Climate variability, climate change and climate prediction

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Climate – all quantities defined by averaging over the weather.

Climate change

Climate variability – ice ages and the long-term warm climate enjoyed by the dinosaurs, the drought that has plagued the Sahel region in Africa, and ENSO.

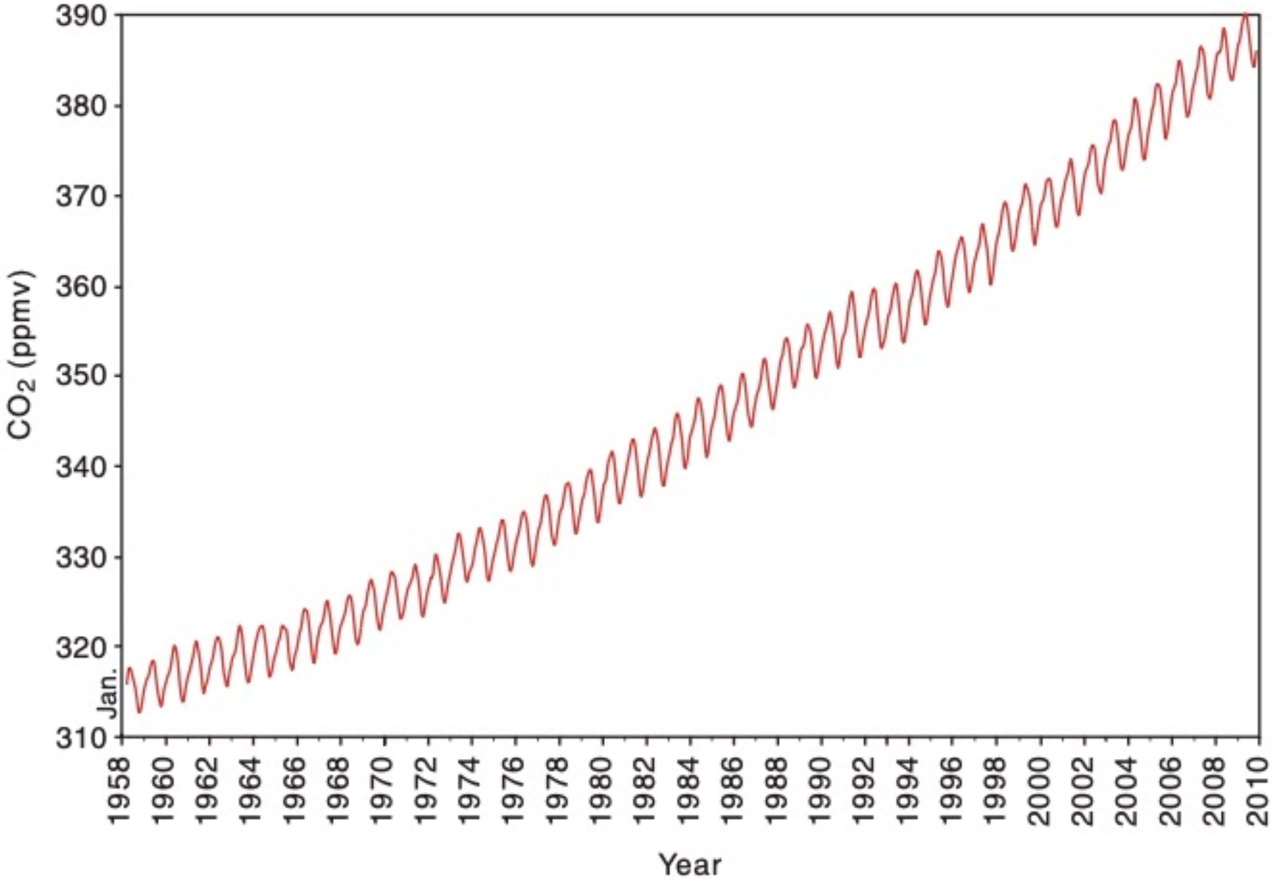
Anthropogenic climate change – ozone hole, acid rain and global warming.

Global warming – predicted warming, and other associated changes in the climate system in response to the increased amounts of greenhouse gases that are being emitted into the atmosphere by human activities.

Greenhouse gases – CO_2, CH_4, N_2O, O_3, CFC that absorb infrared radiation and thus affect the Earth's energy budget of incoming sunlight and outgoing infrared radiation to space.

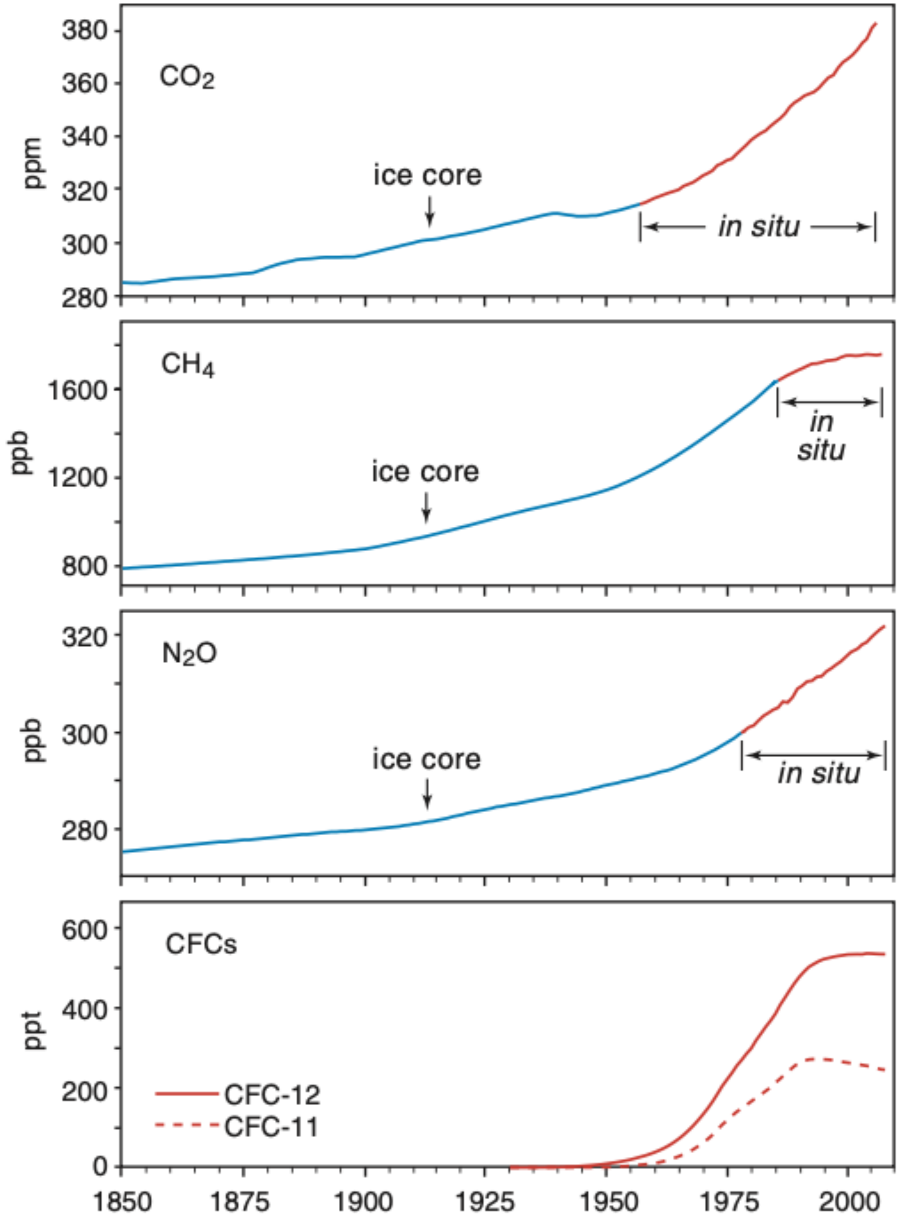
Climate prediction – predict not only human-induced changes in the global environment but also the natural variations of climate that affect us. Climate prediction heavily relies on physically based climate models.

Global change in recent history



Carbon dioxide concentrations (monthly mean) since 1958, measured at Mauna Loa, Hawaii. Units are parts per million by volume, and tick marks occur at January of the indicated year. From the National Oceanographic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory. Data prior to 1974 are from Keeling *et al*. (1976).

- ❖ Increase throughout the time series
- ❖ Yearly variations in concentration



Concentration of various trace gases, carbon dioxide, methane, nitrous oxide and two chlorofluorocarbons, respectively, estimated since 1850. The part of the record from direct atmospheric measurements is marked "*in situ*." Data from Goddard Institute for Space Studies following Hansen *et al*. (1998).

- ❖ Increases in concentration, with a greater rate of increase in recent times
- ❖ All the gases shown contribute to the greenhouse effect, while the CFCs have an additional effect – stratospheric ozone loss.

Ozone hole

- 1974 – The role of CFCs in ozone destruction was predicted by Sherwood Rowland and Mario Molina.

- 1985 – Observations of Antarctic ozone depletion in southern spring by Farman and coworkers – the *ozone hole*.

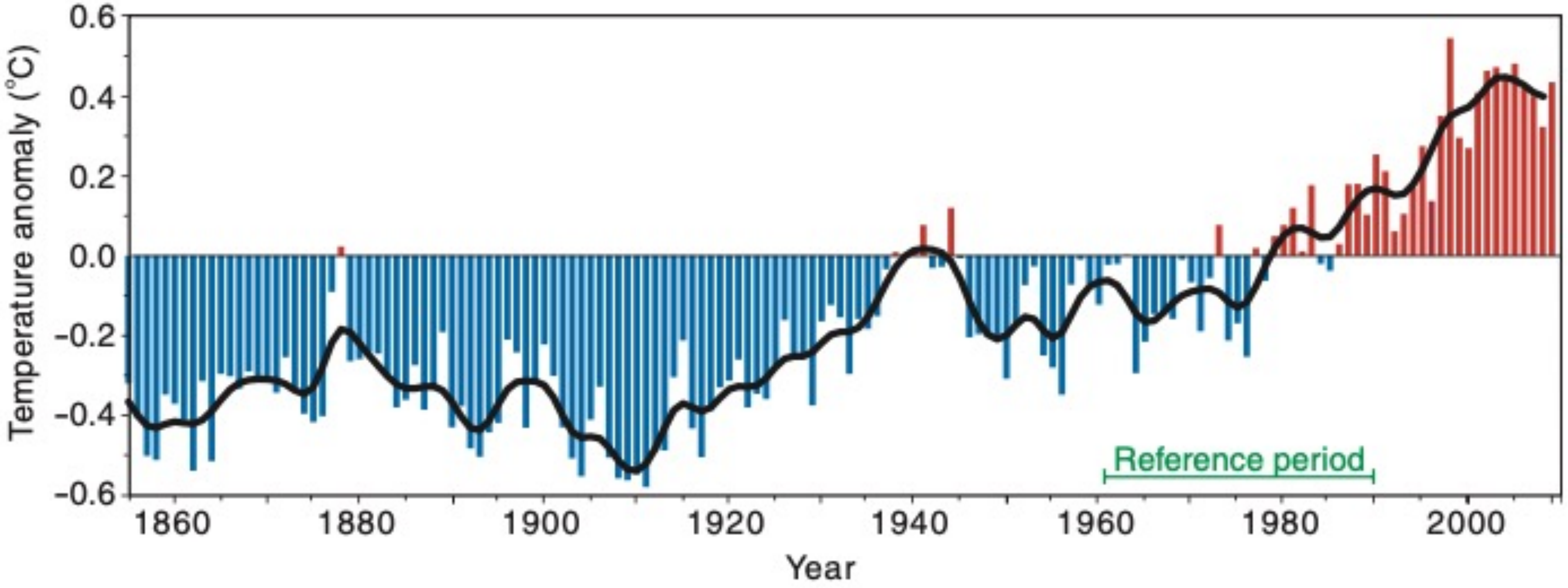
- 1987 – The Montreal Protocol set a timetable for phase-out of CFC emissions.

Some events in the history of global warming studies

	1850s	Beginning of the industrial revolution.
	1958	Start of C. D. Keeling's monitoring of CO_2 at Mauna Loa.
	1975	First three-dimensional global climate model of CO_2-induced climate change by Suki Manabe.
AR1	1990 and 92	Intergovernmental Panel on Climate Change (IPCC) Report and Supplement.
AR2	1995–96	Second Assessment Report of the IPCC: *"The balance of evidence suggests a discernible human influence on global climate. [...] There are still many uncertainties."*
AR3	2001	Third Assessment Report of the IPCC.
AR4	2007	Fourth Assessment Report of the IPCC. Nobel Peace Prize awarded to the few thousand scientists of the IPCC process and one politician.

AR5 (2013-2014) and AR6 (2022)

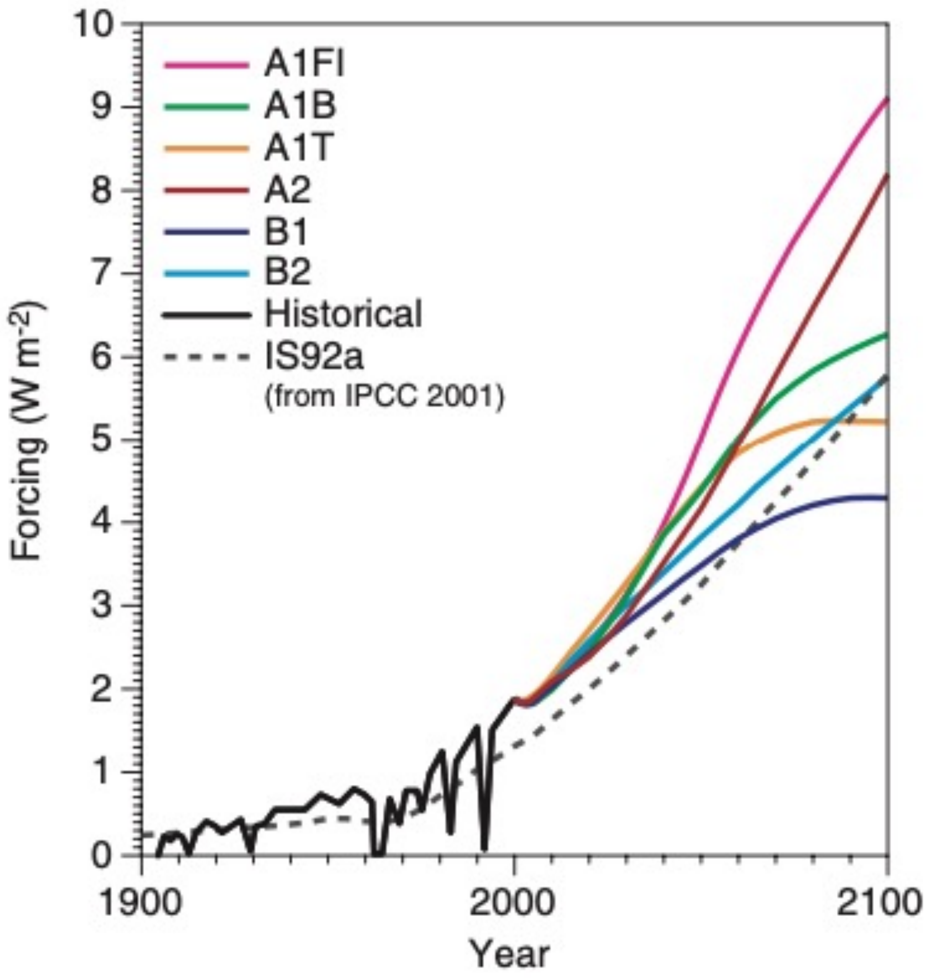
Global temperature



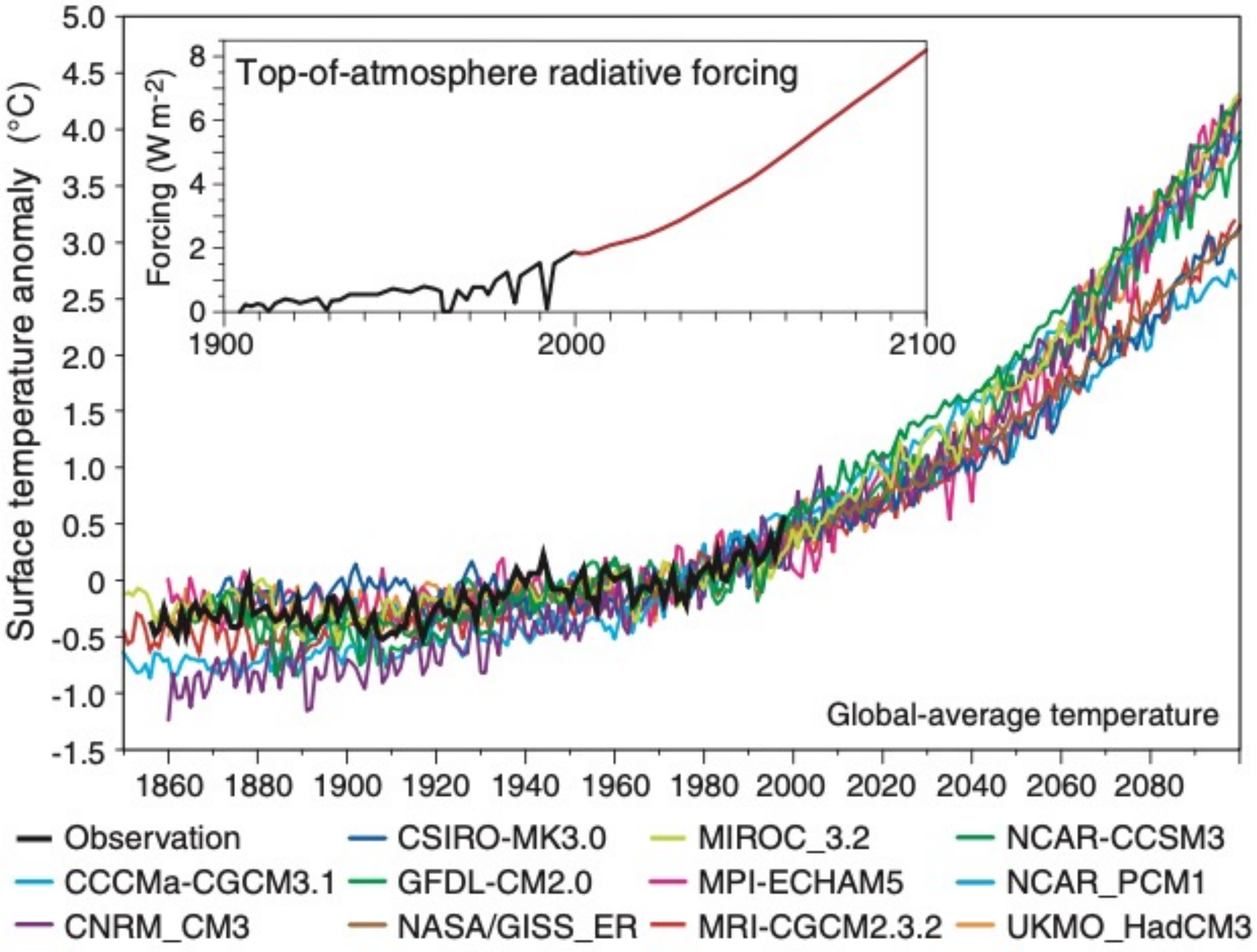
Global mean surface temperatures estimated since preindustrial times shown as anomalies relative to the 1961–1990

- Temperatures have been rising, although not uniformly.
- The presence of natural variability
- How to detect global warming?

Climate model for global warming

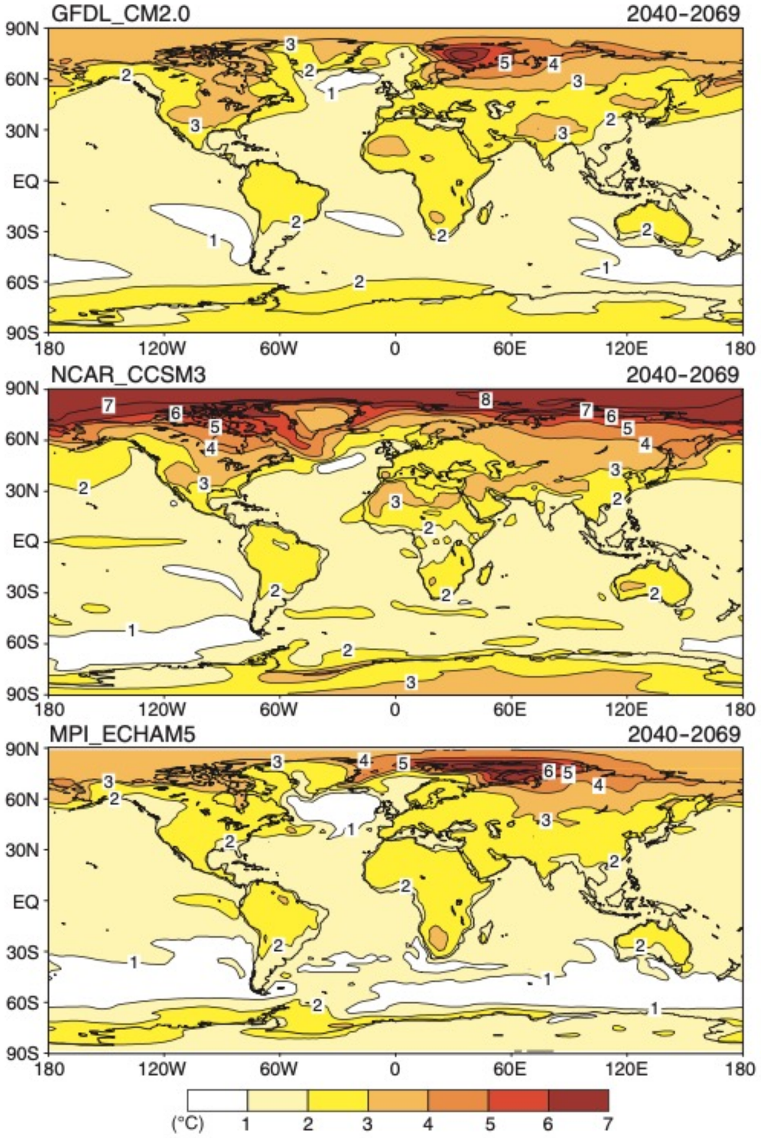


- ❖ Forcing – radiative effects of greenhouse gases in the atmosphere
- ❖ Driver of climate change
- ❖ Scenarios

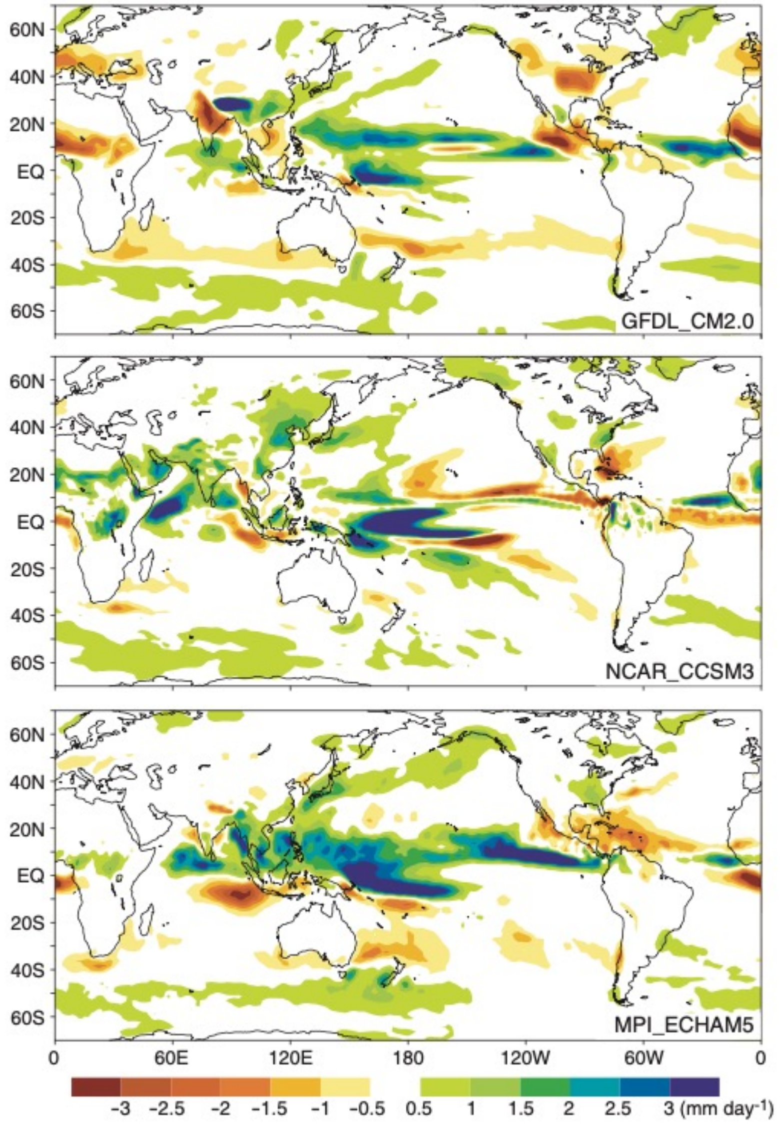


Top-of-atmosphere radiative forcing
Forcing (W m-2)
1900
2000
2100
Surface temperature anomaly (°C)
Global-average temperature
Observation
CSIRO-MK3.0
MIROC_3.2
NCAR-CCSM3
CCCMa-CGCM3.1
GFDL-CM2.0
MPI-ECHAM5
NCAR_PCM1
CNRM_CM3
NASA/GISS_ER
MRI-CGCM2.3.2
UKMO_HadCM3

Comparing projections of different climate models



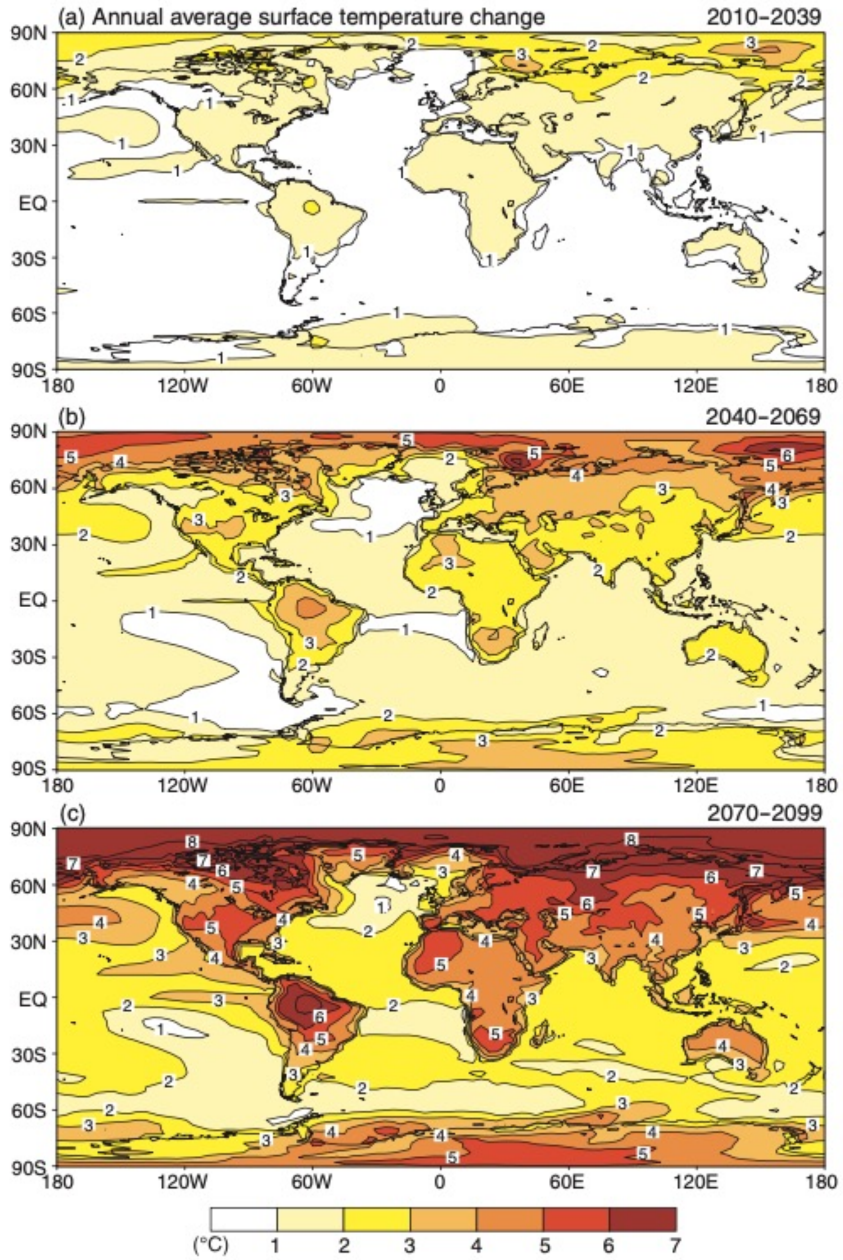
Annual-average change in surface air temperature (relative to 1961–90) from three climate models (denoted by acronyms – see endnotes) for a 30-year average centered on 2055 from simulations with GHG and sulphate aerosol forcing. Contour interval 1 °C.



Precipitation change for June–August average (relative to 1961–90) from three climate models (as in Figure 7.7) for a 30-year average centered on 2085 from simulations with SRES A2 GHG and sulfate aerosol forcing. Contour interval 1 mm day^{-1} (0.5 mm day^{-1} for the first interval).

Spatial patterns of warming

❖ Poleward amplification or polar amplification

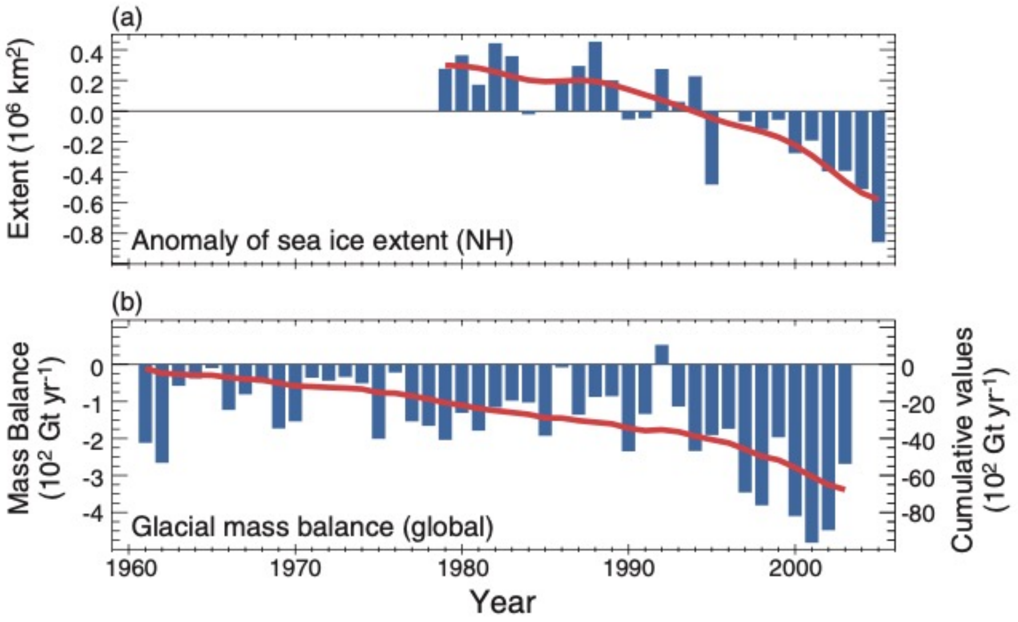


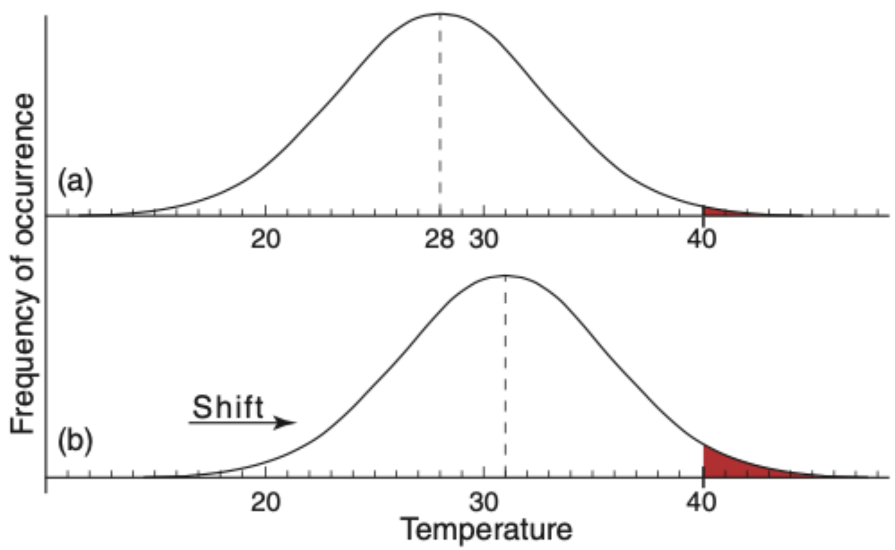
Response to GHG and sulfate aerosol forcing from the Hadley Centre climate model (HadCM3). The change in surface air temperature, relative to the average during 1961–90, is shown as 30-year averages centered on (a) 2025, (b) 2055, (c) 2085. Contour interval 1 °C.

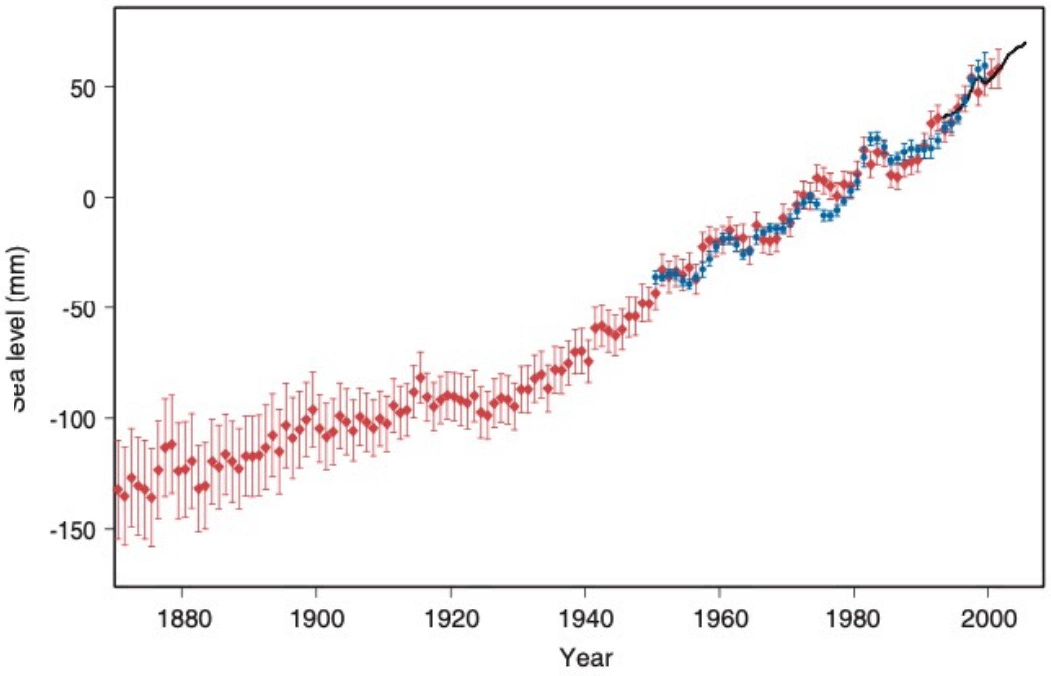
Polar amplification of warming

- *Snow/ice feedback*.

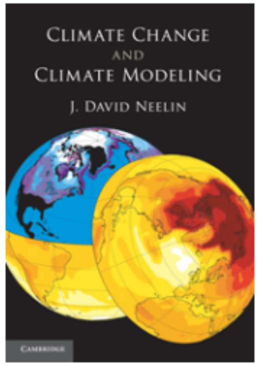
- *Lapse rate feedback:* The lapse rate (rate of temperature decrease with height) is larger at high latitudes than in the tropics. This affects the greenhouse feedback between the atmospheric temperature in the upper troposphere and the surface temperature.


(a)
Extent (10^6 km^2)
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
Anomaly of sea ice extent (NH)
(b)
Mass Balance (10^2 Gt yr^{-1})
0
-1
-2
-3
-4
Glacial mass balance (global)
Cumulative values (10^2 Gt yr^{-1})
0
-20
-40
-60
-80
1960
1970
1980
1990
2000
Year


Frequency of occurrence
(a)
20
28
30
40
Shift
(b)
20
30
40
Temperature


level (mm)
50
0
-50
-100
-150
1880
1900
1920
1940
1960
1980
2000
Year

Summary



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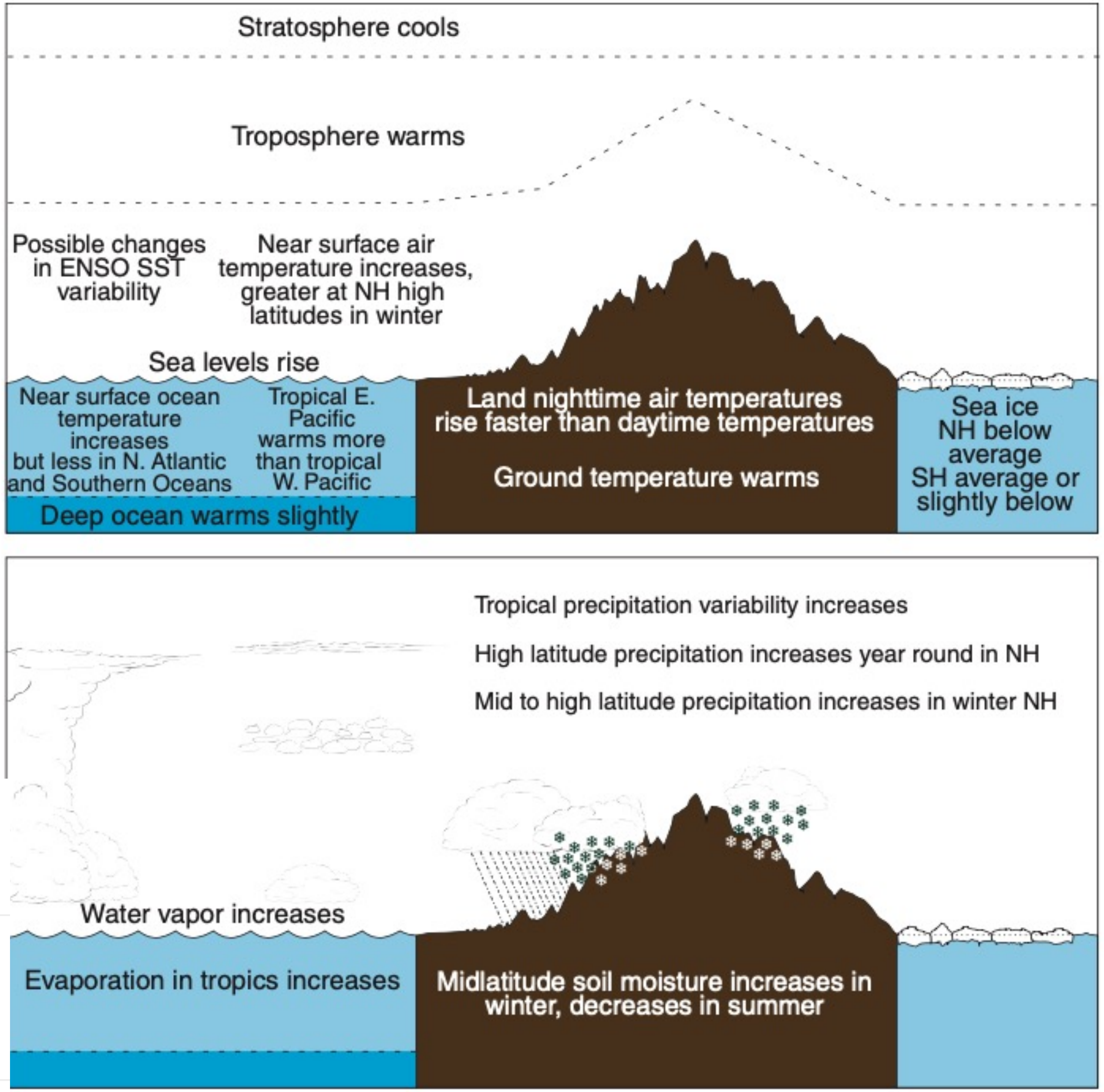

Schematic summary of best-estimate climate changes due to greenhouse warming. NH, northern hemisphere; SH, southern hemisphere. Schematic adapted from IPCC (2001) and updated.