CITY OF CORVALLIS
CLIMATE ACTION TASK FORCE
AGENDA

Tuesday, December 15, 2015
5:00-7:00 p.m.
Madison Avenue Meeting Room
500 SW Madison Avenue

I.	Call Meeting to Order / Chair Comments	Chair Baker
II.	Review of November 24, 2015 Minutes	Task Force
III.	Review of Revised Climate Action Plan Goals	Project Manager Smith
IV.	Development of Climate Action Plan Framework/Outline	Project Manager Smith
V.	Georgetown University Energy Prize/Take Charge Corvallis Update	Scott Dybvad
VI.	Visitor Comments	
VII.	Next Steps A. Operational Check-in B. Background Materials for GHG Reduction Target Discussion	Chair Baker
VIII.	Adjourn	

Task Force Members

Zachariah Baker, Chair
Penny York
Roen Hogg
Kirk Bailey
Cindy Dahl
Marjorie Stevens
Brandon Trelstad

Climate Action Goal

Over the next two years, take bold action to address climate change by (1) supporting the energy conservation efforts of the Corvallis Georgetown University Energy Prize team, and (2) adopting and beginning to implement a comprehensive long-term climate action plan that will significantly reduce Corvallis' greenhouse gas emissions and foster Corvallis' resilience to the effects of climate change.

DRAFT
CITY OF CORVALLIS
CLIMATE ACTION TASK FORCE ACTION MINUTES
November 24, 2015

The City of Corvallis Climate Action Task Force meeting was called to order at 5:02 PM, November 24, 2015, in the Madison Avenue Meeting Room Corvallis, Oregon, with Chair Zachariah Baker presiding.

ROLL CALL:

Members Present: Kirk Bailey, Zachariah Baker, Cindy Dahl, Roen Hogg, Marjorie Stevens, Brandon Trelstad, Penny York

Excused: N/A

Staff Present: Susie Smith, Kris Kelly

SUMMARY OF DISCUSSION:

Agenda Item	Actions/Recommendations
Call Meeting to Order	Chair Baker called the meeting to order and provided an overview of the meeting agenda.

Agenda Item	Actions/Recommendations
Chair Comments	Chair Baker provided an overview of progress made by Project Manager Smith since the last Task Force meeting noting that Task Force information and documents are available on the web for review.

Agenda Item	Actions/Recommendations
Review of October 13, 2015 Minutes	Approved by consensus.

Agenda Item	Actions/Recommendations
Status and Revisions to Work Plan and Timeline	Project Manager Smith provided an overview of hard copy handouts provided for the Task Force meeting. Following discussion Task Force members agreed upon the types of handouts to be provided for future meetings. Project Manager Smith reviewed changes to the Corvallis Climate Action Plan Project Approach, Work Plan, and Timeline resulting from discussion at the October 13, 2015 meeting. She highlighted the need to alter some meeting dates for future Task Force meetings. Following discussion, Task Force members approved the revised documents by consensus.

Agenda Item	Actions/Recommendations
Plan Development and Public Review Process	Project Manager Smith provided an overview of areas where the Climate Action Task Force, Vision & Action Plan Task Force, Housing Development Task Force, and Sustainable Budget Task Force may align efforts associated with public outreach and document review. She emphasized the opportunity to align Climate Action Plan public outreach with concurrent efforts from other Task Forces, Benton County and Oregon State University.

Agenda Item	Actions/Recommendations
Development of Climate Action Plan Goals	Project Manager Smith provided an overview of the Draft Climate Action Plan Goals detailed in the staff report. Chair Baker guided discussion on each goal to ensure understanding and allow for modifications. Task Force members provided suggestions and following discussion approved the revised goals by consensus.

Agenda Item	Actions/Recommendations
Visitor Comments	Linda Lovett opined the importance of using the climate action plan proposed by the Corvallis Community Climate Action Plan Task Force as a starting point for the public process. She offered resources, suggestions for the list of stakeholders and encouraged the involvement of the Corvallis Sustainability Coalition.

Agenda Item	Actions/Recommendations
Next Steps	Chair Baker informed Task Force members that the next meeting is scheduled for December 15. He noted next steps will include reviewing the list of members for the Task Team and Reviewer group and establishing the Climate Action Plan outline.

The Task Force adjourned at 6:33 PM.

An audio recording of the entire meeting can be listened to at:
http://archive.corvallisoregon.gov/Browse.aspx?startid=47285&dbid=0

Reference resources available at:
http://archive.corvallisoregon.gov/Browse.aspx?startid=47285&dbid=0

TO:	Climate Action Task Force for December 15, 2015 Meeting
FROM:	Susie Smith, Project Manager
DATE:	December 11, 2015
THROUGH:	Mark W. Shepard, P.E., City Manager
SUBJECT:	Revised Corvallis Climate Action Plan (CAP) Goals

CORVALLIS
ENHANCING COMMUNITY LIVABILITY

Action Requested:

The draft goals for development of and inclusion in the CAP have been revised based on feedback received at the November 24, 2015 Climate Action Task Force meeting. The Task Force is requested to review and confirm the revised goals.

Discussion:

At its November 24, 2015 meeting, the Climate Action Task Force reviewed background information and a set of draft goals proposed to provide over-arching guidance in developing and implementing the CAP. The Task Force provided guidance for modifying the goals. The revised draft goals are shown below in “marked up” format to highlight the deletions and additions that were made as directed by the Task Force. Please refer to the original goals memo in the November 24, 2015 meeting packet for additional background information on how the draft goals were developed.

REVISED DRAFT CAP GOALS

CAP Goal 1: The CAP will establish and monitor GHG emissions reduction targets for the Corvallis community that guide short-, medium-, and long-term priority strategies and actions the City and community partners will undertake to achieve at least Corvallis’ proportionate share (*or some other expression of commitment*) of GHG mitigation. Periodic reporting and updates to the CAP will enable the City to respond to changing conditions and needs~~.~~

(*Note: This goal is intended to call for a framework that will enable the City to establish and modify the targets over time as new science, policy and conditions change over time, and to establish the expectation for continuous performance tracking and adaptive management.)*

CAP Goal 2: The CAP will reflect the urgent need to effect significant GHG emissions reductions in the near term by prioritizing, as highest and most immediate, actions which are relatively the most effective and readily achievable ~~within available~~by the City organization and community partners.~~’ resources.~~

(*Note: This goal recognizes the urgency to make early gains where we can so the magnitude of the problem is not compounded by failure to take pragmatic, impactful steps now.*)

CAP Goal 3: The CAP will support community preparation for anticipated climate change-related impacts (such as water shortages, severe weather events, and unpredictable energy prices and availability) and enhance the community’s ability to adapt and be resilient.

(*Note: This goal is intended to address community adaptation and the institutions’ capacities to respond and provide needed services.)*

CAP Goal 4: The CAP will seek and foster cooperative partnerships and leadership from local public institutions, private businesses, ~~and~~ non-profit organizations, and community members, as well as regional, state and federal agencies and interests that can have a significant impact on the CAP's success.

(*Note: This goal recognizes that there are numerous other parties in addition to the City whose willingness to play a role in the CAP will be vital to its success. It also recognizes that outreach and influence beyond the community may be necessary for Corvallis to be successful.*)

CAP Goal 5: The CAP will incorporate actions that achieve other co-benefits in addition to GHG emissions reductions, including:

- Energy efficiency and greater energy independence from fossil fuels
- Sound economic investments (positive cost-benefit or return on investments)
- Community livability
- ~~Sustainability (i.e. triple bottom line)~~
- Environmental quality and ecosystem resiliency
- Public health and well being
- Healthy local economy and local self-reliance
- Equity and accessibility for low income/disadvantaged community members

(Note: This goal helps establish expected considerations or criteria in evaluating GHG reduction actions and reflects the community's emphasis on overall sustainability, which includes the "triple bottom line" inclusive of social, economic, and environmental considerations.)

CLIMATE ACTION PLAN: CONTENT OUTLINE

Letter from the Mayor

Executive Summary

Introduction (These Sections will be Brief)

- Need for Climate Protection and Community Preparedness
- Importance to Corvallis Community
    - Benefits of Taking Action Now
    - Risks of Not Acting Now
    - Past City/Community Efforts Leading to this Plan
- Goals (Council and CAP)
- Corvallis GHG Emissions
    - Current City and Community GHG Emissions Inventories and Projections (the numbers, how we compared to other local urban areas, relationship to state context)
    - GHG Emissions Reductions Targets (2050 and Interim Target Dates, and relationship to state targets)
- Scope (Geographic, Timeframe, inclusion of mitigation and adaptation/preparedness, and organizational/operational and community plan action plan elements)
- Summary of Plan Development Process
    - CATF; Task Team/Consultant prep; Interested Party/Expert Reviewers; Public Outreach
    - Generation of Plan Components, Development of Criteria, Analytical Tools/Process
    - Formulation of Final Plan
- Plan Organization/Action Areas—Objectives and Actions (Prioritized and Phased)
    - Buildings and Energy
    - Land Use and Transportation
    - Consumption and Waste
    - Urban Natural Resources
    - Food and Agriculture
    - Health and Social Services
- Plan Implementation—What Happens Next?
    - Work Plans and Funding
    - Implement Priorities, but also Capture Available Opportunities that Arise
    - Tracking and Reporting
    - Reviewing and Updating

Buildings and Energy

- Summary of Sector Impacts, Opportunities, and Efforts Completed or Underway in the Community and Organization.
- Objectives
    - Mitigation—City and Community Partners
        - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)

        - ✓ Short-term (e.g. complete within 3 years)
        - ✓ Mid-term (e.g. complete within 7 years)
        - ✓ Long-term (e.g. complete within 10 years)
  - Adaptation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
      - ✓ Short-term (e.g. complete within 3 years)
      - ✓ Mid-term (e.g. complete within 7 years)
      - ✓ Long-term (e.g. complete within 10 years)
  - What Citizens Can Do
- Reference to City Operational Plan in Appendix ___ for Operations Strategies/Actions

Land Use and Transportation

- Summary of Sector Impacts, Opportunities, and Efforts Completed or Underway in the Community and Organization.
- Objectives
  - Mitigation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
      - ✓ Short-term (e.g. complete within 3 years)
      - ✓ Mid-term (e.g. complete within 7 years)
      - ✓ Long-term (e.g. complete within 10 years)
  - Adaptation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
      - ✓ Short-term (e.g. complete within 3 years)
      - ✓ Mid-term (e.g. complete within 7 years)
      - ✓ Long-term (e.g. complete within 10 years)
  - What Citizens Can Do
- Reference to City Operational Plan in Appendix ___ for Operations Strategies/Actions

Consumption and Waste

- Summary of Sector Impacts, Opportunities, and Efforts Completed in the Community and Organization.
- Objectives
  - Mitigation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
      - ✓ Short-term (e.g. complete within 3 years)
      - ✓ Mid-term (e.g. complete within 7 years)

        - ✓ Long-term (e.g. complete within 10 years)
  - Adaptation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
      - ✓ Short-term (e.g. complete within 3 years)
      - ✓ Mid-term (e.g. complete within 7 years)
      - ✓ Long-term (e.g. complete within 10 years)
  - What Citizens Can Do
- Reference to City Operational Plan in Appendix ___ for Operations Strategies/Actions

Urban Natural Resources

- Summary of Sector Impacts, Opportunities, and Efforts Completed in the Community and Organization.
  - Objectives
  - Mitigation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
      - ✓ Short-term (e.g. complete within 3 years)
      - ✓ Mid-term (e.g. complete within 7 years)
      - ✓ Long-term (e.g. complete within 10 years)
  - Adaptation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
      - ✓ Short-term (e.g. complete within 3 years)
      - ✓ Mid-term (e.g. complete within 7 years)
      - ✓ Long-term (e.g. complete within 10 years)
  - What Citizens Can Do
- Reference to City Operational Plan in Appendix __ for Operations Strategies/Actions

Food and Agriculture

- Summary of Sector Impacts, Opportunities, and Efforts Completed in the Community and Organization.
- Objectives
  - Mitigation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
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      - ✓ Mid-term (e.g. complete within 7 years)
      - ✓ Long-term (e.g. complete within 10 years)

- Adaptation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
      - ✓ Short-term (e.g. complete within 3 years)
      - ✓ Mid-term (e.g. complete within 7 years)
      - ✓ Long-term (e.g. complete within 10 years)
  - What Citizens Can Do
- Reference to City Operational Plan in Appendix __ for Operations Strategies/Actions

Health and Social Services

- Summary of Sector Impacts, Opportunities, and Efforts Completed in the Community and Organization.
- Objectives
  - Mitigation—City and Community Partners
    - High Priority Actions with Recommended Phasing or Timing, and with Responsible Parties and Prerequisite Resources/Funding Needs Identified (possibly identify co-benefits with symbols)
      - ✓ Short-term (e.g. complete within 3 years)
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  - What Citizens Can Do
- Reference to City Operational Plan in Appendix __ for Operations Strategies/Actions

Tracking, Reporting, Reviewing and Updating

- Progress Report to City Council and Community Partners—Every ___ Years
- Collect Data and Update GHG Emissions Inventory—Every ___ Years
- Review State and National Context and Update CAP—Every ____ Years

Appendices:

- Glossary, including acronyms
- Issue paper addressing: science-based climate assessment, conclusions and calls for action for mitigation and adaptation (global, national and local levels); trends in federal, state and local government, and business climate action planning and strategies; and summary of Corvallis community actions setting context for this CAP.
- Project development process, participants, methods, tools, and resources (reference how CATF guiding principles and goals guided efforts)

- Description of co-benefits
- Entire compilation of objectives and actions considered in the process, with evaluation information included (such as application of criteria, ratings, priorities and identified co-benefits)
- City Operational CAP
- References (documents and web-based information with links included)

*(Note that recommendation is to have actual GHG Emissions Inventories as separate documents. They will be updated independently from this document and this document already will summarize the snap shot in time represented by current inventories. Reason is to keep document of manageable size and not have information become outdated)

Reference material for CATF
January 26, 2016 meeting.
Full report available at:
http://www.ipcc.ch/report/ar5/syr/

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

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[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.

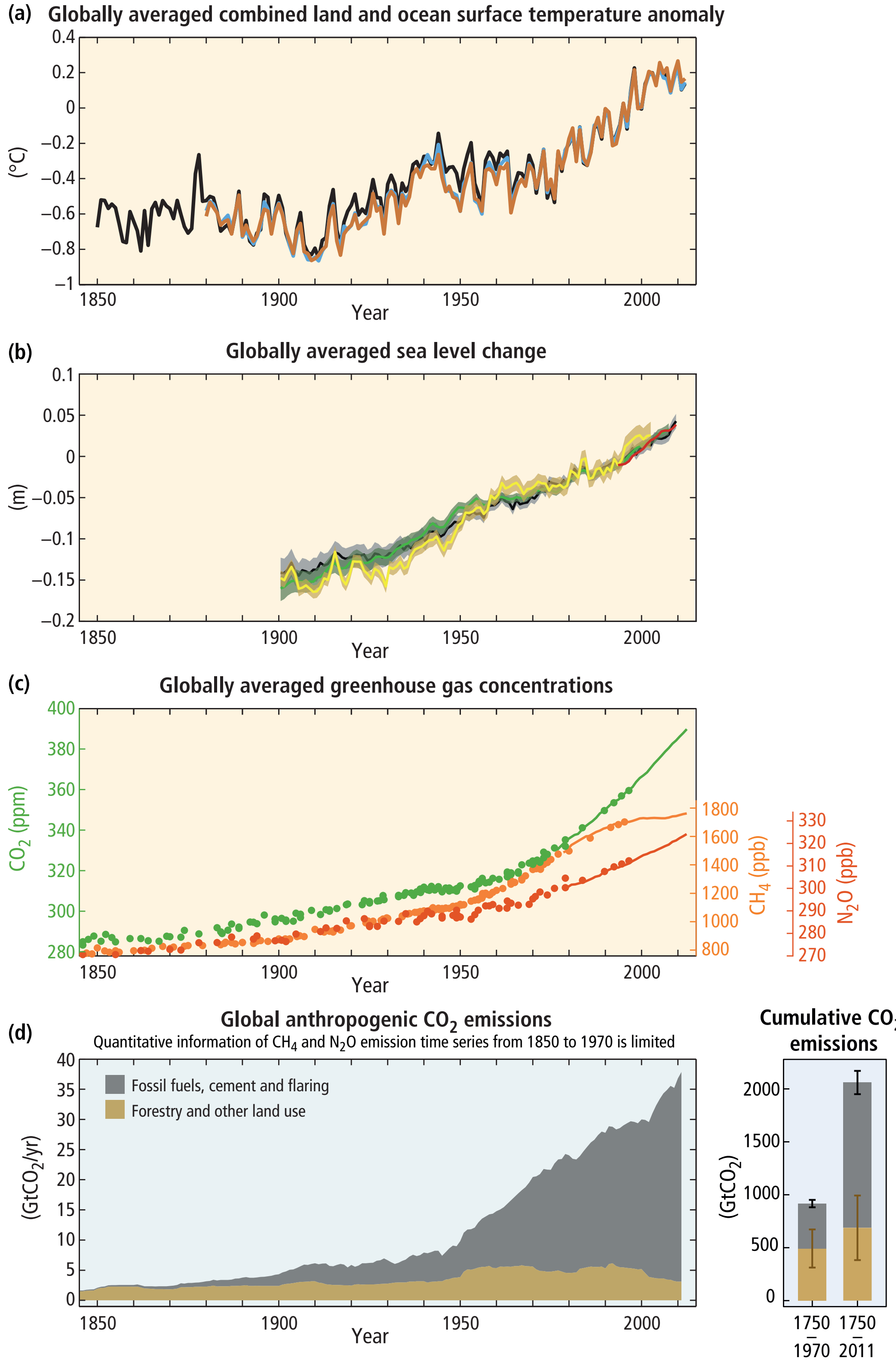

Figure SPM.1 | The complex relationship between the observations (panels a, b, c, yellow background) and the emissions (panel d, light blue background) is addressed in Section 1.2 and Topic 1. Observations and other indicators of a changing global climate system. Observations: **(a)** Annually and globally 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}*

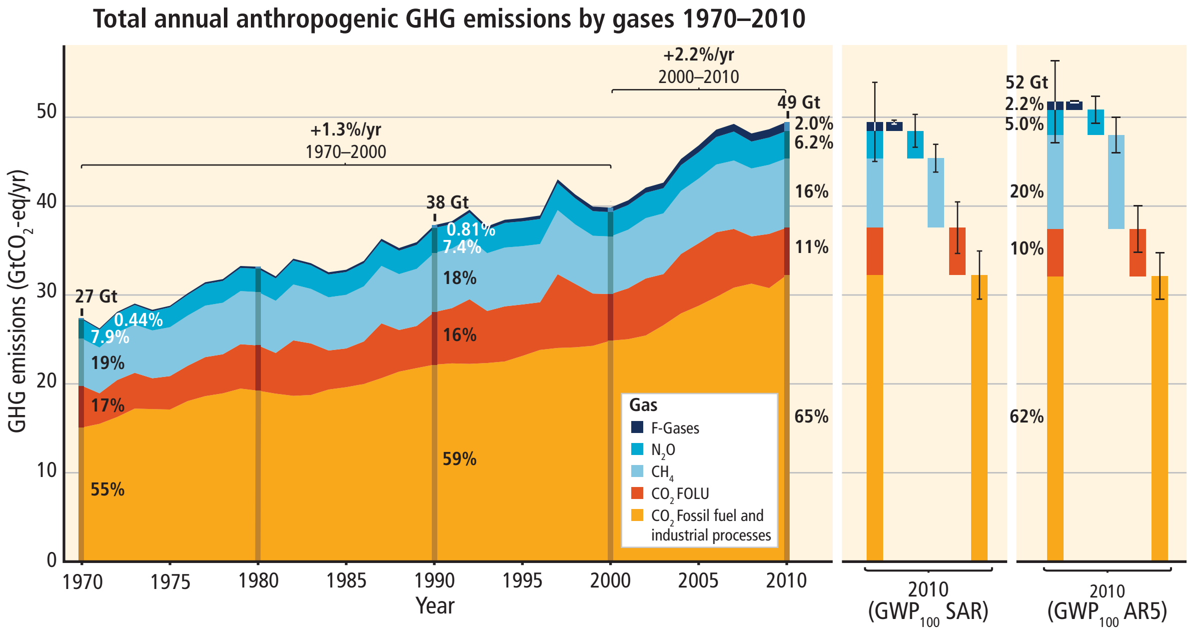

Figure SPM.2 | Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) for the period 1970 to 2010 by gases: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (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}*

[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.

SPM

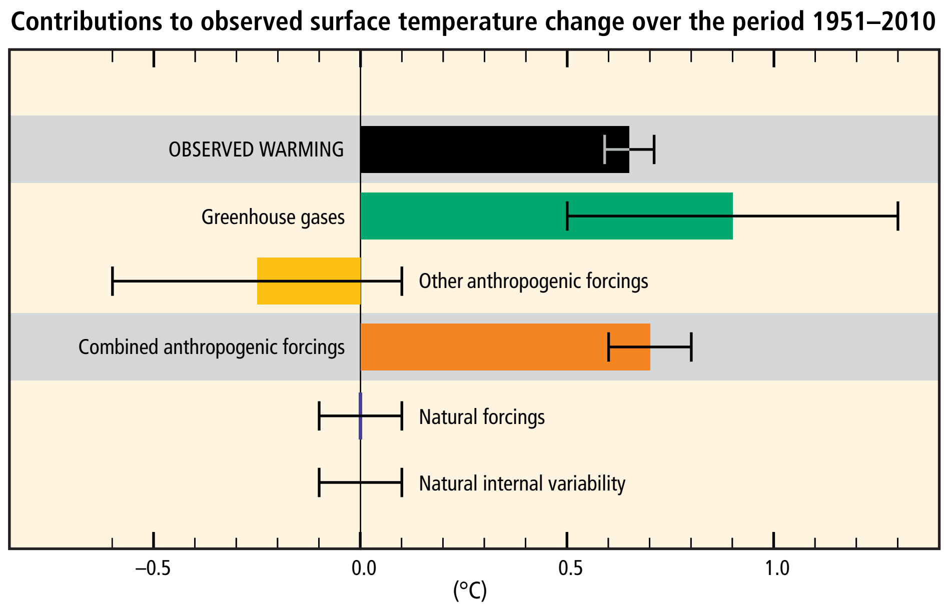

Figure SPM.3 | Assessed *likely* ranges (whiskers) and their mid-points (bars) for warming trends over the 1951–2010 period from well-mixed greenhouse gases, other anthropogenic forcings (including the cooling effect of aerosols and the effect of land use change), combined anthropogenic forcings, natural 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}*

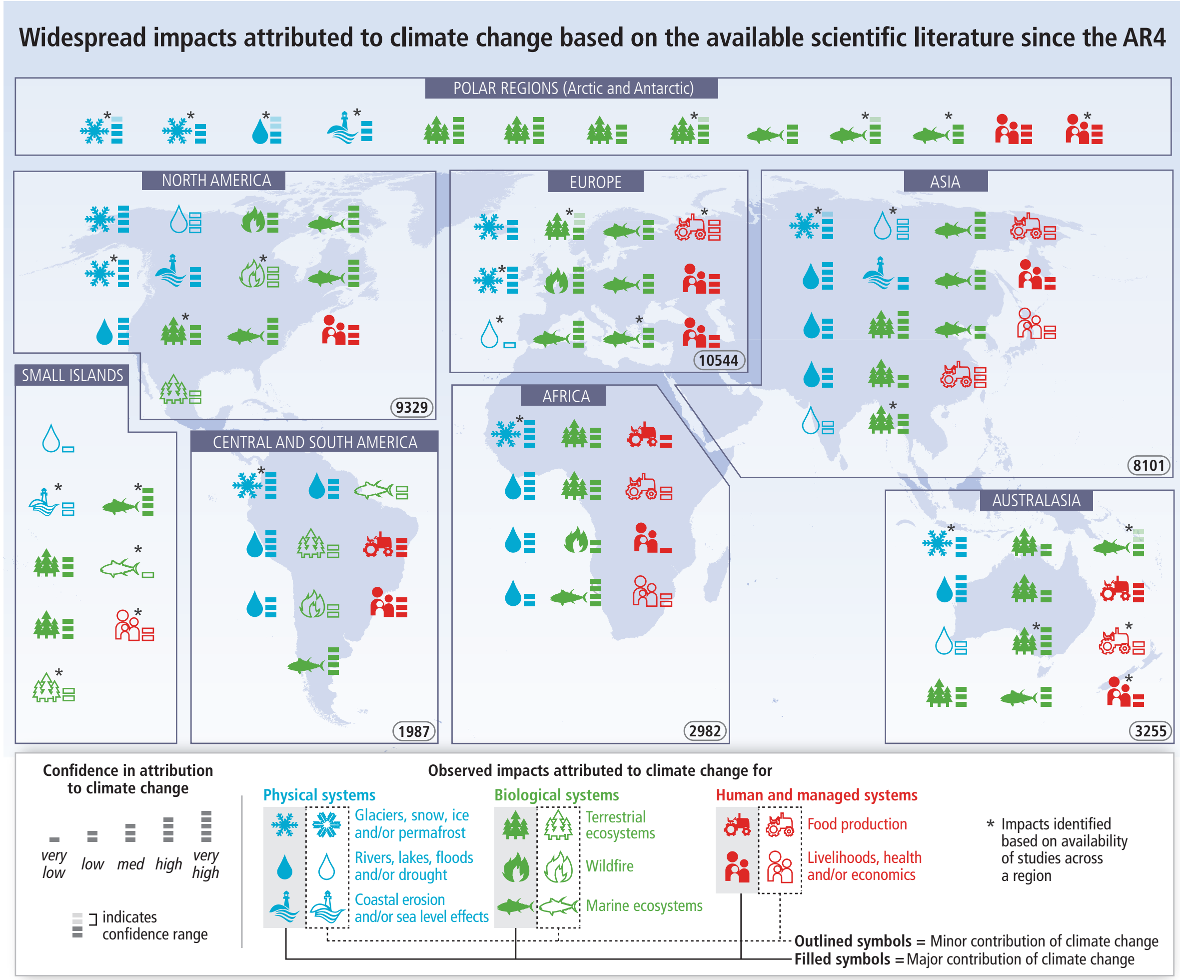

Figure SPM.4 | Based on the available scientific literature since the IPCC Fourth Assessment Report (AR4), there are substantially more impacts in recent decades now attributed to climate change. Attribution requires defined scientific evidence on the role of climate change. Absence from the map of additional 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 *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}*

[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.

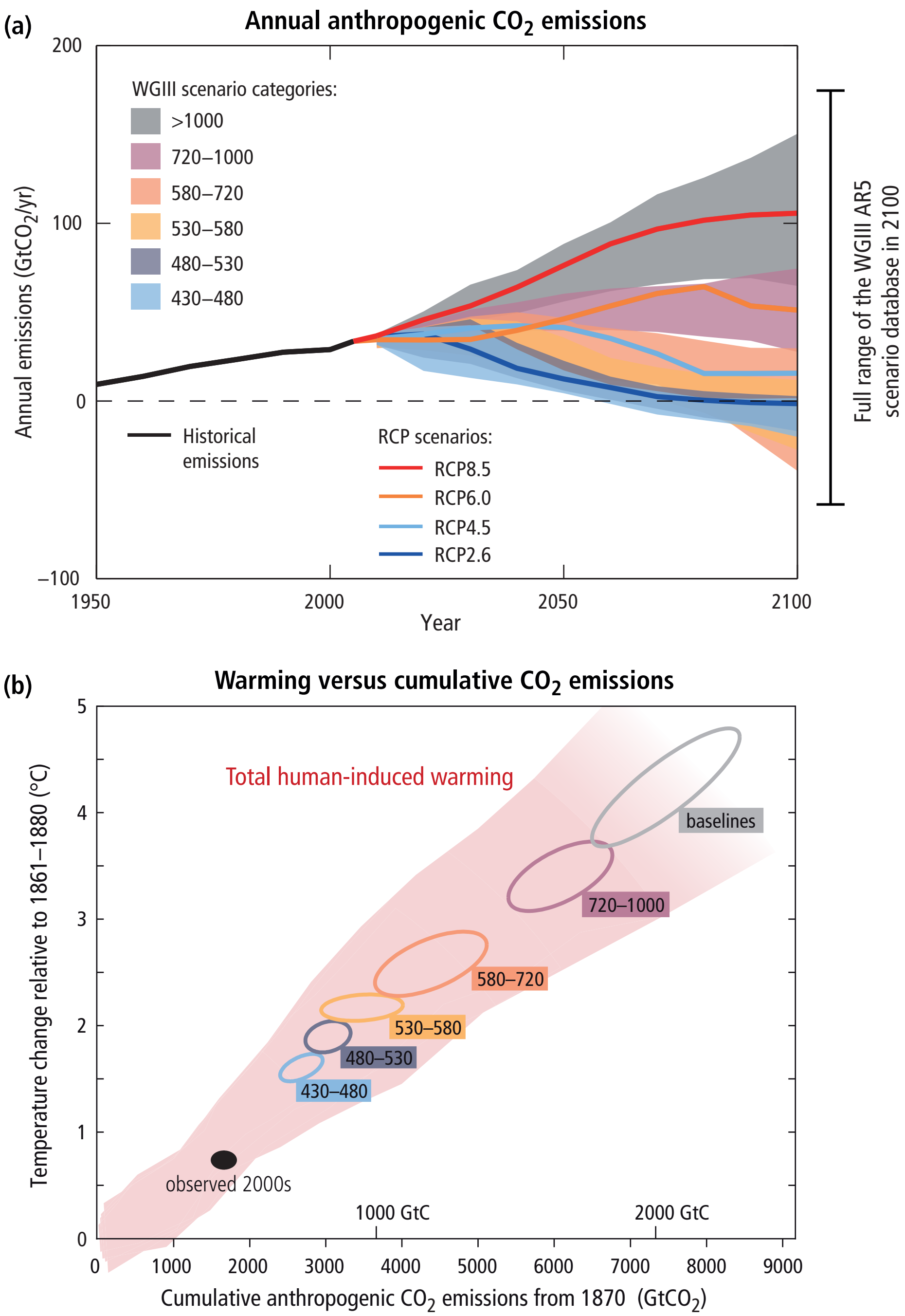

Figure SPM.5 | **(a)** Emissions of carbon dioxide (CO_2) alone in the Representative Concentration Pathways (RCPs) (lines) and the associated scenario categories used in WGIII (coloured areas show 5 to 95% range). The WGIII scenario categories summarize the wide range of emission scenarios published 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}*

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}*

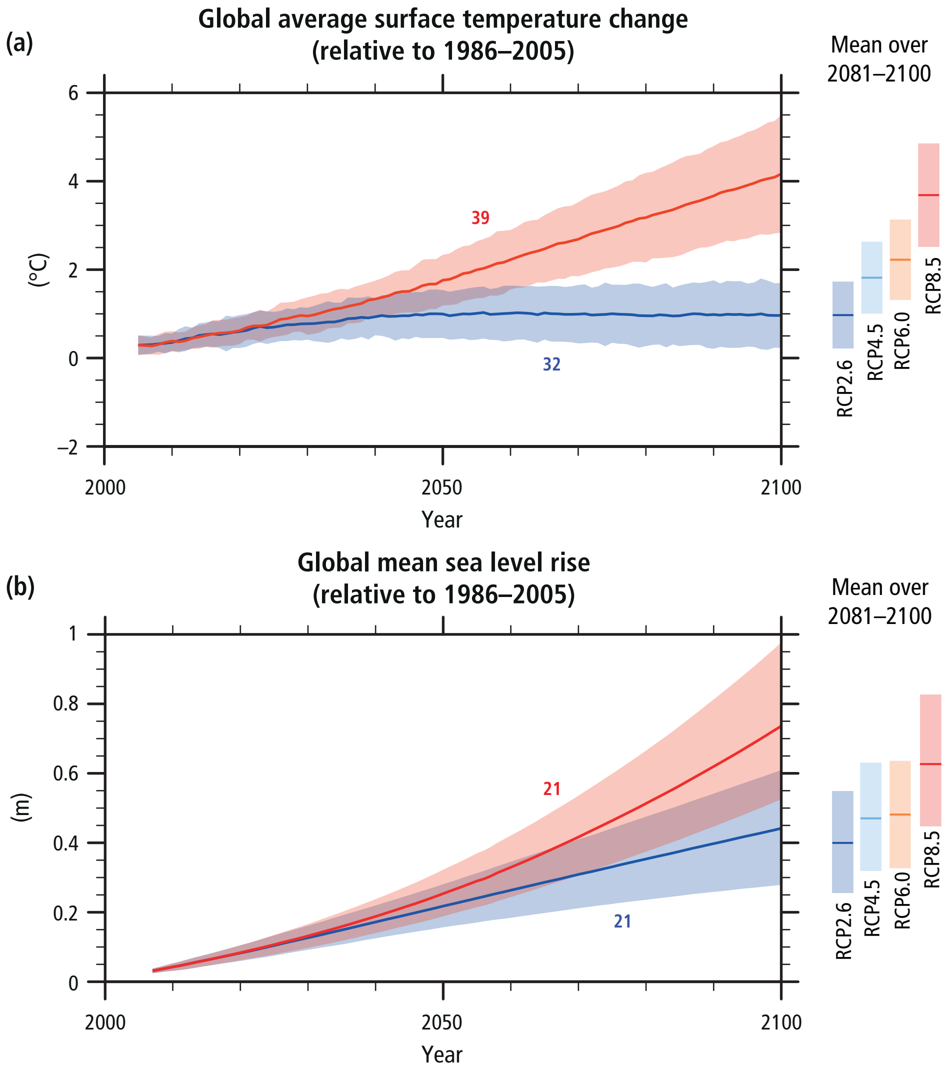

Figure SPM.6 | Global average surface temperature change **(a)** and global mean sea level rise[10] **(b)** from 2006 to 2100 as determined by multi-model simulations. All changes are relative to 1986–2005. Time series of projections and a measure of uncertainty (shading) are shown for scenarios RCP2.6 (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.

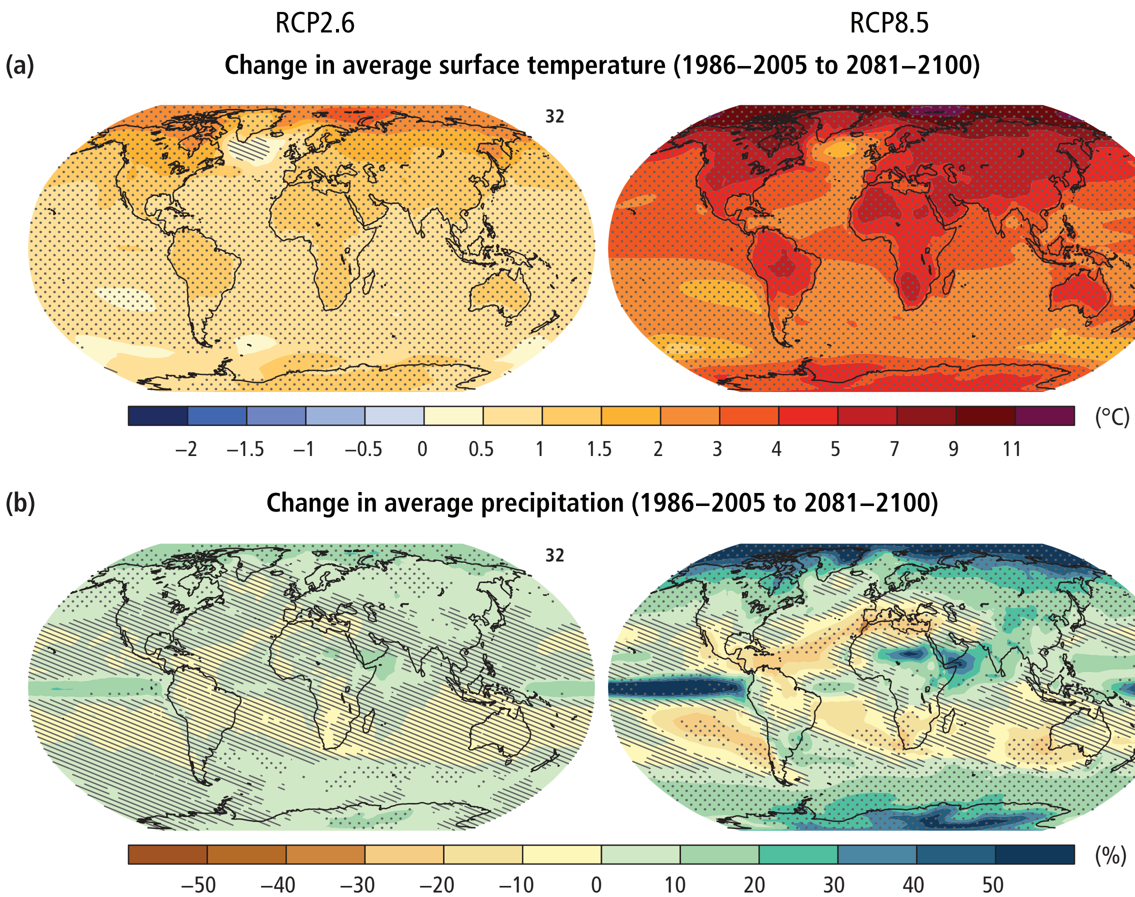

Figure SPM.7 | Change in average surface temperature **(a)** and change in average precipitation **(b)** based on multi-model mean projections for 2081–2100 relative to 1986–2005 under the RCP2.6 (left) and RCP8.5 (right) scenarios. The number of models used to calculate the multi-model mean is indicated 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}*

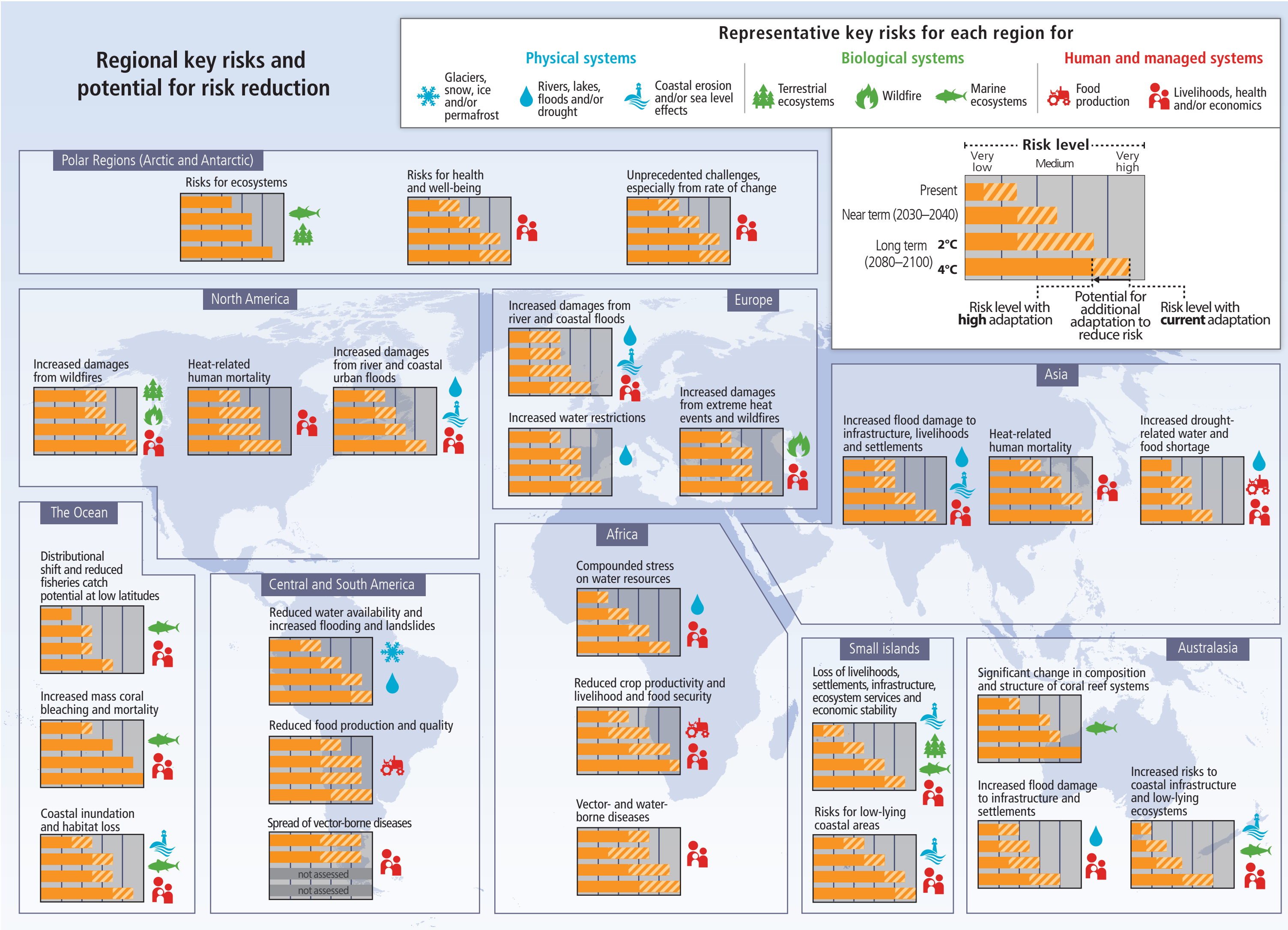

Figure SPM.8 | Representative key risks[14] for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high or very high. Risk levels are presented for three time frames: present, 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}*

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[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.

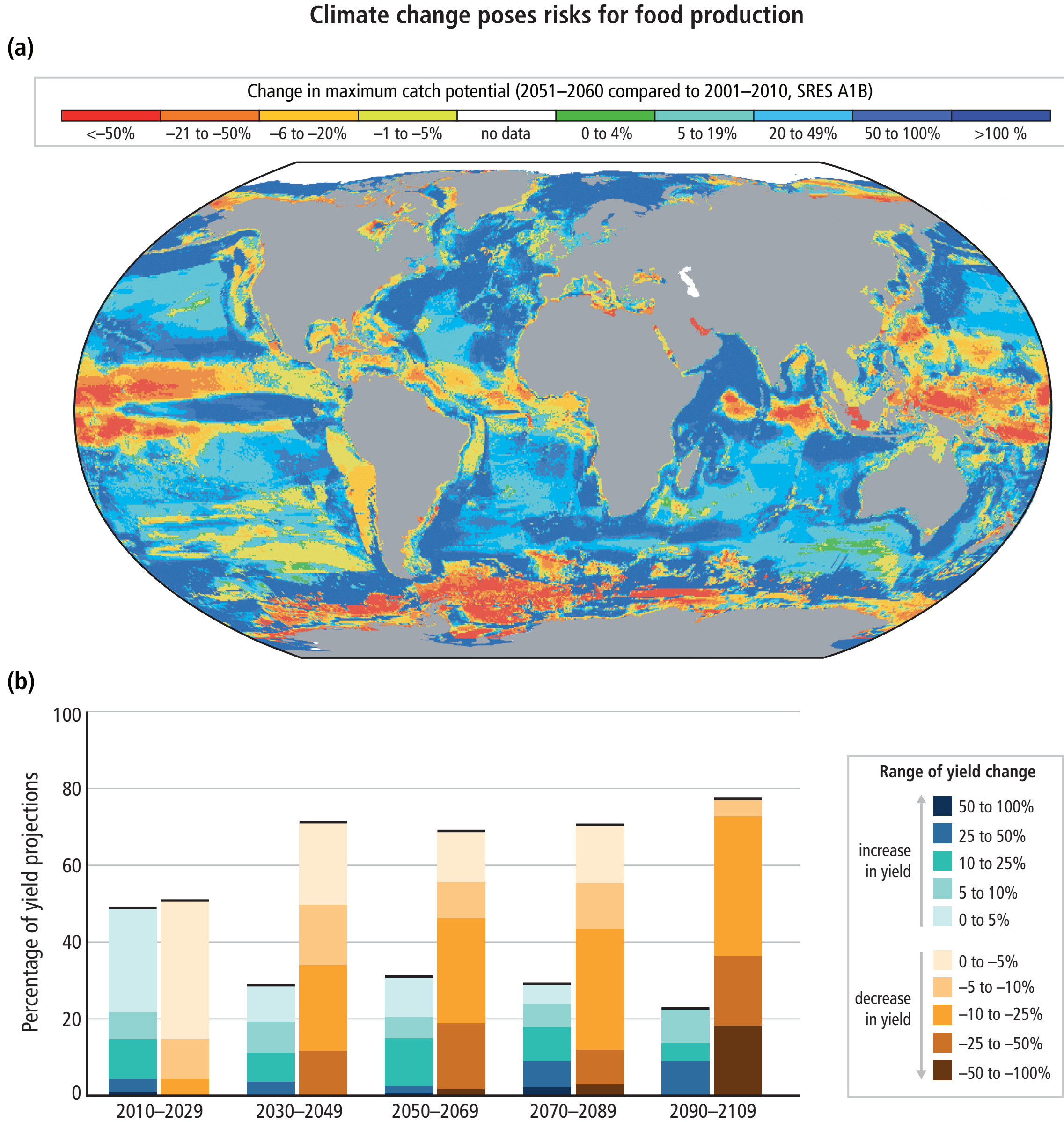

Figure SPM.9 | (a) Projected global redistribution of maximum catch potential of ~1000 exploited marine fish and invertebrate species. Projections compare the 10-year averages 2001–2010 and 2051–2060 using ocean conditions based on a single climate model under a moderate to high warming scenario, without 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}*

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}*

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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 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

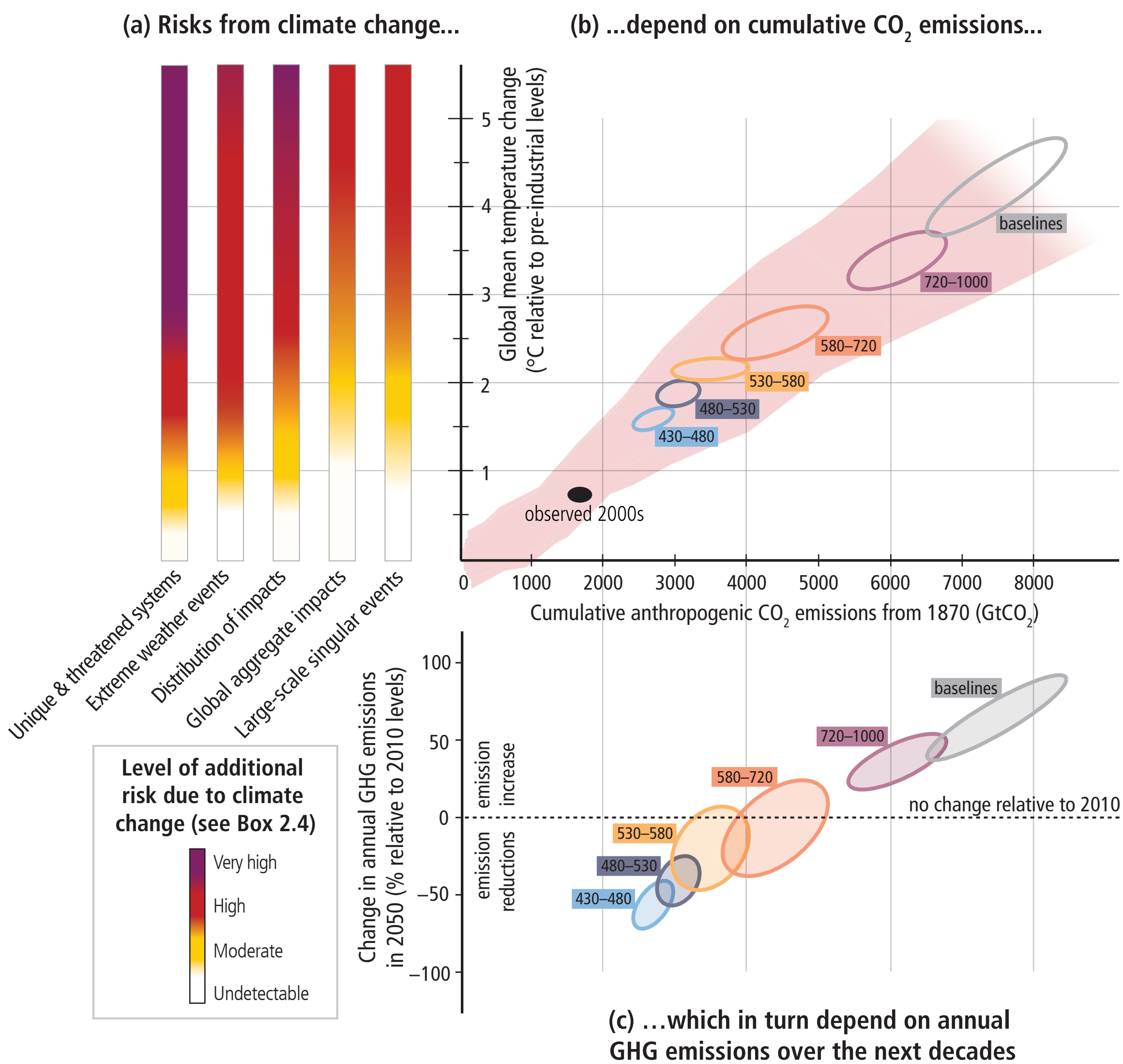

Figure SPM.10 | The relationship between risks from climate change, temperature change, cumulative carbon dioxide (CO_2) emissions and changes in annual greenhouse gas (GHG) emissions by 2050. Limiting risks across Reasons For Concern **(a)** would imply a limit for cumulative emissions of CO_2 **(b)** 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}*

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}*

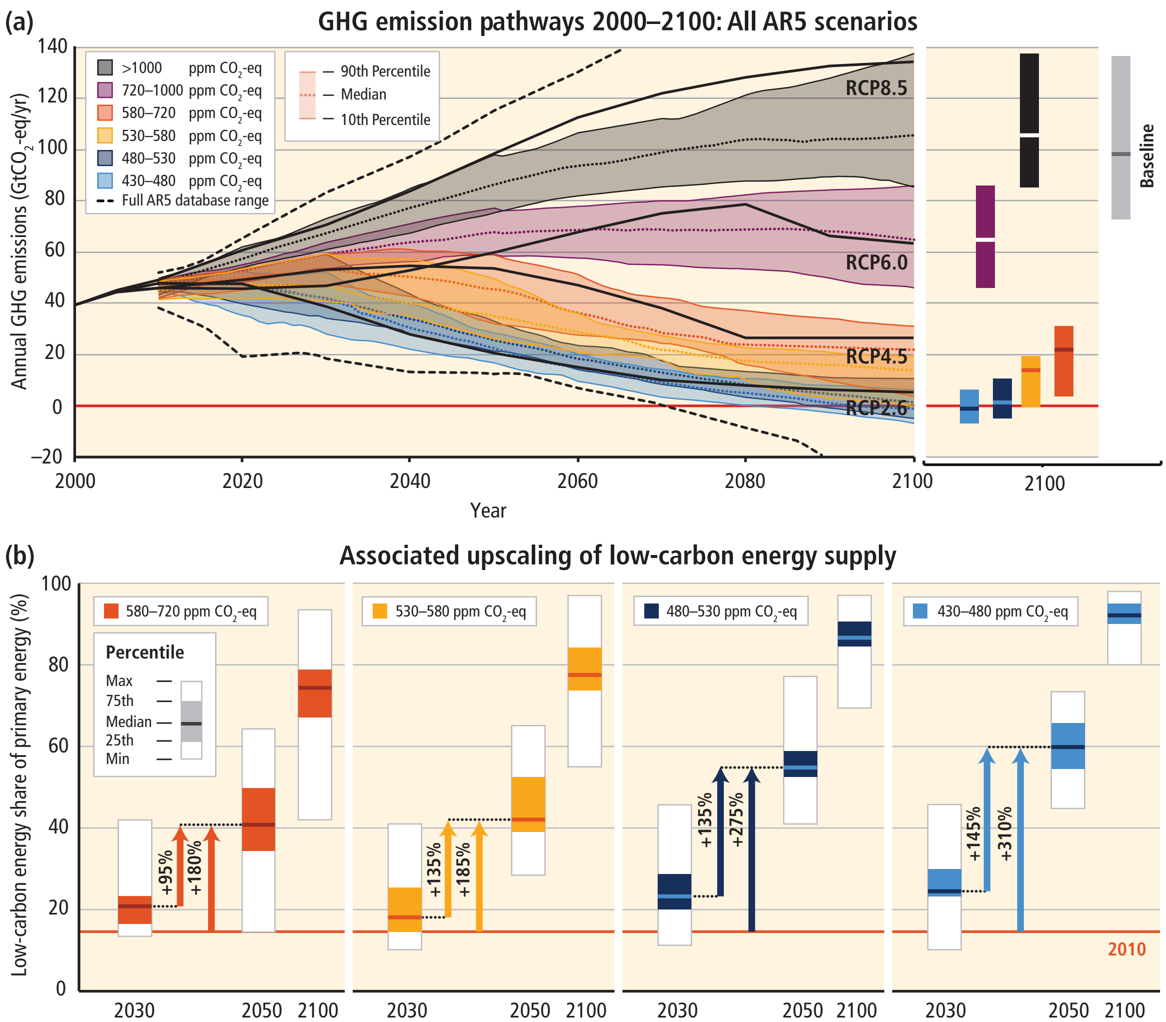

Figure SPM.11 | Global greenhouse gas emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) in baseline and mitigation scenarios for different long-term concentration levels **(a)** and associated upscaling requirements of low-carbon energy (% of primary energy) for 2030, 2050 and 2100 compared 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>1.5ºC</th><th>2ºC</th><th>3ºC</th><th>4ºC</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="9">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.

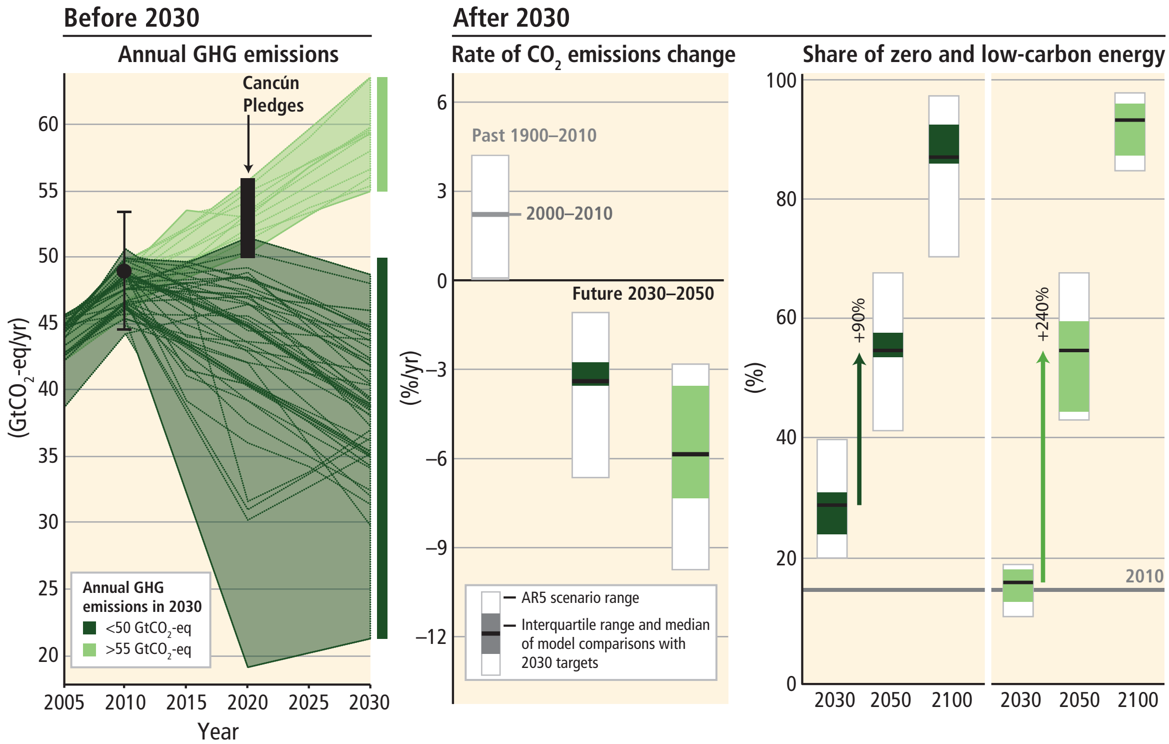

Figure SPM.12 | The implications of different 2030 greenhouse gas (GHG) emissions levels for the rate of carbon dioxide (CO_2) emissions reductions and low-carbon energy upscaling in mitigation scenarios that are at least *about as likely as not* to keep warming throughout the 21st century below 2°C 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.

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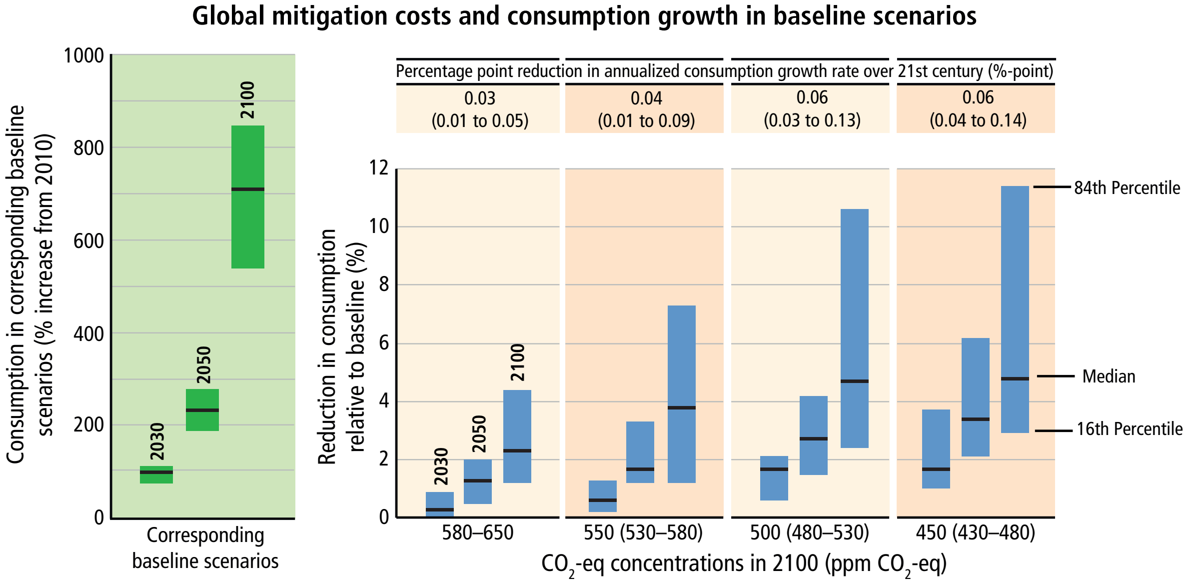

Figure SPM.13 | Global mitigation costs in cost-effective scenarios at different atmospheric concentrations levels in 2100. Cost-effective scenarios assume immediate mitigation in all countries and a single global carbon price, and impose no additional limitations on technology relative to the models' 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
- (tan): between 80 and 100% of models successful
- (orange): between 50 and 80% 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

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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

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}*

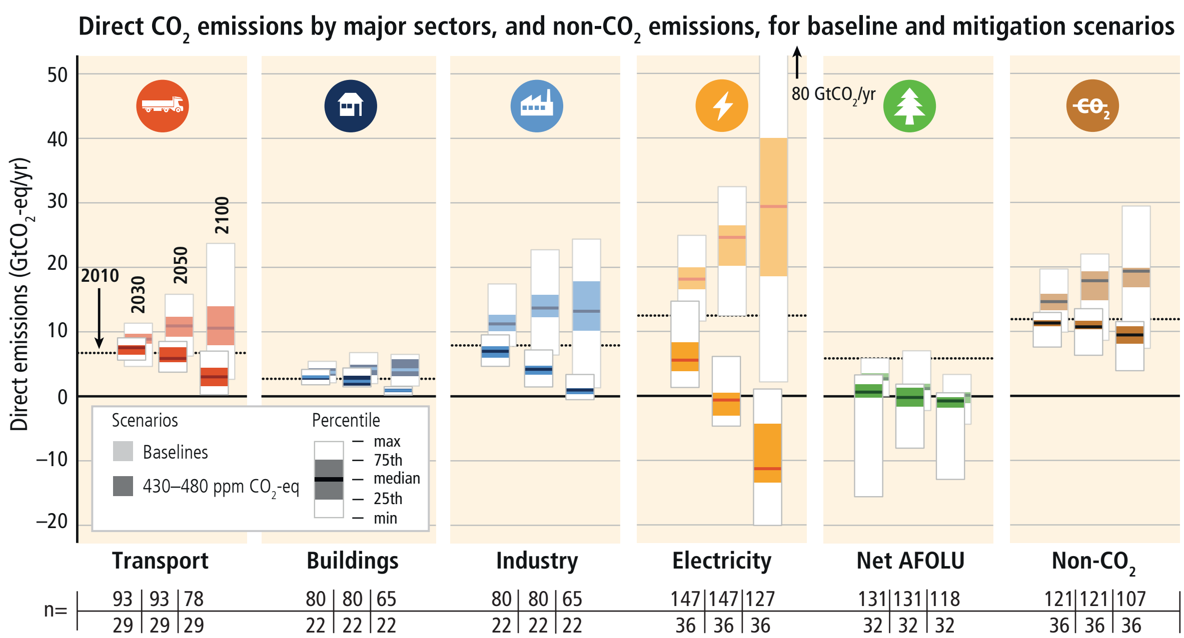


Figure SPM.14 | Carbon dioxide (CO_2) emissions by sector and total non-CO_2 greenhouse gases (Kyoto gases) across sectors in baseline (faded bars) and mitigation scenarios (solid colour bars) that reach about 450 (430 to 480) ppm CO_2-eq concentrations in 2100 (*likely* to limit warming to 2°C above 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}*

[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}*

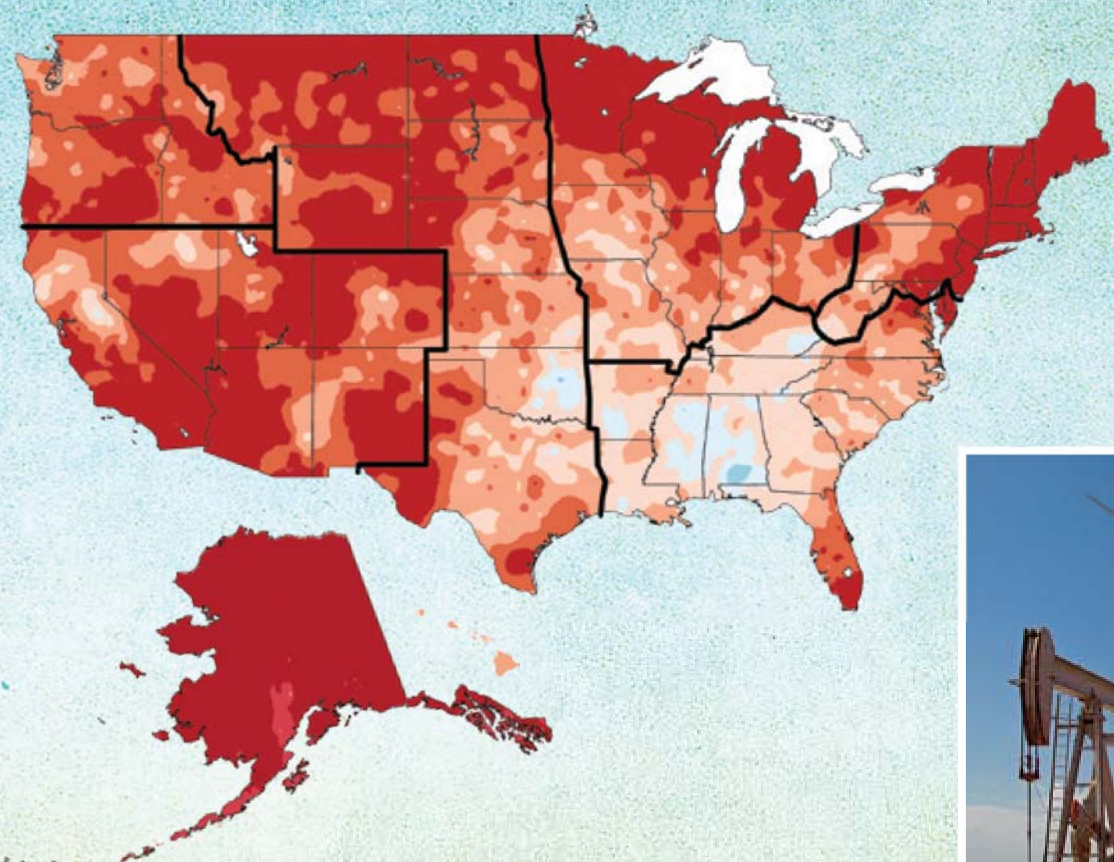
Climate change exacerbates other threats to social and natural systems, placing additional burdens particularly on the poor (*high confidence*). Aligning climate policy with sustainable development requires attention to both adaptation and mitigation (*high confidence*). Delaying global mitigation actions 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}*

Reference material for CATF January 26, 2016 meeting.
Full report available at:
http://nca2014.globalchange.gov/

OVERVI

Climate Change Impacts in the United States



U.S. National Climate Assessment

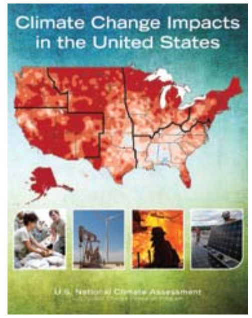
U.S. Global Change Research Program

About the NATIONAL CLIMATE ASSESSMENT

The National Climate Assessment assesses the science of climate change and its impacts across the United States, now and throughout this century. It documents climate change related impacts and responses for various sectors and regions, with the goal of better informing public and private decision-making at all levels.

A team of more than 300 experts (see full report), guided by a 60-member National Climate Assessment and Development Advisory Committee (listed on the inside back cover) produced the full report – the largest and most diverse team to produce a U.S. climate assessment. Stakeholders involved in the development of the assessment included decision-makers from the public and private sectors, resource and environmental managers, researchers, representatives from businesses and non-governmental organizations, and the general public. More than 70 workshops and listening sessions were held, and thousands of public and expert comments on the draft report provided additional input to the process.

The assessment draws from a large body of scientific peer-reviewed research, technical input reports, and other publicly available sources; all sources meet the standards of the Information Quality Act. The report was extensively reviewed by the public and experts, including a panel of the National Academy of Sciences, the 13 Federal agencies of the U.S. Global Change Research Program, and the Federal Committee on Environment, Natural Resources, and Sustainability.

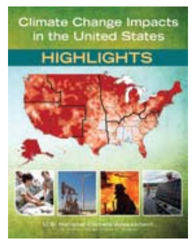


Online at:
nca2014.globalchange.gov

About the HIGHLIGHTS

The 148-page *Highlights* book presents the major findings and selected highlights from *Climate Change Impacts in the United States*, the third National Climate Assessment.

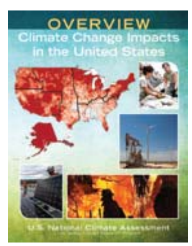
The *Highlights* report is organized around the National Climate Assessment's 12 Report Findings, which take an overarching view of the entire report and its 30 chapters. All material in the *Highlights* report is drawn from the full report. The Key Messages from each of the 30 report chapters appear throughout the *Highlights*.



Online at:
nca2014.globalchange.gov/highlights

About the OVERVIEW

This booklet provides a high level compendium of *Climate Change Impacts in the United States*, the Third National Climate Assessment. The *Overview* covers the most important impacts at the national level but does not attempt to provide a comprehensive summary of the entire assessment. Numbered references can be found in the *Highlights*.
To supplement this *Overview*, regional fact sheets are available that offer highlights from each of the eight regions. These and other resources can found at the website nca2014.globalchange.gov.



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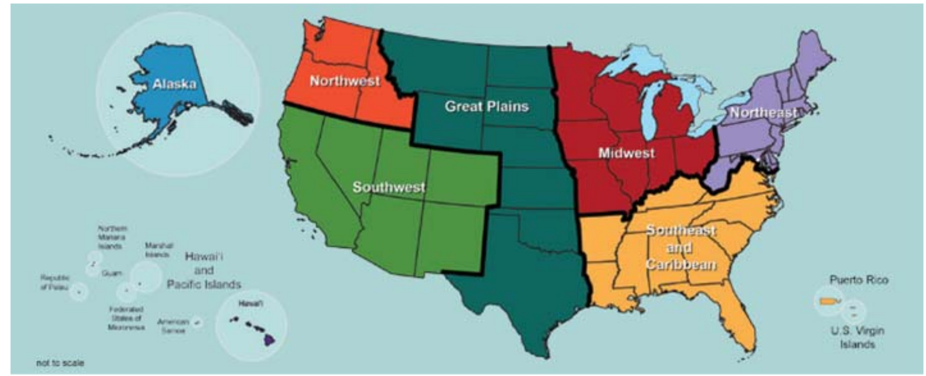
Climate Change Impacts in the United States describes current and future impacts on various U.S. regions and sectors. It also describes some of the responses underway and planned. The eight regions are shown on the map, and icons and titles below identify the various subjects, sectors, cross-sector topics, and responses to climate change covered in the assessment.



- Our Changing Climate
- Water Resources
- Energy Supply and Use
- Transportation
- Agriculture
- Forests
- Ecosystems and Biodiversity
- Human Health
- Energy, Water, and Land Use
- Urban Systems and Infrastructure
- Indigenous Peoples, Lands, and Resources
- Land Use and Land Cover Change
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- Biogeochemical Cycles
- Oceans and Marine Resources
- Coastal Zones
- Decision Support
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- FAQ Frequently Asked Questions
- APP Climate Science Supplement

CLIMATE CHANGE AND THE AMERICAN PEOPLE

Climate change, once considered an issue for a distant future, has moved firmly into the present. Corn producers in Iowa, oyster growers in Washington State, and maple syrup producers in Vermont are all observing climate-related changes that are outside of recent experience. So, too, are coastal planners in Florida, water managers in the arid Southwest, city dwellers from Phoenix to New York, and Native Peoples on tribal lands from Louisiana to Alaska. This National Climate Assessment concludes that the evidence of human-induced climate change continues to strengthen and that impacts are increasing across the country.

Americans are noticing changes all around them. Summers are longer and hotter, and extended periods of unusual heat last longer than any living American has ever experienced. Winters are generally shorter and warmer. Rain comes in heavier downpours. People are seeing changes in the length and severity of seasonal allergies, the plant varieties that thrive in their gardens, and the kinds of birds they see in any particular month in their neighborhoods.

Other changes are even more dramatic. Residents of some coastal cities see their streets flood more regularly during storms and high tides. Inland cities near large rivers also experience more flooding, especially in the Midwest and Northeast. Insurance rates are rising in some vulnerable locations, and insurance is no longer available in others. Hotter and drier weather and earlier snow melt mean that wildfires in the West start earlier in the spring, last later into the fall, and burn more acreage. In Arctic Alaska, the summer sea ice that once protected the coasts has receded, and autumn storms now cause more erosion, threatening many communities with relocation.

Scientists who study climate change confirm that these observations are consistent with significant changes in Earth's climatic trends. Long-term, independent records from weather stations, satellites, ocean buoys, tide gauges, and many other data sources all confirm that our nation, like the rest of the world, is warming. Precipitation patterns are changing, sea level is rising, the oceans are becoming more acidic, and the frequency and intensity of some extreme weather events are increasing. Many lines of independent evidence demonstrate that the rapid warming of the past half-century is due primarily to human activities.

The observed warming and other climatic changes are triggering wide-ranging impacts in every region of our country and throughout our economy. Some of these changes can be beneficial over the short run, such as a longer growing season in some regions and a longer shipping season on the Great Lakes. But many more are detrimental, largely because our society and its infrastructure were designed for the climate that we have had, not the rapidly changing climate we now have and can expect in the future. In addition, climate change does not occur in isolation. Rather, it is superimposed on other stresses, which combine to create new challenges.

This National Climate Assessment collects, integrates, and assesses observations and research from around the country, helping us to see what is actually happening and understand what it means for our lives, our livelihoods, and our future. The report includes analyses of impacts on seven sectors – human health, water, energy, transportation, agriculture, forests, and ecosystems – and the interactions among sectors at the national level. The report also assesses key impacts on all U.S. regions: Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, Hawai`i and Pacific Islands, as well as the country's coastal areas, oceans, and marine resources.

Over recent decades, climate science has advanced significantly. Increased scrutiny has led to increased certainty that we are now seeing impacts associated with human-induced climate change. With each passing year, the accumulating evidence further expands our understanding and extends the record of observed trends in temperature, precipitation, sea level, ice mass, and many other variables recorded by a variety of measuring systems and analyzed by independent research groups from around the world. It is notable that as these data records have grown longer and climate models have become more comprehensive, earlier predictions have largely been confirmed. The only real surprises have been that some changes, such as sea level rise and Arctic sea ice decline, have outpaced earlier projections.

What is new over the last decade is that we know with increasing certainty that climate change is happening now. While scientists continue to refine projections of the future, observations unequivocally show that climate is changing and that the warming of the past 50 years is primarily due to human-induced emissions of heat-trapping gases. These emissions come mainly from burning coal, oil, and gas, with additional contributions from forest clearing and some agricultural practices.

Global climate is projected to continue to change over this century and beyond, but there is still time to act to limit the amount of change and the extent of damaging impacts.

This report documents the changes already observed and those projected for the future.

It is important that these findings and response options be shared broadly to inform citizens and communities across our nation. Climate change presents a major challenge for society. This report advances our understanding of that challenge and the need for the American people to prepare for and respond to its far-reaching implications.

OVERVIEW

Climate change is already affecting the American people in far-reaching ways. Certain types of extreme weather events with links to climate change have become more frequent and/or intense, including prolonged periods of heat, heavy downpours, and, in some regions, floods and droughts. In addition, warming is causing sea level to rise and glaciers and Arctic sea ice to melt, and oceans are becoming more acidic as they absorb carbon dioxide. These and other aspects of climate change are disrupting people's lives and damaging some sectors of our economy.

Climate Change: Present and Future

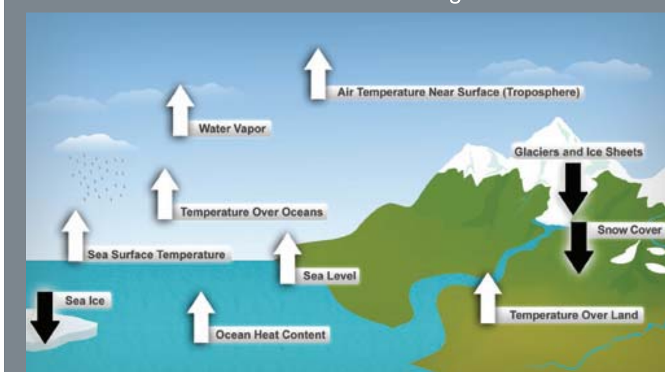
Evidence for climate change abounds, from the top of the atmosphere to the depths of the oceans. Scientists and engineers from around the world have meticulously collected this evidence, using satellites and networks of weather balloons, thermometers, buoys, and other observing systems. Evidence of climate change is also visible in the observed and measured changes in location and behavior of species and functioning of ecosystems. Taken together, this evidence tells an unambiguous story: the planet is warming, and over the last half century, this warming has been driven primarily by human activity.

Multiple lines of independent evidence confirm that human activities are the primary cause of the global warming of the past 50 years. The burning of coal, oil, and gas, and clearing of forests have increased the concentration of carbon dioxide in the atmosphere by more than 40% since the Industrial Revolution, and it has been known for almost two centuries that this carbon dioxide traps heat. Methane and nitrous oxide emissions from agriculture and other human activities add to the atmospheric burden of heat-trapping gases. Data show that natural factors like the sun and volcanoes cannot have caused the warming observed over the past 50 years. Sensors on satellites have measured the sun's output with great accuracy and found no overall increase during the past half century. Large volcanic eruptions during this period, such as Mount Pinatubo in 1991, have exerted a short-term *cooling* influence. In fact, if not for human activities, global climate would actually have cooled slightly over the past 50 years. The pattern of temperature change through the layers of the atmosphere, with warming near the surface and cooling higher up in the stratosphere, further confirms that it is the buildup of heat-trapping gases (also known as "greenhouse gases") that has caused most of the Earth's warming over the past half century.

Coal-fired power plants emit heat-trapping carbon dioxide to the atmosphere.

Because human-induced warming is superimposed on a background of natural variations in climate, warming is not uniform over time. Short-term fluctuations in the long-term upward trend are thus natural and expected.

Ten Indicators of a Warming World

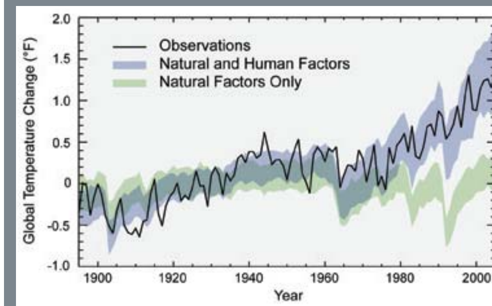


These are just some of the indicators measured globally over many decades that show that the Earth's climate is warming. White arrows indicate increasing trends; black arrows indicate decreasing trends. All the indicators expected to increase in a warming world are increasing, and all those expected to decrease in a warming world are decreasing. (Figure source: NOAA NCDC, based on data updated from Kennedy et al. 2010[a]).

For example, a recent slowing in the rate of surface air temperature rise appears to be related to cyclic changes in the oceans and in the sun's energy output, as well as a series of small volcanic eruptions and other factors. Nonetheless, global temperatures are still on the rise and are expected to rise further.

U.S. average temperature has increased by 1.3°F to 1.9°F since 1895, and most of this increase has occurred since 1970. The most recent decade was the nation's and the world's hottest on record, and 2012 was the hottest year on record in the continental United States. All U.S. regions have experienced warming in recent decades, but the extent of warming has not been uniform. In general, temperatures are rising more quickly in the north. Alaskans have experienced some of the largest increases in temperature between 1970 and the present. People living in the Southeast have experienced some of the smallest temperature increases over this period.

Separating Human and Natural Influences on Climate

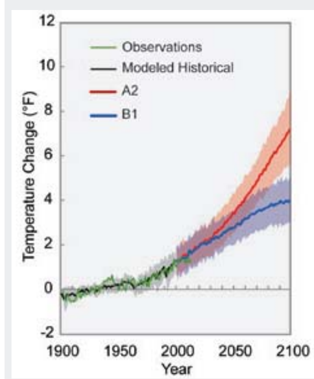


The green band shows how global average temperature would have changed over the last century due to natural forces alone, as simulated by climate models. The blue band shows model simulations of the effects of human and natural forces (including solar and volcanic activity) combined. The black line shows the actual observed global average temperatures. Only with the inclusion of human influences can models reproduce the observed temperature changes. (Figure source: adapted from Huber and Knutti 2012[b]).

Temperatures are projected to rise another 2°F to 4°F in most areas of the United States over the next few decades. Reductions in some short-lived human-induced emissions that contribute to warming, such as black carbon (soot) and methane, could reduce some of the projected warming over the next couple of decades, because, unlike carbon dioxide, these gases and particles have relatively short atmospheric lifetimes.

The amount of warming projected beyond the next few decades is directly linked to the cumulative global emissions of heat-trapping gases and particles. By the end of this century, a roughly 3°F to 5°F rise is projected under a lower emissions scenario, which would require substantial reductions in emissions (referred to as the "B1 scenario"), and a 5°F to 10°F rise for a higher emissions scenario assuming continued increases in emissions, predominantly from fossil fuel combustion (referred to as the "A2 scenario"). These projections are based on results from 16 climate models that used the two emissions scenarios in a formal inter-model comparison study. The range of model projections for each emissions scenario is the result of the differences in the ways the models represent key factors such as water vapor, ice and snow reflectivity, and clouds, which can either dampen or amplify the initial effect of human influences on temperature. The net effect of these feedbacks is expected to amplify warming. More information about the models and scenarios used in this report can be found in Appendix 5 of the full report.[1]

Projected Global Temperature Change



Different amounts of heat-trapping gases released into the atmosphere by human activities produce different projected increases in Earth's temperature. The lines on the graph represent a central estimate of global average temperature rise (relative to the 1901-1960 average) for the two main scenarios used in this report. A2 assumes continued increases in emissions throughout this century, and B1 assumes significant emissions reductions, though not due explicitly to climate change policies. Shading indicates the range (5th to 95th percentile) of results from a suite of climate models. In both cases, temperatures are expected to rise, although the difference between lower and higher emissions pathways is substantial. (Figure source: NOAA NCDC / CICS-NC).

Prolonged periods of high temperatures and the persistence of high nighttime temperatures have increased in many locations (especially in urban areas) over the past half century. High nighttime temperatures have widespread impacts because people, livestock, and wildlife get no respite from the heat. In some regions, prolonged periods of high temperatures associated with droughts contribute to conditions that lead to larger wildfires and longer fire seasons. As expected in a warming climate, recent trends show that extreme heat is becoming more common, while extreme cold is becoming less common. Evidence indicates that the human influence on climate has already roughly doubled the probability of extreme heat events such as the record-breaking summer heat experienced in 2011 in Texas and Oklahoma. The incidence of record-breaking high temperatures is projected to rise.[2]

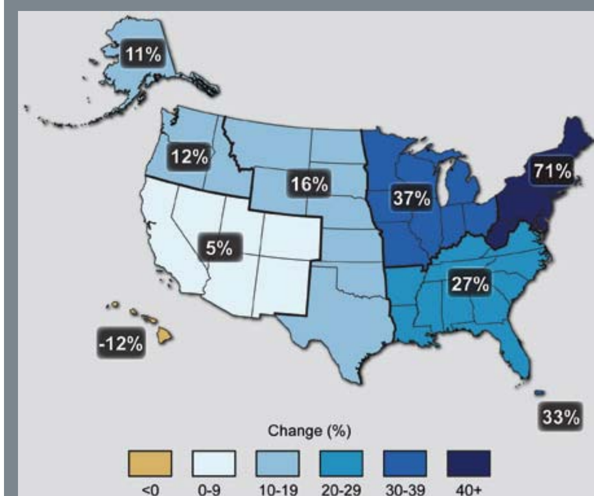
Human-induced climate change means much more than just hotter weather. Increases in ocean and freshwater temperatures, frost-free days, and heavy downpours have all been documented. Global sea level has risen, and there have been large reductions in snow-cover extent, glaciers, and sea ice. These changes and other climatic changes have affected and will continue to affect human health, water supply, agriculture, transportation, energy, coastal areas, and many other sectors of society, with increasingly adverse impacts on the American economy and quality of life.[3]

Some of the changes discussed in this report are common to many regions. For example, large increases in heavy precipitation have occurred in the Northeast, Midwest, and Great Plains, where heavy downpours have frequently led to runoff that exceeded the capacity of storm drains and levees, and caused flooding events and accelerated erosion. Other impacts, such as those associated with the rapid thawing of permafrost in Alaska, are unique to a particular U.S. region. Permafrost thawing is causing extensive damage to infrastructure in our nation's largest state.[4]

Some impacts that occur in one region ripple beyond that region. For example, the dramatic decline of summer sea ice in the Arctic – a loss of ice cover roughly equal to half the area of the continental United States – exacerbates global warming by reducing the reflectivity of Earth's surface and increasing the amount of heat absorbed. Similarly, smoke from wildfires in one location can contribute to poor air quality in faraway regions, and evidence suggests that particulate matter can affect atmospheric properties and therefore weather patterns. Major storms and the higher storm surges exacerbated by sea level rise that hit the Gulf Coast affect the entire country through their cascading effects on oil and gas production and distribution.[5]

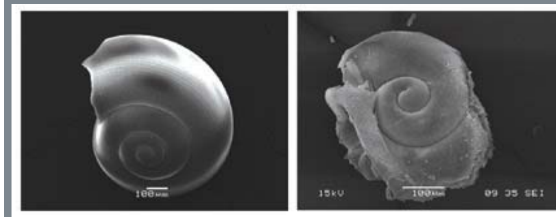
Water expands as it warms, causing global sea levels to rise; melting of land-based ice also raises sea level by adding water to the oceans. Over the past century, global average sea level has risen by about 8 inches. Since 1992, the rate of global sea level rise measured by satellites has been roughly twice the rate observed over the last century, providing evidence of acceleration. Sea level rise, combined with coastal storms, has increased the risk of erosion, storm surge damage, and flooding for coastal communities, especially along the Gulf Coast, the Atlantic seaboard, and in Alaska. Coastal infrastructure, including roads, rail lines, energy infrastructure, airports, port facilities, and military bases, are increasingly at risk from sea level rise and damaging storm surges. Sea level is projected to rise by another 1 to 4 feet in this century, although the rise in sea level in specific regions is expected to vary from this global average for a number of reasons. A wider range of scenarios, from 8 inches to more than 6 feet by 2100, has been used in risk-based analyses in this report. In general, higher emissions scenarios that lead to more warming would be expected to lead to higher amounts of sea level rise. The stakes are high, as nearly five million Americans and hundreds of billions of dollars of property are located in areas that are less than four feet above the local high-tide level.[6]

Observed Change in Very Heavy Precipitation



Percent changes in the amount of precipitation falling in very heavy events (the heaviest 1%) from 1958 to 2012 for each region. There is a clear national trend toward a greater amount of precipitation being concentrated in very heavy events, particularly in the Northeast and Midwest. (Figure source: updated from Karl et al. 2009[c]).

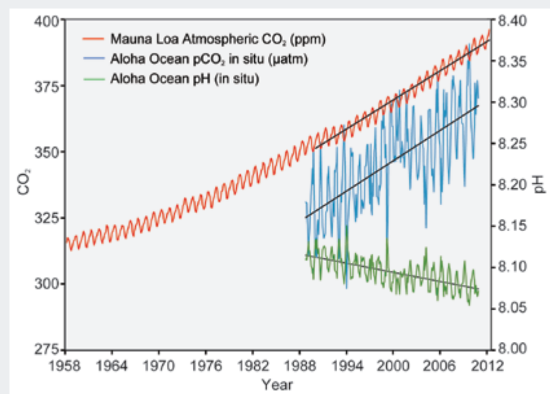
Shells Dissolve in Acidified Ocean Water



Pteropods, or "sea butterflies," are eaten by a variety of marine species ranging from tiny krill to salmon to whales. The photos show what happens to a pteropod's shell in seawater that is too acidic. On the left is a shell from a live pteropod from a region in the Southern Ocean where acidity is not too high. The shell on the right is from a pteropod in a region where the water is more acidic. (Figure source: (left) Bednaršek et al. 2012[e] (right) Nina Bednaršek).

In addition to causing changes in climate, increasing levels of carbon dioxide from the burning of fossil fuels and other human activities have a direct effect on the world's oceans. Carbon dioxide interacts with ocean water to form carbonic acid, increasing the ocean's acidity. Ocean surface waters have become 30% more acidic over the last 250 years as they have absorbed large amounts of carbon dioxide from the atmosphere. This ocean acidification makes water more corrosive, reducing the capacity of marine organisms with shells or skeletons made of calcium carbonate (such as corals, krill, oysters, clams, and crabs) to survive, grow, and reproduce, which in turn will affect the marine food chain.[7]

As Oceans Absorb CO_2 They Become More Acidic



The correlation between rising levels of carbon dioxide in the atmosphere (red) with rising carbon dioxide levels (blue) and falling pH in the ocean (green). As carbon dioxide accumulates in the ocean, the water becomes more acidic (the pH declines). (Figure source: modified from Feely et al. 2009[d]).

Widespread Impacts

Impacts related to climate change are already evident in many regions and sectors and are expected to become increasingly disruptive across the nation throughout this century and beyond. Climate changes interact with other environmental and societal factors in ways that can either moderate or intensify these impacts.

Some climate changes currently have beneficial effects for specific sectors or regions. For example, current benefits of warming include longer growing seasons for agriculture and longer ice-free periods for shipping on the Great Lakes. At the same time, however, longer growing seasons, along with higher temperatures and carbon dioxide levels, can increase pollen production, intensifying and lengthening the allergy season. Longer ice-free periods on the Great Lakes can result in more lake-effect snowfalls.

Observed and projected climate change impacts vary across the regions of the United States. Selected impacts emphasized in the regional chapters are shown below, and many more are explored in detail in this report.

Northeast	Communities are affected by heat waves, more extreme precipitation events, and coastal flooding due to sea level rise and storm surge.
Southeast and Caribbean	Decreased water availability, exacerbated by population growth and land-use change, causes increased competition for water. There are increased risks associated with extreme events such as hurricanes.
Midwest	Longer growing seasons and rising carbon dioxide levels increase yields of some crops, although these benefits have already been offset in some instances by occurrence of extreme events such as heat waves, droughts, and floods.
Great Plains	Rising temperatures lead to increased demand for water and energy and impacts on agricultural practices.
Southwest	Drought and increased warming foster wildfires and increased competition for scarce water resources for people and ecosystems.
Northwest	Changes in the timing of streamflow related to earlier snowmelt reduce the supply of water in summer, causing far-reaching ecological and socioeconomic consequences.
Alaska	Rapidly receding summer sea ice, shrinking glaciers, and thawing permafrost cause damage to infrastructure and major changes to ecosystems. Impacts to Alaska Native communities increase.
Hawai‘i and Pacific Islands	Increasingly constrained freshwater supplies, coupled with increased temperatures, stress both people and ecosystems and decrease food and water security.
Coasts	Coastal lifelines, such as water supply infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, and other climate-related changes.
Oceans	The oceans are currently absorbing about a quarter of human-caused carbon dioxide emissions to the atmosphere and over 90% of the heat associated with global warming, leading to ocean acidification and the alteration of marine ecosystems.

Sectors affected by climate changes include agriculture, water, human health, energy, transportation, forests, and ecosystems. Climate change poses a major challenge to U.S. agriculture because of the critical dependence of agricultural systems on climate. Climate change has the potential to both positively and negatively affect the location, timing, and productivity of crop, livestock, and fishery systems at local, national, and global scales. The United States produces nearly $330 billion per year in agricultural commodities. This productivity is vulnerable to direct impacts on crops and livestock from changing climate conditions and extreme weather events and indirect impacts through increasing pressures from pests and pathogens. Climate change will also alter the stability of food supplies and create new food security challenges for the United States as the world seeks to feed nine billion people by 2050. While the agriculture sector has proven to be adaptable to a range of stresses, as evidenced by continued growth in production and efficiency across the United States, climate change poses a new set of challenges.[8]

Water quality and quantity are being affected by climate change. Changes in precipitation and runoff, combined with changes in consumption and withdrawal, have reduced surface and groundwater supplies in many areas. These trends are expected to continue, increasing the likelihood of water shortages for many uses. Water quality is also diminishing in many areas, particularly due to sediment and contaminant concentrations after heavy downpours.

Increasing air and water temperatures, more intense precipitation and runoff, and intensifying droughts can decrease water quality in many ways. Here, middle school students in Colorado test water quality.

Climate change can exacerbate respiratory and asthma-related conditions through increases in pollen, ground-level ozone, and wildfire smoke.

Sea level rise, storms and storm surges, and changes in surface and groundwater use patterns are expected to compromise the sustainability of coastal freshwater aquifers and wetlands. In most U.S. regions, water resources managers and planners will encounter new risks, vulnerabilities, and opportunities that may not be properly managed with existing practices.[9]

Certain groups of people are more vulnerable to the range of climate change related health impacts, including the elderly, children, the poor, and the sick.

Climate change affects human health in many ways. For example, increasingly frequent and intense heat events lead to more heat-related illnesses and deaths and, over time, worsen drought and wildfire risks, and intensify air pollution. Increasingly frequent extreme precipitation and associated flooding can lead to injuries and increases in waterborne disease. Rising sea surface temperatures have been linked with increasing levels and ranges of diseases. Rising sea levels intensify coastal flooding and storm surge, and thus exacerbate threats to public safety during storms. Certain groups of people are more vulnerable to the range of climate change related health impacts, including the elderly, children, the poor, and the sick. Others are vulnerable because of where they live, including those in floodplains, coastal zones, and some urban areas. Improving and properly supporting the public health infrastructure will be critical to managing the potential health impacts of climate change.[10]

Climate change also affects the living world, including people, through changes in ecosystems and biodiversity. Ecosystems provide a rich array of benefits and services to humanity, including habitat for fish and wildlife, drinking water storage and filtration, fertile soils for growing crops, buffering against a range of stressors including climate change impacts, and aesthetic and cultural values. These benefits are not always easy to quantify, but they support jobs, economic growth, health, and human well-being. Climate change driven disruptions to ecosystems have direct and indirect human impacts, including reduced water supply and quality, the loss of iconic species and landscapes, effects on food chains and the timing and success of species migrations, and the potential for extreme weather and climate events to destroy or degrade the ability of ecosystems to provide societal benefits.[11]

Human modifications of ecosystems and landscapes often increase their vulnerability to damage from extreme weather events, while simultaneously reducing their natural capacity to moderate the impacts of such events. For example, salt marshes, reefs, mangrove forests, and barrier islands defend coastal ecosystems and infrastructure, such as roads and buildings, against storm surges. The loss of these natural buffers due to coastal development, erosion, and sea level rise increases the risk of catastrophic damage during or after extreme weather events. Although floodplain wetlands are greatly reduced from their historical extent, those that remain still absorb floodwaters and reduce the effects of high flows on river-margin lands. Extreme weather events that produce sudden increases in water flow, often carrying debris and pollutants, can decrease the natural capacity of ecosystems to cleanse contaminants.[12]

The climate change impacts being felt in the regions and sectors of the United States are affected by global trends and economic decisions. In an increasingly interconnected world, U.S. vulnerability is linked to impacts in other nations. It is thus difficult to fully evaluate the impacts of climate change on the United States without considering consequences of climate change elsewhere.

Response Options

As the impacts of climate change are becoming more prevalent, Americans face choices. Especially because of past emissions of long-lived heat-trapping gases, some additional climate change and related impacts are now unavoidable. This is due to the long-lived nature of many of these gases, as well as the amount of heat absorbed and retained by the oceans and other responses within the climate system. The amount of future climate change, however, will still largely be determined by choices society makes about emissions. Lower emissions of heat-trapping gases and particles mean less future warming and less-severe impacts; higher emissions mean more warming and more severe impacts. Efforts to limit emissions or increase carbon uptake fall into a category of response options known as "mitigation," which refers to reducing the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing carbon dioxide from the atmosphere.[13]

The other major category of response options is known as "adaptation," and refers to actions to prepare for and adjust to new conditions, thereby reducing harm or taking advantage of new opportunities. Mitigation and adaptation actions are linked in multiple ways, including that effective mitigation reduces the need for adaptation in the future. Both are essential parts of a comprehensive climate change response strategy. The threat of irreversible impacts makes the timing of mitigation efforts particularly critical. This report includes chapters on Mitigation, Adaptation, and Decision Support that offer an overview of the options and activities being planned or implemented around the country as local, state, federal, and tribal governments, as well as businesses, organizations, and individuals begin to respond to climate change. These chapters conclude that while response actions are under development, current implementation efforts are insufficient to avoid increasingly negative social, environmental, and economic consequences.[14]

> The amount of future climate change will still largely be determined by choices society makes about emissions.

Large reductions in global emissions of heat-trapping gases, similar to the lower emissions scenario (B1) analyzed in this assessment, would reduce the risks of some of the worst impacts of climate change. Some targets called for in international climate negotiations to date would require even larger reductions than those outlined in the B1 scenario. Meanwhile, global emissions are still rising and are on a path to be even higher than the high emissions scenario (A2) analyzed in this report. The recent U.S. contribution to annual global emissions is about 18%, but the U.S. contribution to cumulative global emissions over the last century is much higher. Carbon dioxide lasts for a long time in the atmosphere, and it is the cumulative carbon emissions that determine the amount of global climate change. After decades of increases, U.S. CO_2 emissions from energy use (which account for 97% of total U.S. emissions) declined by around 9% between 2008 and 2012, largely due to a shift from coal to less CO_2-intensive natural gas for electricity production. Governmental actions in city, state, regional, and federal programs to promote energy efficiency have also contributed to reducing U.S. carbon emissions. Many, if not most of these programs are motivated by other policy objectives, but some are directed specifically at greenhouse gas emissions. These U.S. actions and others that might be undertaken in the future are described in the Mitigation chapter of this report. Over the remainder of this century, aggressive and sustained greenhouse gas emission reductions by the United States and by other nations would be needed to reduce global emissions to a level consistent with the lower scenario (B1) analyzed in this assessment.[15]

With regard to adaptation, the pace and magnitude of observed and projected changes emphasize the need to be prepared for a wide variety and intensity of impacts. Because of the growing influence of human activities, the climate of the past is not a good basis for future planning. For example, building codes and landscaping ordinances could be updated to improve energy efficiency, conserve water supplies, protect against insects that spread disease (such as dengue fever), reduce susceptibility to heat stress, and improve protection against extreme events. The fact that climate change impacts are increasing points to the urgent need to develop and refine approaches that enable decision-making and increase flexibility and resilience in the face of ongoing and future impacts. Reducing non-climate-related stresses that contribute to existing vulnerabilities can also be an effective approach to climate change adaptation.[16]

Adaptation can involve considering local, state, regional, national, and international jurisdictional objectives. For example, in managing water supplies to adapt to a changing climate, the implications of international treaties should be considered in the context of managing the Great Lakes, the Columbia River, and the Colorado River to deal with increased drought risk. Both "bottom up" community planning and "top down" national strategies may help regions deal with impacts such as increases in electrical brownouts, heat stress, floods, and wildfires.[17]

Proactively preparing for climate change can reduce impacts while also facilitating a more rapid and efficient response to changes as they happen. Such efforts are beginning at the federal, regional, state, tribal, and local levels, and in the corporate and non-governmental sectors, to build adaptive capacity and resilience to climate change impacts. Using scientific information to prepare for climate changes in advance can provide economic opportunities, and proactively managing the risks can reduce impacts and costs over time.[18]

There are a number of areas where improved scientific information or understanding would enhance the capacity to estimate future climate change impacts. For example, knowledge of the mechanisms controlling the rate of ice loss in Greenland and Antarctica is limited, making it difficult for scientists to narrow the range of expected future sea level rise. Improved understanding of ecological and social responses to climate change is needed, as is understanding of how ecological and social responses will interact.[19]

A sustained climate assessment process could more efficiently collect and synthesize the rapidly evolving science and help supply timely and relevant information to decision-makers. Results from all of these efforts could continue to deepen our understanding of the interactions of human and natural systems in the context of a changing climate, enabling society to effectively respond and prepare for our future.[20]

The cumulative weight of the scientific evidence contained in this report confirms that climate change is affecting the American people now, and that choices we make will affect our future and that of future generations.

Cities providing transportation options including bike lanes, buildings designed with energy saving features such as green roofs, and houses elevated to allow storm surges to pass underneath are among the many response options being pursued around the country.

CLIMATE TRENDS

These two pages present the Key Messages from the "Our Changing Climate" chapter of the full report. They pertain to Report Findings 1, 2, and 3.

Global climate is changing and this change is apparent across a wide range of observations. The global warming of the past 50 years is primarily due to human activities. Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases emitted globally, and how sensitive the Earth's climate is to those emissions.

Temperature

U.S. average temperature has increased by 1.3°F to 1.9°F since record keeping began in 1895; most of this increase has occurred since about 1970. The most recent decade was the nation's warmest on record. Temperatures in the United States are expected to continue to rise. Because human-induced warming is superimposed on a naturally varying climate, the temperature rise has not been, and will not be, uniform or smooth across the country or over time.

Extreme Weather

There have been changes in some types of extreme weather events over the last several decades. Heat waves have become more frequent and intense, especially in the West. Cold waves have become less frequent and intense across the nation. There have been regional trends in floods and droughts. Droughts in the Southwest and heat waves everywhere are projected to become more intense, and cold waves less intense everywhere.

Hurricanes

The intensity, frequency, and duration of North Atlantic hurricanes, as well as the frequency of the strongest (Category 4 and 5) hurricanes, have all increased since the early 1980s. The relative contributions of human and natural causes to these increases are still uncertain. Hurricane-associated storm intensity and rainfall rates are projected to increase as the climate continues to warm.

Severe Storms

Winter storms have increased in frequency and intensity since the 1950s, and their tracks have shifted northward over the United States. Other trends in severe storms, including the intensity and frequency of tornadoes, hail, and damaging thunderstorm winds, are uncertain and are being studied intensively.

Precipitation

Average U.S. precipitation has increased since 1900, but some areas have had increases greater than the national average, and some areas have had decreases. More winter and spring precipitation is projected for the northern United States, and less for the Southwest, over this century.

Heavy Downpours

Heavy downpours are increasing nationally, especially over the last three to five decades. Largest increases are in the Midwest and Northeast. Increases in the frequency and intensity of extreme precipitation events are projected for all U.S. regions.

Frost-free Season

The length of the frost-free season (and the corresponding growing season) has been increasing nationally since the 1980s, with the largest increases occurring in the western United States, affecting ecosystems and agriculture. Across the United States, the growing season is projected to continue to lengthen.

Ice Melt

Rising temperatures are reducing ice volume and surface extent on land, lakes, and sea. This loss of ice is expected to continue. The Arctic Ocean is expected to become essentially ice free in summer before mid-century.

Sea Level

Global sea level has risen by about 8 inches since reliable record keeping began in 1880. It is projected to rise another 1 to 4 feet by 2100.

Ocean Acidification

The oceans are currently absorbing about a quarter of the carbon dioxide emitted to the atmosphere annually and are becoming more acidic as a result, leading to concerns about intensifying impacts on marine ecosystems.

REPORT FINDINGS

These findings distill important results that arise from this National Climate Assessment. They do not represent a full summary of all of the chapters' findings, but rather a synthesis of particularly noteworthy conclusions.

1. Global climate is changing and this is apparent across the United States in a wide range of observations. The global warming of the past 50 years is primarily due to human activities, predominantly the burning of fossil fuels.

Many independent lines of evidence confirm that human activities are affecting climate in unprecedented ways. U.S. average temperature has increased by 1.3°F to 1.9°F since record keeping began in 1895; most of this increase has occurred since about 1970. The most recent decade was the warmest on record. Because human-induced warming is superimposed on a naturally varying climate, rising temperatures are not evenly distributed across the country or over time.[21]

2. Some extreme weather and climate events have increased in recent decades, and new and stronger evidence confirms that some of these increases are related to human activities.

Changes in extreme weather events are the primary way that most people experience climate change. Human-induced climate change has already increased the number and strength of some of these extreme events. Over the last 50 years, much of the United States has seen an increase in prolonged periods of excessively high temperatures, more heavy downpours, and in some regions, more severe droughts.[22]

3. Human-induced climate change is projected to continue, and it will accelerate significantly if global emissions of heat-trapping gases continue to increase.

Heat-trapping gases already in the atmosphere have committed us to a hotter future with more climate-related impacts over the next few decades. The magnitude of climate change beyond the next few decades depends primarily on the amount of heat-trapping gases that human activities emit globally, now and in the future.[23]

4. Impacts related to climate change are already evident in many sectors and are expected to become increasingly disruptive across the nation throughout this century and beyond.

Climate change is already affecting societies and the natural world. Climate change interacts with other environmental and societal factors in ways that can either moderate or intensify these impacts. The types and magnitudes of impacts vary across the nation and through time. Children, the elderly, the sick, and the poor are especially vulnerable. There is mounting evidence that harm to the nation will increase substantially in the future unless global emissions of heat-trapping gases are greatly reduced.[24]

5. Climate change threatens human health and well-being in many ways, including through more extreme weather events and wildfire, decreased air quality, and diseases transmitted by insects, food, and water.

Climate change is increasing the risks of heat stress, respiratory stress from poor air quality, and the spread of waterborne diseases. Extreme weather events often lead to fatalities and a variety of health impacts on vulnerable populations, including impacts on mental health, such as anxiety and post-traumatic stress disorder. Large-scale changes in the environment due to climate change and extreme weather events are increasing the risk of the emergence or reemergence of health threats that are currently uncommon in the United States, such as dengue fever.[25]

6. Infrastructure is being damaged by sea level rise, heavy downpours, and extreme heat; damages are projected to increase with continued climate change.

Sea level rise, storm surge, and heavy downpours, in combination with the pattern of continued development in coastal areas, are increasing damage to U.S. infrastructure including roads, buildings, and industrial facilities, and are also increasing risks to ports and coastal military installations. Flooding along rivers, lakes, and in cities following heavy downpours, prolonged rains, and rapid melting of snowpack is exceeding the limits of flood protection infrastructure designed for historical conditions. Extreme heat is damaging transportation infrastructure such as roads, rail lines, and airport runways.[26]

7. Water quality and water supply reliability are jeopardized by climate change in a variety of ways that affect ecosystems and livelihoods.

Surface and groundwater supplies in some regions are already stressed by increasing demand for water as well as declining runoff and groundwater recharge. In some regions, particularly the southern part of the country and the Caribbean and Pacific Islands, climate change is increasing the likelihood of water shortages and competition for water among its many uses. Water quality is diminishing in many areas, particularly due to increasing sediment and contaminant concentrations after heavy downpours.[27]

8. Climate disruptions to agriculture have been increasing and are projected to become more severe over this century.

Some areas are already experiencing climate-related disruptions, particularly due to extreme weather events. While some U.S. regions and some types of agricultural production will be relatively resilient to climate change over the next 25 years or so, others will increasingly suffer from stresses due to extreme heat, drought, disease, and heavy downpours. From mid-century on, climate change is projected to have more negative impacts on crops and livestock across the country – a trend that could diminish the security of our food supply.[28]

REPORT FINDINGS

9. Climate change poses particular threats to Indigenous Peoples' health, well-being, and ways of life.

Chronic stresses such as extreme poverty are being exacerbated by climate change impacts such as reduced access to traditional foods, decreased water quality, and increasing exposure to health and safety hazards. In parts of Alaska, Louisiana, the Pacific Islands, and other coastal locations, climate change impacts (through erosion and inundation) are so severe that some communities are already relocating from historical homelands to which their traditions and cultural identities are tied. Particularly in Alaska, the rapid pace of temperature rise, ice and snow melt, and permafrost thaw are significantly affecting critical infrastructure and traditional livelihoods.[29]

10. Ecosystems and the benefits they provide to society are being affected by climate change. The capacity of ecosystems to buffer the impacts of extreme events like fires, floods, and severe storms is being overwhelmed.

Climate change impacts on biodiversity are already being observed in alteration of the timing of critical biological events such as spring bud burst and substantial range shifts of many species. In the longer term, there is an increased risk of species extinction. These changes have social, cultural, and economic effects. Events such as droughts, floods, wildfires, and pest outbreaks associated with climate change (for example, bark beetles in the West) are already disrupting ecosystems. These changes limit the capacity of ecosystems, such as forests, barrier beaches, and wetlands, to continue to play important roles in reducing the impacts of these extreme events on infrastructure, human communities, and other valued resources.[30]

11. Ocean waters are becoming warmer and more acidic, broadly affecting ocean circulation, chemistry, ecosystems, and marine life.

More acidic waters inhibit the formation of shells, skeletons, and coral reefs. Warmer waters harm coral reefs and alter the distribution, abundance, and productivity of many marine species. The rising temperature and changing chemistry of ocean water combine with other stresses, such as overfishing and coastal and marine pollution, to alter marine-based food production and harm fishing communities.[31]

12. Planning for adaptation (to address and prepare for impacts) and mitigation (to reduce future climate change, for example by cutting emissions) is becoming more widespread, but current implementation efforts are insufficient to avoid increasingly negative social, environmental, and economic consequences.

Actions to reduce emissions, increase carbon uptake, adapt to a changing climate, and increase resilience to impacts that are unavoidable can improve public health, economic development, ecosystem protection, and quality of life.[32]

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U.S. National Climate Assessment

This report summarizes the impacts of climate change on the United States, now and in the future.

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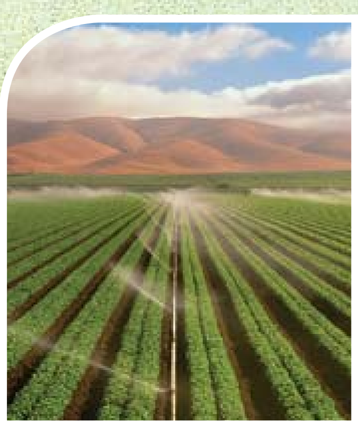


Reference material for CATF January 26, 2016 meeting.
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Climate Change in the Northwest

Implications for Our Landscapes, Waters, and Communities

Executive Summary

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Executive Summary

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Chapter 1 Introduction: The Changing Northwest

The Northwest's climatic, ecological, and socioeconomic diversity set the stage for a diverse array of climate impacts, many of which will be united by their dependence on availability of water and other natural resources. (Section 1.1)

Nestled between the Pacific Ocean and the Rocky Mountains, the Northwest (NW, fig. 1.1) experiences relatively wet winters and dry summers, with locations west of the Cascade Range considerably wetter than the sometimes desert-like conditions on the east side. In addition, the thousands of miles of NW coastline support a variety of coastal environments. On the whole, the Northwest's diverse climate and landscape make it one of the most ecologically rich areas in the United States, a feature that has been integral to sustaining the region's economy, culture, and way of life. NW tribes have cultural, social,

Figure 1.1 The Northwest, comprising the states of Washington, Oregon and Idaho and including the Columbia River basin (shaded).

and spiritual traditions that are inseparable from the landscape and environmental conditions on and beyond reserved tribal lands. The region's water resources and seasonality of snow accumulation and melt shape the migration of iconic salmon and steelhead; growth and distribution of forests; and availability of water for drinking, irrigation, and hydropower production, among many other uses. Land ownership, population distribution, economic and cultural dependence on natural resources, current ecological conditions, and patterns of resource use will substantially shape the regional and local consequences of a changing climate.

Key regionally consequential risks in the Northwest include impacts of warming on watersheds where snowmelt is important, coastal consequences of sea level rise combined with other stressors, and the cumulative effects of fire, insects, and disease on forest ecosystems. (Section 1.2)

This report focuses on the major drivers of regional climate change and impacts on systems of high regional and local importance. Three key issues of concern were identified through a qualitative risk assessment that evaluated the relative likelihood and consequences of climate change impacts for the region's economy, infrastructure, natural systems, and human health. These are: impacts of warming on snow accumulation and melt and their effects on regional hydrology and related systems; coastal consequences of sea level rise combined with other drivers of change, including river flooding, coastal storms and changes in the coastal ocean, and the cumulative effects of climate change on fire, insects, and tree diseases in forest ecosystems. In addition to these three risk areas, this report focuses on three climate-sensitive sectors of regional importance: agriculture, human health, and NW tribes. Regionally-identified risks are complemented with discussion of locally-specific risks and vulnerabilities.

This assessment of climate change in the Northwest reveals a familiar story of climate impacts, but highlights new details at multiple scales considering multiple interacting drivers of change and vulnerabilities resulting from human choices throughout time. (Section 1.3.1)

The findings presented in this report largely confirm over fifteen years of research, but add new details regarding how impacts are likely to vary across the region. Analyzing climate impacts at local to regional scales and how impacts vary between natural and managed systems is essential to ensure a complete picture of projected climate impacts on the region and development of appropriate adaptive responses. Considering multiple drivers of change and their interactions is also necessary as some of the largest impacts can occur when multiple drivers align and some individual drivers of change can offset each other. Past and present human choices and actions are a large determinant of current social and ecological vulnerability to climate; understanding these causal linkages and adjusting relevant choices and actions could help reduce future climate vulnerability.

The Northwest has been a leader in applied regional climate impacts science since the 1990s, and the region's resource managers, planners, and policy makers have been early engagers in climate change issues. This report provides a solid foundation for

identifying challenges posed by climate change in order to assist adaptation efforts throughout the region. (Section 1.3.2)

Climate change adaptation focuses on adjusting existing practices in order to reduce negative consequences and take advantage of opportunities. Adaptation begins with identifying and characterizing the problem posed by climate change, a goal this report aims to serve. It then proceeds with identifying, assessing, and selecting alternative actions, and ultimately implementing, monitoring, and evaluating the selected actions. Many federal, state, local, and tribal entities in the Northwest are already engaged in various stages of climate change adaptation, including state-level climate change response strategies; however, adaptation is not yet wide-spread and few efforts have moved beyond planning to implementation.

Chapter 2 Climate: Variability and Change in the Past and the Future

Variations in solar output, volcanic eruptions, and changes in greenhouse gases all contribute to the energy balance at the top of the atmosphere, which influences global surface temperature fluctuations and changes over time. (Section 2.1)

Global surface temperature is governed by the balance at the top of the atmosphere between incoming and reflected solar radiation and outgoing infrared radiation, or heat, radiated from the Earth. Clouds and certain gases in the atmosphere (e.g., water vapor, CO_2, methane, ozone, etc.) absorb some of Earth's radiated energy reducing the amount escaping to space. Changes in these infrared–absorbing gases (or more commonly, greenhouse gases) force a change in the energy balance of the climate system, with CO_2 changes being the dominant factor. Other important factors include changes in solar output and volcanic eruptions. Variations in solar output are partially responsible for changes in the past climate, but play a small role in climate changes today. Large volcanic eruptions act to cool the Earth for a few years afterward as tiny sunlight-reflecting particles spread throughout the upper atmosphere.

Climate variability and change in the Northwest is influenced by both global and local factors, such as the El Niño-Southern Oscillation and mountain ranges. (Section 2.2)

More important than global changes in the Earth's energy balance for understanding regional and local climate variability and change are the natural variability of atmospheric and ocean circulation and effects of local topography. NW climate variability is dominated by the interaction between the atmosphere and ocean in the tropical Pacific Ocean responsible for El Niño and La Niña. During El Niño, winter and spring in the Northwest have a greater chance of being warmer and drier than normal. The complex topography of the Northwest, which includes the Coast, Cascade, and Rocky Mountain ranges, results in large changes in temperature and precipitation over relatively short distances.

During 1895–2011, the Northwest warmed approximately 0.7 °C (1.3 °F) while precipitation fluctuated with no consistent trend. (Section 2.2)

For the last 30 years, temperatures averaged over the Northwest have generally exceeded the 20th century average. During 1895–2011, the Northwest warmed by about 0.7 °C (1.3 °F). Year-to-year fluctuations in precipitation averaged over the Northwest have been slightly larger since 1970 compared with the previous 75 years, with some of the wettest and driest years occurring in the most recent 40 years. However, there has not been a clear overall increase or decrease in average precipitation over the 20th century. The observed changes in temperature include contributions from both natural climate variability and human influences. Seasonal trends in temperature, while influenced by fluctuations in atmospheric circulation patterns, are consistent with expected changes from human activities.

The frequency of extreme high nighttime minimum temperatures increased in the Northwest during 1901–2009, but observed changes in extreme precipitation are ambiguous. (Section 2.3)

Confidently detecting changes in extreme events is challenging. During 1901–2009, the number of extreme high nighttime minimum temperatures increased in the Northwest, but other extreme temperature measures showed no clear change. Observed changes in extreme precipitation are ambiguous in most areas, with some increases and some decreases, and depend on the specific type of extreme precipitation event examined. Changes are most pronounced in western Washington where most measures show increases of 10–20%.

State-of-the-art global and regional climate modeling provides a consistent basis for understanding projections of future climate and related impacts in the Northwest. (Section 2.4)

Coordinated global and regional climate modeling approaches provide a framework for understanding uncertainty associated with model projections of future climate. Three such modeling frameworks are the Coupled Model Intercomparison Project phases 3 and 5 (CMIP3/5), the North American Regional Climate Change Assessment Program (NARCCAP), and regional climateprediction.net (regCPDN) with spatial resolutions ranging from 300 to 25 km (186 to 15 mi). All three datasets are generally consistent in the broad story of projected future NW climate.

The Northwest is expected to experience an increase in temperature year-round with more warming in summer and little change in annual precipitation, with the majority of models projecting decreases for summer and increases during the other seasons. (Section 2.4.1)

Over the period from 1950–1999 to 2041–2070, CMIP5 models project NW mean annual warming of 1.1 °C to 4.7 °C (2 °F to 8.5 °F), with the lower end possible only if greenhouse gas emissions are significantly reduced (RCP4.5 scenario; fig. 2.5 *a*). All models project warming of at least 0.5 °C (0.9 °F) in every season. Projected warming is greater during the summer with increases ranging from 1.9 °C to 5.2 °C (3.4 °F to 9.4 °F) for the very high growth scenario (RCP8.5). Annual average precipitation is projected to change by about +3% with individual models ranging from –4.7% to +13.5%. For every season, some models project decreases and others increases, although for summer more models project decreases than increases, with the largest projected change of about –30%

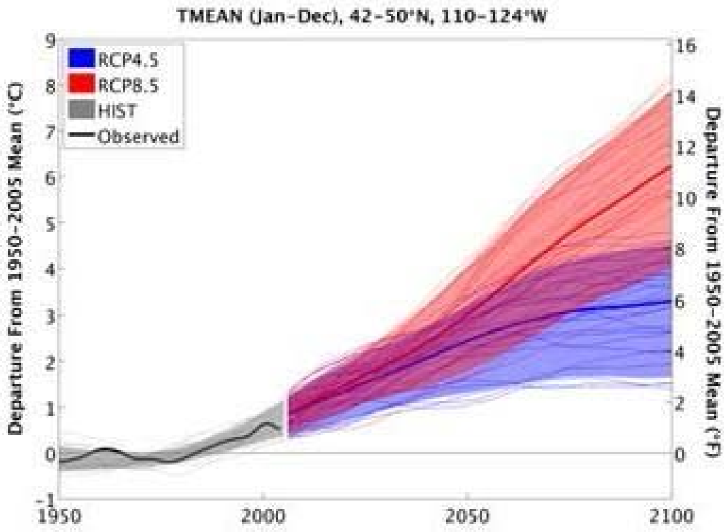

Figure 2.5. (a) Observed (1950–2011) and simulated (1950–2100) regional mean annual temperature for selected CMIP5 global models for the RCP4.5 and RCP8.5 scenarios.

by 2041–2070. In addition, the models that project the largest warming in summer also tend to project the largest precipitation decreases.

Measures of temperature and precipitation extremes are projected to increase in the Northwest. (Section 2.4.2)

Climate models are unanimous that measures of heat extremes will increase and measures of cold extremes will decrease. Averaged over the Northwest, NARCCAP results project that in the period averaged over 2041 to 2070 there will be more days above maximum temperature thresholds and fewer days below minimum temperature thresholds compared with the 1971–2000 average. For example, the number of days greater than 32 °C (90 °F) increases by 8 days (± 7), and the number of days below freezing decreases by 35 days (± 6). Future changes in precipitation extremes are more certain than changes in total seasonal precipitation. The number of days with greater than 1 in (2.5 cm) of precipitation is projected to increase by 13% (± 7%) and the 20-year and 50-year return period extreme precipitation events are projected to increase 10% (-4 to +22%) and 13% (-5 to +28%), respectively, by mid-century.

Chapter 3 Water Resources: Implications of Changes in Temperature and Precipitation

Changes in precipitation and increasing air temperatures are already having, and will continue to have, significant impacts on hydrology and water resources in the Northwest. (Section 3.1)

Such climate changes will alter streamflow magnitude and timing, water temperatures, and water quality. Hydrologic impacts will vary by watershed type. Snow-dominant watersheds are projected to shift toward mixed rain-snow conditions, resulting in earlier and reduced spring peak flow, increased winter flow, and reduced late-summer flow; mixed rain-snow watersheds are projected to shift toward rain-dominant conditions; and rain-dominant watersheds could experience higher winter streamflows if winter precipitation increases, but little change in streamflow timing (fig. 3.3). Such hydrologic impacts have important consequences for reservoir systems, hydropower production, irrigated agriculture, floodplain and municipal drinking water infrastructure, freshwater aquatic ecosystems, and water-dependent recreation.

Reduced snowpack and shifts in streamflow seasonality due to climate change pose an additional challenge to reservoir system managers as they strive both to minimize flood risk and to satisfy warm season water demands. (Section 3.2.1)

Reservoir systems in the Northwest rely heavily on the ability of snowpack to act as additional water storage. During the snowmelt season, reservoir managers face the challenge of simultaneously maximizing water storage for summer water supply and maintaining sufficient space for capturing floodwaters to minimize downstream flood risk. Earlier snowmelt and peak flow means that more water will run off when it is not needed for human uses and that less water will be available to help satisfy early summer water demand. Flood risk may decrease in some basins and will likely increase in others.

The Columbia River Basin, whose reservoir storage capacity is much smaller than its annual flow volume, is ill-equipped to handle the projected shift to earlier snowmelt and peak flow timing and will likely be forced to pass much of these earlier flows out of the system, under current operating rules. With reservoir drawdown starting earlier in the year, managers would be faced with complex tradeoffs between multiple objectives; namely, hydropower, irrigation, instream flow augmentation for fish, and flood control.

Due to earlier peak streamflow, summer hydropower generation is projected to decline, but winter hydropower generation may increase. (Section 3.3.2)

Hydropower production provides two-thirds of the region's electricity and the Northwest produces 40% of all US hydropower. The shifts in streamflow timing caused by reduced snowpack and earlier snowmelt will reduce the opportunity for hydropower generation in the late spring and summer. In one study, summer hydropower production is projected to decline by about 15% by 2040, while winter hydropower production may

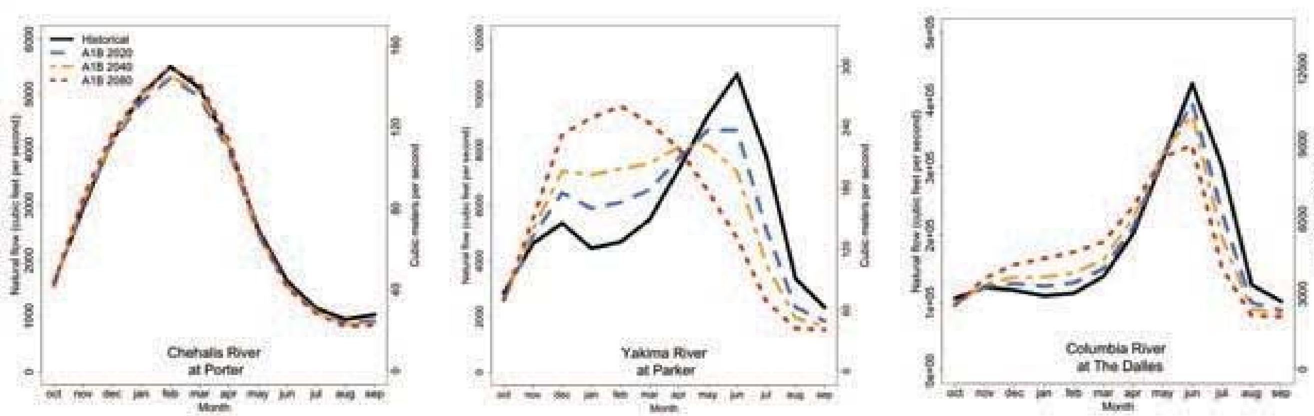

Figure 3.3. Simulated monthly streamflow hydrographs for the historical baseline (1916–2006 average, black) and the 2020s (blue), 2040s (yellow), and 2080s (red) under the SRES-A1B scenario of continued emissions growth peaking at mid-century (after Elsner et al. 2010) for three representative watershed types in the Northwest, namely rain dominant (Chehalis River at Porter, *top*), mixed rain-snow (Yakima River at Parker, *center*), and snowmelt dominant (Columbia River at The Dalles, *bottom*).

slightly increase (4%) compared to 1917–2006 levels. Further reductions in hydropower generation may also result from climate change adaptation for other competing water management objectives; for example, flood control and instream flow augmentation for fish.

Reduced water supply combined with increased water demands in the summer could lead to water shortages, reducing the proportion of irrigable cropland and the value of agricultural production. (Section 3.3.1)

Irrigated agriculture is the largest consumptive water user in the Columbia River Basin and poses the greatest demands on regional reservoir systems. Warmer, drier summers and a longer growing season may increase those demands. A case study in the Yakima River Basin projects the more frequent occurrence of conditions in which senior water right holders experience shortage. Water shortages could impact the proportion of cropland able to be irrigated during the growing season and lead to substantially reduced value of agricultural production; however, certain producer strategies may mitigate the shortage. Some evidence also suggests that increased atmospheric CO_2 concentrations may benefit water use efficiency in plants, possibly mitigating potential effects of drought.

Floodplain and municipal water supply infrastructure are vulnerable to projected increases in extreme precipitation and flood risk. (Section 3.3.3, 3.3.4)

Increases in extreme precipitation and flooding are expected, though changes in flood risk depend on the type of basin. Warmer winter temperatures and increased precipitation variability have already increased winter flood risk in mixed rain-snow basins in Washington and Oregon. Developed areas in floodplains may be particularly vulnerable to the increased flood risk, depending on flood control capacity. Water management may be stressed also by more frequent temperature extremes, warmer stream temperatures, lower summer flows, and the projected increase in municipal water demands. State and local government agencies in the Northwest are building strategies to address issues around how climate and hydrological change affects municipal water supply and use.

Changes in hydrologic flow regimes and warming stream and lake temperatures pose significant threats to aquatic ecosystems and are expected to alter key habitat conditions for salmon and other aquatic species. (Section 3.3.5)

Hydrologic changes in streamflow may harm the spawning and migration of salmon and trout species. Continued warming of stream and lake temperatures may also affect the health of and the extent of suitable habitat for many other aquatic species. Salmonids and other species that currently live in conditions near the upper range of their thermal tolerance are particularly vulnerable to higher stream temperatures, increasing susceptibility to disease and rates of mortality. Upstream migration for thermally-stressed species may be impeded by changes in channel structure from altered low-flow regimes. Reduced glacier area and volume over the long-term, which is projected for the future in the North Cascades, may challenge Pacific salmonids in those streams in which glacier melt comprises a significant portion of streamflow, although the consequences of glacial loss are not well quantified.

Water-dependent recreational activities will be affected by dry conditions, reduced snowpack, lower summer flows, impaired water quality, and reduced reservoir storage. (Section 3.3.6)

The sport fishing industry is likely to be affected by climate change effects on native fish including Pacific salmon. Mid-elevation ski resorts, located near the freezing elevation, will be the most sensitive to decreased snow, increased rain, and earlier spring snowmelt. The shortened ski-season will not only affect skiers, but the livelihood of local communities that are dependent on snow-recreation.

Chapter 4 Coasts: Complex Changes Affecting the Northwest's Diverse Shorelines

Sea level along the Northwest coast is projected to rise 4–56″ (9–143 cm) by 2100, with significant local variations. (Section 4.2)

Global mean sea level rose 0.12 in/year (3.1 mm/year) during 1993–2012, and there is high confidence that global sea level will continue to rise throughout the 21st century and beyond. Many local and regional factors modify the global trend in the Northwest. The active tectonics underlying western Oregon and Washington cause uplift in some locations, such as the Olympic Peninsula, at nearly the same rate as sea level rise resulting in little observed local sea level change, whereas subsidence in other locations leads to larger local sea level rise. End-of-the-century sea level rise projections along the NW coast range from 4 to 56 in (9–143 cm) relative to the year 2000, with variation in local factors adding to or subtracting from this range in different locations. Increasing wave heights in recent decades may have been a dominant factor in the observed increased frequency of coastal flooding along the outer coast. Regional sea levels can rise up to 12 in (30.5 cm) during an El Niño event, compounding impacts of sea level rise, but it is unknown whether and how El Niño-Southern Oscillation (ENSO) intensity and frequency may change in the future.

Increasingly acidified waters hinder the ability of some marine organisms to build shells and skeletons, which could alter key ecological processes, threatening our coastal marine ecosystems, fisheries, and aquaculture. (Sections 4.3, 4.5.3)

Anthropogenic additions of CO_2, seasonal coastal upwelling, and inputs of nutrients and organic matter combine to produce some of the most acidified marine waters worldwide along our coast; conditions in estuaries can reduce pH even further. Decreased abundance of shell forming species, many of which are highly vulnerable to ocean acidification, may alter the abundance and composition of other marine species. A simulation of ocean acidification impacts on the shelled species at the base of the marine food web resulted in a 20–80% decline of commercially important groundfish such as English sole. The rate at which mussels and oysters form shells is projected to decline by 25% and 10%, respectively, by the end of the century, and oyster larval growth rates are slower under low pH levels. Some species, such as sea grasses, may actually benefit from increased ocean acidification. Because of the serious implications of ocean acidification for marine species, several recent research initiatives have focused on identifying the impacts of ocean acidification in the Northwest.

Ocean temperatures off the Northwest coast have increased in the past and, though highly variable, are likely to increase in the future, causing shifts in distribution of marine species and contributing to more frequent harmful algal blooms. (Sections 4.4, 4.5.2)

Future increases in ocean temperature will continue to be highly variable and will affect the distribution of marine species found in NW coastal waters. Cooling of the eastern equatorial Pacific and ENSO-related changes in wind over the North Pacific may moderate warming of the northeast Pacific. Near coastal sea surface temperature (SST) varies by about 4–6 °C (7–11 °F) annually and is influenced by local coastal upwelling and downwelling and other weather and oceanographic-related factors. The range and abundance of Pacific Coast marine fish, birds, and mammals vary from year-to-year and serve as important indicators for potential fish species' responses to future climate change. For example, Pacific mackerel and hake are drawn to warmer coastal waters during El Niño events. One study found that long-term climate change, rather than climate variability, was the predominant factor in observed changes in the breeding and abundance of several seabird species in the California Current System. Blue whale and California sea lion habitats are projected to decrease over the 21st century, while northern elephant seal habitat is projected to increase. Increases in SST also contribute to more frequent and extended incidences of harmful algal blooms, increasing risks associated with paralytic shellfish toxins.

Coastal marine ecosystems in the Northwest provide important habitat for a diverse range of species. Coastal changes, such as sea level rise, erosion, and saltwater intrusion, could lead to loss or decline of some habitats, with impacts varying along the coast. (Section 4.5.1, Fig. 4.2.b)

Coastal wetlands, tidal flats, and beaches in low-lying areas with limited opportunity to move upslope (either by migrating inland or directly upwards by accumulating sediment) are highly vulnerable to sea level rise and coastal erosion, threatening the loss of key habitats and supported species. Significant beach erosion has occurred in north-central Oregon, where local sea levels have been rising, whereas southern Oregon beaches, where local sea levels have not risen, are relatively stable. Beach erosion increasingly exposes upland habitat to extreme tides and storm surges, affecting, for example, haul-out sites used by harbor seals for resting, breeding, and rearing pups. Coastal freshwater marsh and swamp habitats are projected to convert to salt or transitional marsh due to increasing saltwater inundation, reducing the extent of tidal flats and estuarine and outer coast beaches and affecting associated species, such as shorebirds and forage fish. Sea level rise could reduce the extent of certain coastal marshes and riparian habitat used by juvenile Chinook salmon as they transition between freshwater and ocean life stages. Potential increases in surface and groundwater salinity, due to sea level rise, may affect coastal plant and animal species unable to tolerate such increases. Some coastal habitats may be able to accommodate moderate rates of sea level rise by migrating inland, provided that there are no barriers such as dikes and seawalls.

Sea level rise and flooding will affect Northwest coastal transportation infrastructure, though the degree of potential impacts will vary. (Section 4.6.1)

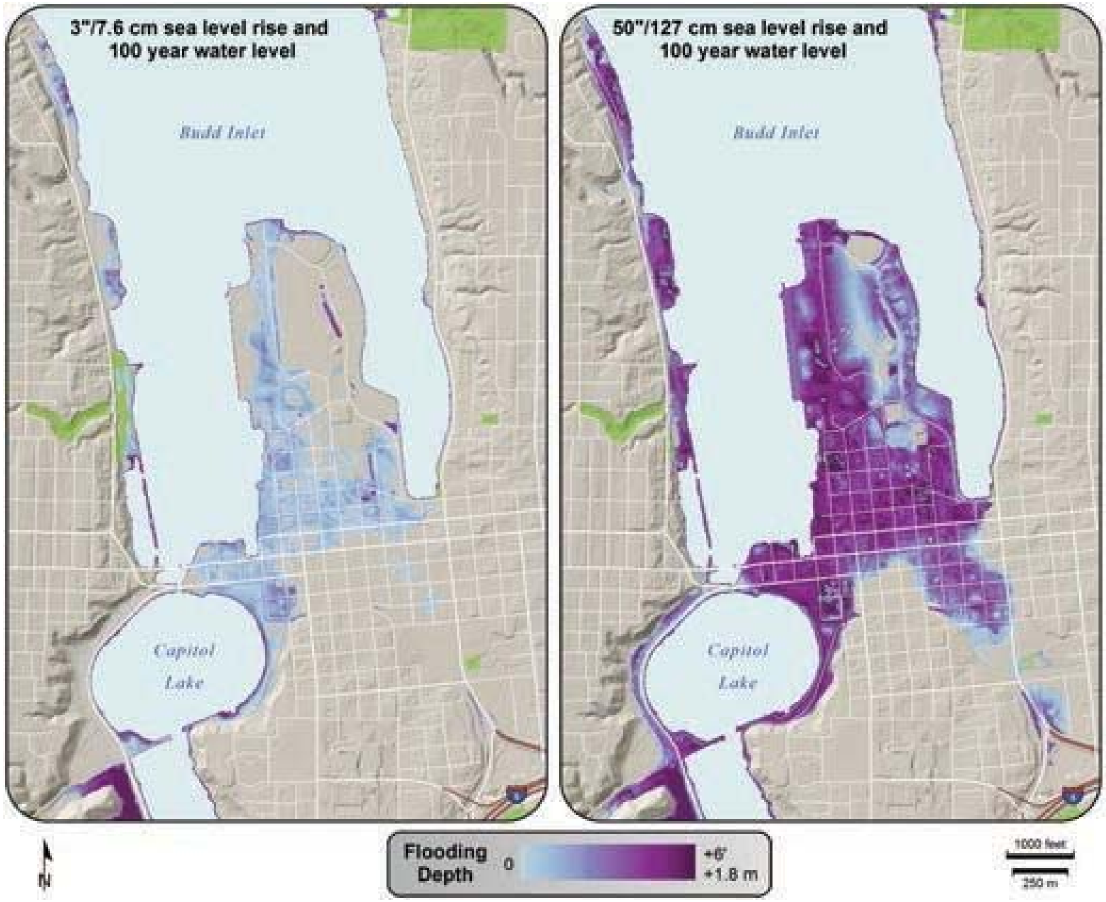

Figure 4.6 Projected flooding of downtown Olympia with a 100-year water level and 127 cm (50 in) of sea level rise. Redrawn from Coast and Harbor Engineering (2011).

About 2800 miles of roads in Washington and Oregon coastal counties are in the 100-year floodplain. The Washington State Department of Transportation assessed the climate change vulnerability of state-owned transportation infrastructure, identifying some outer coast and low-lying highways near Puget Sound that may face long-term inundation from 2 ft (0.6 m) of sea level rise. Most major state highways in Washington are situated high enough to experience only temporary closures. Highways near the mouth of the Columbia River near Astoria, Oregon, are also at risk. Inundation of low-lying secondary transportation routes in many coastal areas of the Northwest will very likely worsen and has the potential to temporarily cut off access to some communities during high tide and storm events.

Northwest coastal cities face multiple climate impacts and risks, including sea level rise, erosion, and flooding. Some local governments are evaluating and preparing for climate-related risks and vulnerabilities. (Section 4.6.2, Box 4.1)

The City of Seattle is assessing the vulnerability of its infrastructure to sea level rise and storm surge and is developing adaptation options. The City of Olympia is similarly examining areas of future exposure to inundation in the downtown core under various sea level rise and creek flooding scenarios (fig. 4.6), examining engineering and regulatory responses, and incorporating sea level rise response in their comprehensive planning process. The City of Anacortes has examined risks to their water treatment facility from projected increases in river flooding and resultant increases in sediment loading. The Swinomish Indian Tribal Community has examined a wide range of climate vulnerabilities and corresponding adaptation strategies and is incorporating assessment findings into ongoing regulatory and economic development efforts.

Climate driven changes in ocean conditions may have important economic impacts on marine fisheries, including shellfish aquaculture and fish landings. (Section 4.7.1)

Marine and coastal resources, particularly marine fisheries, provide communities in the Northwest with numerous economic benefits. The response of fish species to climate change will vary, so there may be both positive and negative economic impacts on commercial and recreational fisheries. Shellfish aquaculture, which provides many jobs and 49% and 72% of the commercial fishing landing value in Oregon and Washington, respectively, is threatened by ocean acidification. Climate–driven changes in the distribution, abundance, and productivity of key commercial species in Oregon and Washington could impact landings and revenues, which averaged around $275 million per year from 2000 to 2009.

Chapter 5 Forest Ecosystems: Vegetation, Disturbance, and Economics

The spatial distribution of suitable climate for many important Northwest tree species and vegetation types may change considerably by the end of the 21st century, and some vegetation types, such as subalpine forests, will probably become extremely limited. (Section 5.2)

Climate change is likely to affect the distribution, growth, and function of NW forests. Tree growth responses to future climate change will vary both within the region and in time with climate variability, but some locations are likely to experience higher growth (e.g., higher elevations) whereas other areas are likely to experience reduced growth (e.g., the lower elevation eastern parts of the Cascade Range). Forests limited by water availability will likely experience longer, more severe water-limitation under projected warming and reduced warm-season precipitation, resulting in decreased tree growth. Forests limited by energy or temperature will likely experience increased growth, depending on water availability. Area climatically favorable for Douglas-fir is projected to decrease by 32% by the 2060s in Washington in one study, but another study suggests that Douglas-fir may be able to balance loss of climate suitability at lower elevations with increases at higher elevations. Sub-alpine tree species are projected to decline and have limited potential to migrate upslope, resulting in potential loss of these high-elevation habitats, affecting associated wildlife and biodiversity. Vulnerability to disturbances is expected to increase in most forests.

Grasslands in some areas may expand under warmer and drier conditions, while sagebrush steppe habitat may transition to other vegetation (woodland or even forest)

depending on the amount and seasonality of precipitation change. Increased fire activity and expansion of invasive species will also determine the response of these systems to climate change. (Box 5.1)

Grassland and shrubland systems have already declined through land use and management changes, and the effect of future climate change will vary. Grass-dominated prairies and oak savannas in western parts of the Northwest are adapted to periodic drought and may expand under future warmer and drier conditions. Sagebrush steppe systems and associated species are sensitive to altered precipitation patterns and may decline, being replaced by woodland and forest vegetation. Expansion of new and current invasive species, both native (e.g., western juniper) and non-native (e.g., yellow starthistle), will influence the response of grassland and shrubland systems to climate change. Many grassland and shrubland systems are adapted to frequent fires, but projected increases in future fire activity threaten fire intolerant shrubs and the greater sage-grouse that depend on them for feeding, nesting, and protection.

The cumulative effects of climate change on disturbances (fire, insects, tree disease), and the interactions between them, will dominate changes in forest landscapes over the coming decades. (Sections 5.3, 5.3.4)

Large areas have been affected by disturbances in recent years (fig. 5.7), and climate change is expected to increase the probability of disturbance. The interaction between multiple disturbances (insect or disease outbreaks and wildfires) will heighten impacts on forests. The forests that establish after disturbance will depend on disturbance, climate, and other conditions that affect forest processes, though cumulative effects will vary. At least in the first half of the 21st century, climate change impacts on plant productivity, life history, and distribution are likely to be secondary to disturbance in terms of the area affected and risk presented to human values via altered forest ecosystem services.

Fire activity in the Northwest is projected to increase in the future in response to warmer and drier summers that reduce the moisture of existing fuels, facilitating fire. One study estimated that the regional area burned per year will increase by roughly 900 sq. mi. by the 2040s. (Section 5.3.1)

Climate influences both vegetation growth prior to the fire season and short-term vegetation moisture during the fire season, which influence fire-season activity. Fire activity in most NW forests tends to increase with higher summer temperature and lower summer precipitation. In one study, regional area burned is projected to increase by 0.3, 0.6, and 1.5 million acres by the 2020s, 2040s, and 2080s, respectively. Years with abnormally high area burned may become more frequent in the future: the chance of a given year being what was historically a "high" fire year is projected to increase by up to 30% for non-forested systems, 19% for the western Cascade Range, and 76% for the eastern Cascade Range. Greater fire severity is expected as increases in extreme events, particularly droughts and heat waves, will likely increase fire activity in the Northwest.

Recent mountain pine beetle and other insect outbreaks were facilitated by higher-than-average temperatures and drought stress, and the frequency and area of such

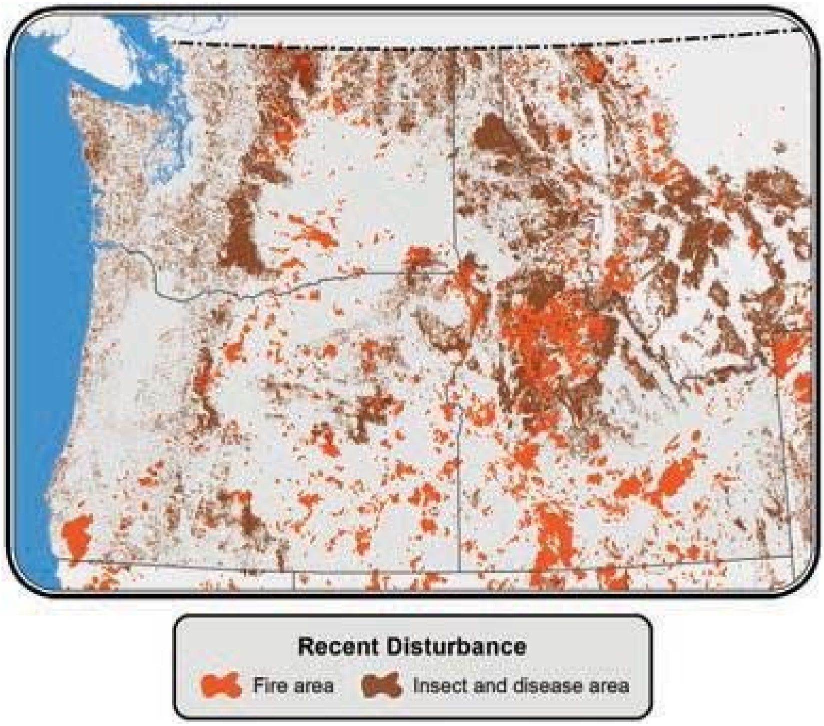

Figure 5.7. Areas of recent fire and insect disturbance in the Northwest.

outbreaks is expected to increase, particularly in high-elevation forests. Certain forest diseases, such as Swiss needle cast in Douglas-fir, are also expected to increase in the future. (Sections 5.3.2, 5.3.3)

Insect life-stage development and mortality rates are influenced by temperature, and drought can cause host trees to be more vulnerable to insects, leading to higher tree mortality. The frequency and area of mountain pine and spruce beetle outbreaks is expected to increase with future warming in the Northwest, particularly in high-elevation forests that are typically too cold to support the insect. Climate also influences the range and survival of forest pathogens, but the climate-disease relationship is unclear for many diseases and depends on pathogen-host interaction. Higher average temperatures and increased spring precipitation in the Oregon Coast Range have contributed to an increase in severity and distribution of Swiss needle cast in Douglas-fir, which is projected to have a greater impact in the future.

While the Northwest's forest economy is sensitive to climate changes, federal and state policies governing management and harvest have and will continue to impact the net returns to this sector, and the magnitudes of the impacts from policy changes and from climate change are difficult to separate. (Section 5.4.1)

The sustainability, net returns, and long-term future of the forest economy depend on the interaction of climate factors and management practices and policies. In the Northwest, while yields may increase due to a more favorable set of climate changes, leading to increased timber production, timber markets may be adversely impacted because of declining global prices and reduced net returns to timber producers. Timber yield losses due to regional insect and disease outbreaks and wildfires could also offset any potential economic benefit from increased growth in the Northwest. Furthermore, increasing severity and intensity of Swiss needle cast affecting the commercially and culturally important Douglas-fir could pose a threat to the NW timber industry west of the Cascade Range; the dominant commercial species east of the Cascade Range, ponderosa pine, is increasingly affected by mountain pine beetle and other insect and disease attacks, decreasing growth and yield.

Tourism and recreation on publicly owned lands (about two-thirds of Northwest forests) are important economically and socially in the region and may be affected by climate change. (Section 5.4.1.3)

Although no specific studies have been conducted on the NW economy, national scale estimates suggest forest recreation revenue losses of $650 million by 2060. Given the extent of forested and recreational land in the Northwest, along with projected increased risk of wildfire and decreased snowpack, impacts on the NW recreational economy will likely be negative. In the short-term, summer recreational opportunities in publicly owned forest land could increase due to lengthening of the high-use summer season, while winter recreational opportunities may decline. The local economies in drier regions of the Northwest could experience economic losses because of forest closures from wildfires.

Forest ecosystem services, such as flood protection or water purification, and goods, such as species habitat or forest products, add wealth to society and will be affected by climate change. (Section 5.4.1.4)

Valuing changes in these ecosystem goods and services is based on demand for these services. Changes in the demand of these services is influenced by many factors including land development, water demands, and air pollution, which all interact with climate change, making it difficult to isolate the impact of climate change on the value of ecosystem goods and services. However, values of some ecosystem goods and services in the Northwest have been estimated: water purification function of forests ($3.2 million per year); erosion control in the Willamette Valley ($5.5 million per year); cultural and aesthetic uses ($144 per household per year); and endangered species habitat ($95 per household per year).

Northwest forest ecosystems that will be affected by climate change support many species of fish and wildlife whose abundance and distribution may also be affected. (Section 5.4.2)

Wolverines and pika are particularly vulnerable to projected loss of alpine and subalpine habitat provided by snow cover and high-elevation tree species. Changes in fire regime could negatively impact old-growth habitat species, such as marbled murrelets and northern spotted owls, and affect stream temperatures and riparian vegetation important for spawning and juvenile bull trout. Some species, such as the northern flicker and hairy woodpecker, may thrive with more frequent fires. The effects of climate change may exacerbate existing stressors to natural systems.

Chapter 6 Agriculture: Impacts, Adaptation, and Mitigation

Agriculture is important to the Northwest's economy, environment, and culture. Our region's diverse crops depend on adequate water supplies and temperature ranges, which are projected to change during the 21st century. (Sections 6.1, 6.2, 6.3)

Agriculture contributes 3% of the Northwest's gross domestic product, crop and pastureland comprise about one-quarter of NW land area, and farming and ranching have been a way of life for generations. Wheat, potatoes, tree fruit, vineyards, and over 300 minor crops, as well as livestock grazing and confined animal feeding operations such as beef and dairy, depend on adequate supply of water and temperature ranges. Higher temperatures and altered precipitation patterns throughout the 21st century may benefit some cropping systems, but challenge others. Vulnerabilities differ among agricultural sectors, cropping systems (fig. 6.3), and location. Climate changes could alter pressure from pests, diseases, and invasive species. Available studies specifically examining climate change and NW agriculture are limited, and have focused on major commodities.

Projected climate changes will have mixed implications for dryland crops. Warmer, drier summers increase risks of heat and drought stress. At the same time, warmer winters could be advantageous for winter wheat and other winter crops, and increases in atmospheric CO_2 can improve yields at least until mid-century (Section 6.4.1.1)

Dryland cereal-based cropping systems occur mainly in the semiarid portion of central Washington and the Columbia Plateau of northeastern Oregon and northern Idaho. Winter wheat may benefit from warmer winters, but drier summers may delay fall planting of this crop. Increased winter precipitation could hamper spring wheat planting, but could also mitigate projected reductions in summer precipitation. Taking into account the beneficial effects of atmospheric CO_2, winter wheat yields are projected to increase 13–25% while spring wheat yields are projected to change by –7% to +2% by mid-21st century across several locations in Washington.

Irrigated crops are vulnerable to higher temperatures and projected water shortages from increasing demands and reduced supplies; potato yields are generally projected to increase with increasing atmospheric CO_2 to mid-century and decline to levels similar to or substantially below current yields by end of century. (Section 6.4.1.2)

The rivers of the Columbia and Klamath Basins provide irrigation water for surrounding agricultural areas that receive low summer and annual precipitation. Irrigation demands are expected to increase in the summertime with warmer temperatures, while water supplies are likely to be reduced, which could exacerbate water shortages in some areas, potentially reducing yields of irrigated wheat, potatoes, sugarbeets, forages, corn, tree fruit, and vegetable crops. Potatoes, grown under irrigation primarily in central Washington and the Snake River valleys of Idaho, are projected to experience yield losses from higher temperature, but when considering CO_2 fertilization, losses may only be 2–3% by the end of the century. Some studies project higher losses of up to 40% in Boise, Idaho.

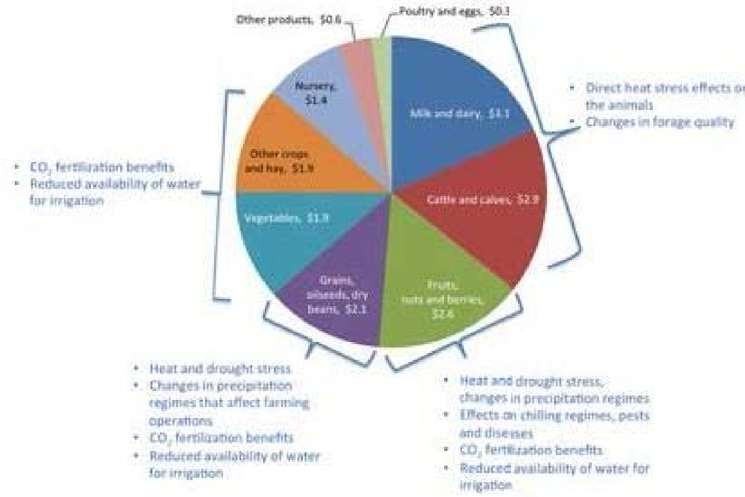

Figure 6.3. Northwest agricultural commodities with market values shown in $ (billion) in 2007. Potential effects of climate change on these sectors, if any have been projected, are shown.

Warmer winters could adversely affect tree fruits dependent on chilling for fruit set and quality. Tree fruits, most of which are produced with irrigation, are vulnerable to projected reduction in water supplies. Increased CO_2 may offset these effects; irrigated apple production is projected to increase 9% by the 2040s. (Section 6.4.2.1)

Payette County, Idaho, the Willamette Valley in Oregon, and central Washington are home to major tree-fruit production that requires irrigation and adequate chilling periods. Projected warmer temperatures that disrupt chilling requirements could hamper production of some existing tree fruits while allowing new cold-sensitive varieties to be grown. Under warming, irrigated apple production is projected to decrease by 3% in the 2040s, but increase by 9% when CO_2 fertilization is included. In addition, early budding from warmer spring temperatures could put trees more at risk to damage by frost. Tree fruits are water-intensive crops, making them vulnerable to projected reduced water supplies in some locations.

Northwest wine regions are already seeing an increase in the length of the frost-free period and warmer temperatures, which could adversely impact this growing industry. (Section 6.4.2.2)

Wine grapes are primarily grown in western Oregon and the Columbia River Basin. Each wine grape varietal has an optimal growing-season temperature range. Warmer temperatures could shift which varieties are produced in specific locations and alter wine quality. While some varietals, such as Pinot Noir and Pinot Gris (dominant grapes grown in Oregon), may experience temperatures in excess of optimal thresholds by mid-century, other varietals may become viable or more favorable in Oregon and Washington, although the cost of replacing long-lived vines must be considered.

Warming may reduce the productivity and nutritional value of forage in rangelands and pastures, though alfalfa production may increase as long as water is available. Higher temperatures can affect animal health, hampering milk production and beef cattle growth. (Section 6.4.3)

Grazing lands provide important ecosystem services. A warming climate may reduce productivity and nutritional value in rangelands located in warmer, drier climates while benefiting those in wetter environments. As long as water is not limiting, alfalfa production may increase in the Northwest under warmer temperatures and higher CO_2 concentrations. Climate change in rangeland systems may alter pressure from invasive species leading to degradation. Decreased availability, nutritional quality, and digestibility of forages, projected under higher CO_2 concentrations, may adversely affect livestock. Increased temperatures and extreme heat days can also affect animal health. Warmer temperatures can reduce milk production and decrease the rate of beef cattle growth, reducing the economic value of these products.

Agriculture is both impacted by and contributes to climate change. There are opportunities to reduce Northwest agriculture's contribution to climate change. (Box 6.1)

Opportunities to mitigate emissions in the Northwest include reducing tillage (which increases carbon storage in the soil), improving nitrogen fertilization efficiency to limit nitrous oxide production and release to the atmosphere (nitrous oxide is a greenhouse gas), and capturing methane emissions from manure. Mitigation strategies may have co-benefits that help with adaptation, sustainability and profitability of farming.

Northwest agriculture may be well positioned to adapt autonomously to climate changes due to the flexible nature of agriculture in responding to variable weather conditions and the relatively moderate projected impacts for the Northwest region. (Section 6.5)

Inherent adaptability varies by cropping system, with diversified systems potentially more adaptable than semi-arid inland wheat production and rangeland grazing. Agriculture's adaptive capacity is constrained by availability and time required for transitioning to new varieties, risk aversion among farmers, water availability in irrigation-dependent regions, and some economic, environmental, and energy policies. Partnerships and investments between public and private sectors have helped ensure agriculture remained strong in the preceding century and will be essential in the future.

Chapter 7 Human Health: Impacts and Adaptation

While the potential health impact of climate change is low for the Northwest relative to others parts of the United States, key climate-related risks facing our region include heat waves, changes in infectious disease epidemiology, river flooding, and wildfires. (Section 7.1)

Climate change in the Northwest will have implications for all aspects of society, including human health. Communities in the Northwest will experience the effects of climate change differently depending on existing climate and varying exposure to climate-related risks. While vulnerability remains relatively low in the Northwest, the negative impacts of climate change outweigh any positive ones. Increasing temperatures, changing precipitation patterns, and the possibility of more extreme weather could increase morbidity and mortality due to heat-related illness, extreme weather hazards, air pollution and allergenic disease exacerbation, and emergence of infectious diseases.

Average temperatures and heat events are projected to increase in the Northwest with an expected increase in incidence of heat-related illness and death (Section 7.2.1)

Heat-related deaths in the US have increased over the past few decades. In Oregon, the hottest days in the 2000s had about three times the rate of heat-related illness compared with days 10 °F (5.6 °C) cooler. Warmer temperatures and more extreme heat events are expected to increase the incidence of heat-related illnesses (e.g., heat rash, heat stroke) and deaths. One study projected up to 266 excess deaths among persons 65 and older in 2085 in the greater Seattle area compared to 1980–2006. Outdoor workers are especially vulnerable to heat-related illnesses.

People in the Northwest are threatened by projected increases in the risk of extreme climate-related hazards such as winter flooding and drought. (Section 7.2.2)

Wintertime flood-risk is likely to increase in mixed rain-snow basins in Washington and Oregon due to increased temperatures and, potentially, increased winter precipitation. Decreased summer precipitation and temperature-driven loss of snowpack can lead to more frequent drought conditions in the Northwest, leading to human health impacts due to food insecurity and associated wildfires. Drought can reduce global food supply and increase food prices, threatening food insecurity, especially for the poor and those living in rural areas of the Northwest. The 2012 US drought, one of the most extensive in 25 years with an estimated loss of up to $7–$20 billion, resulted in disaster declarations across the country, including counties in Oregon and Idaho.

Climate change can have a negative impact on respiratory disorders due to longer and more potent pollen seasons, increases in ground-level ozone, and more wildfire particulate matter (Section 7.2.3, 7.2.2)

Extended growing periods due to increased temperature can lengthen the pollen season and increase pollen production. Greater CO_2 concentrations can also heighten the potency of some pollens such as ragweed, found throughout the Northwest. A relatively small increase in ozone is expected for the Northwest (fig. 7.2) compared to other regions of the US, but increased ground-level ozone, or air pollution, can exacerbate asthma symptoms and lead to a higher risk of cardio-pulmonary death. Excess deaths due to ground-level ozone between 1997–2006 and mid-21st century are projected to increase from 69 to 132 and 37 to 74, respectively, in King and Spokane counties in Washington under a scenario of continued emissions growth (SRES-A2). The Northwest is expected to experience more burned acres during the wildfire season, releasing more particulate matter into the air. Wildfire risk is greatest east of the Cascade Range, but all population centers in the region are at risk of poor air quality from drifting smoke plumes, which could exacerbate respiratory disease.

Changes in climate can potentially impact the spread of vector-borne, water-borne, and fungal diseases, raising the risk of exposure to infectious diseases. (Section 7.2.4)

Longer, drier, warmer summers in the Northwest may have a significant impact on the incidence of arboviruses, such as West Nile virus. Higher ocean and estuarine temperatures in the Northwest have the potential to increase the number of *Vibrio parahaemolyticus* infections from eating raw oysters or other shellfish. Anticipated increases in

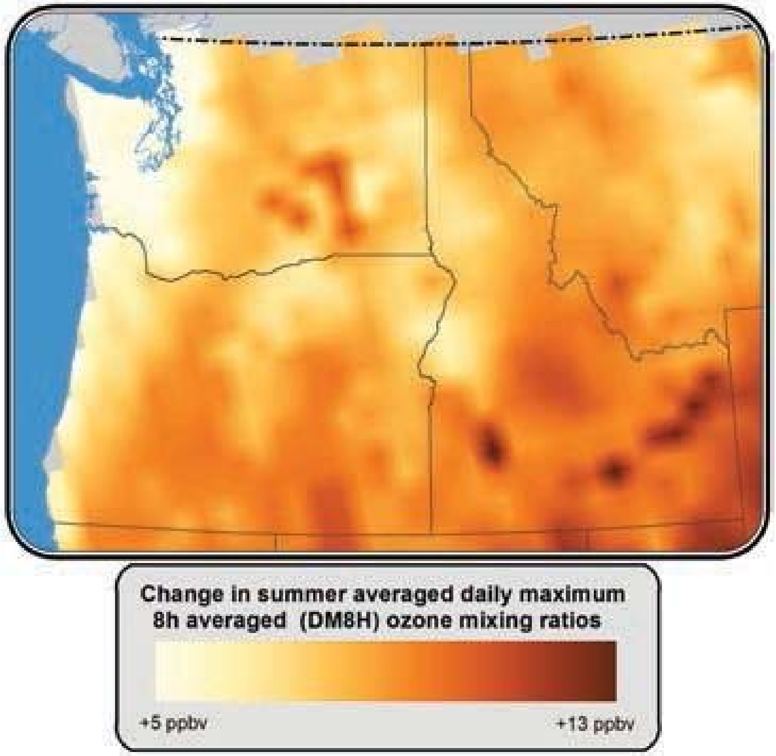

Figure 7.2. Change in summer averaged daily maximum 8-hr ozone mixing ratios (ppbv) between a future case (2045–2054) and base case (1990–1999) based on future climate from a model forced with the continued growth emissions scenario (SRES-A2). Changes in ground-level ozone are due to global and local emissions, changes in environmental conditions and urbanization, and increasing summer temperatures. Adapted from Chen et al. (2009).

precipitation and subsequent flooding have the potential to wash animal intestinal pathogens into drinking water reservoirs and recreational waters, potentially increasing the risk of *Cryptosporidium* outbreaks. The emergence of the fungus *Cryptococcus gattii* in the Northwest in the early 2000s may have some relationship to climate change.

Longer harmful algal blooms increase the risk of paralytic shellfish and domoic acid poisoning in humans. (Section 7.2.5)

The frequency, intensity, and duration of harmful algal blooms appear to be increasing globally, but the exact relationship to climate change is unknown. In the Puget Sound, rising water temperatures promote earlier and longer lasting harmful algal blooms, which can cause paralytic shellfish and domoic acid poisoning in humans who consume infected shellfish.

Climate change may affect mental health and well-being. (Section 7.2.6)

Like physical health impacts, there are direct and indirect mental health impacts of climate change. Extreme weather events can cause mental distress, and even the threat of a climate event, the uncertainty of the future, or the loss of control over a situation can result in feelings of depression or helplessness.

Public health practitioners and researchers in the Northwest are actively engaging local communities regarding adaptation measures for climate change. Additional efforts

are needed to engage a greater number of communities and build our understanding of how climate change will affect human health. (Sections 7.3, 7.4)

Public health officials, universities, and state agencies in the Northwest are engaged in numerous adaptation activities to address the potential impact of climate change on human health by developing public health adaptation resources, integrating planning at various government levels, and creating programs to monitor and respond to public health issues. Even some local health departments are creating their own climate change adaptation plans. In order to better understand the full impact of climate change on human health and for communities to effectively adapt, several needs must be addressed including accurate surveillance data on climate-sensitive health and environmental indicators.

Chapter 8 Northwest Tribes: Cultural Impacts and Adaptation Responses

Northwest tribes are intimately connected to the land's resources, and are tied to their homelands by law as well as by culture. The impacts of climate change will not recognize geographic or political boundaries. (Sections 8.1, 8.2)

Climate change will have complex and profound effects on tribal resources, cultures, and economies. In ceding lands and resources to the US, tribes were guaranteed the rights to hunt, fish, and gather on their usual and accustomed places both on and off reservation lands (fig. 8.2). Climate change could potentially affect these treaty-protected rights. For example, treaty-protected fish and shellfish populations may become threatened or less accessible to tribes due to climate change. Treaty water rights could also be affected by climate change through changes to water quantity and quality that affect salmon and other fisheries.

Reduced snowpack and shifts in timing and magnitude of precipitation and runoff could significantly affect culturally and economically important aquatic species, such as salmon. (Section 8.3.1, Box 8.1)

Salmon are culturally and economically significant to inland and coastal tribes throughout the Northwest. Spring Chinook salmon that spawn in the Nooksack River watershed, for example, are especially important to the Nooksack Indian Tribe for ceremonial, commercial, and subsistence uses. Past land-use practices have resulted in loss of fish habitat in the Nooksack watershed; observed changes in climate, such as decreased summer flows, increased stream temperatures, and higher peak winter flows, exacerbate the existing stressors that affect the migration and spawning of Chinook and other Pacific salmonids. Continued climate change will further challenge salmonid survival, highlighting the need for effective restoration strategies that consider both existing stressors and those added by climate change.

Increasing ocean acidification, hypoxia, and warmer air and water temperatures threaten many species of fish and shellfish widely used by tribes. (Section 8.3.2)

In the Puget Sound, fish and shellfish harvests are primary sources of income for tribal members. The health of these fisheries depends on how they are managed and the

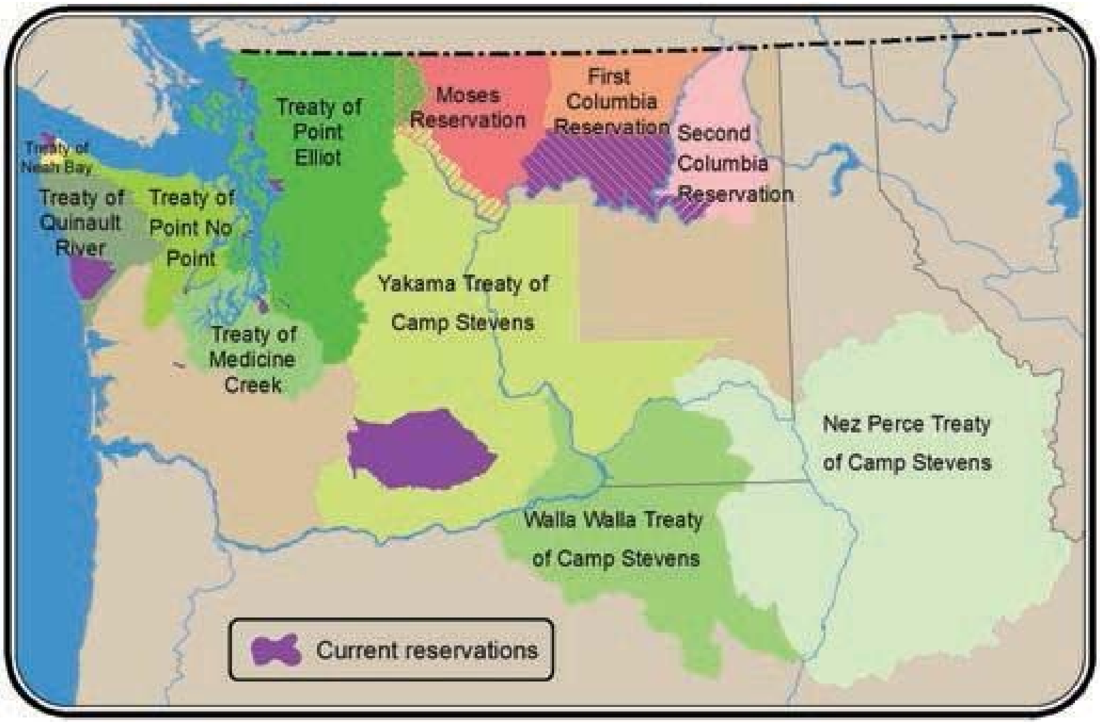

Figure 8.2. Treaty Ceded Lands. Washington State Historic Tribal Lands (Tribal Areas of Interest. Washington Department of Ecology)

health of the waters and ecosystems they inhabit. Decreasing pH is already associated with observed declines in the abundance and mean size of mussels from Tatoosh Island on the Makah Reservation in Washington. Warmer air temperatures have led to a decrease in the vertical extent of the California mussel in the Strait of Juan de Fuca.

Tribal coastal infrastructure and ecosystems are threatened by sea level rise, storm surge, and increasing wave heights. (Section 8.3.3)

Rising seas threaten culturally important areas of coastal tribes' homelands, such as burial grounds and traditional fishing and shellfish gathering areas, as well as infrastructure in low-lying areas. Small coastal reservations may face tension between allowing coastal habitat to shift inland (to limit habitat loss from sea level rise) and maintaining space for land-based needs and infrastructure.

Changes in forest ecosystems and disturbances will affect important tribal resources. (Section 8.3.4)

Projected changes in large-scale tree distribution across the Northwest, including those already occurring such as northward and elevational migration of temperate forests, will affect resources and habitats that are important for the cultural, medicinal, economic, and community health of tribes. Compounding impacts from forest disturbances, including wildfires and insect outbreaks, also pose a threat to traditional foods, plants, and wildlife that tribes depend on.

There are numerous tribes in the region pro-actively addressing climate change and bridging opportunities with non-tribal entities to engage in climate change research, assessments, plans, and policies. (Section 8.4)

There are many tribes in the Northwest pro-actively addressing climate change through a myriad of efforts. The Swinomish Indian Tribal Community showed early innovation in developing a tribal climate change impacts assessment and adaptation plan. The Tulalip Tribes are taking an ecosystem-based approach to understand and address interrelated changes in local ecosystems due to climate change. The Suquamish Tribe is engaged in federal, state, and academic research partnerships to study the effects of pH on crab larvae and is creating an online database to direct teachers to high quality climate change education materials. Other tribes in the region have initiated efforts to reduce greenhouse gas emissions through energy efficiency, renewable energy sources, and carbon sequestration.

Tribes in the Northwest have identified climate change needs and opportunities, including understanding the role of traditional ecological knowledge in climate initiatives and improving the government-to-government relationship. (Section 8.5)

Vulnerability to climate change and tribal adaptation strategies require explicit attention because of the unique social, legal, and regulatory context for tribes. It will be important for future climate research and policies to consider how reserved rights, treaty rights, and tribal access to cultural resources will be affected by climate change, potential species and habitat migration, and implementation of adaptation and mitigation strategies. Traditional knowledge can inform tribal and non-tribal understanding of how climate change may impact tribal resources and traditional ways of life. Strengthening government-to-government relationships is important in order to protect tribal rights and resources in the face of climate change, as is effective communication, collaboration, and federal-tribal partnerships.