Information from paleoclimate archives : executive summary

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Information from Paleoclimate Archives - Executive Summary
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Greenhouse-Gas Variations and Past Climate Responses

It is a fact that present-day (2011) concentrations of the atmospheric greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) exceed the range of concentrations recorded in ice cores during the past 800,000 years. Past changes in atmospheric greenhouse-gas concentrations can be determined with *very high confidence* [for explanations see pp. 5, 19 of this Bulletin] from polar ice cores. Since assessment report 4 these records have been extended from 650,000 years to 800,000 years ago.

With very *high confidence*, the current rates of CO_2, CH_4 and N_2O rise in atmospheric concentrations and the associated radiative forcing are unprecedented with respect to the highest resolution ice core records of the last 22,000 years. There is *medium confidence* that the rate of change of the observed greenhouse gas rise is also unprecedented compared with the lower resolution records of the past 800,000 years.

There is *high confidence* that changes in atmospheric CO_2 concentration play an important role in glacial-interglacial cycles. While the primary driver of glacial-interglacial cycles lies in the seasonal and latitudinal distribution of incoming solar energy driven by changes in the geometry of the Earth's orbit around the Sun («orbital forcing»), reconstructions and simulations together show that the full magnitude of glacial-interglacial temperature and ice volume changes cannot be explained without accounting for changes in atmospheric CO_2 content and the associated climate feedbacks. During the last deglaciation, it is *very likely* that global mean temperature increased by 3 °C to 8 °C. While the mean rate of global warming was *very likely* 0.3 °C to 0.8 °C per thousand year, two periods were marked by faster warming rates, *likely* between 1 °C and 1.5 °C per thousand year, although regionally and on shorter time scales higher rates may have occurred.

New estimates of the equilibrium climate sensitivity based on reconstructions and simulations of the Last Glacial Maximum (21,000 years to 19,000 years ago) show that values below 1 °C as well as above 6 °C for a doubling of atmospheric CO_2 concentration are *very unlikely*. In some models climate sensitivity differs between warm and cold climates because of differences in the representation of cloud feedbacks.

With *medium confidence*, global mean surface temperature was significantly above pre-industrial level during several past periods characterised by high atmospheric CO_2 concentrations. During the mid-Pliocene (3.3 to 3.0 million years ago), atmospheric

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CO_2 concentrations between 350 ppm and 450 ppm (*medium confidence*) occurred when global mean surface temperatures were approximately 2 °C to 3.5 °C (*medium confidence*) higher than for pre-industrial climate. During the Early Eocene (52 to 48 million years ago), atmospheric CO_2 concentrations exceeded ~1000 ppm (*medium confidence*) when global mean surface temperatures were 9 °C to 14 °C (*medium confidence*) higher than for pre-industrial conditions.

New temperature reconstructions and simulations of past climates show with *high confidence* polar amplification in response to changes in atmospheric CO_2 concentration. For high CO_2 climates such as the Early Eocene (52 to 48 million years ago) or mid-Pliocene (3.3 to 3.0 million years ago), and low CO_2 climates such as the Last Glacial Maximum (21,000 to 19,000 years ago), sea-surface and land-surface air temperature reconstructions and simulations show a stronger response to changes in atmospheric greenhouse gas concentrations at high latitudes as compared to the global average.

Global Sea Level Changes During Past Warm Periods

The current rate of global mean sea level change, starting in the late 19th-early 20th century, is, with *medium confidence*, unusually high in the context of centennial-scale variations of the last two millennia. The magnitude of centennial-scale global mean sea level variations did not exceed 25 cm over the past few millennia (*medium confidence*).

There is *very high confidence* that the maximum global mean sea level during the last interglacial period (129,000 to 116,000 years ago) was at least 5 m higher than present and *high confidence* that it did not exceed 10 m above present. The best estimate is 6 m higher than present. Based on ice-sheet model simulations consistent with elevation changes derived from a new Greenland ice core, the Greenland ice sheet *very likely* contributed between 1.4 and 4.3 m sea level equivalent, implying with *medium confidence* a contribution from the Antarctic ice sheet to the global mean sea level during the last interglacial period.

There is *high confidence* that global mean sea level was above present during some warm intervals of the mid-Pliocene (3.3 to 3.0 million years ago), implying reduced volume of polar ice sheets. The best estimates from various methods imply with *high confidence* that sea level has not exceeded +20 m during the warmest periods of the Pliocene, due to deglaciation of the Greenland and West Antarctic ice sheets and areas of the East Antarctic ice sheet.

Observed Recent Climate Change in the Context of Interglacial Climate Variability

New temperature reconstructions and simulations of the warmest millennia of the last interglacial period (129,000 to 116,000 years ago) show with *medium confidence* that global mean annual surface temperatures were never more than 2 °C higher than pre-industrial. Greater warming at high-latitudes, seasonally and annually, confirm the importance of cryosphere feedbacks to the seasonal orbital forcing. During these periods, atmospheric greenhouse-gas concentrations were close to the pre-industrial level.

There is *high confidence* that annual mean surface warming since the 20th century has reversed long-term cooling trends of the past 5,000 years in mid-to-high latitudes of the Northern Hemisphere. New continental- and hemispheric-scale annual surface temperature reconstructions reveal multi-millennial cooling trends throughout the past 5,000 years. The last mid-to-high latitude cooling trend persisted until the 19th century, and can be attributed with *high confidence* to orbital forcing, according to climate model simulations.

There is *medium confidence* from reconstructions that the current (1980 to 2012) summer sea-ice retreat and increase in sea-surface temperatures in the Arctic are anomalous in the perspective of at least the last 2,000 years. Lower than late 20th century summer Arctic sea ice cover is reconstructed and simulated for the period between 8,000 and 6,500 years ago in response to orbital forcing.

There is *high confidence* that minima in Northern Hemisphere extratropical glacier extent between 8,000 and 6,000 years ago were primarily due to high summer insolation (orbital forcing). The current glacier retreat occurs within a context of orbital forcing that would be favourable for Northern Hemisphere glacier growth. If glaciers continue to reduce at current rates, most extratropical Northern Hemisphere glaciers will shrink to their minimum extent, which existed between 8,000 and 6,000 years ago, within this century (*medium confidence*).

For average annual Northern Hemisphere temperatures, the period 1983–2012 was *very likely* the warmest 30-year period of the last 800 years (high confidence) and *likely* the warmest 30-year period of the last 1400 years (*medium confidence*). This is supported by comparison of instrumental temperatures with multiple reconstructions from a variety of proxy data and statistical methods, and is consistent with AR4. In response to solar, volcanic and anthropogenic radiative changes, climate models simulate multidecadal temperature changes over the last 1200 years in the Northern Hemisphere, that are generally consistent in magnitude and timing with reconstructions, within their uncertainty ranges.

Continental-scale surface temperature reconstructions show, with *high confidence*, multidecadal intervals during the Medieval Climate Anomaly (950 to 1250) that were in some regions as warm as in the mid-20th century and in others as warm as in the late 20th century. With *high confidence*, these intervals were not as synchronous across seasons and regions as the warming since the mid-20th century. Based on the comparison between reconstructions and simulations, there is *high confidence* that not only external orbital, solar and volcanic forcing, but also internal variability, contributed substantially to the spatial pattern and timing of surface-temperature changes between the Medieval Climate Anomaly and the Little Ice Age (1450 to 1850).

There is *high confidence* for droughts during the last millennium of greater magnitude and longer duration than those observed since the beginning of the 20th century in many regions. There is *medium confidence* that more megadroughts occurred in monsoon Asia and wetter conditions prevailed in arid Central Asia and the South American monsoon region during the Little Ice Age (1450 to 1850) compared to the Medieval Climate Anomaly (950 to 1250).

With *high confidence*, floods larger than those recorded since 1900 occurred during the past five centuries in northern and central Europe, western Mediterranean region, and eastern Asia. There is *medium confidence* that modern large floods are comparable to or surpass historical floods in magnitude and/or frequency in the Near East, India, and central North America.

Past Changes in Climate Modes

New results from high-resolution coral records document with *high confidence* that the El Niño-Southern Oscillation (ENSO) system has remained highly variable throughout the past 7,000 years, showing no discernible evidence for an orbital modulation of ENSO. This is consistent with the weak reduction in mid-Holocene ENSO amplitude of only 10% simulated by the majority of climate models, but contrasts with reconstructions reported in AR4 that showed a reduction in ENSO variance during the first half of the Holocene.

With *high confidence*, decadal and multidecadal changes in the winter North Atlantic Oscillation index (NAO) observed since the 20th century are not unprecedented in the context of the past 500 years. Periods of persistent negative or positive winter NAO phases, similar to those observed in the 1960s and 1990 to 2000s, respectively, are not unusual in the context of NAO reconstructions during at least the past 500 years. The increase in the strength of the observed summer Southern Annular Mode since 1950 has been anomalous, with *medium confidence*, in the context of the past 400 years. No similar spatially coherent multidecadal trend can be detected in tree-ring indices from New Zealand, Tasmania and South America.

Abrupt Climate Change and Irreversibility

With *high confidence*, the interglacial mode of the Atlantic Ocean meridional overturning circulation (AMOC) can recover from a short-term freshwater input into the subpolar North Atlantic. Approximately 8,200 years ago, a sudden freshwater release occurred during the final stages of North America ice-sheet melting. Paleoclimate observations and model results indicate, with *high confidence*, a marked reduction in the strength of the AMOC followed by a rapid recovery, within approximately 200 years after the perturbation.

Confidence in the link between changes in North Atlantic climate and low-latitude precipitation patterns has increased since AR4. From new paleoclimate reconstructions and modelling studies, there is *very high confidence* that reduced AMOC and the associated surface cooling in the North Atlantic region caused southward shifts of the Atlantic Intertropical Convergence Zone, and also affected the American (North and South), African and Asian monsoon systems.

It is *virtually certain* that orbital forcing will be unable to trigger widespread glaciation during the next 1,000 years. Paleoclimate records indicate that, for orbital configurations close to present-day, glacial inceptions only occurred for atmospheric CO_2 concentrations significantly lower than pre-industrial levels. Climate models simulate no glacial inception during the next 50,000 years if CO_2 concentrations remain above 300 ppm.

There is *high confidence* that the volumes of the Greenland and West Antarctic ice sheets were reduced during periods of the past few million years that were globally warmer than present. Ice-sheet model simulations and geological data suggest that the West Antarctic ice sheet is very sensitive to subsurface Southern Ocean warming and imply with *medium confidence* a West Antarctic ice-sheet retreat if atmospheric CO_2 concentration remains above approximately 400 ppm for several millennia.