls, heat waves, destructive storms, droughts, and floods. The second volume is dedicated to adaptation measures that need to be consolidated or developed in the agglomeration of Montréal in order to reduce the risks of climate change.

Municipalities have also released plans to address specific challenges. For example, the City of Vancouver, British Columbia introduced a *Sewer Separation Strategy* (2016) to separate stormwater from wastewater to prevent flooding and eliminate combined sewer overflow during heavy rain events. Additionally, the City of Vancouver developed the *Greenest City 2020 Action Plan* (2011), which outlined ten goal areas and 15 measurable targets to guide Vancouver toward becoming the greenest city in the world by 2020. The strategy was updated in 2015, *Greenest City 2020 Action Plan Part Two: 2015–2020*, to include 50 new actions, which included adaptation commitments and the development of an Integrated Rainwater Management Plan (2016), which recognizes the importance of considering climate change impacts in the management of stormwater. Similarly, the City of Toronto, Ontario introduced the *Toronto Hot Weather Response Plan* (2016), which is a protocol for hot weather response that includes both proactive and reactive actions.

6.4.3.2 Municipal Adaptation Initiatives

As part of the Town of Oakville, Ontario's ongoing implementation activities, the municipality spreads the word about emergency preparedness and the importance of local action to the public using communications and gamification. For example, in 2017 the Town of Oakville's outreach work involved public talks, adaptation games, and the Prepare 2 Be Prepared Challenge, all centered on the Keep Calm and Adapt: Emergency and Extreme Weather Preparedness Event. This type of creative and "out-of-the-box" engagement is reaching new audiences and is helping to ensure that residents know what they can do to prepare for more extreme weather and a changing climate.

Non-Governmental Organizations Supporting Municipal Adaptation Action

Municipal adaptation action in Canada is supported by all levels of governments, as well as the Federation of Canadian Municipalities and ICLEI Canada.

The **Federation of Canadian Municipalities** supports municipalities on climate change through policy and capacity building programming. The Municipalities for Climate Innovation Program further raises awareness about climate change, offers technical assistance, direct grants for municipalities and mobilizes knowledge on climate mitigation, adaptation, and infrastructure asset management. This program will generate new knowledge on transitioning to low carbon communities along with ways to integrate climate change into asset management through peer learning programs like the Climate and Asset Management Network and Transition 2050. In parallel, the Federation of Canadian Municipalities delivers the Partners for Climate Protection program in partnership with ICLEI Canada as a resource for municipalities.

ICLEI Canada works with local governments on sustainability issues, including supporting communities in preparing for climate change. ICLEI's *Building Adaptive and Resilient Communities* program is a framework guiding municipalities through a comprehensive planning methodology that includes research and climate impact assessment frameworks, plan development, action-setting processes, implementation planning, and monitoring and review strategies. It is supported through a variety of resources and tools to build municipal capacity to respond to climate change. The BARC method has been applied by municipalities across the country, including in British Columbia, Alberta, Ontario, New Brunswick, Nova Scotia, and Nunavut.

The City of Windsor, Ontario is enhancing public awareness of the steps individual home owners can take to minimize the risk of basement flooding by making a city-owned 1920s home flood resilient and installing a number of stormwater management practices on site. The City of Windsor will document the improvements through a series of YouTube videos as part of a larger basement flooding education campaign. Each measure will be permanently displayed on site, outlining their purpose, how they function, and any required maintenance, and the home will be available for public open houses.

Similarly, Calgary, Alberta initiated a low impact development project in the redevelopment of the Currie Barracks Brownfield in order to ensure that the rate of the runoff leaving the site would not exceed the capacity of the downstream stormwater system. The project was pursued in order to deal with extreme rain events which have caused Calgary hundreds of millions of dollars in damages since 2005. In particular, abandoned fields were converted into rain gardens, and vegetated swales and gravel infiltration trenches were incorporated at strategic locations as part of the green space in the new urban fabric.

Vancouver launched a unique program in 2016 that provides extreme weather shelter spaces to those who are homeless or at risk of homelessness when a community issues an extreme weather alert. The Extreme Weather Response program is an initiative that "funds community based services to provide temporary emergency shelter spaces during periods of extreme winter weather which threaten the health and safety of homeless individuals". Emergency shelter, safe refuge, and hospitality are provided by community members, congregations from faith groups, and advocates. The expected outcomes of the Extreme Weather Response program are decreased health and safety risks to homeless people during periods of extreme winter weather and a reduction of street homelessness during extreme winter weather.

6.4.4 Indigenous Adaptation Policies, Plans and Programs

Indigenous Peoples are active drivers and agents of change who contribute vital knowledge, experience, and leadership to adaptation efforts across Canada. Indigenous Peoples have responded to climate change impacts in Canada in a number of ways, such as developing and implementing climate change adaptation plans in their communities, adjusting subsistence activities in response to environmental changes, launching a multi-media website to share Indigenous Knowledge of the impacts of climate change, and developing Indigenous guardians programs.

Indigenous Peoples are Active Drivers and Agents of Change

"All across Canada…there are…ground-breaking First Nations' initiatives addressing food security, sustainable land-use management, the preservation of oral histories about the land, and the charting of territories. Clearly, First Nations have been, and, will continue to be, diligent in the face of this ongoing threat to our social, cultural, environmental, and economic well-being." (Assembly of First Nations, 4, 2016)

"We are among the first to put a human face on the unprecedented climate changes happening in the Arctic. We have been active partners in efforts to understand and develop policies and actions to adapt to the changes we are experiencing and to increase the awareness of other Canadians and people around the world of climate impacts." (Inuit Tapiriit Kanatami, 31, 2016)

"The Métis people have historically and in contemporary times excelled as entrepreneurs, as environmental stewards and conservationists, as negotiators and middlemen across cultures, landscapes and economies, adapting to the changing landscape and times with a keen enthusiasm and sweat on the brow." (Métis National Council, 2, 2016)

"Indigenous peoples have known for thousands of years how to care for our planet. The rest of us have a lot to learn. And no time to waste." (Prime Minister Justin Trudeau, COP21, 2015)

The Government of Canada has committed to a renewed, nation-to-nation, government-to-government, and Inuit-to-Crown relationships with First Nations, the Métis Nation, and Inuit. Sustained and meaningful collaboration between the federal government and Indigenous Peoples must recognize the rights and interests of Indigenous Peoples as set out in Canada's Constitution. This approach must also advance the implementation of the United Nations Declaration on the Rights of Indigenous Peoples, of which the Government of Canada is a full supporter, without qualification, and which includes the principle of free, prior, and informed consent. Collaboration must also recognize the treaty rights of Indigenous Peoples to make laws and manage resources on their Settlement

Lands where comprehensive land claim agreements have been signed. This engagement should be community led, regionally facilitated, and nationally coordinated.

The Government of Canada upholds its commitment to respect the rights of Indigenous Peoples, undertake robust, meaningful engagement, and respectfully receive and consider Indigenous Knowledge while implementing the Pan-Canadian Framework on Clean Growth and Climate Change.

The Government of Canada as well as provincial, territorial and municipal governments, non-governmental organizations, Indigenous organizations and universities support adaptation efforts for Indigenous Peoples. Indigenous communities have used the results of vulnerability assessments to inform the prioritization of adaptation measures and plan future infrastructure investments and emergency preparedness measures with climate change in mind. They have developed culturally appropriate tools for their communities and have integrated their planning into regional adaptation planning initiatives. The following are examples of a number of projects funded through these initiatives. The Nunavik project Life on Permafrost: Community Planning Empowerment, funded by Indigenous and Northern Affairs Canada, focused on communities becoming better informed technically and more knowledgeable about local and regional permafrost and climate conditions. This way, leaders and members of the Nunavik communities were in a better position to address the challenges arising from environmental changes, including permafrost issues related to buildings and road infrastructure, and to make well supported, science-based recommendations and decisions relative to their development. In addition, the education component of this project was implemented in collaboration with the Kativik School Board and the local schools, enabling it to have an impact on youth through the practice of hands-on scientific activities of actual significance for them and their community.

Indigenous Knowledge systems are cumulative, dynamic, and adaptive knowledge systems that are intertwined with personal, community, and national/cultural knowledge. Indigenous Knowledge is heterogeneous, and varies between Indigenous Peoples and groups.

Indigenous Knowledge systems are broader than what is commonly referred to as Traditional Knowledge. However, it is important to note that Indigenous Knowledge systems are a "way of being" that is broader than just specific ecological knowledge. Further, it is important to recognize that "Traditional" does not mean narrow, static, or historic. Indigenous Knowledge continues to be applicable to policy and can support a more comprehensive understanding of climate change's social, economic, and environmental impacts.

Inuit Qaujimajatuqangit is the system of Inuit Indigenous knowledge and societal values. It includes "all aspects of traditional Inuit culture including values, world-view, language, social organization, knowledge, life skills, perceptions and expectations" and provides detailed insight into climate change in Inuit Nunangat.

Another successful community project took place in Georgina Island First Nation. This community received funding from Indigenous and Northern Affairs Canada from 2012–2015. Over the course of the three years, the community completed a vulnerability assessment, developed adaptation recommendations, released the *Georgina Island First Nation Climate Change Adaptation Plan*, and conducted a review of the Band's policies to integrate climate change considerations. This stepwise approach, engaging with the community to identify priorities and addressing these through planning exercises was successful because it built on the community's internal capacity to develop and manage the project in a way that was meaningful to the community as a whole. All members of the community were engaged throughout the process and became more involved in the project as it progressed. The community now has better and more detailed information regarding the likely risks posed by climate change and is better prepared to respond to those threats by planning proactive adaptation measures.

The First Nations of Québec and Labrador Sustainable Development Institute is developing a guide to support First Nations who want to create their own climate change adaptation plan, and has collaborated with seven

First Nations (Akwesasne, Odanak, Opitciwan, Pessamit, Pikogan, Uashat mak Mani-Utenam and Wôlinak) to support them in the development of their first climate change adaptation plans. The First Nations of Québec and Labrador Sustainable Development Institute also supported Uashat mak Mani-Utenam in implementing their first climate change adaptation plan, starting in 2014. Implementation included creating working committees for each of the challenges specified in the plan, networking with local and regional environmental organizations, and conducting outreach activities in schools.[38]

IsumaTV is a Canadian collaborative multimedia platform for Indigenous filmmakers and media organizations to share their work with a broader audience. IsumaTV hosts over 6,000 videos in over 80 languages, representing cultures and media organizations across Canada and the world. IsumaTV has also developed an IsumaTV Mediaplayer to ensure remote communities, as well as anyone with access to the internet, a computer, or a mobile device, can participate. IsumaTV uses its platform to provide a comprehensive overview of human rights challenges Indigenous peoples face globally, and a number of their featured products provide information on climate change and Inuit Qaujimajatuqangit, and how climate change is impacting the lives of Inuit living in Northern Canada. IsumaTV enables Indigenous Peoples to share their experiences and perspectives on a range of topics (e.g., human rights, resource development, climate change), in their own language, with a global audience.

Indigenous guardians programs in the Northwest Territories provide significant social, economic, and environmental benefits by using Indigenous Knowledge to help preserve Indigenous culture and land. The Ni Hat'ni Dene program in Lutsel K'e, modelled after the Haida Gwaii Watchmen program, partners youth with older community members to maintain the integrity of cultural sites, provide tours of the area, monitor and record activity on and changes to the land and water, and transmit cultural and scientific knowledge to youth. The Deh Co K'ehondi program in the Dehco First Nations uses the Dene language and culture to rebuild relationships with the land. These programs are only two of the approximately 30 Indigenous guardians programs across Canada. Community level Indigenous guardians programs are part of broader efforts to create a National Indigenous Guardians Network in Canada. The Government of Canada provided funding to support the development of the national network and prepare Indigenous Peoples to launch their own Indigenous Guardian programs ($25 million over five years in Budget 2017).

The Métis have made significant efforts to build relationships at the local and regional level, including by entering into relationships with municipalities and developing urban governance authorities and regional governance authorities to support future relationship building. Some Métis authorities have also been party to provincial agreements on the environment or resource management, creating an opportunity to focus on climate change.

6.5 International Adaptation Policies and Strategies

At the international level, the United Nations Framework Convention on Climate Change and other fora (e.g., the World Health Organization, North American Climate Change and Human Health Working Group, the United Nations Convention to Combat Desertification, and the United Nations Office for Disaster Risk Reduction) offer the opportunity for Canada to strengthen and disseminate research and science; share best practices and lessons learned about climate change and climate change adaptation; and assist developing countries in increasing their resilience.

The Government of Canada committed to strong action to address climate change through the ratification of the Paris Agreement on October 5, 2016. Canada declared it would continue to support a prominent international focus on adaptation actions. In Paris, Canada offered support to vulnerable countries faced with the challenge of adapting to the impacts of climate change by contributing $30 million to the Least Developed Countries Fund. Canada also pledged $2.65 billion over five years (2015–2020) to help developing countries tackle climate change, including $10 million to improve early warning systems for hazards like tropical cyclones, floods, heat waves and forest fires in developing countries.

The Paris Agreement recognizes the need to strengthen knowledge, technologies, practices and efforts of local communities and Indigenous Peoples related to addressing and responding to climate change, and establishes a platform under the United Nations Framework Convention on Climate Change for the exchange of experiences and sharing of best practices on mitigation and adaptation in a holistic and integrated manner. Through the Pan-Canadian Framework on Clean Growth and Climate Change, the federal government committed to continue to engage and support Indigenous Peoples' action on international climate change issues, including by advancing the implementation of this platform. In 2017, Canada, including the Government of Canada working in partnership with First Nations, Inuit, and the Métis Nation, took a leadership role in working with the international community—including by convening informal discussions and in the formal negotiations at the 23rd Conference of the Parties to the United Nations Framework Convention on Climate Change—towards launching the meaningful operationalization of the platform.

Canada also rejoined the United Nations Convention to Combat Desertification (UNCCD) in March, 2017. The UNCCD works to improve the living conditions for people in drylands (both domestically and internationally), maintain and restore land and soil productivity, and mitigate the effects of drought. Through the UNCCD, Canada is exploring options to engage internationally and provide scientific and technical expertise on topics related to sustainable land management, drought monitoring, land restoration, and landscape resilience.

Canada collaborates with the United States of America and Mexico on the conservation, protection, and enhancement of the North American environment through the Commission for Environmental Cooperation. Canada assumed chairmanship of the Commission for Environmental Cooperation in 2016. Canada's chairmanship enables Canada to take proactive action on climate change priorities, which include advancing efforts on the commitments made at the North American Leaders' Summit in 2016.

The Government of Canada supported the Arctic Council's development of an *Arctic Resilience Action Framework* (2017), and will continue to support its implementation. The *Arctic Resilience Action Framework* provides a framework of common priorities and targets that promote improved collaboration and effectiveness among the Arctic Council and Arctic Council partners as they strive to enhance Arctic resilience. The *Arctic Resilience Action Framework* will be the first comprehensive regional adaptation and resilience framework for the Arctic.

In 2010, Canada and other Parties to the *Convention on Biological Diversity* (CBD) adopted the global *Strategic Plan for Biodiversity 2011–2020*. The Strategic Plan is comprised of a shared vision, a mission, strategic goals and 20 targets, collectively known as the Aichi Targets. These international Targets acknowledge the linkages between biodiversity and climate change mitigation and adaptation.

Provinces and territories also work with the international community to share best practices, and support adaptation efforts in developing countries. For example, following the Paris Agreement, the Québec government announced a set of cooperative measures totaling $25.5 million to fight climate change to help the most vulnerable developing countries face the impacts of climate change, especially in Francophone countries. It since gave $6 million to the Global Environment Facility's Least Developed Countries Fund, and launched calls for projects centered on climate cooperation and youth initiatives.

The governments of Québec, British Columbia, Alberta, and Prince Edward Island also joined the international RegionsAdapt initiative that supports and reports efforts on adaptation at the state and regional level. Québec and British Columbia are also members of the International Alliance to Combat Ocean Acidification, a worldwide network of governments and organizations that addresses the impact of acidification on the health of oceans.

British Columbia also participates in the Pacific Coast Collaborative, a forum for cooperative action, leadership, and information sharing between California, Oregon, Washington, and British Columbia on the issues facing Pacific North America, such as climate change.

The Northwest Territories has also collaborated with the United States on climate projections and landscape conservation cooperatives. In conjunction with the University of Alaska, Fairbanks, the Northwest Territories has developed easy to use climate change projections to support communities in adapting to climate change. Additionally, through the Northwest Boreal Landscape Conservation cooperative, the Northwest Territories has coordinated with Alaska, northern British Columbia, and Yukon to share climate change information and resilience best practices.

6.6 Oversight and Reporting

Measuring progress on adaptation is challenging, as the various approaches, goals, timelines, and scales of adaptation actions make it difficult to develop single, uniform, meaningful metrics to measure progress. Coordinated reporting on progress on adaptation across the federal government is carried out through a *Horizontal Management Framework* and the *Results and Delivery Charter on Clean Growth and Climate Change* (the Charter) on an ongoing basis. The Charter was developed in collaboration with federal counterparts to serve as the key monitoring and reporting platform for measuring progress against the Pan-Canadian Framework on Clean Growth and Climate Change outcomes. Regular public reporting of progress using the indicators described in the Charter ensures that the Government of Canada remains accountable to Canadians. The *Horizontal Management Framework for Clean Growth and Climate Change* demonstrates the linkages between the authorities being sought for climate change adaptation programs and activities by federal partners to adaptation and resilience in the Charter.

As discussed in Chapter 4: Policies and Measures, First Ministers from federal, provincial, and territorial governments receive annual reports on the Pan-Canadian Framework on Clean Growth and Climate Change through a federal, provincial and territorial process established for this purpose. This reporting provides relevant and timely information on the effectiveness of policy development towards implementing the Pan-Canadian Framework and ensuring Canadians are resilient and can adapt to the impacts of climate change.

Respect and recognition of the distinct cultures of First Nations, Inuit, and Métis people in Canada is central to Canada's approach to climate change policy. Three separate senior-level tables are being established to implement the Pan-Canadian Framework on Clean Growth and Climate Change. The tables will support First Nations, Métis, and Inuit clean growth and climate change priorities, including adaptation and resilience building actions. These efforts support Canada's broader commitment to reconciliation with Indigenous Peoples. The Government of Canada, through Indigenous and Northern Affairs Canada, has committed to providing funding support for Indigenous engagement in domestic climate policy, which will include supporting the implementation of the three tables.

The Government of Canada also reports through the 2016–2019 *Federal Sustainable Development Strategy*, which is the Government's primary vehicle for sustainable development reporting to both Parliament and Canadians. The *Federal Sustainable Development Strategy* demonstrates federal leadership towards implementing the environmentally-related global United Nations' Sustainable Development Goals. The *Federal Sustainable Development Strategy* will report on several goals, including those that support adaptation and climate resilience, such as Effective Action on Climate Change and Modern and Resilient Infrastructure.

As a Party to the United Nations Convention on Biological Diversity (CBD), Canada has also developed national biodiversity goals and targets. Target 5 of Canada's 2020 Biodiversity Goals and Targets relates to climate change adaptation: "By 2020, the ability of Canadian ecological systems to adapt to climate change is better understood, and priority adaptation measures are underway." The targets, announced in 2015, were developed collaboratively by federal, provincial and territorial governments, with input from Indigenous organizations and others, and are intended to encourage and promote collective action. National progress toward the targets will be reported in December 2018, in *Canada's 6th National Report* to the CBD.

The Government of Canada, led by Environment and Climate Change Canada, launched an external Expert Panel on Climate Change Adaptation and Resilience Results in 2017 to provide advice on measuring progress on adaptation and climate resilience under the Pan-Canadian Framework on Clean Growth and Climate Change, in an effort to overcome the challenges associated with identifying successful adaptation actions. The advice of the Expert Panel on Climate Change Adaptation and Resilience Results will support the federal government and others in better communicating results to Canadians, and demonstrating progress in enhancing Canada's resilience to climate change.

Provinces, territories, and municipal organizations (e.g., ICLEI Canada, the Federation of Canadian Municipalities) will be engaged in the work of the Expert Panel on Climate Change Adaptation and Resilience Results; however, they are also leading their own efforts to develop and examine monitoring and evaluation strategies for climate change adaptation. For example, the Government of Alberta is launching a process to identify climate specific indicators and metrics relevant to Alberta's social, economic, and environmental systems and assess the potential impacts of climate change and climate change policy inaction in the province.

ICLEI Canada, with funding from Natural Resources Canada's Enhancing Competitiveness in a Changing Climate program, led a project to examine how available metrics from varying sectors and orders of government can contribute to measuring the effectiveness and progress of implementing climate change adaptation actions.[39] ICLEI Canada examined indicators currently used to measure sustainability through a case study series, and evaluated the potential application of sustainability indicators to measuring progress on climate change adaptation.

More specifically, ICLEI Canada and the Clean Air Partnership conducted a series of sector-focused case studies and catalogued existing sustainability indicators that are currently being used to measure and/or monitor the effectiveness of policies or actions in coastal management, flood management, health and infrastructure, and examined the pertinence of such indicators in measuring climate change adaptation.

6.7 Conclusion

The wide range of impacts being experienced across Canada will be exacerbated as the climate continues to change. Taking action now to adapt to current and future climate impacts will help protect Canadians from climate change risks, reduce costs, and ensure that society continues towards a more resilient future.

Adaptation requires a sustained, ambitious, and collaborative approach across regions, orders of government, and sectors. The Pan-Canadian Framework on Clean Growth and Climate Change marked a significant effort by federal, provincial, and territorial governments to collaborate on adaptation efforts, and all levels of government will continue to work together to implement the framework.

Federal, provincial, territorial, and municipal governments have developed independent adaptation strategies and policy frameworks, and have been facilitating climate change adaptation through the establishment of collaborative mechanisms to enable applied research, development of decision-support tools, sharing of adaptation experiences, and support for local adaptation projects. Indigenous Peoples have also developed adaptation strategies and policies, and have worked with federal, provincial, territorial, and municipal governments, universities, non-governmental and Indigenous organizations to enhance their resilience to climate change.

Since Canada's *6th National Communication* federal, provincial, territorial, and municipal governments universities, non-governmental and Indigenous organizations and Indigenous Peoples have made significant progress in implementing adaptation measures. These measures include improvements to climate science, impacts and adaptation research and science assessments (including regional and sectoral assessments), community monitoring programs, and capacity-building and awareness raising efforts (particularly at the municipal level and for Indigenous Peoples).

Building from existing efforts and past successes, Canada will continue to play an important leadership role on climate change adaptation through measures such as strategic investments for building resilience in priority areas and facilitating collaboration.

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IN THE MATTER OF A REFERENCE to the Court of Appeal pursuant to section 8 of the *Courts of Justice Act*, RSO 1990, c. C.34, by Order-in-Council 1014/2018 respecting the constitutionality of the *Greenhouse Gas Pollution Pricing Act*, Part 5 of the *Budget Implementation Act, 2018, No. 1,* SC 2018, c. 12

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