This Summary for Policymakers should be cited as:

A. Introduction

The Working Group I contribution to the IPCC’s Fifth Assessment Report (AR5) considers new evidence of climate change based on many independent scientific analyses from observations of the climate system, paleoclimate archives, theoretical studies of climate processes and simulations using climate models. It builds upon the Working Group I contribution to the IPCC’s Fourth Assessment Report (AR4), and incorporates subsequent new findings of research. As a component of the fifth assessment cycle, the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) is an important basis for information on changing weather and climate extremes.

This Summary for Policymakers (SPM) follows the structure of the Working Group I report. The narrative is supported by a series of overarching highlighted conclusions which, taken together, provide a concise summary. Main sections are introduced with a brief paragraph in italics which outlines the methodological basis of the assessment.

The degree of certainty in key findings in this assessment 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). Confidence in the validity of a finding is based on the type, amount, quality, and consistency of evidence (e.g., data, mechanistic understanding, theory, models, expert judgment) and the degree of agreement. Probabilistic estimates of quantified measures of uncertainty in a finding are based on statistical analysis of observations or model results, or both, and expert judgment. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers. (See Chapter 1 and Box TS.1 for more details about the specific language the IPCC uses to communicate uncertainty).

The basis for substantive paragraphs in this Summary for Policymakers can be found in the chapter sections of the underlying report and in the Technical Summary. These references are given in curly brackets.

B. Observed Changes in the Climate System

Observations of the climate system are based on direct measurements and remote sensing from satellites and other platforms. Global-scale observations from the instrumental era began in the mid-19th century for temperature and other variables, with more comprehensive and diverse sets of observations available for the period 1950 onwards. Paleoclimate reconstructions extend some records back hundreds to millions of years. Together, they provide a comprehensive view of the variability and long-term changes in the atmosphere, the ocean, the cryosphere, and the land surface.

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, sea level has risen, and the concentrations of greenhouse gases have increased (see Figures SPM.1, SPM.2, SPM.3 and SPM.4). (2.2, 2.4, 3.2, 3.7, 4.2–4.7, 5.2, 5.3, 5.5–5.6, 6.2, 13.2)

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1 In this Summary for Policymakers, the following summary terms are used to describe the available evidence: limited, medium, or robust; and for the degree of agreement: 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. For a given evidence and agreement statement, different confidence levels can be assigned, but increasing levels of evidence and degrees of agreement are correlated with increasing confidence (see Chapter 1 and Box TS.1 for more details).

2 In this Summary for Policymakers, 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%, and extremely unlikely 0–5%) may also be used when appropriate. Assessed likelihood is typeset in italics, e.g., very likely (see Chapter 1 and Box TS.1 for more details).
Each of the last three decades has been successively warmer at the Earth’s surface than any preceding decade since 1850 (see Figure SPM.1). In the Northern Hemisphere, 1983–2012 was likely the warmest 30-year period of the last 1400 years (medium confidence). (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, based on the single longest dataset available (see Figure SPM.1). (2.4)

- For the longest period when calculation of regional trends is sufficiently complete (1901 to 2012), almost the entire globe has experienced surface warming (see Figure SPM.1). (2.4)

- In addition to robust multi-decadal warming, global mean surface temperature exhibits substantial decadal and interannual variability (see Figure SPM.1). Due to 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 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). (2.4)

- Continental-scale surface temperature reconstructions show, with high confidence, multi-decadal periods during the Medieval Climate Anomaly (year 950 to 1250) that were in some regions as warm as in the late 20th century. These regional warm periods did not occur as coherently across regions as the warming in the late 20th century (high confidence). (5.5)

- It is virtually certain that globally the troposphere has warmed since the mid-20th century. More complete observations allow greater confidence in estimates of tropospheric temperature changes in the extratropical Northern Hemisphere than elsewhere. There is medium confidence in the rate of warming and its vertical structure in the Northern Hemisphere extratropical troposphere and low confidence elsewhere. (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 (see Figure SPM.2). (TS TFE.1, Figure 2; 2.5)

- Changes in many extreme weather and climate events have been observed since about 1950 (see Table SPM.1 for details). 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. There are likely more land regions where the number of heavy precipitation events has increased than where it has decreased. 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. (2.6)

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3 In the WGI contribution to the AR5, uncertainty is quantified using 90% uncertainty intervals unless otherwise stated. The 90% uncertainty interval, reported in square brackets, is expected to have a 90% likelihood of covering the value that is being estimated. Uncertainty intervals are not necessarily symmetric about the corresponding best estimate. A best estimate of that value is also given where available.

4 Both methods presented in this bullet were also used in AR4. The first calculates the difference using a best fit linear trend of all points between 1880 and 2012. The second calculates the difference between averages for the two periods 1850–1900 and 2003–2012. Therefore, the resulting values and their 90% uncertainty intervals are not directly comparable. (2.4)

5 Trends for 15-year periods starting in 1995, 1996, and 1997 are 0.13 [0.02 to 0.24] °C per decade, 0.14 [0.03 to 0.24] °C per decade, and 0.07 [–0.02 to 0.18] °C per decade, respectively.

6 See the Glossary for the definition of these terms: cold days/cold nights, warm days/warm nights, heat waves.
Figure SPM.1 | (a) Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. Top panel: annual mean values. Bottom panel: decadal mean values including the estimate of uncertainty for one dataset (black). Anomalies are relative to the mean of 1961–1990. (b) Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset (orange line in panel a). Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign. For a listing of the datasets and further technical details see the Technical Summary Supplementary Material. (Figures 2.19–2.21; Figure TS.2)
<table>
<thead>
<tr>
<th>Phenomenon and direction of trend</th>
<th>Assessment of human contribution to observed changes</th>
<th>Likelihood of further changes</th>
<th>Early 21st century</th>
<th>Late 21st century</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warmer and/or fewer cold days and nights over most land areas</td>
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<td>Likely (very likely)</td>
<td>[2.6]</td>
<td>[12.4]</td>
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<tr>
<td>Warmer and/or more frequent heat waves and nights over most land areas</td>
<td>Very likely</td>
<td>Very likely</td>
<td>[10.6]</td>
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</tr>
<tr>
<td>Frequency and/or duration of drought</td>
<td>Medium confidence on a global scale</td>
<td>Likely</td>
<td>[11.3]</td>
<td>[13.7]</td>
</tr>
<tr>
<td>Heavy precipitation events, increases in the frequency, intensity, and/or amount of heavy precipitation</td>
<td>Likely</td>
<td>Likely</td>
<td>[10.6]</td>
<td>[13.7]</td>
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<td>Medium confidence in some regions</td>
<td>Likely</td>
<td>[7.6, 10.6]</td>
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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 (see Figure SPM.3), and it likely warmed between the 1870s and 1971. (3.2, Box 3.1)

- 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. Since AR4, instrumental biases in upper-ocean temperature records have been identified and reduced, enhancing confidence in the assessment of change. (3.2)

- It is likely that the ocean warmed between 700 and 2000 m from 1957 to 2009. Sufficient observations are available for the period 1992 to 2005 for a global assessment of temperature change below 2000 m. There were likely no significant observed temperature trends between 2000 and 3000 m for this period. It is likely that the ocean warmed from 3000 m to the bottom for this period, with the largest warming observed in the Southern Ocean. (3.2)

- More than 60% of the net energy increase in the climate system is stored in the upper ocean (0–700 m) during the relatively well-sampled 40-year period from 1971 to 2010, and about 30% is stored in the ocean below 700 m. The increase in upper ocean heat content during this time period estimated from a linear trend is likely 17 [15 to 19] × 10^22 J (see Figure SPM.3). (3.2, Box 3.1)

- It is about as likely as not that ocean heat content from 0–700 m increased more slowly during 2003 to 2010 than during 1993 to 2002 (see Figure SPM.3). Ocean heat uptake from 700–2000 m, where interannual variability is smaller, likely continued unabated from 1993 to 2009. (3.2, Box 9.2)

- 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). (2.5, 3.3, 3.5)

- There is no observational evidence of a 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. (3.6)

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\(^7\) A constant supply of heat through the ocean surface at the rate of 1 W m\(^{-2}\) for 1 year would increase the ocean heat content by 1.1 × 10^22 J.
### B.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*) (see Figure SPM.3). (4.2–4.7)

- The average rate of ice loss\(^8\) from glaciers around the world, excluding glaciers on the periphery of the ice sheets\(^9\), was *very likely* 226 [91 to 361] Gt yr\(^{-1}\) over the period 1971 to 2009, and *very likely* 275 [140 to 410] Gt yr\(^{-1}\) over the period 1993 to 2009\(^{10}\). (4.3)

- 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. (4.4)

- 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. (4.4)

- 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 (perennial sea ice). The average decrease in decadal mean extent of Arctic sea ice has been most rapid in summer (*high confidence*); the spatial extent has decreased in every season, and in every successive decade since 1979 (*high confidence*) (see Figure SPM.3). There is medium confidence from reconstructions that over the past three decades, Arctic summer sea ice retreat was unprecedented and sea surface temperatures were anomalously high in at least the last 1,450 years. (4.2, 5.5)

- 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. There is *high confidence* that there are strong regional differences in this annual rate, with extent increasing in some regions and decreasing in others. (4.2)

- There is very *high confidence* that the extent of Northern Hemisphere snow cover has decreased since the mid-20th century (see Figure SPM.3). Northern Hemisphere snow cover extent decreased 1.6 [0.8 to 2.4] % per decade for March and April, and 11.7 [8.8 to 14.6] % per decade for June, over the 1967 to 2012 period. During this period, snow cover extent in the Northern Hemisphere did not show a statistically significant increase in any month. (4.5)

- There is *high confidence* that permafrost temperatures have increased in most regions since the early 1980s. Observed warming was up to 3°C in parts of Northern Alaska (early 1980s to mid-2000s) and up to 2°C in parts of the Russian European North (1971 to 2010). In the latter region, a considerable reduction in permafrost thickness and areal extent has been observed over the period 1975 to 2005 (*medium confidence*). (4.7)

- Multiple lines of evidence support very substantial Arctic warming since the mid-20th century. (Box 5.1, 10.3)

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8 All references to ‘ice loss’ or ‘mass loss’ refer to net ice loss, i.e., accumulation minus melt and iceberg calving.

9 For methodological reasons, this assessment of ice loss from the Antarctic and Greenland ice sheets includes change in the glaciers on the periphery. These peripheral glaciers are thus excluded from the values given for glaciers.

10 100 Gt yr\(^{-1}\) of ice loss is equivalent to about 0.28 mm yr\(^{-1}\) of global mean sea level rise.
Figure SPM.3 | Multiple observed indicators of a changing global climate: (a) Extent of Northern Hemisphere March-April (spring) average snow cover; (b) extent of Arctic July-August-September (summer) average sea ice; (c) change in global mean upper ocean (0–700 m) heat content aligned to 2006–2010, and relative to the mean of all datasets for 1970; (d) global mean sea level relative to the 1900–1905 mean of the longest running dataset, and with all datasets aligned to have the same value in 1993, the first year of satellite altimetry data. All time-series (coloured lines indicating different data sets) show annual values, and where assessed, uncertainties are indicated by coloured shading. See Technical Summary Supplementary Material for a listing of the datasets. (Figures 3.2, 3.13, 4.19, and 4.3; FAQ 2.1, Figure 2; Figure TS.1)
B.4 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 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (see Figure SPM.3). (3.7, 5.6, 13.2)

- Proxy and instrumental sea level data indicate a transition in the late 19th to the early 20th century from relatively low mean rates of rise over the previous two millennia to higher rates of rise (high confidence). It is likely that the rate of global mean sea level rise has continued to increase since the early 20th century. (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. (3.7)

- 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 to 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 (1.1 [0.8 to 1.4] mm yr\(^{-1}\)), from changes in glaciers (0.76 [0.39 to 1.13] mm yr\(^{-1}\)), Greenland ice sheet (0.33 [0.25 to 0.41] mm yr\(^{-1}\)), Antarctic ice sheet (0.27 [0.16 to 0.38] mm yr\(^{-1}\)), and land water storage (0.38 [0.26 to 0.49] mm yr\(^{-1}\)). The sum of these contributions is 2.8 [2.3 to 3.4] mm yr\(^{-1}\). (13.3)

- 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). (5.3, 5.6)

B.5 Carbon and Other Biogeochemical Cycles

The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification (see Figure SPM.4). (2.2, 3.8, 5.2, 6.2, 6.3)

- The atmospheric concentrations of the greenhouse gases carbon dioxide (CO\(_2\)), methane (CH\(_4\)), and nitrous oxide (N\(_2\)O) have all increased since 1750 due to human activity. In 2011 the concentrations of these greenhouse gases were 391 ppm\(^{11}\), 1803 ppb, and 324 ppb, and exceeded the pre-industrial levels by about 40%, 150%, and 20%, respectively. (2.2, 5.2, 6.1, 6.2)

- Concentrations of CO\(_2\), CH\(_4\), and N\(_2\)O now substantially exceed the highest concentrations recorded in ice cores during the past 800,000 years. The mean rates of increase in atmospheric concentrations over the past century are, with very high confidence, unprecedented in the last 22,000 years. (5.2, 6.1, 6.2)

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\(^{11}\) ppm (parts per million) or ppb (parts per billion, 1 billion = 1,000 million) is the ratio of the number of gas molecules to the total number of molecules of dry air. For example, 300 ppm means 300 molecules of a gas per million molecules of dry air.
- Annual CO$_2$ emissions from fossil fuel combustion and cement production were 8.3 [7.6 to 9.0] GtC$^{12}$ yr$^{-1}$ averaged over 2002–2011 (high confidence) and were 9.5 [8.7 to 10.3] GtC yr$^{-1}$ in 2011, 54% above the 1990 level. Annual net CO$_2$ emissions from anthropogenic land use change were 0.9 [0.1 to 1.7] GtC yr$^{-1}$ on average during 2002 to 2011 (medium confidence). (6.3)

- From 1750 to 2011, CO$_2$ emissions from fossil fuel combustion and cement production have released 375 [345 to 405] GtC to the atmosphere, while deforestation and other land use change are estimated to have released 180 [100 to 260] GtC. This results in cumulative anthropogenic emissions of 555 [470 to 640] GtC. (6.3)

- Of these cumulative anthropogenic CO$_2$ emissions, 240 [230 to 250] GtC have accumulated in the atmosphere, 155 [125 to 185] GtC have been taken up by the ocean and 160 [70 to 250] GtC have accumulated in natural terrestrial ecosystems (i.e., the cumulative residual land sink). (Figure TS.4, 3.8, 6.3)

- Ocean acidification is quantified by decreases in pH$^{13}$. The pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (high confidence), corresponding to a 26% increase in hydrogen ion concentration (see Figure SPM.4). (3.8, Box 3.2)

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**Figure SPM.4** | Multiple observed indicators of a changing global carbon cycle: (a) atmospheric concentrations of carbon dioxide (CO$_2$) from Mauna Loa (19°32'N, 155°34'W – red) and South Pole (89°59'S, 24°48'W – black) since 1958; (b) partial pressure of dissolved CO$_2$ at the ocean surface (blue curves) and in situ pH (green curves), a measure of the acidity of ocean water. Measurements are from three stations from the Atlantic (29°10’N, 15°30’W – dark blue/dark green; 31°40’N, 64°10’W – blue/green) and the Pacific Oceans (22°45’N, 158°00’W – light blue/light green). Full details of the datasets shown here are provided in the underlying report and the Technical Summary Supplementary Material. (Figures 2.1 and 3.18; Figure TS.5)

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$^{12}$ 1 Gigatonne of carbon = 1 GtC = $10^{15}$ grams of carbon. This corresponds to 3.667 GtCO$_2$.

$^{13}$ pH is a measure of acidity using a logarithmic scale: a pH decrease of 1 unit corresponds to a 10-fold increase in hydrogen ion concentration, or acidity.
C. Drivers of Climate Change

Natural and anthropogenic substances and processes that alter the Earth’s energy budget are drivers of climate change. Radiative forcing (RF) quantifies the change in energy fluxes caused by changes in these drivers for 2011 relative to 1750, unless otherwise indicated. Positive RF leads to surface warming, negative RF leads to surface 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. Some emitted compounds affect the atmospheric concentration of other substances. The RF can be reported based on the concentration changes of each substance. Alternatively, the emission-based RF of a compound can be reported, which provides a more direct link to human activities. It includes contributions from all substances affected by that emission. The total anthropogenic RF of the two approaches are identical when considering all drivers. Though both approaches are used in this Summary for Policymakers, emission-based RFs are emphasized.

Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO₂ since 1750 (see Figure SPM.5). (3.2, Box 3.1, 8.3, 8.5)

- The total anthropogenic RF for 2011 relative to 1750 is 2.29 [1.13 to 3.33] W m⁻² (see Figure SPM.5), and it has increased more rapidly since 1970 than during prior decades. The total anthropogenic RF best estimate for 2011 is 43% higher than that 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 (negative RF). (8.5)

- The RF from emissions of well-mixed greenhouse gases (CO₂, CH₄, N₂O, and Halocarbons) for 2011 relative to 1750 is 3.00 [2.22 to 3.78] W m⁻² (see Figure SPM.5). The RF from changes in concentrations in these gases is 2.83 [2.26 to 3.40] W m⁻². (8.5)

- Emissions of CO₂ alone have caused an RF of 1.68 [1.33 to 2.03] W m⁻² (see Figure SPM.5). Including emissions of other carbon-containing gases, which also contributed to the increase in CO₂ concentrations, the RF of CO₂ is 1.82 [1.46 to 2.18] W m⁻². (8.3, 8.5)

- Emissions of CH₄ alone have caused an RF of 0.97 [0.74 to 1.20] W m⁻² (see Figure SPM.5). This is much larger than the concentration-based estimate of 0.48 [0.38 to 0.58] W m⁻² (unchanged from AR4). This difference in estimates is caused by concentration changes in ozone and stratospheric water vapour due to CH₄ emissions and other emissions indirectly affecting CH₄. (8.3, 8.5)

- Emissions of stratospheric ozone-depleting halocarbons have caused a net positive RF of 0.18 [0.01 to 0.35] W m⁻² (see Figure SPM.5). Their own positive RF has outweighed the negative RF from the ozone depletion that they have induced. The positive RF from all halocarbons is similar to the value in AR4, with a reduced RF from CFCs but increases from many of their substitutes. (8.3, 8.5)

- Emissions of short-lived gases contribute to the total anthropogenic RF. Emissions of carbon monoxide (CO) are virtually certain to have induced a positive RF, while emissions of nitrogen oxides (NOₓ) are likely to have induced a net negative RF (see Figure SPM.5). (8.3, 8.5)

- The RF of the total aerosol effect in the atmosphere, which includes cloud adjustments due to aerosols, is −0.9 [−1.9 to −0.1] W m⁻² (medium confidence), and results from a negative forcing from most aerosols and a positive contribution

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14 The strength of drivers is quantified as Radiative Forcing (RF) in units watts per square metre (W m⁻²) as in previous IPCC assessments. RF is the change in energy flux caused by a driver, and is calculated at the tropopause or at the top of the atmosphere. In the traditional RF concept employed in previous IPCC reports all surface and tropospheric conditions are kept fixed. In calculations of RF for well-mixed greenhouse gases and aerosols in this report, physical variables, except for the ocean and sea ice, are allowed to respond to perturbations with rapid adjustments. The resulting forcing is called Effective Radiative Forcing (ERF) in the underlying report. This change reflects the scientific progress from previous assessments and results in a better indication of the eventual temperature response for these drivers. For all drivers other than well-mixed greenhouse gases and aerosols, rapid adjustments are less well characterized and assumed to be small, and thus the traditional RF is used. (8.1)

15 This approach was used to report RF in the AR4 Summary for Policymakers.
from black carbon absorption of solar radiation. There is high confidence that aerosols and their interactions with clouds have offset a substantial portion of global mean forcing from well-mixed greenhouse gases. They continue to contribute the largest uncertainty to the total RF estimate. (7.5, 8.3, 8.5)

- The forcing from stratospheric volcanic aerosols can have a large impact on the climate for some years after volcanic eruptions. Several small eruptions have caused an RF of −0.11 [−0.15 to −0.08] W m⁻² for the years 2008 to 2011, which is approximately twice as strong as during the years 1999 to 2002. (8.4)

- The RF due to changes in solar irradiance is estimated as 0.05 [0.00 to 0.10] W m⁻² (see Figure SPM.5). Satellite observations of total solar irradiance changes from 1978 to 2011 indicate that the last solar minimum was lower than the previous two. This results in an RF of −0.04 [−0.08 to 0.00] W m⁻² between the most recent minimum in 2008 and the 1986 minimum. (8.4)

- The total natural RF from solar irradiance changes and stratospheric volcanic aerosols made only a small contribution to the net radiative forcing throughout the last century, except for brief periods after large volcanic eruptions. (8.5)

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**Figure SPM.5** Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Values are global average radiative forcing (RF), partitioned according to the emitted compounds or processes that result in a combination of drivers. The best estimates of the net radiative forcing are shown as black diamonds with corresponding uncertainty intervals; the numerical values are provided on the right of the figure, together with the confidence level in the net forcing (VH – very high, H – high, M – medium, L – low, VL – very low). Albedo forcing due to black carbon on snow and ice is included in the black carbon aerosol bar. Small forcings due to contrails (0.05 W m⁻², including contrail induced cirrus), and HFCs, PFCs and SF₆ (total 0.03 W m⁻²) are not shown. Concentration-based RFs for gases can be obtained by summing the like-coloured bars. Volcanic forcing is not included as its episodic nature makes it difficult to compare to other forcing mechanisms. Total anthropogenic radiative forcing is provided for three different years relative to 1750. For further technical details, including uncertainty ranges associated with individual components and processes, see the Technical Summary Supplementary Material. (8.5; Figures 8.14–8.18; Figures TS.6 and TS.7)
D. Understanding the Climate System and its Recent Changes

Understanding recent changes in the climate system results from combining observations, studies of feedback processes, and model simulations. Evaluation of the ability of climate models to simulate recent changes requires consideration of the state of all modelled climate system components at the start of the simulation and the natural and anthropogenic forcing used to drive the models. Compared to AR4, more detailed and longer observations and improved climate models now enable the attribution of a human contribution to detected changes in more climate system components.

Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system. (2–14)

D.1 Evaluation of Climate Models

Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions (very high confidence). (9.4, 9.6, 9.8)

- The long-term climate model simulations show a trend in global-mean surface temperature from 1951 to 2012 that agrees with the observed trend (very high confidence). There are, however, differences between simulated and observed trends over periods as short as 10 to 15 years (e.g., 1998 to 2012). (9.4, Box 9.2)

- The observed reduction in surface warming trend over the period 1998 to 2012 as compared to the period 1951 to 2012, is due in roughly equal measure to a reduced trend in radiative forcing and a cooling contribution from natural internal variability, which includes a possible redistribution of heat within the ocean (medium confidence). The reduced trend in radiative forcing is primarily due to volcanic eruptions and the timing of the downward phase of the 11-year solar cycle. However, there is low confidence in quantifying the role of changes in radiative forcing in causing the reduced warming trend. There is medium confidence that natural internal decadal variability causes to a substantial degree the difference between observations and the simulations; the latter are not expected to reproduce the timing of natural internal variability. There may also be a contribution from forcing inadequacies and, in some models, an overestimate of the response to increasing greenhouse gas and other anthropogenic forcing (dominated by the effects of aerosols). (9.4, Box 9.2, 10.3, Box 10.2, 11.3)

- On regional scales, the confidence in model capability to simulate surface temperature is less than for the larger scales. However, there is high confidence that regional-scale surface temperature is better simulated than at the time of the AR4. (9.4, 9.6)

- There has been substantial progress in the assessment of extreme weather and climate events since AR4. Simulated global-mean trends in the frequency of extreme warm and cold days and nights over the second half of the 20th century are generally consistent with observations. (9.5)

- There has been some improvement in the simulation of continental-scale patterns of precipitation since the AR4. At regional scales, precipitation is not simulated as well, and the assessment is hampered by observational uncertainties. (9.4, 9.6)

- Some important climate phenomena are now better reproduced by models. There is high confidence that the statistics of monsoon and El Niño-Southern Oscillation (ENSO) based on multi-model simulations have improved since AR4. (9.5)
• Climate models now include more cloud and aerosol processes, and their interactions, than at the time of the AR4, but there remains low confidence in the representation and quantification of these processes in models. (7.3, 7.6, 9.4, 9.7)

• There is robust evidence that the downward trend in Arctic summer sea ice extent since 1979 is now reproduced by more models than at the time of the AR4, with about one-quarter of the models showing a trend as large as, or larger than, the trend in the observations. Most models simulate a small downward trend in Antarctic sea ice extent, albeit with large inter-model spread, in contrast to the small upward trend in observations. (9.4)

• Many models reproduce the observed changes in upper-ocean heat content (0–700 m) from 1961 to 2005 (high confidence), with the multi-model mean time series falling within the range of the available observational estimates for most of the period. (9.4)

• Climate models that include the carbon cycle (Earth System Models) simulate the global pattern of ocean-atmosphere CO₂ fluxes, with outgassing in the tropics and uptake in the mid and high latitudes. In the majority of these models the sizes of the simulated global land and ocean carbon sinks over the latter part of the 20th century are within the range of observational estimates. (9.4)

D.2 Quantification of Climate System Responses

Observational and model studies of temperature change, climate feedbacks and changes in the Earth’s energy budget together provide confidence in the magnitude of global warming in response to past and future forcing. (Box 12.2, Box 13.1)

• The net feedback from the combined effect of changes in water vapour, and differences between atmospheric and surface warming is extremely likely positive and therefore amplifies changes in climate. The net radiative feedback due to all cloud types combined is likely positive. Uncertainty in the sign and magnitude of the cloud feedback is due primarily to continuing uncertainty in the impact of warming on low clouds. (7.2)

• The equilibrium climate sensitivity quantifies the response of the climate system to constant radiative forcing on multi-century time scales. It is defined as the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric CO₂ concentration. Equilibrium climate sensitivity is likely in the range 1.5°C to 4.5°C (high confidence), extremely unlikely less than 1°C (high confidence), and very unlikely greater than 6°C (medium confidence). The lower temperature limit of the assessed likely range is thus less than the 2°C in the AR4, but the upper limit is the same. This assessment reflects improved understanding, the extended temperature record in the atmosphere and ocean, and new estimates of radiative forcing. (TS TFE.6, Figure 1; Box 12.2)

• The rate and magnitude of global climate change is determined by radiative forcing, climate feedbacks and the storage of energy by the climate system. Estimates of these quantities for recent decades are consistent with the assessed likely range of the equilibrium climate sensitivity to within assessed uncertainties, providing strong evidence for our understanding of anthropogenic climate change. (Box 12.2, Box 13.1)

• The transient climate response quantifies the response of the climate system to an increasing radiative forcing on a decadal to century timescale. It is defined as the change in global mean surface temperature at the time when the atmospheric CO₂ concentration has doubled in a scenario of concentration increasing at 1% per year. The transient climate response is likely in the range of 1.0°C to 2.5°C (high confidence) and extremely unlikely greater than 3°C. (Box 12.2)

• A related quantity is the transient climate response to cumulative carbon emissions (TCRE). It quantifies the transient response of the climate system to cumulative carbon emissions (see Section E.8). TCRE is defined as the global mean

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16 No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies.
surface temperature change per 1000 GtC emitted to the atmosphere. TCRE is likely in the range of 0.8°C to 2.5°C per 1000 GtC and applies for cumulative emissions up to about 2000 GtC until the time temperatures peak (see Figure SPM.10). (12.5, Box 12.2)

- Various metrics can be used to compare the contributions to climate change of emissions of different substances. The most appropriate metric and time horizon will depend on which aspects of climate change are considered most important to a particular application. No single metric can accurately compare all consequences of different emissions, and all have limitations and uncertainties. The Global Warming Potential is based on the cumulative radiative forcing over a particular time horizon, and the Global Temperature Change Potential is based on the change in global mean surface temperature at a chosen point in time. Updated values are provided in the underlying Report. (8.7)

D.3 Detection and Attribution of Climate Change

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (see Figure SPM.6 and Table SPM.1). 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. (10.3–10.6, 10.9)

- 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. (10.3)

- 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 to 2010, with the contributions from other anthropogenic forcings, including the cooling effect of aerosols, likely to be in the range of −0.6°C to 0.1°C. The contribution from natural forcings is likely to be in the range of −0.1°C to 0.1°C, and from natural internal variability is likely to be 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. (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 (see Figure SPM.6). For Antarctica, large observational uncertainties result in low confidence that anthropogenic forcings have contributed to the observed warming averaged over available stations. It is likely that there has been an anthropogenic contribution to the very substantial Arctic warming since the mid-20th century. (2.4, 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. (2.4, 9.4, 10.3)

- 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 (see Figure SPM.6). There is evidence for human influence in some individual ocean basins. (3.2, 10.4)

- 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 sub-surface ocean salinity (very likely). (2.5, 2.6, 3.3, 7.6, 10.3, 10.4)
Figure SPM.6 | Comparison of observed and simulated climate change based on three large-scale indicators in the atmosphere, the cryosphere and the ocean: 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 line is where the coverage of data is good and higher in quality, and the dashed line is where the data coverage is only adequate, and thus, uncertainty is larger. 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. For further technical details, including region definitions see the Technical Summary Supplementary Material. (Figure 10.21; Figure TS.12)
• There has been further strengthening of the evidence for human influence on temperature extremes since the SREX. It is now very likely that human influence has contributed to observed global scale changes in the frequency and intensity of daily temperature extremes since the mid-20th century, and likely that human influence has more than doubled the probability of occurrence of heat waves in some locations (see Table SPM.1). (10.6)

• Anthropogenic influences have very likely contributed to Arctic sea ice loss since 1979. 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 natural internal variability in that region (see Figure SPM.6). (10.5)

• 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 there is low confidence in attributing the causes of the observed loss of mass from the Antarctic ice sheet over the past two decades. (4.3, 10.5)

• It is likely that there has been an anthropogenic contribution to observed reductions in Northern Hemisphere spring snow cover since 1970. (10.5)

• 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. (10.4, 10.5, 13.3)

• There is high confidence that changes in total solar irradiance have not contributed to the increase in global mean surface temperature over the period 1986 to 2008, based on direct satellite measurements of total solar irradiance. There is medium confidence that the 11-year cycle of solar variability influences decadal climate fluctuations in some regions. No robust association between changes in cosmic rays and cloudiness has been identified. (7.4, 10.3, Box 10.2)

E. Future Global and Regional Climate Change

Projections of changes in the climate system are made using a hierarchy of climate models ranging from simple climate models, to models of intermediate complexity, to comprehensive climate models, and Earth System Models. These models simulate changes based on a set of scenarios of anthropogenic forcings. A new set of scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme. In all RCPs, atmospheric CO\(_2\) concentrations are higher in 2100 relative to present day as a result of a further increase of cumulative emissions of CO\(_2\) to the atmosphere during the 21st century (see Box SPM.1). Projections in this Summary for Policymakers are for the end of the 21st century (2081–2100) given relative to 1986–2005, unless otherwise stated. To place such projections in historical context, it is necessary to consider observed changes between different periods. Based on the longest global surface temperature dataset available, the observed change between the average of the period 1850–1900 and of the AR5 reference period is 0.61 [0.55 to 0.67] °C. However, warming has occurred beyond the average of the AR5 reference period. Hence this is not an estimate of historical warming to present (see Chapter 2).

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions. (6, 11–14)

• Projections for the next few decades show spatial patterns of climate change similar to those projected for the later 21st century but with smaller magnitude. Natural internal variability will continue to be a major influence on climate, particularly in the near-term and at the regional scale. By the mid-21st century the magnitudes of the projected changes are substantially affected by the choice of emissions scenario (Box SPM.1). (11.3, Box 11.1, Annex I)