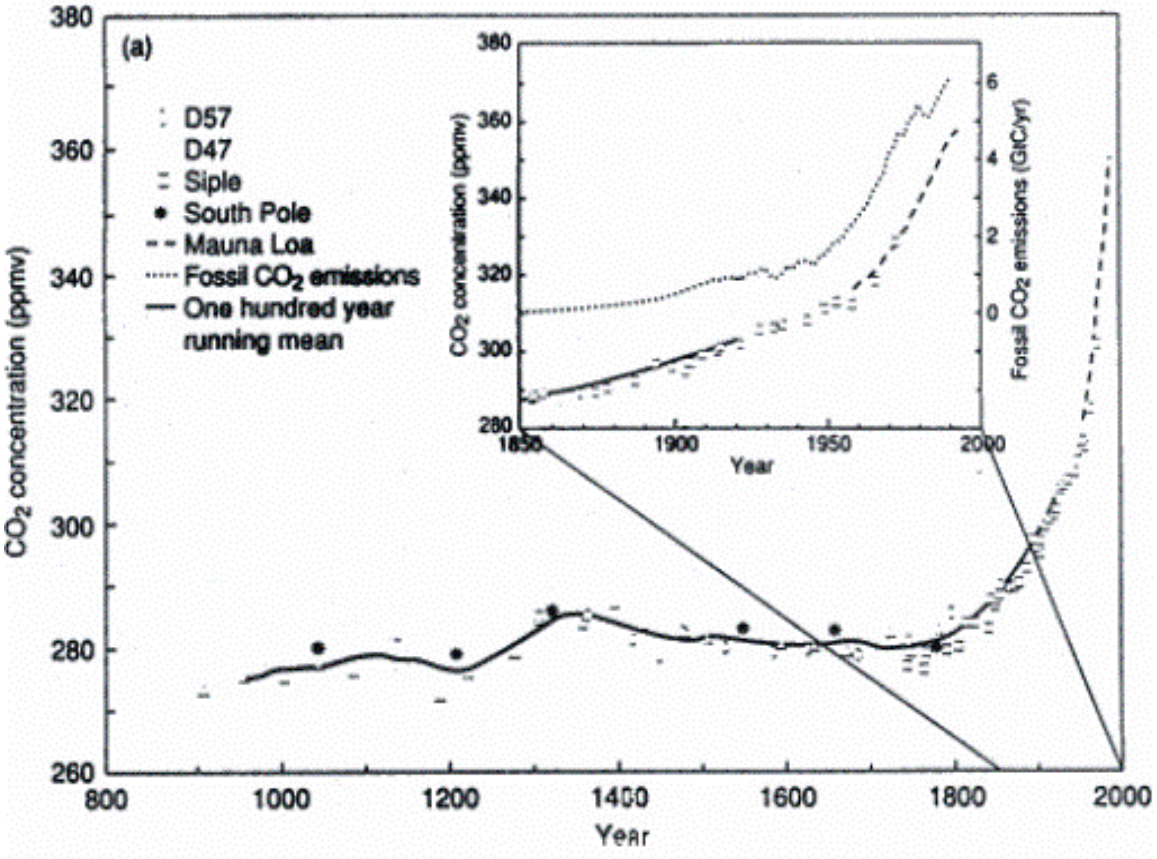
# Mostly Settled Science of Anthropogenic Influence on Earth's Climate

C. F. Keller

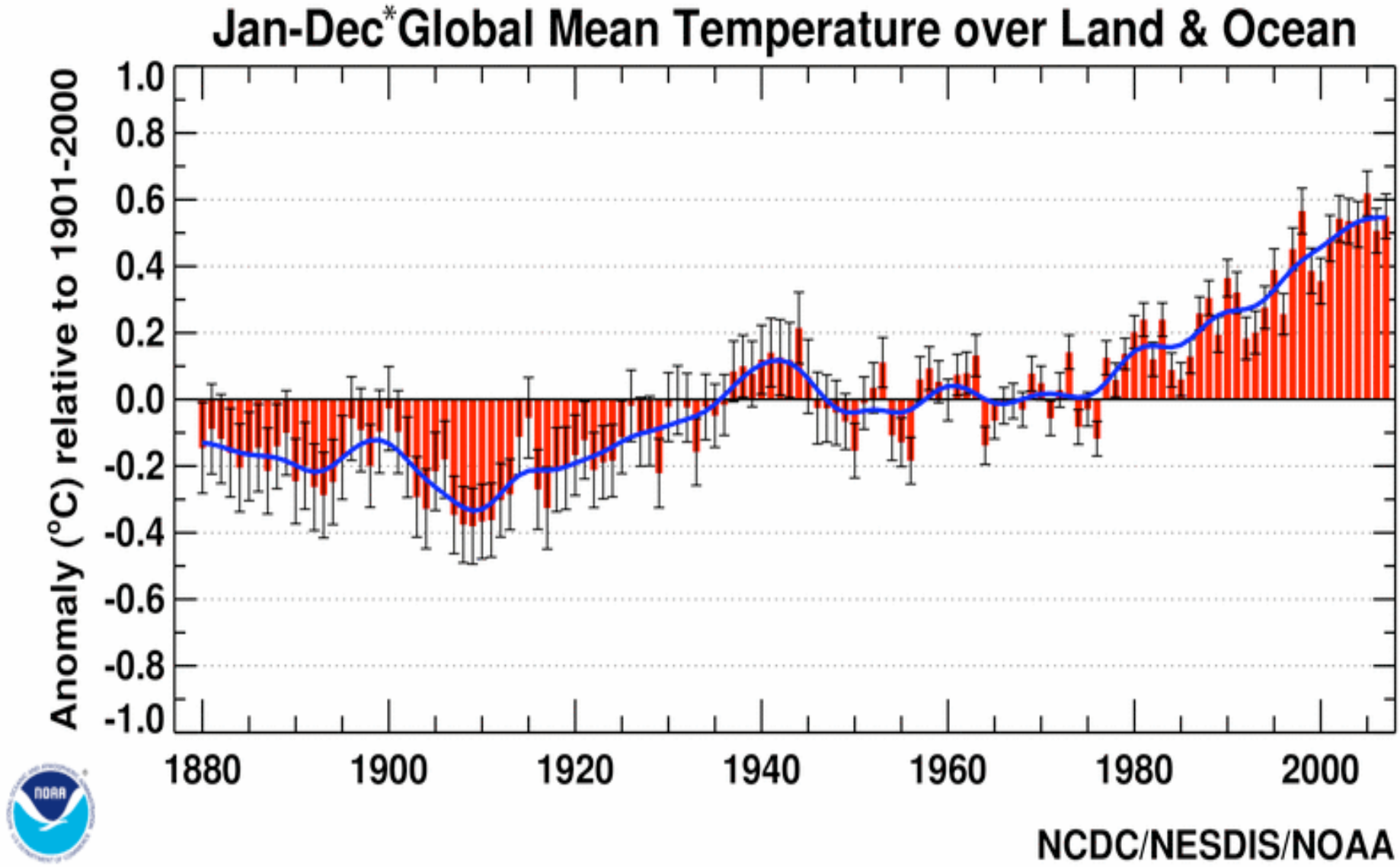
December 17, 2007

Atmospheric concentration of CO2 compared with fossil emissions. Atmospheric concentration of CO2 compared with fossil emissions.

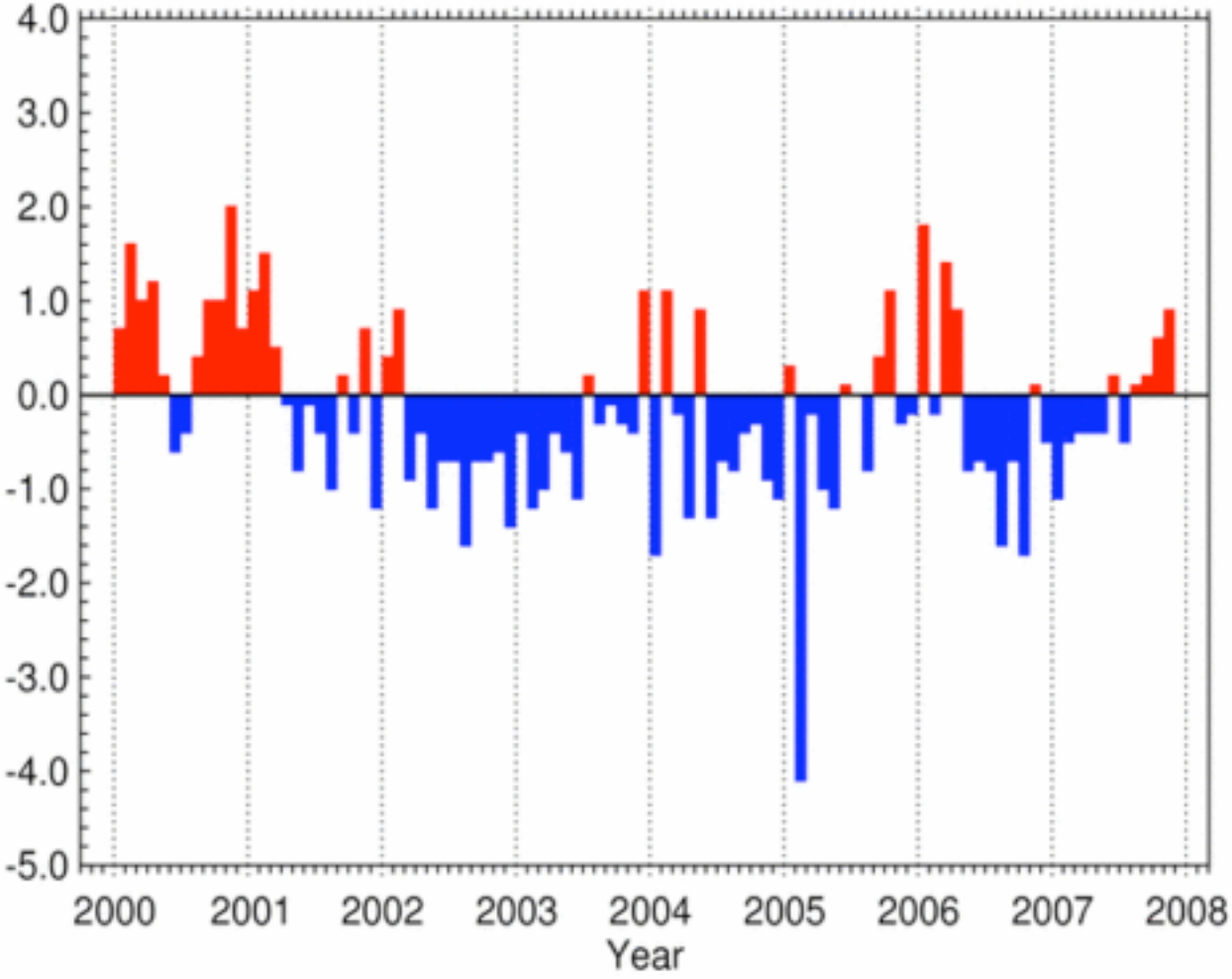


# Four Questions

- 1 Is warming real?
- 2 Is warming special?
- 3 Can we understand/model it?
- 4 Can we project its future?


Jan-Dec* Global Mean Temperature over Land & Ocean
Anomaly (°C) relative to 1901-2000
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
1880
1900
1920
1940
1960
1980
2000
NCDC/NESDIS/NOAA

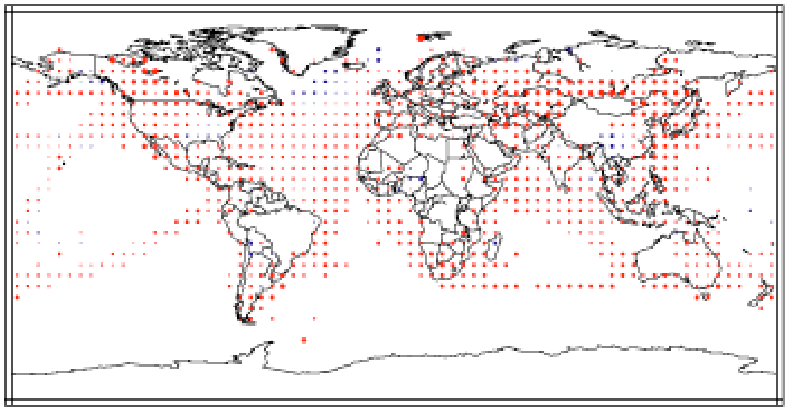
# Standardized Southern Oscillation Index (SOI)



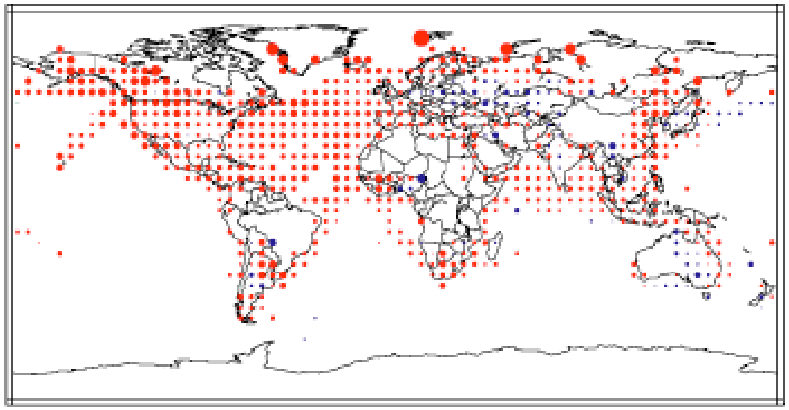

National Climatic Data Center / NESDIS / NOAA

Annual surface temperature trends in deg C/decade, calculated from combined land-surface air and sea surface temperatures adapted from Jones et al. 2001. The red, blue and green circles indicate areas with positive trends, negative trends and little or no trend at all, respectively. The size of the circle reflects the size of the trend it represents. See figure 2.9 in the IPCC report, 'Climate Change 2001: the Scientific Basis.

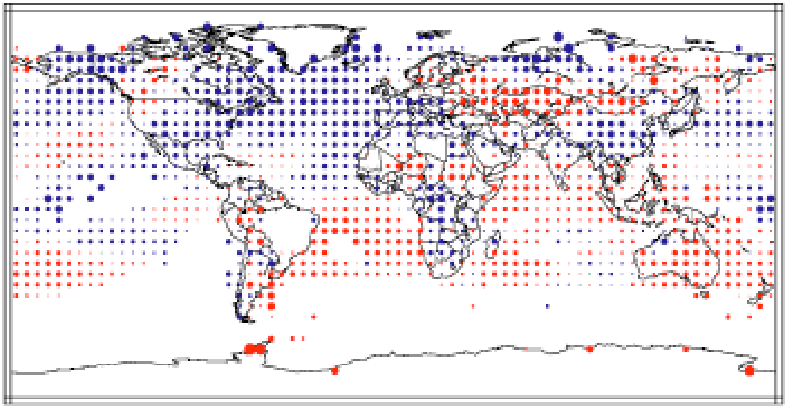
(a) Annual temperature trends, 1901 to 2000



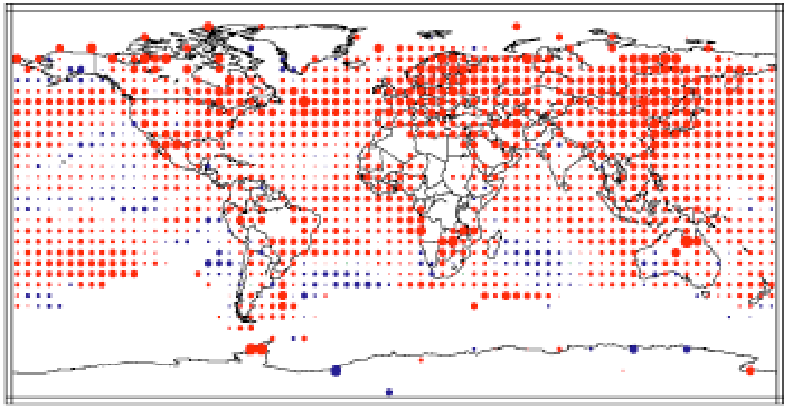
(b) Annual temperature trends, 1910 to 1945



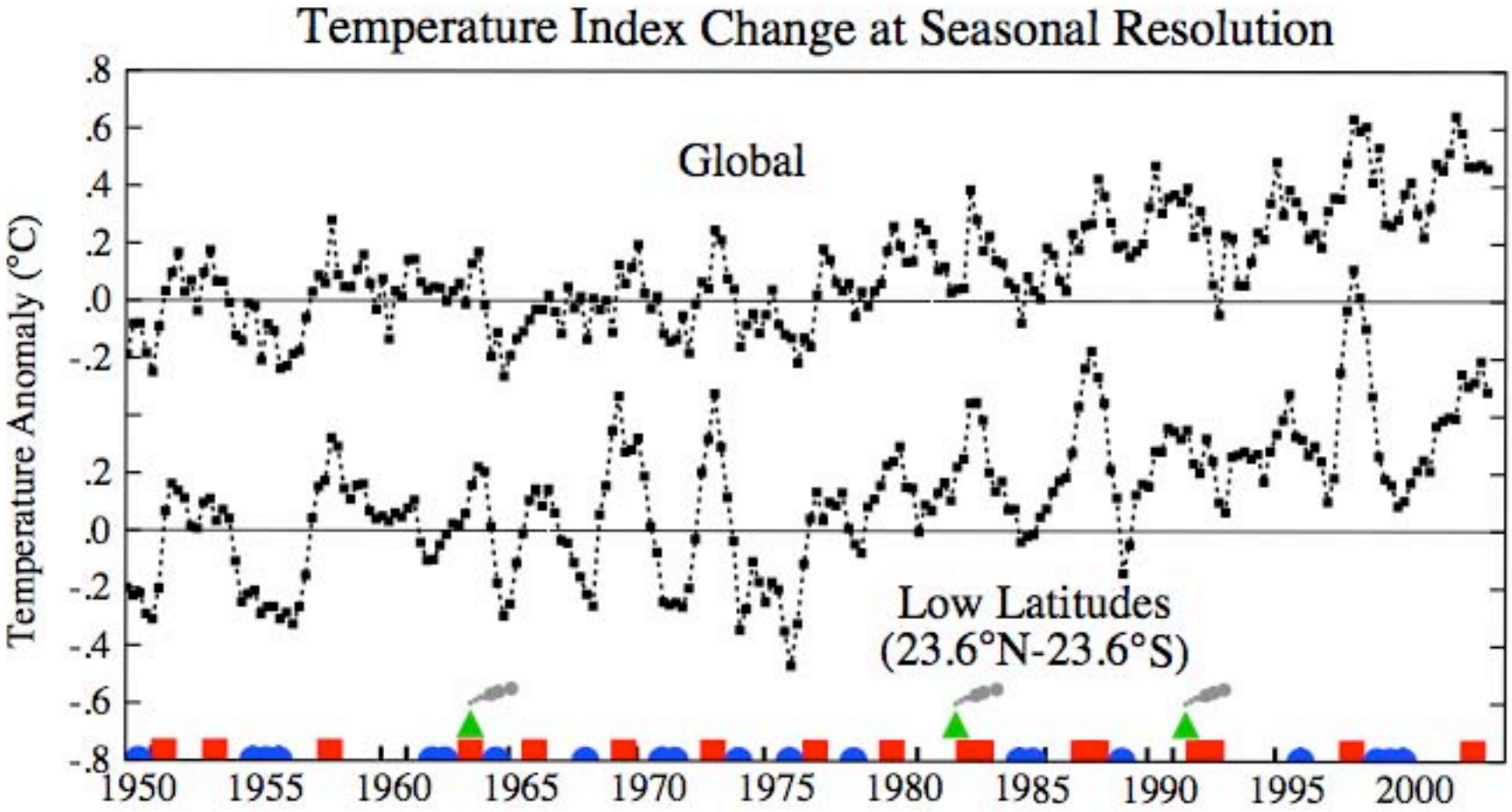
(c) Annual temperature trends, 1946 to 1975



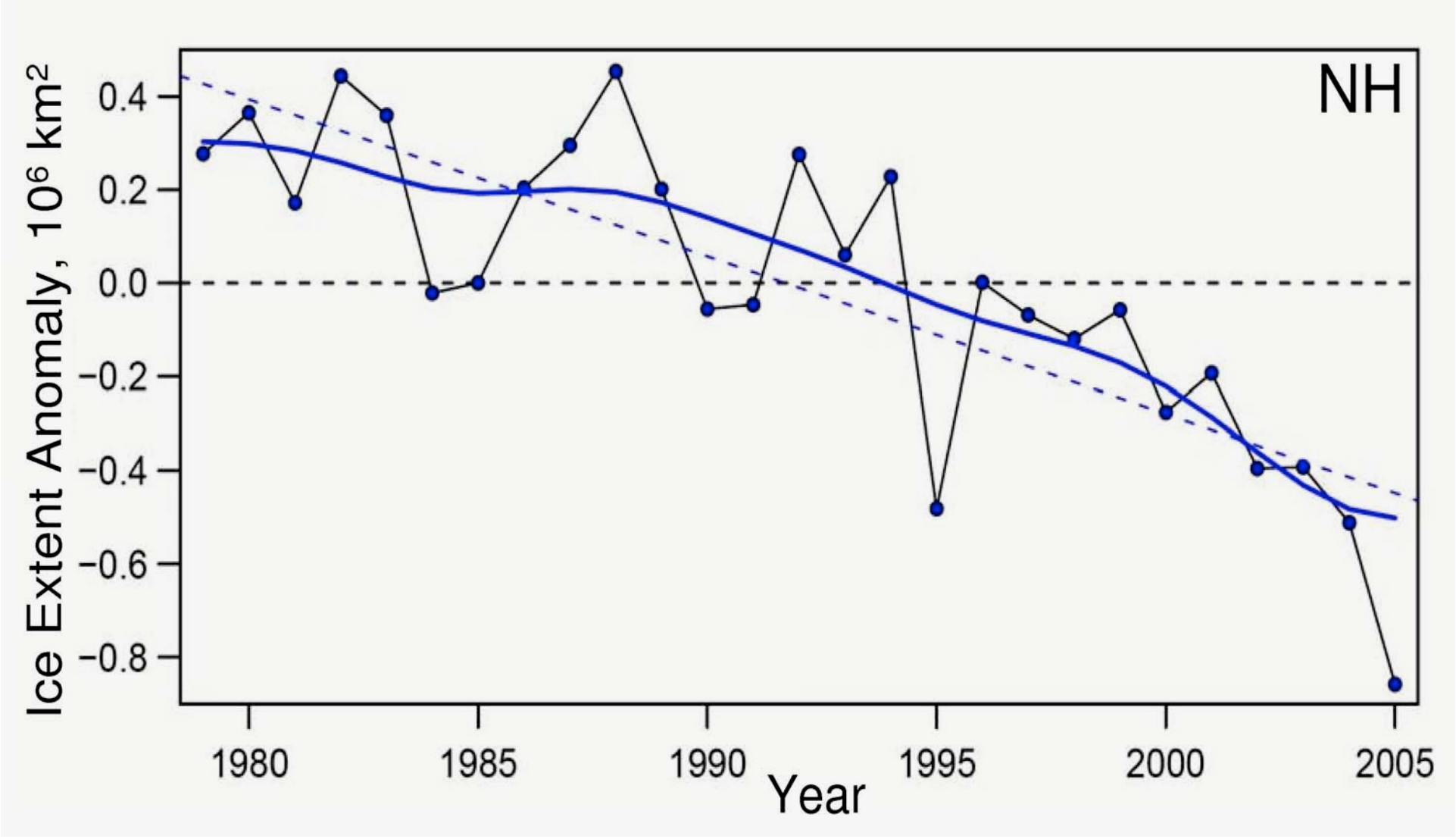
(d) Annual temperature trends, 1976 to 2000



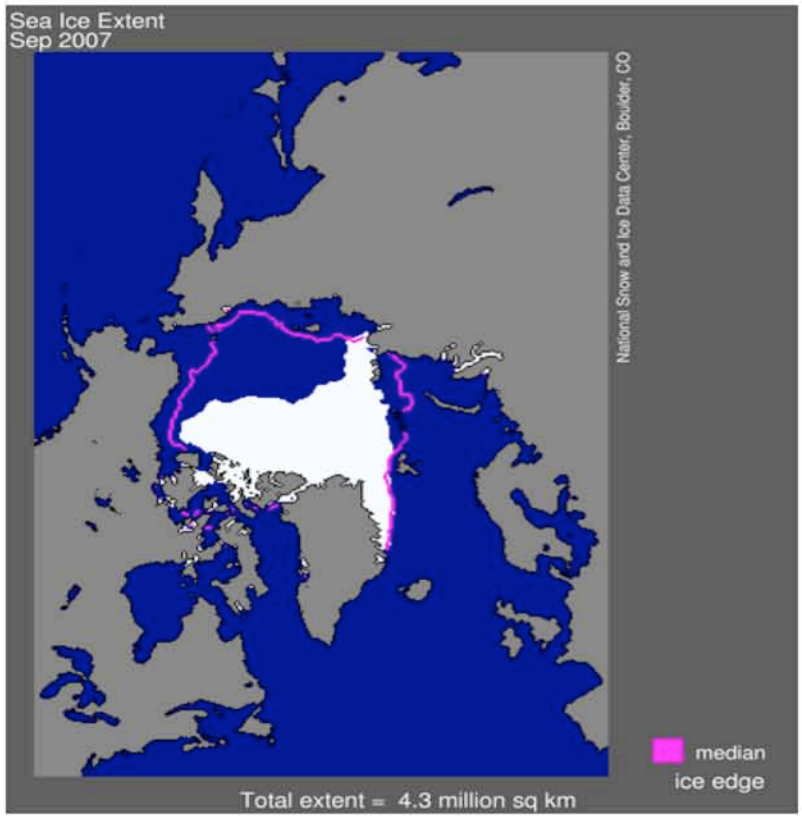

Trend ( C/decade)

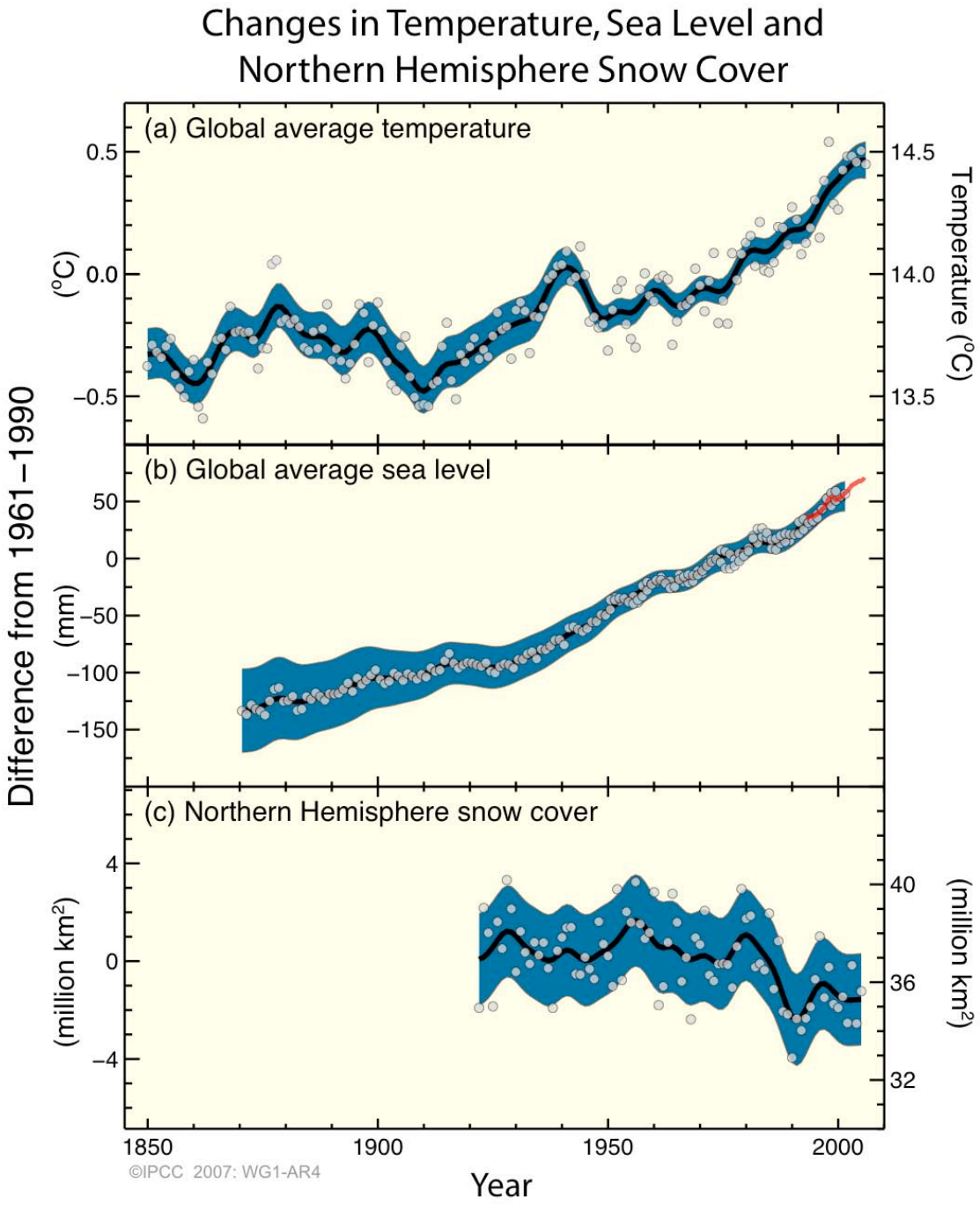

Temperature Index Change at Seasonal Resolution
Temperature Anomaly (°C)
.8
.6
.4
.2
.0
-.2
.2
.0
-.2
-.4
-.6
-.8
Global
Low Latitudes
(23.6°N-23.6°S)
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000

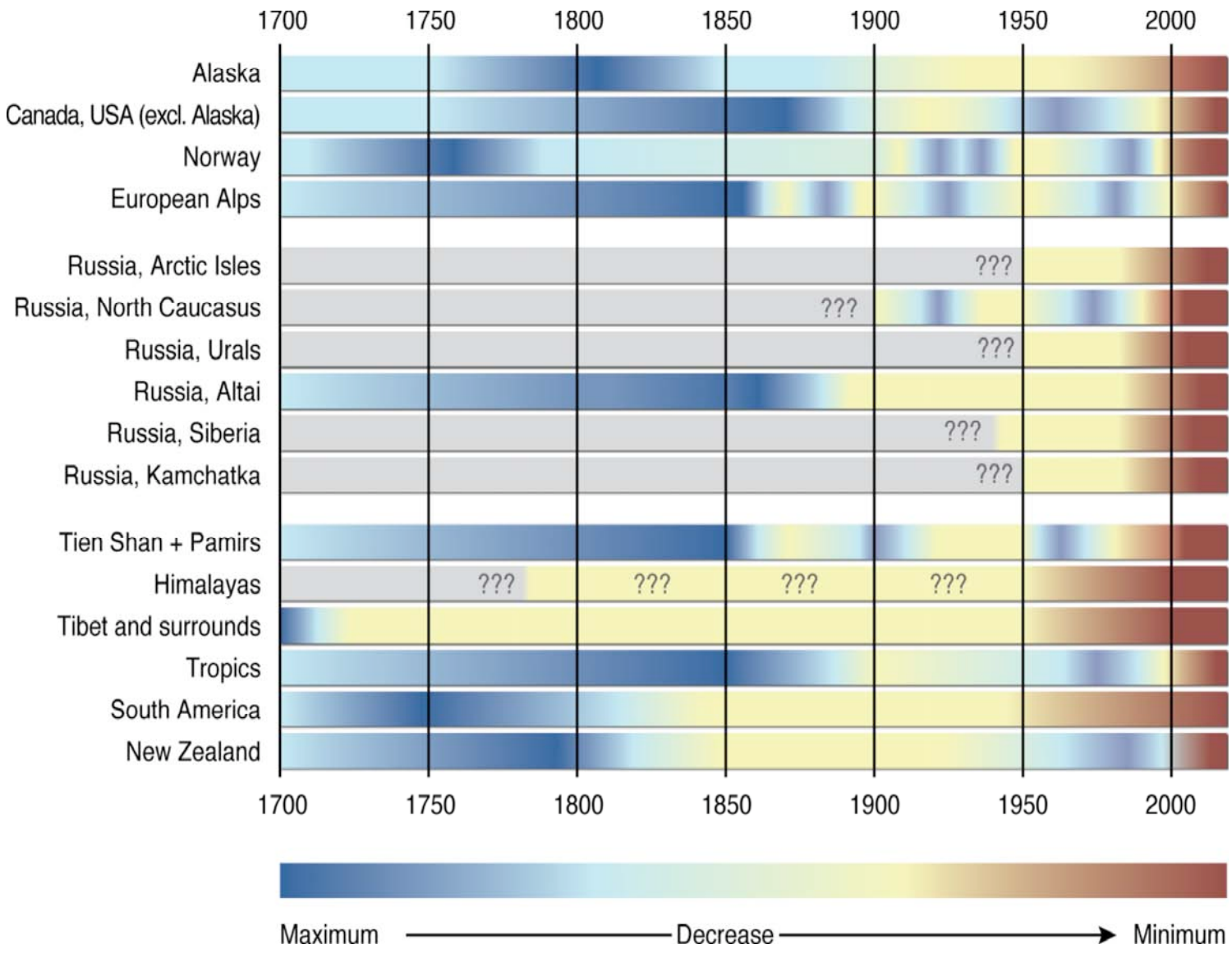
# Arctic Sea Ice Extent

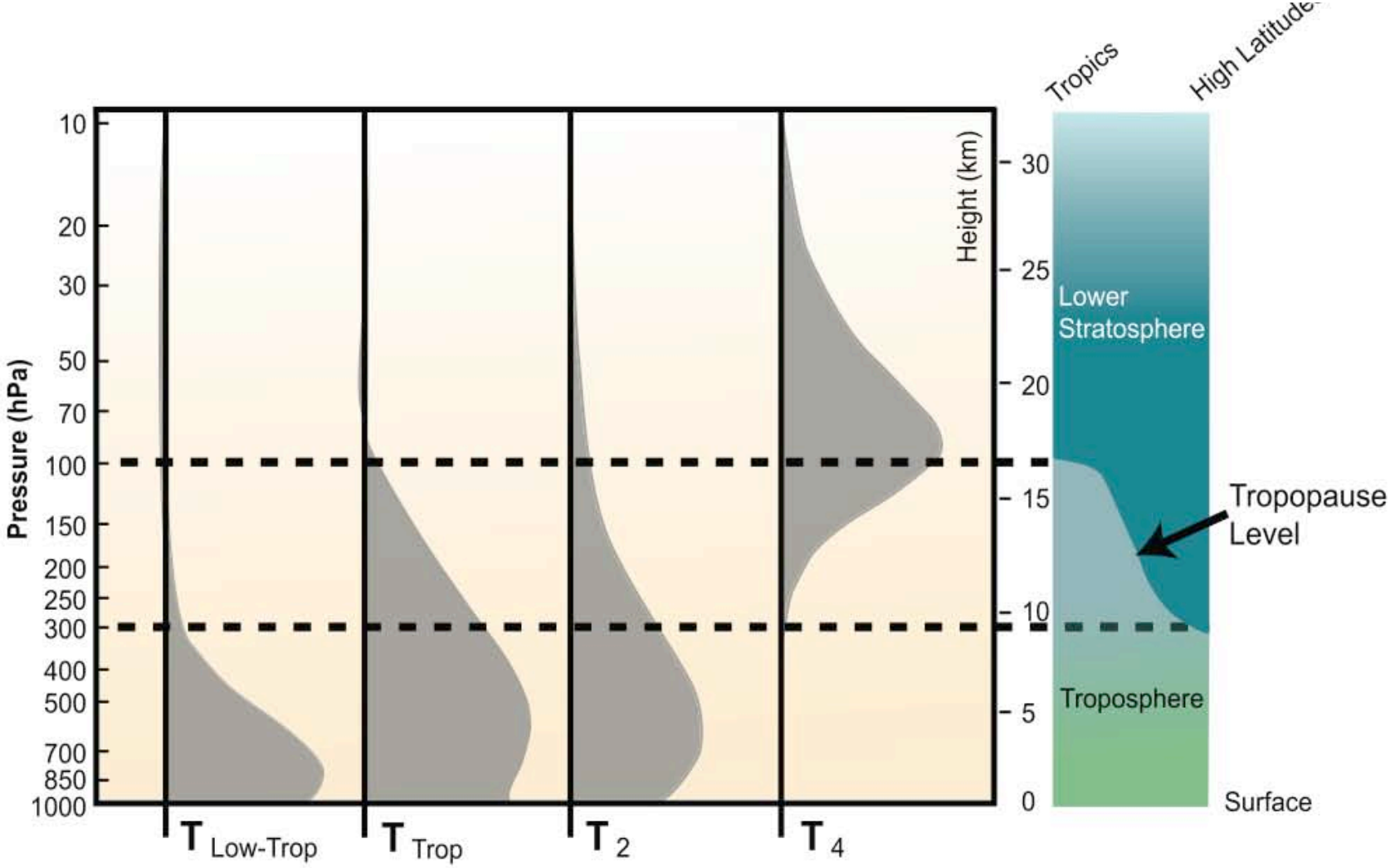


# Polar Sea Ice
# Sept. 2007



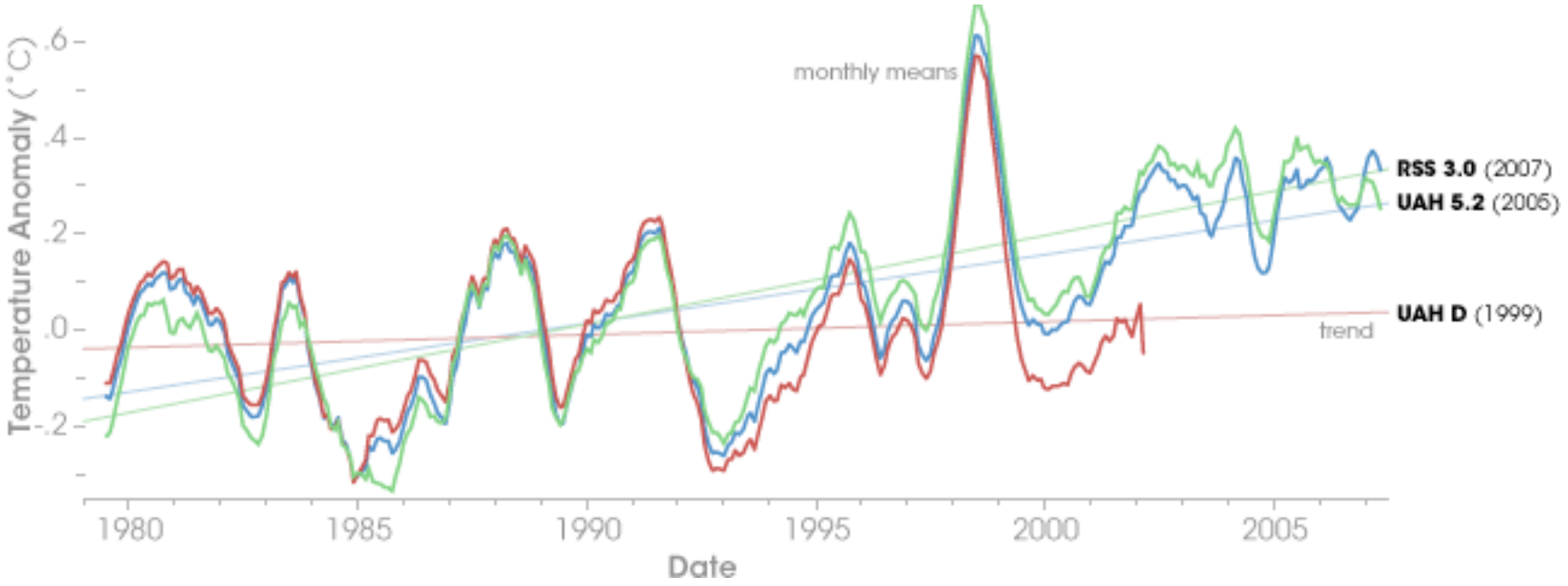

Changes in Temperature, Sea Level and Northern Hemisphere Snow Cover
(a) Global average temperature
(b) Global average sea level
(c) Northern Hemisphere snow cover
Difference from 1961–1990
(°C)
(mm)
(million km²)
Temperature (°C)
(million km²)
0.5
0.0
−0.5
14.5
14.0
13.5
50
0
−50
−100
−150
4
0
−4
40
36
32
1850
1900
1950
2000
Year
©IPCC 2007: WG1-AR4

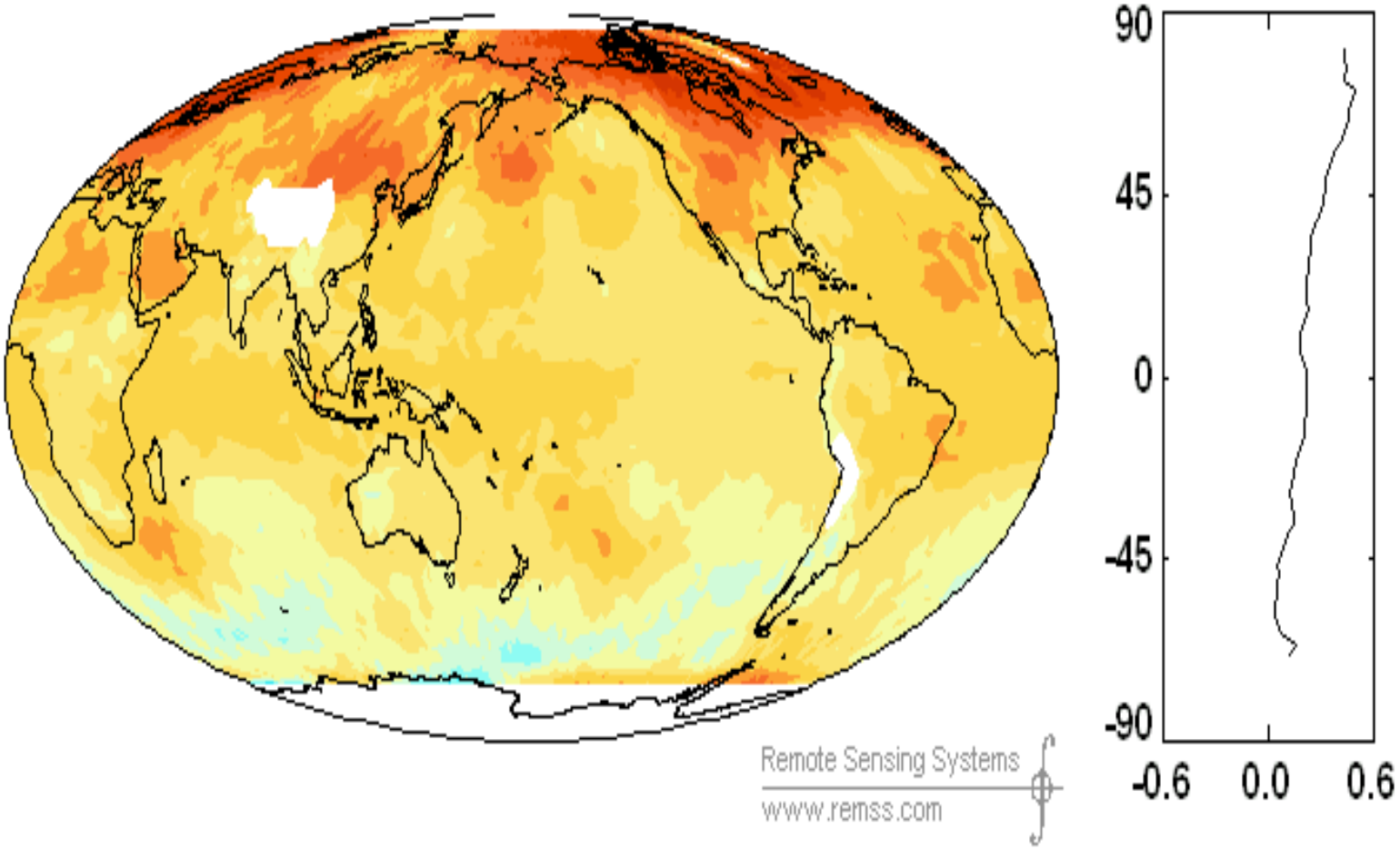

1700
1750
1800
1850
1900
1950
2000
Alaska
Canada, USA (excl. Alaska)
Norway
European Alps
Russia, Arctic Isles
Russia, North Caucasus
Russia, Urals
Russia, Altai
Russia, Siberia
Russia, Kamchatka
Tien Shan + Pamirs
Himalayas
Tibet and surrounds
Tropics
South America
New Zealand
???
Maximum
Decrease
Minimum

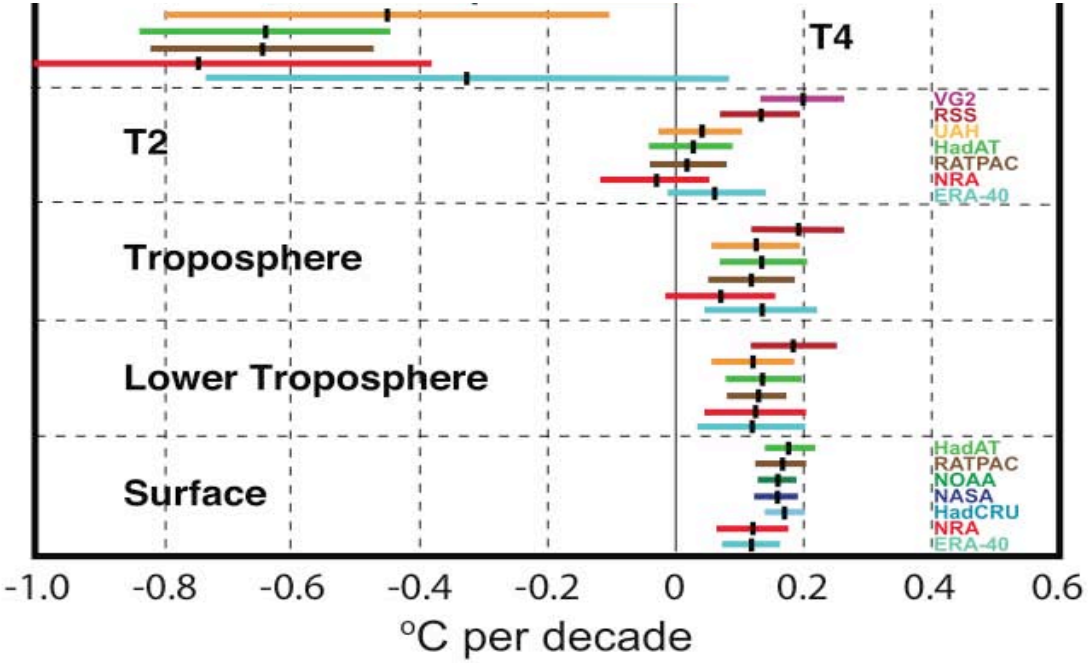


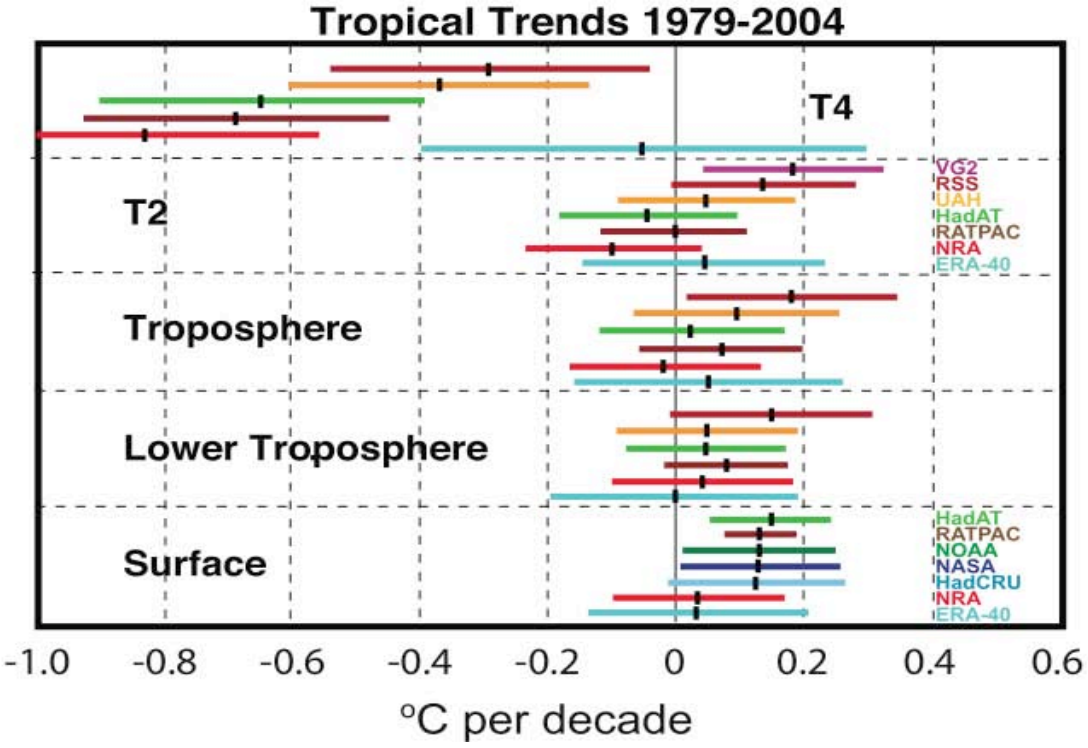

- *Vertical weighting functions (grey) depicting the layers sampled by satellite MSU measurements and their derivatives, and used also for radiosonde and reanalysis records. The right panel schematically depicts the variation in the tropopause (that separates the stratosphere and troposphere) from the tropics (left) to the high latitudes (right). The fourth panel depicts T4 in the lower stratosphere, the third panel shows T2, the second panel shows the troposphere as a combination of T2 and T4 (Fu et al., 2004a) and the first panel shows $T2_{LT}$ from the UAH for the low troposphere. Adapted from Karl et al. (2006).*

# UAH and RSS LT Trends




90
45
0
-45
-90
-0.6
0.0
0.6
Remote Sensing Systems
www.remss.com
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6

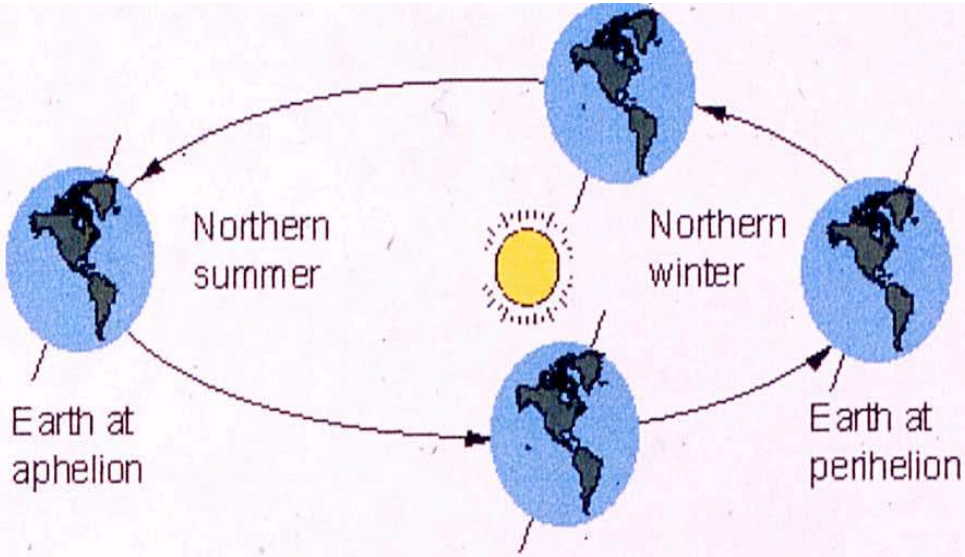

T4
T2
Troposphere
Lower Troposphere
Surface
VG2
RSS
UAH
HadAT
RATPAC
NRA
ERA-40
HadAT
RATPAC
NOAA
NASA
HadCRU
NRA
ERA-40
-1.0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
°C per decade


Tropical Trends 1979-2004
T4
T2
Troposphere
Lower Troposphere
Surface
VG2
RSS
UAH
HadAT
RATPAC
NRA
ERA-40
HadAT
RATPAC
NOAA
NASA
HadCRU
NRA
ERA-40
-1.0
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
°C per decade

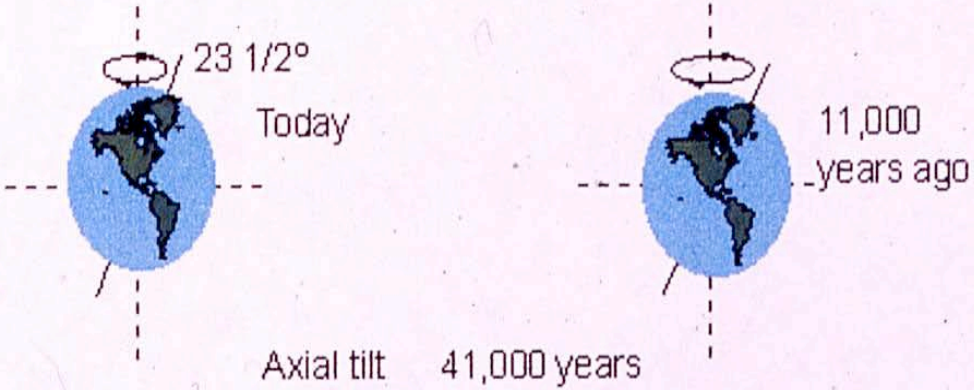
# 2. Is the warming special?

- Is the warming different than what might be expected from our understanding of natural climate variability?

- Why can’t the sun be causing this warming?

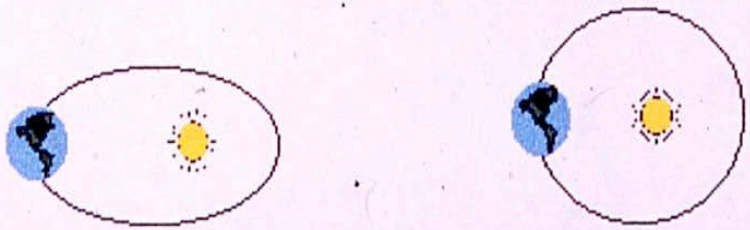



Precession of the equinoxes 19,0000-23,000 years



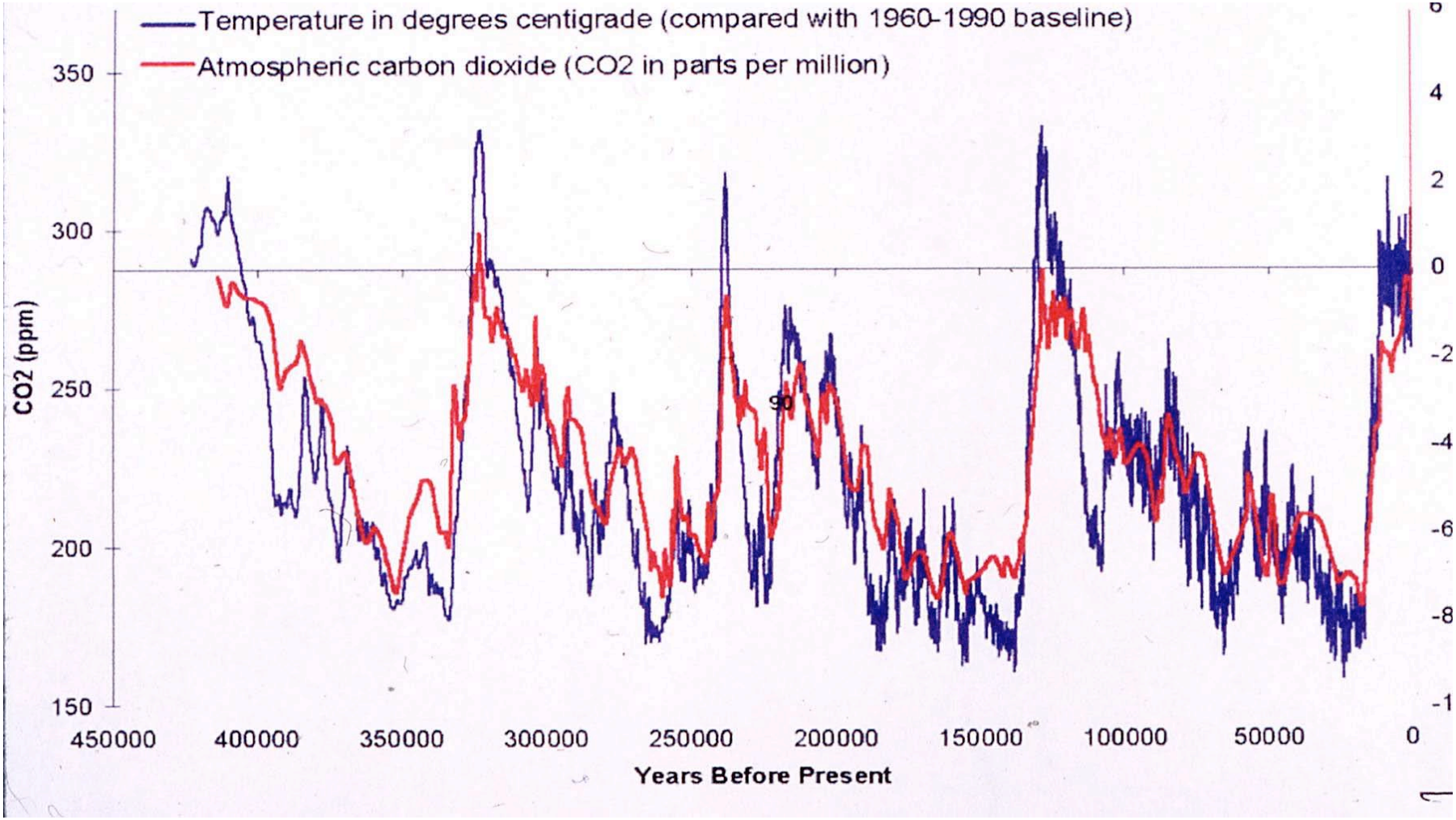

Axial tilt 41,000 years

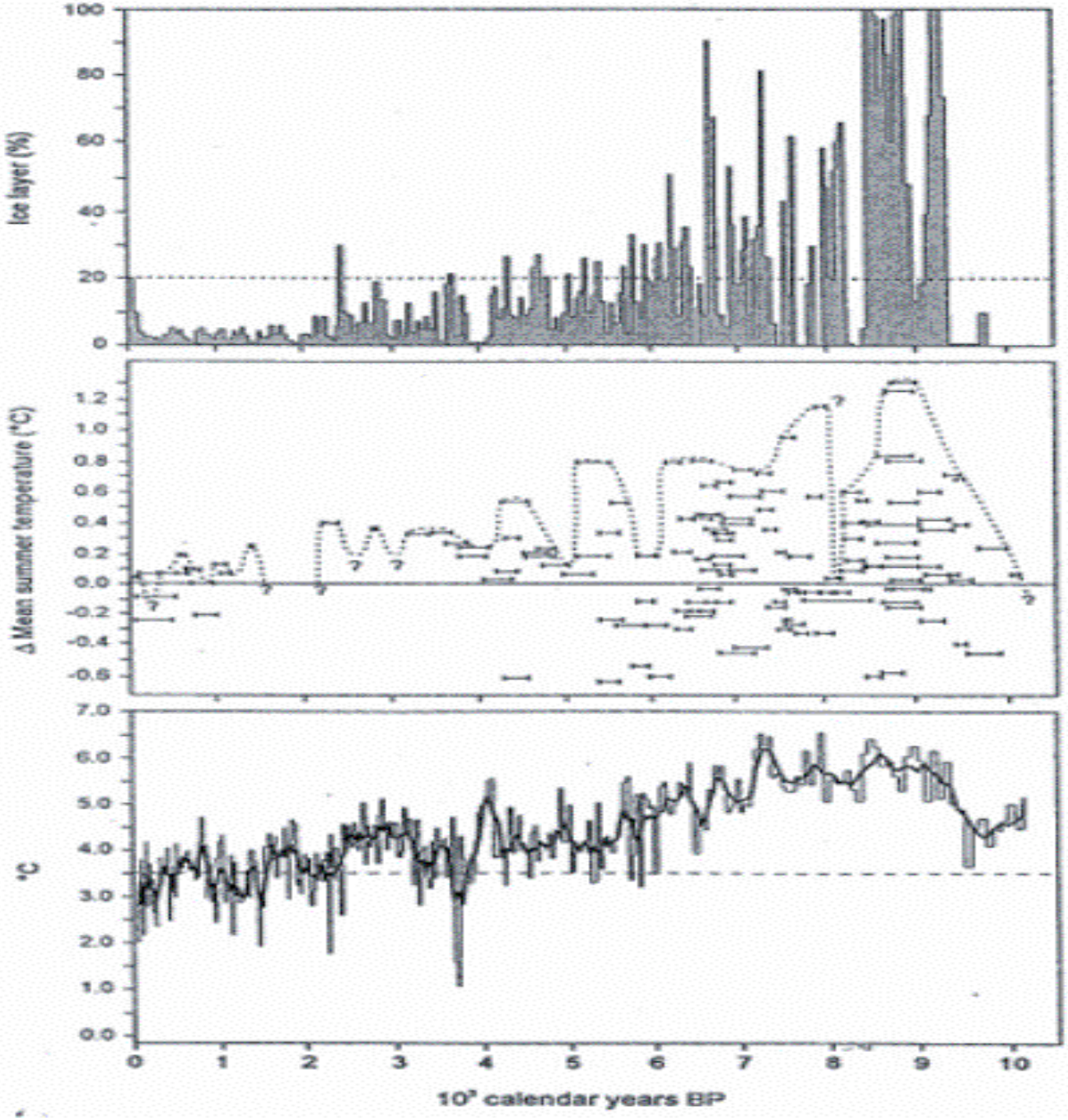
Collectively known as
the
Milankovitch Effect



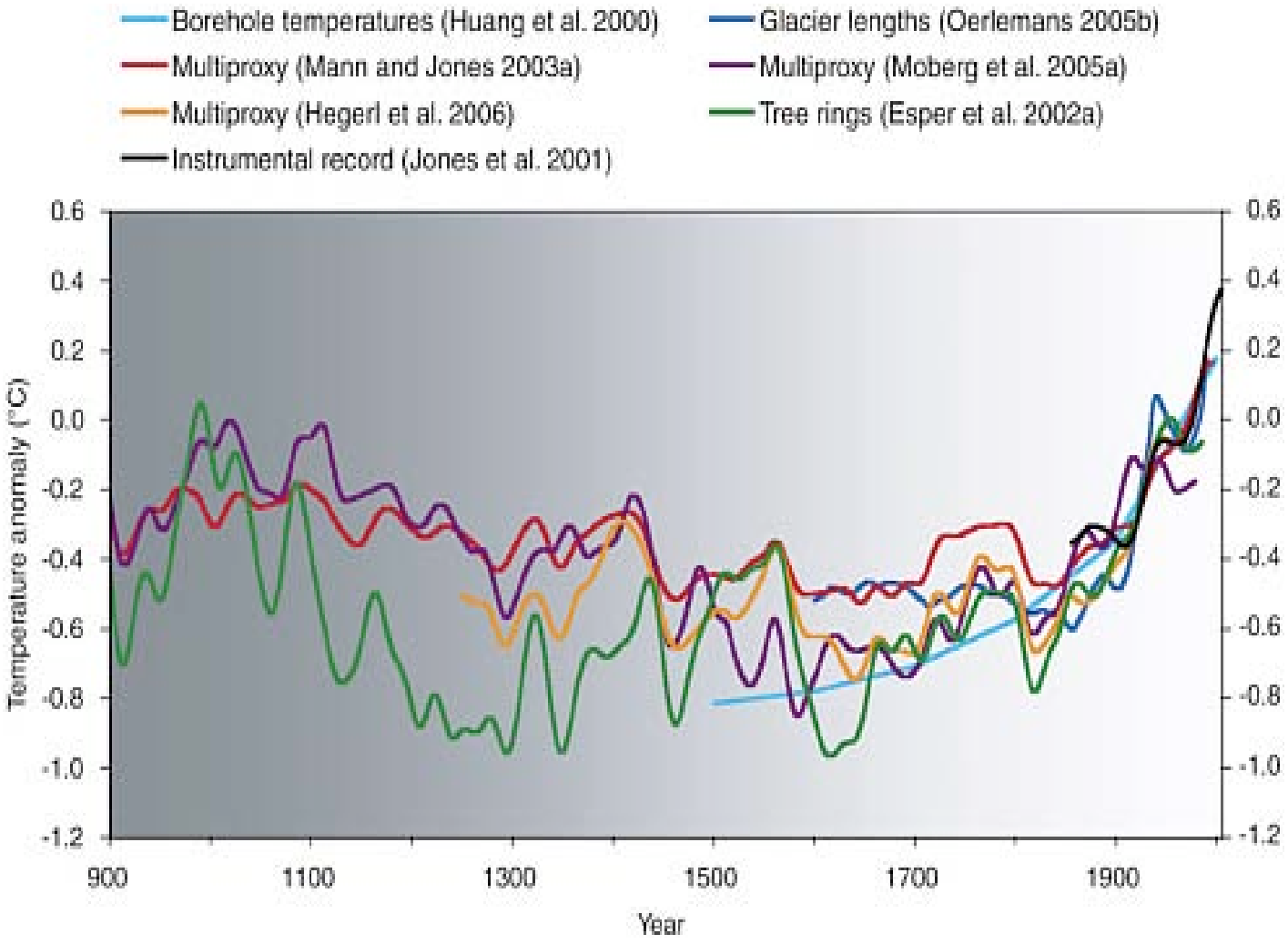
Ellipticity of the earth's orbit 90,000-100,000 years

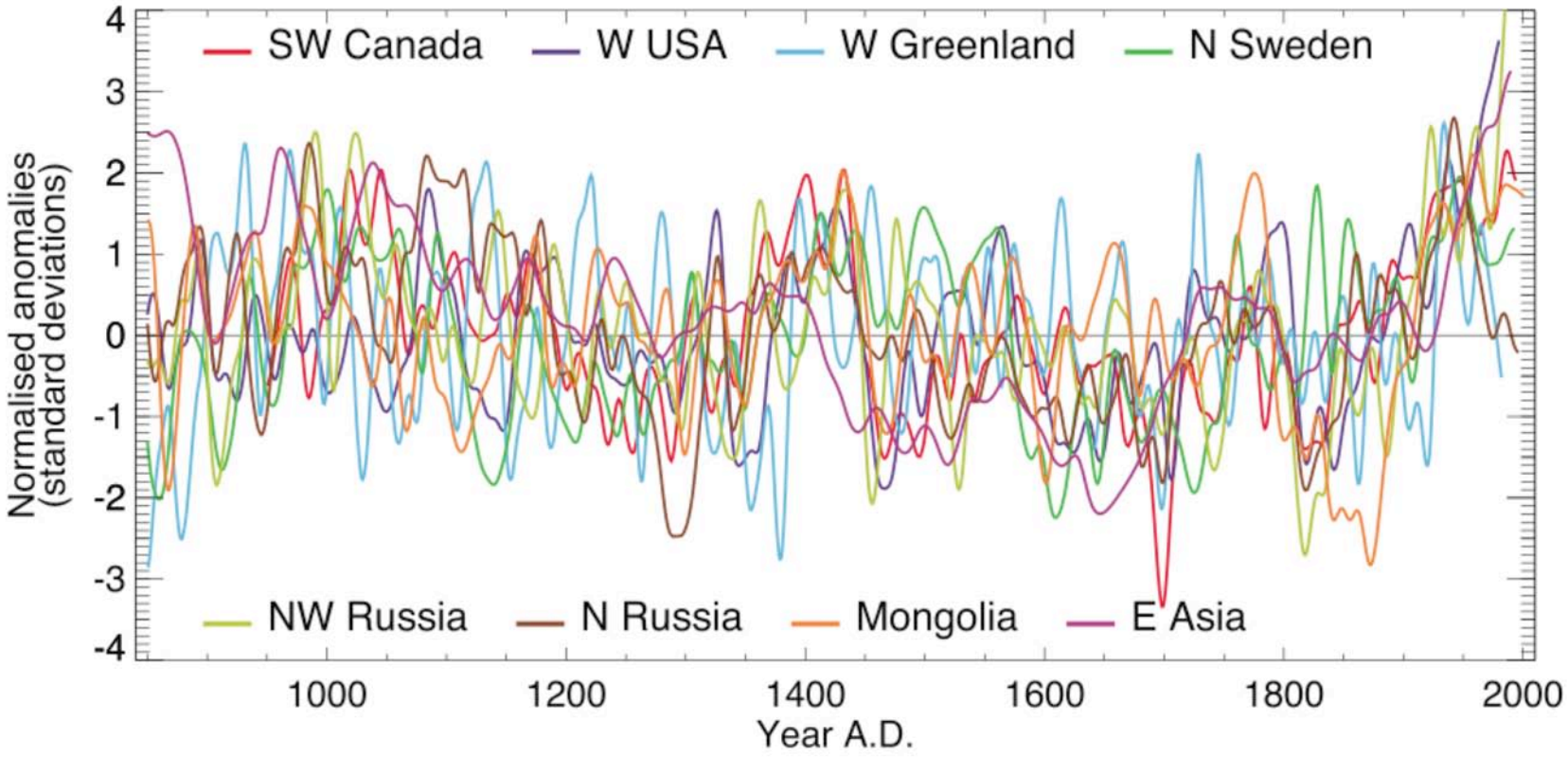
Antarctic ice core records showing temperature and CO2 changes for last 420,000 thousand years.



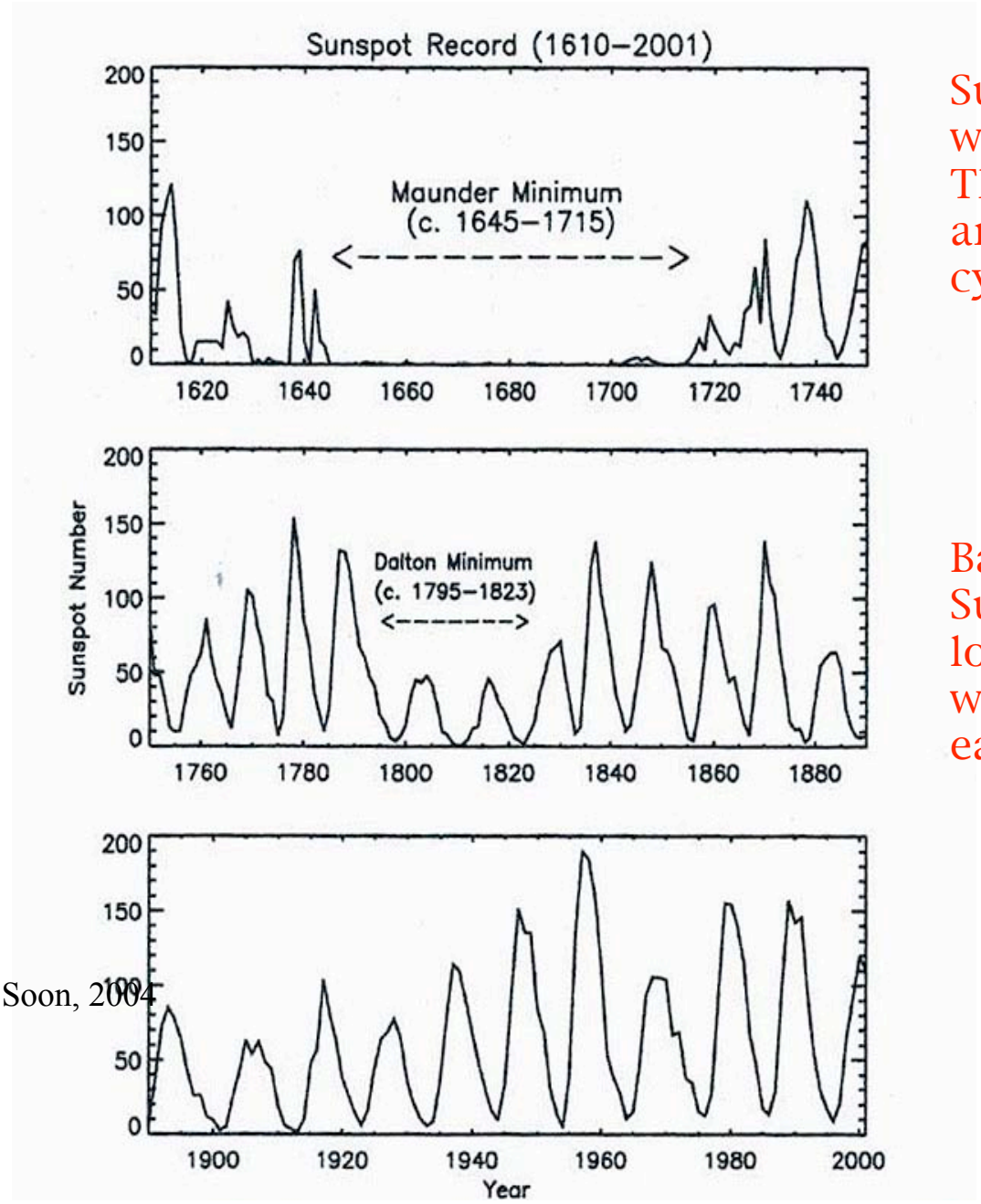

Ice layer (%)
100
80
60
40
20
0
Δ Mean summer temperature (°C)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
°C
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
0
1
2
3
4
5
6
7
8
9
10
10³ calendar years BP

# Recent Paleo-Temperature






**Box 6.4, Figure 1**

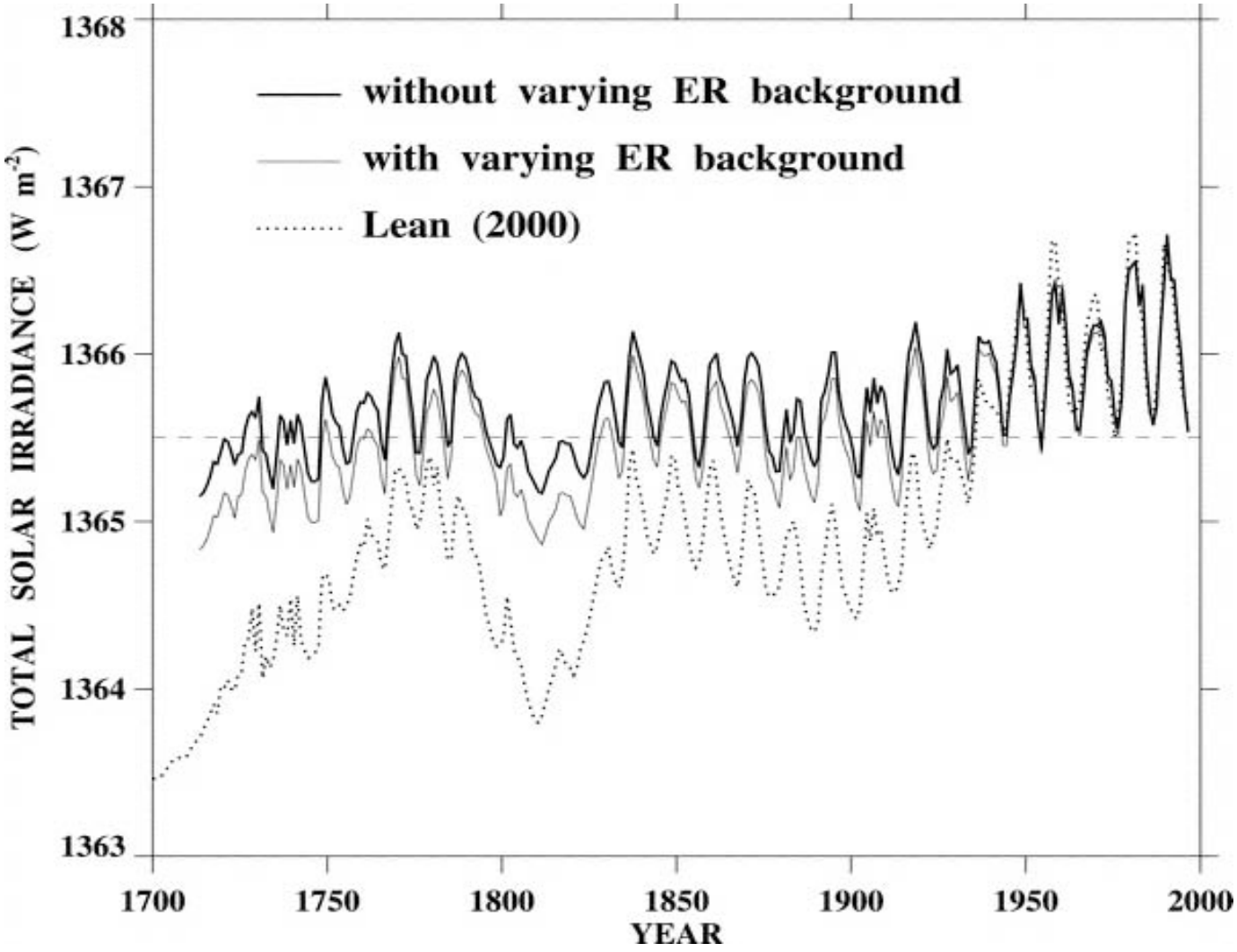


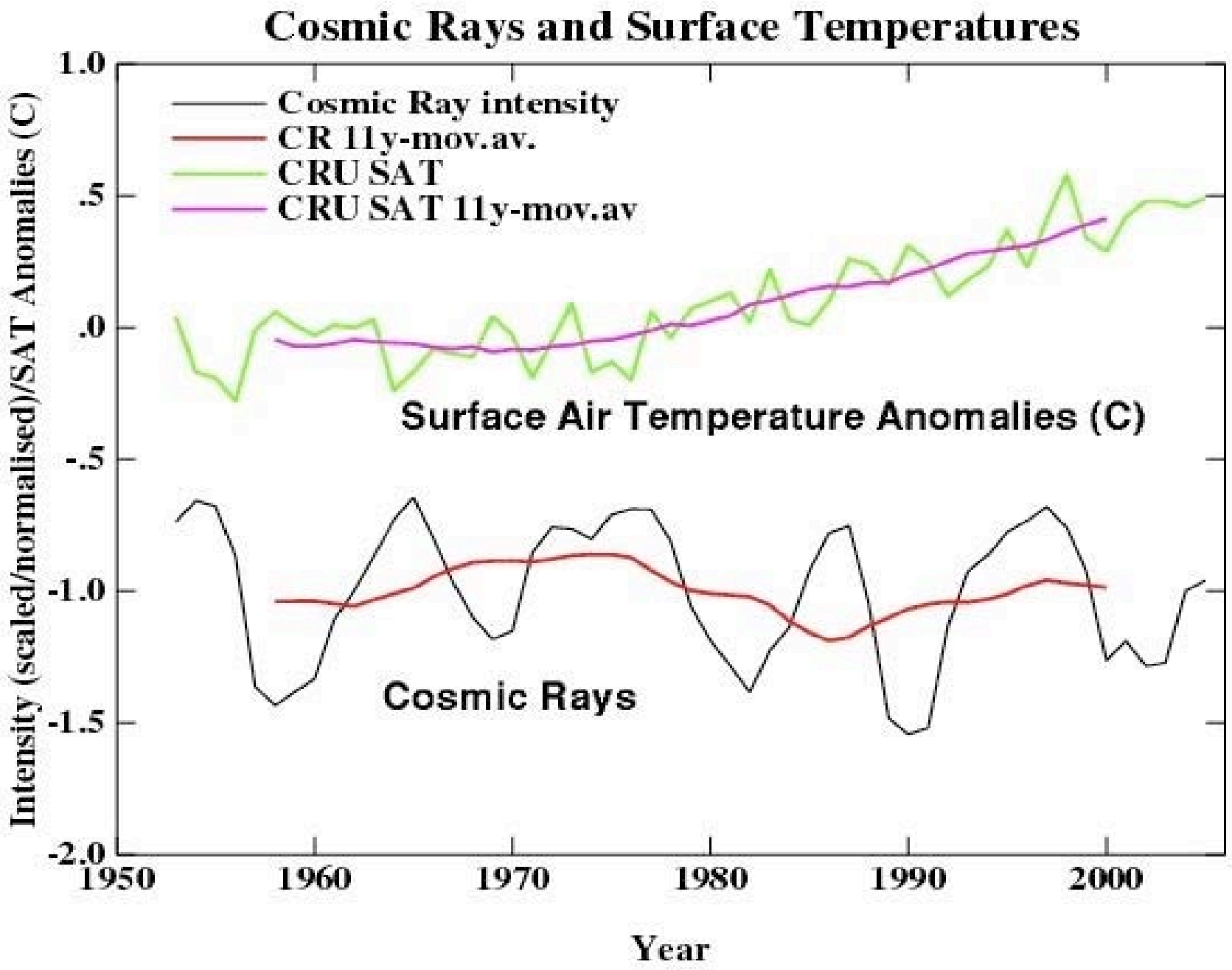

Source:
Wei-Hock Soon, 2004

Sunspot records begin with Galileo in 1610 That is cycle 1. We are currently entering cycle 23

Basically, when Sunspot number is low the earth is cold, when it is high the earth is warm.

# Re-evaluation of TSI

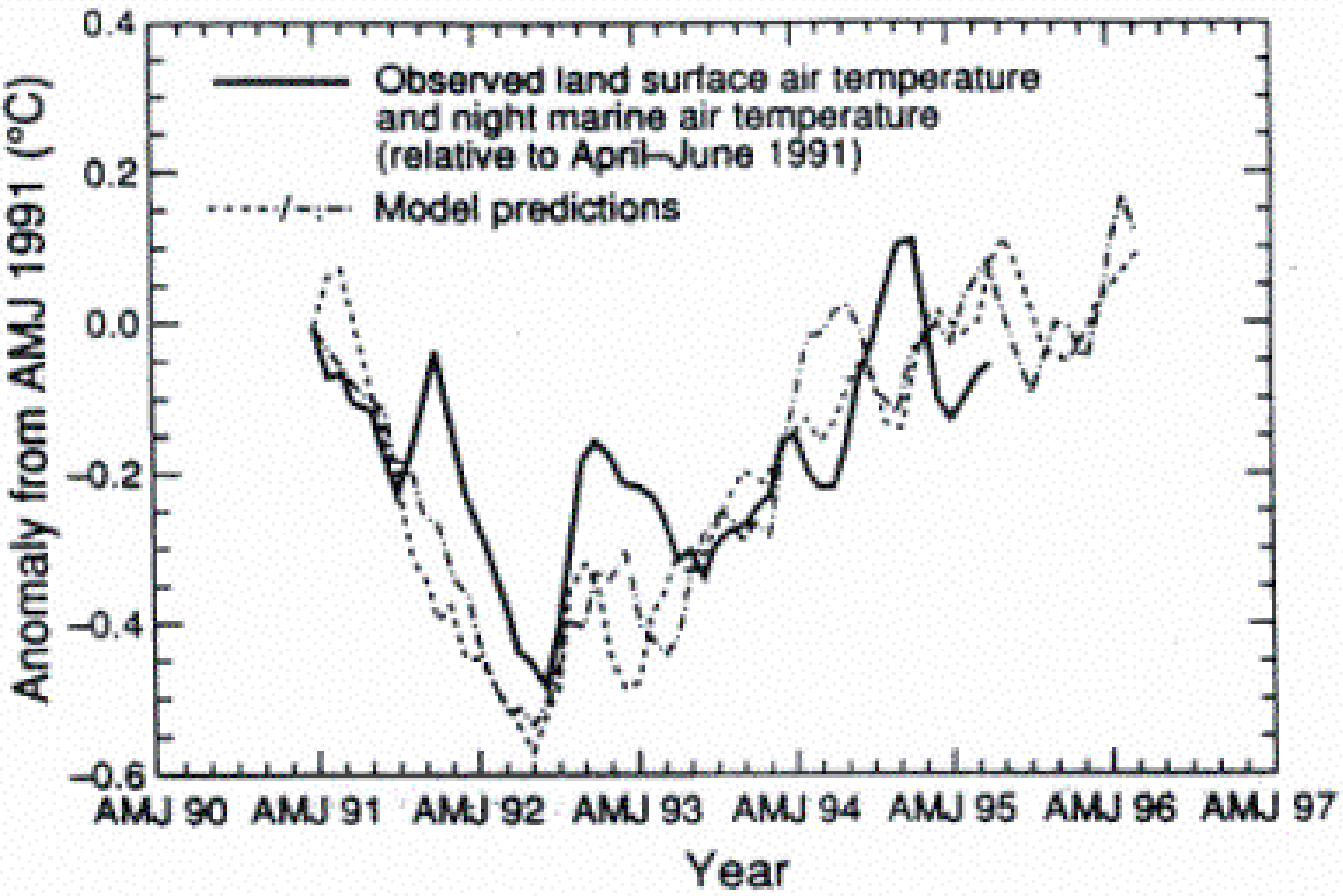


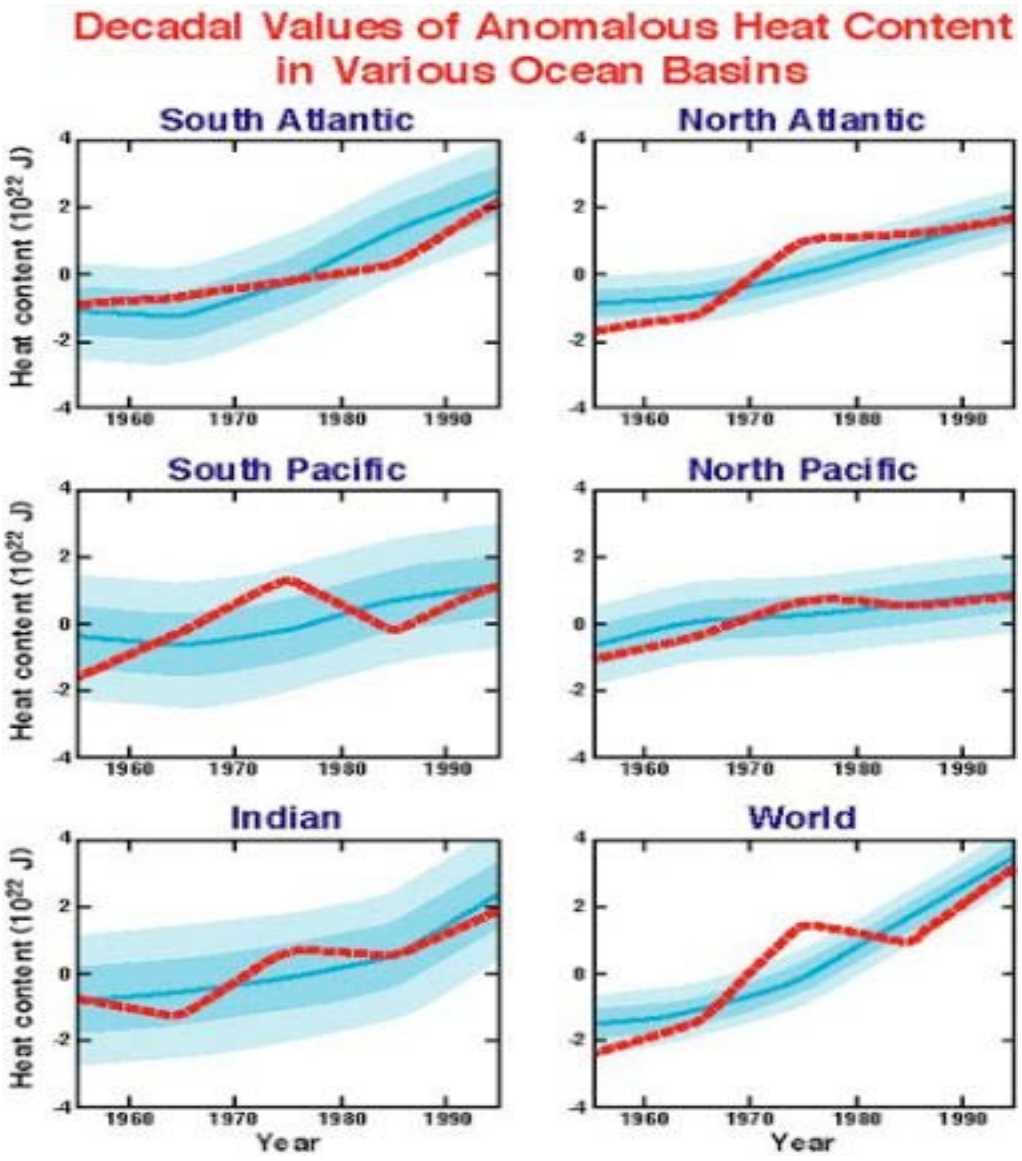

Cosmic Rays and Surface Temperatures
Cosmic Ray intensity
CR 11y-mov.av.
CRU SAT
CRU SAT 11y-mov.av
Surface Air Temperature Anomalies (C)
Cosmic Rays
Intensity (scaled/normalised)/SAT Anomalies (C)
1.0
.5
.0
-.5
-1.0
-1.5
-2.0
1950
1960
1970
1980
1990
2000
Year

# 3a. Can we understand/model it?

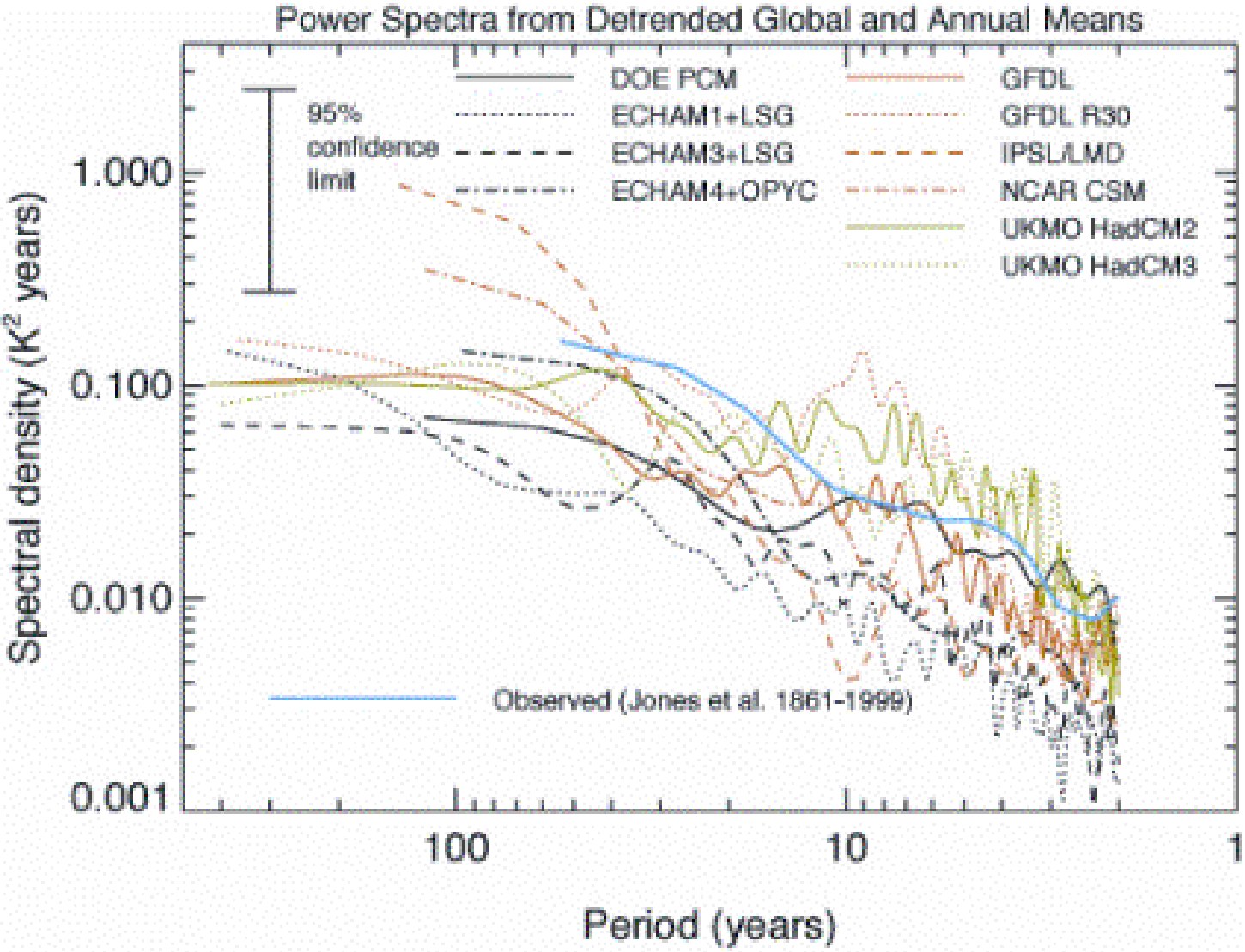
- How good are models?
- Isn't the climate too complex and chaotic to be reliably simulated in a computer?
- If we can't predict next week's weather, how can we expect to predict next decade's?
- Can models really make predictions?

# Model Prediction of Global Temperature Recovery from Mt. Pinatubo-caused Cooling

- 


Decadal Values of Anomalous Heat Content
in Various Ocean Basins
South Atlantic
North Atlantic
South Pacific
North Pacific
Indian
World
Heat content ($10^{22}$ J)
Year
1960
1970
1980
1990
4
2
0
-2
-4

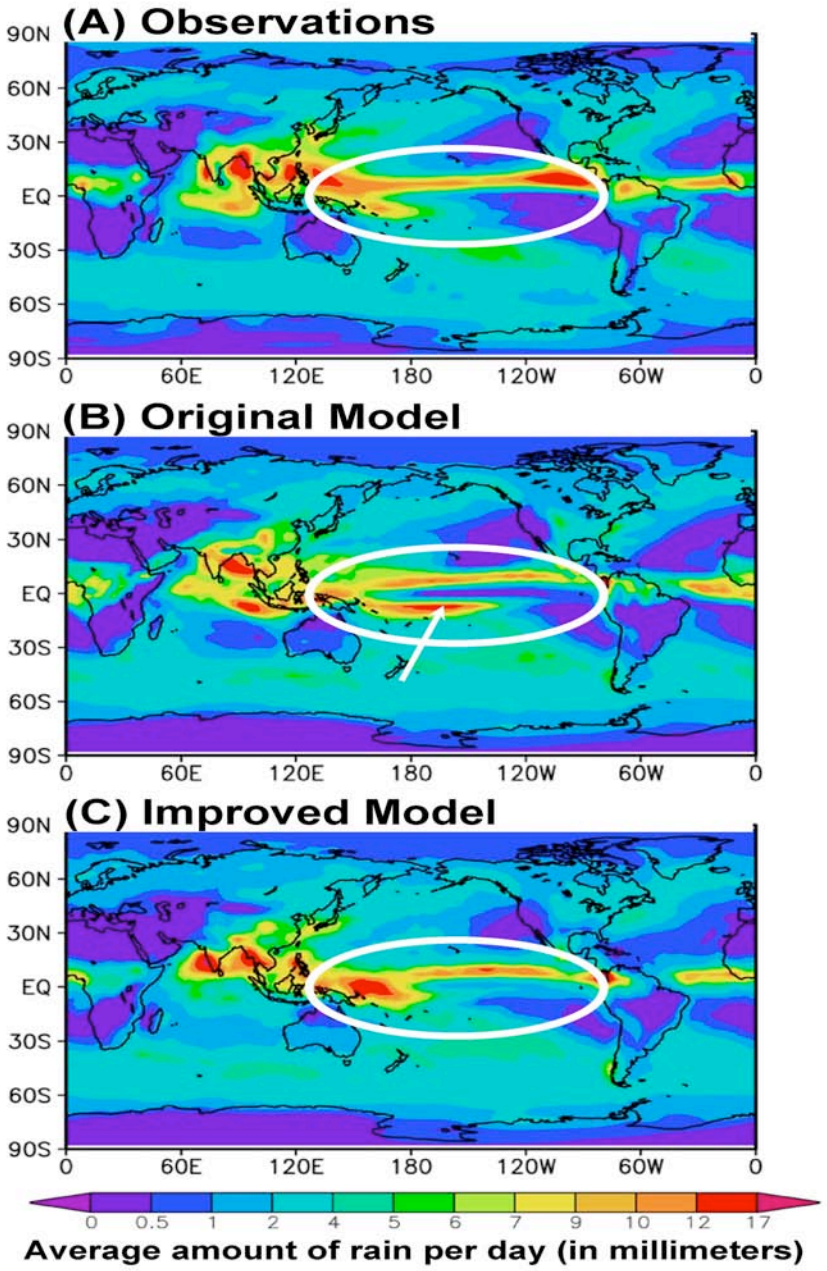
# Natural VS Modeled Climate Variability

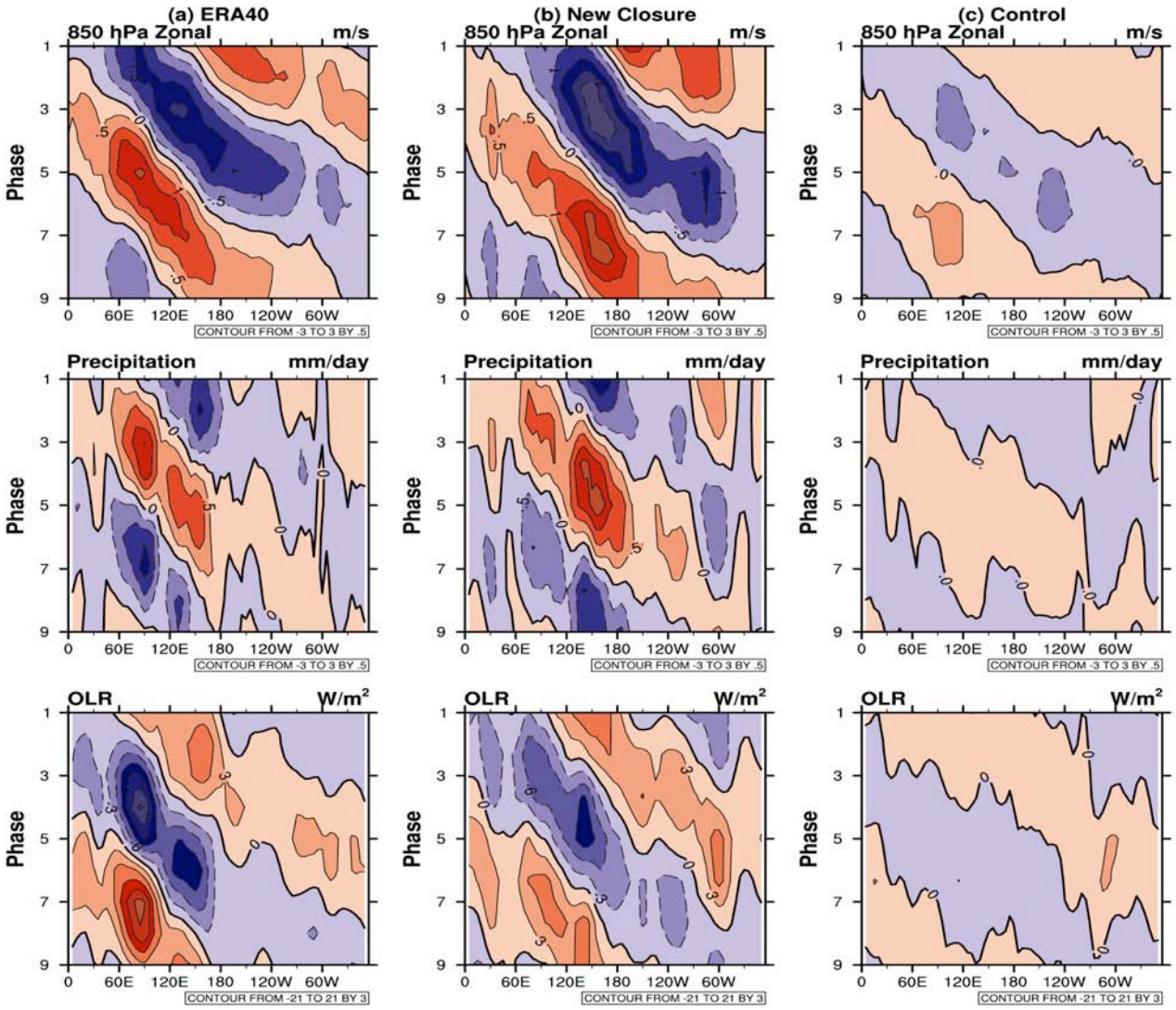


Obs

CCSM3 Ctrl

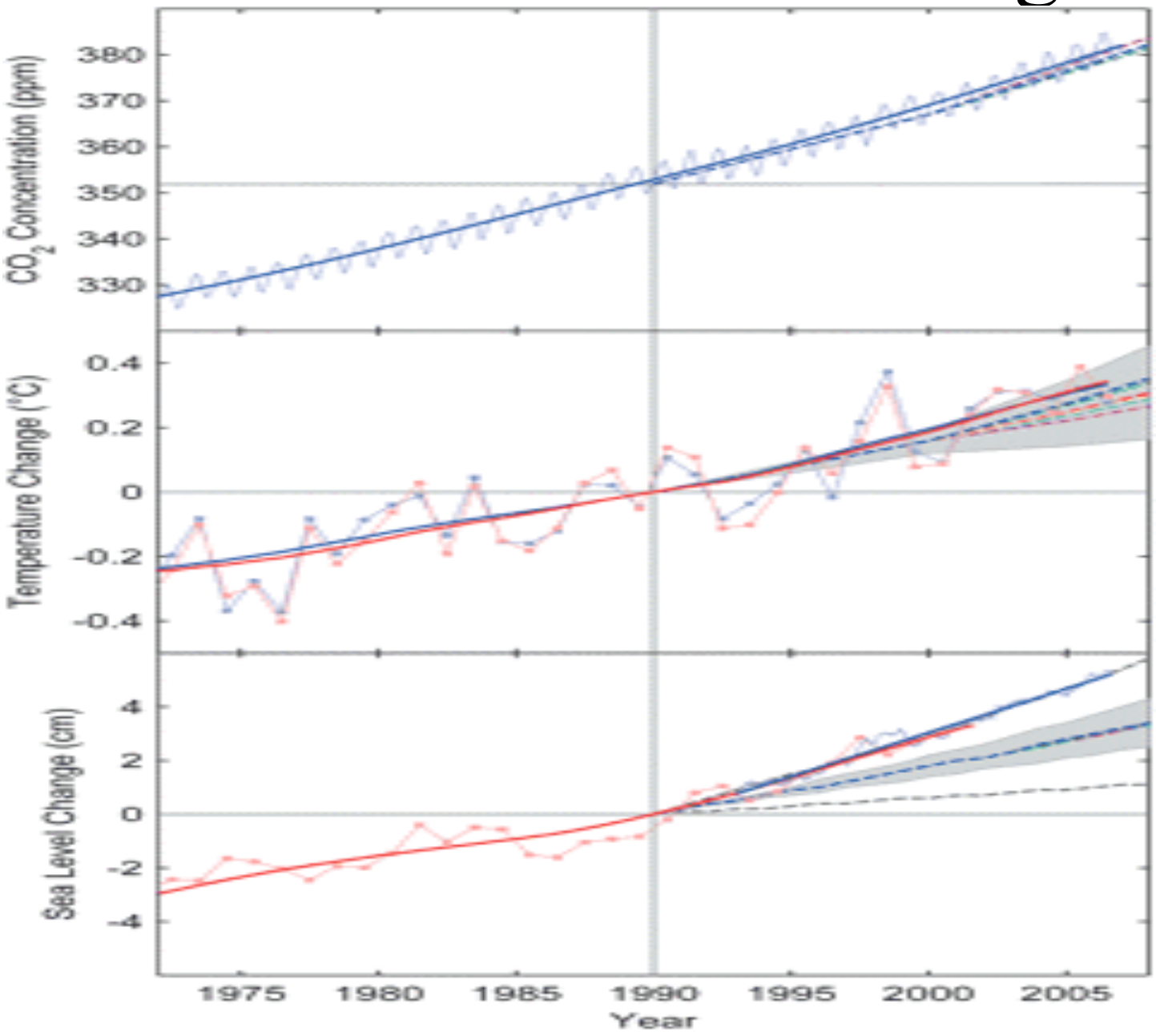
CCSM3 Exp

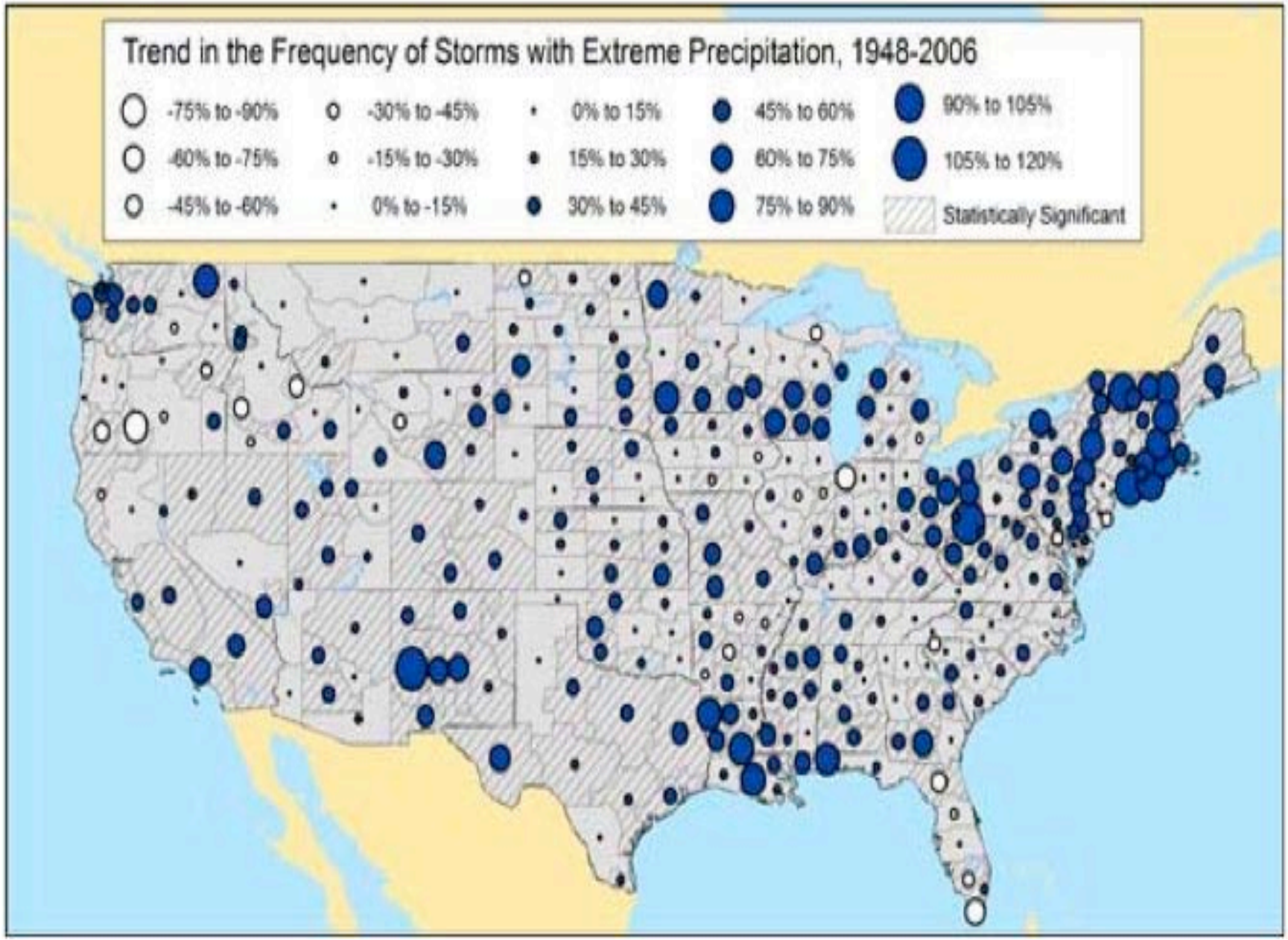





Observations CAM3 Exp CAM3 Ctrl

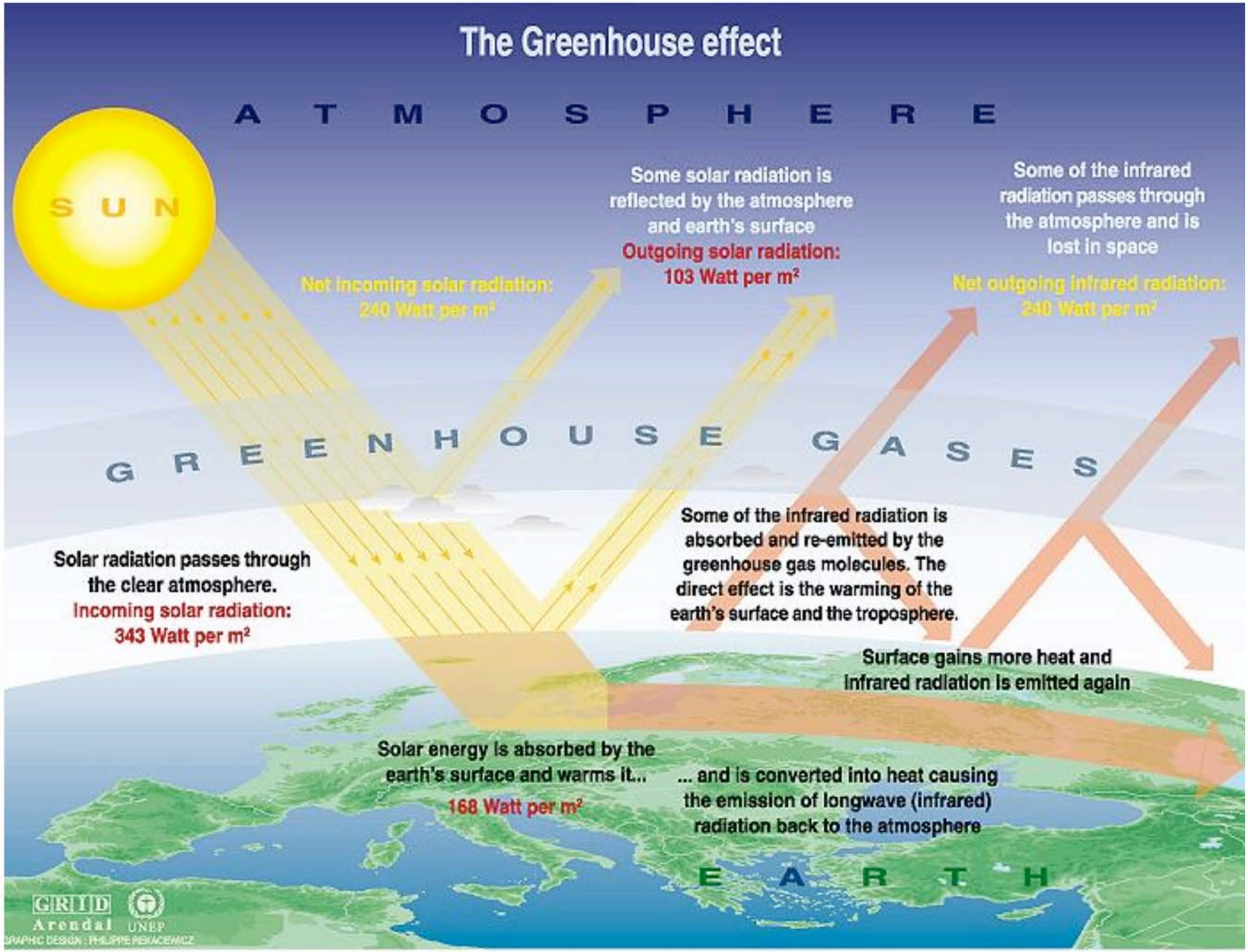
# Model Predictions look good




Trend in the Frequency of Storms with Extreme Precipitation, 1948-2006
-75% to -90%
-60% to -75%
-45% to -60%
-30% to -45%
-15% to -30%
0% to -15%
0% to 15%
15% to 30%
30% to 45%
45% to 60%
60% to 75%
75% to 90%
90% to 105%
105% to 120%
Statistically Significant

# 3b. ATTRIBUTING WARMING TO HUMANS

How does climate forcing by so-called anthropogenic greenhouse gases compare with natural forcings that have caused climate change in the past?




Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

# Radiative Forcings

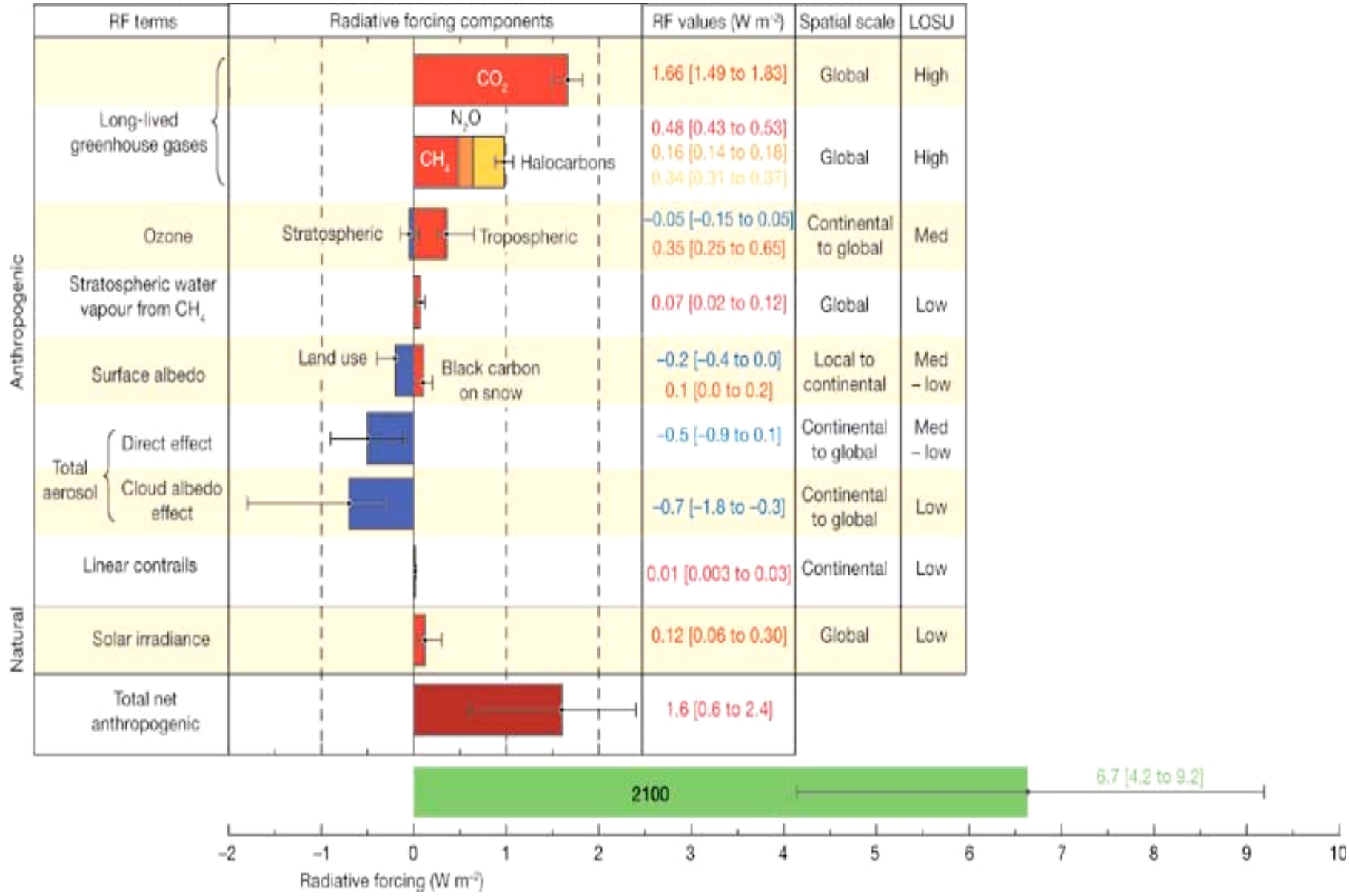
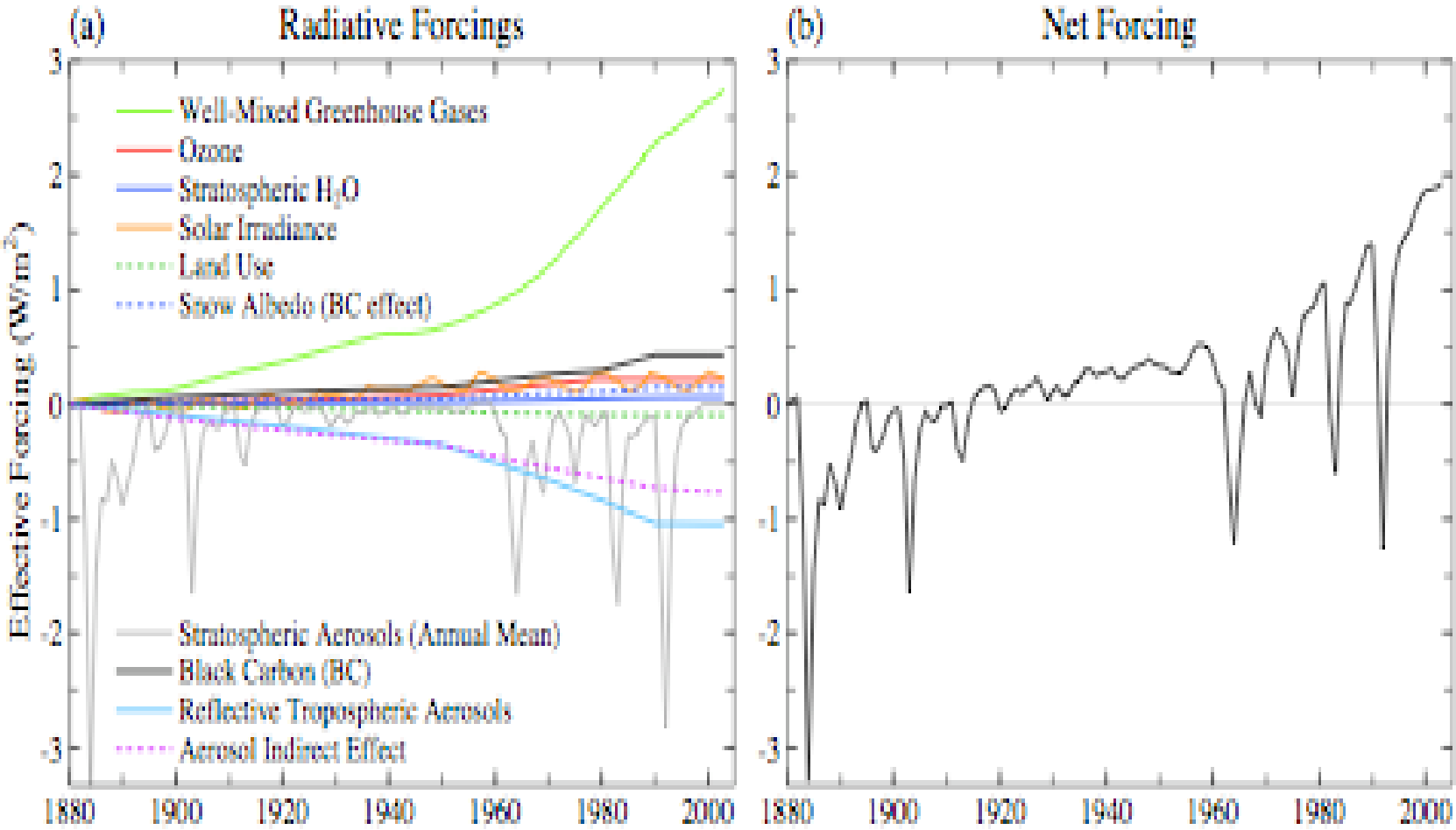
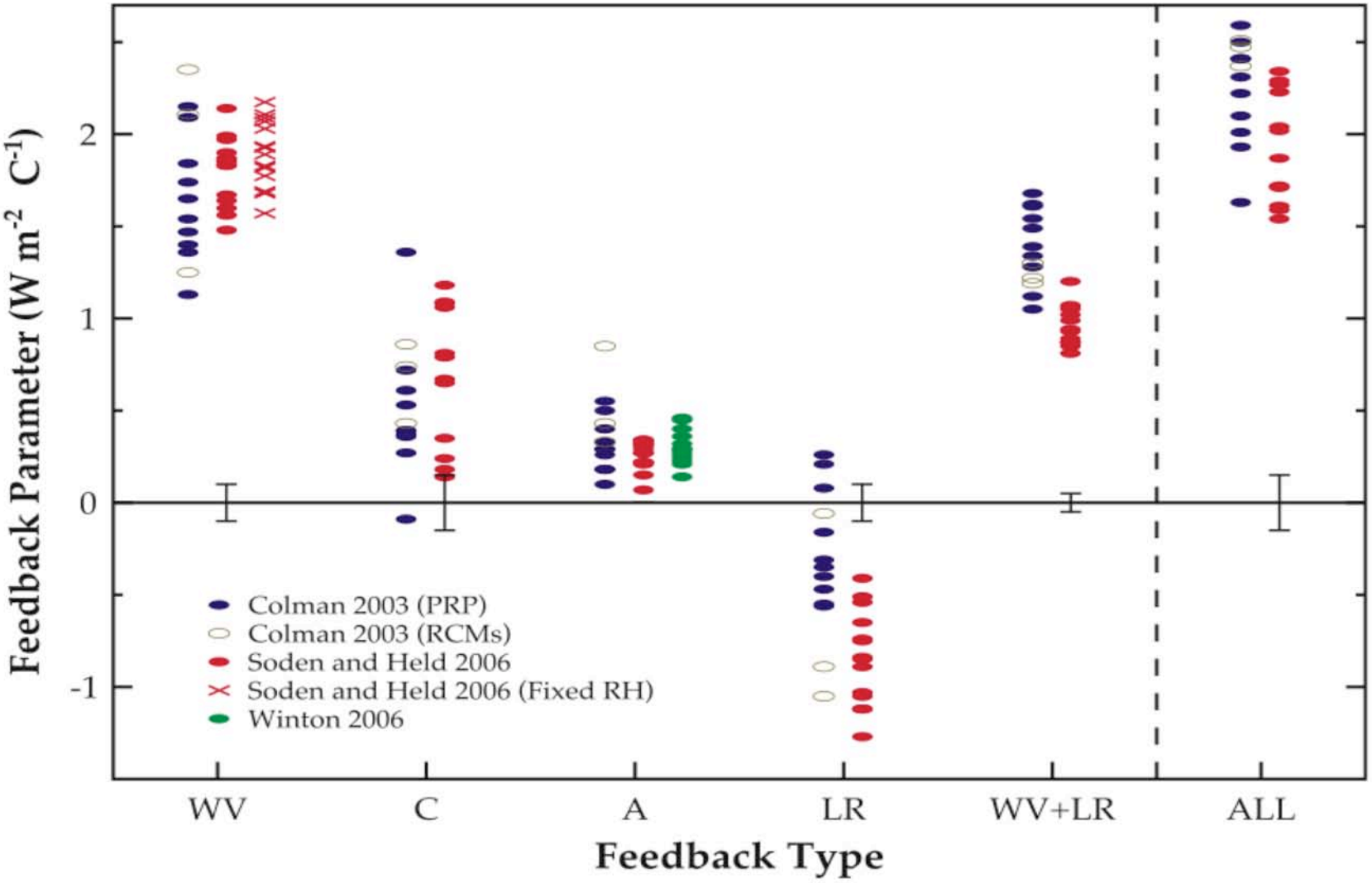


Fig. 5. Effective global climate forcings employed in our global climate simulations, relative to their values in 1880.

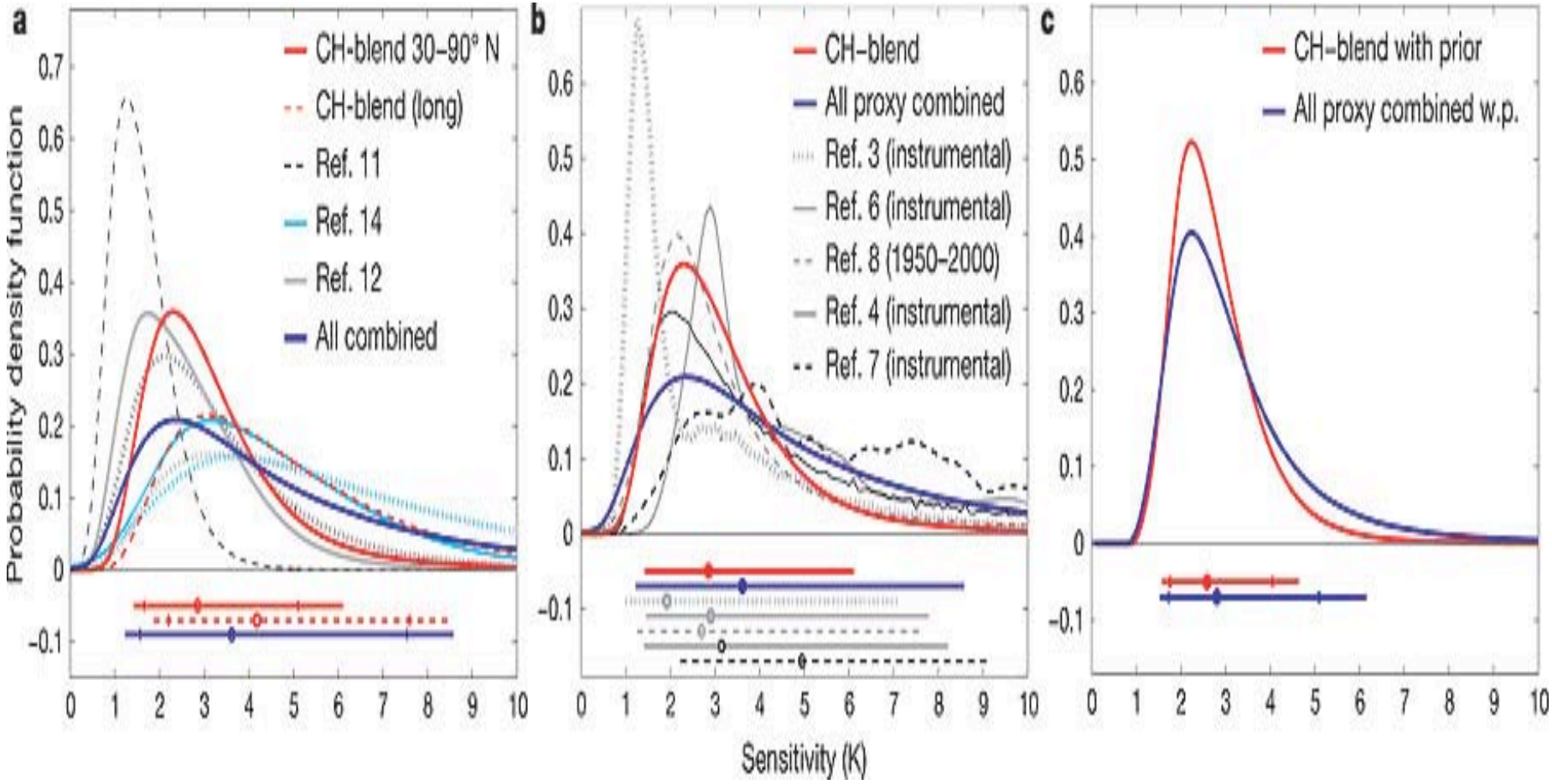


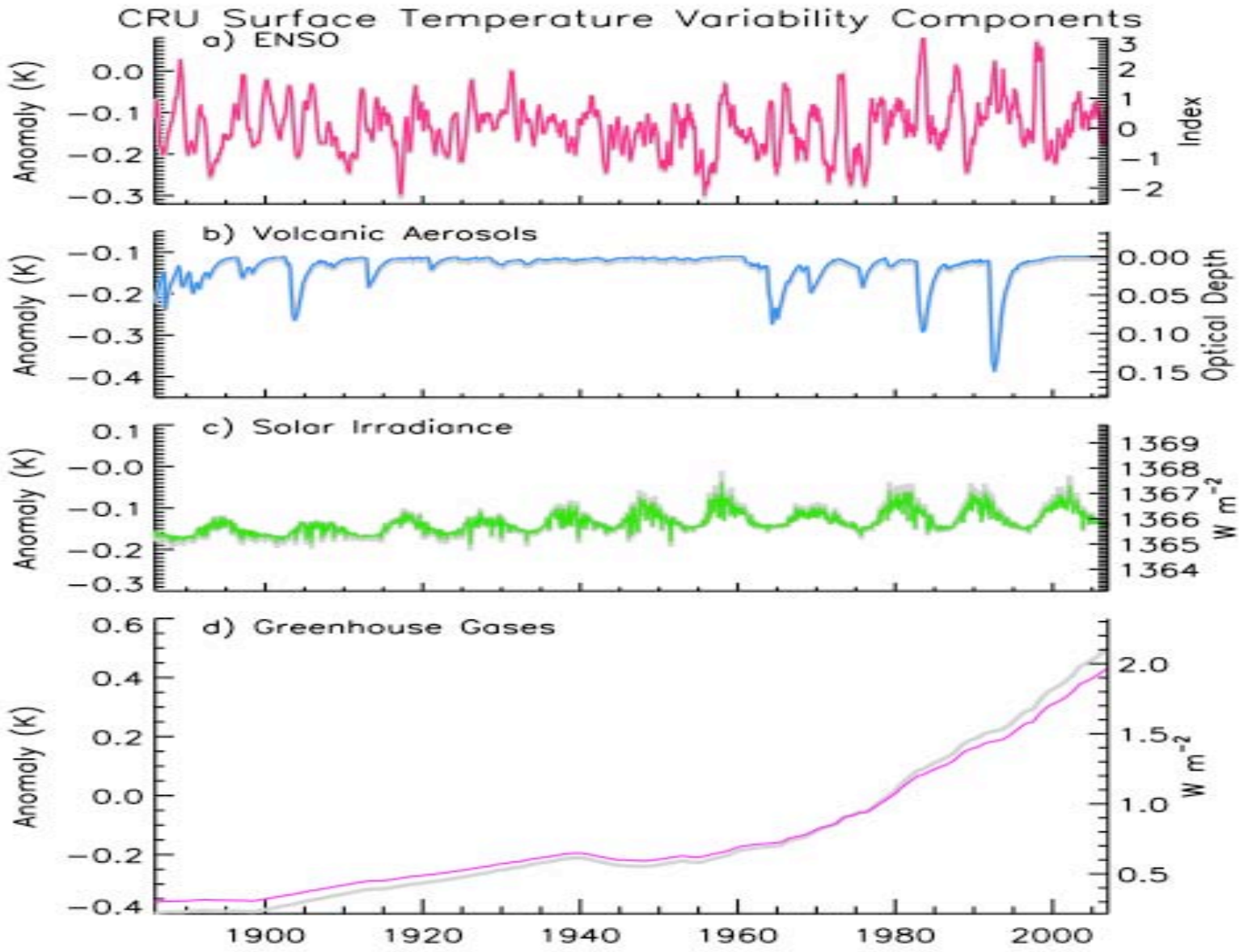
*Comparison of GCM climate feedback parameters for water vapour (WV), cloud (C), surface albedo (A), lapse rate (LR) and the combined water vapour plus lapse rate(WV + LR) in units of W m–2 °C –1. 'ALL' represents the sum of all feedbacks.*

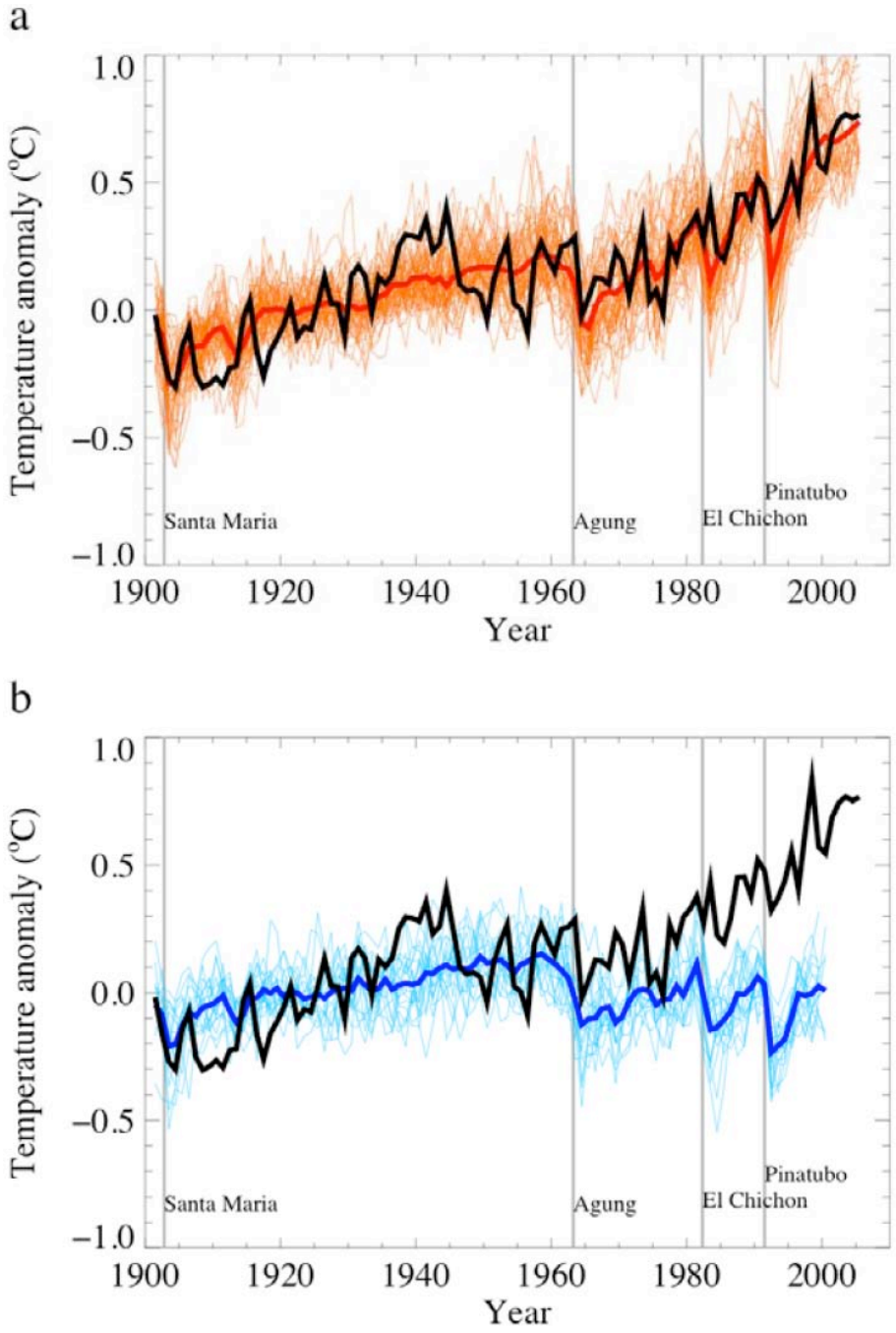


# Probability of climate sensitivity

(from Hegerl et al 2006)




CRU Surface Temperature Variability Components
a) ENSO
b) Volcanic Aerosols
c) Solar Irradiance
d) Greenhouse Gases
Anomaly (K)
Index
Optical Depth
W m-2
1900
1920
1940
1960
1980
2000



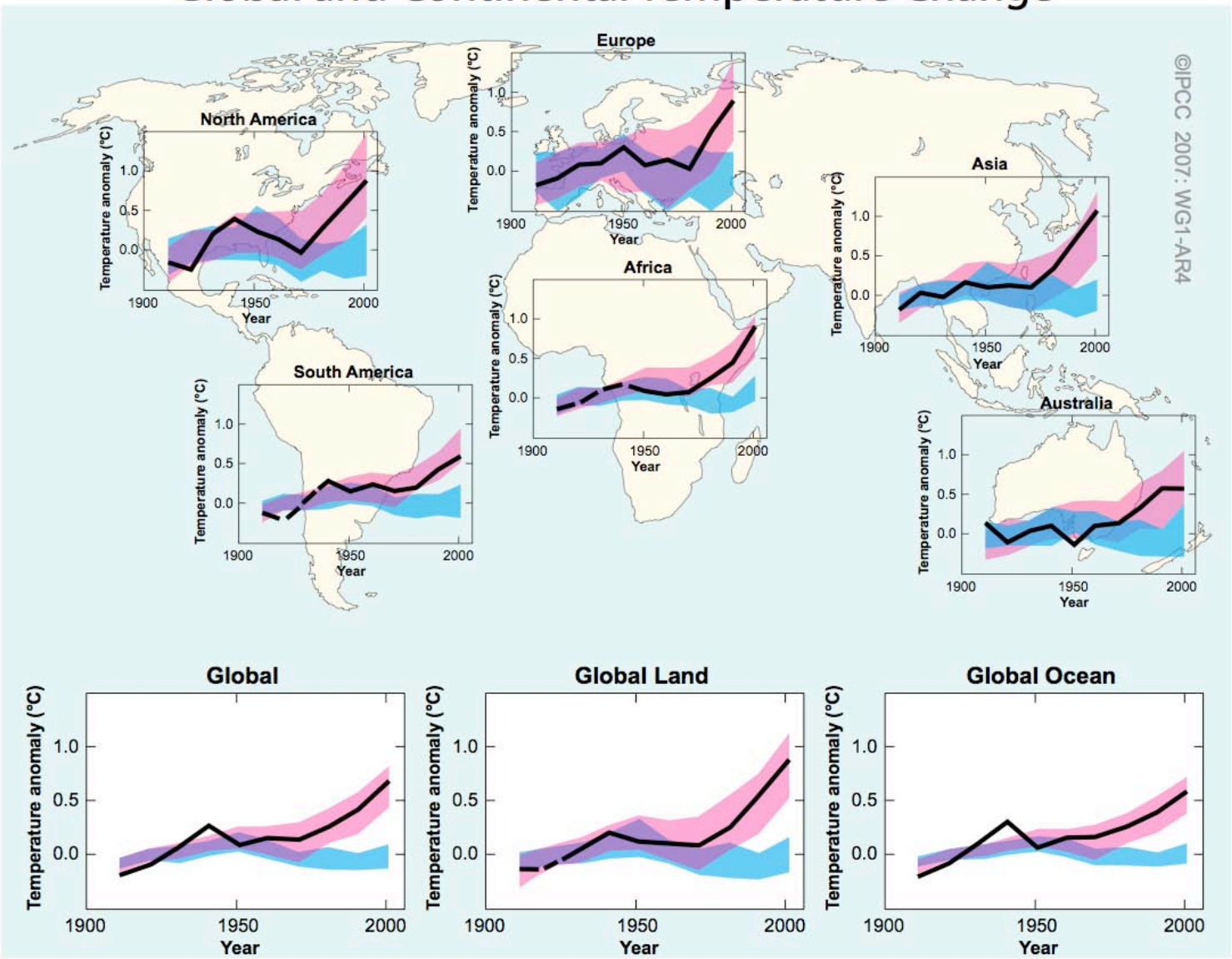

# Ensemble Model Predictions of warming

top:
all forcings

bottom:
natural forcings

Black:
observations

# Global and Continental Temperature Change



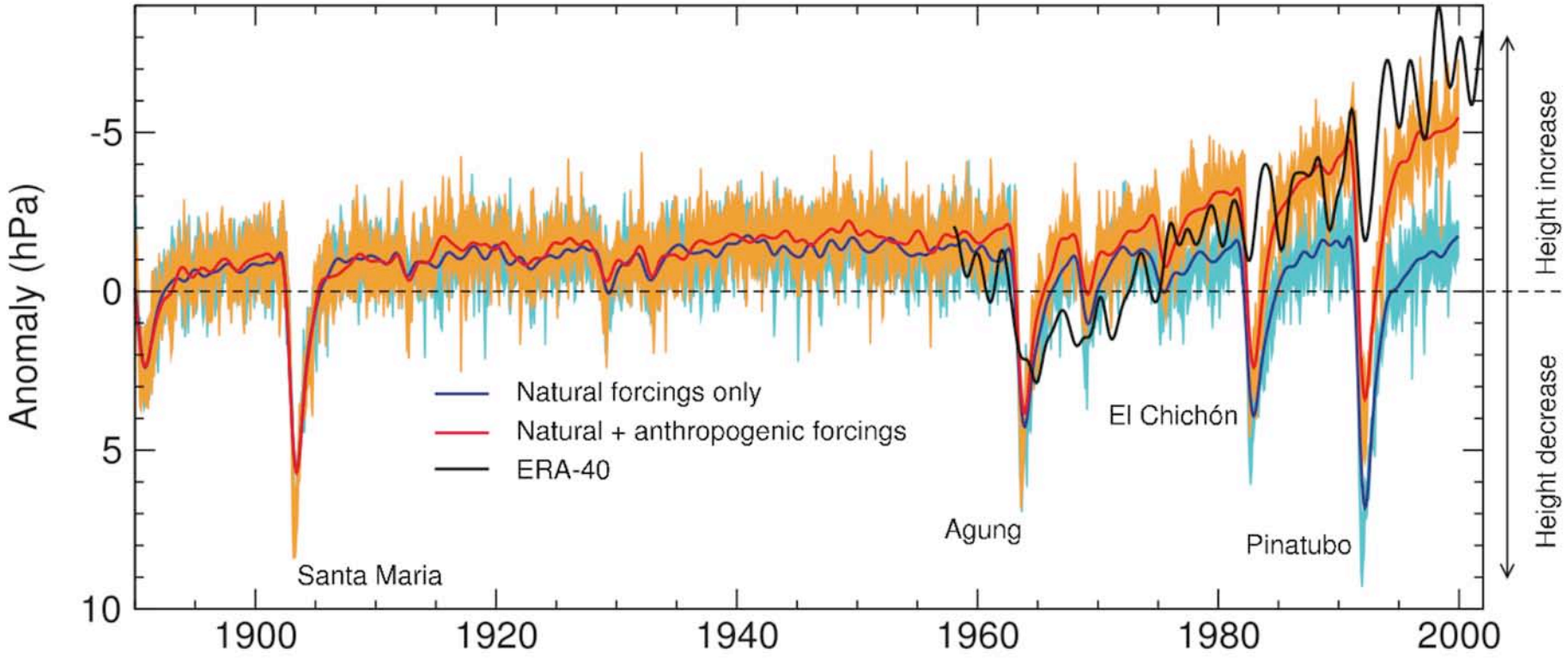

Anomaly (hPa)
-5
0
5
10
1900
1920
1940
1960
1980
2000
Natural forcings only
Natural + anthropogenic forcings
ERA-40
Santa Maria
Agung
El Chichón
Pinatubo
Height increase
Height decrease

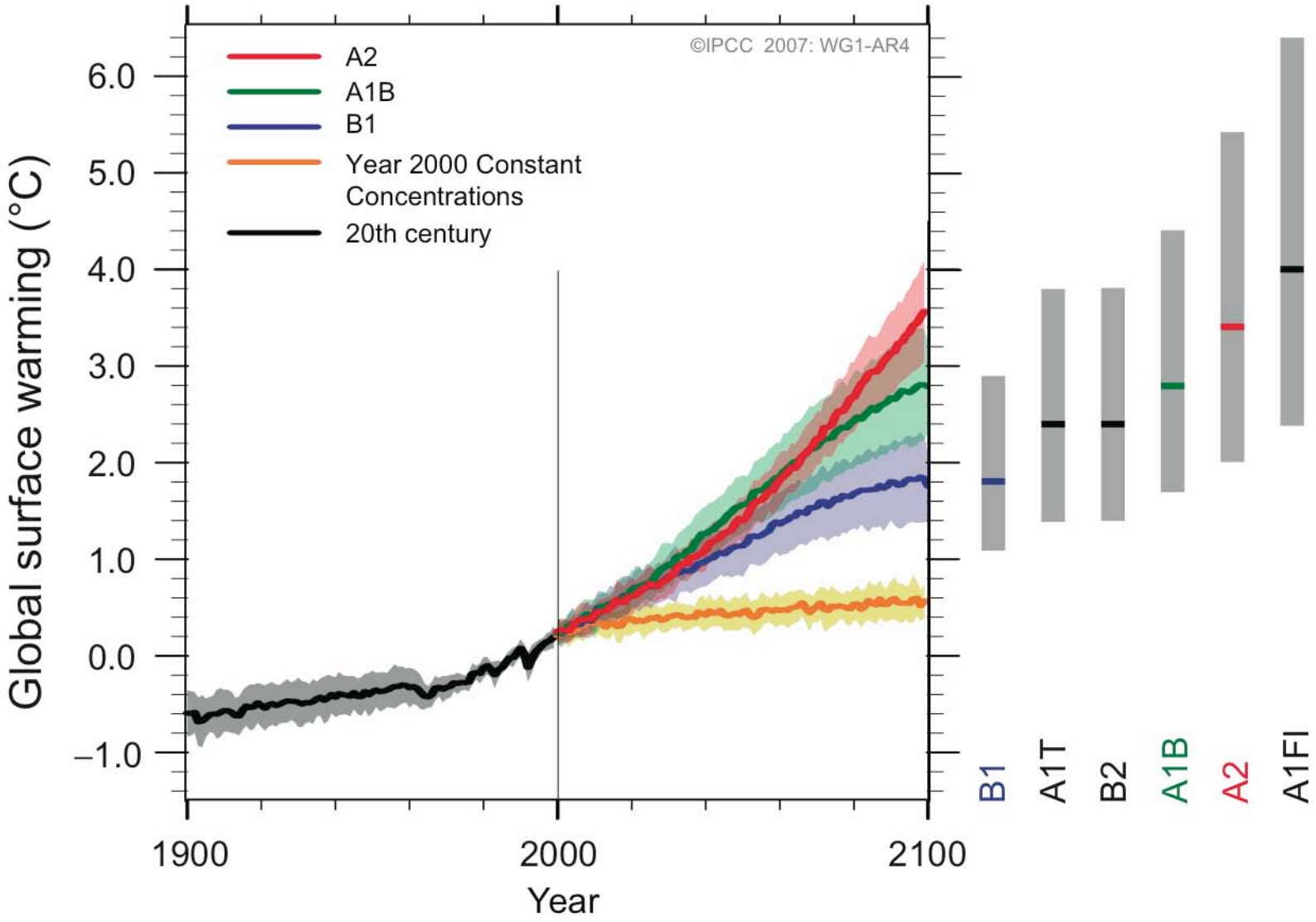
**Figure 9.14**

# http://www.ipcc.ch

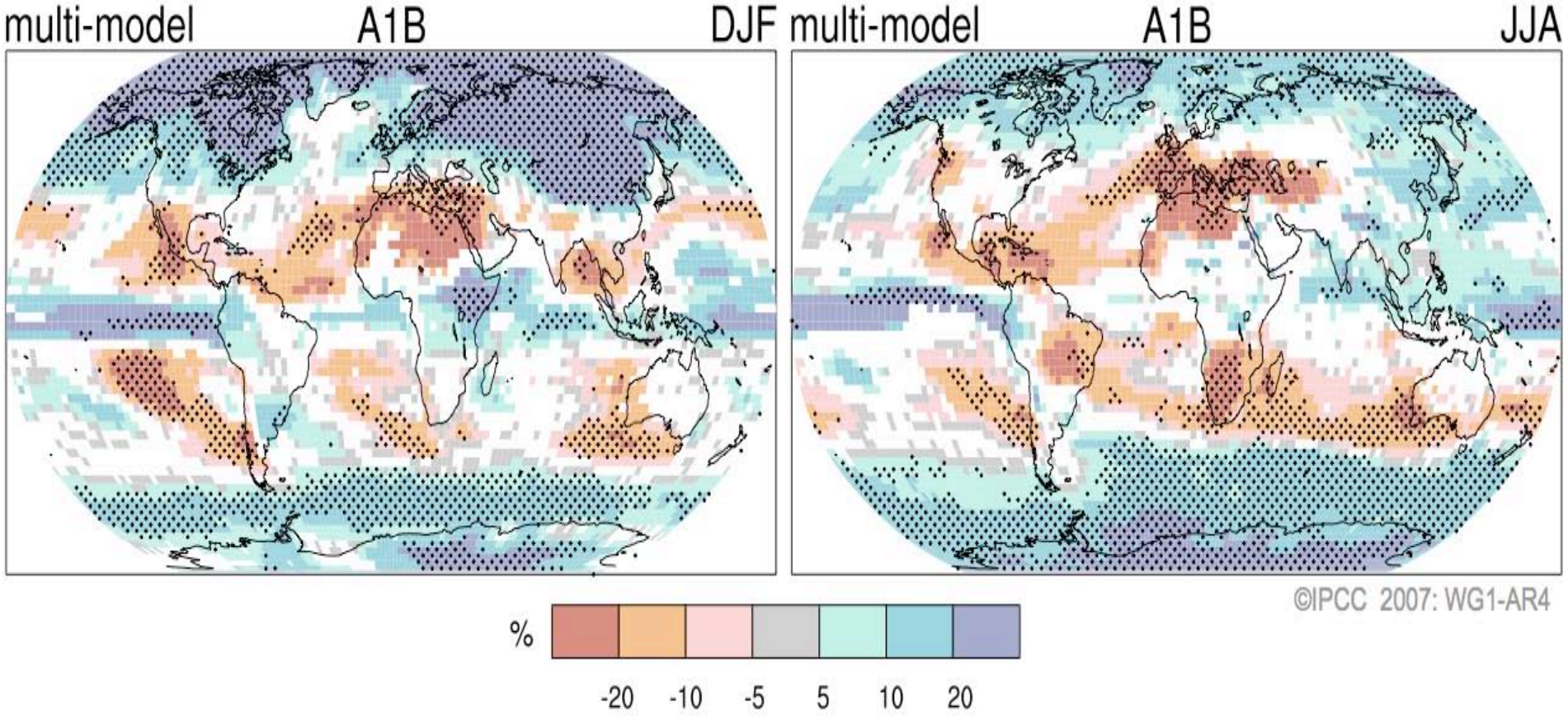
Fourth Assessment Report: 152 lead authors (including 22 coordinating lead authors).

700 author nominations from governments.
25% earned highest degree in last 10 years.
75% were not previous IPCC authors.
35% from developing countries and countries with economies in transition.

# Multi-model Averages and Assessed Ranges for Surface Warming



# Projected Patterns of Precipitation Changes

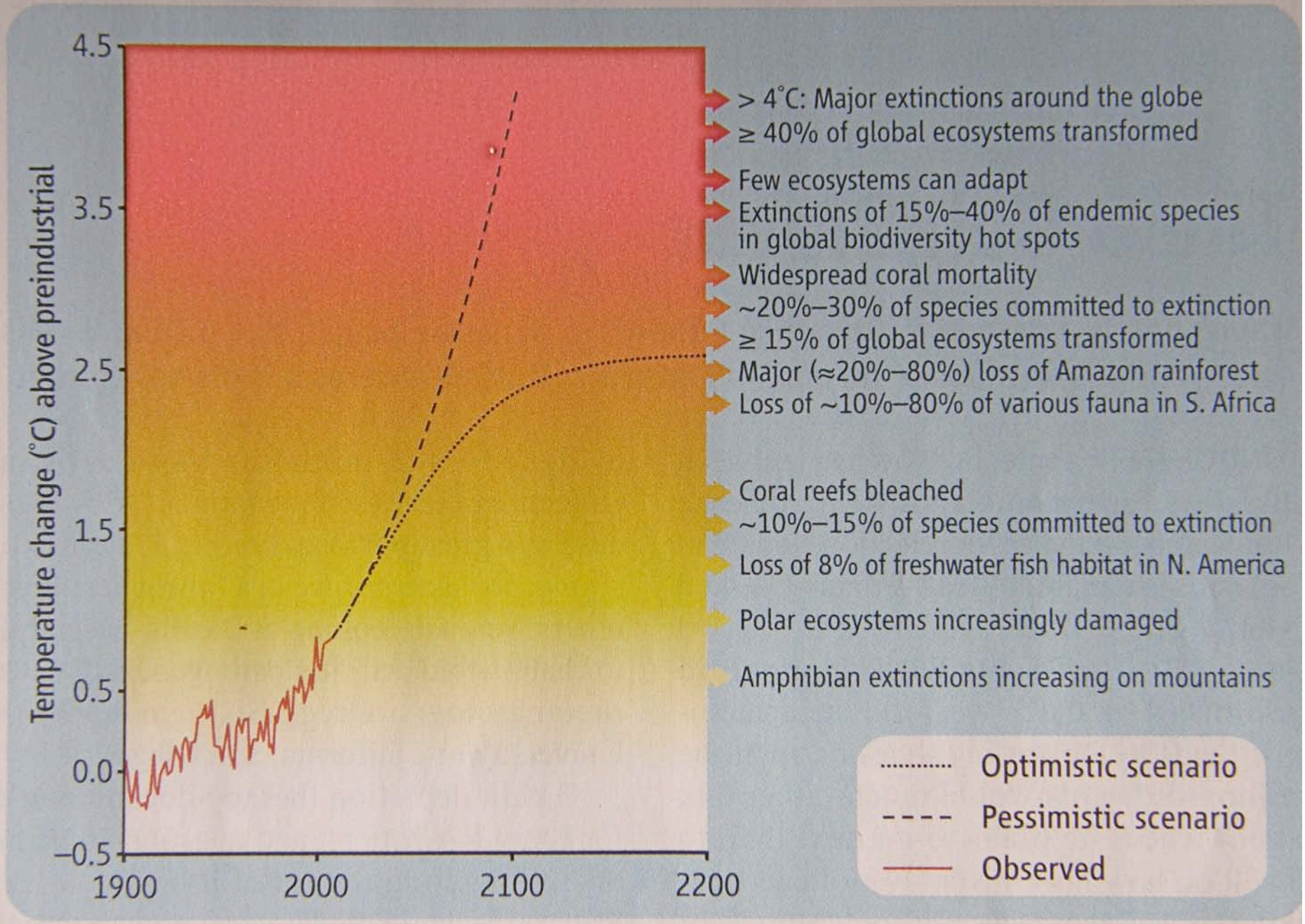


# PROJECTIONS OF FUTURE CHANGES IN CLIMATE

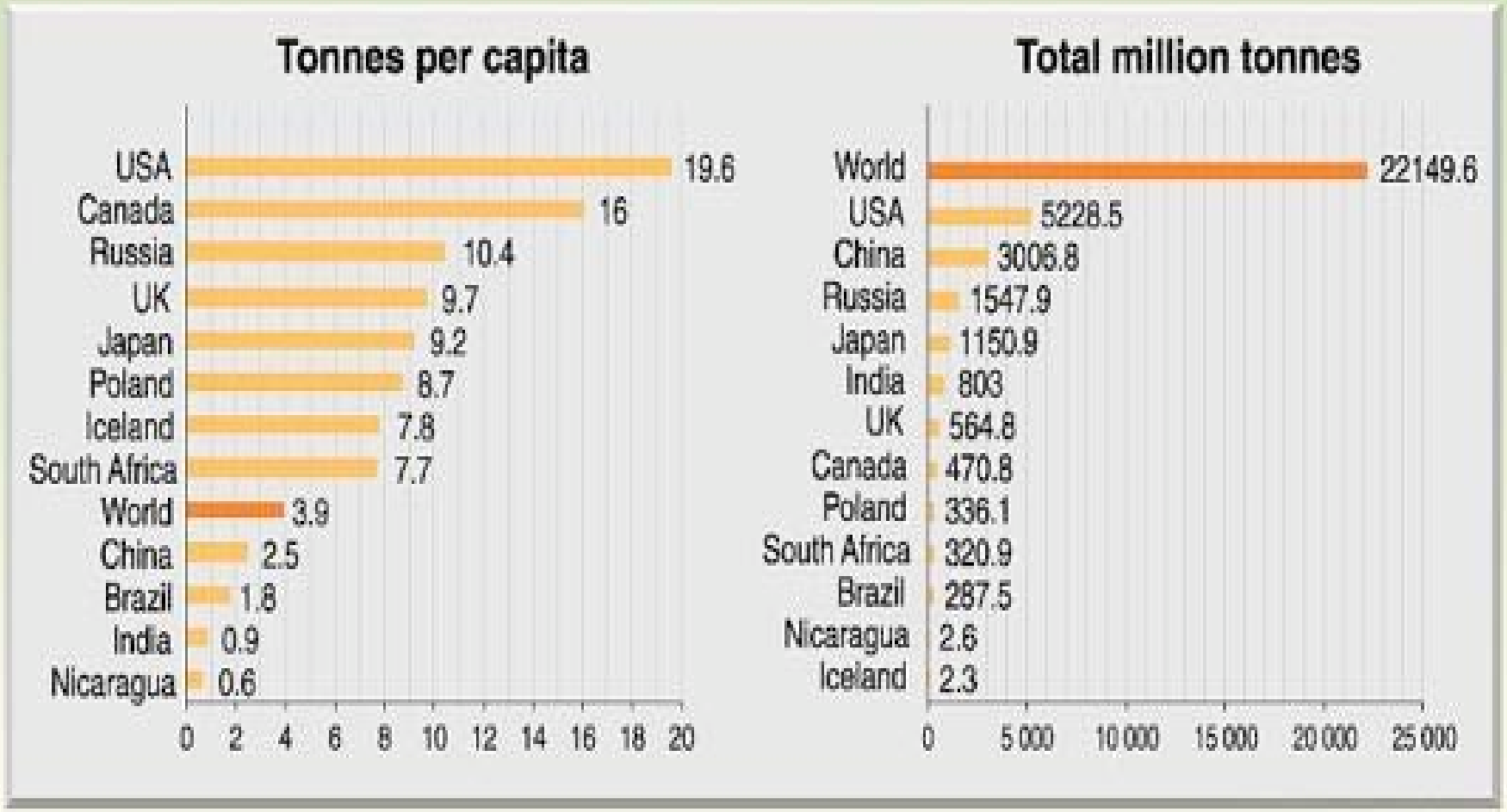
- Snow cover is projected to contract
- Widespread increases in thaw depth most
- permafrost regions
- Sea ice is projected to shrink in both the
- Arctic and Antarctic
- In some projections, Arctic late-summer
- sea ice disappears almost entirely by the
- latter part of the 21st century

# PROJECTIONS OF FUTURE CHANGES IN CLIMATE

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


Temperature change (°C) above preindustrial
4.5
3.5
2.5
1.5
0.5
0.0
−0.5
1900
2000
2100
2200
> 4°C: Major extinctions around the globe
≥ 40% of global ecosystems transformed
Few ecosystems can adapt
Extinctions of 15%–40% of endemic species in global biodiversity hot spots
Widespread coral mortality
~20%–30% of species committed to extinction
≥ 15% of global ecosystems transformed
Major (≈20%–80%) loss of Amazon rainforest
Loss of ~10%–80% of various fauna in S. Africa
Coral reefs bleached
~10%–15% of species committed to extinction
Loss of 8% of freshwater fish habitat in N. America
Polar ecosystems increasingly damaged
Amphibian extinctions increasing on mountains
Optimistic scenario
Pessimistic scenario
Observed

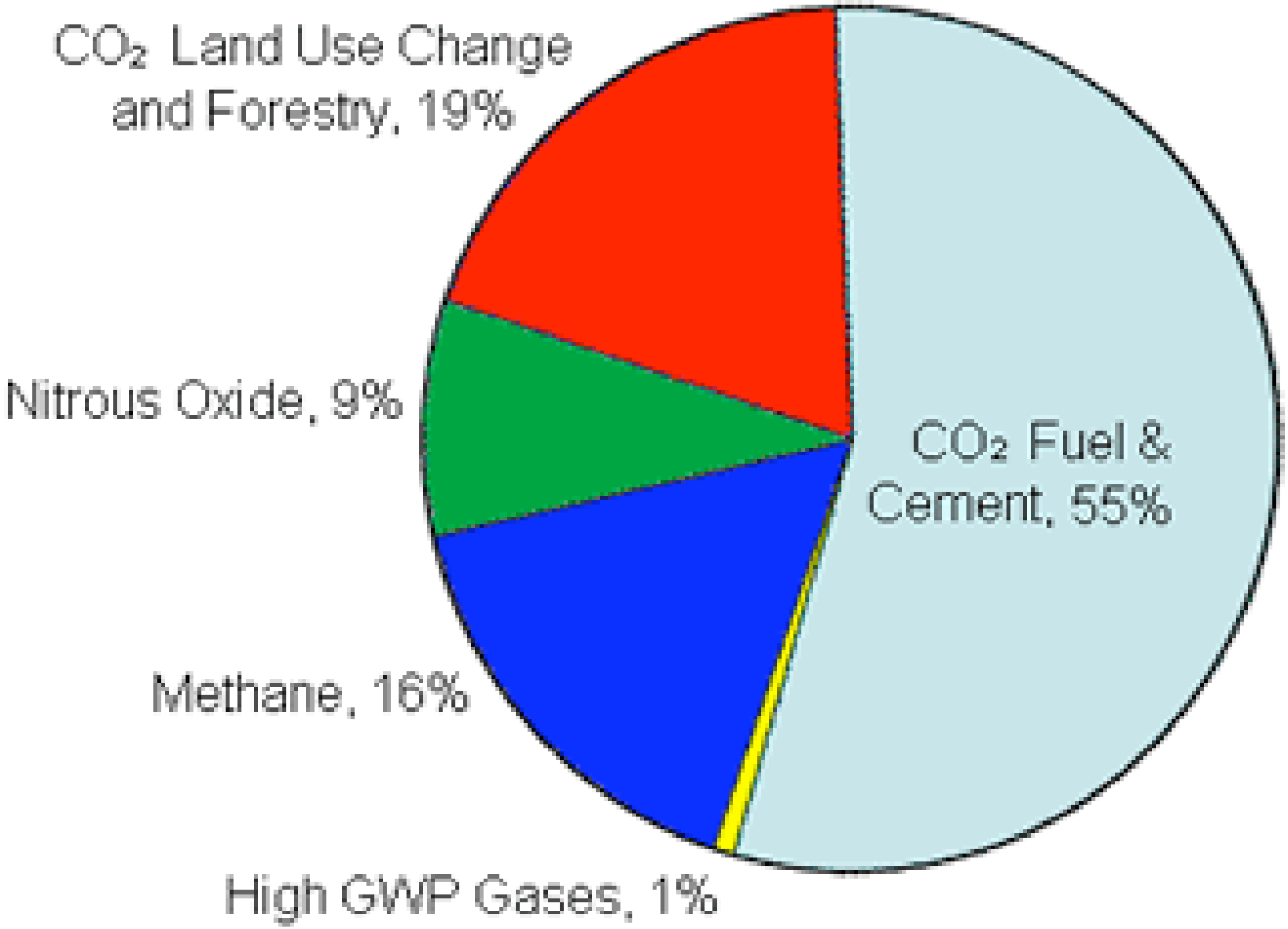
# Emissions of $CO_2$ - selected countries (1995)



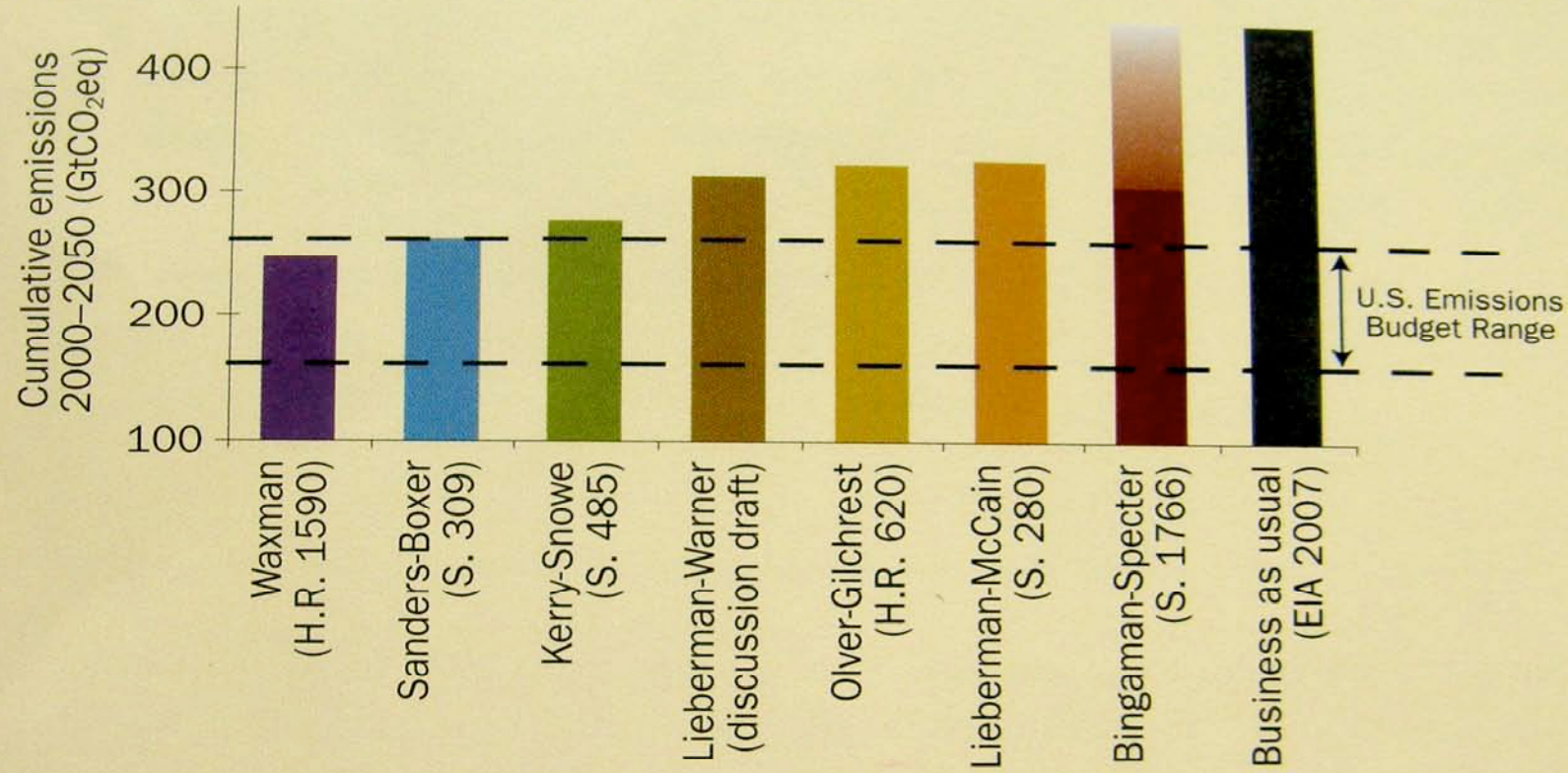

GRID Arendal UNEP

Source : International Energy Agency, 1998.

**Figure 1: Global Greenhouse Gas Emissions 2000**



## Cumulative U.S. Emissions in 2050 under Federal Proposals




**Only two current climate policy proposals (H.R. 1590 and S. 309) would stay within the emissions budget of 160 to 265 $GtCO_2eq$ defined by our analysis, and even these proposals would result in emissions well above the low end of the range. For S. 1766, the potential range of cumulative emissions is provided (the lower portion of the bar represents the best-case scenario assuming all contingencies in the bill occur; the color gradient in the upper portion of the bar represents additional emissions that could occur under other scenarios).**

# Summary

- Warming is real both from instrumental and non-instrumental observations.
- Climate variations are known and largely understood and can be modeled.
- It is likely that current warming exceeds that due to natural variation.
- Computer models do a good job of simulating past and present climate as well as predicting aspects of climate change.
- It is still possible to respond to the threat.