Climate Change 2007:
The Physical Science Basis

Working Group I Contribution to the IPCC Fourth Assessment Report

Presented by
R.K. Pachauri, IPCC Chair
and
Bubu Jallow, WG 1 Vice Chair

Nairobi, 6 February 2007

DIRECT OBSERVATIONS OF RECENT CLIMATE CHANGE

Since the TAR, progress in understanding how climate is changing in space and in time has been gained through:

- improvements and extensions of numerous datasets and data analyses
- broader geographical coverage
- better understanding of uncertainties, and
- a wider variety of measurements

Direct Observations of Recent Climate Change

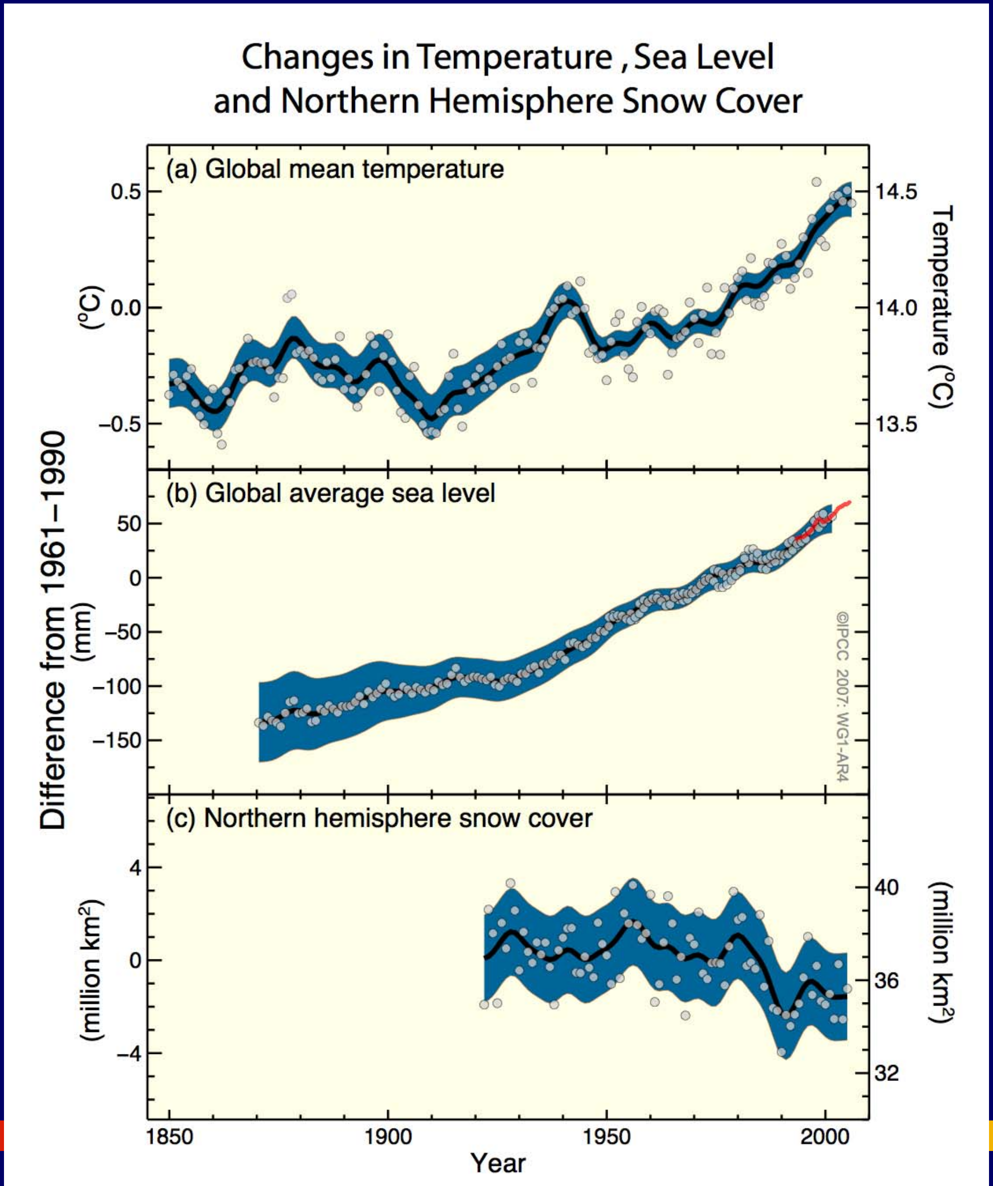
Warming of the climate system is **unequivocal**, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level.

Direct Observations of Recent Climate Change

Gobal mean temperature

Global average sea level

Northern hemisphere Snow cover



Direct Observations of Recent Climate Change

Global average air temperature

- Updated 100-year linear trend of 0.74 [0.56 to 0.92] ^{o}C for 1906-2005
- Larger than corresponding trend of 0.6 [0.4 to 0.8] ^{o}C for 1901-2000 given in TAR

- Average ocean temperature increased to depths of at least 3000 m – ocean has absorbed 80% of heat added

  > seawater expansion and SLR

Direct Observations of Recent Climate Change

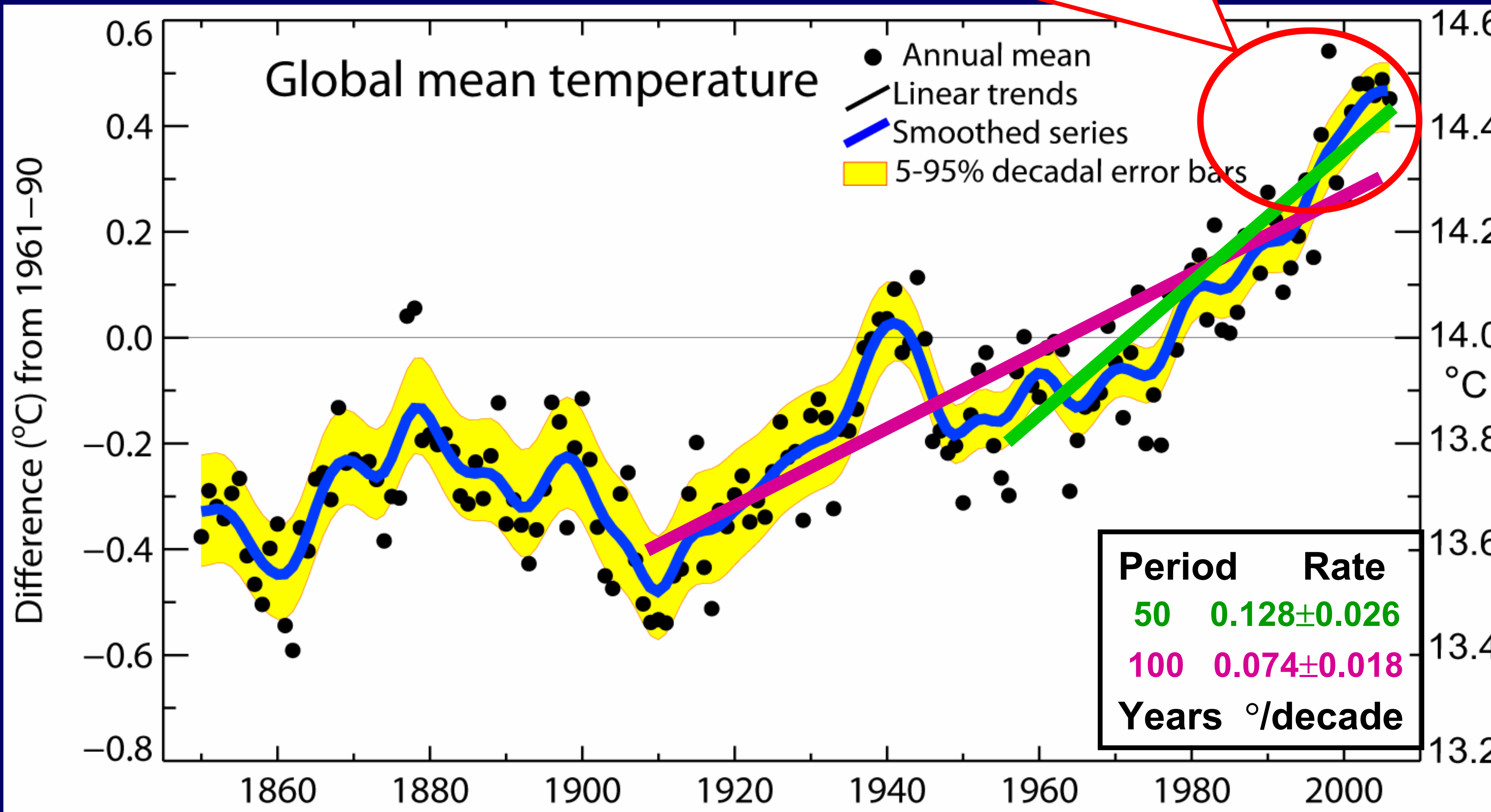
At continental, regional, and ocean basin scales, numerous long-term changes in climate have been observed. These include:

- Changes in Arctic temperatures and ice,
- Widespread changes in precipitation amounts, ocean salinity, wind patterns
- and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones

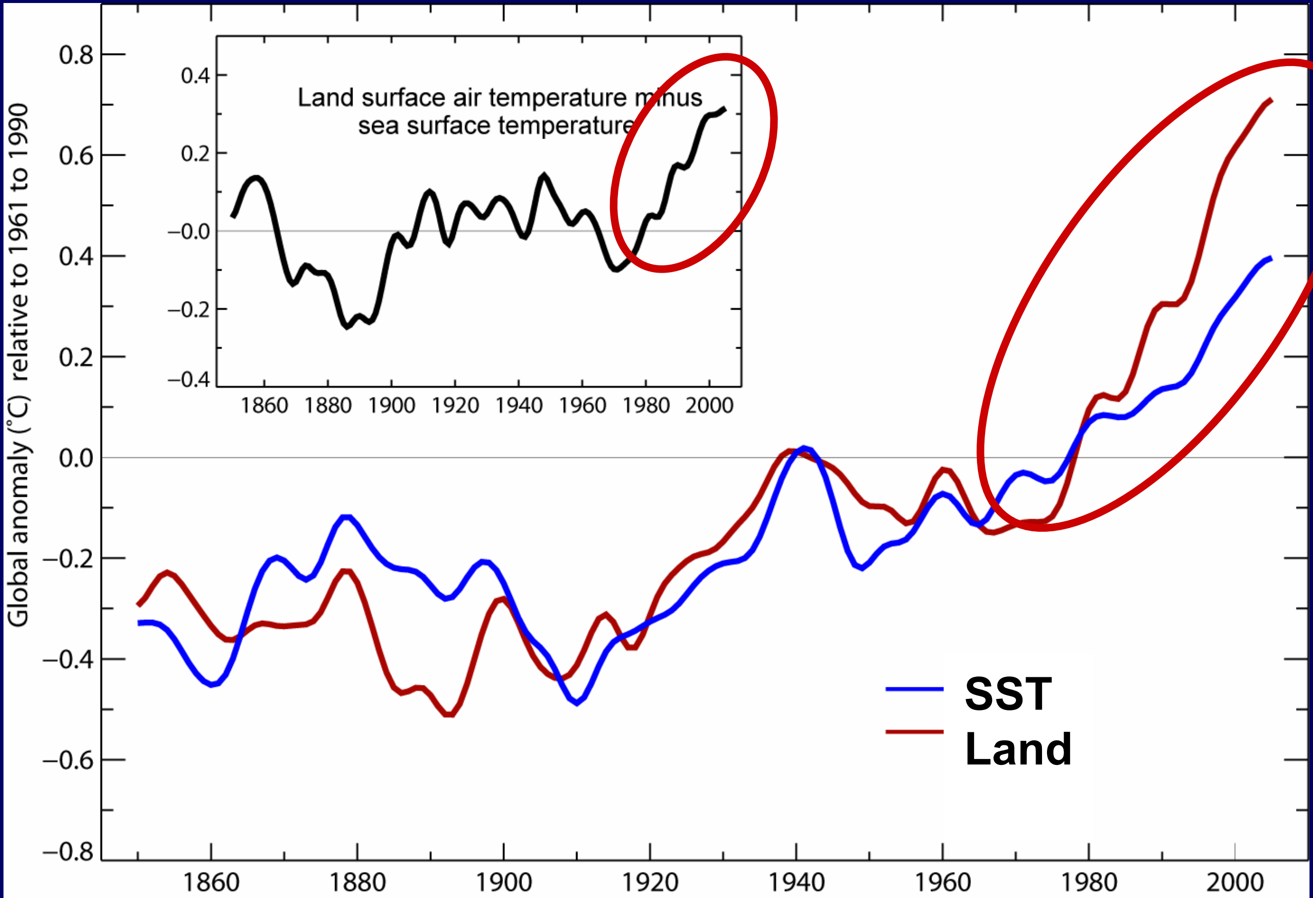
Global mean temper

Warmest 12 years:

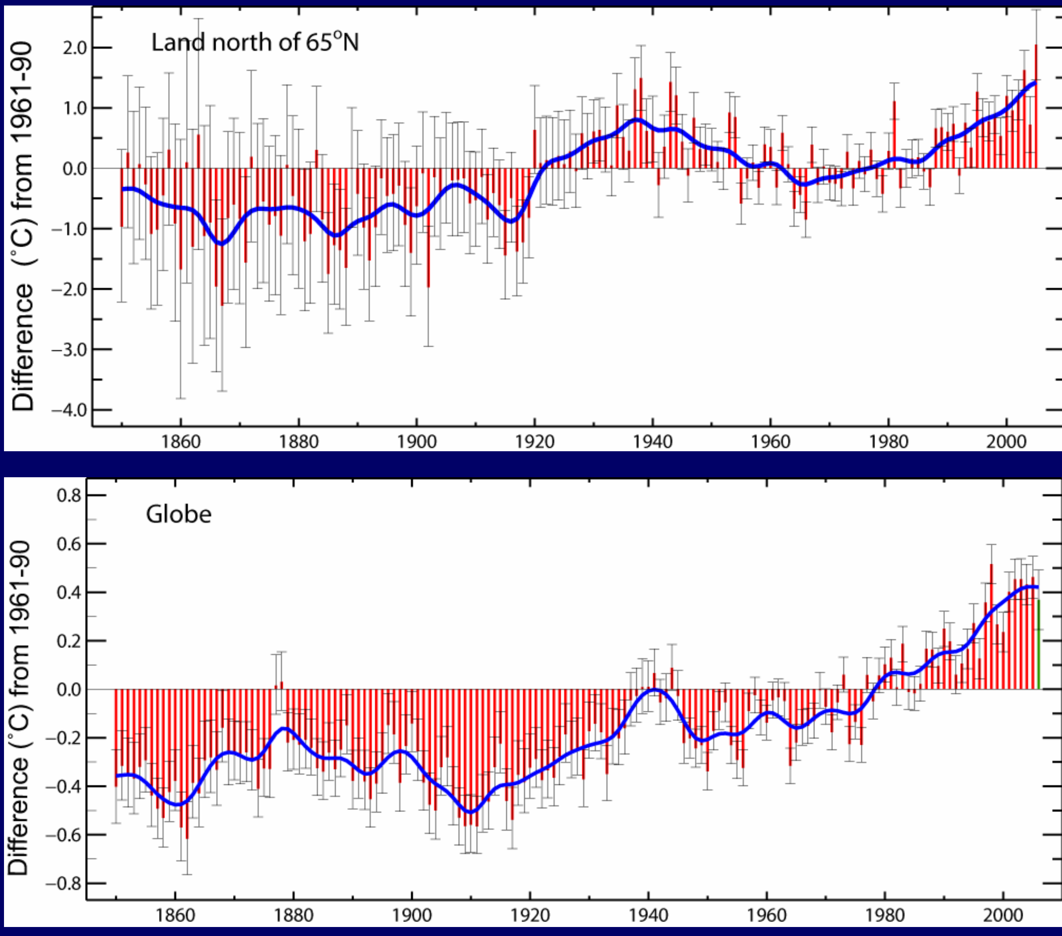
1998,2005,2003,2002,2004,2006, 2001,1997,1995,1999,1990,2000



Land surface temperatures are rising faster than SSTs



Arctic vs Global annual temperature anomalies (°C)



Warming in the Arctic is **double** that for the globe from 19th to 21st century and from late 1960s to present.

Warmth 1925 to 1950 in Arctic was not as widespread as recent global warmth.

Note different scales

Further Changes in Artic and Frozen Ground

- Annual average Arctic sea ice extent shrunk by 2.7 % per decade, decreases in summer 7.4 %
- Temperatures at the top of permafrost layer have generally increased since the 1980s by up to 3°C
- The maximum area covered by seasonally frozen ground has decreased by about 7% in Northern Hemisphere since 1900, in spring of up to 15%.

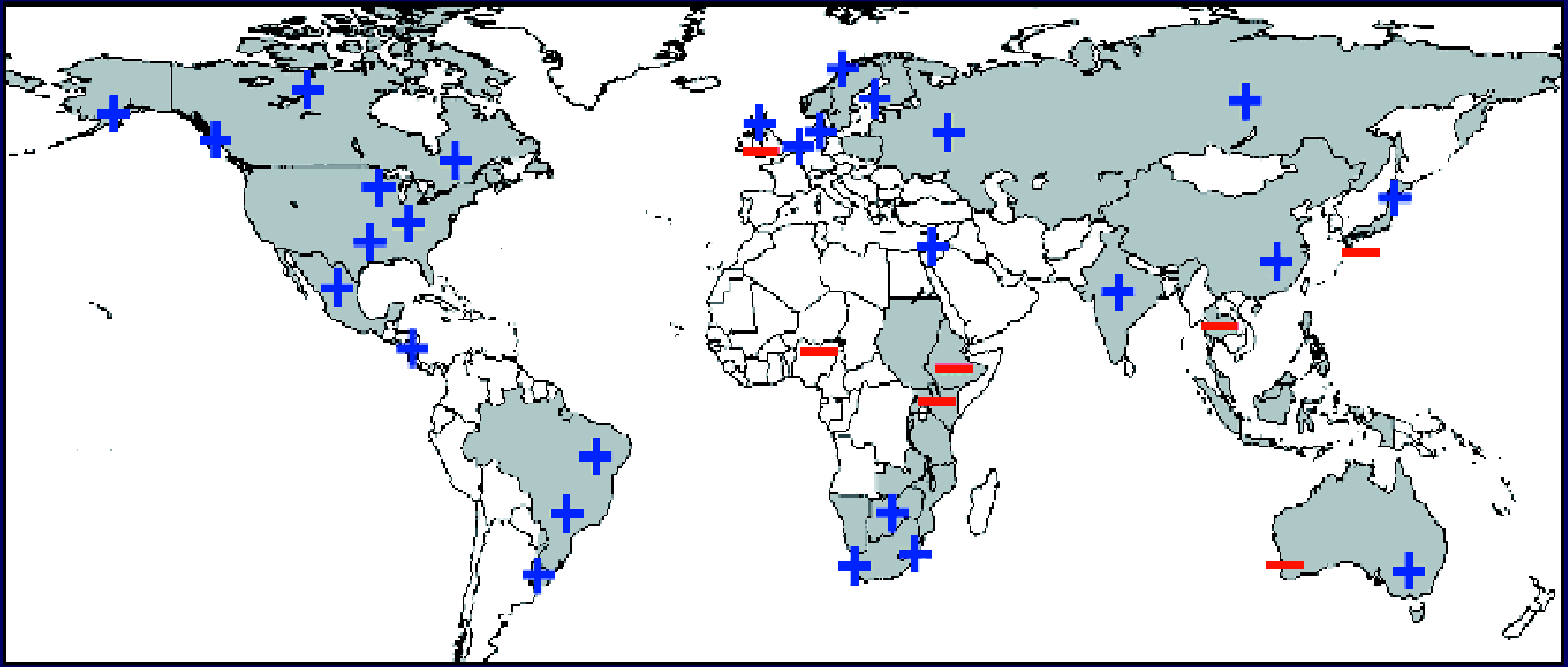
Changes in Precipitation, Increased Drought

- Significantly increased precipitation in eastern parts of North and South America, northern Europe and northern and central Asia.
- The frequency of heavy precipitation events has increased over most land areas - consistent with warming and increases of atmospheric water vapour
- Drying in the Sahel, the Mediterranean, southern Africa and parts of southern Asia.
- More intense and longer droughts observed since the 1970s, particularly in the tropics and subtropics.

Other changes in Extreme Events

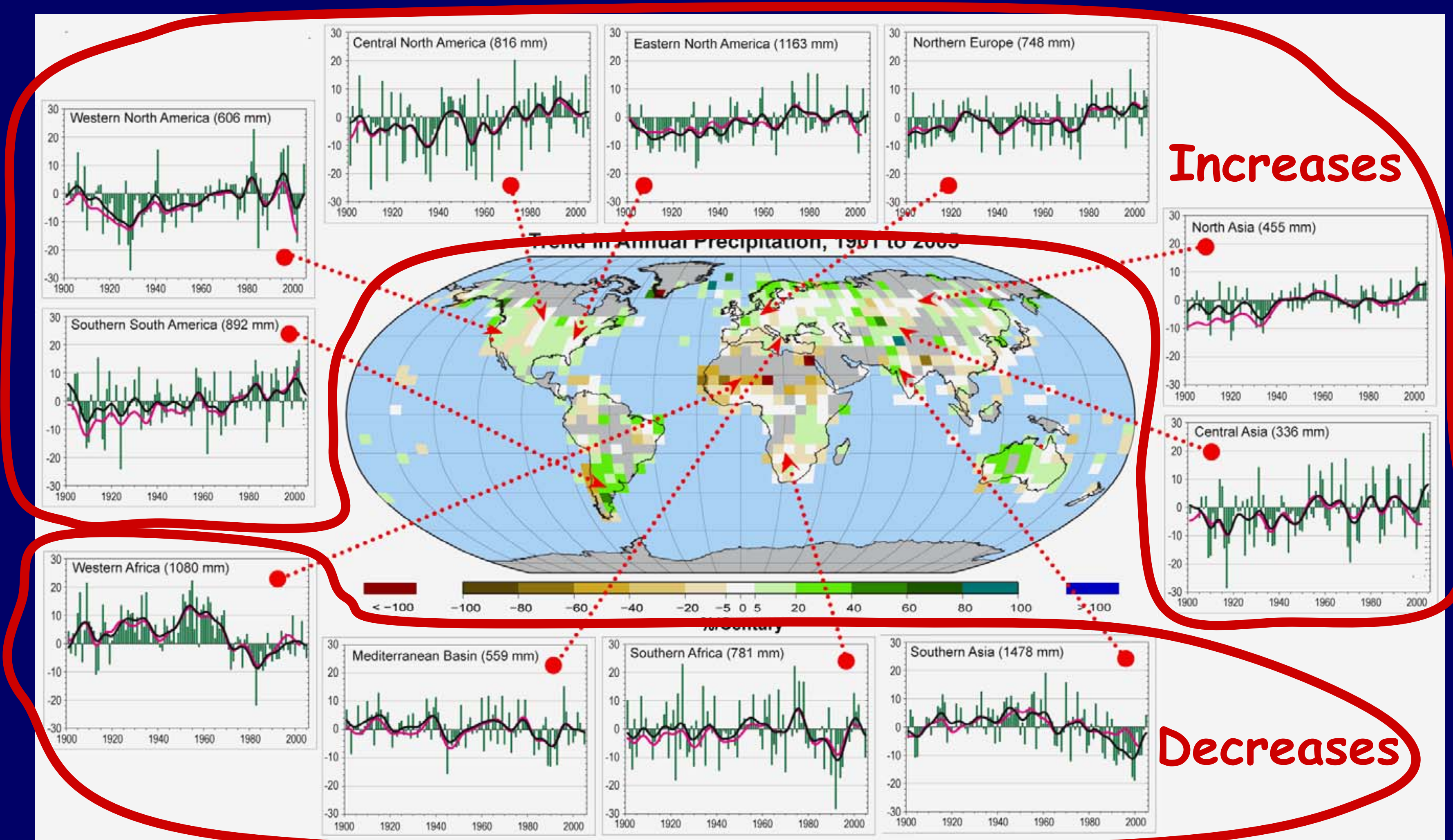
- Widespread changes in extreme temperatures observed
- Cold days, cold nights and frost less frequent
- Hot days, hot nights, and heat waves more frequent
- Observational evidence for an increase of intense tropical cyclone activity in the North Atlantic since about 1970, correlated with increases of tropical sea surface temperatures

Proportion of heavy rainfalls: increasing in most land areas



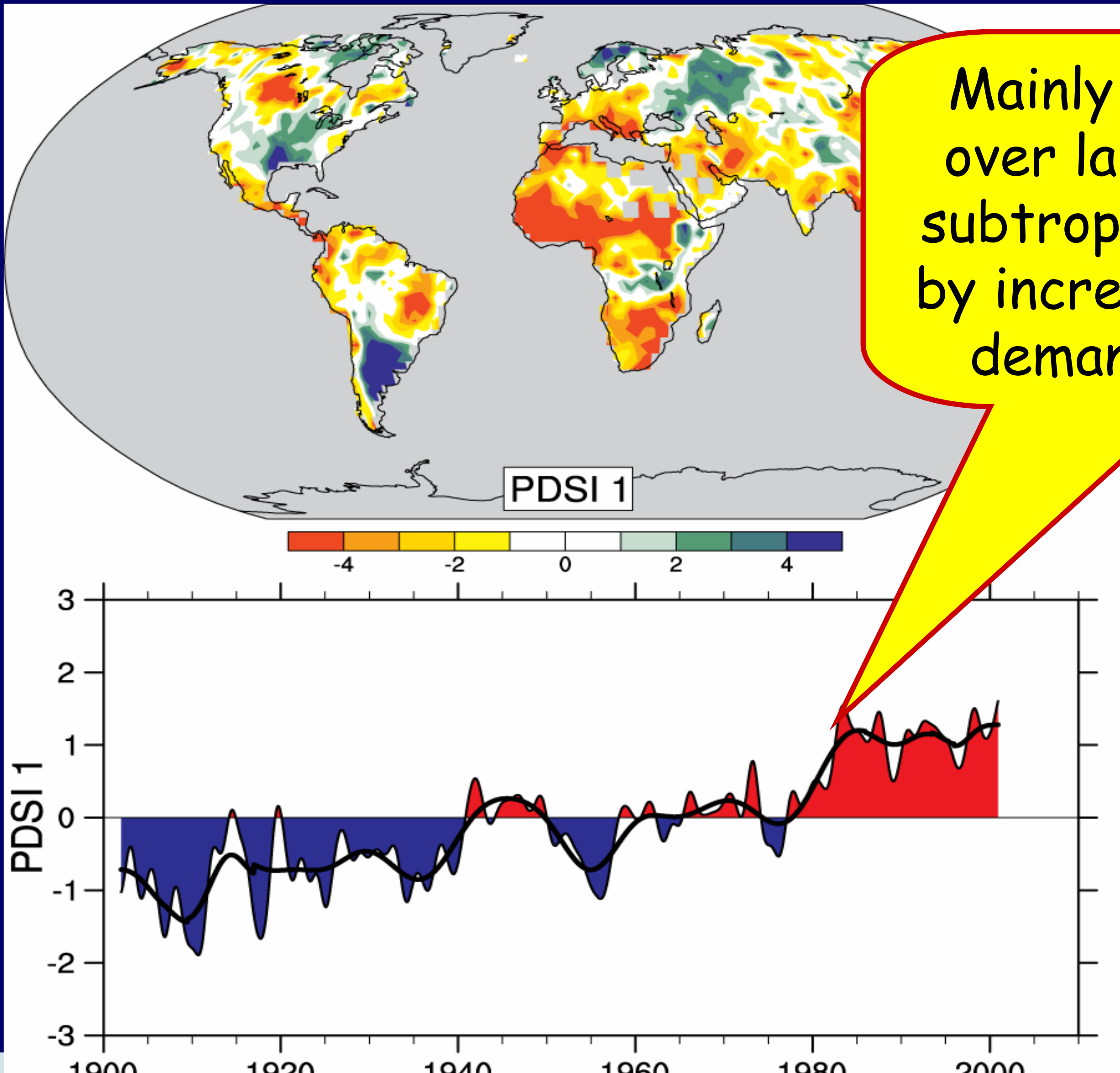
Regions of disproportionate changes in heavy (95th) and very heavy (99th) precipitation

Land precipitation is changing significantly over broad areas



Smoothed annual anomalies for precipitation (%) over land from 1900 to 2005; other regions are dominated by variability.

Drought is increasing most places

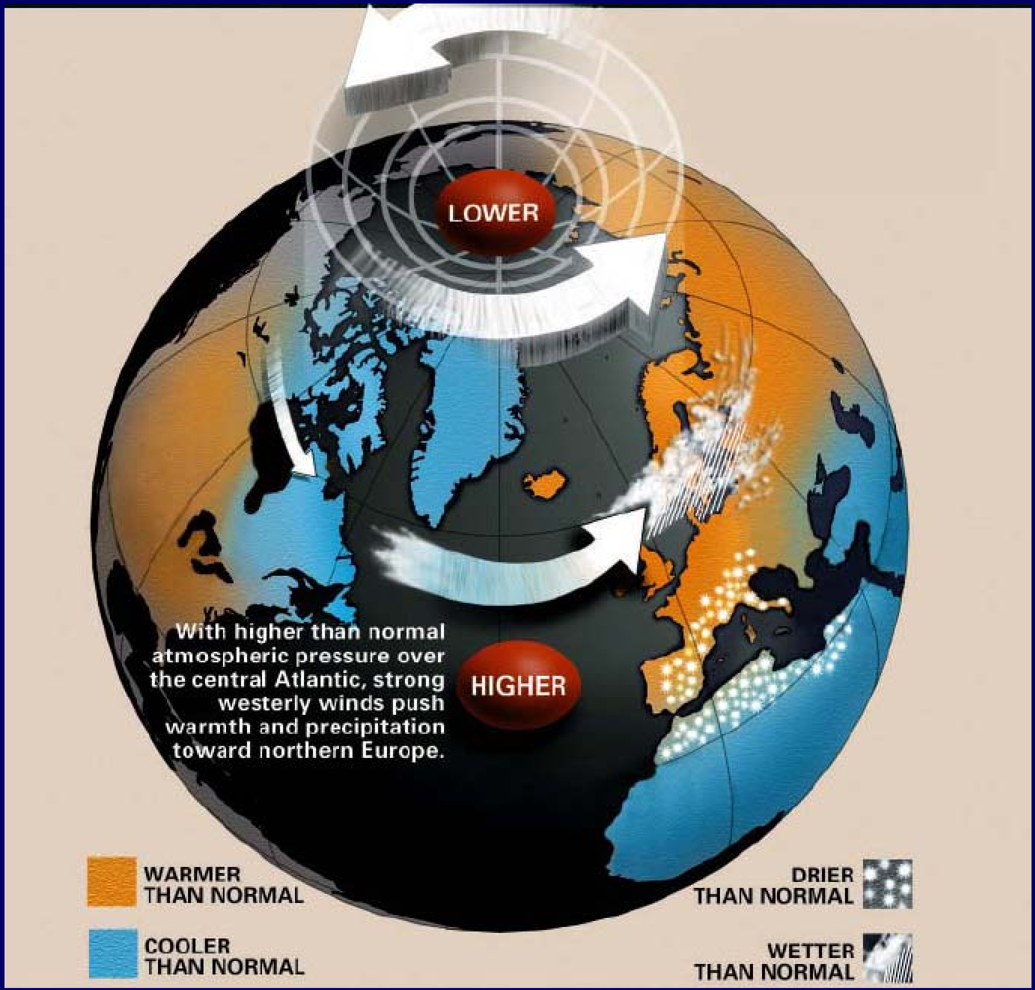


Severity Index (PDSI) for 1900 to 2002.

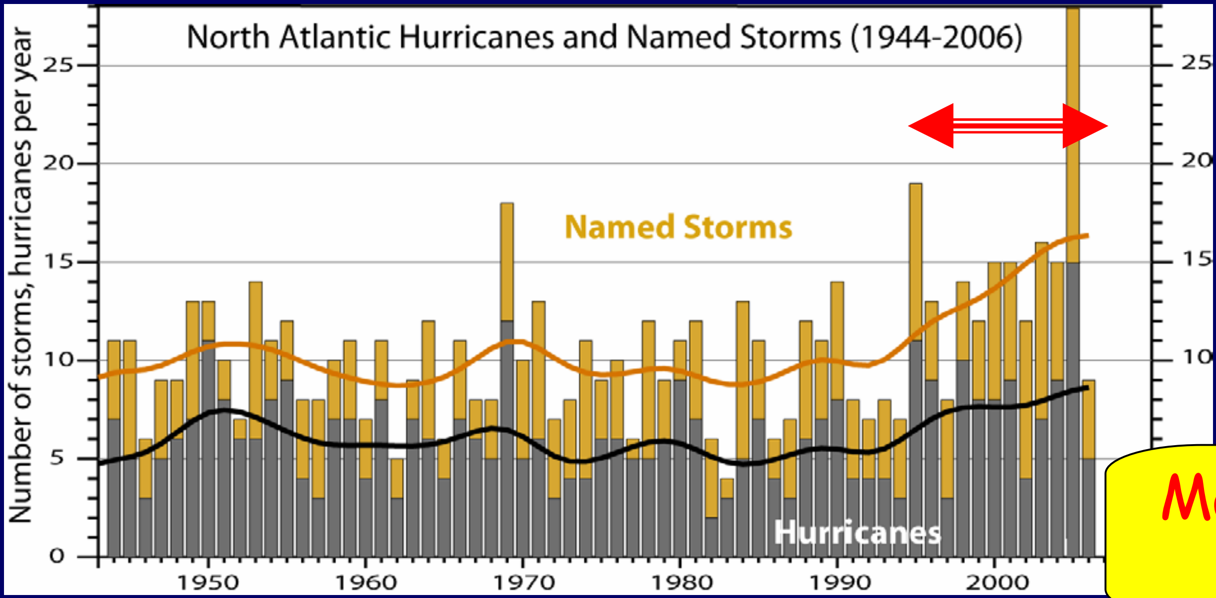
The time series (below) accounts for most of the trend in PDSI.

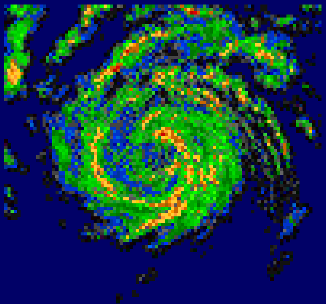
Circulation change

- Climate change is affecting storm tracks, winds and temperature patterns
- Anthropogenic forcing has likely contributed



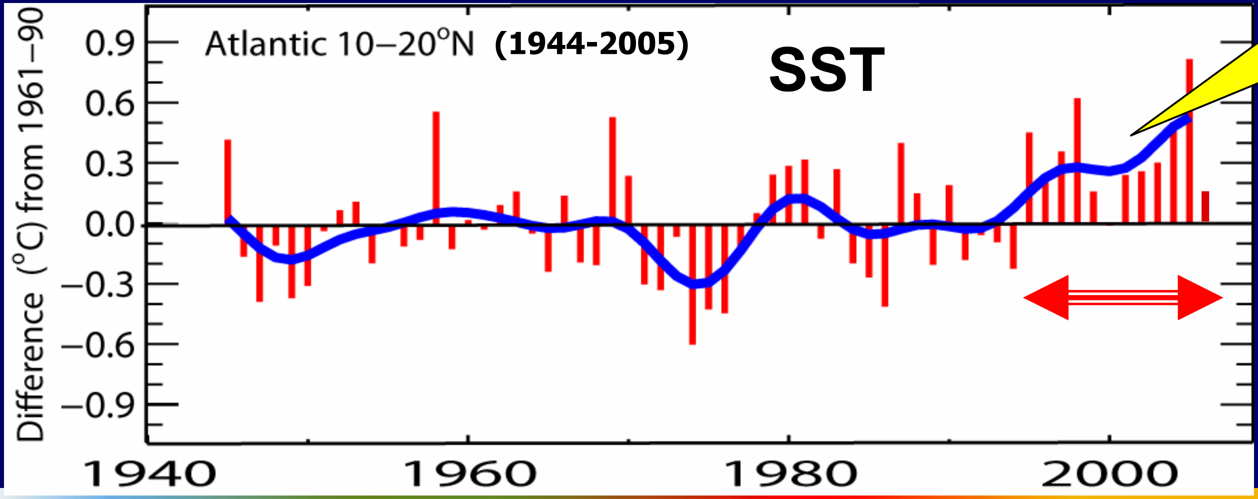
North Atlantic hurricanes have increased with SSTs





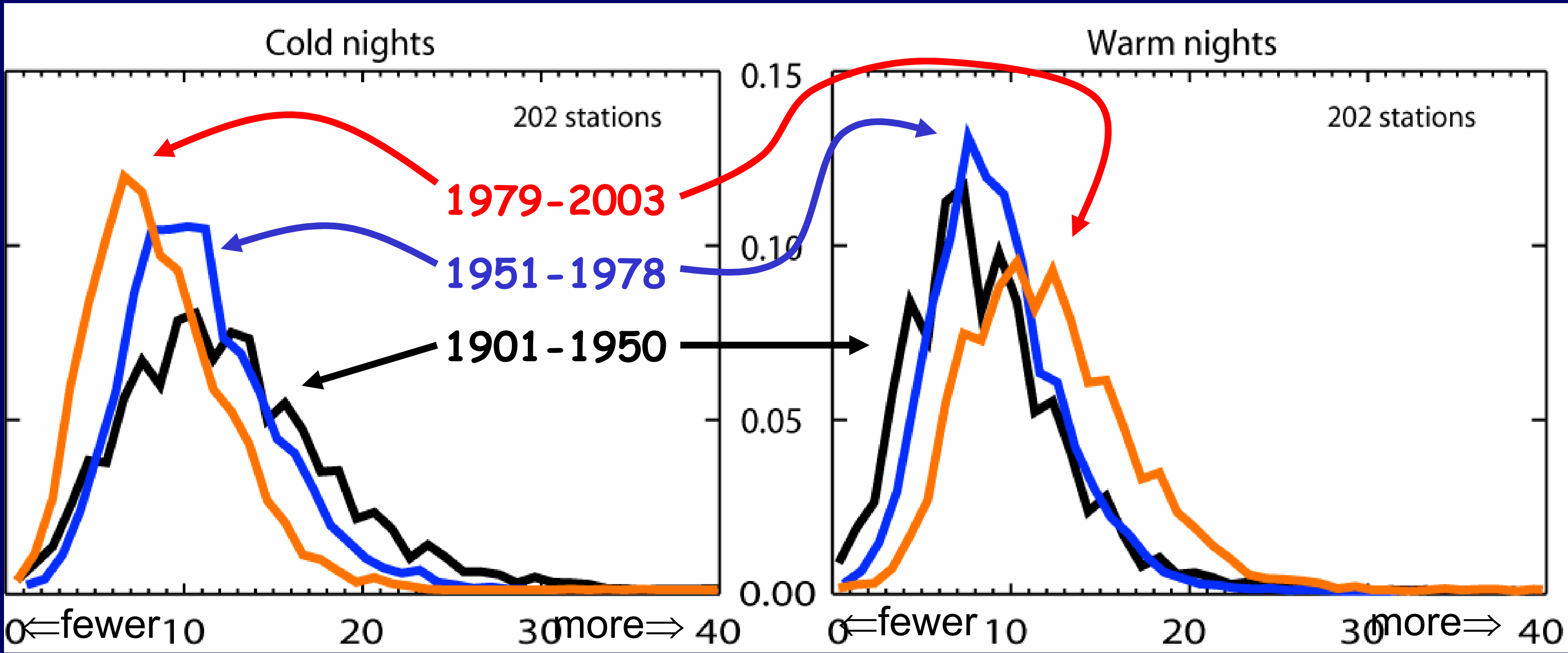
N. Atlantic hurricane record best

Marked increase after 1994



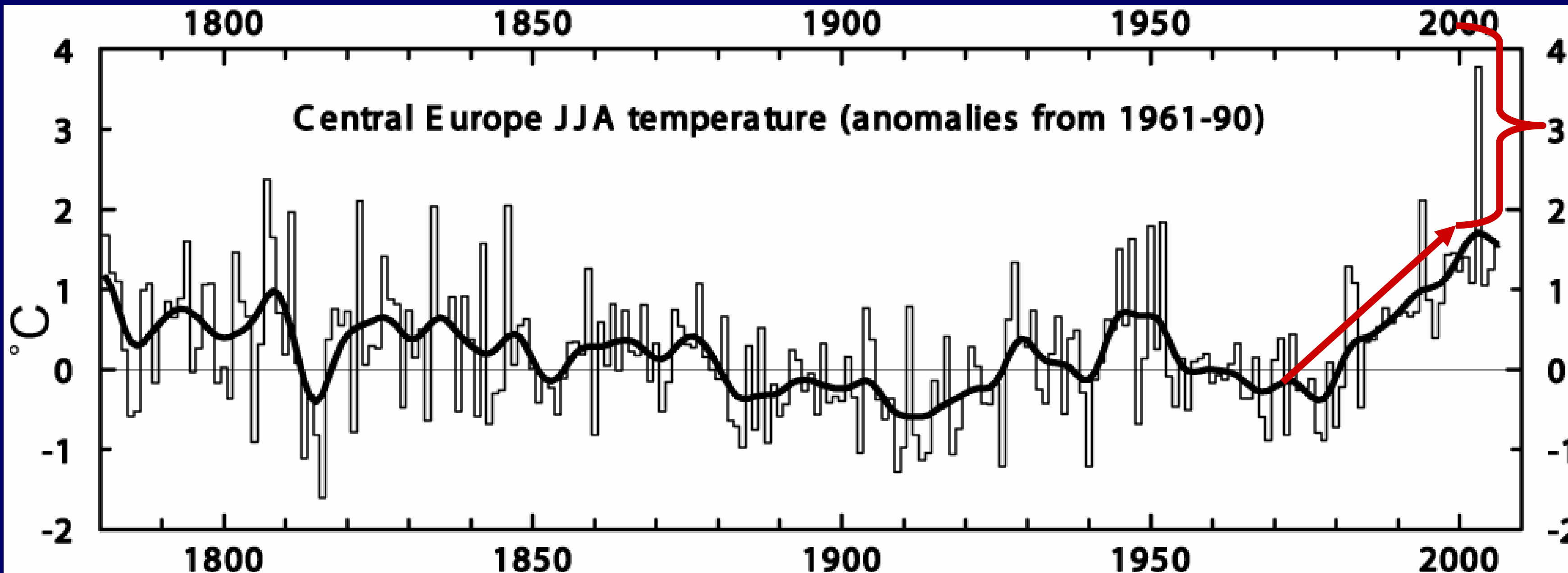
Global number and percentage of intense hurricanes is increasing

Warm nights are increasing; cold nights decreasing



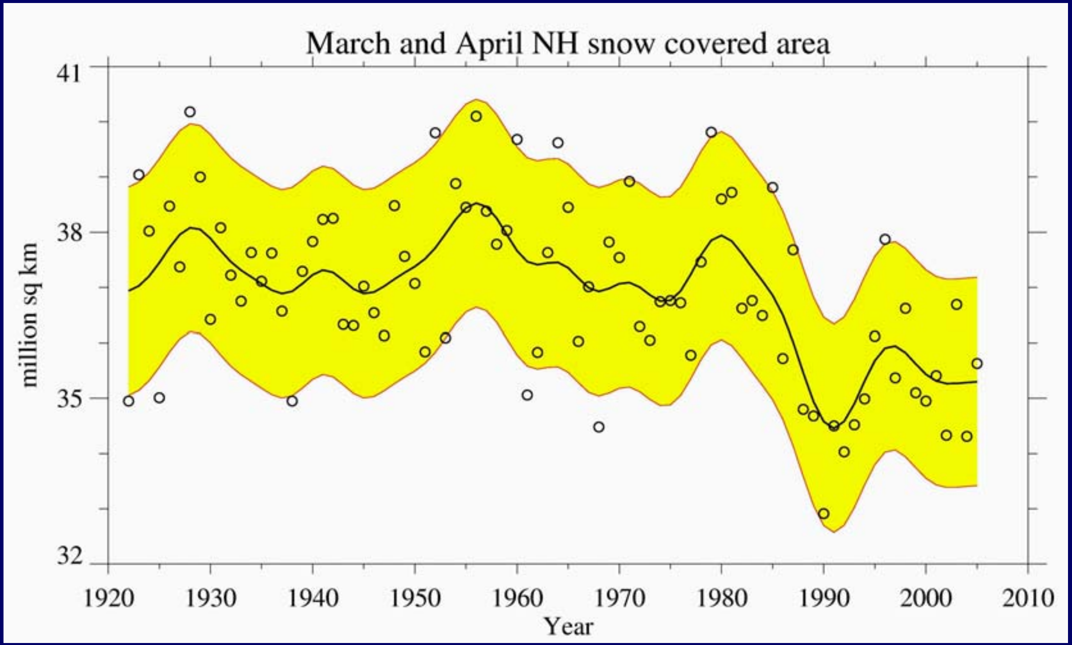
Frequency of occurrence of cold or warm temperatures for 202 global stations for 3 time periods:
1901 to 1950 (black), 1951 to 1978 (blue) and 1979 to 2003 (red).

Heat waves are increasing: an example

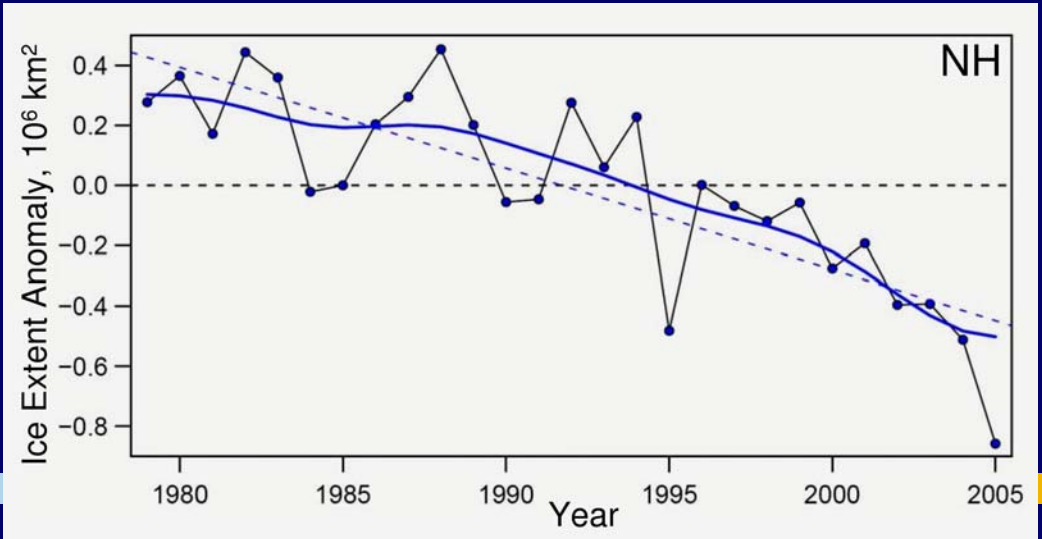


Extreme Heat Wave
Summer 2003
Europe

Snow cover and Arctic sea ice are decreasing

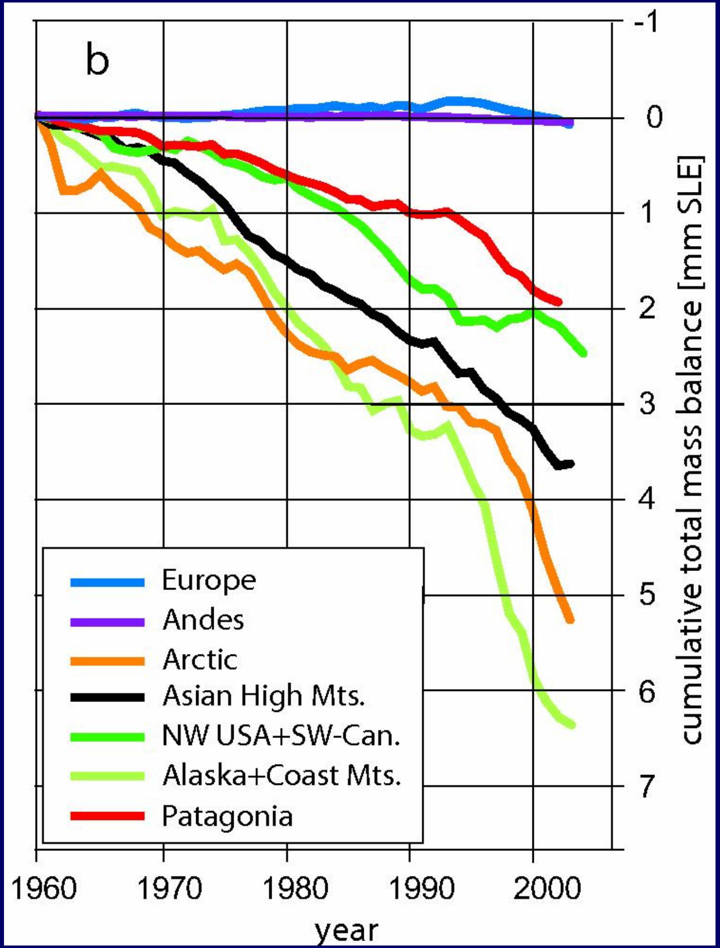


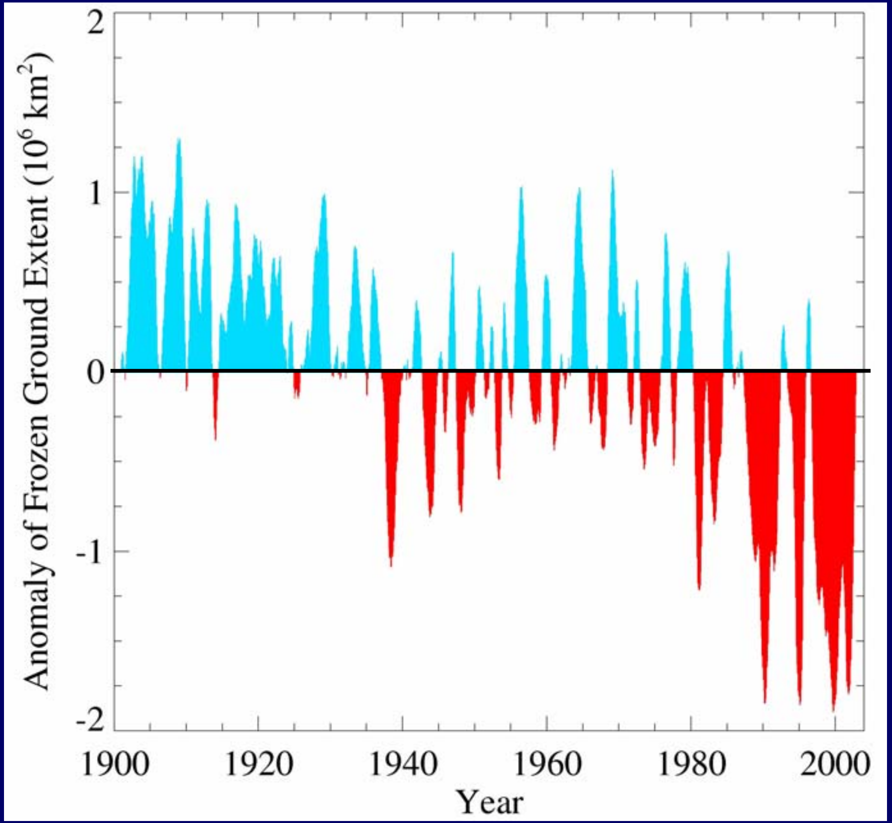
Spring snow cover shows 5% stepwise drop during 1980s



Arctic sea ice area decreased by 2.7% per decade (Summer: -7.4%/decade)

Glaciers and frozen ground are receding





Increased Glacier retreat since the early 1990s

Area of seasonally frozen ground in NH has decreased by 7% from 1901 to 2002

Direct Observations of Recent Climate Change

Some aspects of climate have not been observed to change:

- Tornadoes
- Dust-storms
- Hail
- Lightning
- Antarctic sea ice

A Paleoclimatic Perspective

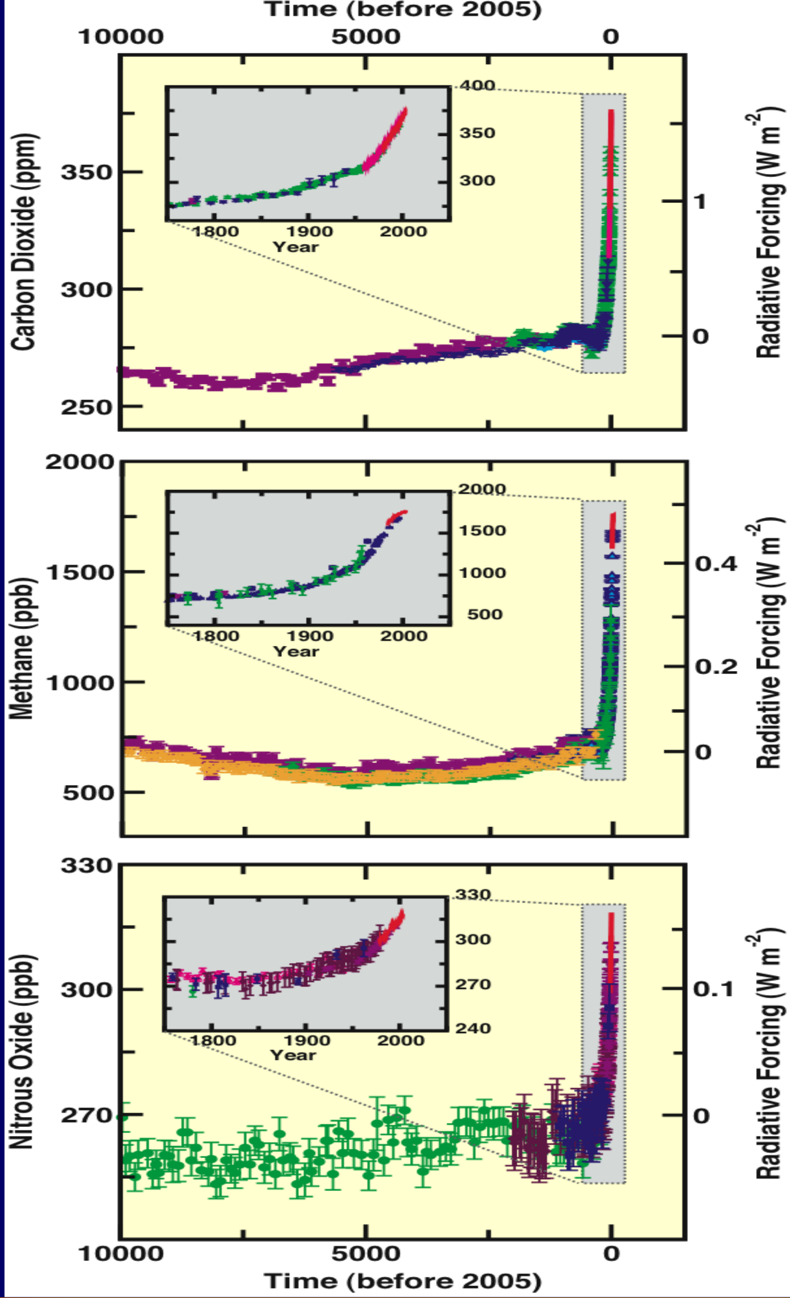
Paleoclimate information supports the interpretation that the warmth of the last half century is unusual in at least the previous 1300 years. The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise.

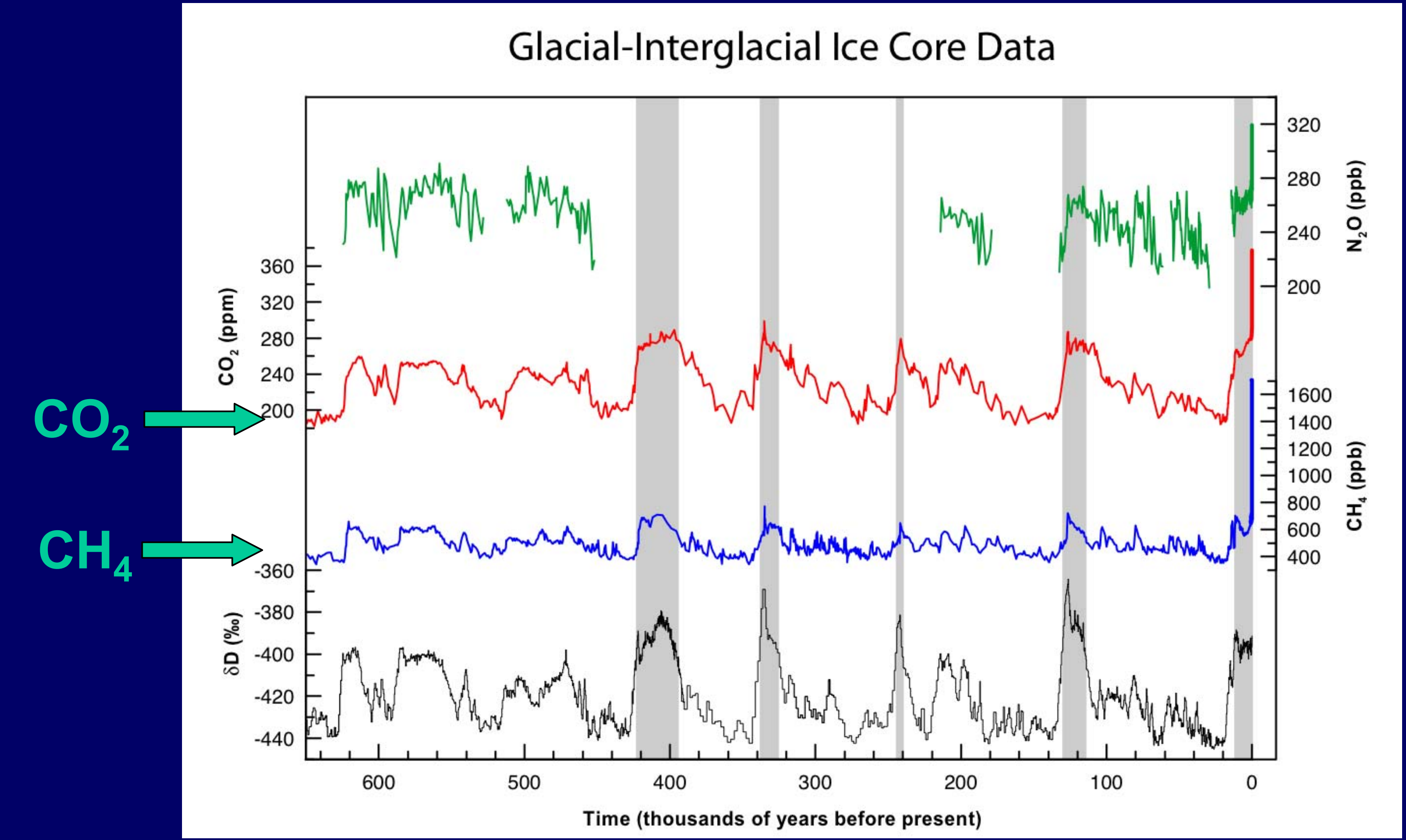
Human and Natural Drivers of Climate Change

CO_2, CH_4 and N_2O Concentrations

- far exceed pre-industrial values
- increased markedly since 1750 due to human activities

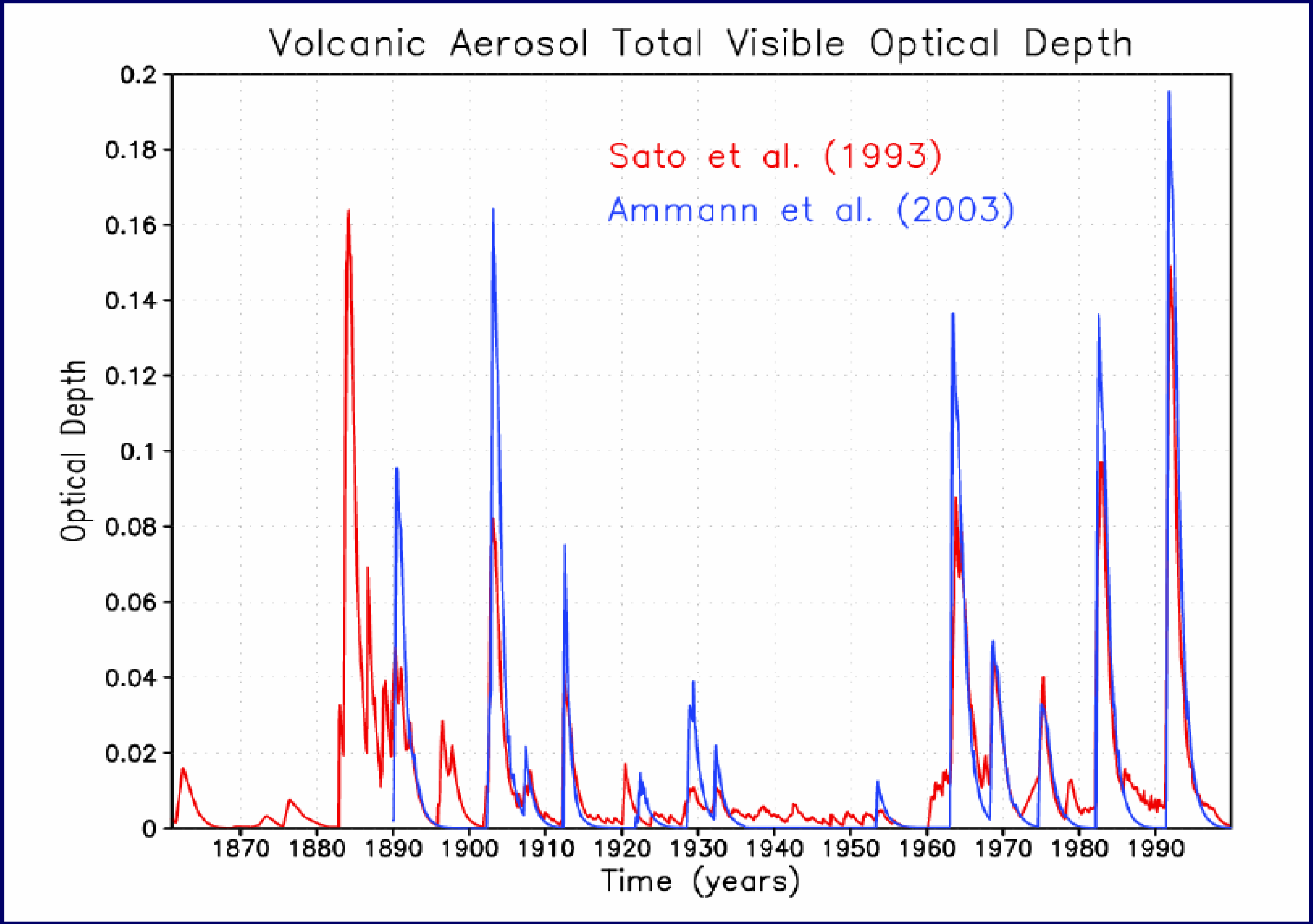
Relatively little variation before the industrial era





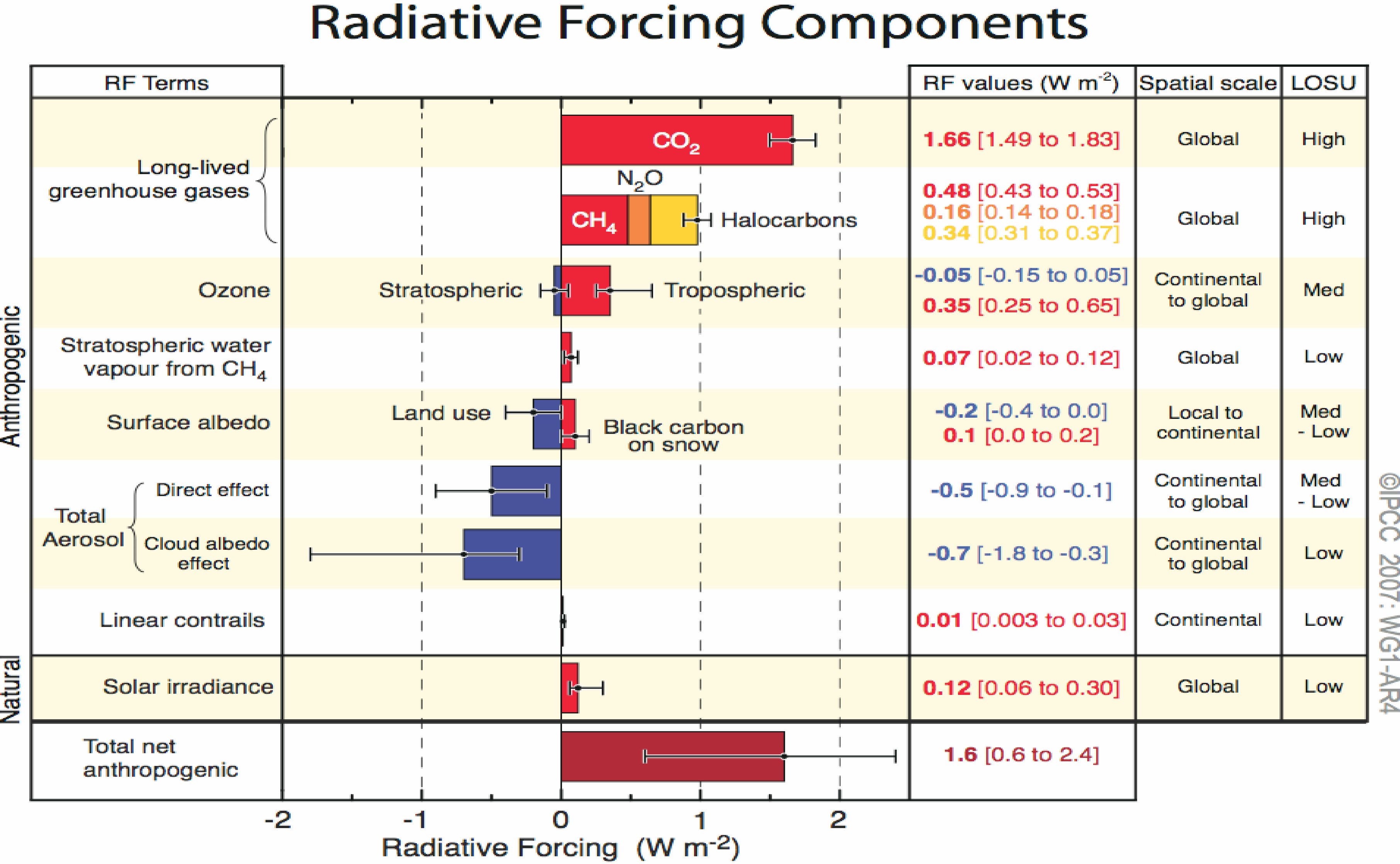
The atmospheric concentration of CO_2 and CH_4 in 2005 exceeds by far the natural range of the last 650,000 years

Volcanic aerosols



Eruptions are episodic and aerosol effects transitory (1-2 years)

Global-average radiative forcing estimates and ranges



Human and natural drivers of climate change

- Annual fossil CO_2 emissions increased from an average of 6.4 GtCper year in the 1990s, to 7.2 GtC per year in 2000-2005
- CO_2 radiative forcing increased by 20%from 1995 to 2005, the largest in any decade in at least the last 200 years

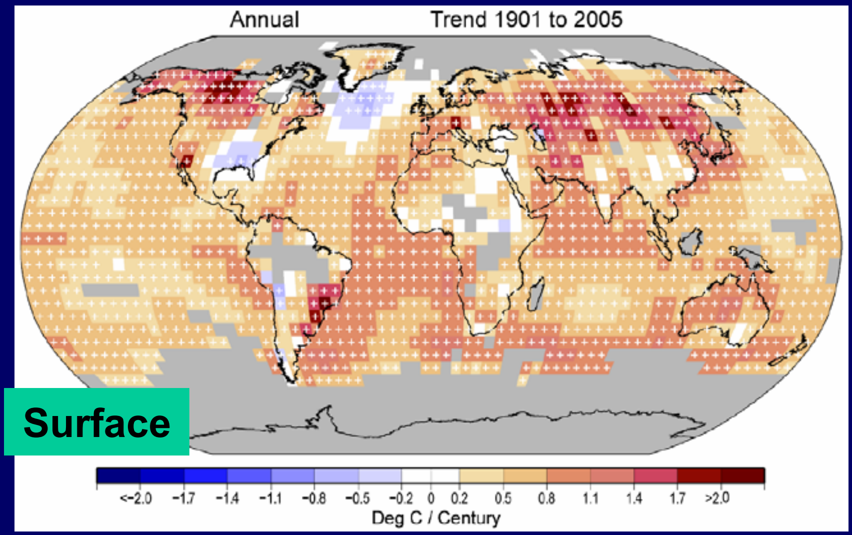
----

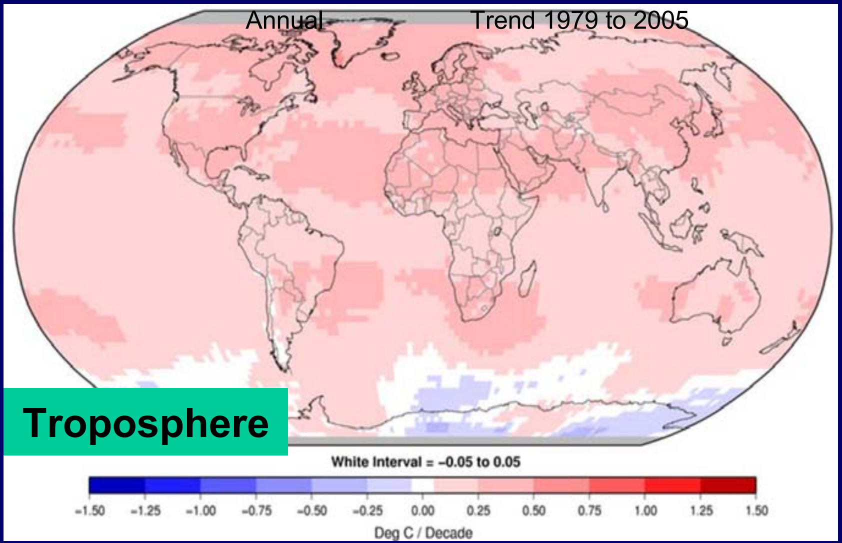
- Changes in solar irradiance since 1750 are exstimated to have caused a radiative forcing of +0.12 [+0.06 to +0.30] Wm^{-2}

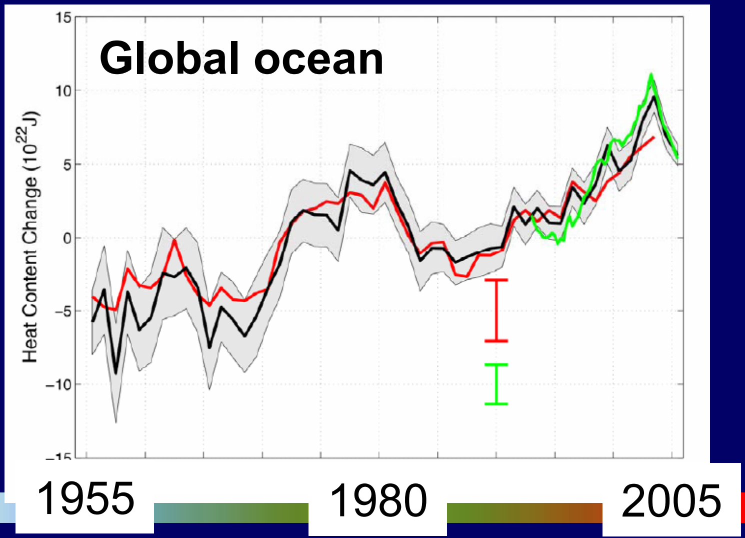
Human and Natural Drivers of Climate Change

The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (TAR), leading to *very high confidence* that the globally averaged net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W m^{-2}.

Observed widespread warming



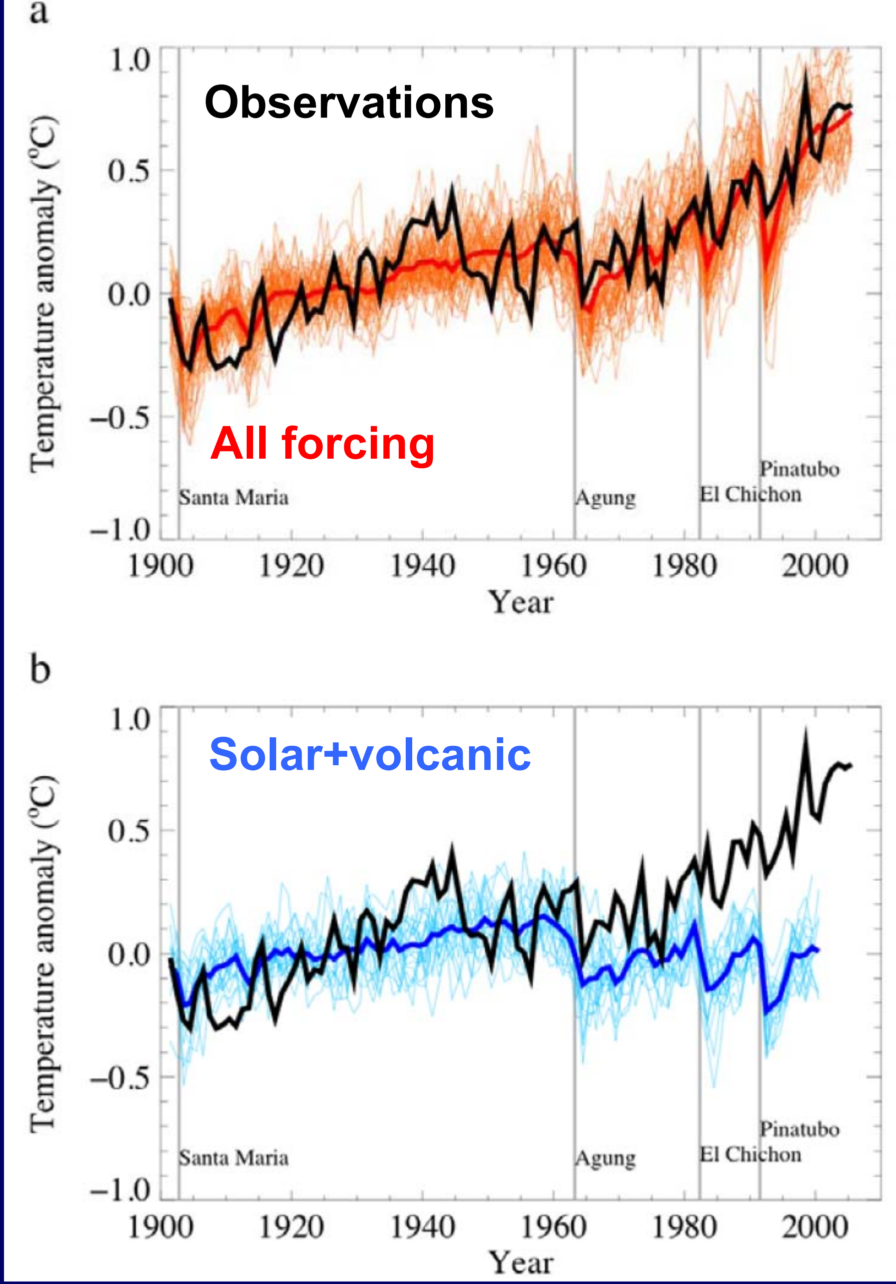




- extremely unlikely without external forcing
- very unlikely due to known natural causes alone

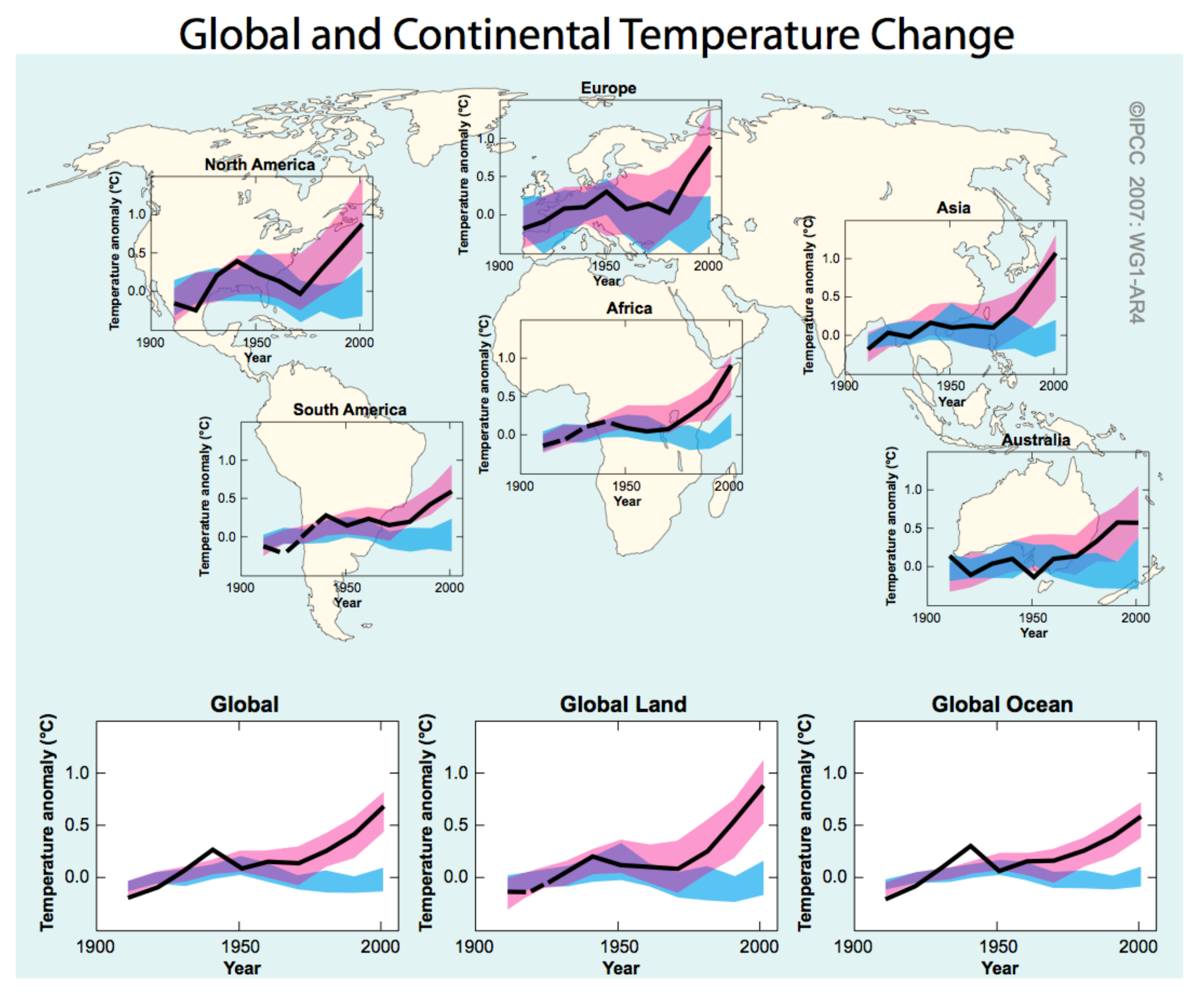
Attribution

- are observed changes consistent with
- ☑ expected responses to forcings
- ☒ inconsistent with alternative explanations



Understanding and Attributing Climate Change

Continental warming *likely* shows a significant anthropogenic contribution over the past 50 years



Understanding and Attributing Climate Change

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. This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations". Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns

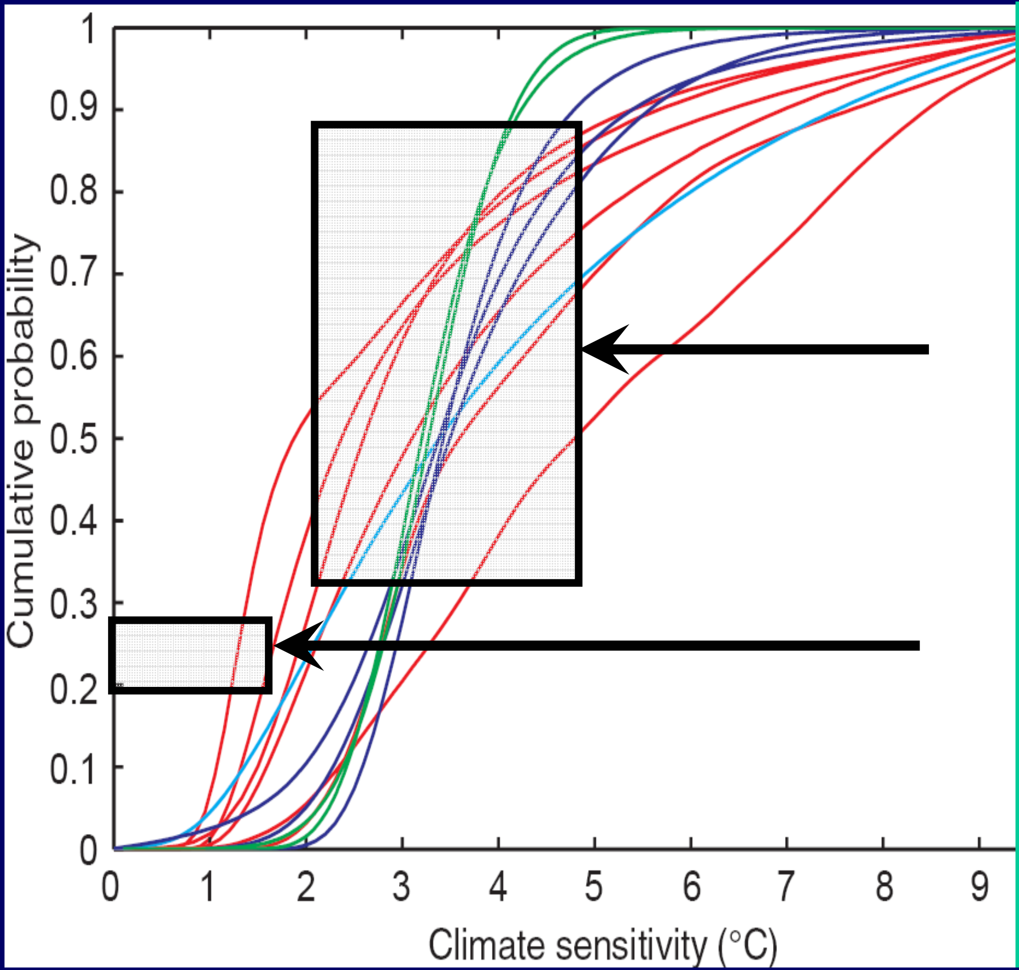
Understanding Climate Change
Climate Sensitivity

Analysis of climate models together with constraints from observations enables an assessed likely range for climate sensitivity and provides increased confidence in the understanding of climate system response to radiative forcing.

- Assumes doubling of carbon dioxide concentration
- Model experiment - not a projection
- Estimates equilibrium response to sustained radiative forcing

Equilibrium Climate Sensitivity

Surface warming following a sustained doubling of CO_2 concentrations



Best estimate 3°C;

likely 2-4.5°C;

very unlikely less than 1.5°C;

higher values not ruled out

Projections of Future Changes in Climate

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 estimate and assessed likelihood range for future temperature projections for first time
- Broadly similar to the TAR but not directly comparable

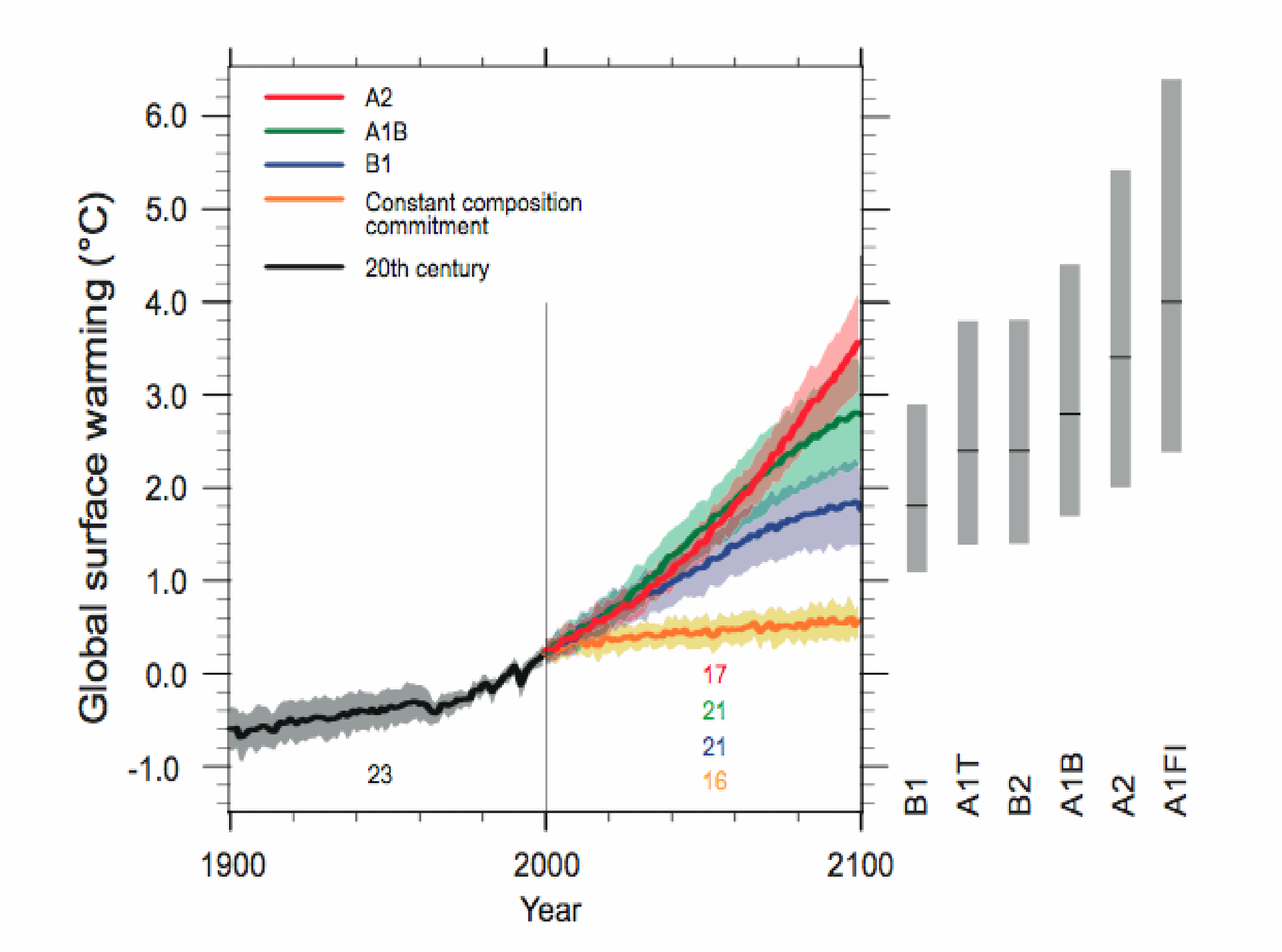
Projections of Future Changes in Climate

- For 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.
- Earlier IPCC projections of 0.15 to 0.3 °C per decade can now be compared with observed values of 0.2 °C

Projections of Future Changes in Climate

Best estimate for low scenario (B1) is 1.8°C (*likely* range is 1.1°C to 2.9°C), and for high scenario (A1FI) is 4.0°C (*likely* range is 2.4°C to 6.4°C).

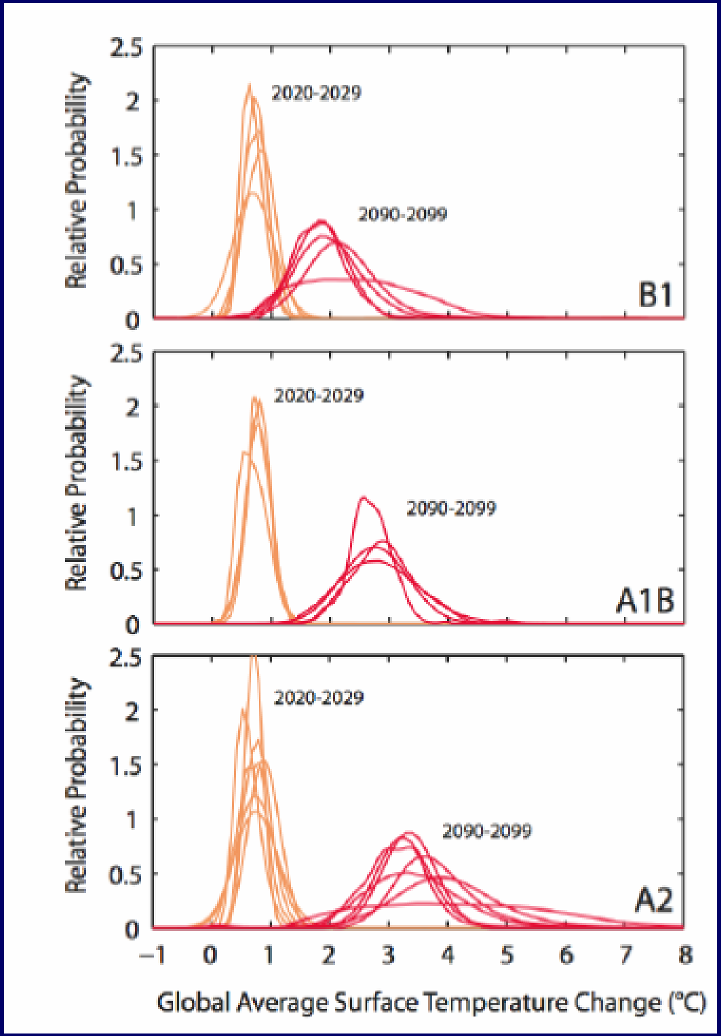
Broadly consistent with span quoted for SRES in TAR, but not directly comparable



Projections of Future Changes in Climate

Near term projections insensitive to choice of scenario

Longer term projections depend on scenario and climate model sensitivities

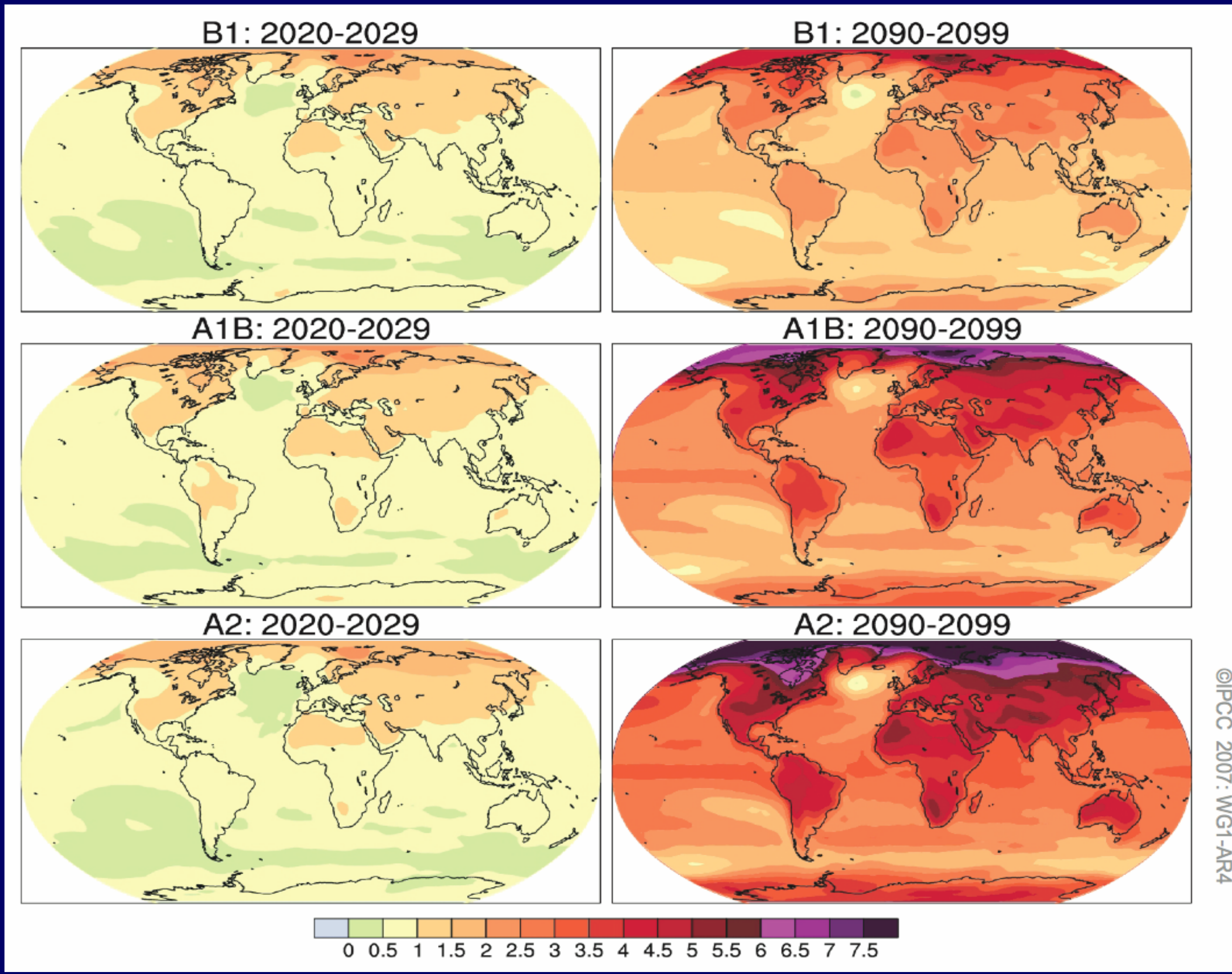


Projections of Future Changes in Climate

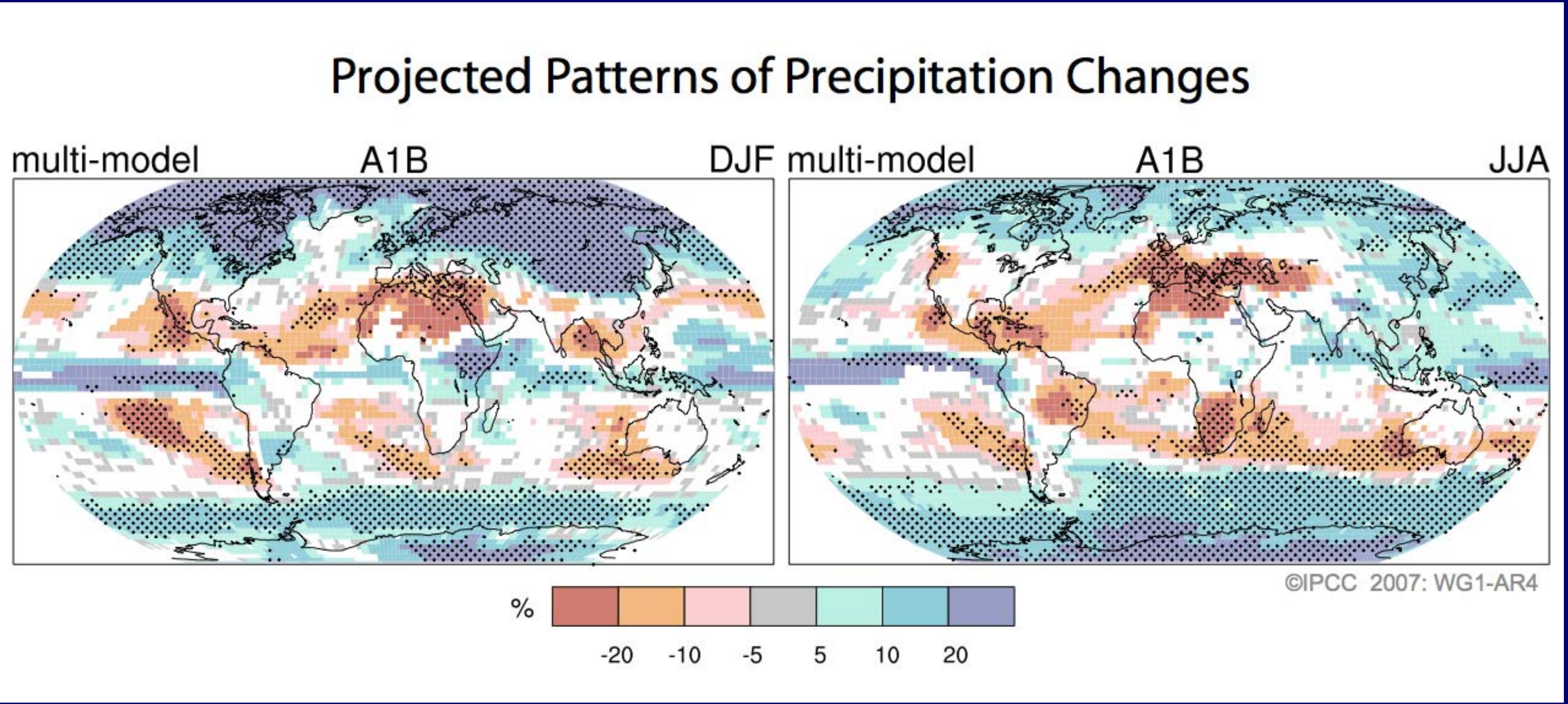
Projected warming in 21st century expected to be

greatest over land and at most high northern latitudes

and least over the Southern Ocean and parts of the North Atlantic Ocean



Projections of Future Changes in Climate



Precipitation increases *very likely* in high latitudes

Decreases *likely* in most subtropical land regions

Projections of Future Changes in Climate

There is now higher confidence in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation, and some aspects of extremes and of ice.

PROJECTIONS OF FUTURE CHANGES IN CLIMATE

- Snow cover is projected to contract
- Widespread increases in thaw depth most permafrost regions
- Sea ice is projected to shrink in both the Arctic and Antarctic
- In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century

PROJECTIONS OF FUTURE CHANGES IN CLIMATE

- *Very likely* that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent
- *Likely* that future tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation
  - less confidence in decrease of total number
- Extra-tropical storm tracks projected to move poleward with consequent changes in wind, precipitation, and temperature patterns

PROJECTIONS OF FUTURE CHANGES IN CLIMATE

- 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.
  - **longer term changes not assessed with confidence**
- 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.

PROJECTIONS OF FUTURE CHANGES IN CLIMATE

- 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.

- Temperatures in excess of 1.9 to 4.6°C warmer than pre-industrial sustained for millennia…eventual melt of the Greenland ice sheet. Would raise sea level by 7 m. Comparable to 125,000 years ago.

Watch out for …

- **Working Group 2**
  Brussels, Belgium; 2-5 April 2007

- **Working Group 3**
  Bangkok,Thailand; 30 April – 3 May 2007

- **Synthesis Report**
  Valencia, Spain; 12-16 November