Topic 1: Observed Changes and their Causes

Human emissions of greenhouse gases have continued to rise since 1970 with larger absolute increases over the last decade.. Human influence on the climate system climate system is clear, and is estimated to have been the dominant cause of warming since 1950. Changing climate has been linked to impacts on natural and human systems on all continents and across the oceans.

1.1 Introduction

Topic 1 focuses on evidence for a changing climate in observations, the impacts caused by it and the human contributions to it. It discusses observed changes in climate (1.2) and external influences on climate (forcings), differentiating those forcings that are of anthropogenic origin, and their contributions by sectors and gases (1.3). Section 1.4 attributes causes to observed changes in human and natural systems and determining the degree to which those impacts can be attributed to climate change. Vulnerability and exposure in the context of extreme events as well as the changing probability of extreme events and their causes are discussed in a separate section (1.5), followed by a brief section on adaptation experience (1.6).

1.2 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.

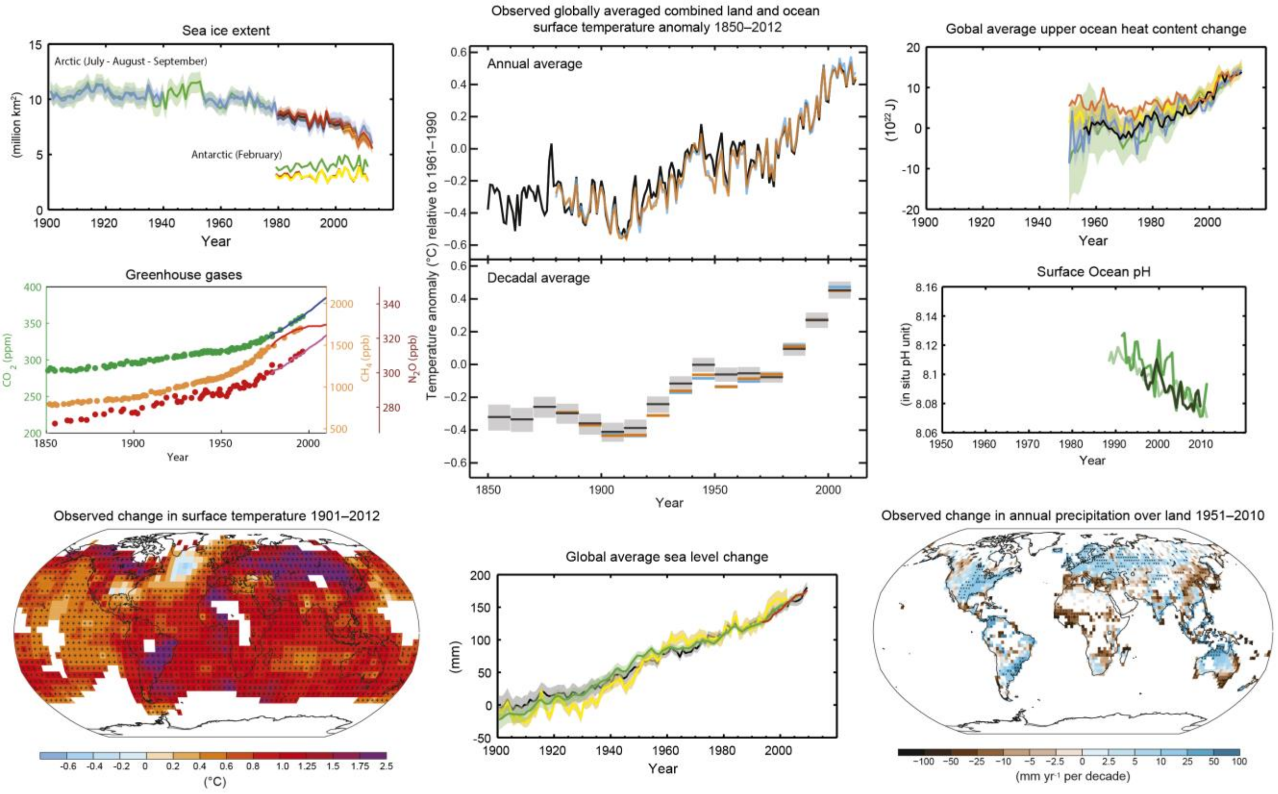

Figure 1.1: Multiple observed indicators of a changing global climate system. Left column, top panel: Arctic (July to September average) and Antarctic (February) sea ice extent; Left column, middle panel: atmospheric concentrations of well mixed greenhouse gases; carbon dioxide (CO_2) determined from ice core data (green dots) and from direct atmospheric measurements (blue line); methane (yellow dots, orange line) and nitrous oxide (red dots, purple line); Left column, bottom panel: map of the observed surface temperature change from 1901 to 2012 from one dataset (orange line in middle columns, top panel); Middle column, top panel: observed globally averaged combined land and ocean surface temperature anomalies (annual and decadal averages) with an estimate of decadal mean uncertainty included for one dataset (grey shading); Middle column, bottom panel: global mean sea level change; Right column, top panel: change in global mean upper ocean (0–700 m) heat content; Right column, middle panel: in situ pH, which is a measure of the acidity of ocean water; Right column, bottom panel: map of observed precipitation change from 1951 to 2010.

For all time-series, coloured lines indicate different datasets, and uncertainties (where assessed in the underlying chapters) are indicated by coloured shading. Trends shown in the maps have been calculated only where data availability permits a robust estimate and grid boxes where the trend is significant at the 10% level are indicated by a + sign. Note that the length of the times-series shown differs between quantities, based on the availability of the observations. For full technical information, and details on the datasets shown, refer to the underlying WGI Summary for Policymakers and Chapter figures, and the supplementary material to the Technical Summary. *{Figures SPM 1 – 4; Figure 4.SM.2, Figure 6.11}*

1.2.1 Atmosphere

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850. In the Northern Hemisphere, 1983–2012 was *likely* the warmest 30-year period of the last 1400 years (*medium confidence*). *{WG1 2.4, 5.3}*

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, over the period 1880 to 2012, when multiple independently produced datasets exist. The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72 to 0.85] °C[5], based on the single longest dataset available (Figure 1.1). *{WGI 2.4}*

*B*ased upon multiple independent analyses of measurements from radiosondes and satellite sensors it is *virtually certain* that globally the troposphere has warmed and the lower stratosphere has cooled since the mid-20th Century. There is at best *medium confidence* in the rate of change and its vertical structure. *{WG I 2.4}*

Confidence in precipitation change averaged over global land areas since 1901 is *low* prior to 1951 and *medium* afterwards. 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* (Figure 1.1). *{WGI Figure SPM.2, 2.5}*

Observed changes in extremes are discussed in Section 1.5.

1.2.2 Ocean changes

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*). 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. *{WG I 3.2, Box 3.1; Figure 1.1}*

On a global scale, the ocean warming is largest near the surface, with the upper 75 m warming by 0.11 [0.09 to 0.13] °C per decade over the period 1971–2010. *{WGI 3.2}*

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. These regional trends in ocean salinity provide indirect evidence that evaporation and precipitation over the oceans have changed (*medium confidence*). *{WGI 2.5, 3.3, 3.5}*

There is no observational evidence of a long-term trend in the Atlantic Meridional Overturning Circulation (AMOC), based on the decade-long record of the complete AMOC and longer records of individual AMOC components. *{WGI 3.6}*

Oceanic uptake of anthropogenic CO_2 results in gradual acidification of the ocean. The pH of surface seawater has decreased by 0.1 since the beginning of the industrial era, corresponding to a 26% increase in hydrogen ion concentration (*high confidence*). *{WGI SPM, 3.8}*

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[5] Ranges in square brackets indicate a 90% uncertainty interval unless otherwise stated.

High agreement among analyses provides *medium confidence* that oxygen concentrations have decreased in the open ocean thermocline in many ocean regions since the 1960s. It is *likely* that the tropical oxygen minimum zones have expanded in recent decades. *{WGI 3.8, Figure 3.20; WGII 6.1.1.3; 30.3.2.3}*

1.2.3 Cryosphere

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (*high confidence*) (Figure 1.1). ***{WGI 4.2–4.7}***

The average rate of ice loss from the Greenland ice sheet has *very likely* substantially increased from 34 [–6 to 74] Gt yr–1 over the period 1992 to 2001 to 215 [157 to 274] Gt yr–1 over the period 2002 to 2011. The average rate of ice loss from the Antarctic ice sheet has *likely* increased from 30 [–37 to 97] Gt yr–1 over the period 1992–2001 to 147 [72 to 221] Gt yr–1 over the period 2002 to 2011. There is *very high confidence* that these losses are mainly from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica. *{WGI 4.4}*

The average decadal extent of Arctic sea ice has decreased in every season and in every successive decade *(high confidence*) since satellite observations commenced in 1979. 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 (range of 0.45 to 0.51 million km^2 per decade), and *very likely* in the range 9.4 to 13.6% per decade (range of 0.73 to 1.07 million km^2 per decade) for the summer sea ice minimum. {*WG1 Figure SPM.1*} It is *very likely* that the annual mean Antarctic sea ice extent increased at a rate in the range of 1.2 to 1.8% per decade (range of 0.13 to 0.20 million km^2 per decade) between 1979 and 2012, with strong regional differences *(high confidence). {WGI 4.2}*

There is *high confidence* that permafrost temperatures have increased in most regions of the Northern Hemisphere since the early 1980s in response to increased air temperature and changing snow cover. *{WG1 4.7.2}*

1.2.4 Changes in Sea Level

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*). Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (Figure 1.1). ***{WGI SPM, 3.7, 5.6, 13.2}***

It is *very likely* that the mean rate of global averaged sea level rise was 1.7 [1.5 to 1.9] mm yr^{-1} between 1901 and 2010, 2.0 [1.7 to 2.3] mm yr^{-1} between 1971 and 2010 and 3.2 [2.8 to 3.6] mm yr^{-1} between 1993 and 2010. Tide-gauge and satellite altimeter data are consistent regarding the higher rate of the latter period. It is *likely* that similarly high rates occurred between 1920 and 1950. *{WGI SPM,3.7, 13.2}*

Since the early 1970s, glacier mass loss and ocean thermal expansion from warming together explain about 75% of the observed global mean sea level rise (*high confidence*). Over the period 1993–2010, global mean sea level rise is, with *high confidence*, consistent with the sum of the observed contributions from ocean thermal expansion due to warming, from changes in glaciers, the Greenland ice sheet, the Antarctic ice sheet, and land water storage. *{WGI SPM, 13.3}*

Rates of sea level rise over broad regions can be several times larger or smaller than the global mean sea level rise for periods of several decades due to fluctuations in ocean circulation. Since 1993, the regional rates are known globally to high precision using satellite altimetry, with rates in the western Pacific up to three times larger than the global mean, while rates over much of the Eastern Pacific are near zero or negative. *{WGI 3.7, FAQ 13.1}*

There is *very high confidence* that maximum global mean sea level during the last interglacial period (129,000 to 116,000 years ago) was, for several thousand years, at least 5 m higher than present and *high confidence* that it did not exceed 10 m above present. During the last interglacial period, the Greenland ice sheet *very likely* contributed between 1.4 and 4.3 m to the higher global mean sea level, implying with *medium confidence* an additional contribution from the Antarctic ice sheet. This change in sea level occurred in the context of different orbital forcing and with high-latitude surface temperature, averaged over several thousand years, at least 2°C warmer than present (*high confidence). {WGI SPM, 5.3, 5.6, 13.2}*

1.3 Past and recent drivers of climate change

Atmospheric concentrations of the main well mixed greenhouse gas (CO_2, CH_4 and N_2O) have all shown large increases since the preindustrial era. Despite of multinational institutions and national policies aimed at mitigating emissions, anthropogenic greenhouse gas emissions have risen more rapidly between 2000-2010 than in the preceding decade, driven mainly by economic and population growth.

1.3.1 Natural and anthropogenic forcings

Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change. Radiative forcing (RF) quantifies the variation in energy fluxes caused by these drivers. All RF values are for the industrial era, defined here as the period from 1750 to 2011, unless otherwise indicated. RFs larger than zero lead to a near-surface warming, and RFs smaller than zero lead to a cooling. RF is estimated based on in-situ and remote observations, properties of greenhouse gases and aerosols, and calculations using numerical models representing observed processes.

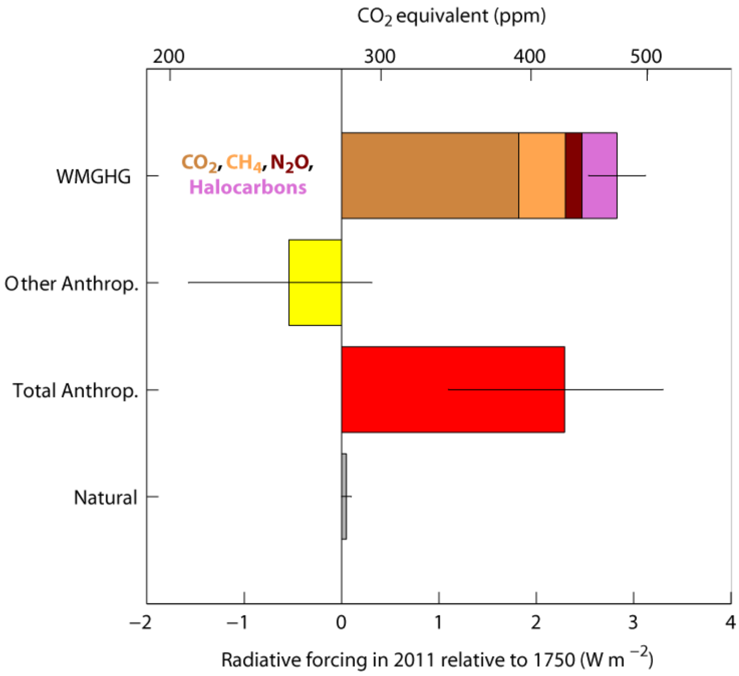
Atmospheric concentrations of the main well mixed greenhouse gases (CO_2, CH_4 and N_2O) have all shown large increases since the preindustrial era (40%, 150% and 20% respectively). The CO_2 concentration (Figure 1.1) is substantially higher than anytime within the last 800,000 years and is now rising at its fastest-observed decadal rate of change (2.0 ± 0.1 ppm yr^{-1}). After almost one decade of stable CH_4 concentrations since the early 1990's, atmospheric measurements have shown renewed growth since 2007. N_2O concentrations are increasing at a current rate of about 0.75 ppb yr^{-1}. {*WGI 2.2, 6.1 6.3*}

Changes in carbon dioxide are the largest single contributor to historical RF from either the emission based or concentration based perspective. The relative importance of other forcing agents varies with the perspective chosen, however. For example methane emissions have a much larger forcing (about 1.0 W m^{-2} over the industrial era) than methane concentration increases (about 0.5 W m^{-2}) due to several indirect effects through atmospheric chemistry.

The total anthropogenic RF since 1750 is 2.29 [1.13 to 3.33] W m^{-2} (Figure 1.2), and it has increased more rapidly since 1970 than during prior decades. The total anthropogenic RF estimate for 2011 is substantially higher than the estimate reported in AR4 for the year 2005. This is caused by a combination of continued growth in most greenhouse gas concentrations and improved estimates of RF by aerosols indicating a weaker net cooling effect. *{WGI SPM, 8.5}*

The other anthropogenic forcing bar shown in Figure 1.2 include a warming contribution from ozone changes and cooling contributions from land-use albedo and aerosol changes. **The RF of the total aerosol effect, which includes cloud adjustments due to aerosols, is –0.9 [–1.9 to −0.1] W m^{-2} *(medium confidence)*. RF from aerosols has two competing components: a dominating negative forcing from most aerosols and an offsetting positive contribution from black carbon**. There is *high confidence* that the combined impact of aerosols has counteracted a substantial portion of global mean forcing from well-mixed greenhouse gases. Aerosols continue to contribute the largest uncertainty to the total RF estimate. *{WGI SPM, 7.5, 8.3, 8.5}*

Changes in solar irradiance and volcanoes can cause natural forcings (Figure 1.2). The forcing from stratospheric volcanic aerosols can have a large impact on the climate system for some years after volcanic eruptions. Several small eruptions have caused an additional RF of −0.11 [–0.15 to –0.08] W m^{-2} for the years 2008−2011. Changes in total solar irradiance contribute only a small fraction, 0.05 [0.00 to 0.10] W m^{-2}, of the total radiative forcing during the industrial era. There was a strong solar minimum in 2008/2009, which contributed a small cooling effect over the last 15 years. The effect of cosmic rays on the concentration of cloud condensation nuclei is too weak to have any detectable climatic influence during a solar cycle or over the last century (*medium evidence, high agreement*). *{WG-I 7.4 8.4}*



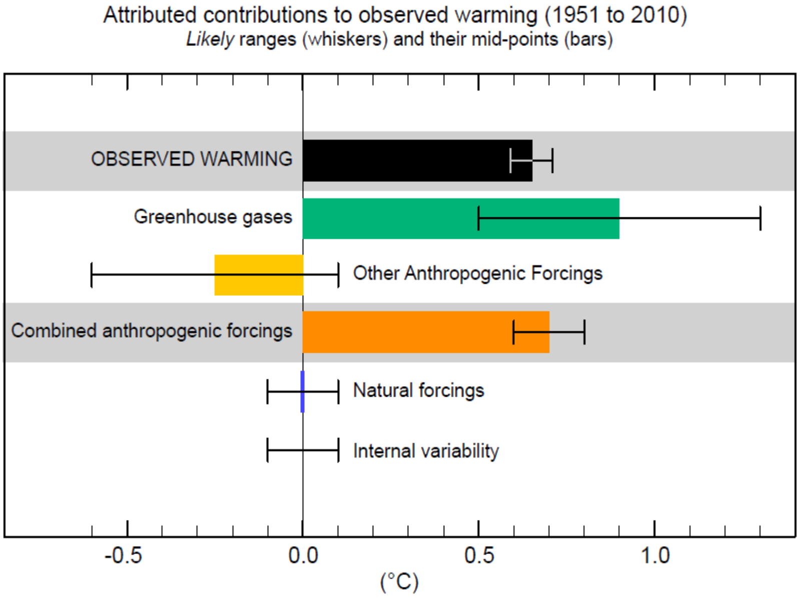


Figure 1.2: Top diagram: Radiative forcing (RF) of climate change during the industrial era (1750-2011) from well-mixed greenhouse gases (WMGHG), other anthropogenic forcings, combined anthropogenic forcings and natural forcings. The error lines indicate the 5%-95% uncertainty. Other Anthropogenic forcings include aerosol, land-use albedo and ozone changes. *{Data from WGI Table 8.6 and Section 7.5}*
Bottom diagram: Assessed *likely* ranges (whiskers) and their mid-points (bars) for attributable warming trends over the 1951–2010 period due to well-mixed greenhouse gases, other anthropogenic forcings, combined anthropogenic forcings, natural forcings, and internal variability. Observations are shown in black with the 5–95% uncertainty range due to observational uncertainty in this record. These attributed ranges (colours) are based on estimating the contribution to observed warming by fingerprints for external forcing derived from climate model simulations; and do not rely on the estimated radiative forcing magnitudes from the top panel. Errorbars are larger when greenhouse gases and other anthropogenic forcing is estimated separately compared to when they are estimated in combination (grey shading). This is because uncertainty in warming attributable to greenhouse gases is correlated with that in cooling attributable to aerosols. Hence while uncertainty is small in the overall anthropogenic contribution, there is uncertainty in how much greenhouse warming is offset by aerosol cooling. *{WGI Figure TS.10, 10.3}*

1.3.2 Human activities affecting climate drivers

About half of cumulative anthropogenic CO$_2$ emissions between 1750 and 2010 have occurred in the last 40 years (*high confidence*). Anthropogenic CO$_2$ emissions were 2000 ± 310 GtCO$_2$ to the atmosphere between 1750 and 2011. In 1970, cumulative CO$_2$ emissions from fossil fuel combustion, cement production and flaring since 1750 were 420±35 $GtCO_2$; in 2010, that cumulative total had tripled to 1300 ±110 $GtCO_2$. Cumulative CO_2 emissions from Forestry and Other Land Use (FOLU) since 1750 increased from 490±180 $GtCO_2$ in 1970 to 680±300 $GtCO_2$ in 2010 (Figure 1.3). *{WGI 6.3, WGIII 5.2}*

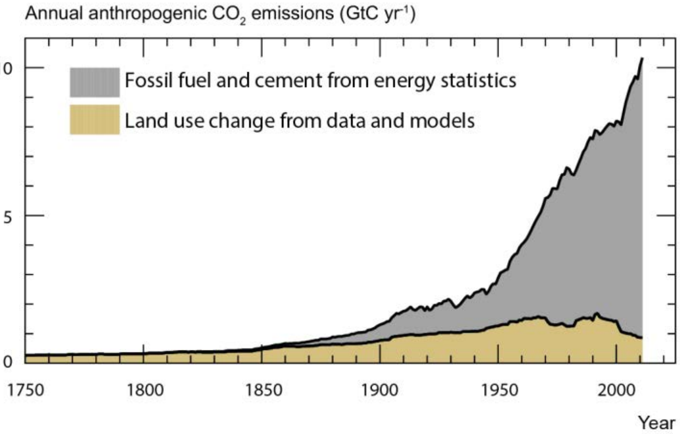


Figure 1.3: Annual anthropogenic CO2 emissions from fossil fuel combustion, flaring, cement, Forestry and Other Land Use (FOLU) 1750-2011. Emissions are reported in gigatonnes carbon per year (Gt/yr). *{WG I Figure TS.4}*

About half of these anthropogenic CO_2 emissions remained in the atmosphere (880 ± 35 $GtCO_2$) since 1750. The rest was removed from the atmosphere by sinks, and stored in the natural carbon cycle reservoirs. It is virtually certain that the ocean is taking up anthropogenic carbon dioxide from the atmosphere since pre-industrial times. This estimate is 570 ± 110 $GtCO_2$ from 1750 to 2011. *{WG1 3.8.1, 6.3}* Vegetation biomass and soils stored 585 ± 330 $GtCO_2$ over the 1750-2011 period. *{WG1 6.3}*

Total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute decadal increases toward the end of this period (*high confidence*). Despite a growing number of climate change mitigation policies, annual GHG emissions grew on average by 1.0 giga tonne carbon dioxide equivalent ($GtCO_2eq$) (2.2%) per year from 2000 to 2010 compared to 0.4 $GtCO_2eq$ (1.3%) per year from 1970 to 2000 (Figure 1.4).[6,7] Total anthropogenic GHG emissions were the highest in human history from 2000 to 2010 and reached 49 (±4.5) $GtCO_2eq$/yr in 2010. The global economic crisis 2007/2008 only temporarily reduced emissions. *{WG III 1.3, 5.2, 13.3, 15.2.2, Box TS.5, Figure 15.1}*

CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000–2010 (*high confidence*). Fossil fuel-related CO_2 emissions reached 32 (±2.7) $GtCO_2$/yr, in 2010, and grew further by about 3% between 2010 and 2011 and by about 1-2% between 2011 and 2012. Of the 49 (±4.5) $GtCO_2eq$/yr in total anthropogenic GHG emissions in 2010, CO_2 remains the major anthropogenic GHG accounting for 76% (38±3.8 $GtCO_2eq$/yr) of total anthropogenic GHG emissions in 2010. 16% (7.8±1.6 $GtCO_2eq$/yr) come from methane (CH_4), 6.2% (3.1±1.9 $GtCO_2eq$/yr) from nitrous oxide (N_2O), and 2.0% (1.0±0.2 $GtCO_2eq$/yr) from fluorinated gases (Figure 1.4). Annually, since 1970, about 25% of anthropogenic GHG emissions have been in the form of non-CO_2 gases.[8] *{WG III 1.2, 5.2}*

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[6] Throughout the SYR, when emissions of GHGs are provided in $GtCO_2eq$, they are weighted by Global Warming Potentials with a 100-year time horizon (GWP_{100}) from the IPCC Second Assessment Report. All metrics have limitations and uncertainties in assessing consequences of different emissions. *{3.9.6, Box TS.5, Annex II.2.9, WGI AR5 SPM}*

[7] Uncertainty in historic GHG emission data is reported using 90% uncertainty intervals unless otherwise stated. GHG emission levels are rounded to two significant digits throughout this document.

[8] In this report, data on non-CO_2 GHGs, including fluorinated gases, is taken from the EDGAR database (Annex II.9), which covers substances included in the Kyoto Protocol in its first commitment period.

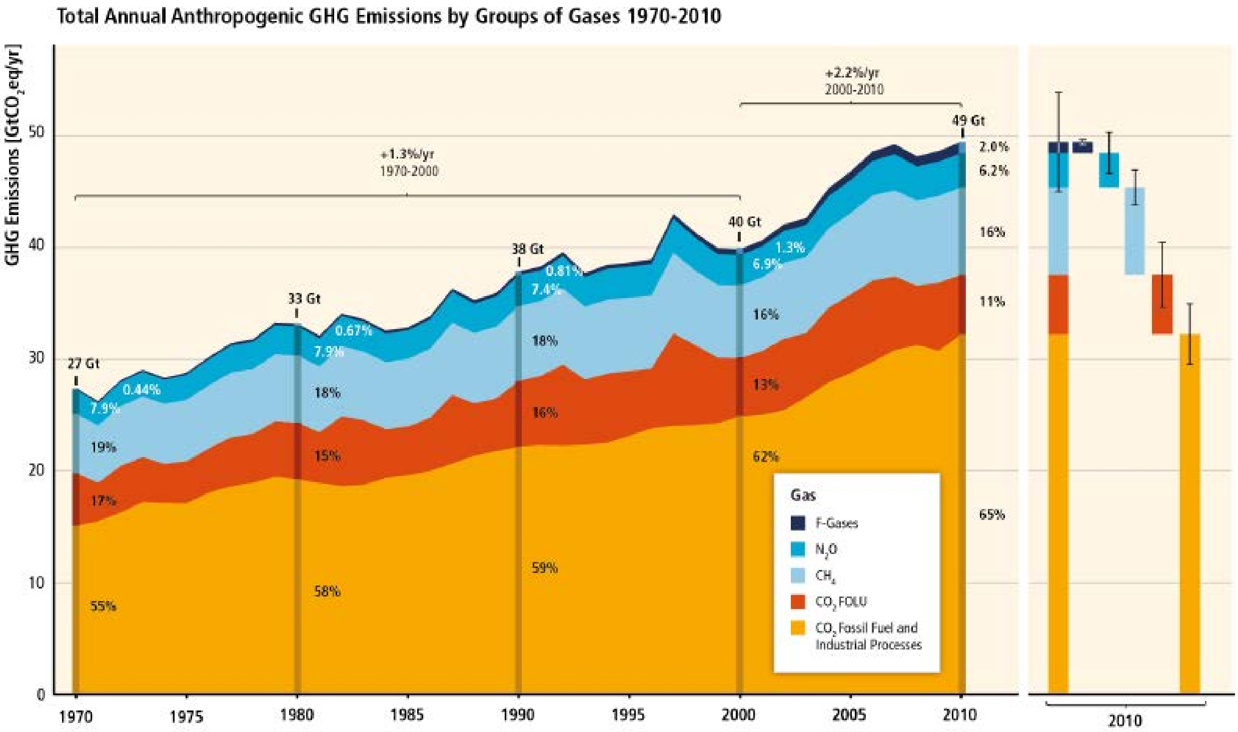


Figure 1.4: Total annual anthropogenic GHG emissions ($GtCO_2eq/yr$) by groups of gases 1970- 2010: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). At the right side of the figure GHG emissions in 2010 are shown again broken down into these components with the associated uncertainties (90% confidence interval) indicated by the error bars. *{WG III Figure SPM.1}*

Annual anthropogenic GHG emissions have increased by 10 $GtCO_2eq$ between 2000 and 2010, with this increase directly coming from energy supply (47%), industry (30%), transport (11%) and buildings (3%) sectors (*medium confidence*). Accounting for indirect emissions raises the contributions of the buildings and industry sectors (*high confidence*). Since 2000, GHG emissions have been growing in all sectors, except AFOLU. Of the 49 (±4.5) $GtCO_2eq$ emissions in 2010, 35% (17 $GtCO_2eq$) of GHG emissions were released in the energy supply sector, 24% (12 $GtCO_2eq$, net emissions) in AFOLU, 21% (10 $GtCO_2eq$) in industry, 14% (7.0 $GtCO_2eq$) in transport and 6.4 % (3.2 $GtCO_2eq$) in buildings. When emissions from electricity and heat production are attributed to the sectors that use the final energy (i.e. indirect emissions), the shares of the industry and buildings sectors in global GHG emissions are increased to 31% and 19%, respectively (Figure SPM.2). *{WG III 7.3, 8.2, 9.2, 10.3, 11.2}*

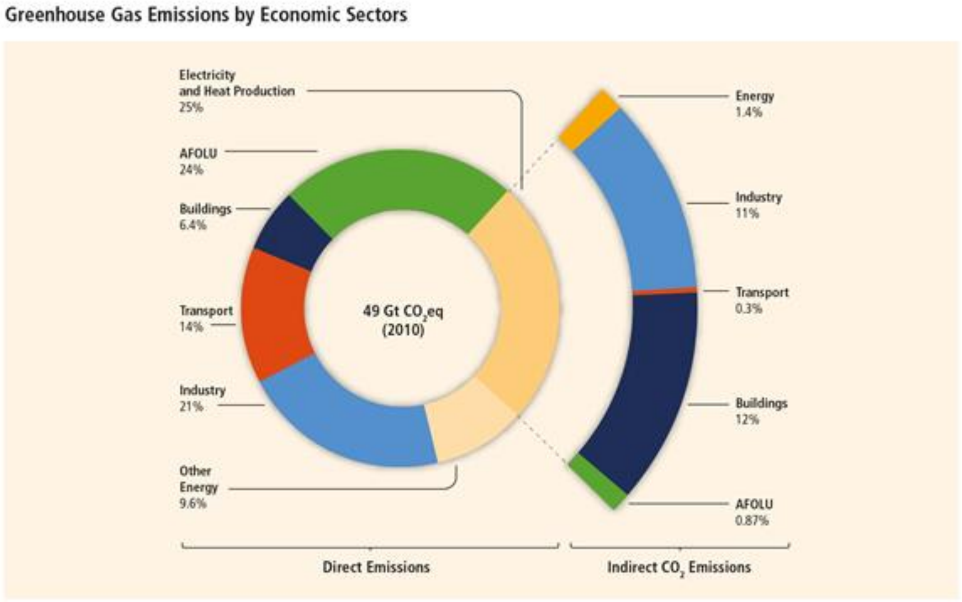


Figure 1.5: Total anthropogenic GHG emissions (GtCO_2eq/yr) by economic sectors. Inner circle shows direct GHG emission shares (in % of total anthropogenic GHG emissions) of five economic sectors in 2010. Pull-out shows how indirect CO_2 emission shares (in % of total anthropogenic GHG emissions) from electricity and heat production are attributed to sectors of final energy use. "Other Energy" refers to all GHG emission sources in the energy sector as defined in Annex II other than electricity and heat production [A.II.9.1]. The emissions data from Agriculture, Forestry and Other Land Use (AFOLU) includes land-based CO_2 emissions from forest fires, peat fires and peat decay that approximate to net CO_2 flux from the Forestry and Other Land Use (FOLU) sub-sector as described in Chapter 11 of this report. Emissions are converted into CO_2-equivalents based on GWP_{100}[6] from the IPCC Second Assessment Report. Sector definitions are provided in Annex II.9. *{WGIII Figure SPM.2}*

Regardless of the perspective taken, the largest share of anthropogenic CO_2 emissions is emitted by a small number of countries *(high confidence)*. In 2010, 10 countries accounted for about 70% of CO_2 emissions from fossil fuel combustion and industrial processes. A similarly small number of countries emit the largest share of consumption-based CO_2 emissions as well as cumulative CO_2 emissions going back to 1750. *{WGIII 1.3}*

Globally, economic and population growth continue 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 (*high confidence*). Between 2000 and 2010, both drivers outpaced emission reductions from improvements in energy intensity (Figure 1.6). Increased use of coal relative to other energy sources has reversed the long-standing trend of gradual decarbonization of the world's energy supply. *{WG III 1.3, 5.3, 7.2, 14.3, TS.2.2}*

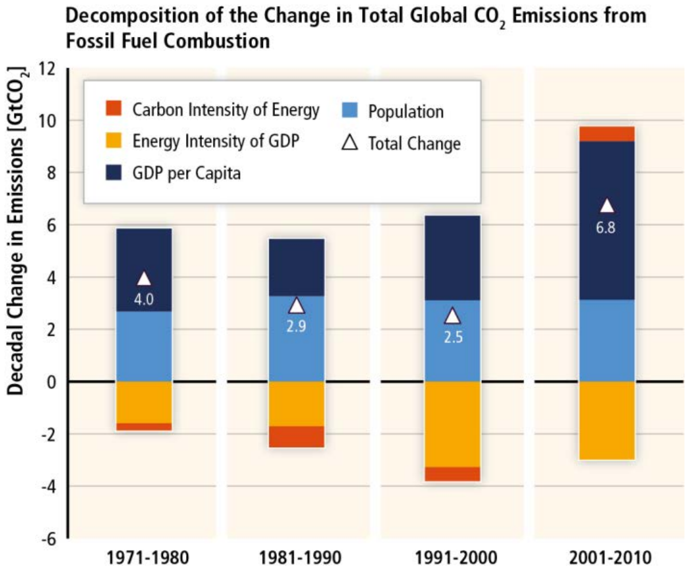


Figure 1.6: Decomposition of the decadal change in total global CO_2 emissions from fossil fuel combustion by four driving factors; population, income (GDP) per capita, energy intensity of GDP and carbon intensity of energy. The bar segments show the changes associated with each factor alone, holding the respective other factors constant. Total decadal changes are indicated by a triangle. Changes are measured in giga tonnes (Gt) of CO_2 emissions per decade; income is converted into common units using purchasing power parities. *{WG III SPM.3}*

1.4 Attribution of climate changes and impacts

Human influence has been detected and attributed in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, and in global mean sea level rise; and has been *extremely likely* been the dominant cause of the observed warming since the mid-20th century. In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans.

The causes of observed changes in the climate system, as well as in any natural or human system impacted by climate are established following a consistent set of methods for detection and attribution that have been developed across working groups (IPCC GPGP, 2010). Detection addresses the question of whether climate or a natural or human systems affected by climate has actually changed in a statistical sense, while attribution evaluates (to the extent possible) the relative contributions of multiple causal factors to a change or event with an assignment of confidence (IPCC GPGP, 2010). The assessment accounts very carefully for the extent to which ‘confounding’ factors have been considered. Results from attribution studies support projections of future climate change (Topic 2). *{WGI 10}* as well as analyses of the sensitivity of natural or human systems to future climate change including the risks associated with these sensitivities. *{WGII 18, 19}*

Attribution of observed impacts to climate change *{WGII}* considers the links between impacts on natural or human systems and observed climate change, regardless of its cause. By comparison, attribution of climate change to causes *{WGI}* quantifies the links between observed climate change and human activity, as well as other external climate drivers. On local scales, such as local precipitation or temperature change, attribution of causes to climate change is much more difficult, due to larger climate variability, the greater role played by dynamical factors (circulation changes), a greater range of forcings or confounding factors that may be regionally important, and the greater difficulty of modelling relevant processes at regional scales. This is why attribution results that directly link impacts of climate change to human drivers are not easy to achieve.

Section 1.4.1 focuses on attribution of climate change to anthropogenic forcing, while section 1.4.2 discusses observed impacts on natural and human systems attributable to climate change. Where possible, section 1.4.2 also presents connections of such impacts to changes in climate for which human influence has been assessed.

1.4.1 Attribution of climate changes to human and natural influences on the climate system

Human influence has been detected and attributed in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, and in global mean sea level rise (Figure 1.6; note that extremes are discussed in section 1.5). This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. *{WG1 SPM, 10.9, Table 10.1}*

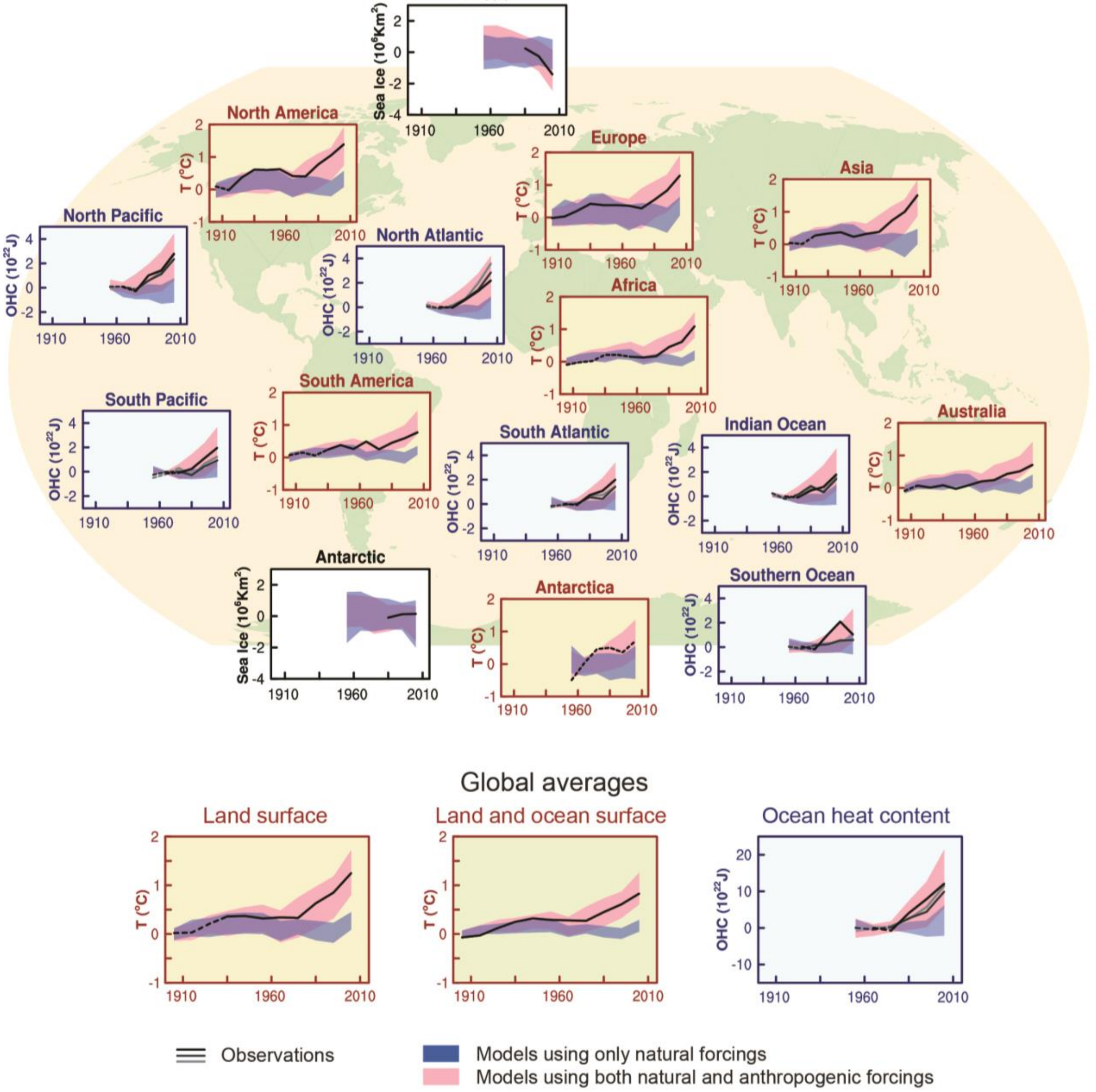


Figure 1.7: Comparison of observed and simulated climate change for change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, 1960–1980 for ocean heat content and 1979–1999 for sea ice. All time-series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels the solid lines are where the coverage of data is good and higher in quality, and the dashed lines are where the data coverage is only adequate, and thus, uncertainty is larger (note that different lines indicate different datasets; details see WG1 Figure SPM6). Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals. *{WG1 Figure SPM 6}*

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 greenhouse gas 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. Greenhouse gases contributed a global mean surface warming *likely* to be in the range of 0.5°C to 1.3°C over the period 1951−2010, with further contributions from other anthropogenic forcings, including the cooling effect of aerosols (*likely* in the range of −0.6°C to 0.1°C), natural forcings (*likely* in the range of −0.1°C to 0.1°C), and from internal variability (*likely* in the range of −0.1°C to 0.1°C). Together these assessed contributions are consistent with the observed warming of approximately 0.6°C to 0.7°C over this period (Figure 1.2). *{WGI SPM, 10.3}*

It is *very likely* that anthropogenic influence, particularly greenhouse gases and stratospheric ozone depletion, has led to a detectable observed pattern of tropospheric warming and a corresponding cooling in the lower stratosphere since 1961. *{WGI SPM, 2.4, 9.4, 10.3}*

Over every continental region except Antarctica, anthropogenic forcings have *likely* made a substantial contribution to surface temperature increases since the mid-20th century (Figure 1.6). For Antarctica, however, large observational uncertainties result in *low confidence* that anthropogenic forcings have contributed to the observed warming averaged over available stations. By contrast, it is *likely* that there has been an anthropogenic contribution to the very substantial Arctic warming since the mid-20th century. Human influence has *likely* contributed to temperature increases in many sub-continental regions. *{WGI SPM, 10.3, TS 4.8}*

It is *likely* that anthropogenic influences have affected the global water cycle since 1960. Anthropogenic influences have contributed to observed increases in atmospheric moisture content in the atmosphere (*medium confidence*), to global-scale changes in precipitation patterns over land (*medium confidence)*, to intensification of heavy precipitation over land regions where data are sufficient (*medium confidence*), and to changes in surface and subsurface ocean salinity (*very likely*). *{WG1 2.5, 2.6, 3.3, 7.6, 10.3, 10.4}*

It is *very likely* that anthropogenic forcings have made a substantial contribution to increases in global upper ocean heat content (0–700 m) observed since the 1970s (Figure 1.6). There is evidence for human influence in some individual ocean basins**.** It is *very likely* that there is a substantial anthropogenic contribution to the global mean sea level rise since the 1970s. This is based on the *high confidence* in an anthropogenic influence on the two largest contributions to sea level rise that is thermal expansion and glacier mass loss. Oceanic uptake of anthropogenic carbon dioxide has resulted in the acidification of ocean surface waters. *{WGI SPM, 3.2, 3.8, 10.4, 10.5, 13.3, Box 3.2, TS 4.4; WGII 6.1.1.2}*

Anthropogenic influences have *very likely* contributed to Arctic sea ice loss since 1979 (Figure 1.6). There is *low confidence* in the scientific understanding of the small observed increase in Antarctic sea ice extent due to the incomplete and competing scientific explanations for the causes of change and *low confidence* in estimates of internal variability in that region. *{WGI 10.5, Figure 10.6}*

Anthropogenic influences *likely* contributed to the retreat of glaciers since the 1960s and to the increased surface mass loss of the Greenland ice sheet since 1993. Due to a low level of scientific understanding, however, there is *low confidence* in attributing the causes of the observed loss of mass from the Antarctic ice sheet over the past two decades. It is *likely* that there has been an anthropogenic contribution to observed reductions in Northern Hemisphere spring snow cover since 1970. *{WGI 4.3, 10.5}*

1.4.2 Observed impacts attributed to climate change

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Evidence of climate-change impacts is strongest and most comprehensive for natural systems. 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 1.8). *{WGII 18.1, 18.3-6}*

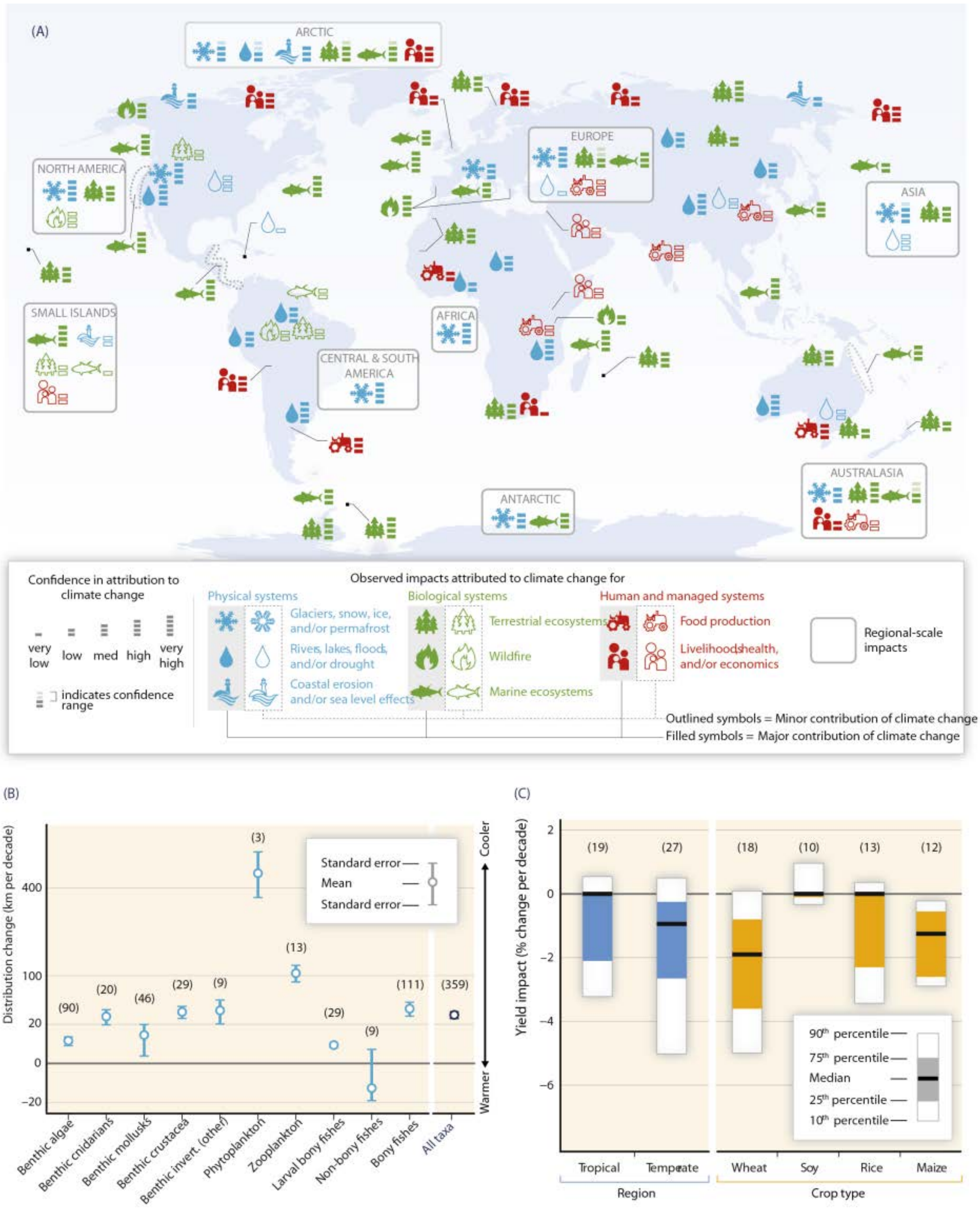


Figure 1.8: Widespread indicators of a changing climate. (A) Global patterns of observed climate change impacts in recent decades attributed to climate change, based on studies since the AR4. For categories of attributed impacts, symbols indicate affected systems and sectors, the relative contribution of climate change (major or minor) to the observed change, and confidence in attribution. (B) Average rates of change in distribution (km per decade) for marine taxonomic groups based on observations over 1900-2010. Positive distribution changes are consistent with warming (moving into previously cooler waters, generally poleward). The number of responses analyzed is given for each category. (C) Summary of estimated impacts of observed climate changes on yields over 1960-2013 for four major crops in temperate and tropical regions, with the number of data points analyzed given for each category. *{WGII Figures 3-3, 4-7, 7-2, 18-3, WGII MB-2, and WG II SPM.2}*

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*). Glaciers continue to shrink almost worldwide due to climate change (*high confidence*), affecting runoff and water resources downstream (*medium confidence*). Climate change is causing permafrost warming and thawing in high-latitude regions and in high-elevation regions (*high confidence*). *{WGII 3.2, 4.3, 18.3, 18.5, 24.4, 26.2, 28.2, WGII Tables 3-1 and 25-1, WGII Figures 18-2 and 26-1}*

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*). While only a few recent species extinctions have been attributed as yet to climate change (*high confidence*), natural global climate change at rates slower than current anthropogenic climate change caused significant ecosystem shifts and species extinctions during the past millions of years (*high confidence*). *{ WGII SPM.2B, WGII 4.2-4, 5.3-4, 6.1, 6.3-4, 18.3, 18.5, 22.3, 24.4, 25.6, 28.2, 30.4-5, WGII Boxes 4-2, 4-3, 25-3, CC-CR, and CC-MB}*

Based on many studies covering a wide range of regions and crops, negative impacts of climate change on crop yields have been more common than positive impacts (*high confidence*). The smaller number of studies showing positive impacts relate mainly to high-latitude regions, though it is not yet clear whether the balance of impacts has been negative or positive in these regions (*high confidence*). Climate change has negatively affected wheat and maize yields for many regions and in the global aggregate (*medium confidence*). Effects on rice and soybean yield have been smaller in major production regions and globally, with a median change of zero across all available data, which are fewer for soy compared to the other crops. Observed impacts relate mainly to production aspects of food security rather than access or other components of food security. See Figure SPM.2C. Since AR4, several periods of rapid food and cereal price increases following climate extremes in key producing regions indicate a sensitivity of current markets to climate extremes among other factors (*medium confidence*). *{WGII SPM.2C, WGII 7.2, 18.4, 22.3, 26.5, WGII Figures 7-2, 7-3, and 7-7}*

At present the world-wide burden of human ill-health from climate change is relatively small compared with effects of other stressors and is not well quantified. However, there has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming (*medium confidence*). Local changes in temperature and rainfall have altered the distribution of some water-borne illnesses and disease vectors (*medium confidence*). *{WG 11.4-6, 18.4, 25.8}*

"Cascading" impacts of climate change from physical climate through ecosystems on people can now be detected along chains of evidence. Examples include systems in the cryosphere, the oceans, and forests (Figure 1.9). *{WGII 18.6.3}* The changes in climate feeding into the cascade are in some cases linked to human drivers through studies (e.g., North American snowpack). In other cases, results from available studies linking climate change to human drivers are only available for different spatial and temporal scales, making it difficult to estimate the magnitude of the contribution by human influences to the observed impacts. *{WGI, 10; WGII 18.6.3}*

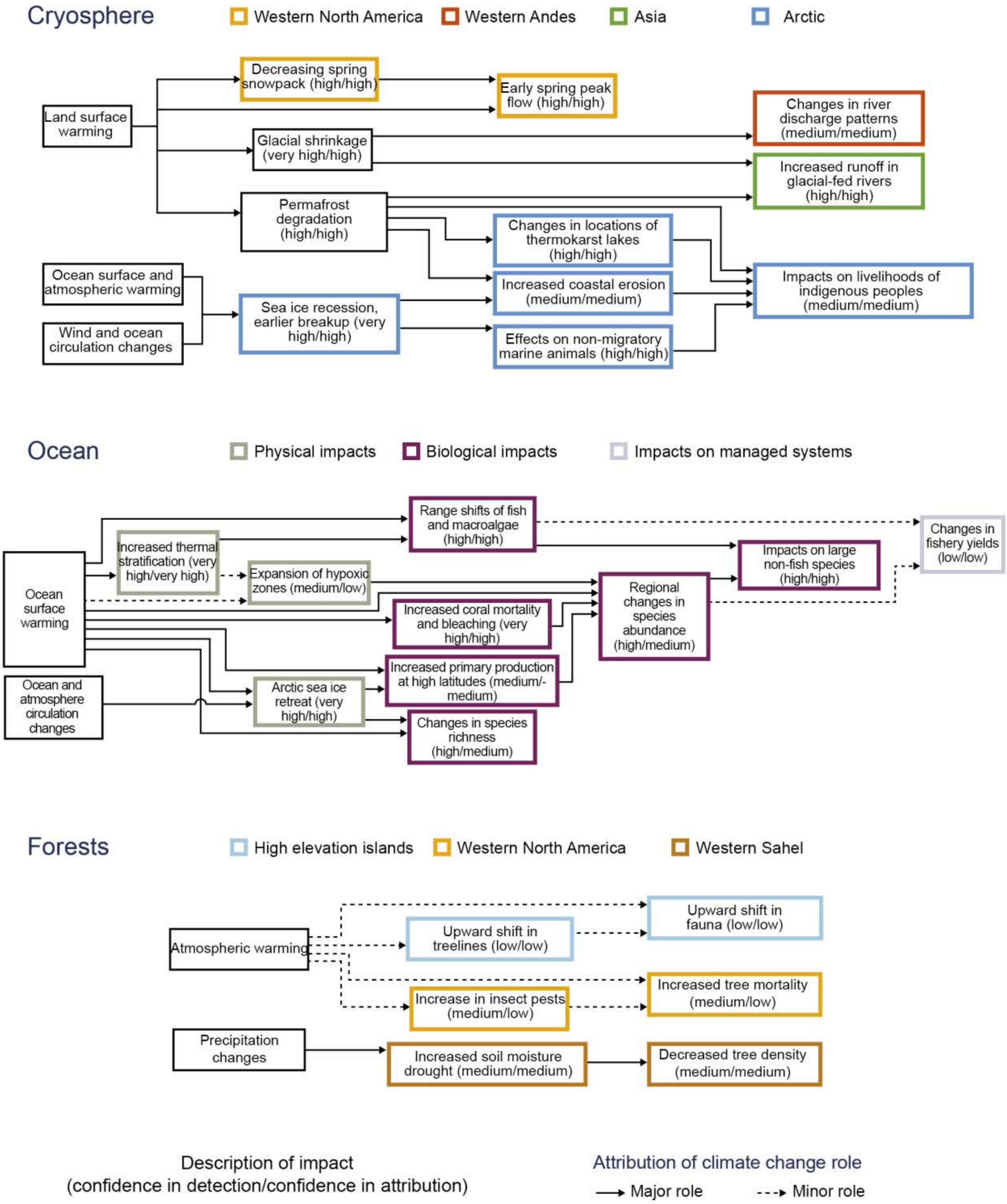


Figure 1.9: Major systems where new evidence indicates interconnected, 'cascading' impacts from recent climate change through several natural and human subsystems. Bracketed text indicates confidence in the detection of a climate change effect and the attribution of observed impacts to climate change. The role of climate change can be major (solid arrow) or minor (dashed arrow). *{WGII Figure 18-4; confidence assessed in WGII 18.3, 18.4, 18.5, and 18.6}*

1.5 Vulnerability, exposure and extreme events

Changes in many extreme weather and climate events have been observed since about 1950, including decrease in cold temperature extremes, increase in hot temperature extremes, and increase in high sea level events, and some of these changes have been linked to human influences. 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.

The character and severity of impacts from climate extremes depends not only on the extremes themselves but also on exposure and vulnerability and consequently does their associated risks. Exposure and vulnerability are influenced by a wide range of social and economic factors *{SREX SPM A}*, which make difficult to make quantitative assessments of their trends.

Changes in many extreme weather and climate events have been observed since about 1950. 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. *{WGI Table SPM.1, WGI FAQ 2.2, 2.6; 10.6; Table SPM.1}*

There has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming (*medium confidence*). *{WGII SPM A-1}* Extreme heat events currently result in increases in mortality and morbidity in North America (*very high confidence*), with impacts that vary by age, location and socioeconomic factors (*high confidence*). *{WGII 26.6.1.2}* In Europe, the summer 2003, which was the hottest summer in the last 500 years, caused 35,000 excess deaths. *{WGII Table 23.1}* An extreme warm event occurred in Moscow during July and August 2010 in the hottest summer since 1500 with estimated 10,000 excess deaths. *{WGII SPM A-1, WGII Table 23.1, WGII 26.6.1.2}*

There are *likely* more land regions where the number of heavy precipitation events has increased than where it has decreased. It is *very likely* that global near surface and tropospheric air specific humidity have increased since the 1970s. The frequency or intensity of heavy precipitation events has *likely* increased in North America and Europe. In other continents, *confidence* in changes in heavy precipitation events is at most *medium*. In land regions where observational coverage is sufficient for assessment, there is *medium confidence* that anthropogenic forcing has contributed to a global-scale intensification of heavy precipitation over the second half of the 20th century. *{WGI 2.6, 10.6, Table SPM.1, FAQ 2.2, SREX Table 3-2}*

There is *low confidence*, that anthropogenic climate change has affected the frequency and magnitude of floods at global scale. The strength of the evidence is limited mainly by lack of long-term records from unmanaged catchments. Moreover, floods are strongly influenced by direct management of the catchments, making the attribution of detected changes to climate change difficult. **However, recent detection of trends in extreme precipitation and discharge in some catchments implies greater risks of flooding at regional scale (*medium confidence*).** Flood damage costs worldwide have been increasing since the 1970s, although this is partly due to increasing exposure of people and assets. *{WGI 2.6.2; Figure 2.33; WGII 3.2.3}*

There is *low confidence* in observed global- scale trends in drought, due to lack of direct observations, dependencies of inferred trends on the choice of drought index, and due to geographical inconsistencies in drought trends. There is also *low confidence* in the attribution of changes in drought over global land areas since the mid-20th century, due to the same observational uncertainties and difficulties in distinguishing decadal scale variability in drought from long-term trends. *{WGI Table SPM1 2.6.2.2, Fig. 2-33b; 10.6}*

After accounting for changes in observing capabilities, there is *low confidence* that long-term changes in tropical cyclone activity are robust and there is *low confidence* in attribution of global changes to any particular cause. However, it is *virtually certain* that tropical cyclone intensity has increased in the North Atlantic since 1970. *{WG1: SPM, 2.6.3, 10.6}*

It is *likely* that extreme sea levels have increased since 1970, being mainly a result of rising mean sea level. Due to a shortage of studies and the difficulty to distinguish any such impacts from other modifications of coastal systems, limited evidence is available on impacts of sea level rise. *{WG1 3.7.4, 3.7.5, Figure 3-14, WGII 5.3.2.1}*

While changes in climate variables depend on the variable itself, as well as in geography, impact changes are even more geographically heterogeneous since they not only depend on changes of climate variables, but also on social and economic factors. Therefore is more frequent that they could be identified locally or regionally than at global scale.

Differences in vulnerability and exposure arise from non-climatic factors and from multidimensional inequalities often produced by uneven development processes (*very high confidence*). These differences shape differential risks from climate change. People who are socially, economically, culturally, politically, institutionally, or otherwise marginalized are especially vulnerable to climate change and also to some adaptation and mitigation responses (*medium evidence, high agreement*). This heightened vulnerability is rarely due to a single cause. Rather, it is the product of intersecting social processes that result in inequalities in socioeconomic status and income, as well as in exposure. Such social processes include, for example, discrimination on the basis of gender, class, ethnicity, age, and (dis)ability. *{WGII Figure SPM.1, WGII 8.1-2, 9.3-4, 10.9, 11.1, 11.3-5, 12.2-5, 13.1-3, 14.1-3, 18.4, 19.6, 23.5, 25.8, 26.6, 26.8, 28.4, WGII Box CC-GC}*

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*). Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality, and consequences for mental health and human well-being. For countries at all levels of development, these impacts are consistent with a significant lack of preparedness for current climate variability in some sectors. *{WGII 3.2, 4.2-3, 8.1, 9.3, 10.7, 11.3, 11.7, 13.2, 14.1, 18.6, 22.3, 25.6-8, 26.6-7, 30.5, WGII Tables 18-3 and 23-1, WGII Figure 26-2, WGII Boxes 4-3, 4-4, 25-5, 25-6, 25-8, and CC-CR}*

Direct and insured losses from weather-related disasters have increased substantially in recent decades both globally and regionally. *{SREX 4.5.3.3, WGII 10.7.3}* Most of this increase has been attributed to increasing exposure of more assets in risk areas. *{SREX 4.5.3.3, WGII 10.7.3, SREX SPM B}*

Climate-related hazards exacerbate other stressors, often with negative outcomes for livelihoods, especially for people living in poverty (*high confidence*). Climate-related hazards affect poor people's lives directly through impacts on livelihoods, reductions in crop yields, or destruction of homes and indirectly through, for example, increased food prices and food insecurity. Observed positive effects for poor and marginalized people, which are limited and often indirect, include examples such as diversification of social networks and of agricultural practices. *{WGII 8.2-3, 9.3, 11.3, 13.1-3, 22.3, 24.4, 26.8}*

Violent conflict increases vulnerability to climate change (*medium evidence, high agreement*). Large-scale violent conflict harms assets that facilitate adaptation, including infrastructure, institutions, natural resources, social capital, and livelihood opportunities. *{WGII 12.5, 19.2, 19.6}*

1.6 Adaptation experience

Adaptation experience is accumulating across regions in the public and private sector and within communities; and adaptation is becoming embedded in some planning processes, with more limited implementation of responses.

Throughout history, people and societies have adjusted to and coped with climate, climate variability, and extremes, with varying degrees of success. This section focuses on adaptive human responses to observed and projected climate-change impacts, which can also address broader risk-reduction and development objectives. Mitigation experience is discussed in Topic 4, Section 4.5.

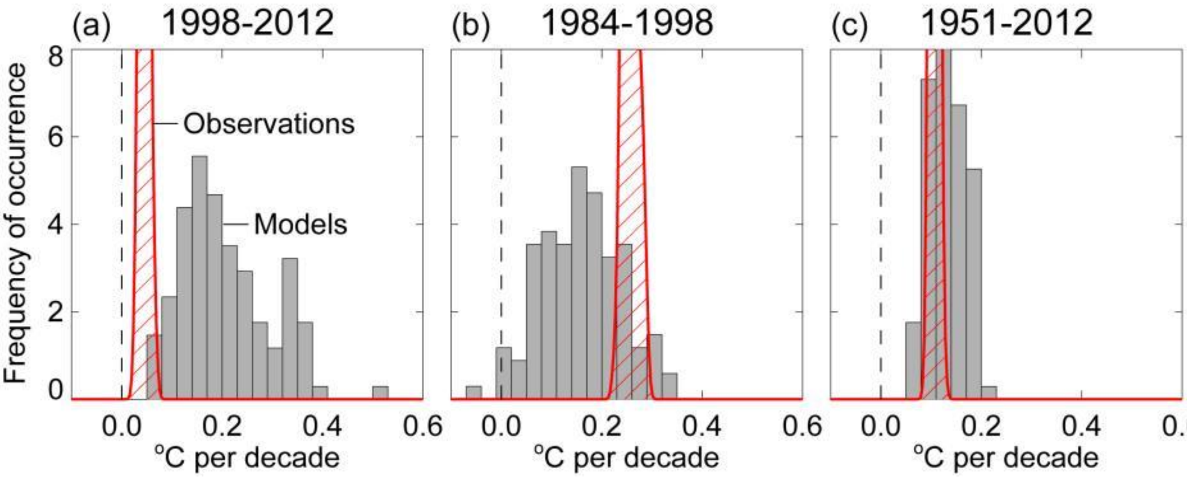
Adaptation is becoming embedded in some planning processes, with more limited implementation of responses (*high confidence*). Engineered and technological options are commonly implemented adaptive responses, often integrated within existing programs such as disaster risk management and water management. There is increasing recognition of the value of social, institutional, and ecosystem-based measures and of the extent of constraints to adaptation. Adaptation options adopted to date continue to emphasize incremental adjustments and co-benefits and are starting to emphasize flexibility and learning (*medium evidence, medium agreement*). Most assessments of adaptation have been restricted to impacts, vulnerability, and adaptation planning, with very few assessing the processes of implementation or the effects of adaptation actions (*medium evidence, high agreement*). *{WGII SPM}*

Adaptation experience is accumulating across regions in the public and private sector and within communities (*high confidence*). Governments at various levels are starting to develop adaptation plans and policies and to integrate climate-change considerations into broader development plans. Examples of adaptation across regions include the following.

- In Africa, most national governments are initiating governance systems for adaptation. Disaster risk management, adjustments in technologies and infrastructure, ecosystem-based approaches, basic public health measures, and livelihood diversification are reducing vulnerability, although efforts to date tend to be isolated.
- In Europe, adaptation policy has been developed across all levels of government, with some adaptation planning integrated into coastal and water management, into environmental protection and land planning, and into disaster risk management.
- In Asia, adaptation is being facilitated in some areas through mainstreaming climate adaptation action into subnational development planning, early warning systems, integrated water resources management, agroforestry, and coastal reforestation of mangroves.
- In Australasia, planning for sea-level rise, and in southern Australia for reduced water availability, is becoming adopted widely. Planning for sea-level rise has evolved considerably over the past two decades and shows a diversity of approaches, although its implementation remains piecemeal.
- In North America, governments are engaging in incremental adaptation assessment and planning, particularly at the municipal level. Some proactive adaptation is occurring to protect longer-term investments in energy and public infrastructure.
- In Central and South America, ecosystem-based adaptation including protected areas, conservation agreements, and community management of natural areas is occurring. Resilient crop varieties, climate forecasts, and integrated water resources management are being adopted within the agricultural sector in some areas.
- In the Arctic, some communities have begun to deploy adaptive co-management strategies and communications infrastructure, combining traditional and scientific knowledge.
- In small islands, which have diverse physical and human attributes, community-based adaptation has been shown to generate larger benefits when delivered in conjunction with other development activities.
- In the ocean, international cooperation and marine spatial planning are starting to facilitate adaptation to climate change, with constraints from challenges of spatial scale and governance issues. *{WGII SPM}*

Box 1.1: Recent temperature trends and their implications

There is *very high confidence* that climate models reproduce the general features of the global-scale annual mean surface temperature increase over the historical period, including the more rapid warming in the second half of the 20th century, and the cooling immediately following large volcanic eruptions. The observed recent decrease in the rate of surface warming is attributable in roughly equal measure to a cooling contribution from internal natural variability and a reduced trend in external forcing (expert judgment, *medium confidence*) (Box 1.1, Figure 1). {*WG1 Box TS.3,4, 2.4, 3.2, 3.7, 8.5, 9.4; Table 2.7; Box 9.2, Box 12.2, Box 13.2*}



Box 1.1, Figure 1: Trends in the global-mean surface temperature over the periods 1998–2012 (a), 1984–1998 (b), and 1951–2012 (c), from observations (red) and the 114 available simulations with current-generation climate models (grey bars). The width of the red-hatched area indicates the statistical uncertainty that arises from constructing a global average from individual station data. The height of each grey bar indicates how often a trend of a certain magnitude (in °C per decade) occurs among the 114 simulations. *{based on WG1 Box 9.2 Figure 1}*

The long-term surface-warming trend observed over 1951–2012 (Figure 1.1a) is consistent with simulations of the historical period with current climate models over the same period (Box SYR.1, Figure 1c, *very high confidence*). The record of observed climate change has also allowed characterisation of the basic properties of the climate system that have implications for future warming, including the equilibrium climate sensitivity (ECS) and the transient climate response (TCR) and thus contributes to the assessment of both climate system properties (see SYR topic 2; WGI 10.8, Box 12.2)**.** Conversely, the independent estimates of radiative forcing, of observed heat storage, and of surface warming that have been available since 1970 combine to give a heat budget for the Earth that is consistent with the assessed *likely* range of equilibrium climate sensitivity (1.5–4.5 ºC)[9].

The rate of warming of the observed global-mean surface temperature has been smaller over the past 15 years (1998–2012) than over the past 30 to 60 years (Box 1.1, Figure 1) and is estimated to be around one-third to one-half of the trend over the period 1951–2012. Nevertheless, the decade of the 2000s has been the warmest in the instrumental record (Figure SYR.1a). *{WGI Box TS.3}*

The radiative forcing of the climate system has continued to increase during the 2000s, as has its largest contributor, the atmospheric concentration of CO_2. Consistent with this radiative forcing, the climate system has *very likely* continued to accumulate heat since 1998, and sea level has continued to rise. The radiative forcing of the climate system has been increasing to a lesser rate over the period 1998–2011 compared to 1984 to 1998 or 1951–2011, due to a downward forcing trend from volcanic eruptions and the downward phase of the solar cycle over 2000–2009. However, there is *low confidence* in quantifying the role of forcing trend in causing the reduction in the rate of surface warming, because of uncertainty in the magnitude of the

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[9] The connection of the heat budget to equilibrium climate sensitivity, which is the long-term surface warming under an assumed doubling of the atmospheric CO_2 concentration, arises because a warmer surface causes enhanced radiation to space, which counteracts the increase in Earth's heat content. How much the radiation to space increases for a given increase in surface temperature, depends on the same feedback processes that determine equilibrium climate sensitivity.

volcanic forcing trend and *low confidence* in the forcing trend due to tropospheric aerosol. *{WG1 8.5; WG1 Box 9.2}*

For the period 1998–2012, 111 of the 114 climate-model simulations show a surface-warming trend larger than the observations (Box 1.1, Figure 1a). There is *medium confidence* that this difference between models and observations is to a substantial degree caused by unpredictable internal climate variability. Variability sometimes enhances and sometimes counteracts the long-term externally forced warming trend (Box 1.1, Figure 1). Internal variability thus diminishes the relevance of short trends for long-term climate change. The difference between models and observations may also contain contributions from inadequacies in the solar, volcanic, and aerosol forcings used by the models and, in some models, from too strong a response to increasing greenhouse gases and other anthropogenic factors. *{WG1 2.4, 9.3, 9.4; 10.3, 11.2, 11.3, WG1 Box 9.2}*