

Climate change 2007: The physical science basis

Jonathan Gregory

Walker Institute for Climate System Research,
Department of Meteorology, University of Reading
and Met Office Hadley Centre, Exeter

**with thanks to Peter Stott, Martin Manning,
Thomas Stocker, Peter Lemke and Nathan Bindoff**

IPCC

The **Intergovernmental Panel on Climate Change** was established in 1988 by WMO and UNEP.

IPCC **Fourth Assessment Report** 2007:

Working Group I: Physical science basis

Working Group II: Impacts, adaptation and vulnerability

Working Group III: Mitigation of climate change

The Working Group I report was written by 152 lead authors from over 30 countries and reviewed by over 600 experts. Its Summary for Policymakers was approved by officials from 113 governments.

Text from the Summary for Policymakers is shown like this.

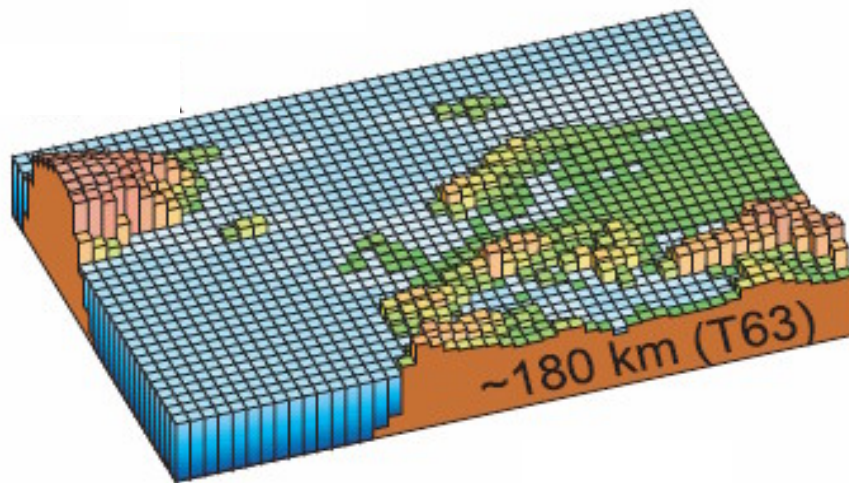
Calibrated language

<i>Very likely</i>	>90% probability	<i>Very unlikely</i>	<10% probability
<i>Likely</i>	>66% probability	<i>Unlikely</i>	<33% probability

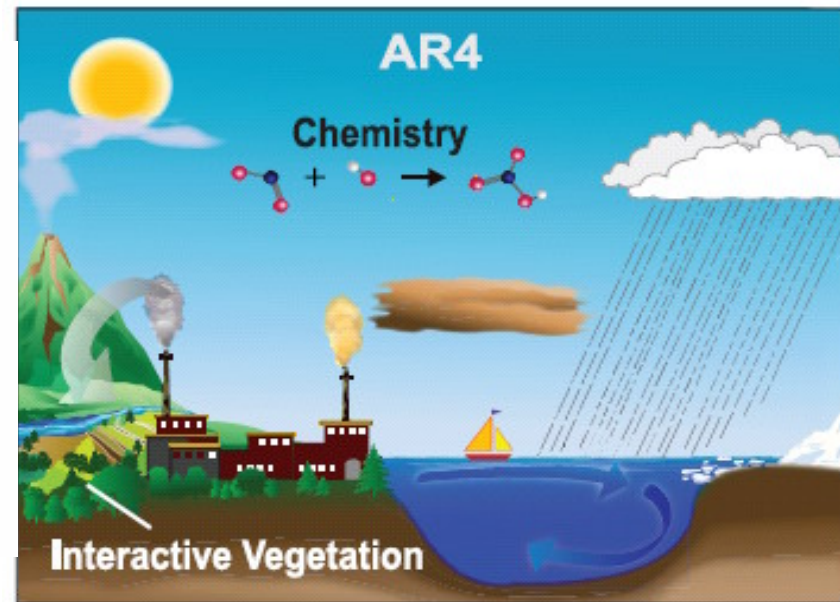
The IPCC does not conduct new research. It makes **policy-relevant (not policy-prescriptive)** assessments of the existing worldwide literature.

Climate change science

Climate change science involves a combination of physical theory, observations of weather and climate, and numerical modelling. Projections are done with atmosphere–ocean general circulation models.

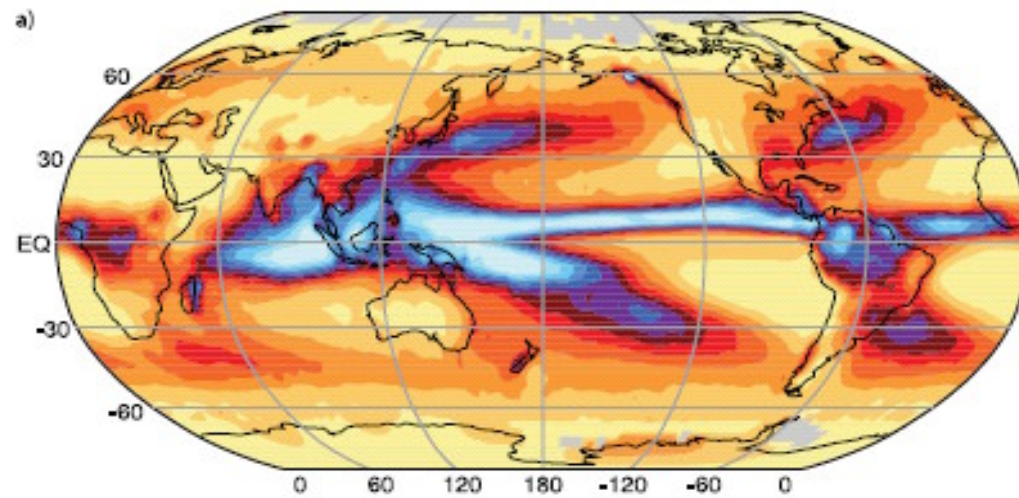


Resolution

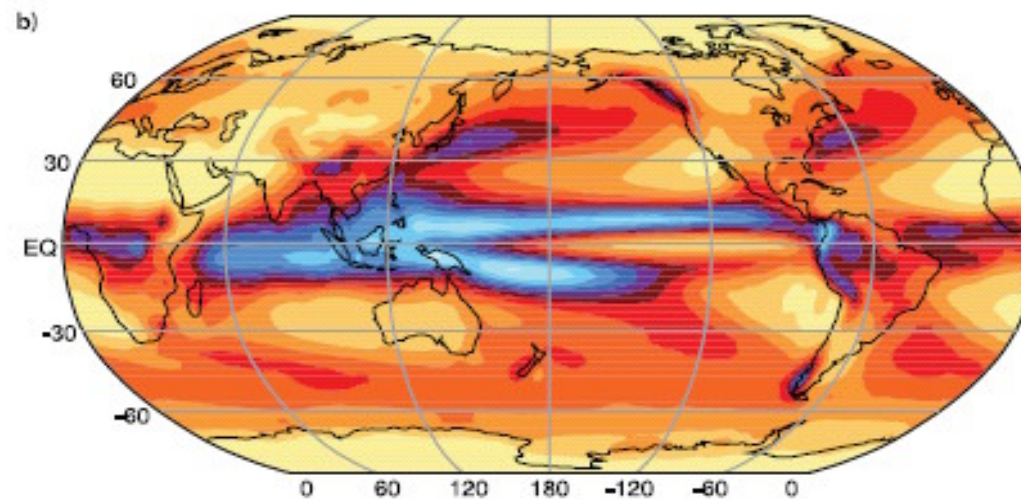


Complexity

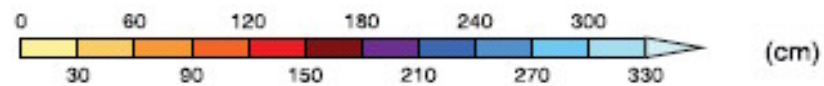
Annual-mean precipitation 1980-1999



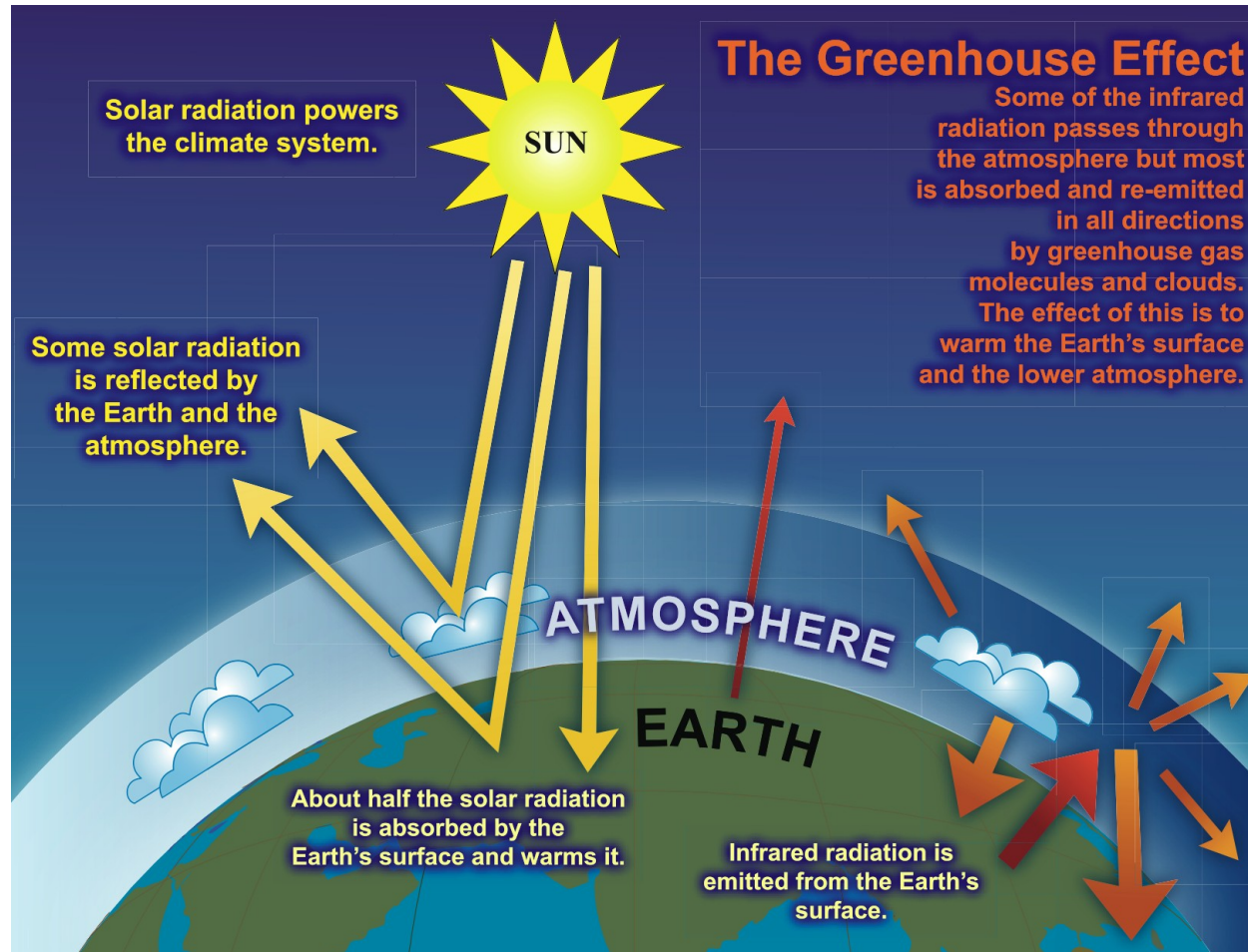
Observed



Simulated

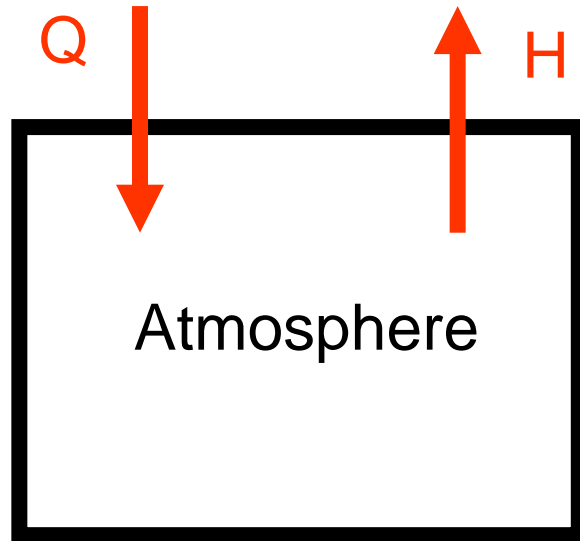


Greenhouse effect



The natural greenhouse effect raises global average surface temperature by about 30°C. Increasing greenhouse gas concentrations tends to increase surface temperatures.

Heat balance of the climate system



Q Radiative forcing

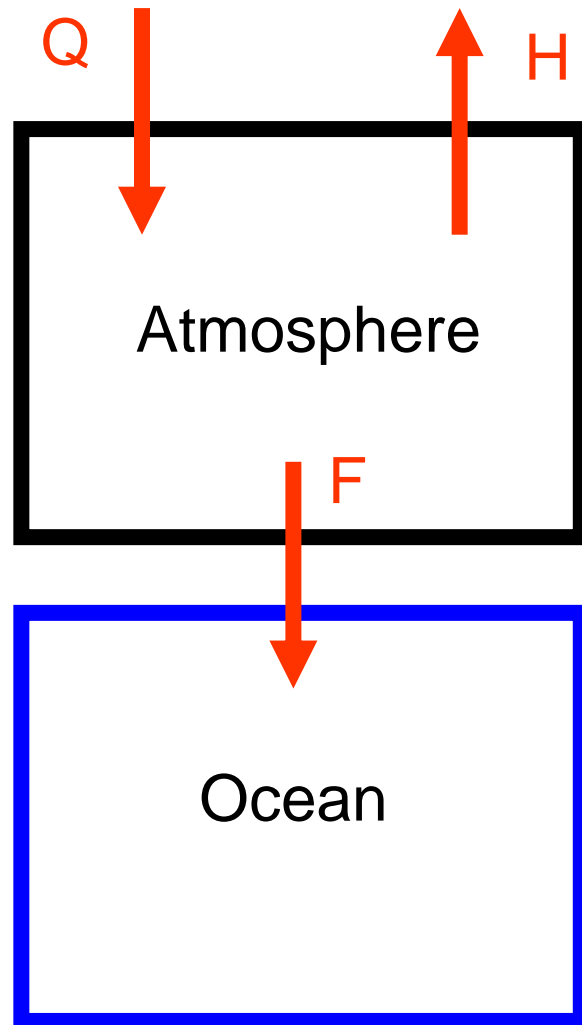
H Radiative response (including feedbacks)

$H \propto \Delta T$ Global average warming

Global average warming for doubled CO₂

Equilibrium climate sensitivity	<i>likely</i> range: 2.0 to 4.5°C <i>very unlikely</i> <1.5°C
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Heat balance of the climate system



Q Radiative forcing

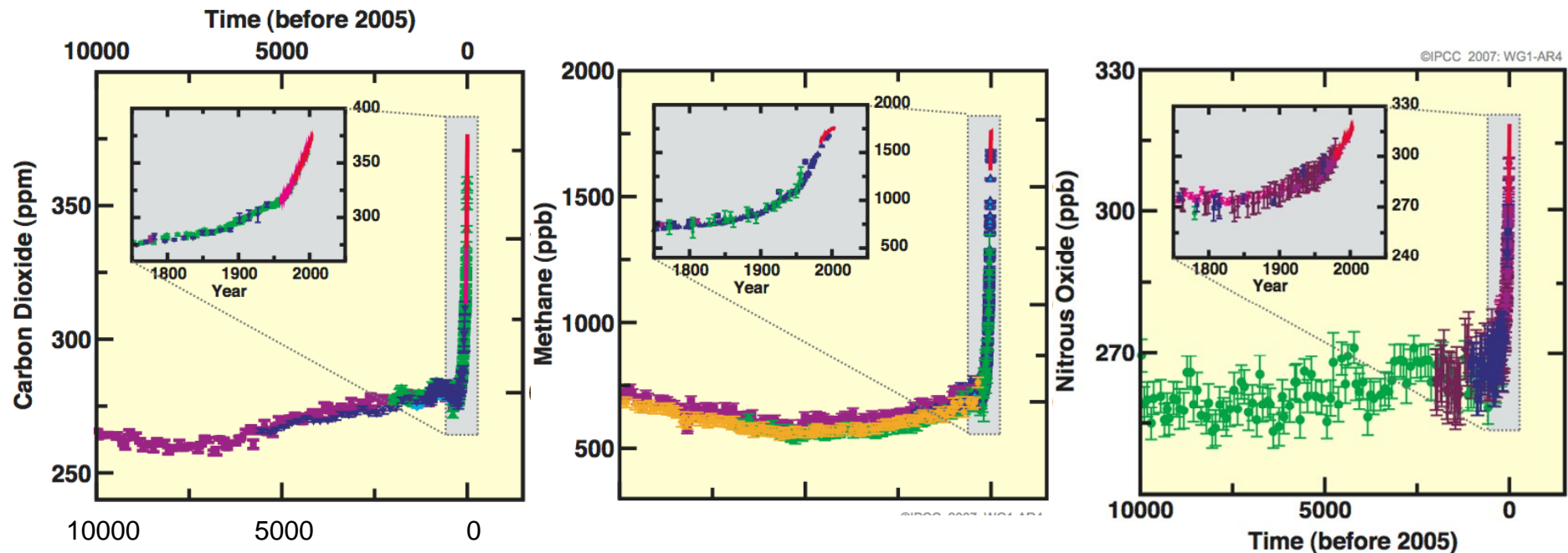
H Radiative response (including feedbacks)

F Heat flux into the ocean

Global average warming for doubled CO₂

Equilibrium climate sensitivity	<i>likely</i> range: 2.0 to 4.5°C <i>very unlikely</i> <1.5°C
Transient climate response	<i>very unlikely</i> <1.0°C <i>very unlikely</i> >3.0°C

Atmospheric greenhouse gas concentrations

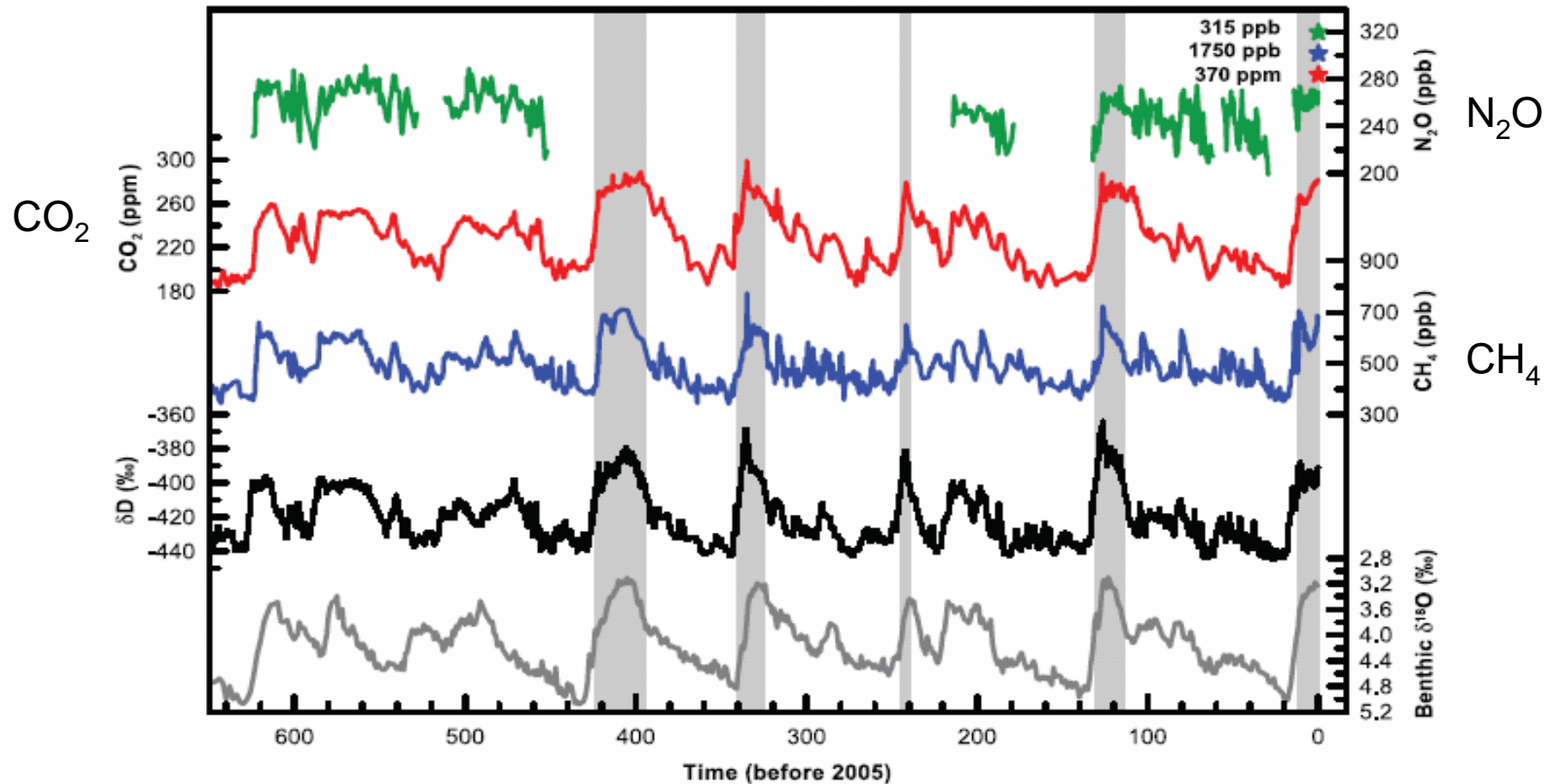


Global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. The global increases in carbon dioxide concentration are due primarily to fossil fuel use and land-use change.



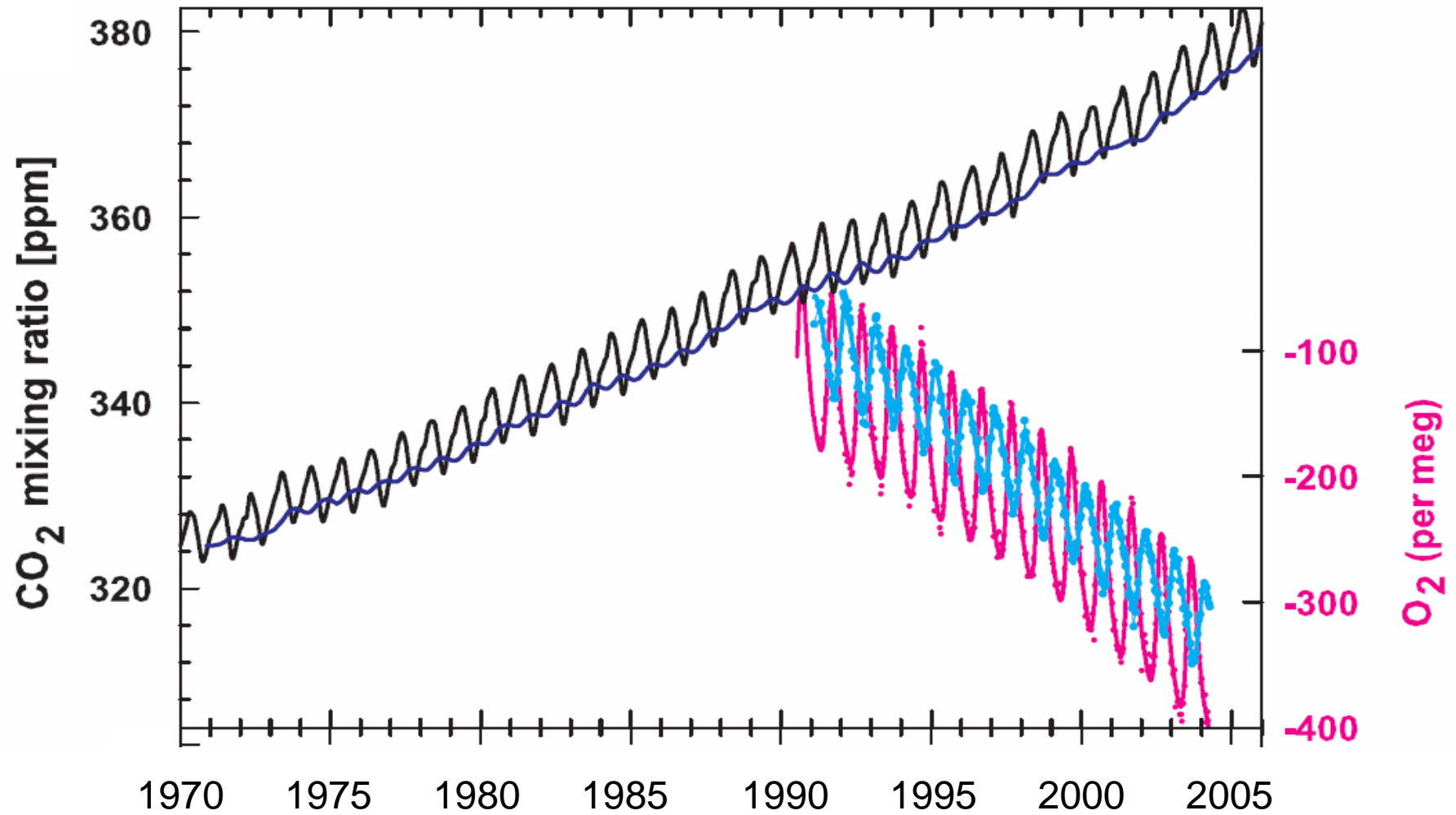
Photo by Guillaume Dargaud

Glacial-interglacial cycles

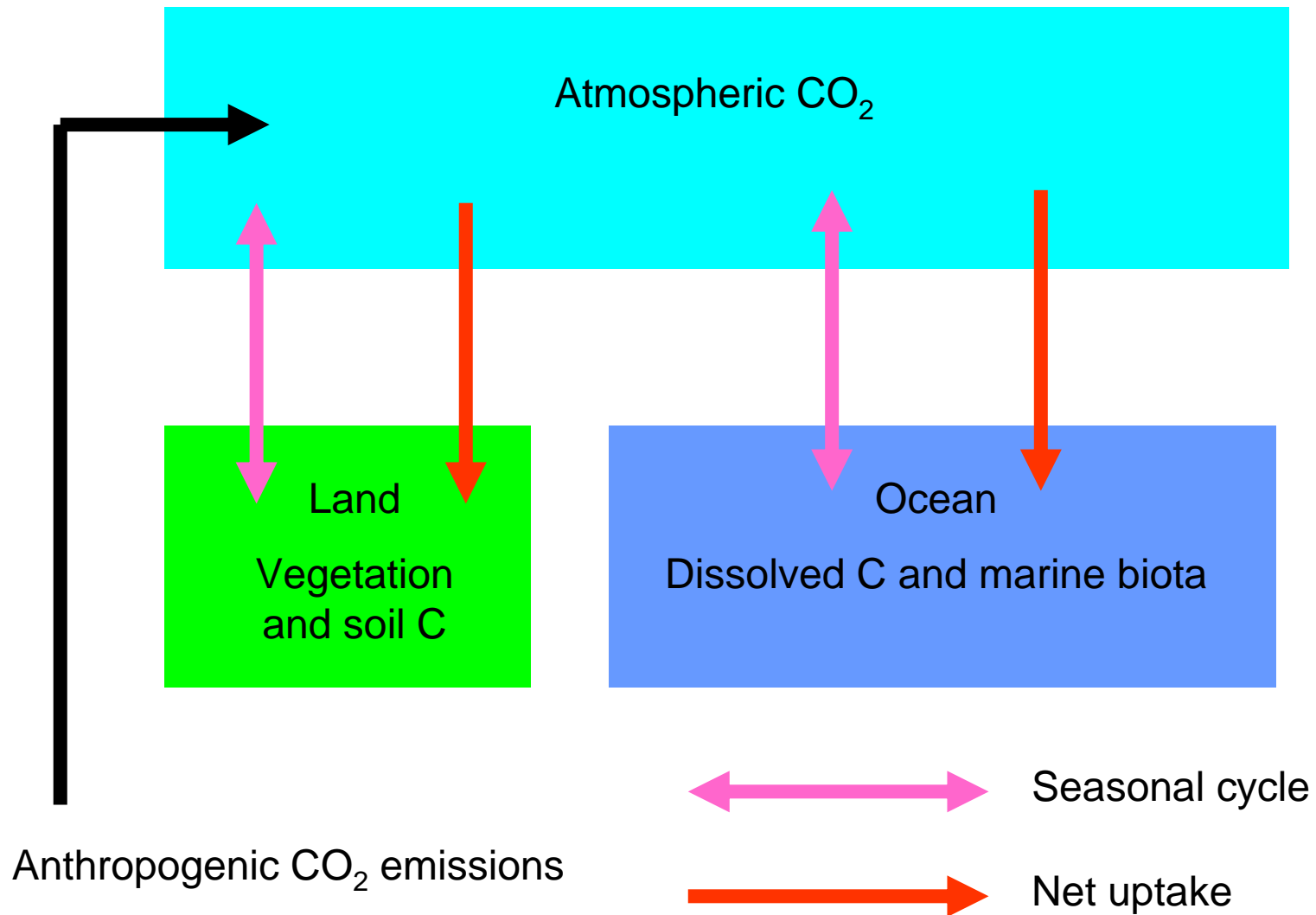


It is *very unlikely* that the Earth would naturally enter another ice age for at least 30 kyr. It is *very likely* that glacial-interglacial CO₂ variations have strongly amplified climate variations, but it is *unlikely* that CO₂ variations have triggered the end of glacial periods.

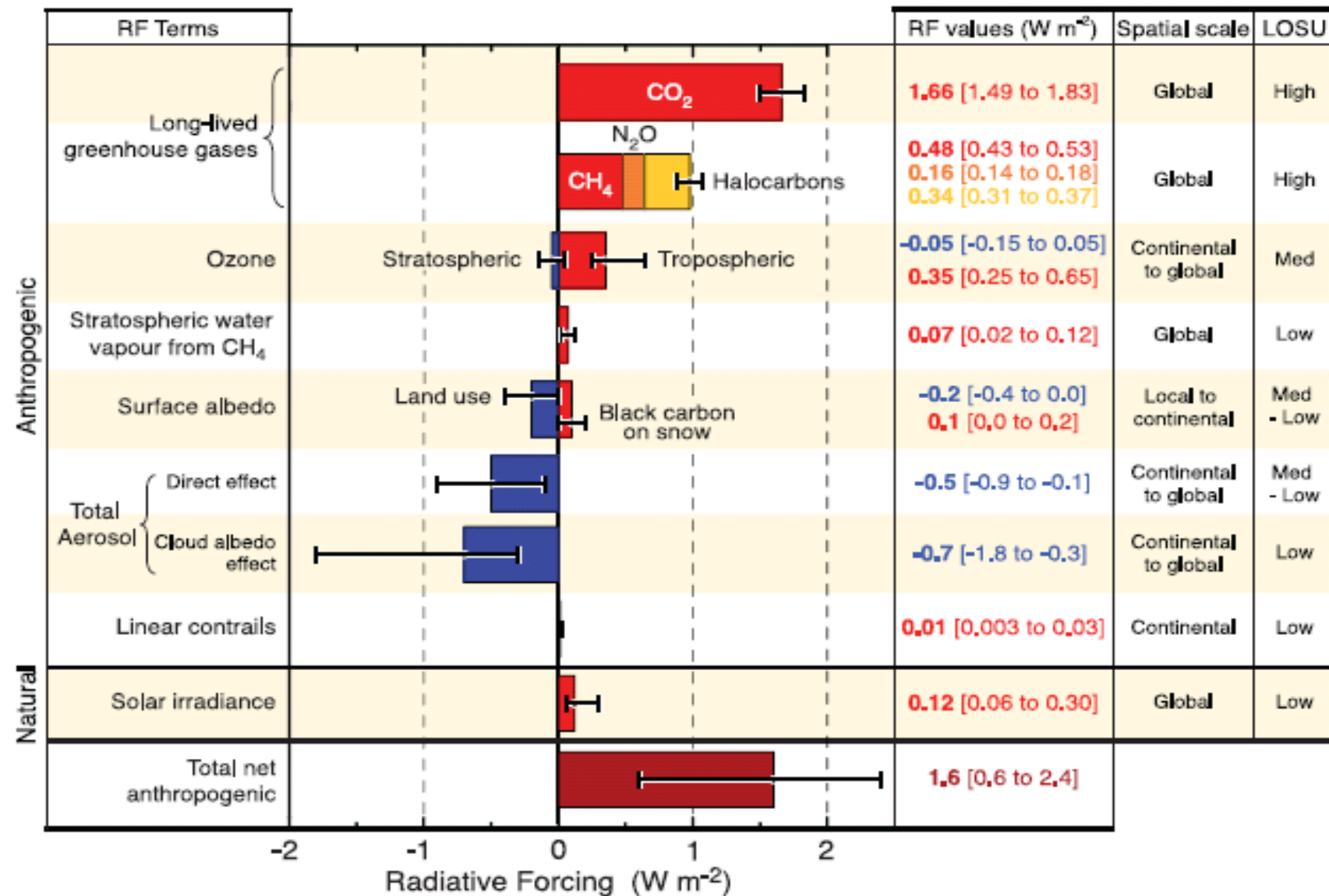
Recent carbon dioxide and oxygen concentrations



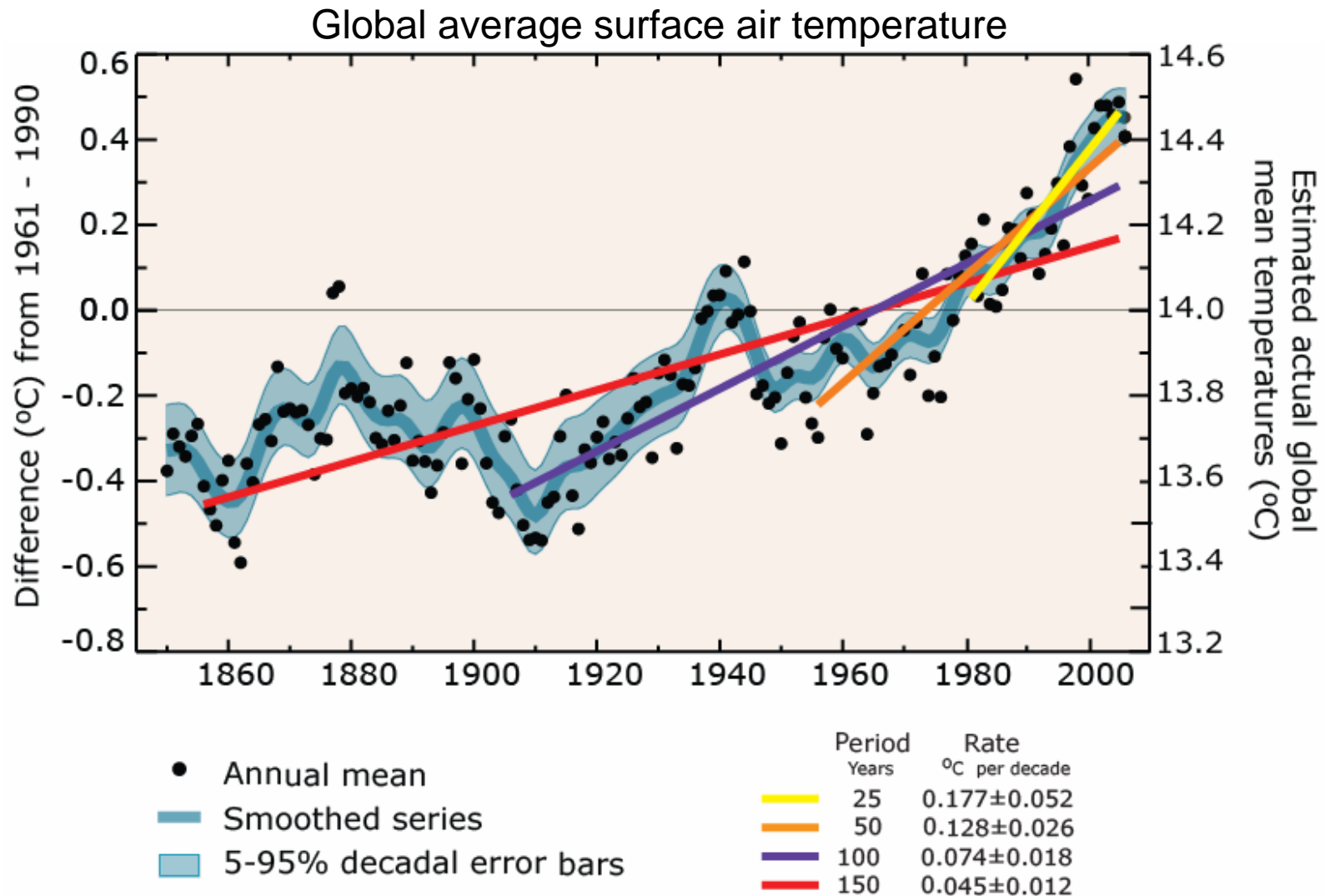
Carbon cycle



Radiative forcing

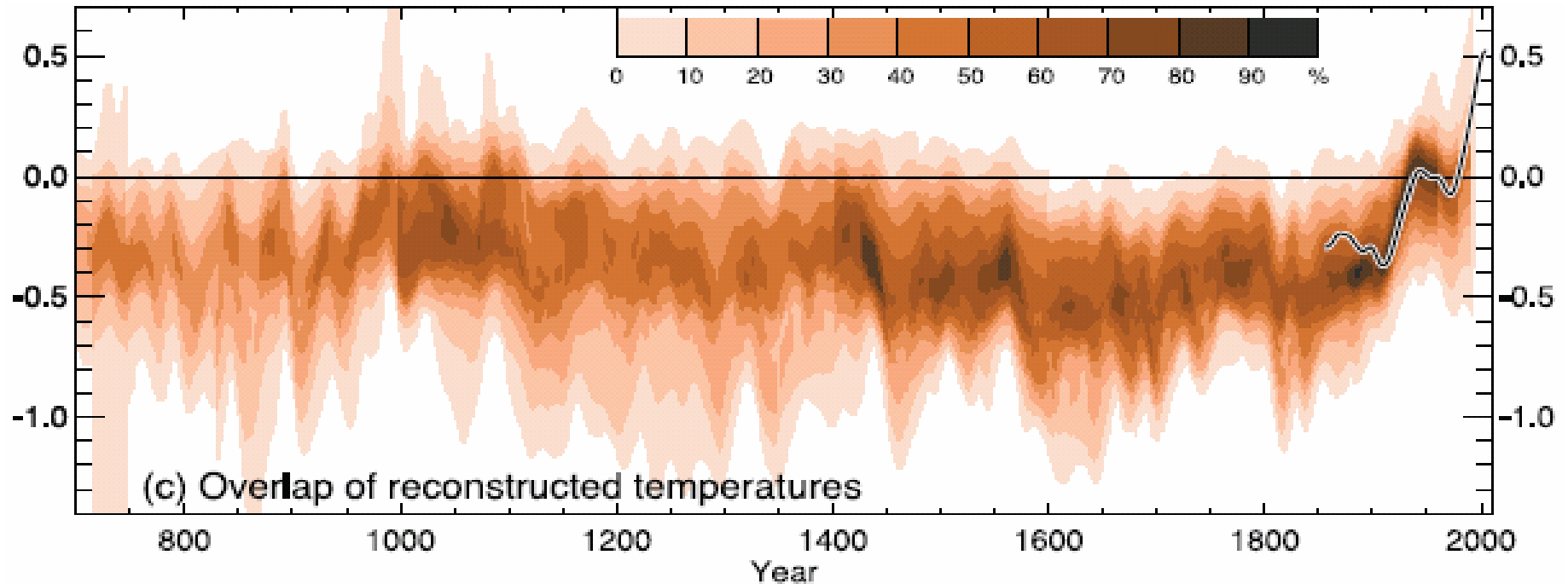


Warming of the climate system is unequivocal



Eleven of the last twelve years (1995 -2006) rank among the 12 warmest years in the instrumental record of global surface temperature.

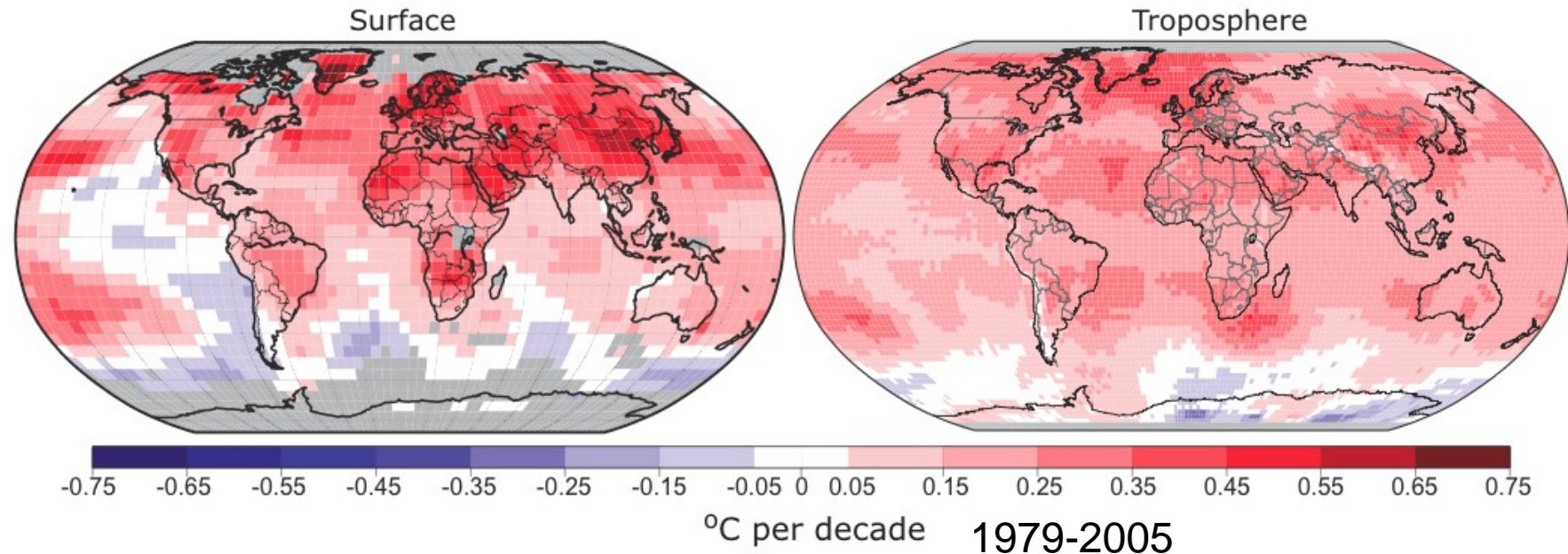
Northern Hemisphere temperature variation



Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years.

It is also *likely* that this warmth was more widespread than during any other 50-year period in the last 1300 yr.

Warming is global

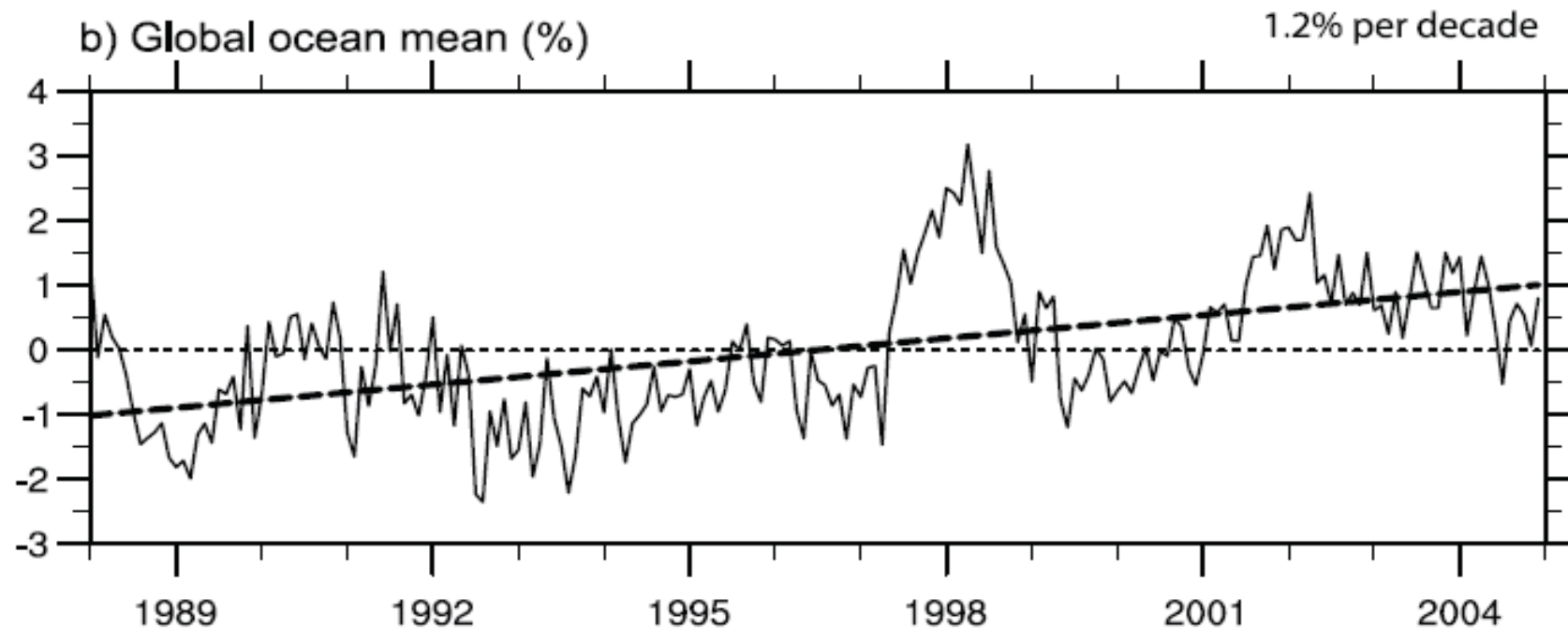


Land regions have warmed at a faster rate than the oceans.

Lower-tropospheric temperatures have slightly greater warming rates than those at the surface.

Changes in extremes of temperature are consistent with warming of the climate.

Water vapour in the atmosphere

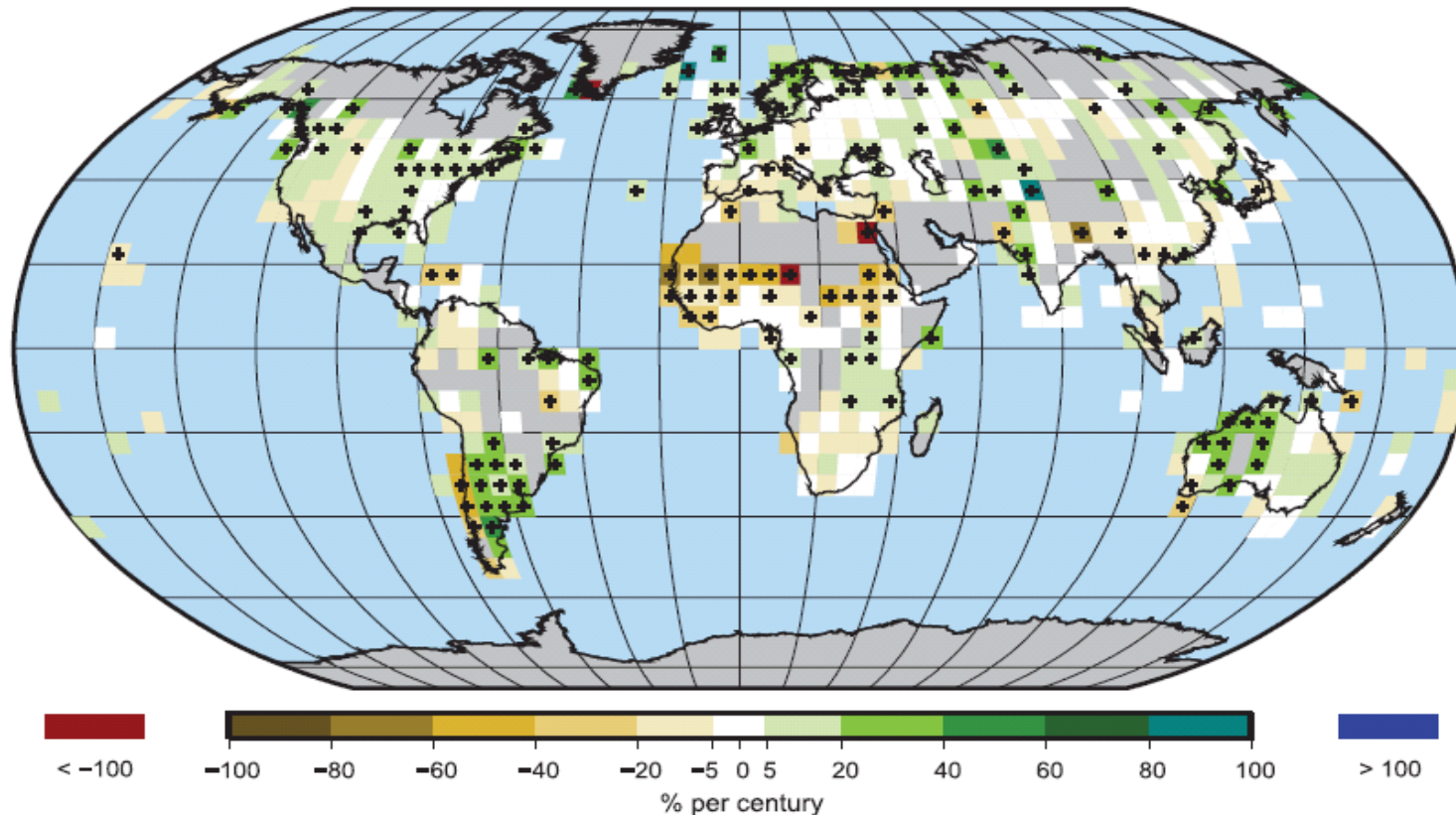


The average atmospheric water vapour content has increased since at least the 1980s over land and ocean as well as in the upper troposphere. The increase is broadly consistent with the extra water vapour that warmer air can hold.

Although water vapour is a strong greenhouse gas, its concentration in the atmosphere changes in response to changes in surface climate and this must be treated as a feedback effect and not as a radiative forcing.

Precipitation

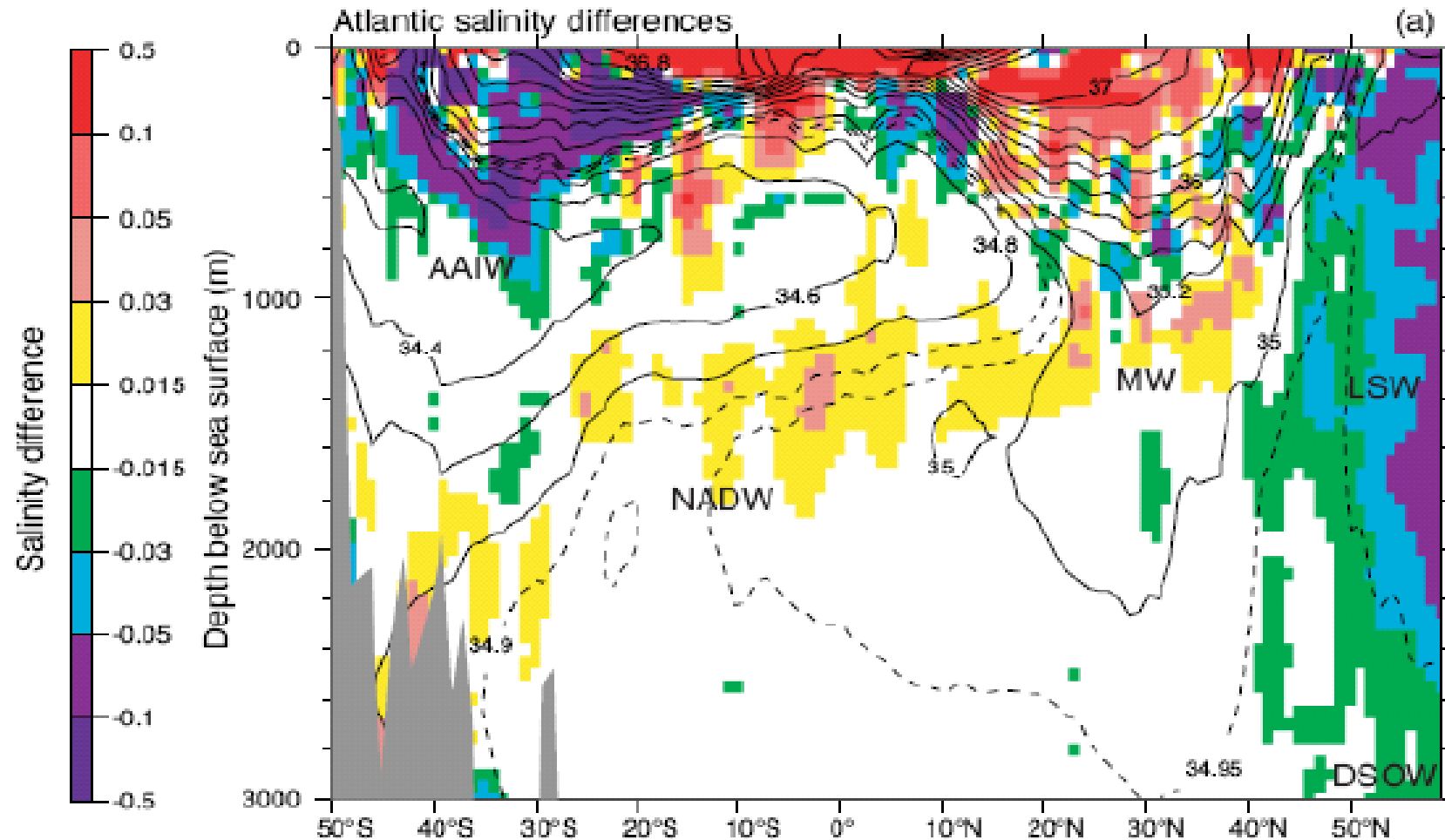
Trend in Annual Precipitation, 1901 to 2005



Long-term trends have been observed in precipitation amount over many large regions. More intense and longer droughts have been observed over wider areas since the 1970s, particularly in the tropics and subtropics. The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour.

Salinity change

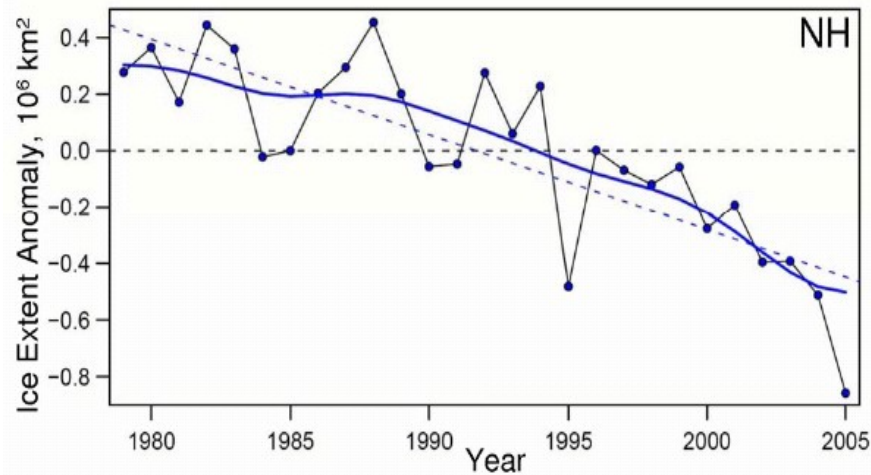
(western Atlantic Ocean 1985-1999 minus 1955-1969)



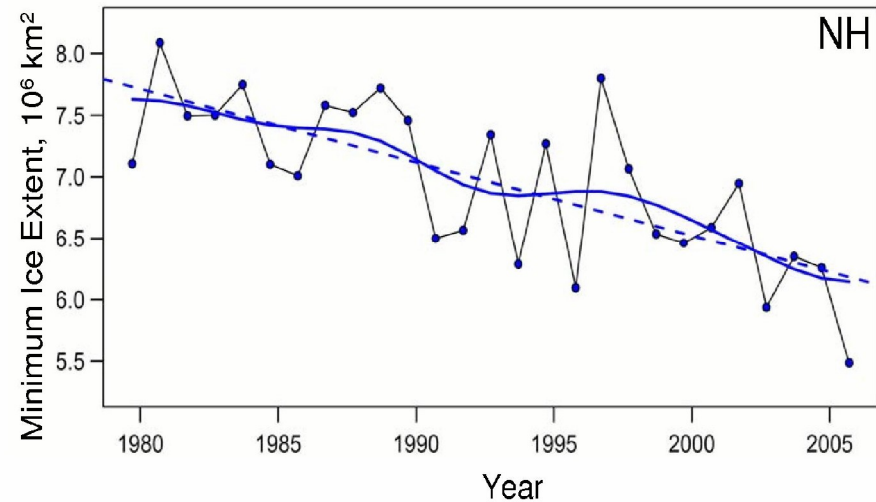
Changes in precipitation and evaporation over the oceans are suggested by freshening of mid and high latitude waters together with increased salinity in low latitude waters.

Change in Arctic sea-ice extent

Annual Mean
(-2.7% per decade)

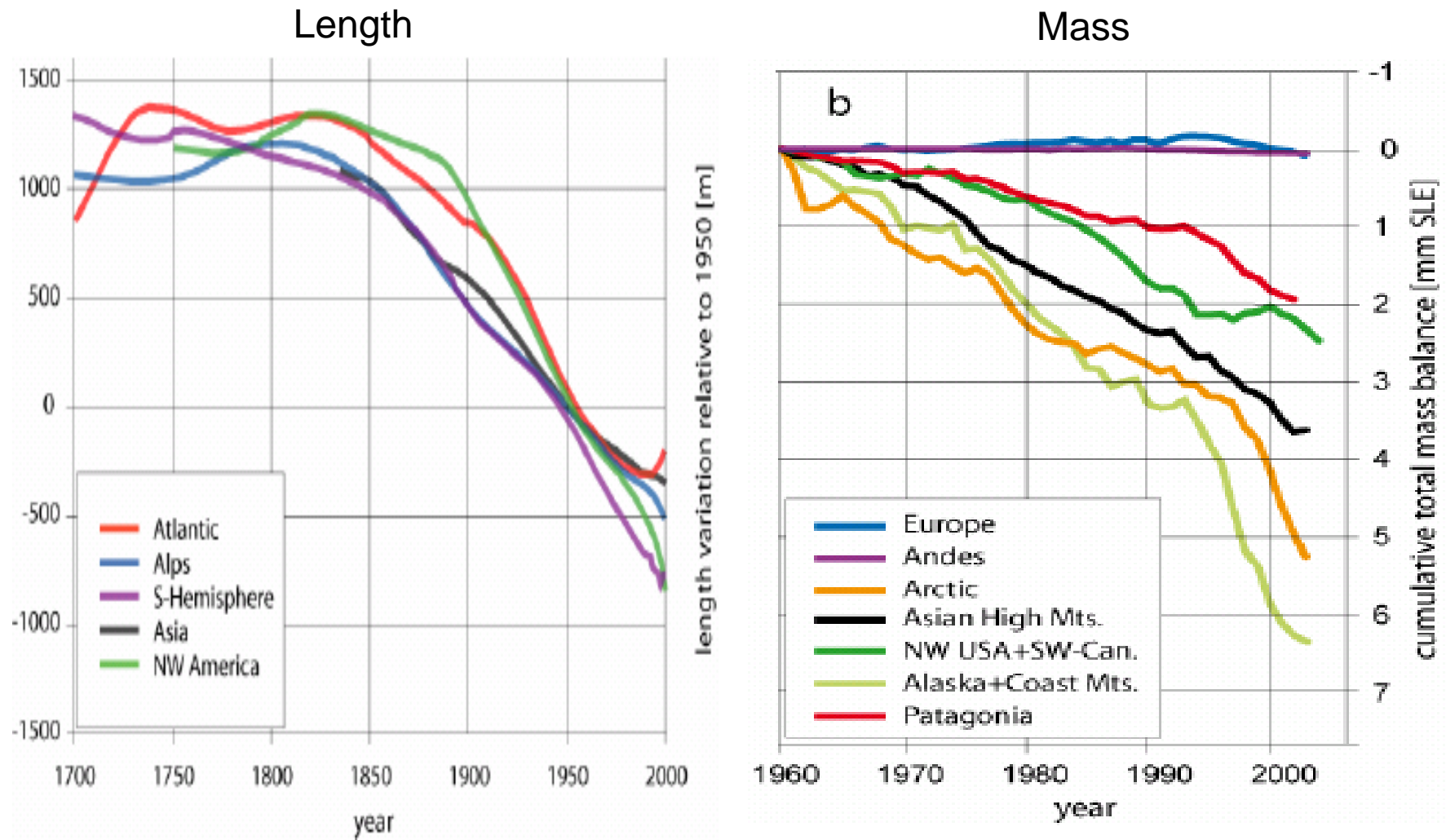


Summer Minimum
(-7.4% per decade)



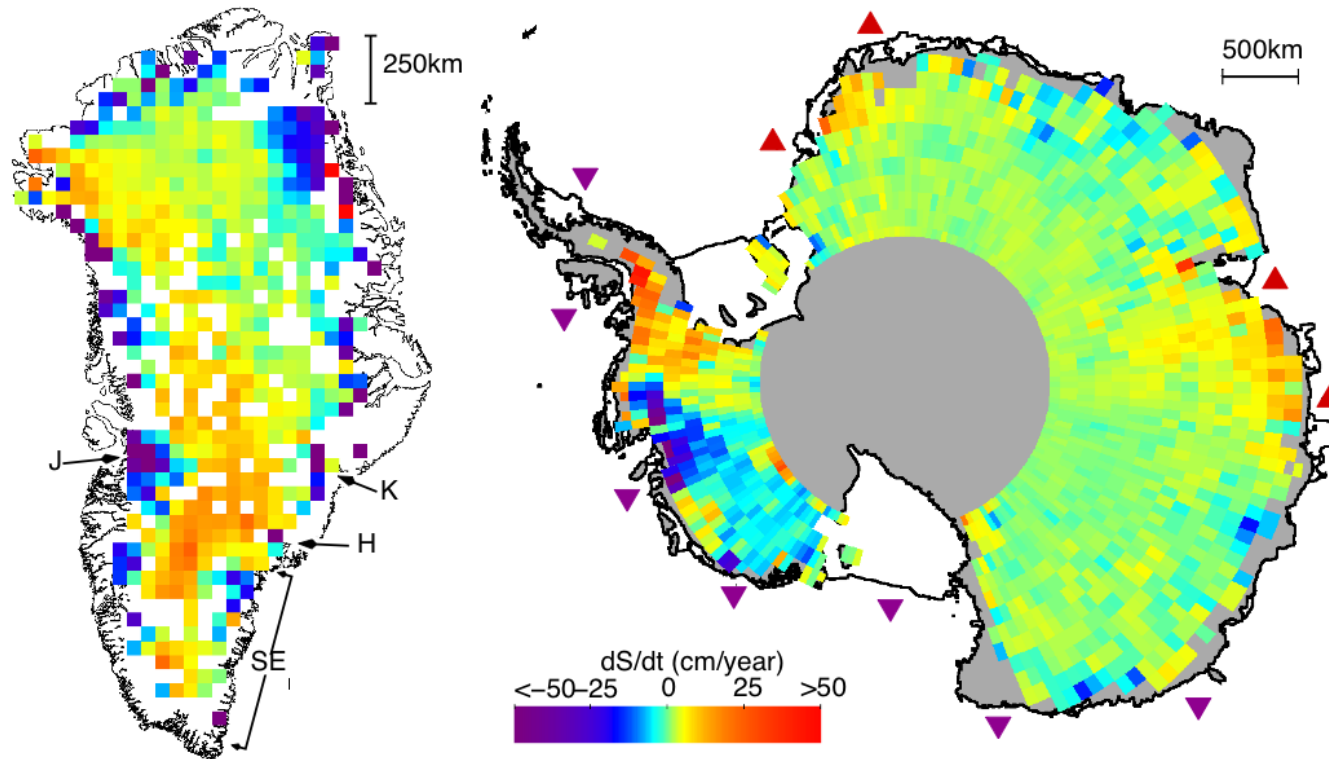
Average Arctic temperatures increased at almost twice the global average rate in the past 100 years. Arctic temperatures have high decadal variability, and a warm period was also observed from 1925 to 1945. Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk.

Glaciers and ice caps



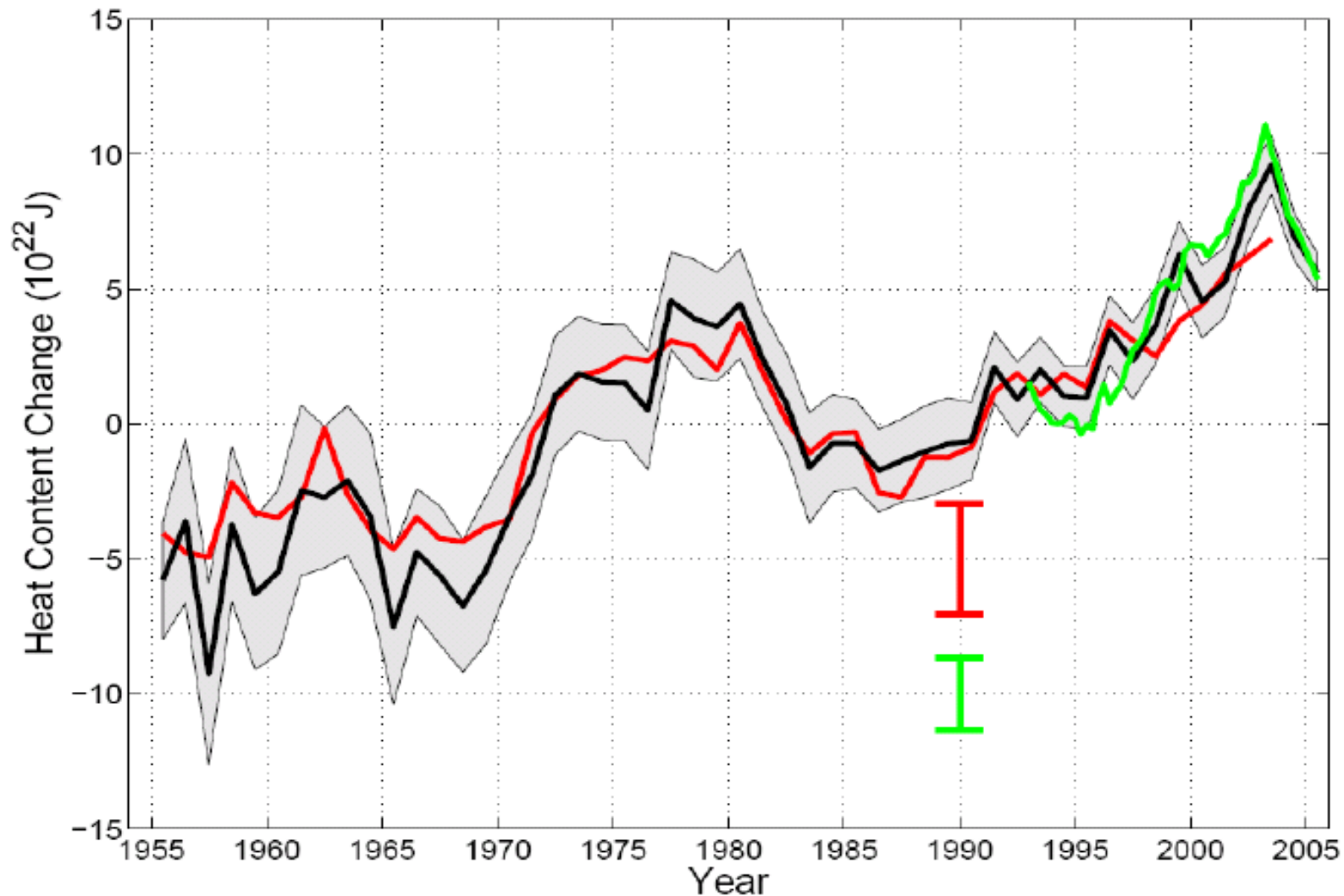
Widespread decreases in glaciers and ice caps have contributed to sea level rise.

Ice sheet volume change



Flow speed has increased for some Greenland and Antarctic outlet glaciers, which drain ice from the interior of the ice sheets. The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves or loss of floating glacier tongues. [Mass] losses from the ice sheets of Greenland and Antarctica have *very likely* contributed to sea level rise over 1993 to 2003.

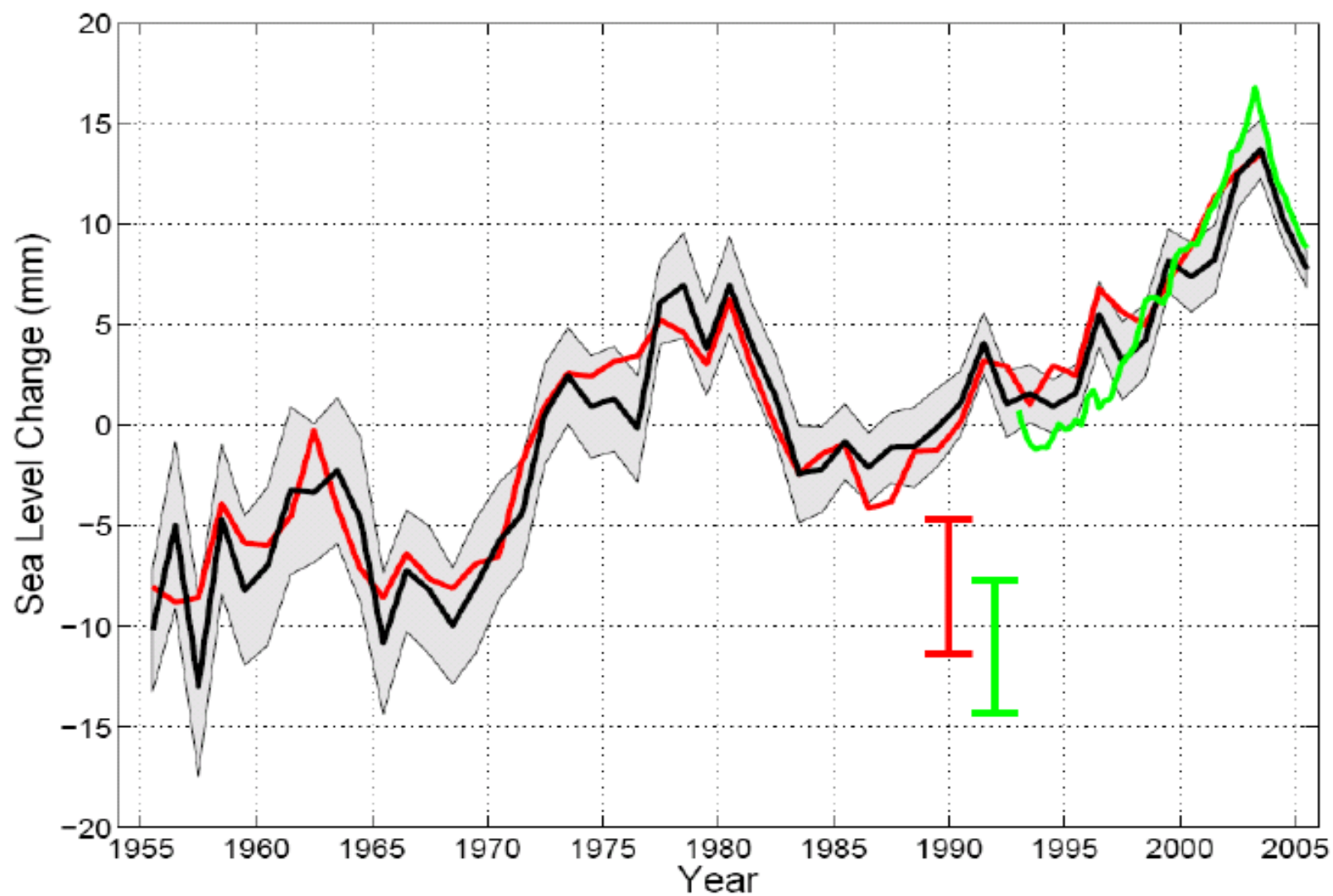
Ocean heat content change



Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000 m.

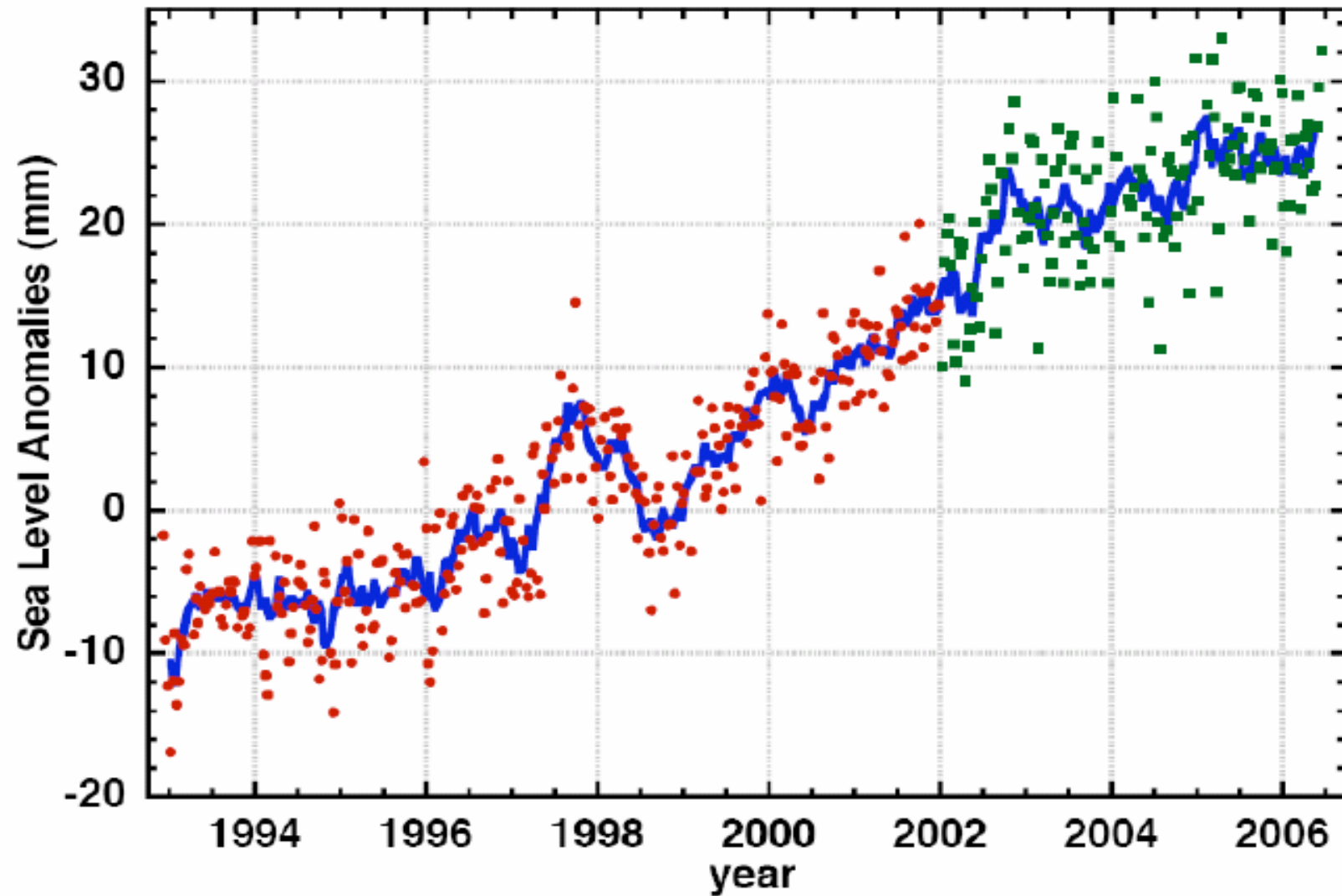
During 1955-2003 the oceans absorbed $0.21 \pm 0.04 \text{ W m}^{-2}$, 2/3 in the upper 700 m.

Ocean thermal expansion



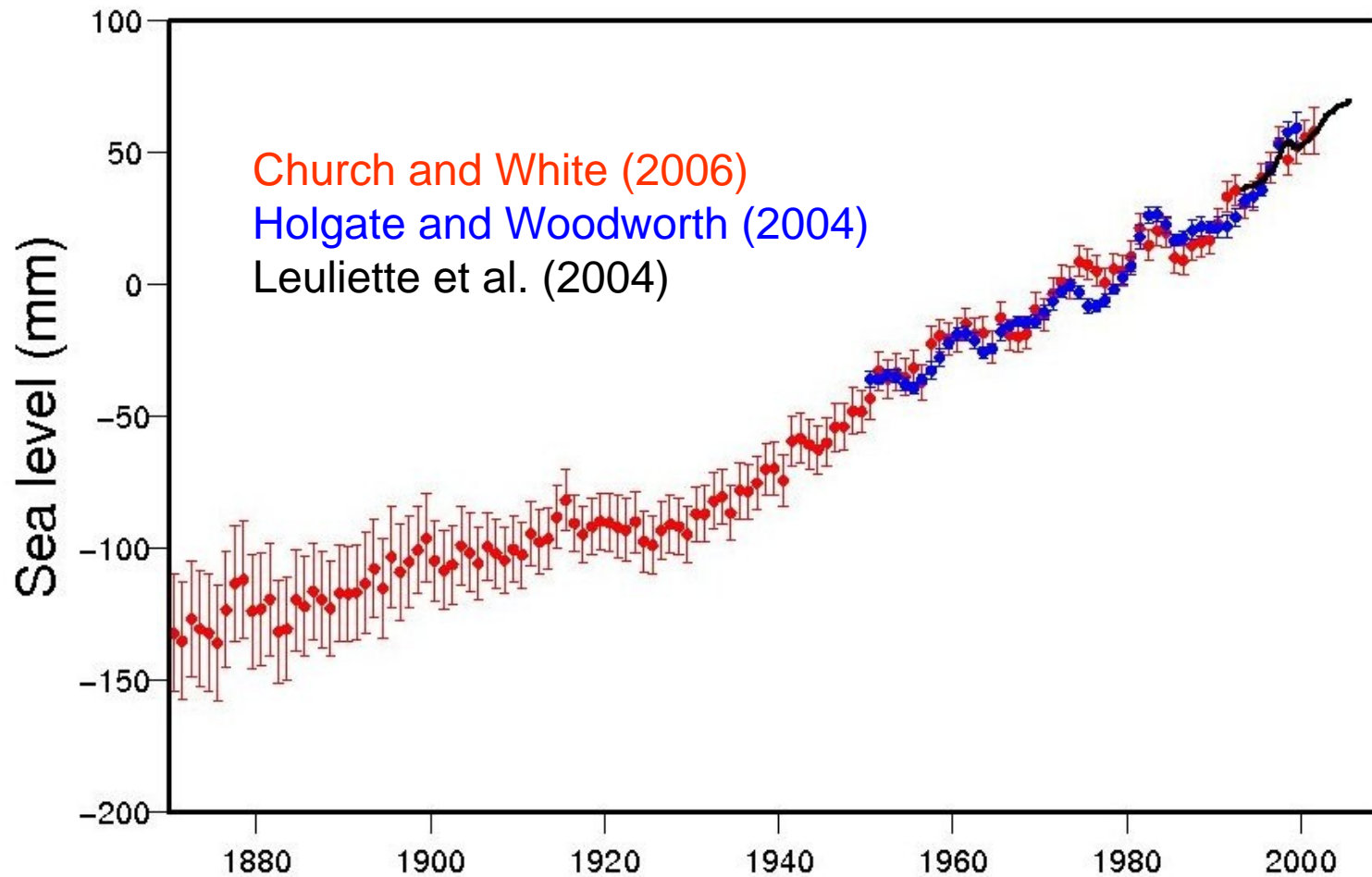
1961-2003 $0.42 \pm 0.12 \text{ mm yr}^{-1}$ 1993-2003 $1.6 \pm 0.5 \text{ mm yr}^{-1}$

Global mean sea level rise observed by satellite altimeter



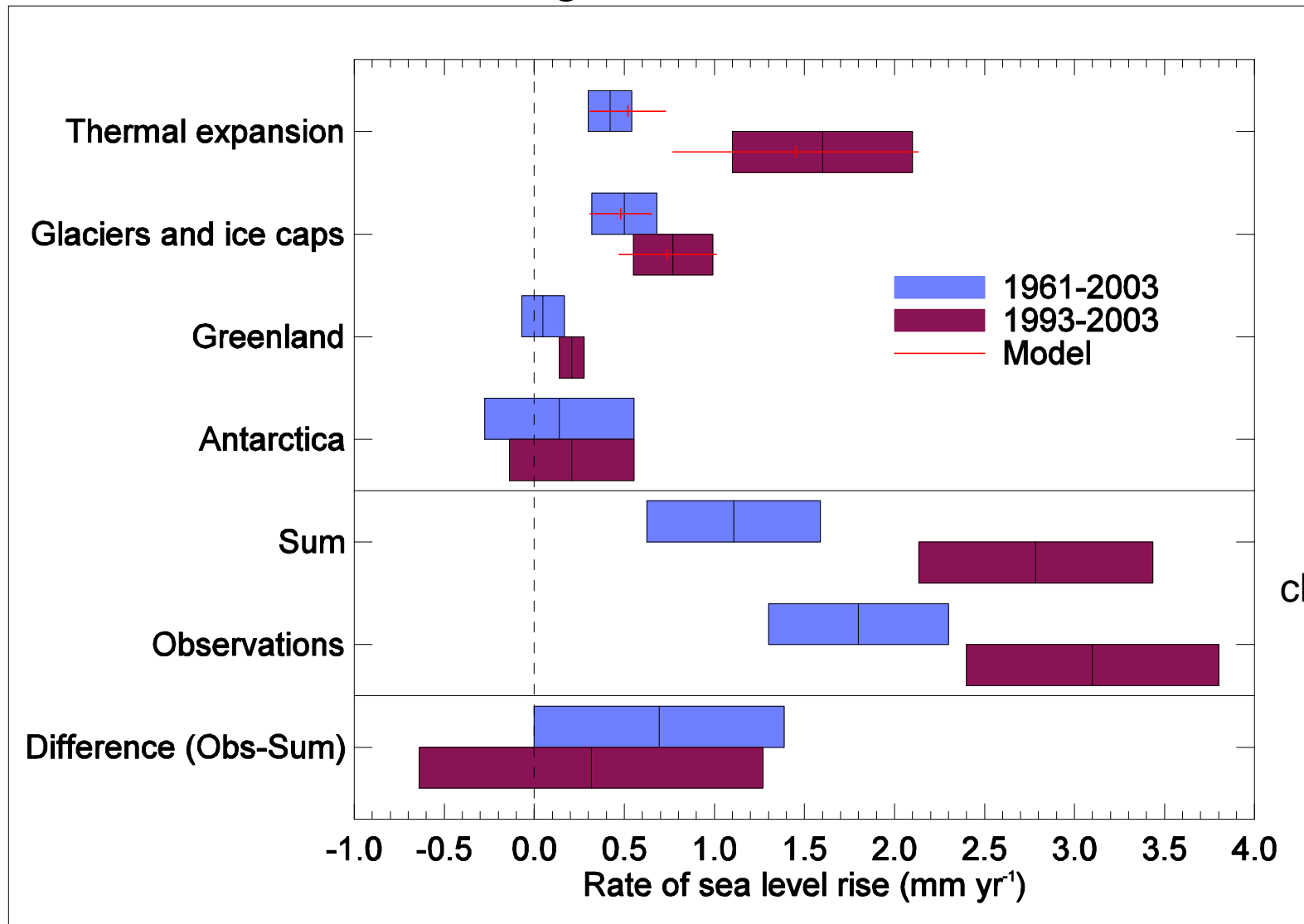
1993-2003 $3.1 \pm 0.7 \text{ mm yr}^{-1}$

Observed global mean sea level rise



Global average sea level rose at an average rate of $1.8 [1.3 \text{ to } 2.3] \text{ mm yr}^{-1}$ over 1961 to 2003. The 20th century rise is estimated to be $0.17 [0.12 \text{ to } 0.22] \text{ m}$. There is *high confidence* that the rate of observed sea level rise increased from the 19th to the 20th century.

Accounting for observed sea level rise



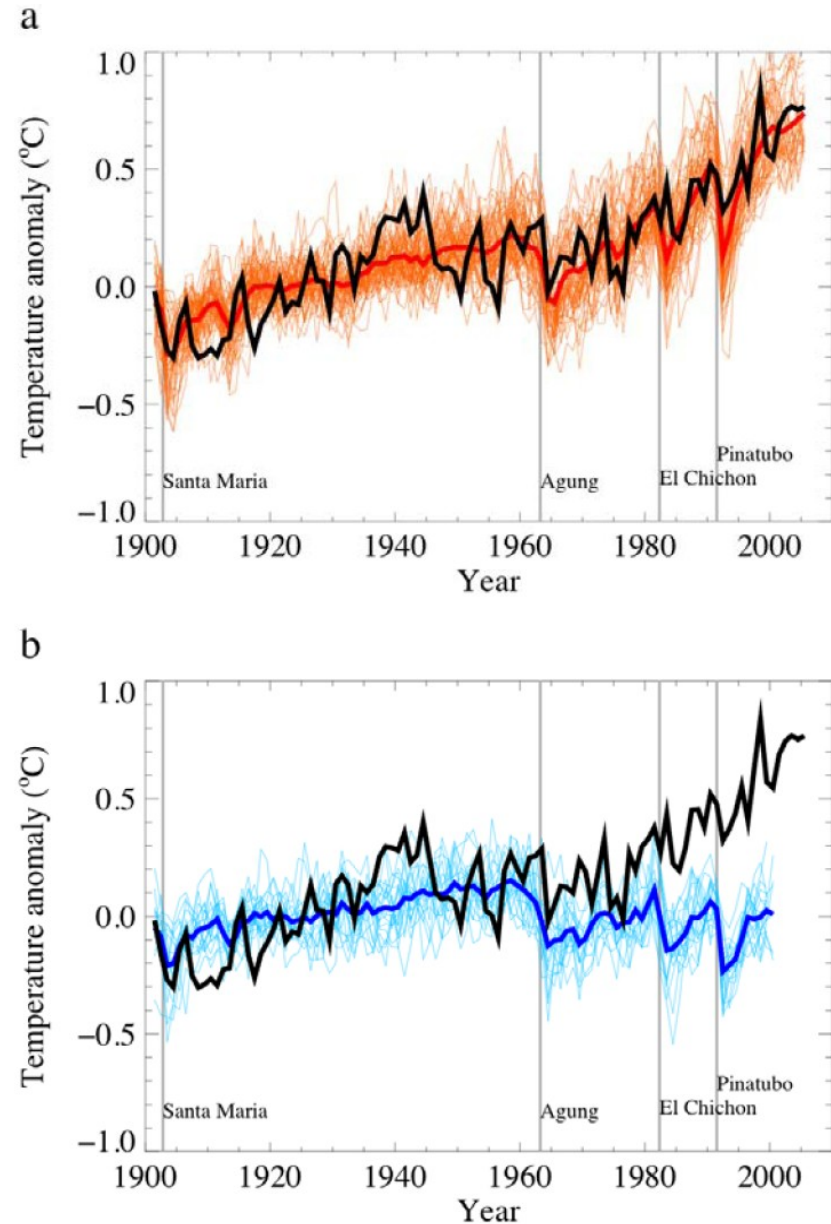
Budget is closed better for 1993-2003 than for 1961-2003.

Whether the faster rate [of sea level rise] for 1993 to 2003 reflects decadal variability or an increase in the longer-term trend is unclear.

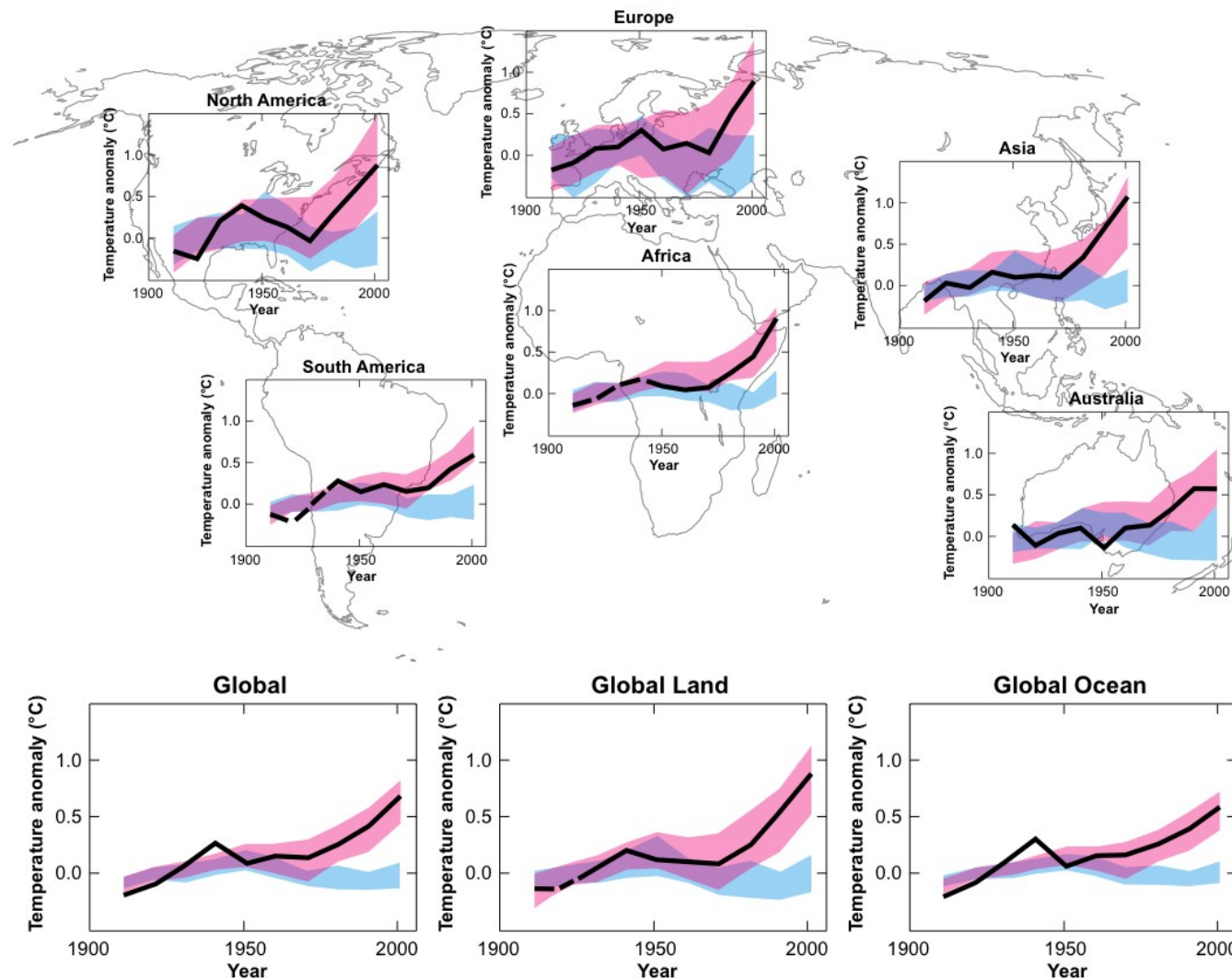
Understanding and attributing climate change

Attribution requires that the observed changes are consistent with the expected (simulated) response to forcings, and inconsistent with other explanations.

Most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic greenhouse gas concentrations.

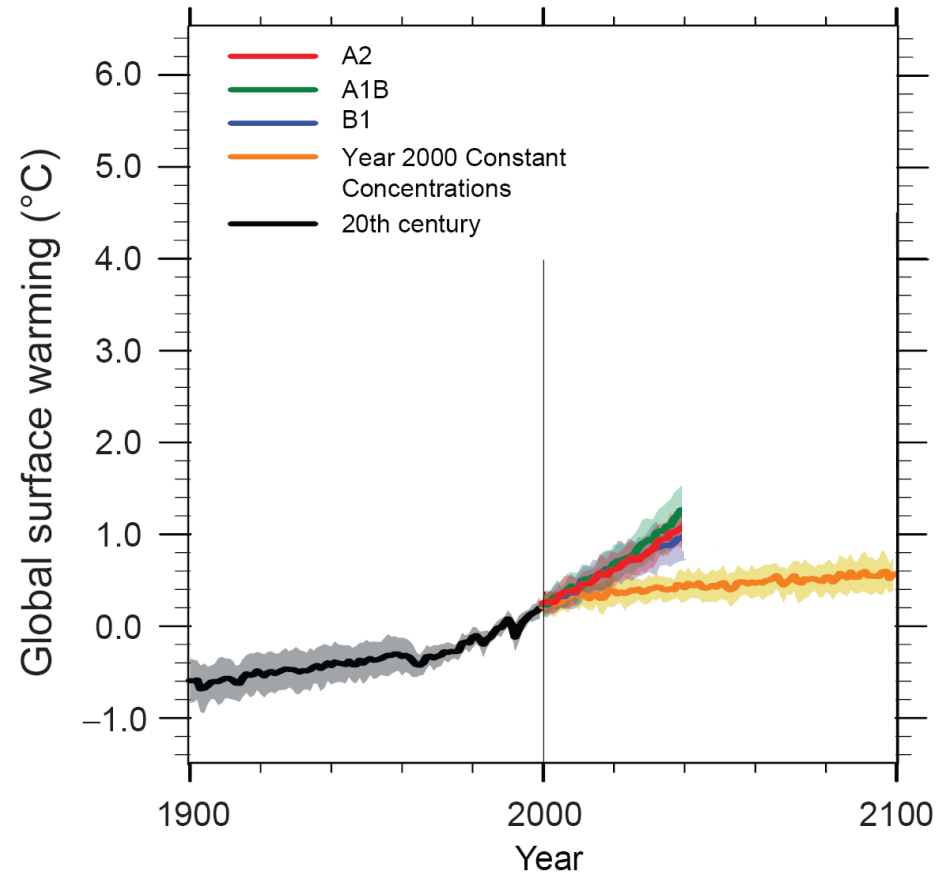


Global and continental temperature change



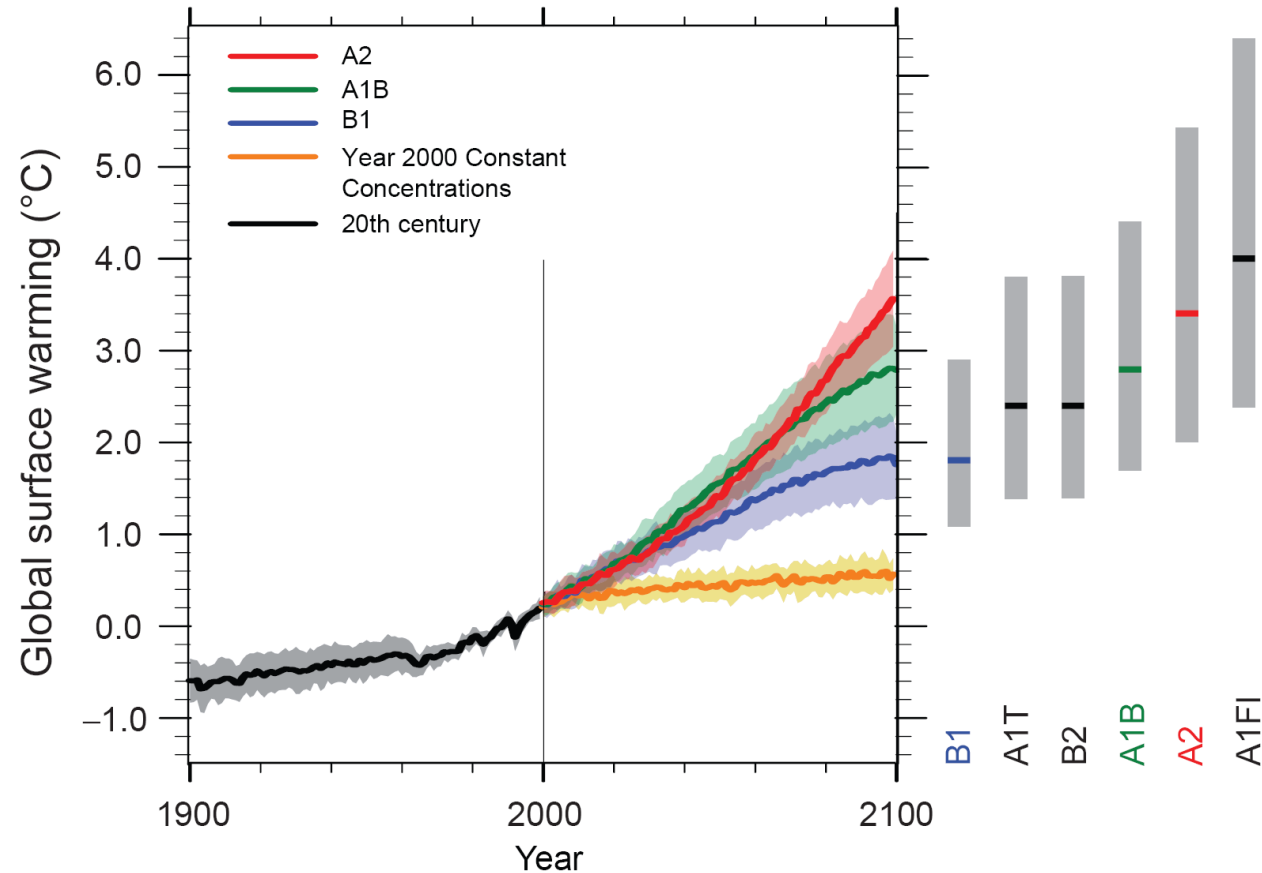
It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent except Antarctica.

Warming during the next two decades

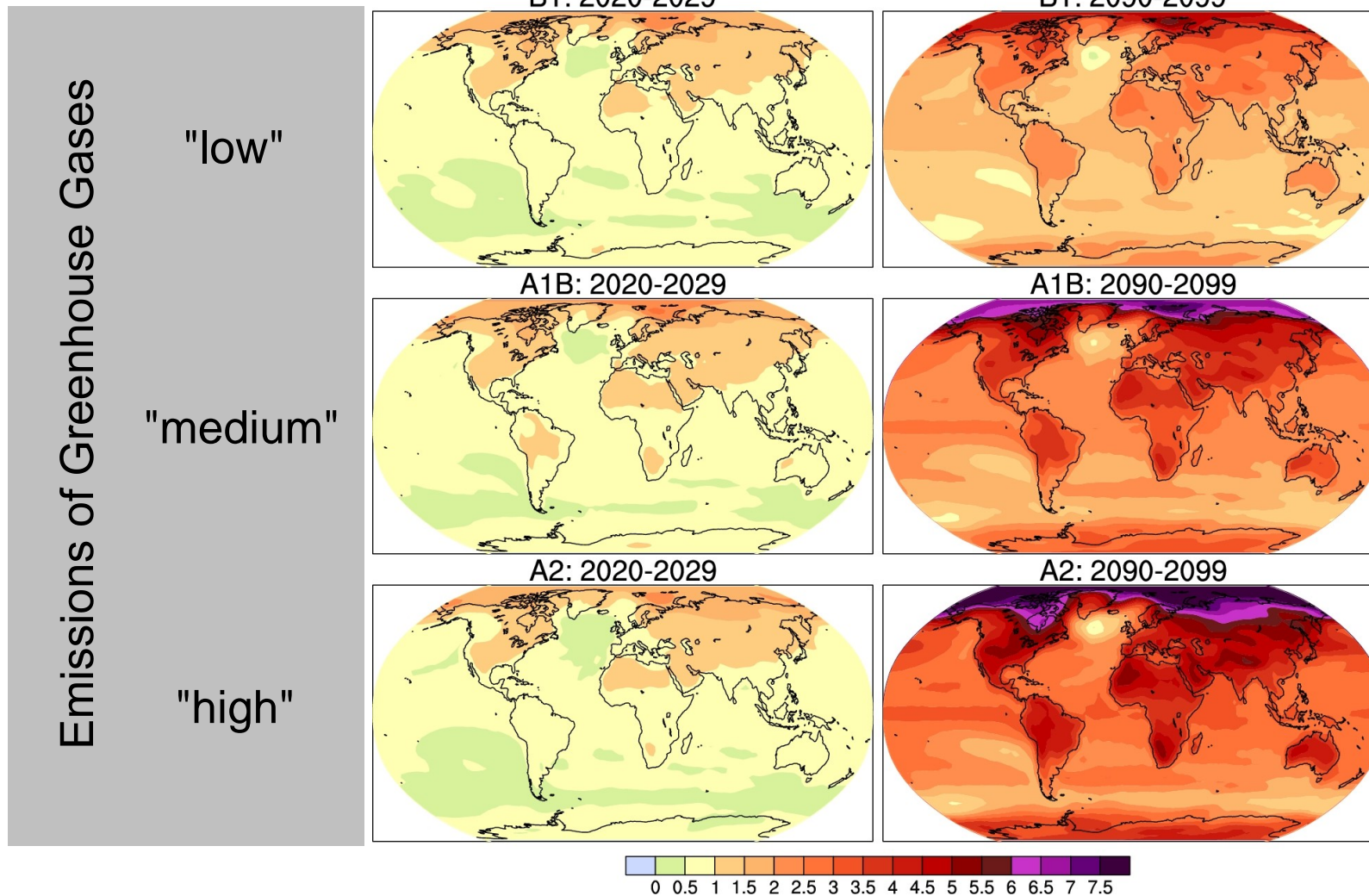


A warming of about 0.2°C per decade is projected for a range of SRES emission scenarios. Even if the concentrations of all greenhouse gases and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected.

Warming during the 21st century

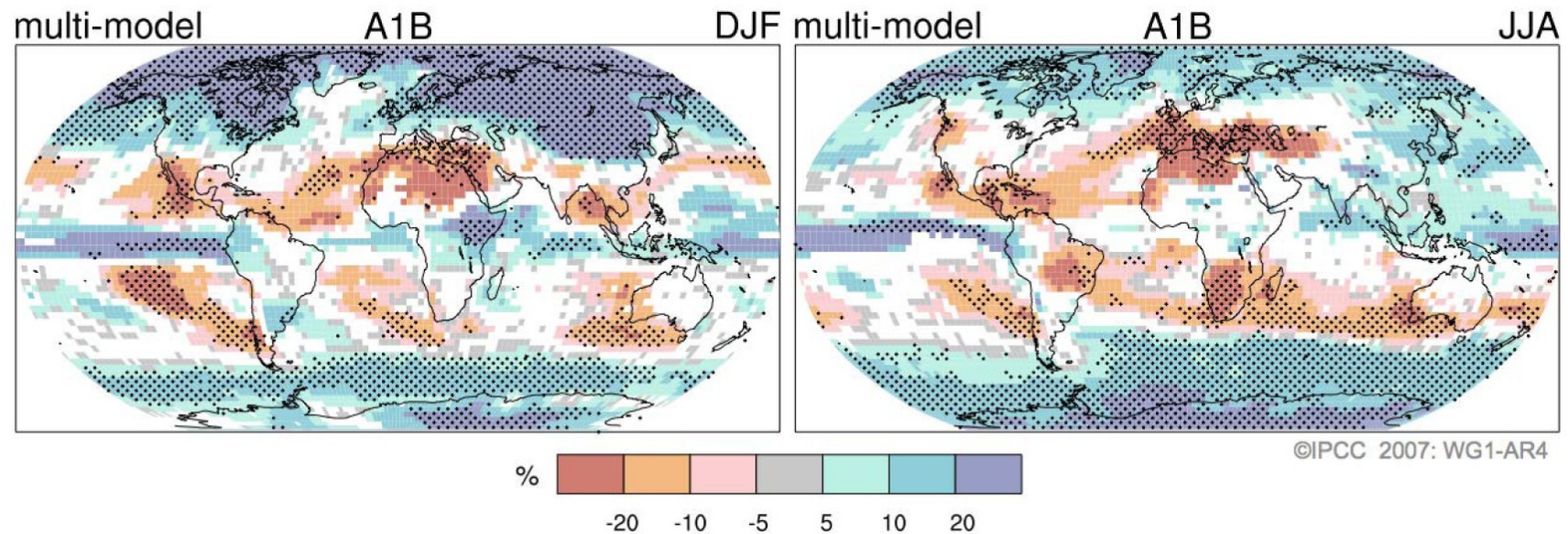


Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. Best estimates and *likely* ranges for globally average surface air warming for six SRES emissions marker scenarios.



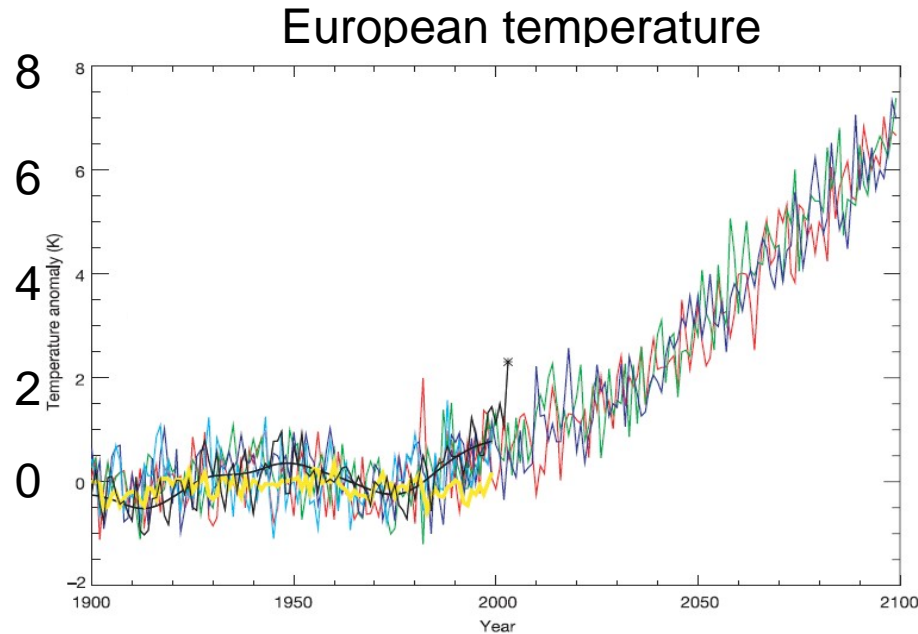
Projected warming in the 21st century shows scenario-independent patterns... Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean and parts of the North Atlantic Ocean.

Projected changes in precipitation

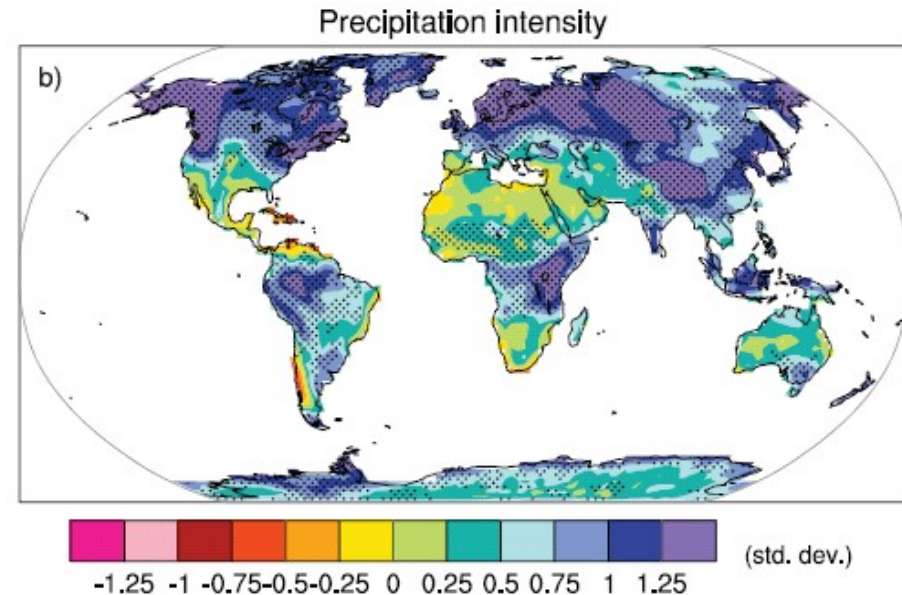


Increases in the amount of precipitation are *very likely* in high-latitudes, while decreases are *likely* in most subtropical land regions ... continuing observed patterns in recent trends.

Changes in extremes



Stott et al. (2004)

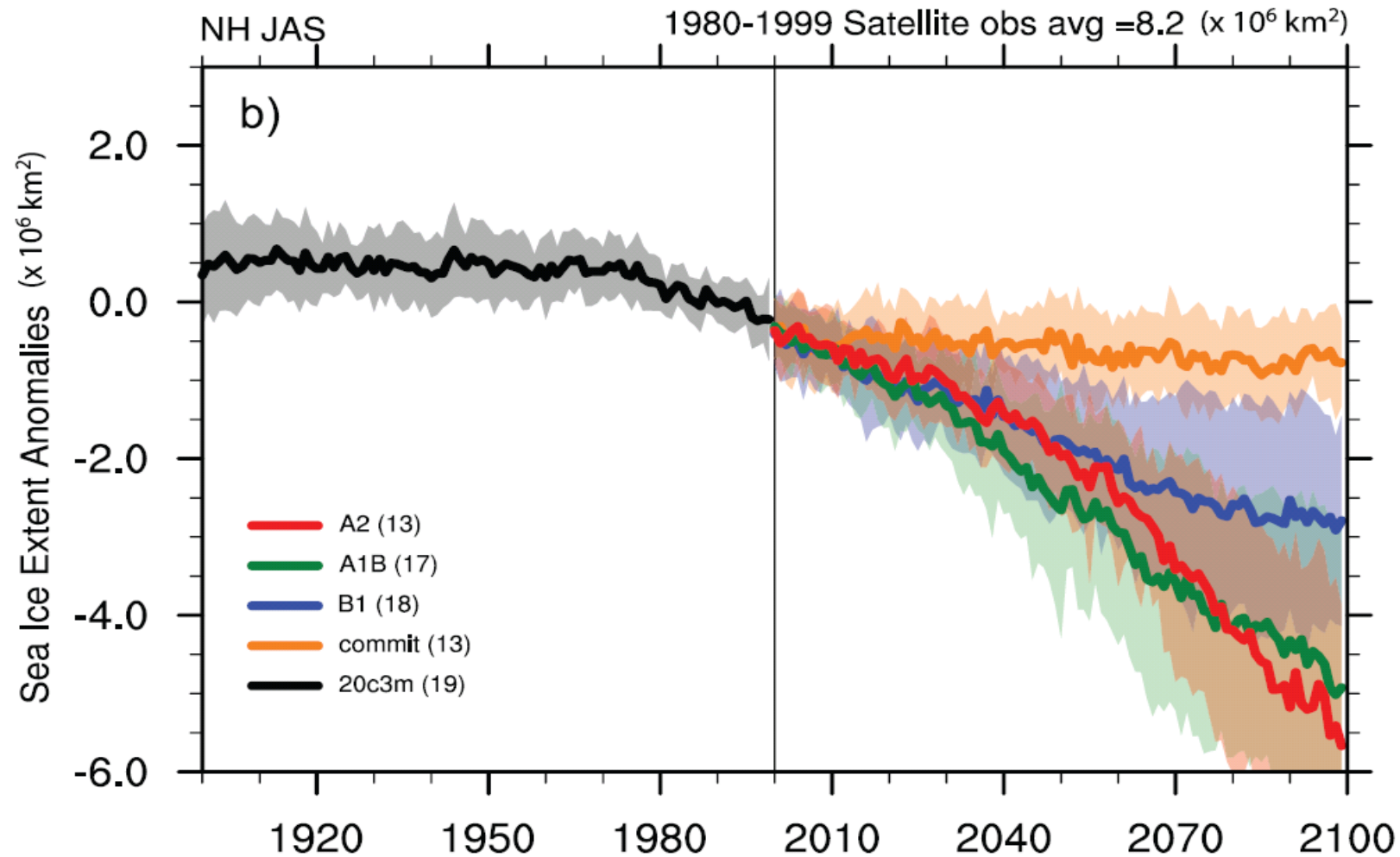


Future warming of day and night extreme temperatures is *virtually certain*.

It is *very likely* that .. heat waves and heavy precipitation events will continue to become more frequent.

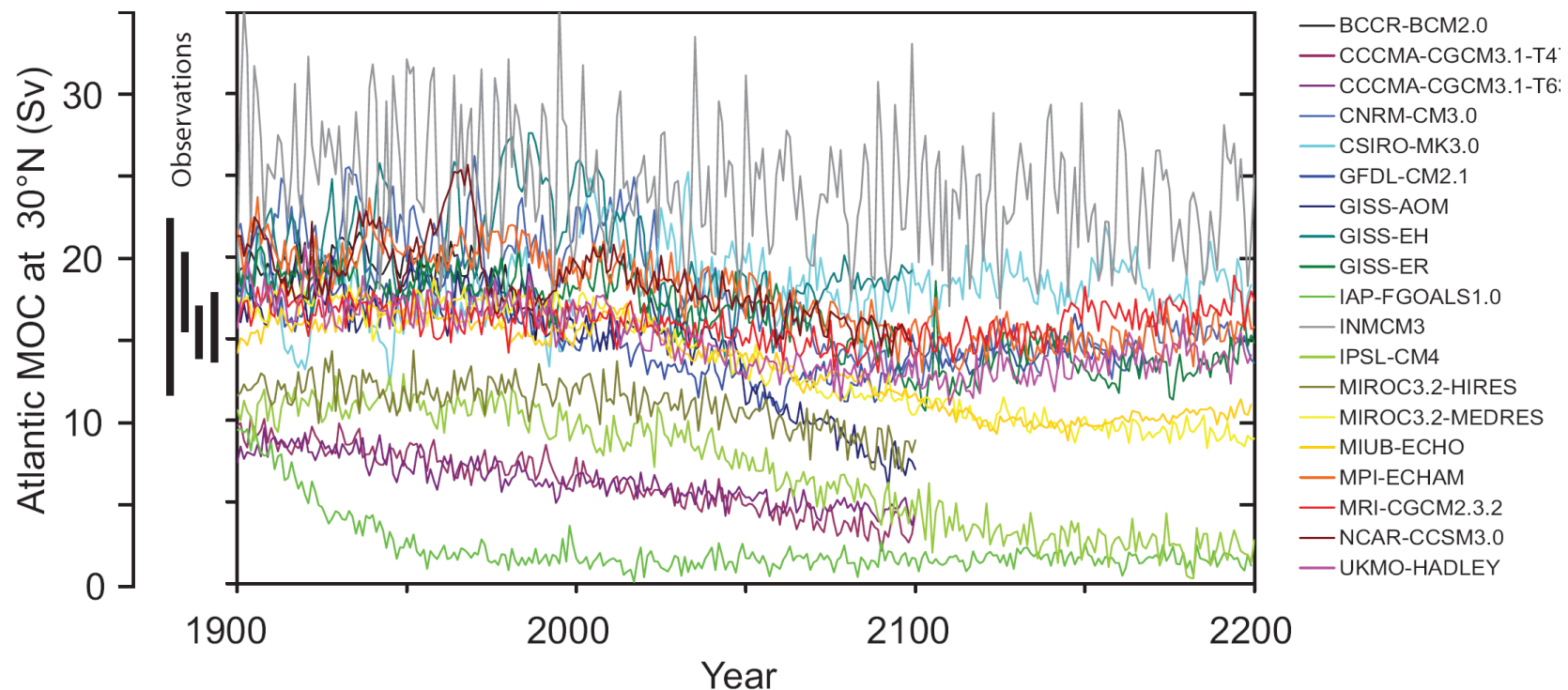
Based on a range of models, it is *likely* that future tropical cyclones (typhoons, hurricanes) will become more intense ...

Changes in Arctic summer sea ice



Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century.

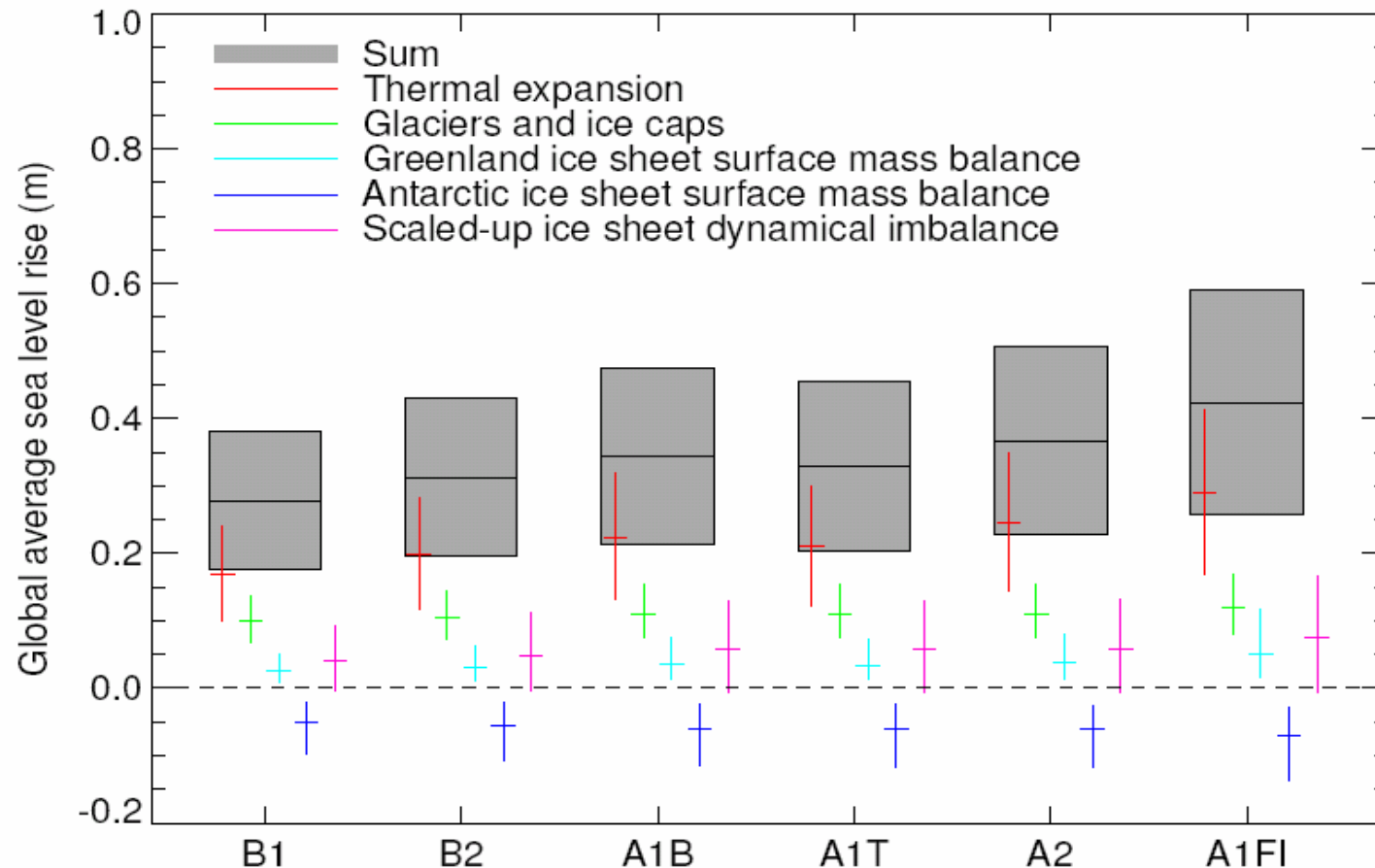
Atlantic meridional overturning circulation



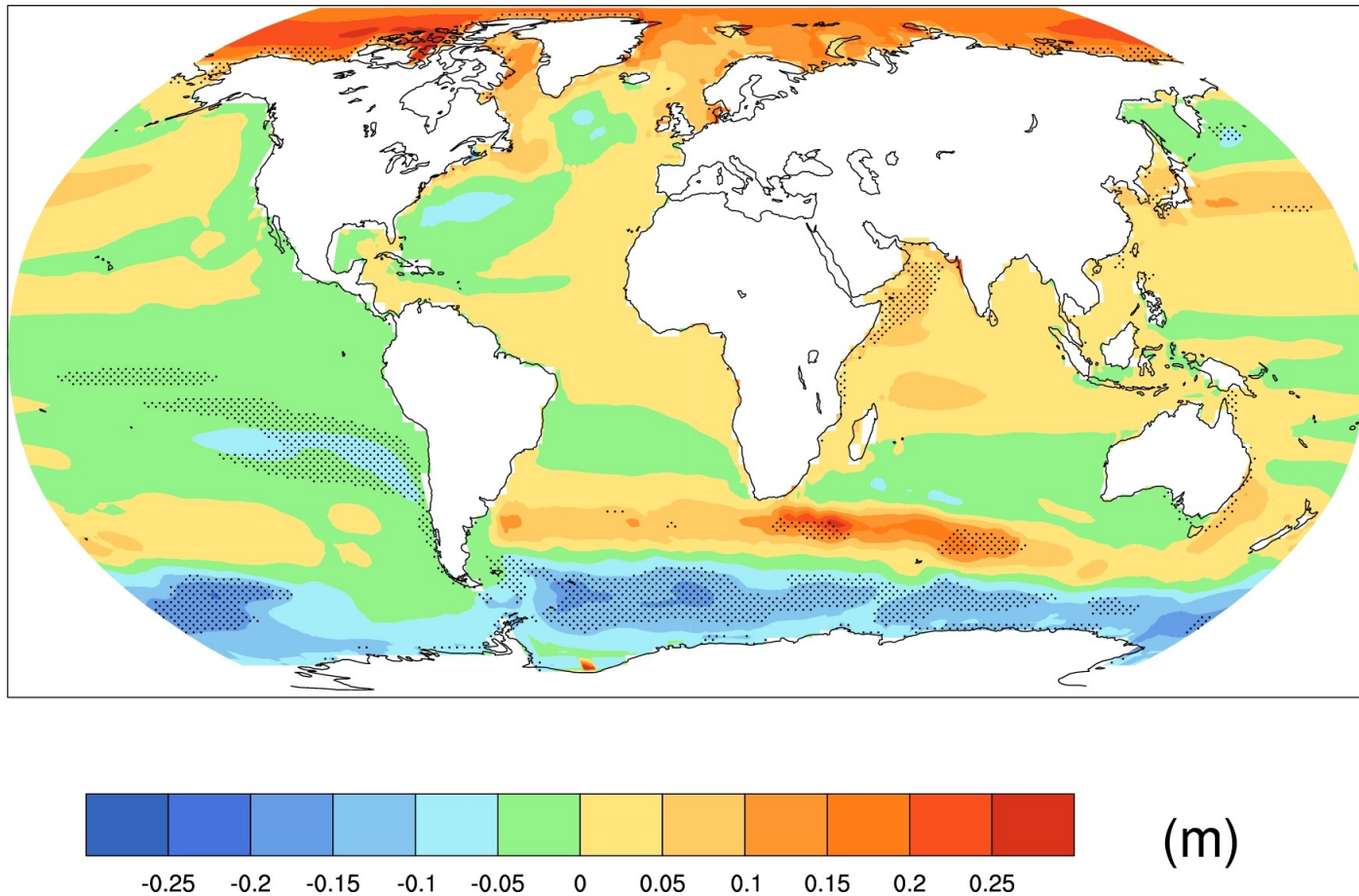
Based on current model simulations, it is *very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century. The multi-model average reduction by 2100 is 25% (range from zero to about 50%) for SRES emission scenario A1B.

Temperatures in the Atlantic region are projected to increase despite such changes due to the much larger warming associated with projected increases of greenhouse gases. It is *very unlikely* that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence.

Projections of sea level rise

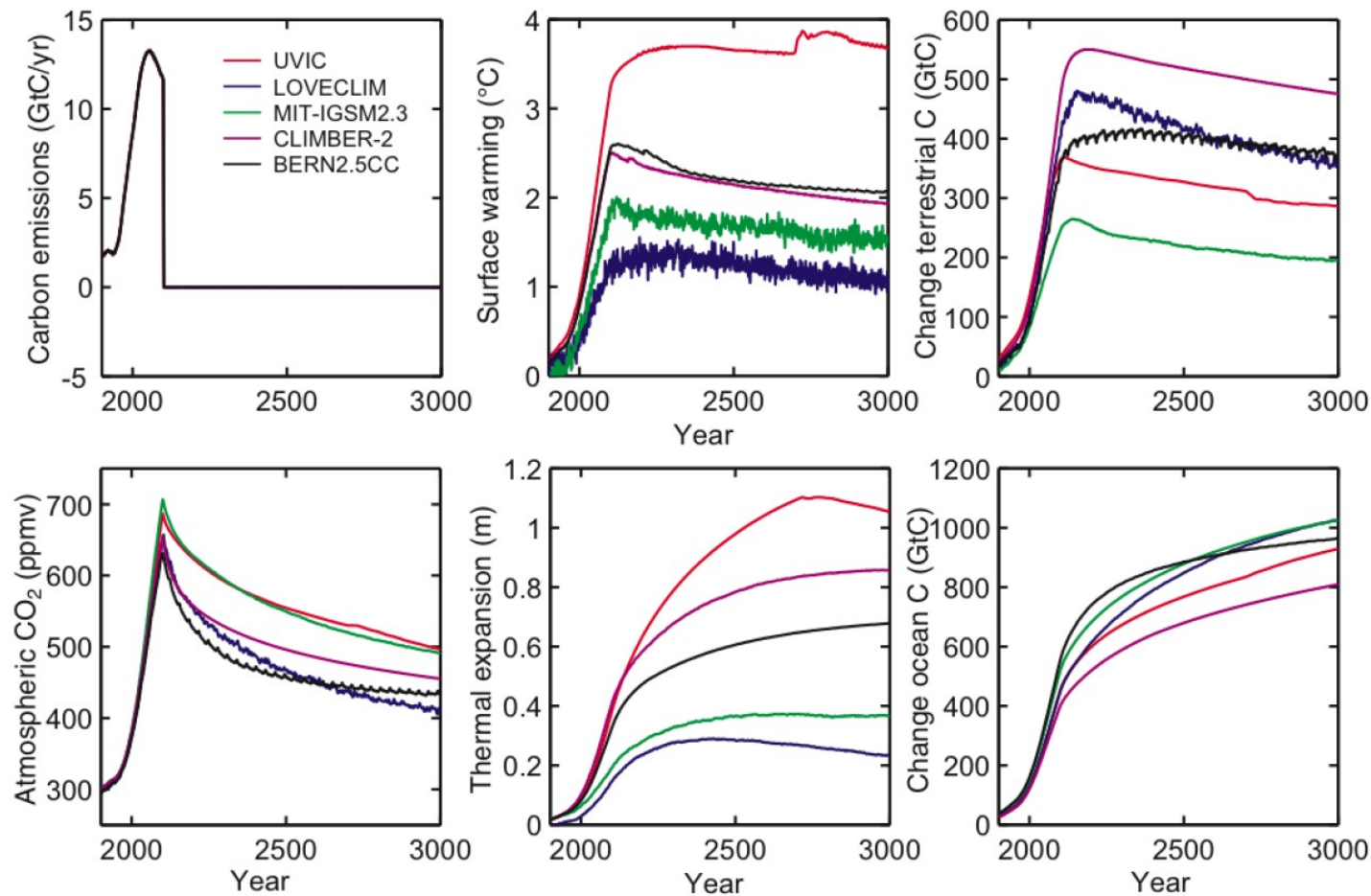


Model-based projections of global average sea level rise at the end of the 21st century (2090-2099). For each scenario, the midpoint of the range ... is within 10% of the TAR ... The ranges are narrower than in the TAR ... The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future.

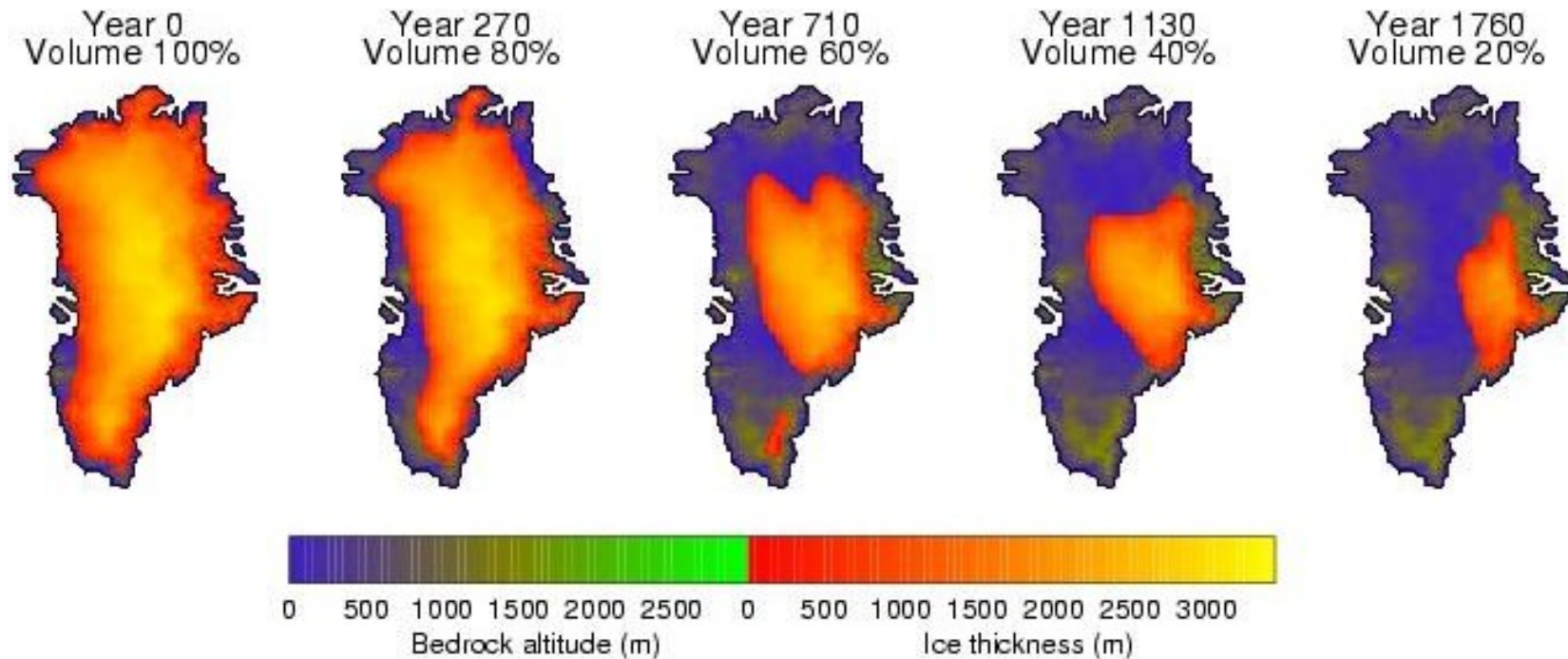


Models indicate that sea level rise during the 21st century will not be geographically uniform. Under scenario A1B for 2070-2099, AOGCMs give a median spatial standard deviation of 0.08 m, which is about 25% of the central estimate of the global average sea level rise.

Changes beyond the 21st century

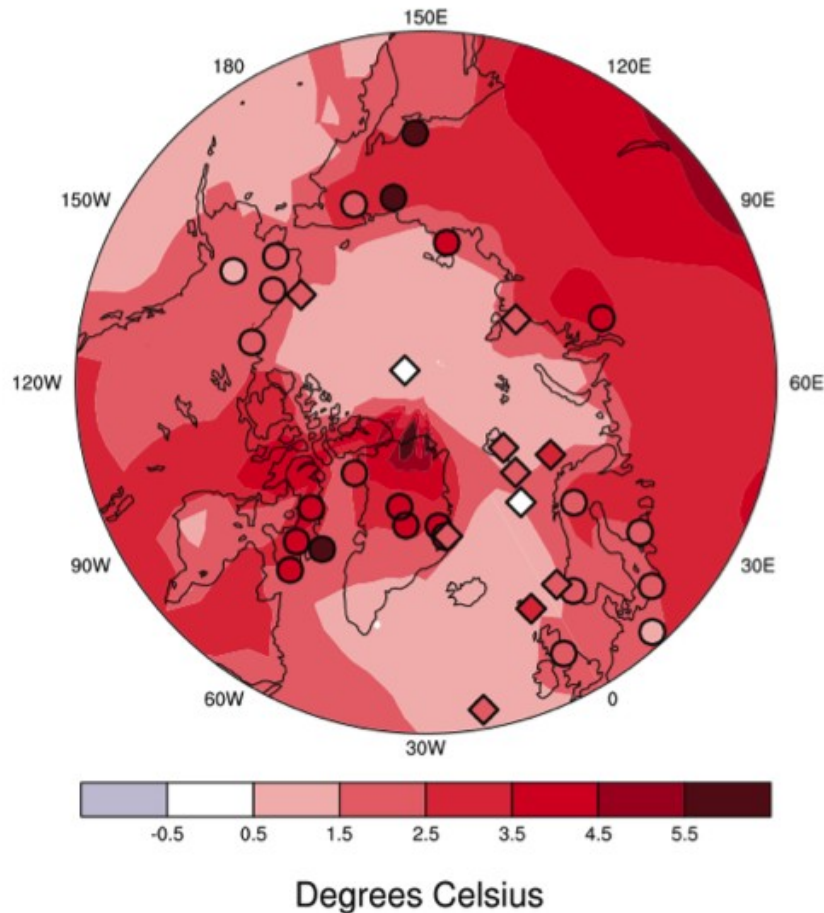


Both past and future anthropogenic carbon dioxide emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the timescales required for removal of this gas from the atmosphere.

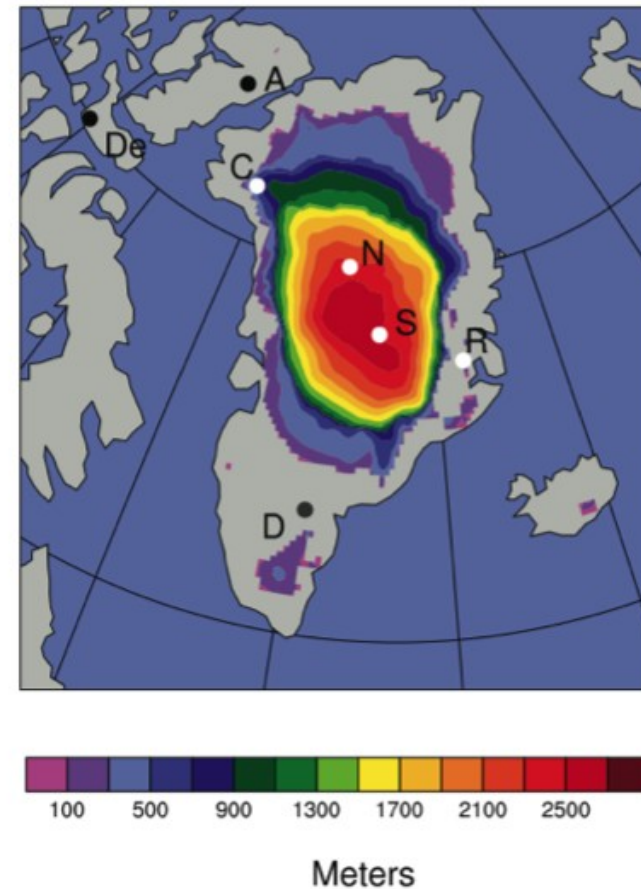


Current models suggest ... that the surface mass balance [of the Greenland ice sheet] becomes negative at a global average warming (relative to pre-industrial values) in excess of 1.9 to 4.6°C. If a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7 m.

The corresponding future temperatures in Greenland are comparable to those inferred for the last interglacial period 125,000 years ago, when paleoclimatic information suggests reductions of polar land ice extent and 4 to 6 m of sea level rise.

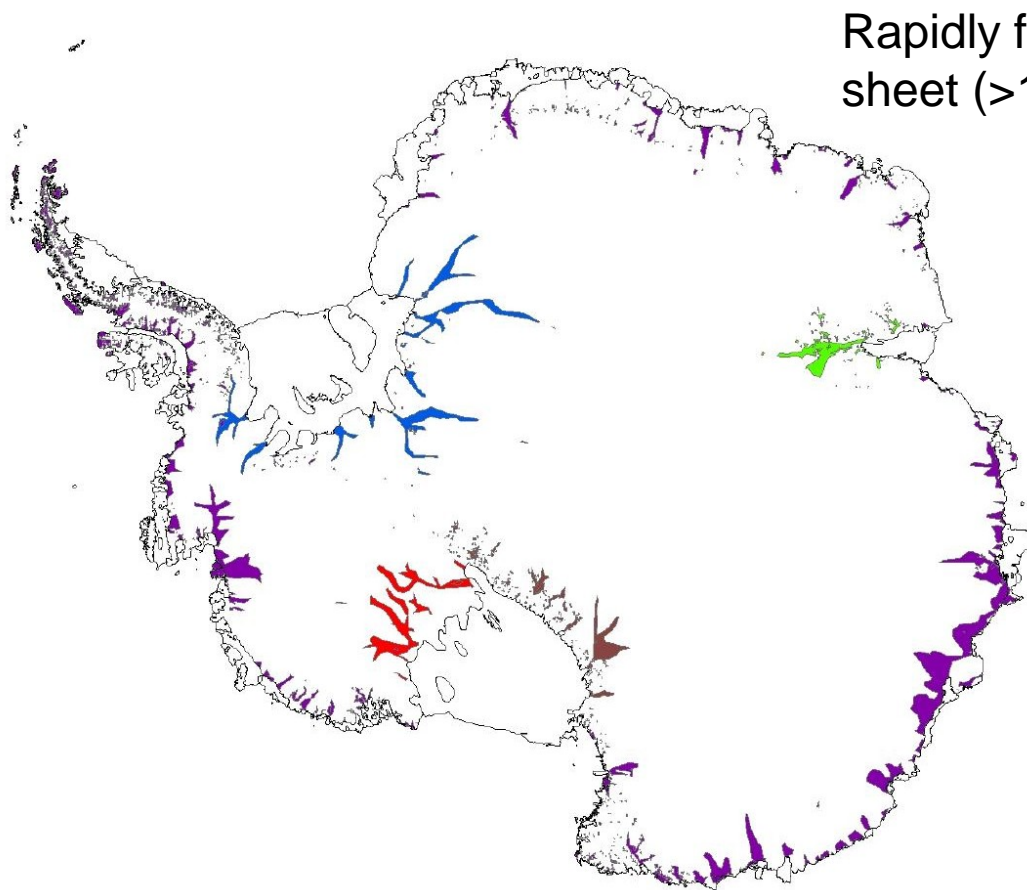


Simulated and observed Arctic warming at 125,000 yr B.P.



Estimated reduction in Greenland ice sheet area and thickness

Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and is expected to gain in mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. Understanding of these [dynamical] processes is limited and there is no consensus on their magnitude.



Rapidly flowing areas of the Antarctic ice sheet ($>100 \text{ m yr}^{-1}$)

If all these areas thinned at 2 m yr^{-1} , they would contribute 3 mm yr^{-1} to sea level

Volume in excess of flotation in these regions is 0.6 m SLE .

Summary of the IPCC WG1 AR4

Owing to fossil-fuel use, land-use change and agriculture, global atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased markedly since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years. Warming of the climate system is unequivocally evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. Paleoclimate information supports the interpretation that the warmth of the last half century is unusual compared with at least the previous 1300 years.

Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. There are discernible human influences on other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns. For the next two decades a warming of about 0.2°C per decade is projected for a range of emission scenarios. Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century. Anthropogenic warming and sea level rise would continue for centuries due to the timescales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized.