

Climate Change and Global Warming

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**ETP 401 Guest Lecture
University of Virginia
April 12, 2005**

**`The balance of evidence
suggests that there is a
discernible human influence
on global climate`**

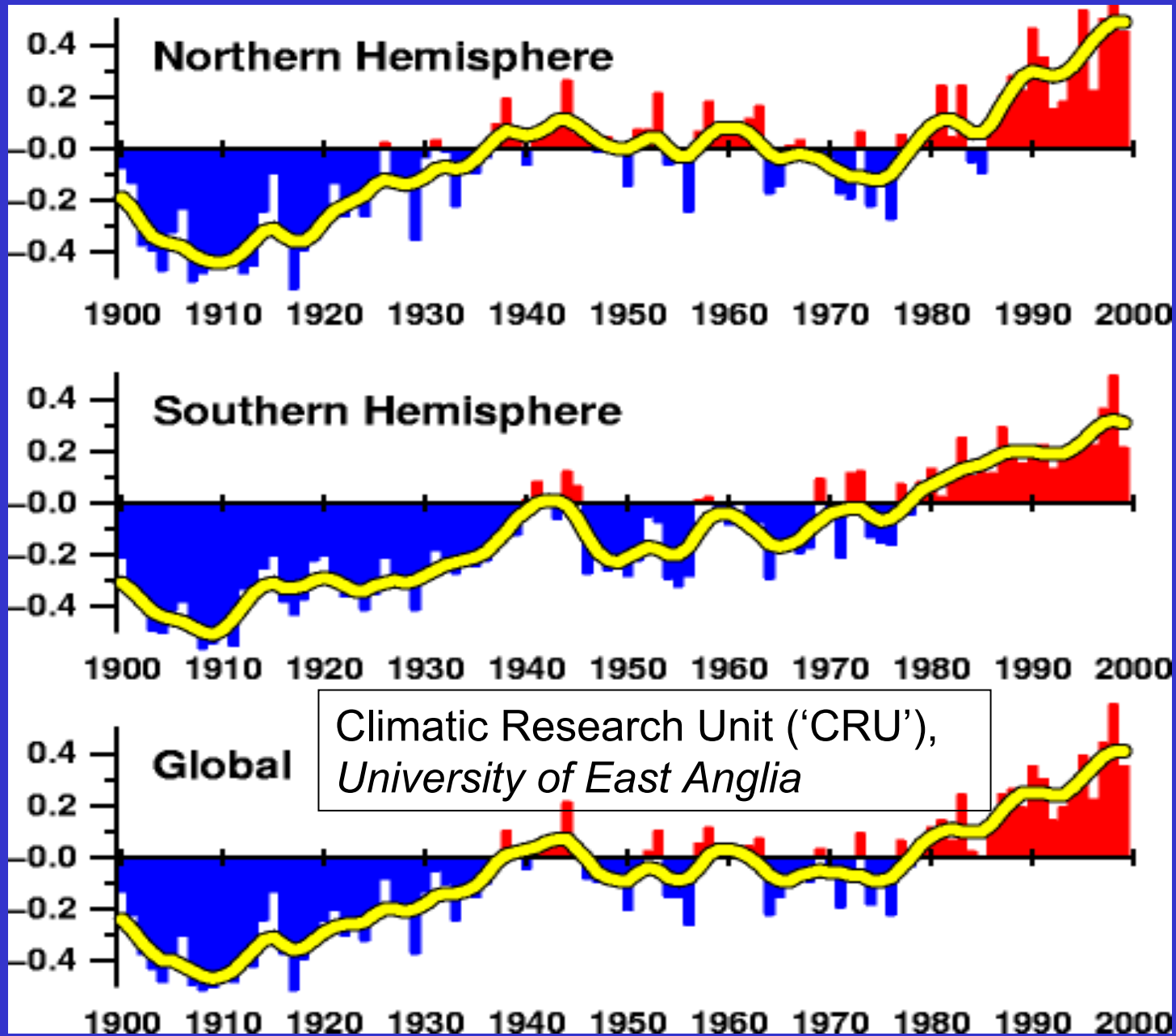
Intergovernmental Panel on Climate Change
(United Nations), Second Assessment Report, 1996

'There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activity'

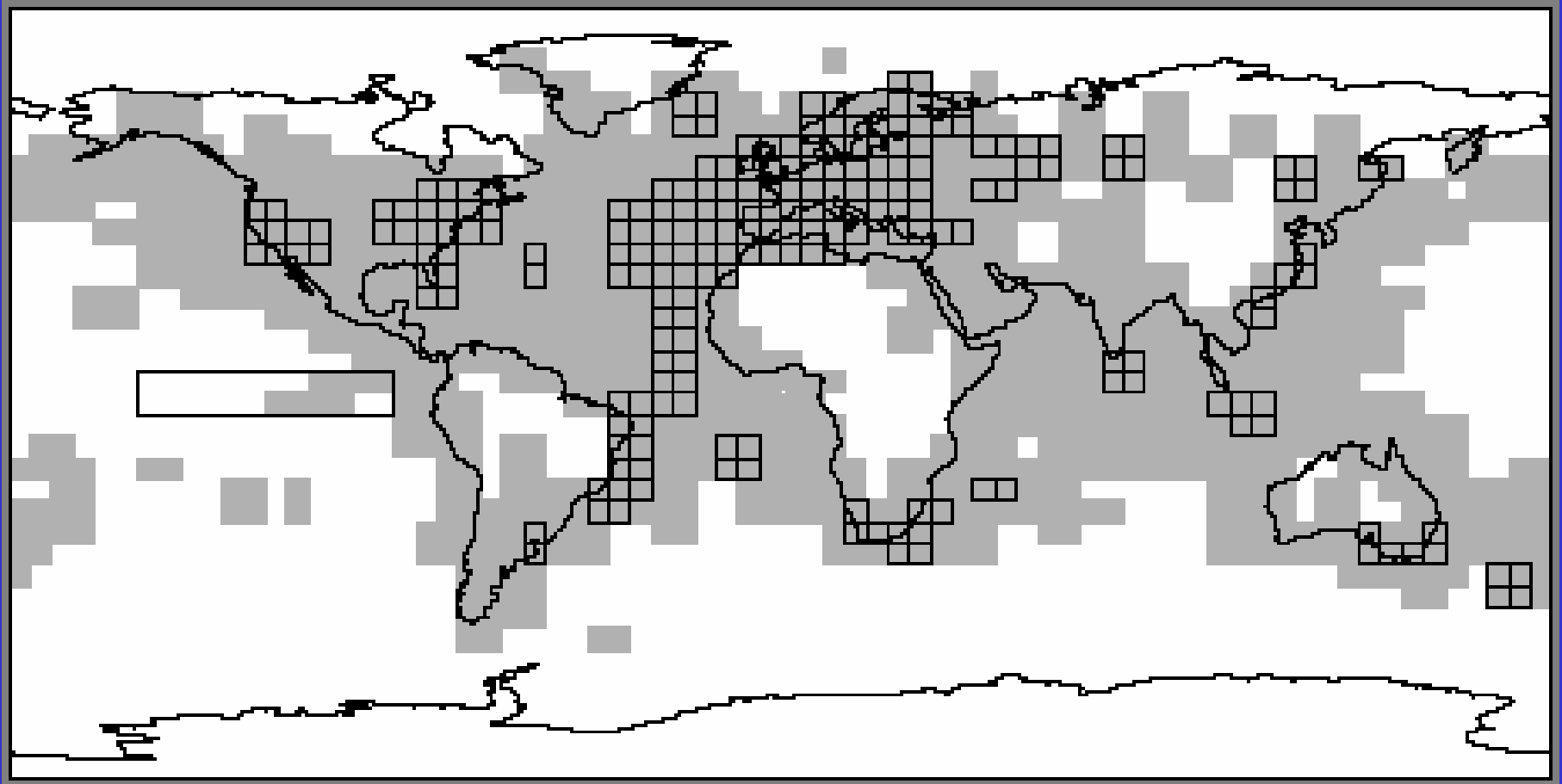
Intergovernmental Panel on Climate Change
(United Nations), Third Assessment Report, 2001

THE EMPIRICAL RECORD

Surface Temperature Changes



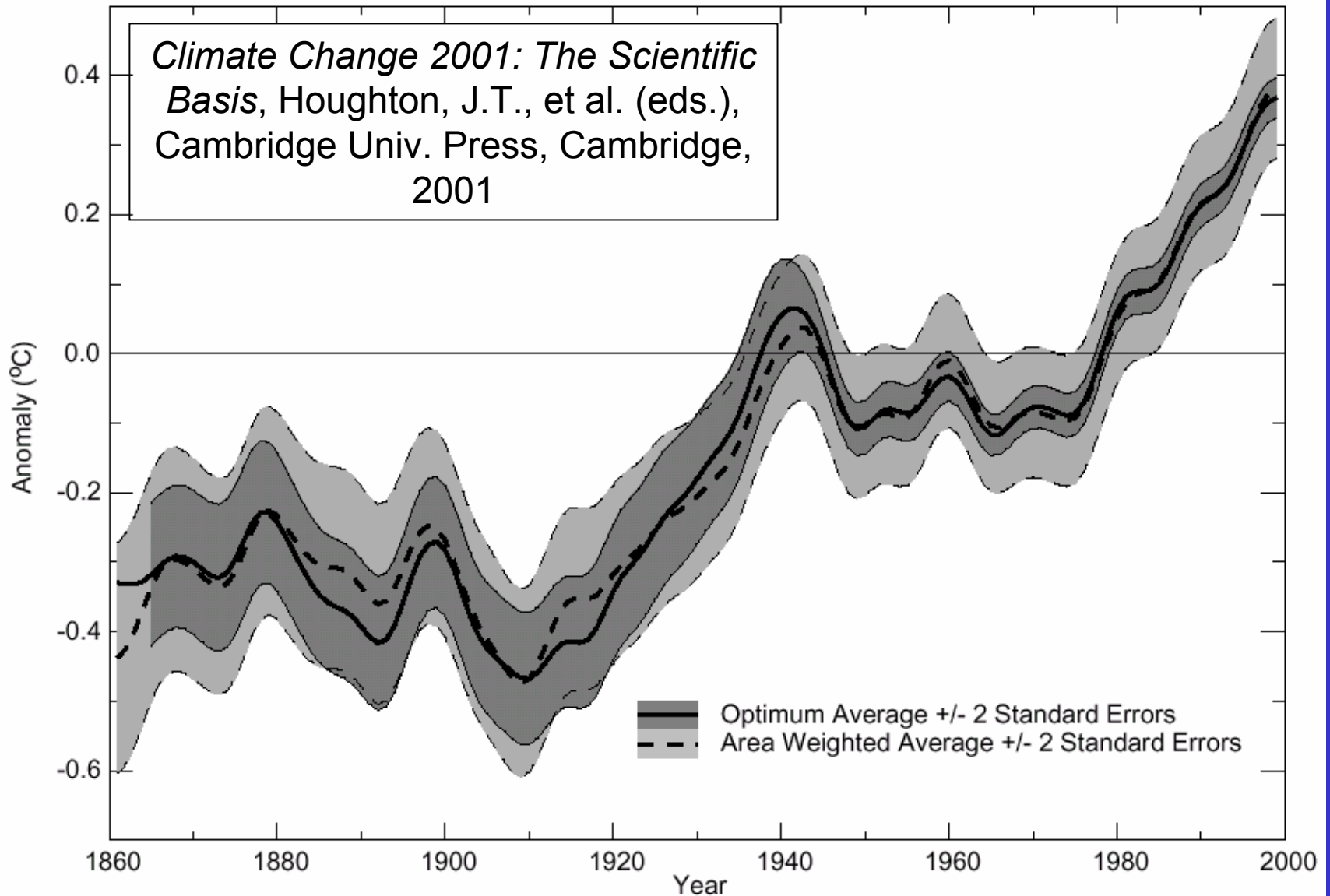
Surface Temperature Changes



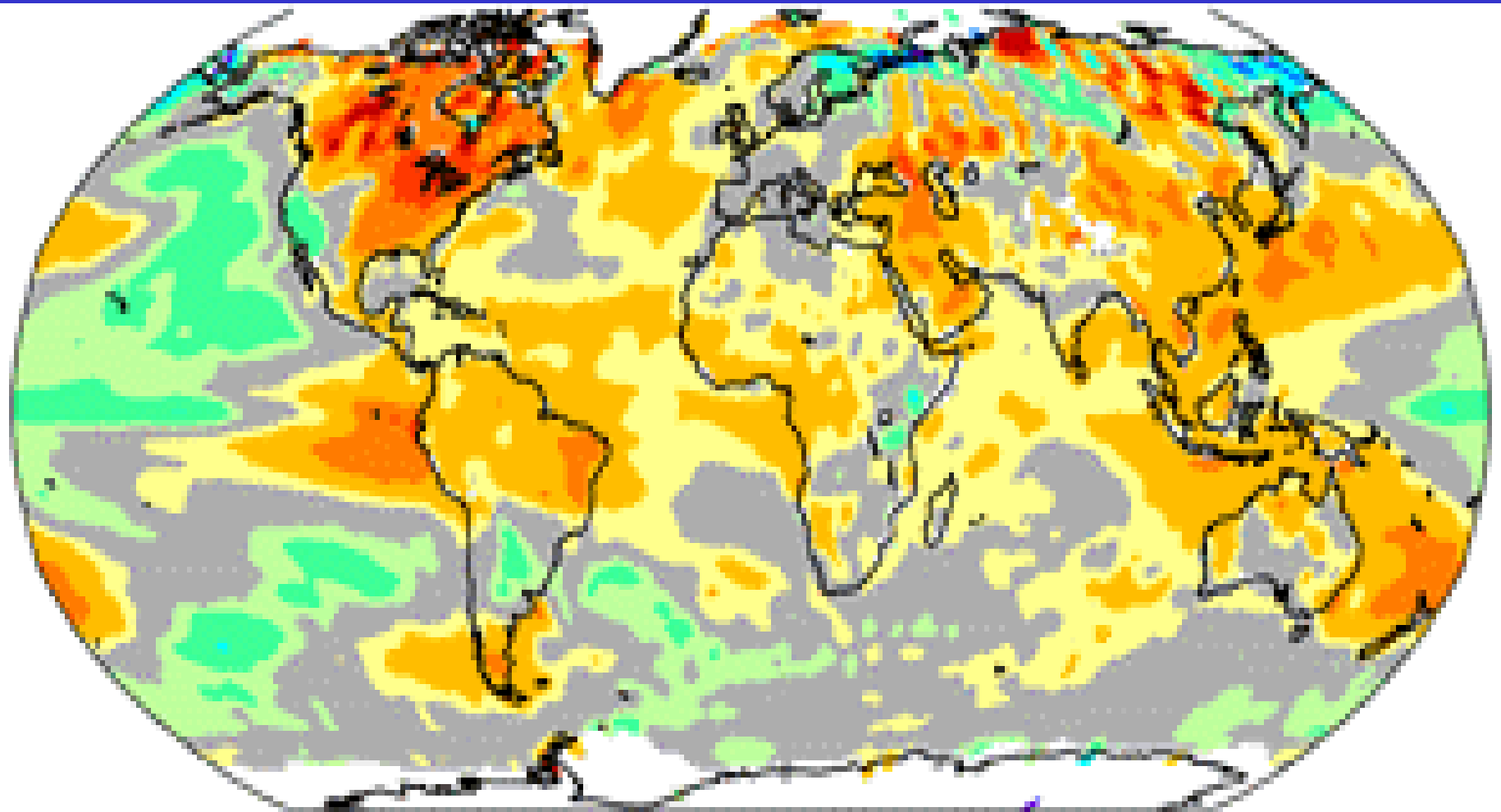
Shaded: 20th century

Boxes: since mid 19th century

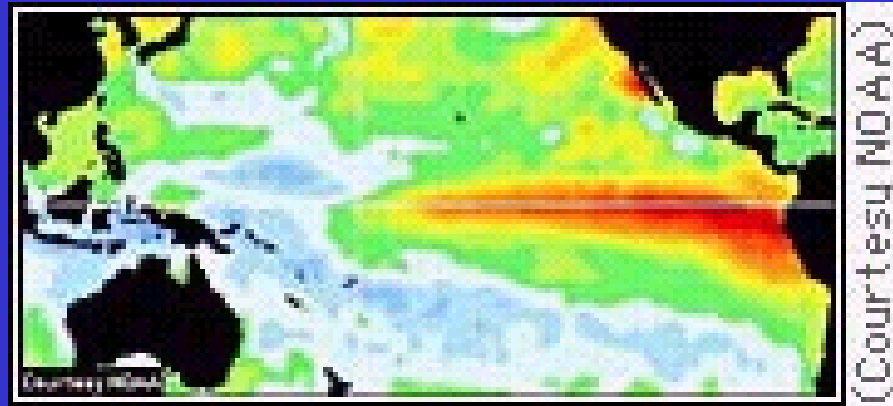
Surface Temperature Changes



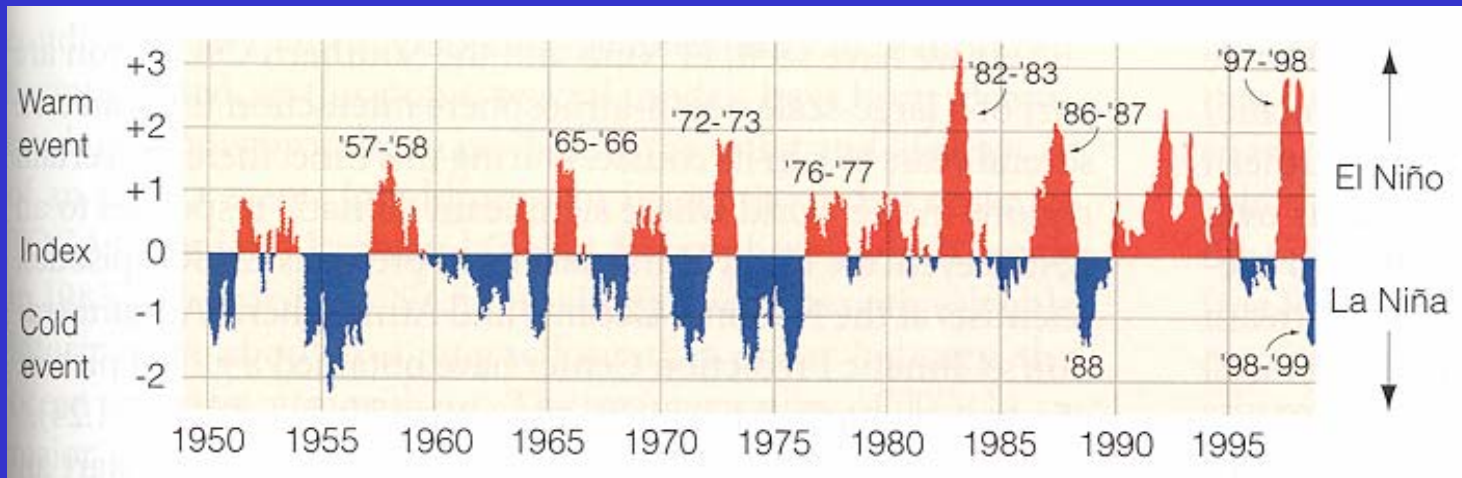
1998 Global Temperature Pattern



EL NINO/SOUTHERN OSCILLATION (“ENSO”)

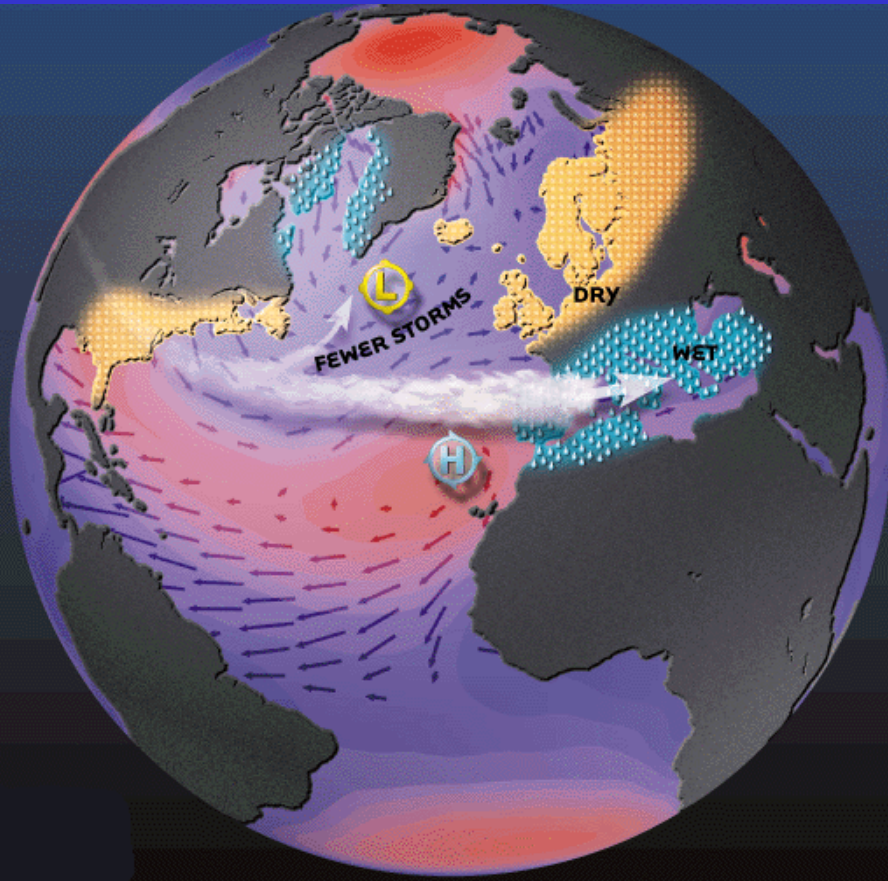


Substantial *interannual* climate variability associated with ENSO, but *decadal* variability is also evident as well. The recent decadal trend towards El Niño conditions *could* be natural or anthropogenic.

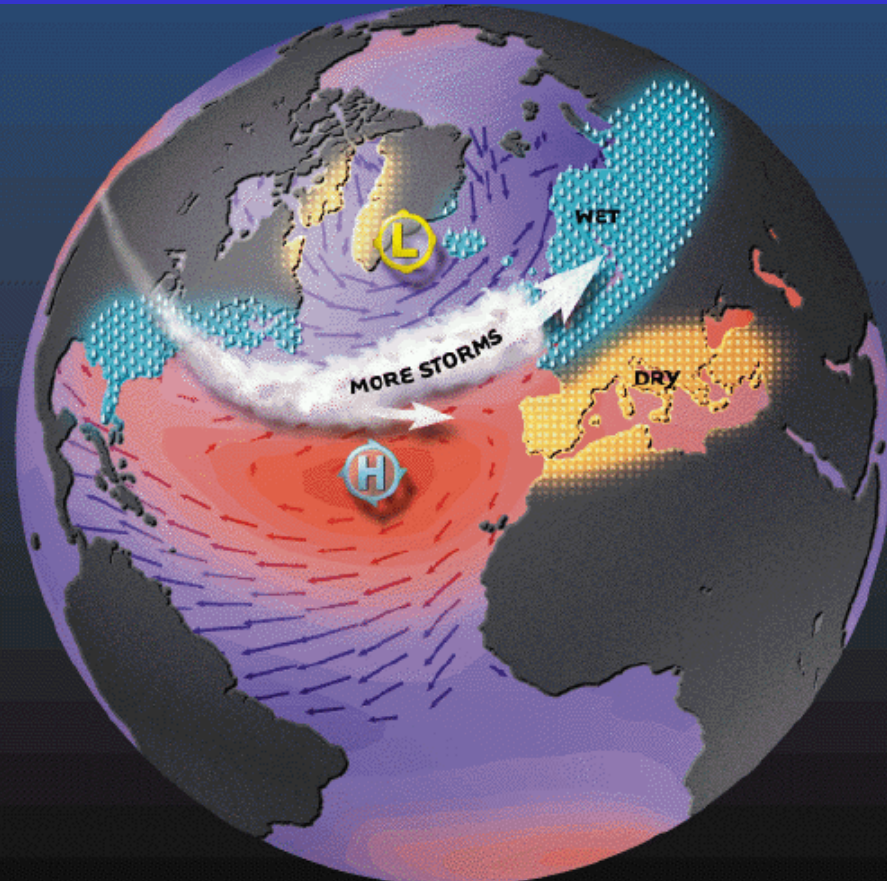


Multivariate
ENSO Index
("MEI")

NORTH ATLANTIC OSCILLATION



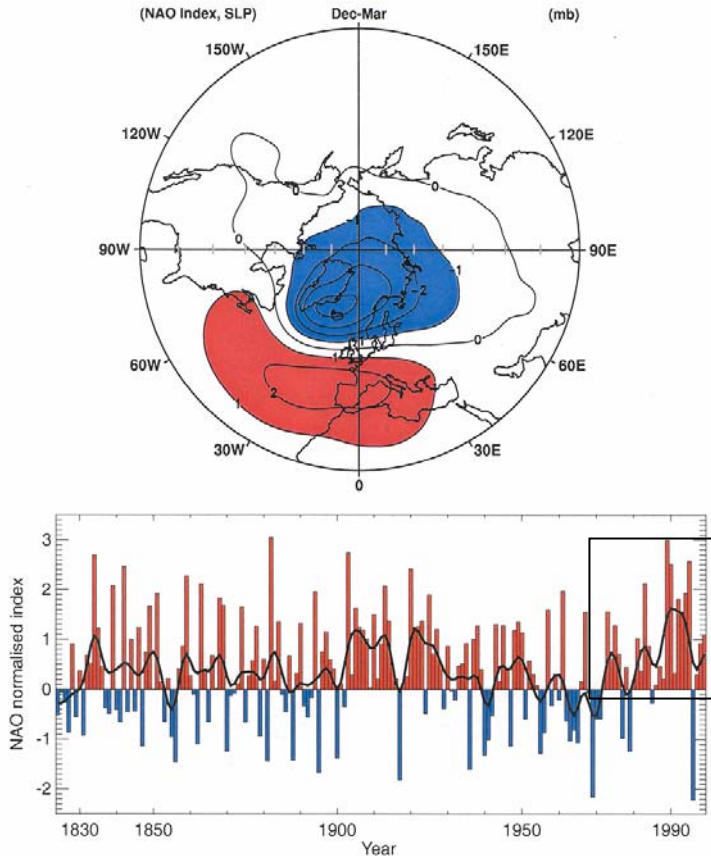
Negative Phase



Positive Phase

NORTH ATLANTIC OSCILLATION

The North Atlantic Oscillation

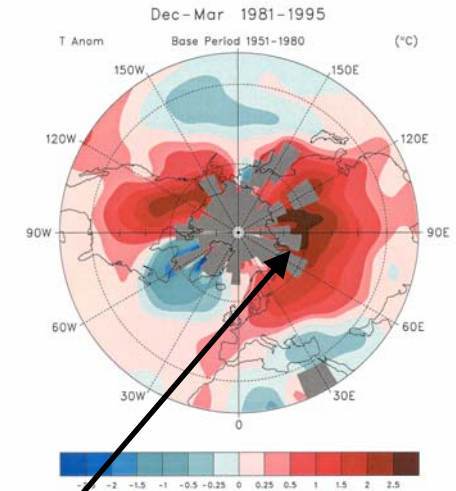


Upper panel: Observed Dec-March change in SLP associated with a 1 standard deviation change in the NAO index (after Hurrell, 1995, Science, 269, 676-679).

Lower Panel: Winter (December to March) index or the NAO based on the difference of normalized pressure between Lisbon, Portugal and Stykkisholmur, Iceland from 1864 to 1995. The SLP anomalies at each station were normalized by division of each seasonal pressure by the long-term mean (1864-1995) standard deviation. The heavy solid line represents the meridional pressure gradient smoothed with a low pass filter with seven weights (1,3,5,6,5,3, and 1) to remove fluctuations with periods less than 4 years (after Hurrell, 1995, Science, 269, 676-679, this version: courtesy of T. Osborn, CRU, UEA).

LB/D1/99-1

Impacts of the NAO

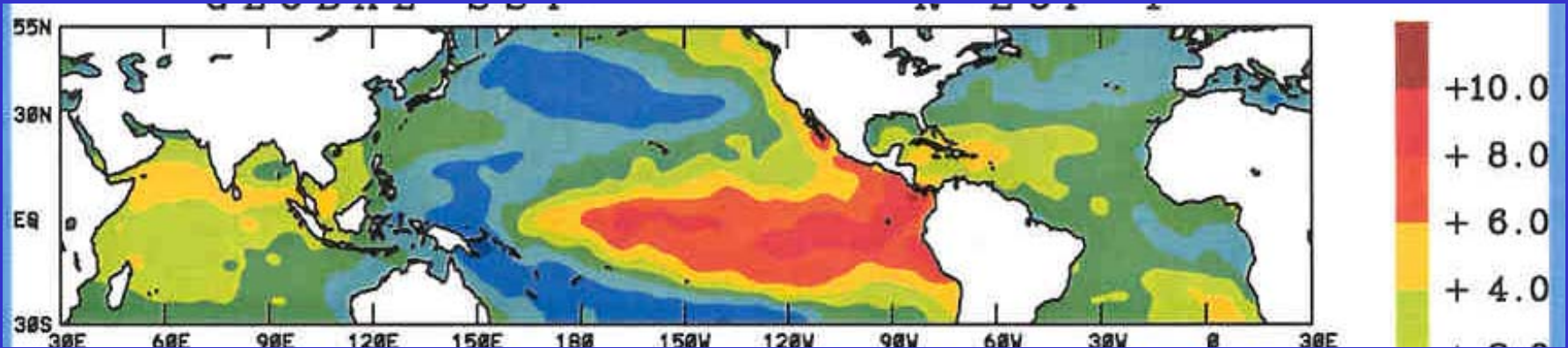


Observed Dec-March surface temperature anomalies associated with a high NAO index; the period 1981-1995, when the NAO was high, relative to the period 1951-1980, when the NAO was low (after Hurrell, 1996). The temperature data consists of land surface temperature blended with SST data (Jones and Briffa, 1992, The Holocene, 2, 174-188).

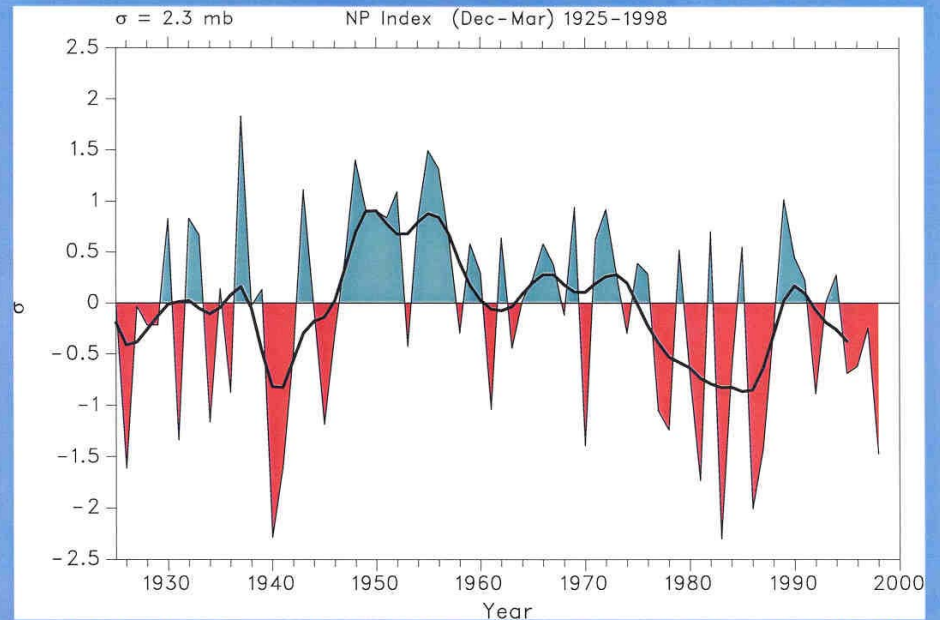
LB/D1/99-5

This NAO trend could be **Anthropogenic**

“PACIFIC DECADAL OSCILLATION”



Decadal Variability in the Pacific - The North Pacific Mode -



The North Pacific (NP) Index is the area-weighted sea level pressure over the region 30°N-65°N, 160°E-140°W and shows a high level of decadal time scale variability (after Trenberth and Hurrell, 1994, *Climate Dynamics*, 9, 303-319).

Atlantic Multidecadal Oscillation

Main Currents in the North Atlantic

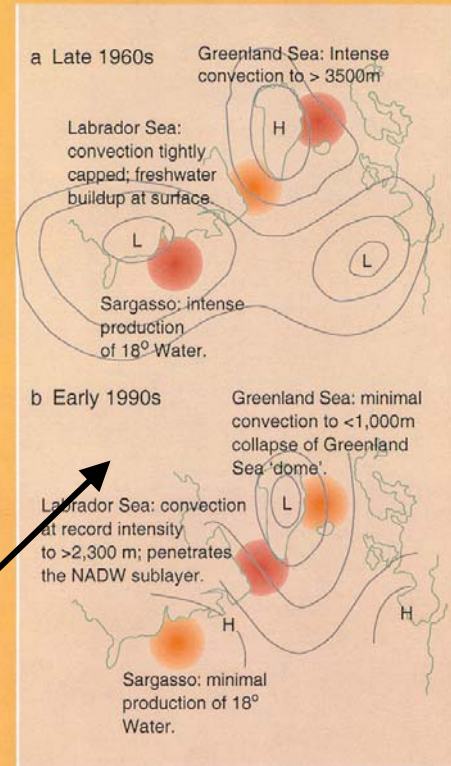


An oceanic roundabout. As warm ocean currents in the subpolar gyre gradually cool, they warm Europe and may trigger seesaws in climate (McCartney et al., 1996, *Oceanus*, 39, 19-23).

AV/D3/99-4

There is evidence of multidecadal natural variability in the North Atlantic ocean circulation

The Thermohaline Circulation and the NAO - A coupled Phenomenon ? -

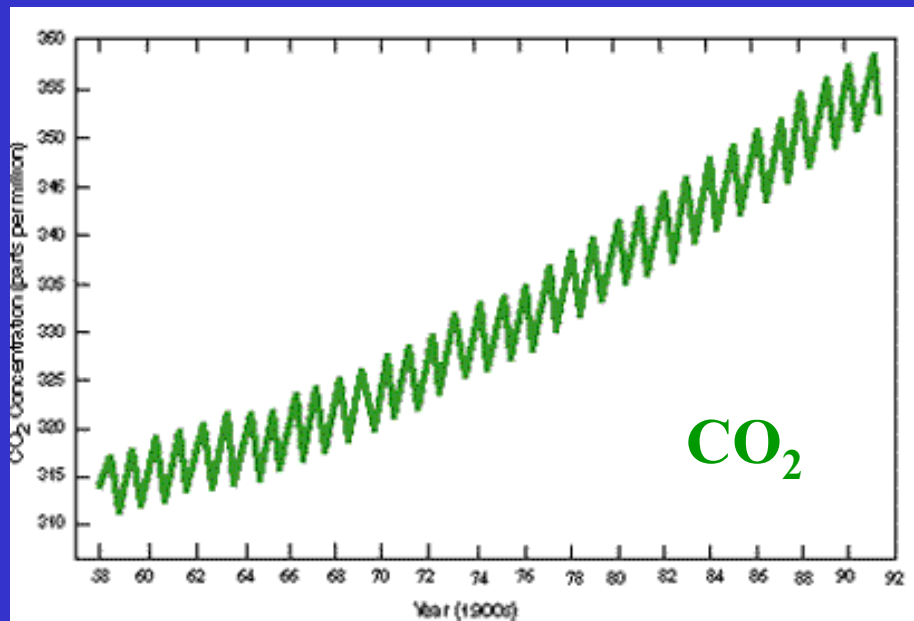


Depiction of the changes in the distribution of winter convective activity in the North Atlantic during contrasting extreme states of the North Atlantic Oscillation (NAO). The main convective centres are in the Greenland, Labrador and Sargasso Seas.

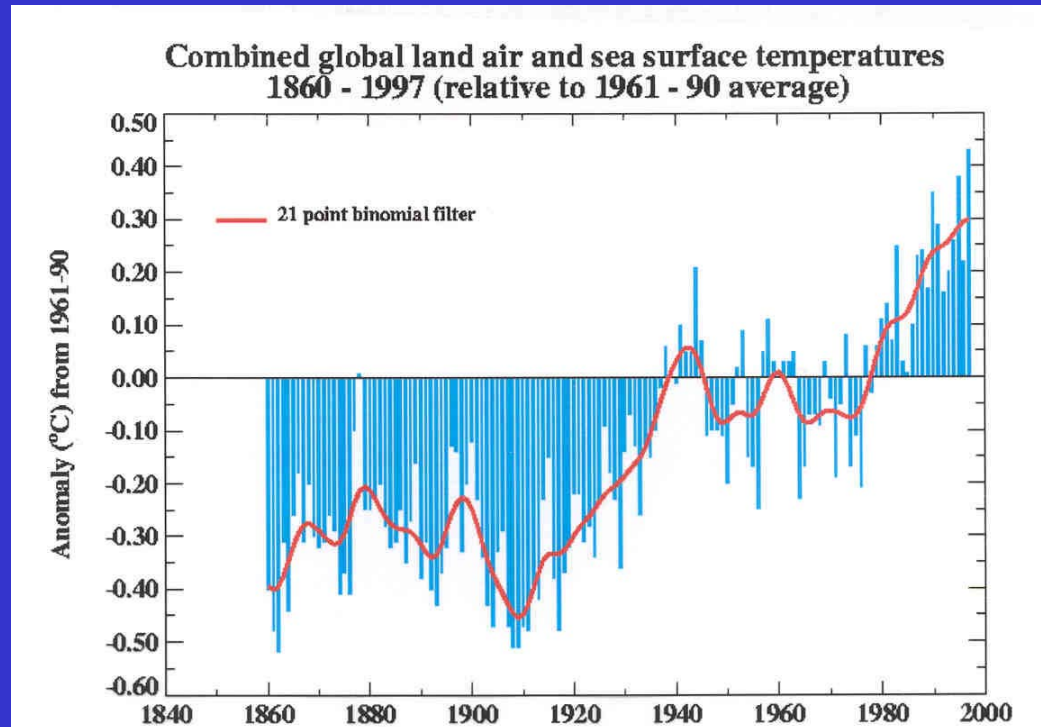
a) Represents the 'low-index' NAO conditions of the late 1960s; b) the 'high-index' state of the early 1990s. A representative mean pressure anomaly field is indicated for each case. 'Mode waters' are formed in winter at each of the three sites, are vertically homogeneous, and through horizontal spreading provide a mechanism for carrying the signal of climate change throughout the North Atlantic basin. '18° Water' is the mode water of the Sargasso Sea. NADW is North Atlantic Deep Water. The Greenland Sea 'dome' is the place where a cyclonic basin circulation brings dense water closest to the surface, promoting convective instability (Dickson R., 1997, *Nature*, 386, 649-650)

AV/D3/99-1

Greenhouse Gases and Warming



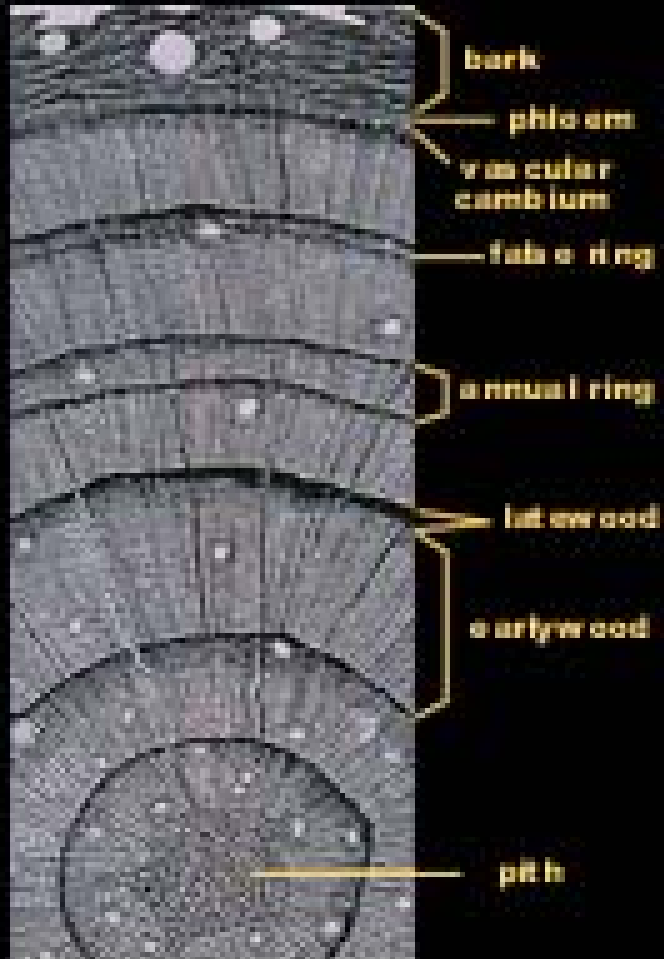
Related?



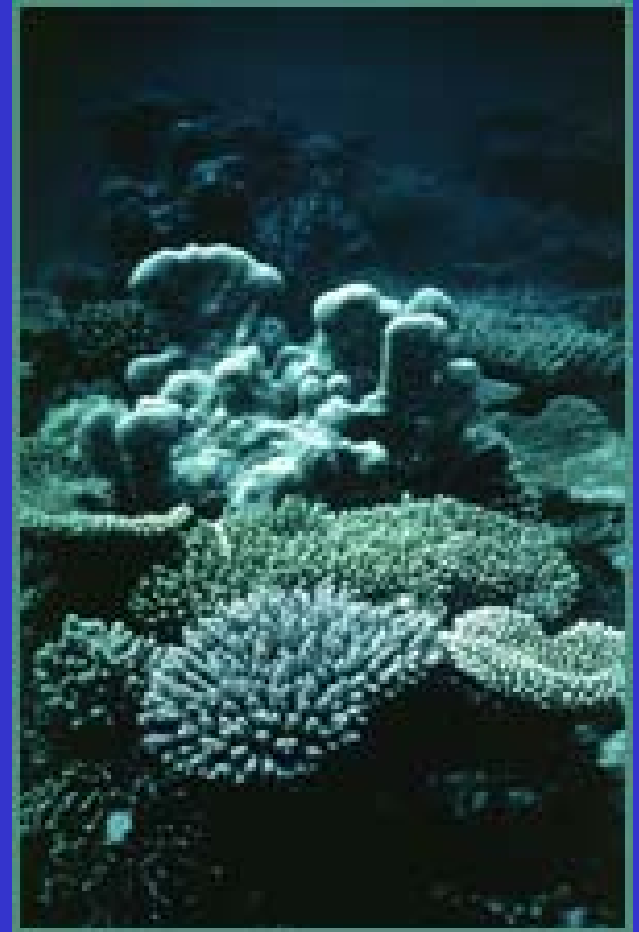
TREE RINGS



Cross Section of a Conifer



CORALS



ICE CORES



VARVED LAKE SEDIMENTS



HISTORICAL DOCUMENTS

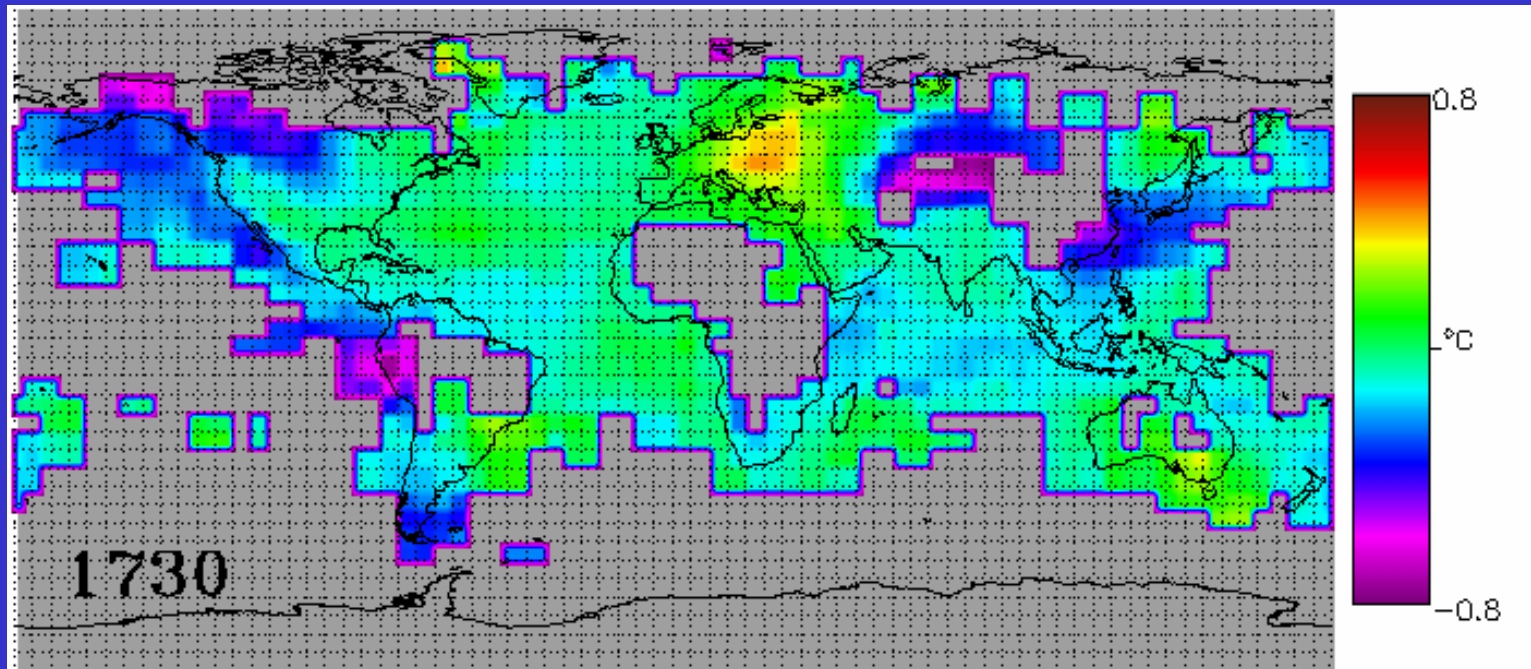
Quicenna.

Manch ghtre leer wyl ich dir gäben/
 Den volg nach/frischt dir din läben.
 In Jenner din bidt thalt by dir/
 Doch vff dem Dum mugst lassen schter.
 Vnd denn hinnach wol nemmen acht/
 Was dir all Monat dinges krafft.

1 gar quic bale vñ edigien lach daz
 2 gar quic bale noch mit tag lach in glanz
 3 vñ d' bale vñ vñ d'el ma. gaus. darnach lach lach
 4 vñ d' bale vñ d'el ma. gaus. darnach lach lach
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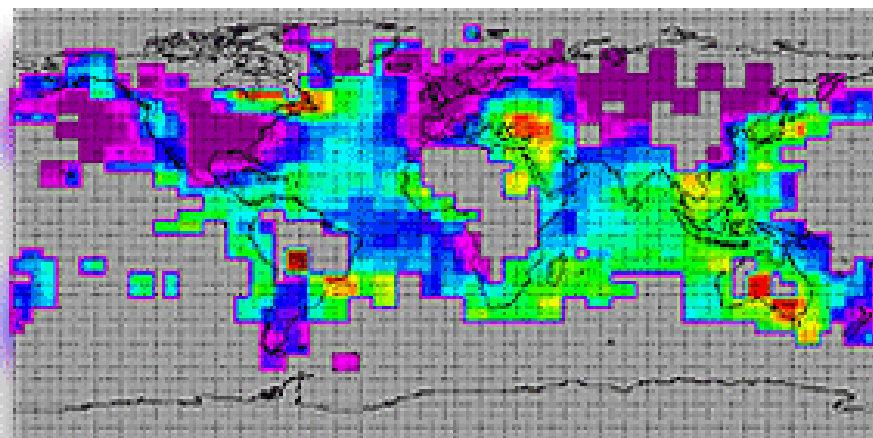


FROST FAIR ON THE THAMES IN THE REIGN OF CHARLES II.

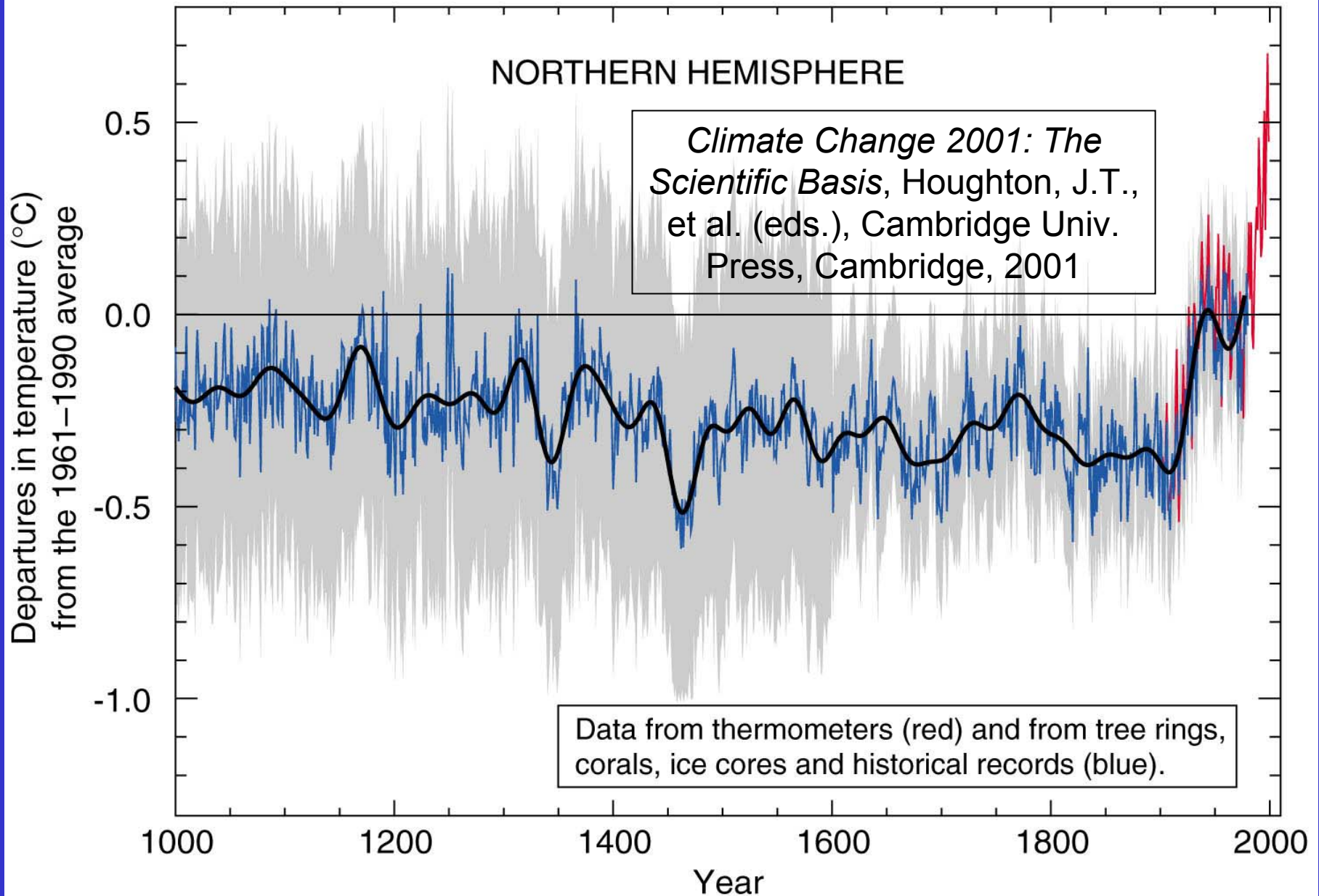


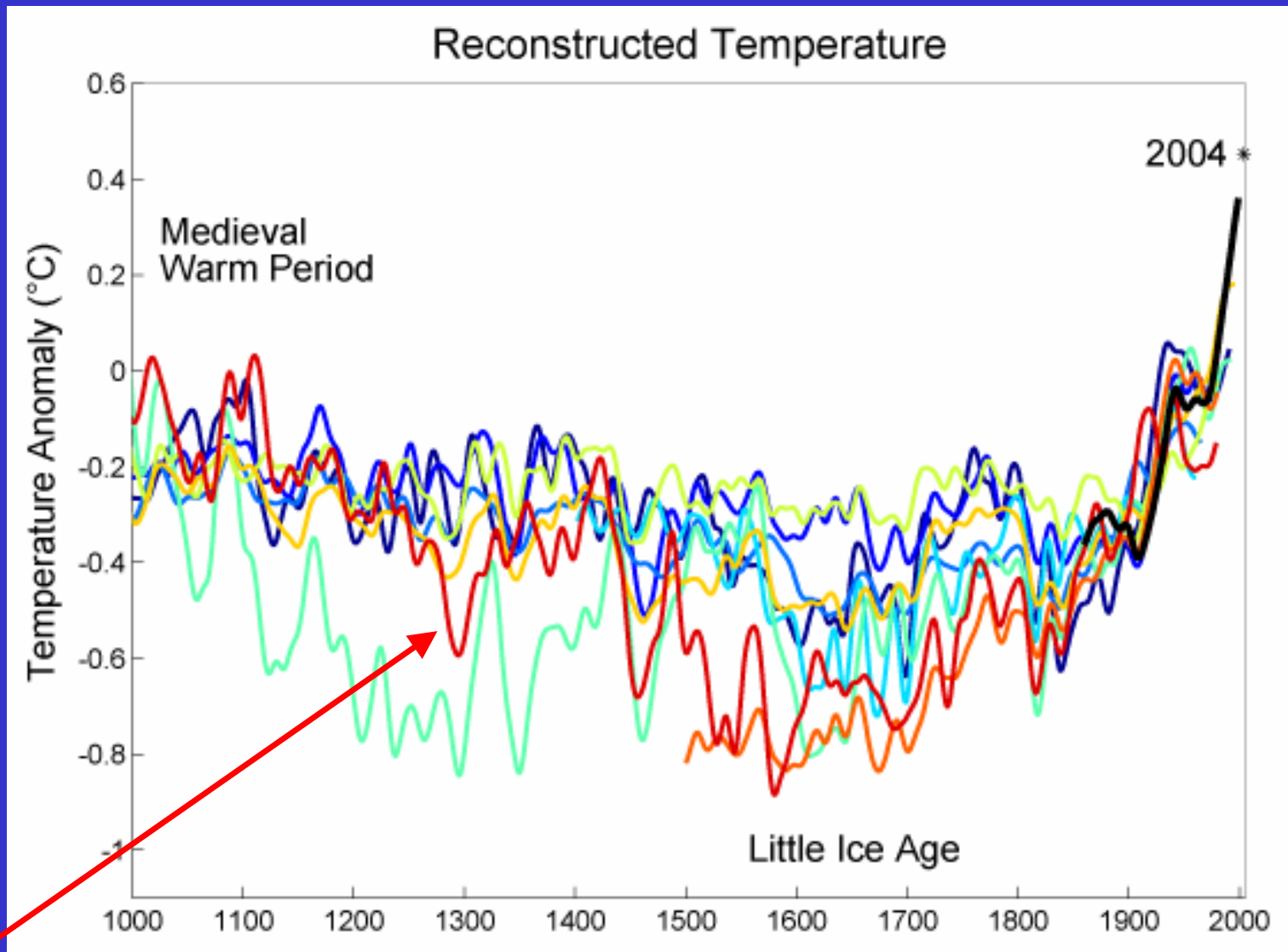
RECONSTRUCTED
GLOBAL
TEMPERATURE
PATTERNS

1816
("A Year Without A Summer")

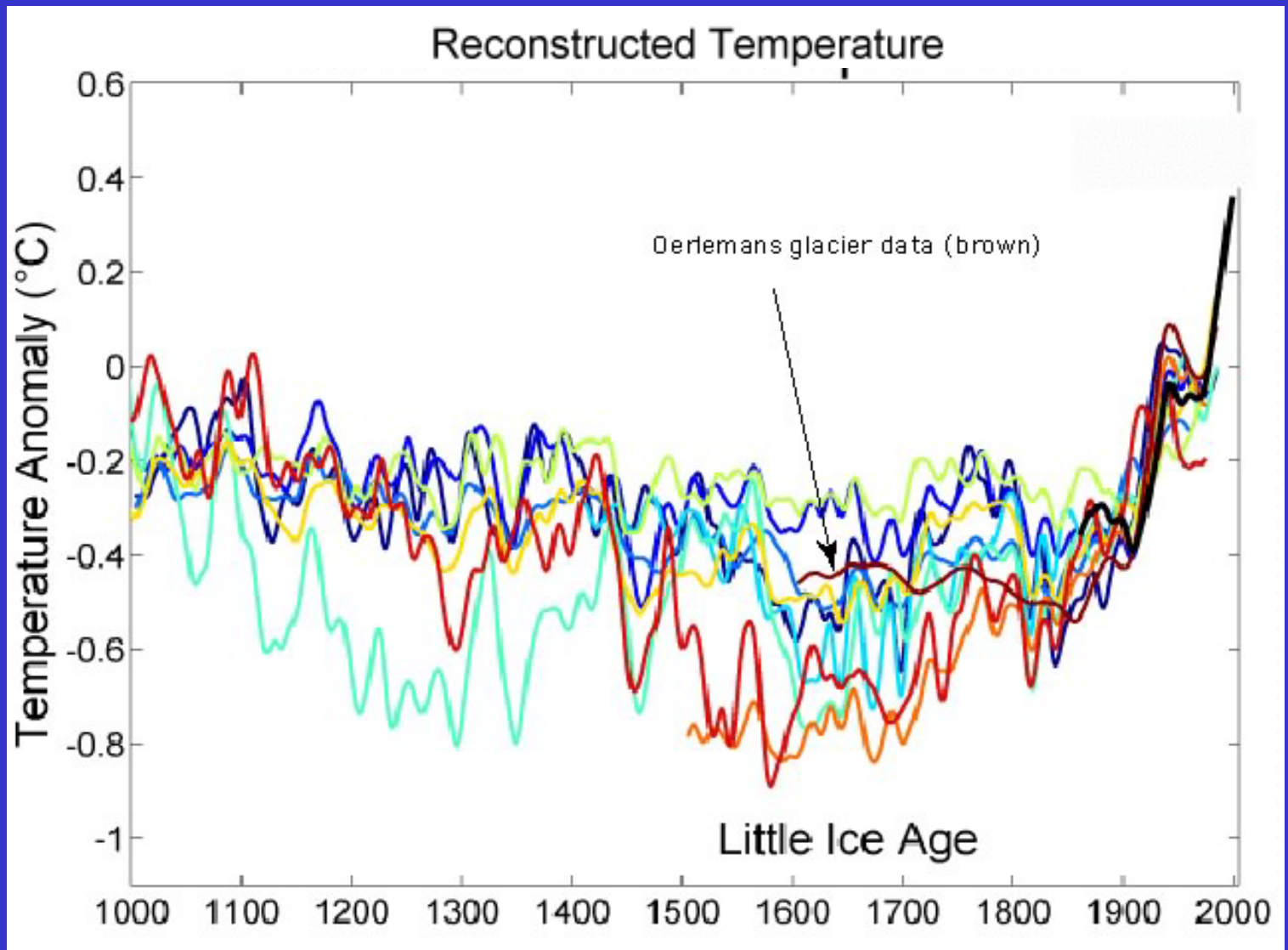


Reconstructed Surface Temperatures





Moberg, A., Sonechkin, D.M., Holmgren, K., Datsenko, N.M., Karlen, W.,
Highly variable Northern Hemisphere temperatures reconstructed from low-
and high-resolution proxy data, *Nature*, 433, 613-617 (2005).



Oerlemans, J., Extracting a climate signal from 169 Glacier Records, *Science (express)*, March 3 (2005).

The Fates of Low-Latitude Glaciers

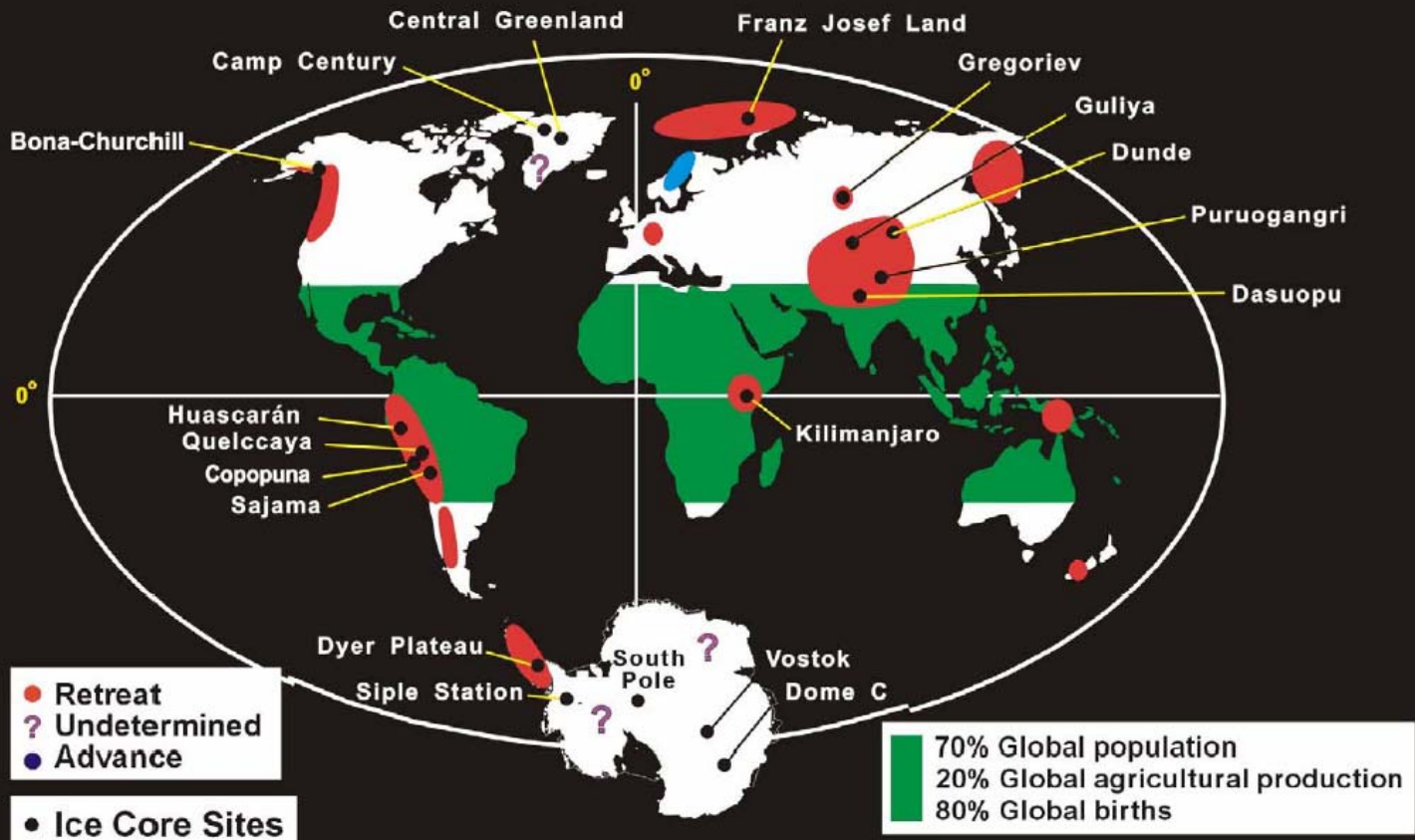
Lonnie G. Thompson

The Ohio State University

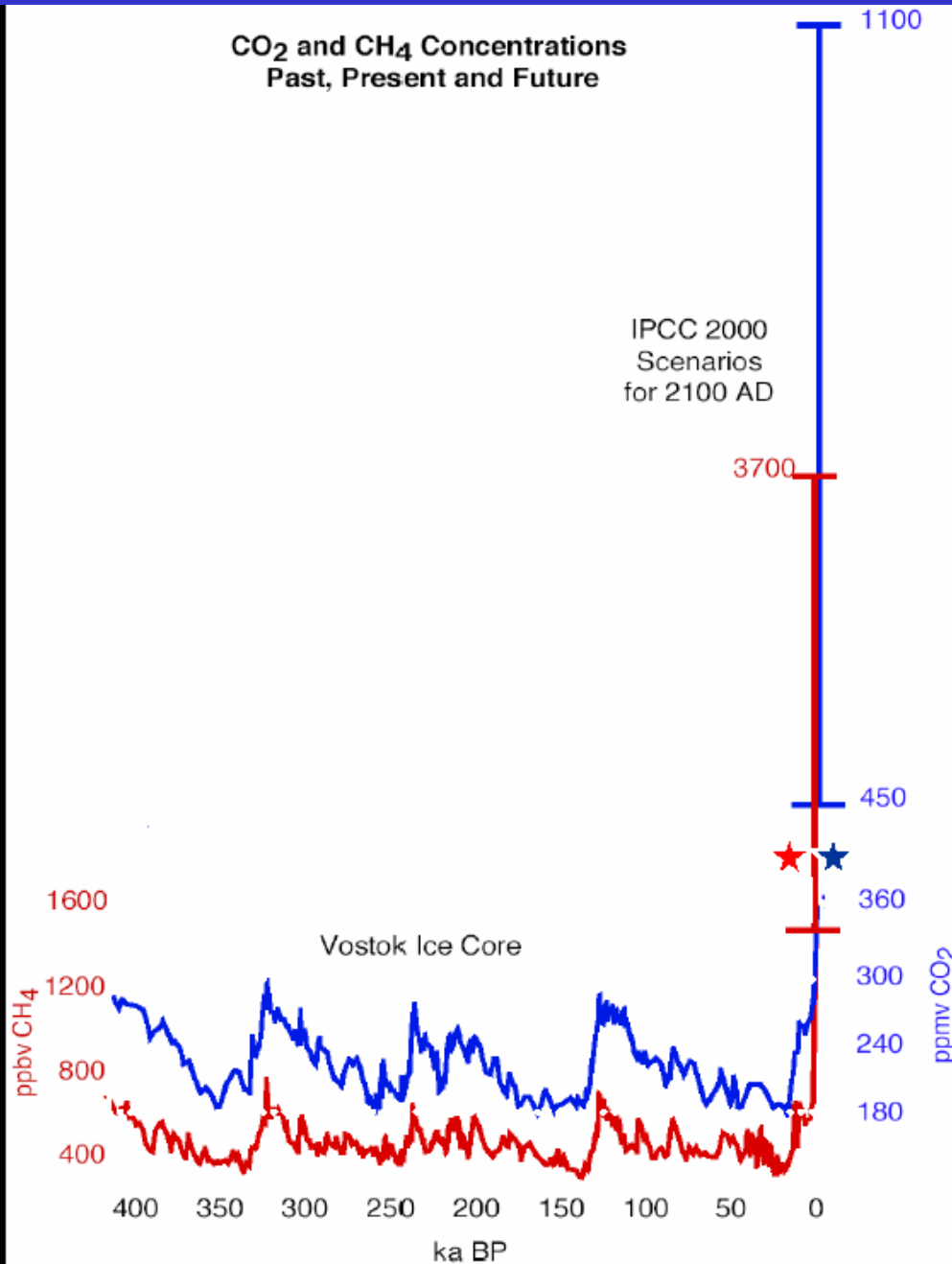
Ice Core Paleoclimate

Research Group

20th Century Changes in Ice Cover



CO₂ and CH₄ Concentrations Past, Present and Future

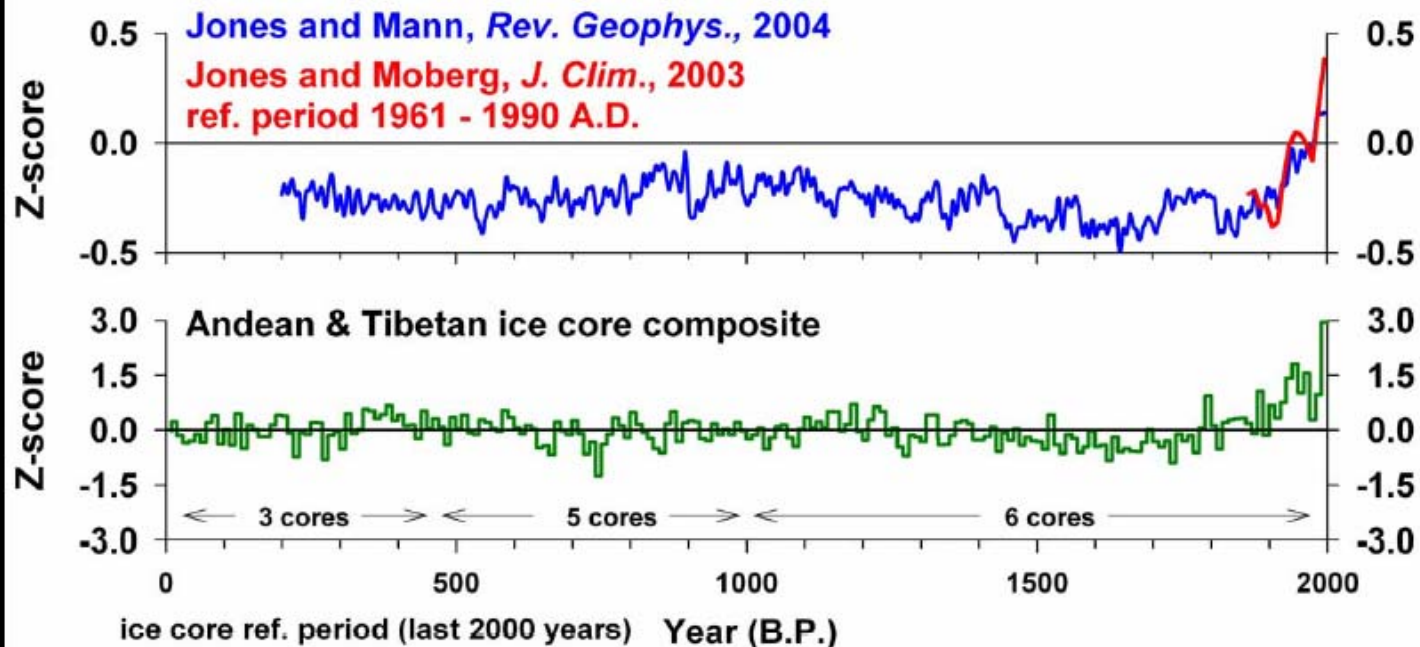
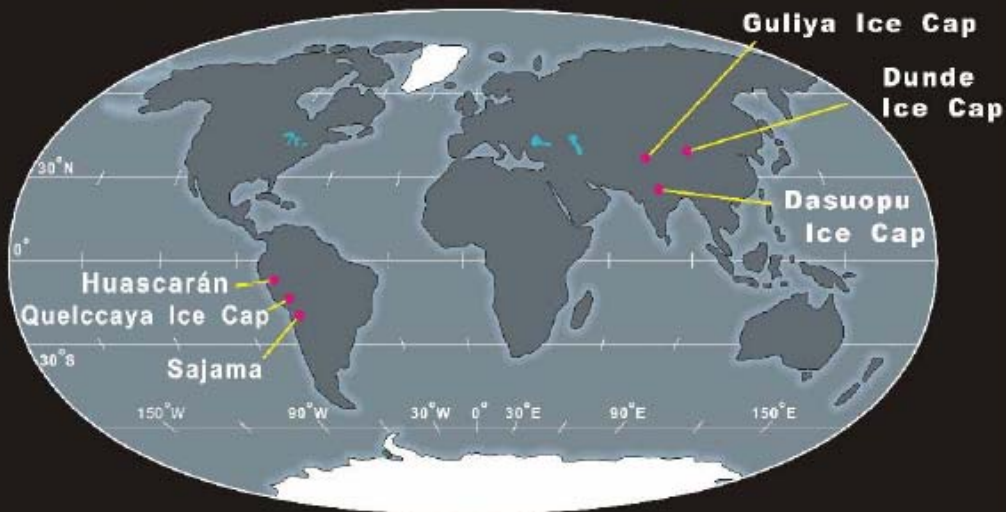


In 2100:
CO₂ ~ 1100 ppmv

2100:
CH₄ ~ 3750 ppbv

Houghton et al., 2001

Cores Used in the Ice Core Composite Record



Ice core data for last 1000 years (Thompson et al., *Climatic Change*, 2003)

1977

Quelccaya Ice Cap, Peru

2002



**Quelccaya
Ice Cap, 2002**

**200 – 400 m
above its
modern range**



Plant

Quelccaya Ice Cap, 2002

200 – 400 m
above its
modern range



← Plant

Radiocarbon dates of plants from base of Quelccaya Ice Cap

	¹⁴ C age	Error (+/-)	Calibrated age (Before 1950 A.D.)	Relative area under probability distribution
Lawrence Livermore National Laboratory				
Sample 1 First run	4470	60	5284-5161 (1σ) 5302-4961 (2σ)	.534 .926
Sample 1 Second run	4525	40	5186-5121 (1σ) 5311-5047 (2σ)	.413 1.000
Sample 2 First run	4530	45	5186-5120 (1σ) 5317-5040 (2σ)	.396 .993
Sample 2 Second run	4465	40	5278-5171 (1σ) 5295-4967 (2σ)	.580 .984
National Ocean Sciences AMS Facility at Woods Hole Oceanographic Institution				
Sample 1	4530	45	5186-5120 (1σ) 5317-5040 (2σ)	.396 .993
Sample 2	4510	40	5188-5119 (1σ) 5307-5040 (2σ)	.404 .988

Glacier National Park, Grinnel Glacier



Photo: Fred Kiser, Glacier National Park archives



Photo: Karen Holzer, US Geological Survey

Glacier National Park, Boulder Glacier



Photo: George Grant, Glacier National Park archives



Photo: Jerry DeSanto, National Park Service

Source: *BioScience*, Vol. 53 No. 2, Feb 2003

McCall Glacier, Brooks Range, Alaska

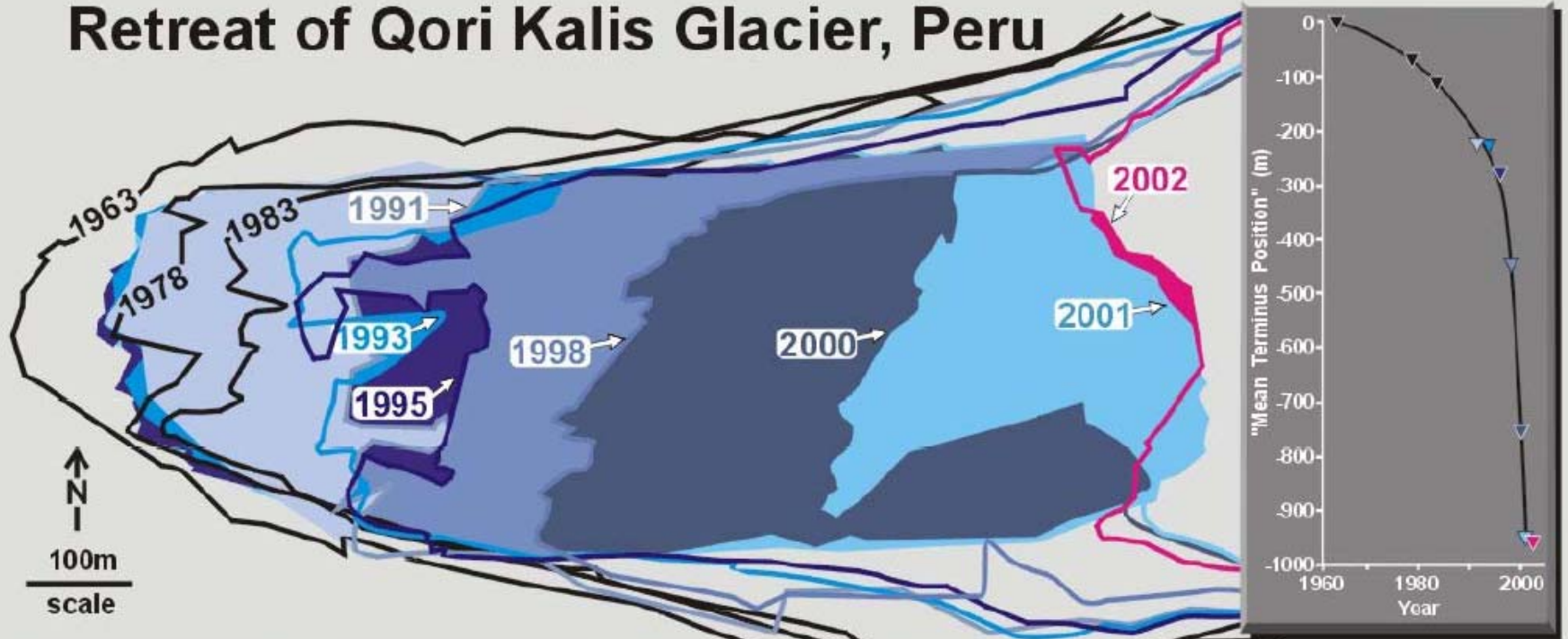


Austin Post, 1958



Matt Nolan, 2003

Retreat of Qori Kalis Glacier, Peru



1978



1991



1998

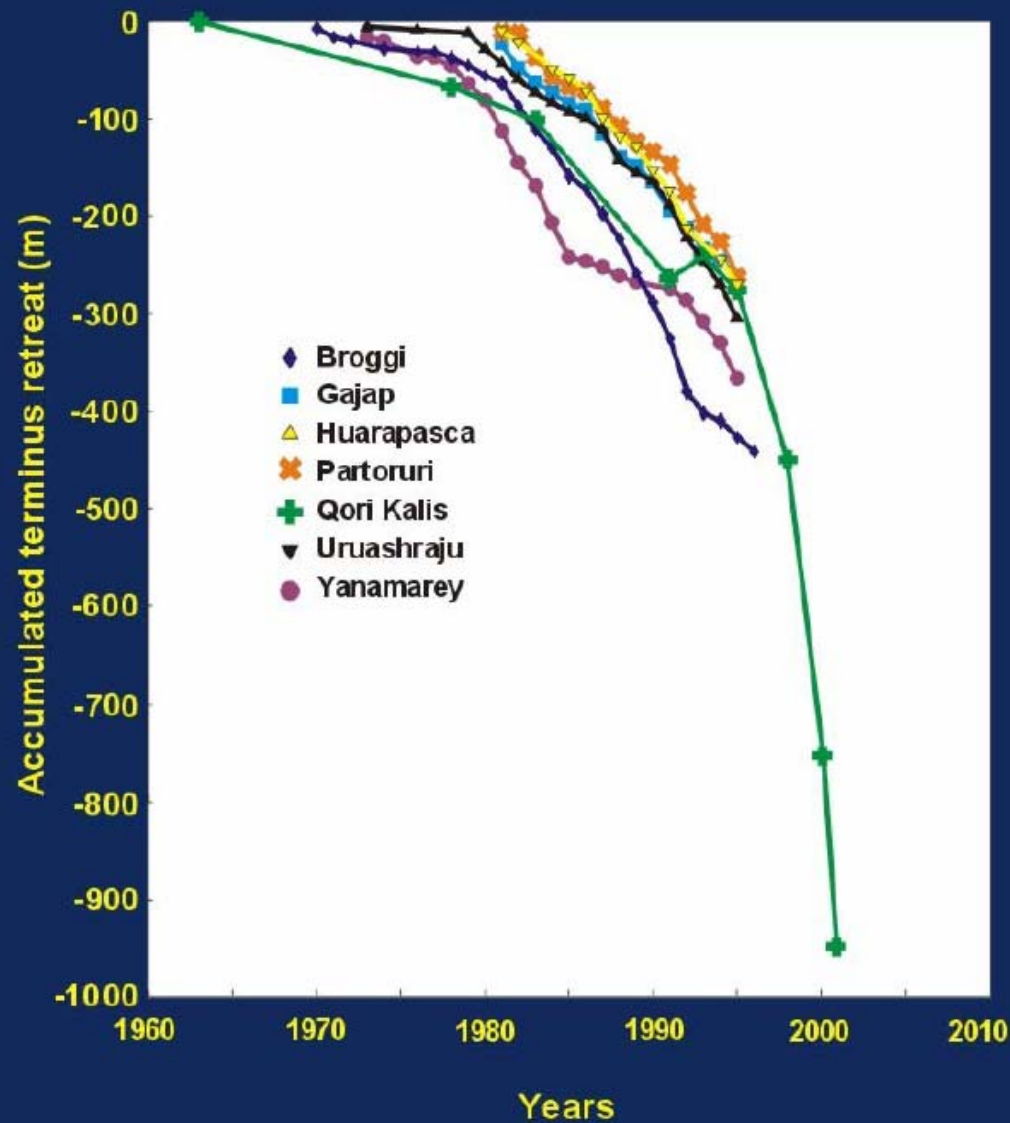


2000



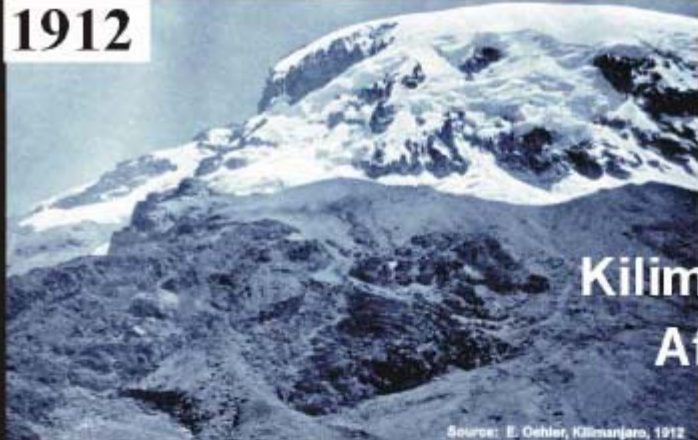
2002

Recent Retreat of Peruvian Glaciers



Portocarrero (personal comm.)
Qori Kalis - Ohio State University

1912



Kilimanjaro,
Africa

Source: E. Oehler, Kilimanjaro, 1912

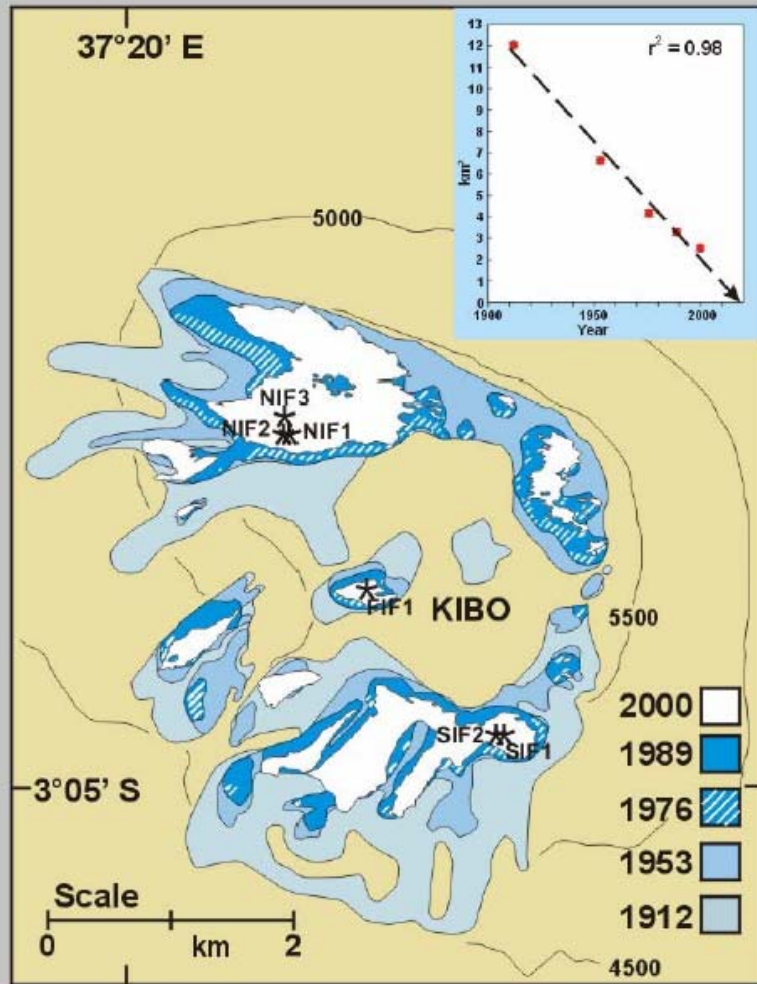
1970



2000



Total Area Of Ice On Kilimanjaro (1912, 1953, 1976, 1989, 2000)



1912 - 1989 after Hastenrath and Greischar, *J. Glaciol.*, 1997

2000 after Thompson *et al.*, *Science*, 2002

1912



Kilimanjaro,
Africa

Source: E. Oehler, Kilimanjaro, 1912

1970

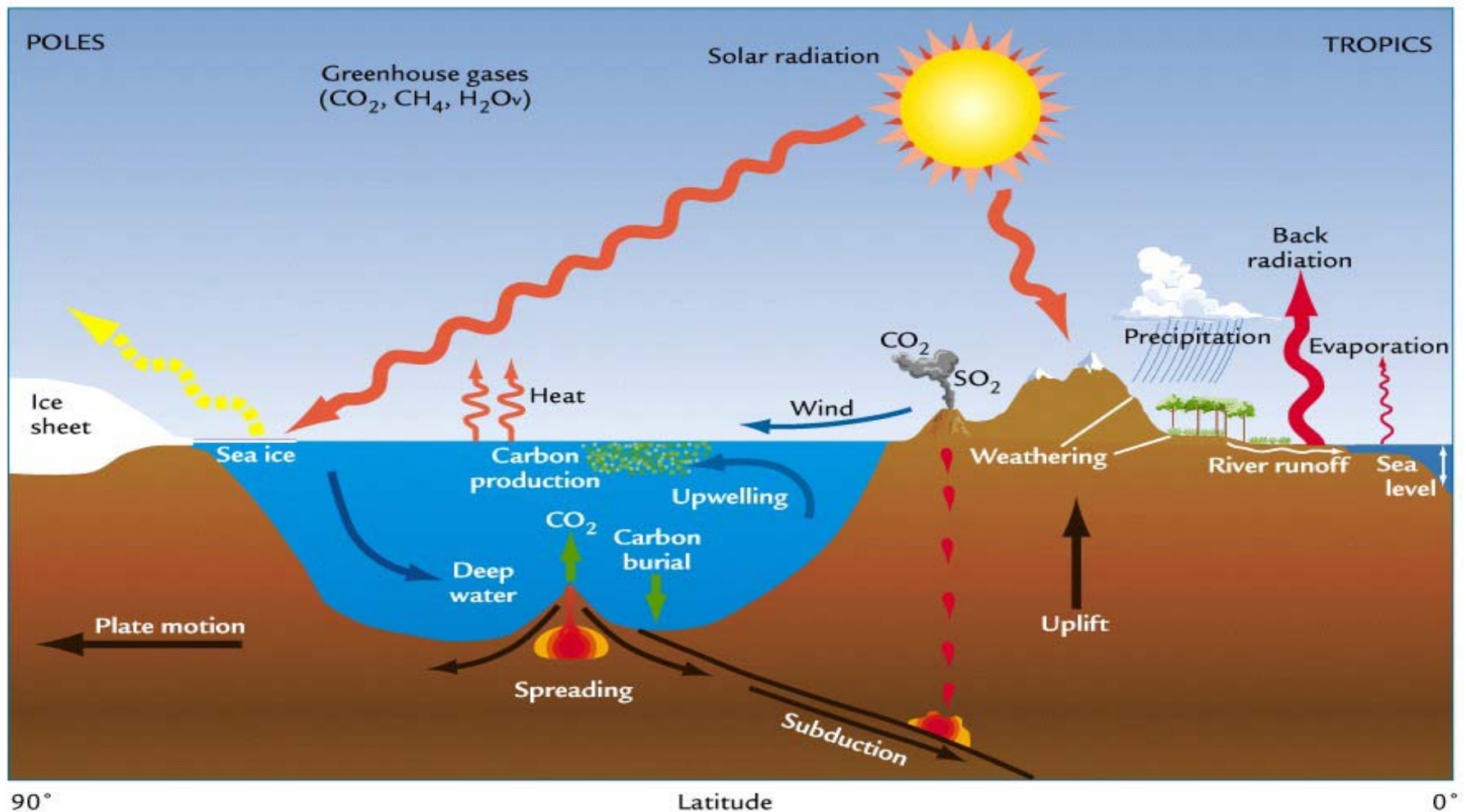


2000

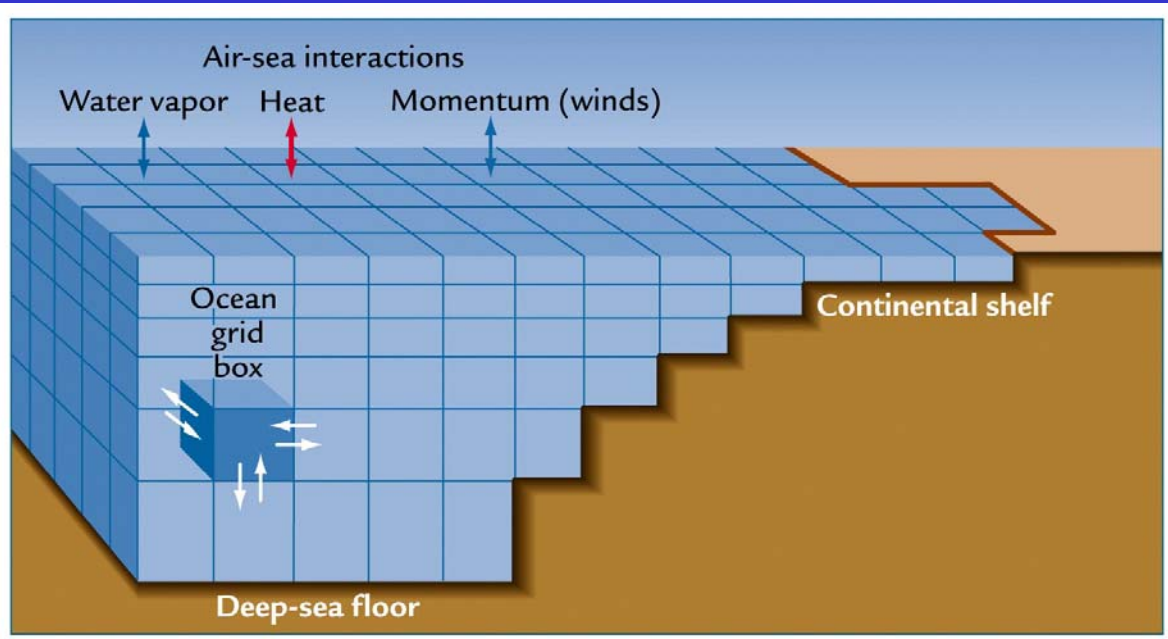
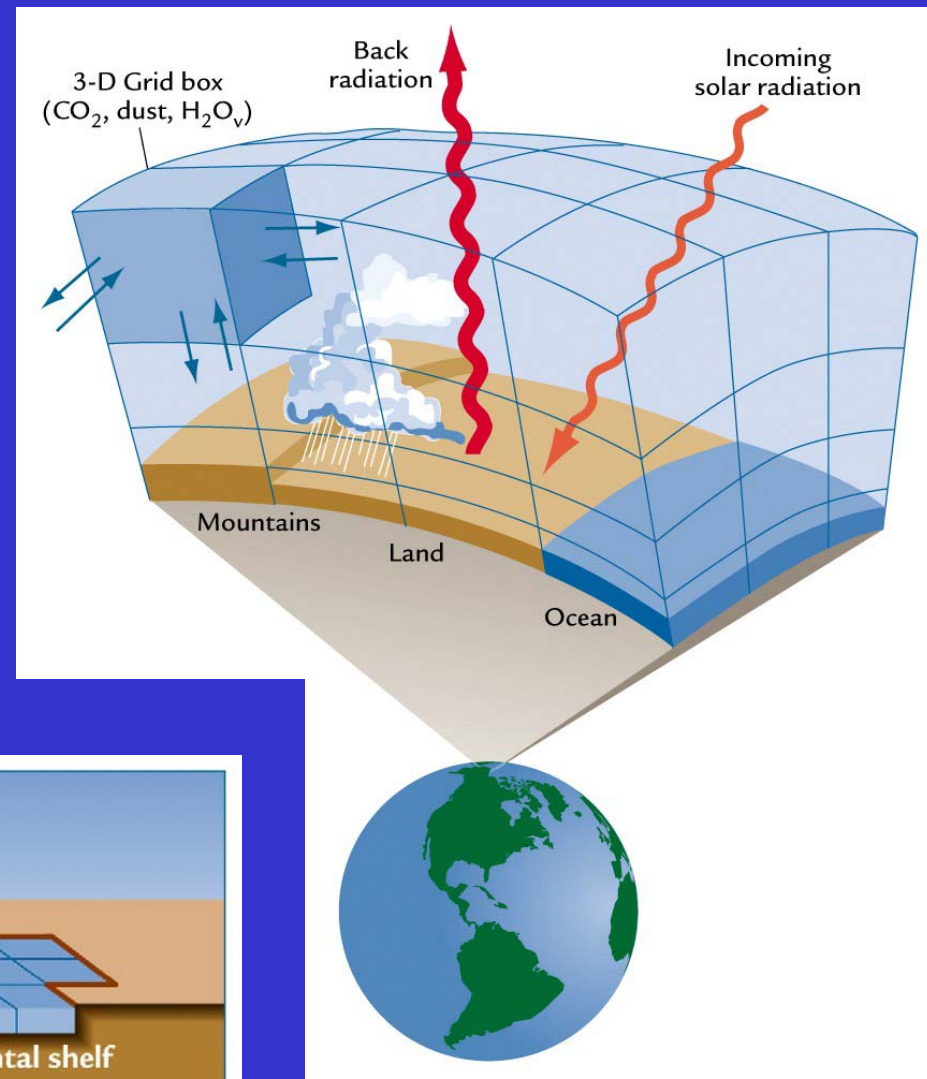


CLIMATE MODELS

The **climate** represents a coupled system consisting of an atmosphere, hydrosphere, biosphere, and cryosphere

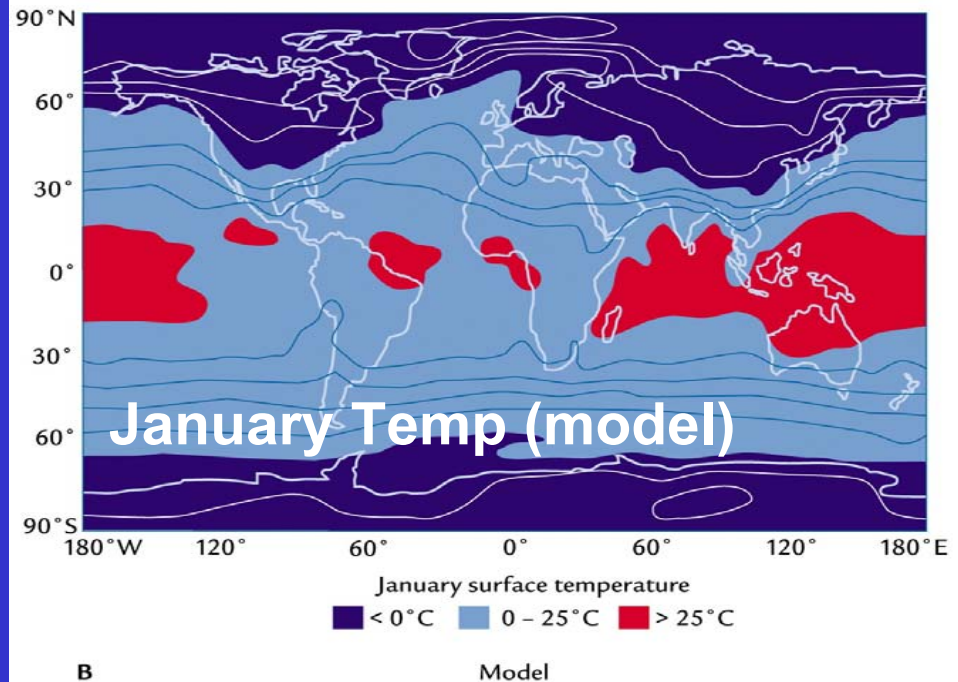
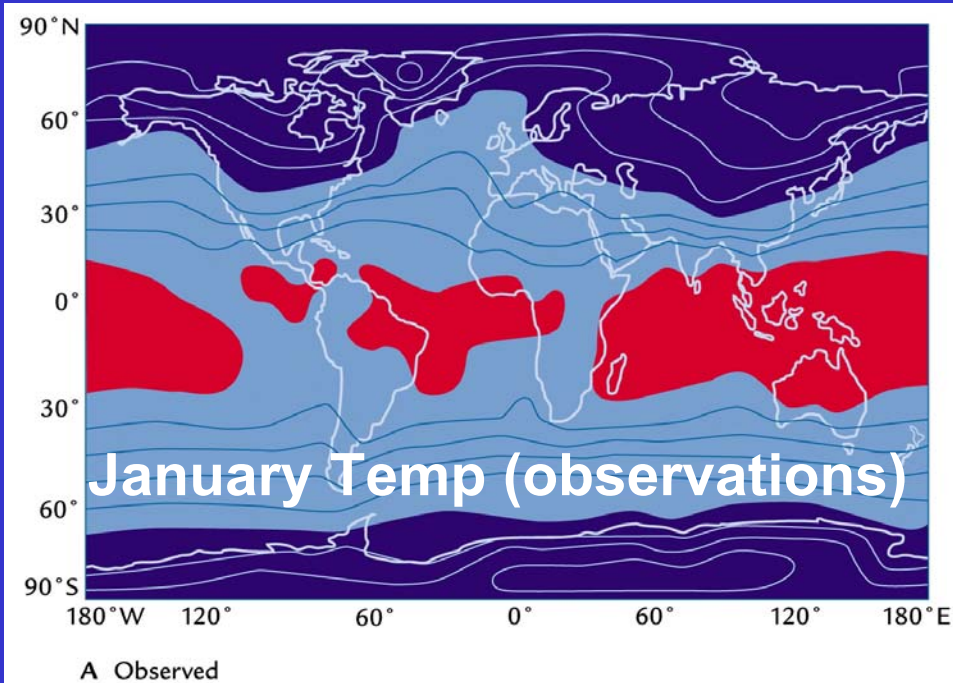


General Circulation Models take into account the full three-dimensional structure of the atmosphere and ocean

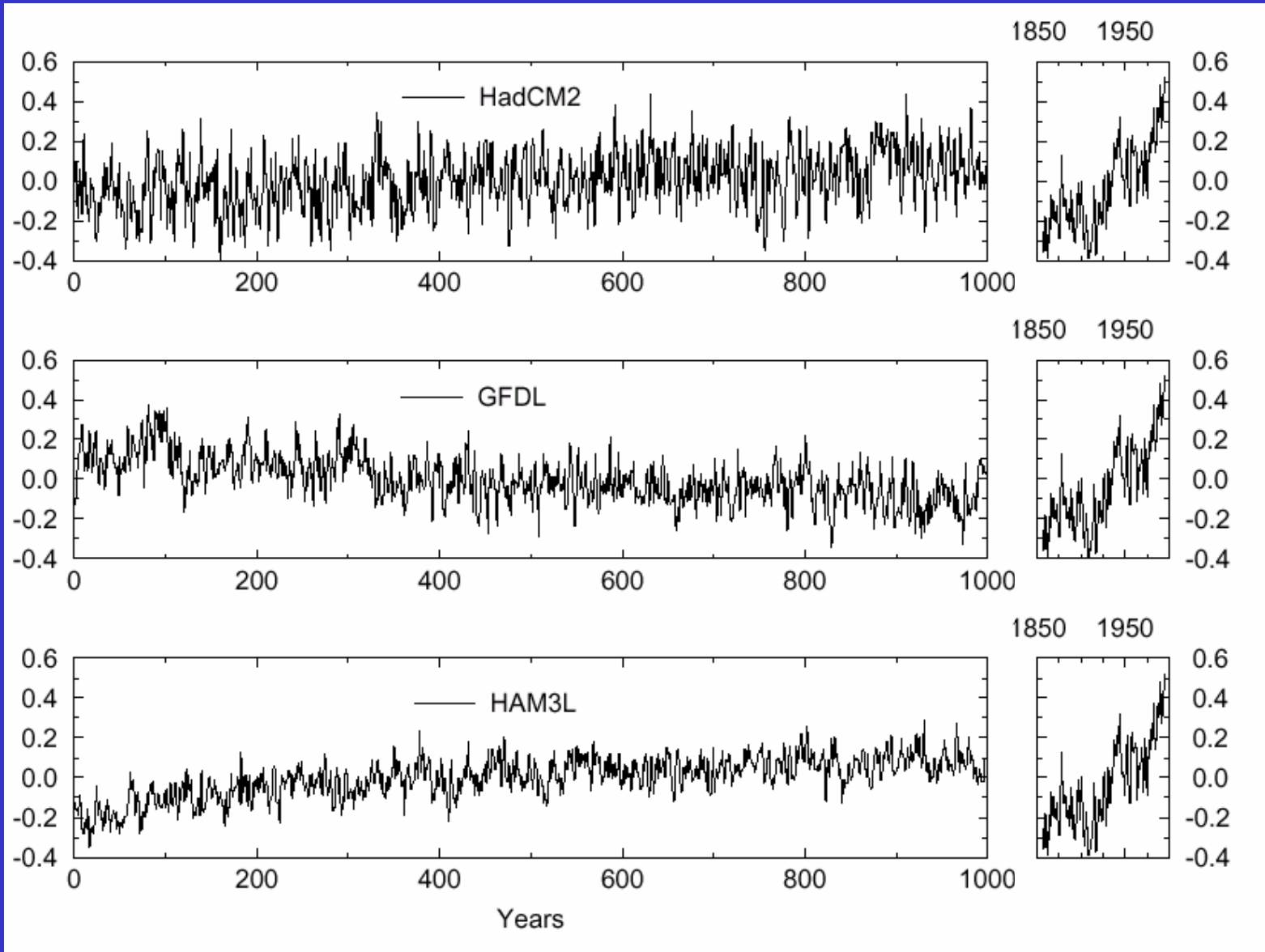


GCMs do a fairly good job of describing the seasonal cycle in surface temperature

This alone doesn't guarantee that they should do a good job in describing climate change!

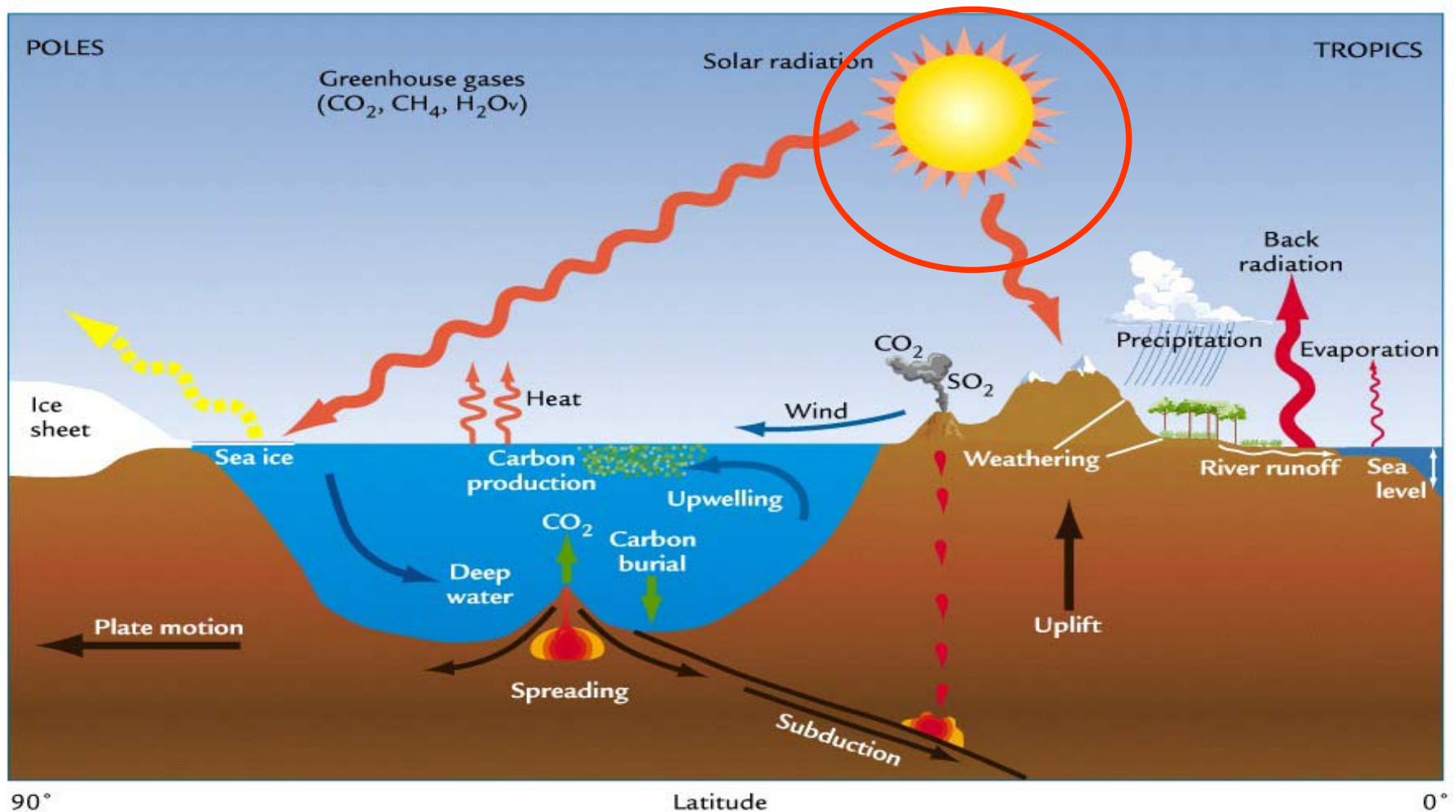


Modeled *Internal* Natural Variability Observations

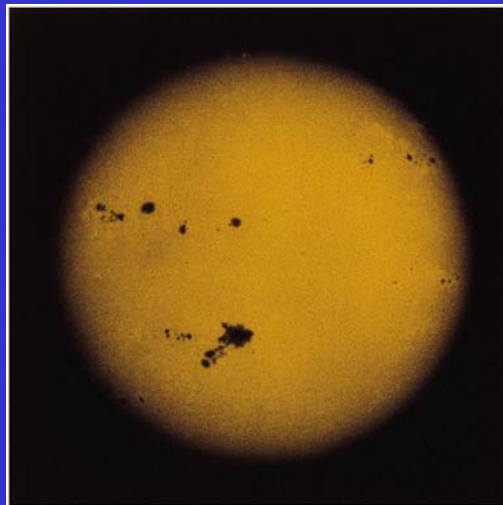
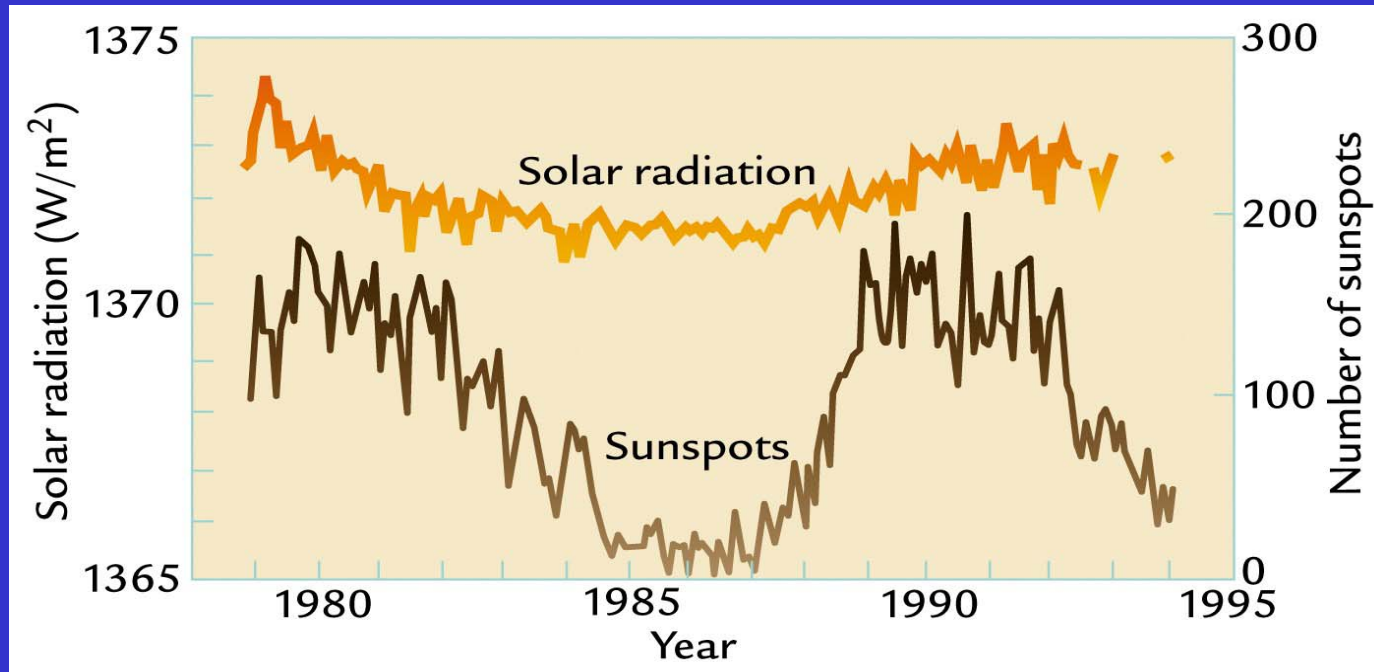


*INFLUENCE OF EXTERNAL
FACTORS*

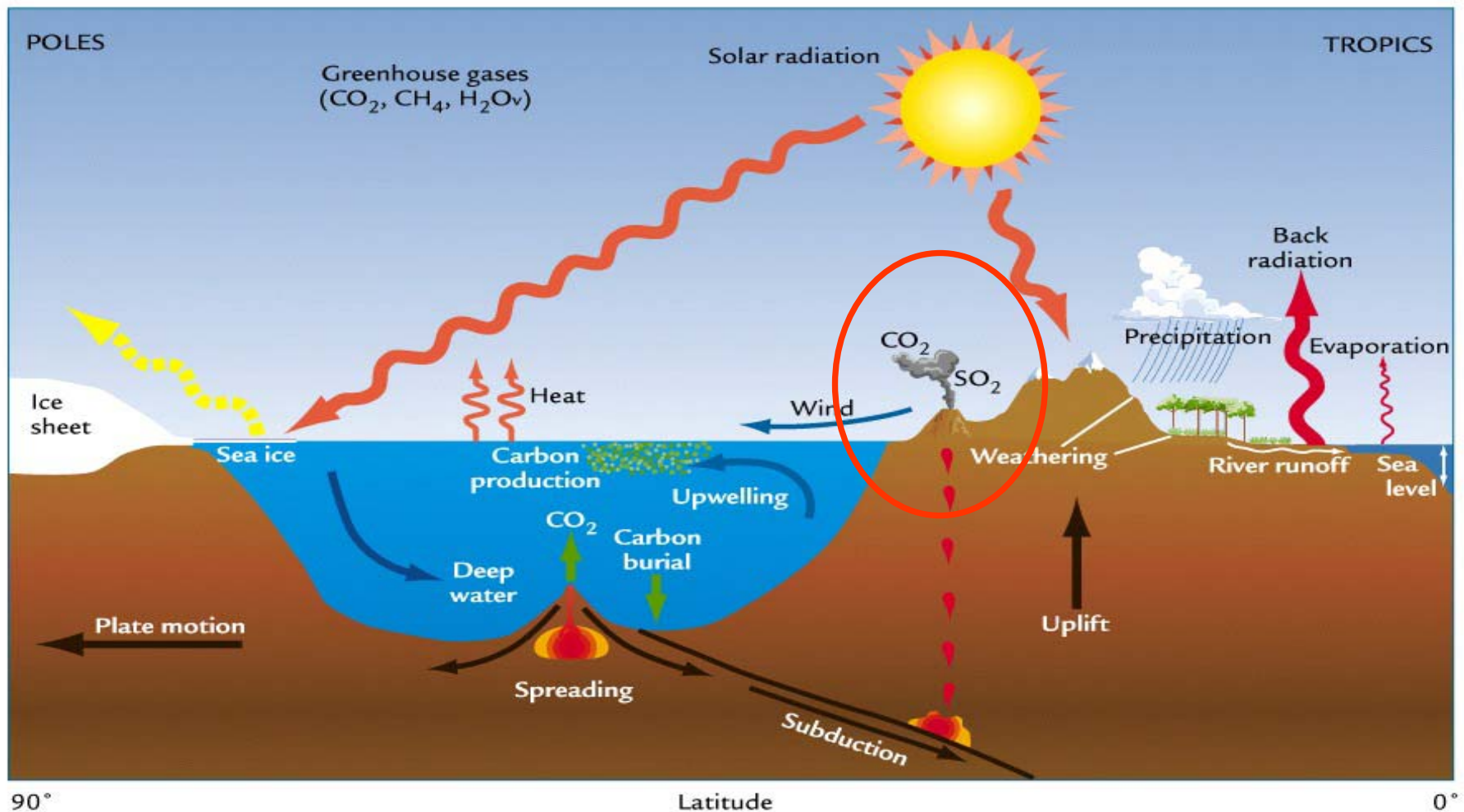
The **climate** is governed by external factors, including the intensity of solar output



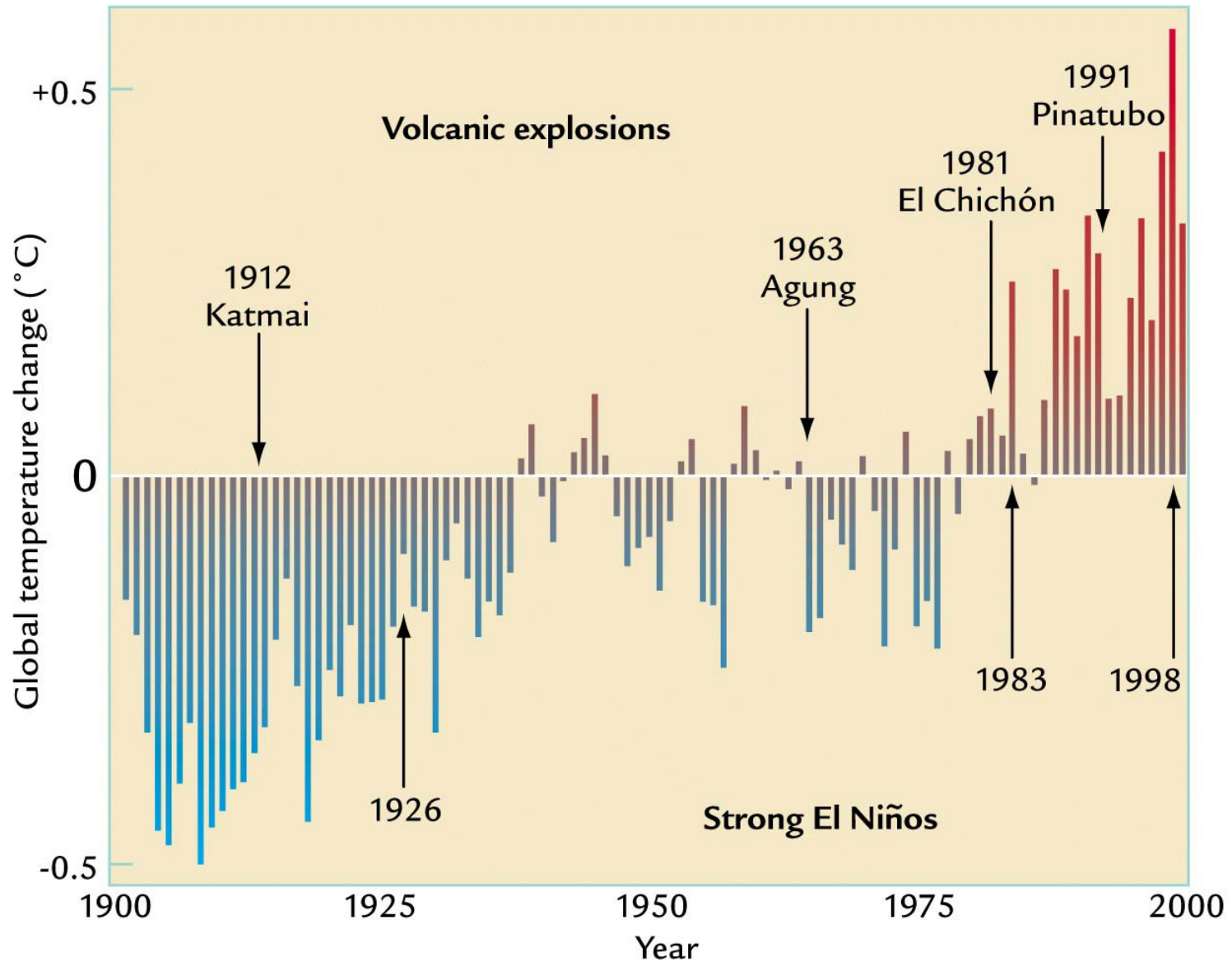
Solar Variations



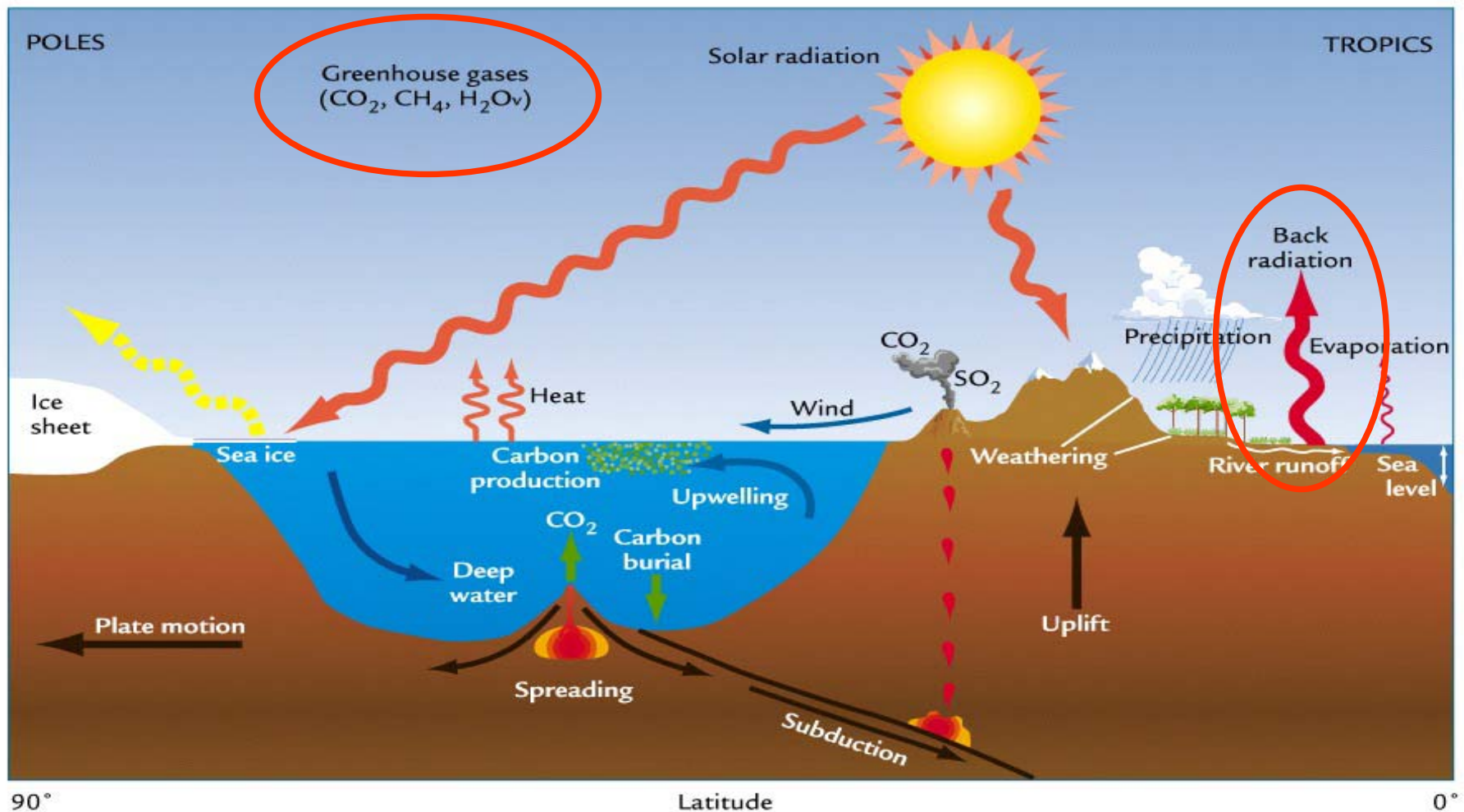
The **climate** is governed by external factors, including the intensity of **solar output** and **volcanic aerosols**



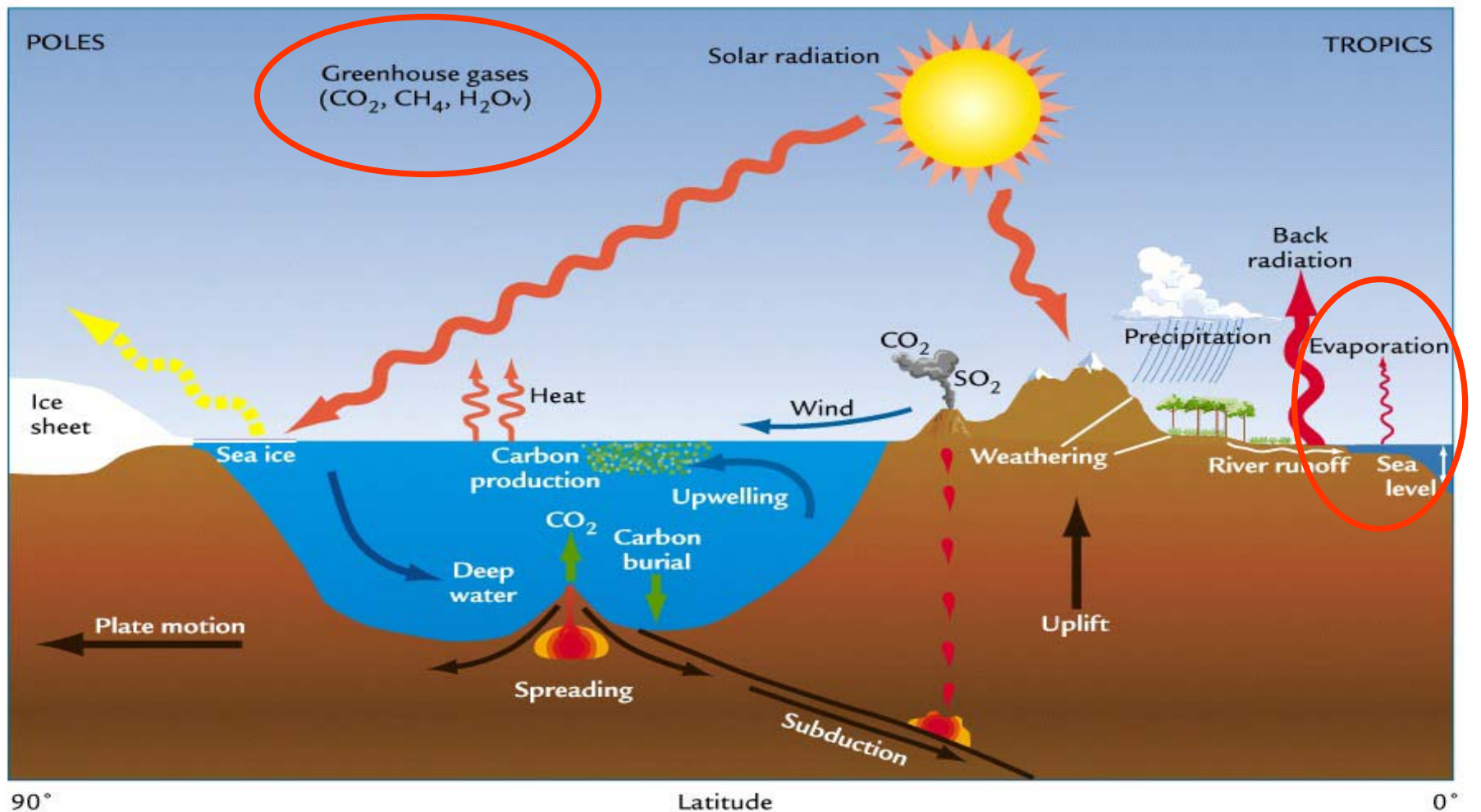
Volcanoes



The **climate** is governed by external factors, including the intensity of **solar output** and **volcanic aerosols** and **greenhouse gas concentrations**



The **climate** is governed by external factors, including the intensity of **solar output** and **volcanic aerosols** and **greenhouse gas concentrations**



GREENHOUSE EFFECT?



The Greenhouse Effect



Some solar radiation is reflected by the Earth and the atmosphere.

Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.

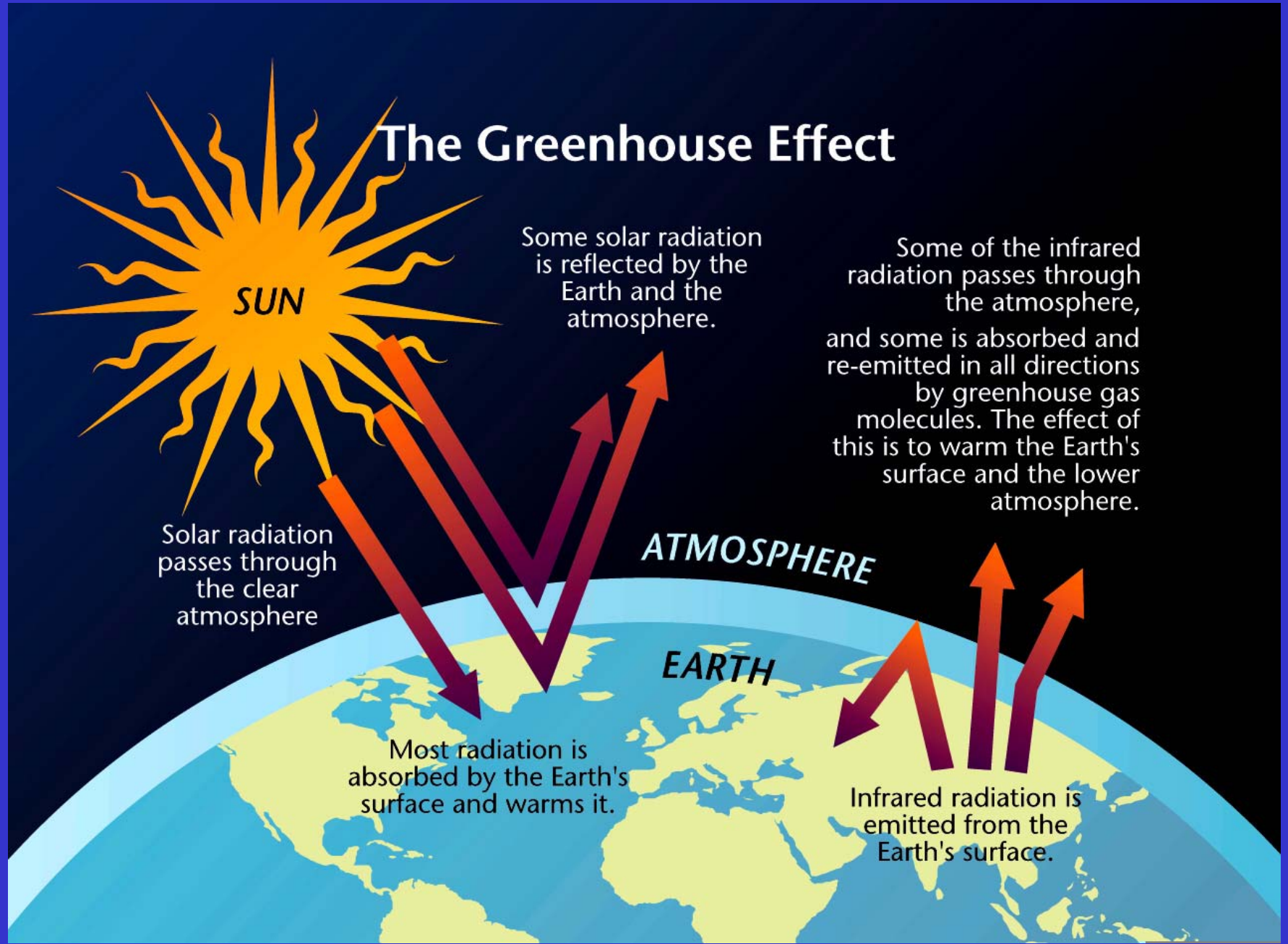
Solar radiation passes through the clear atmosphere

ATMOSPHERE

Most radiation is absorbed by the Earth's surface and warms it.

EARTH

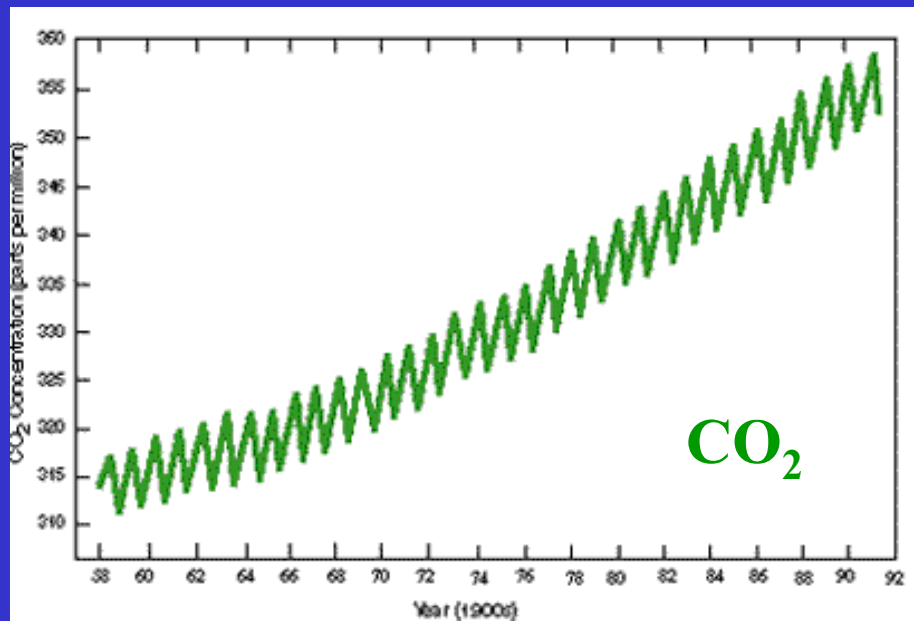
Infrared radiation is emitted from the Earth's surface.



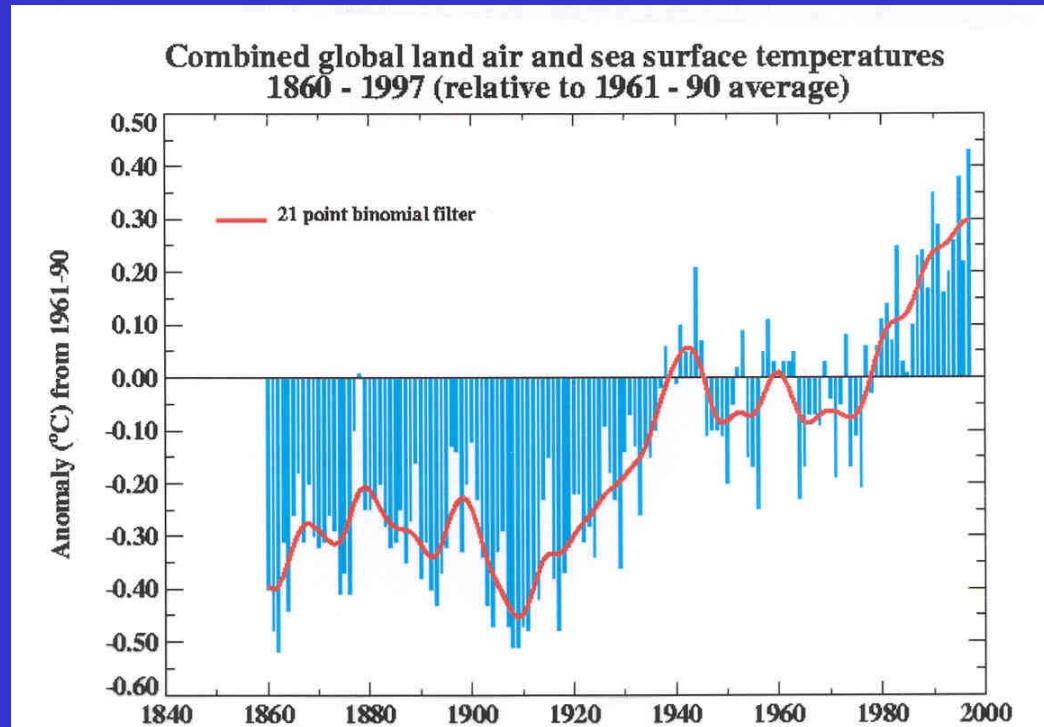
ENHANCED GREENHOUSE EFFECT?



Greenhouse Gases and Warming

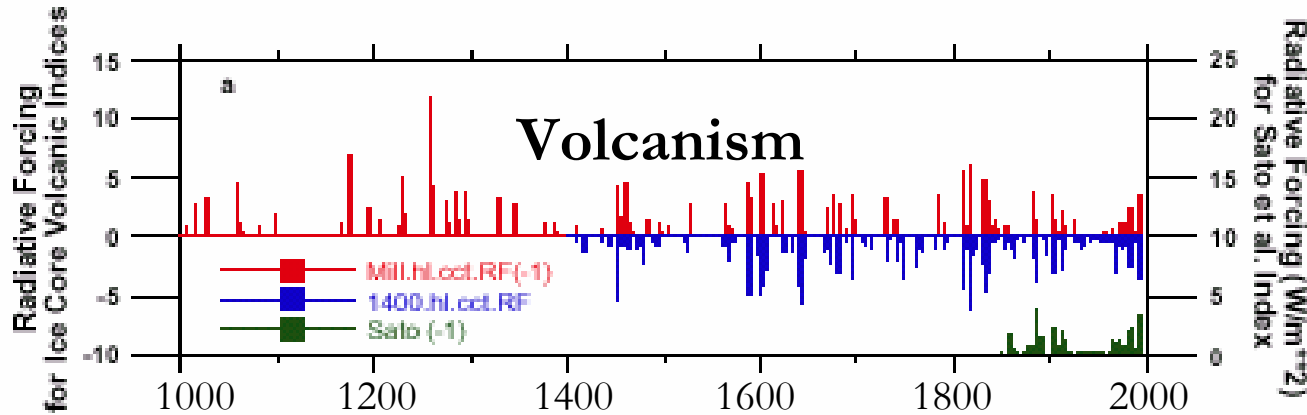


Related?



SIMULATIONS OF CLIMATE CHANGE

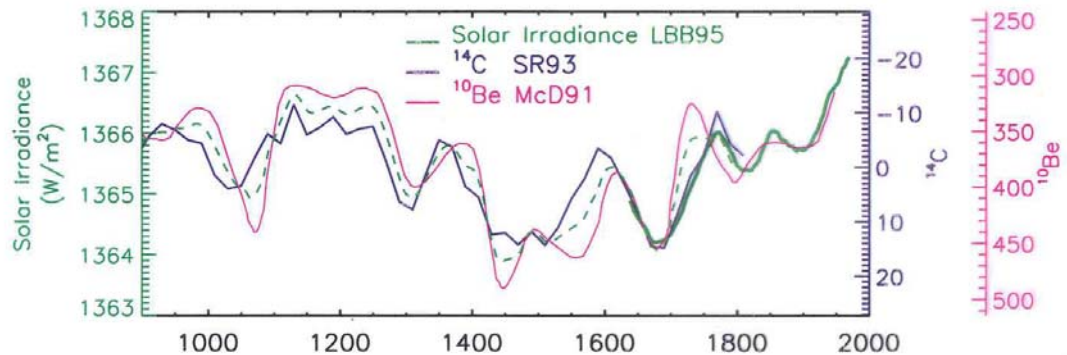
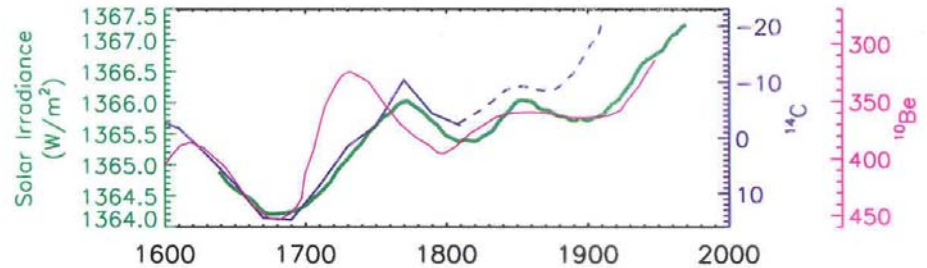
CLIMATE FORCINGS



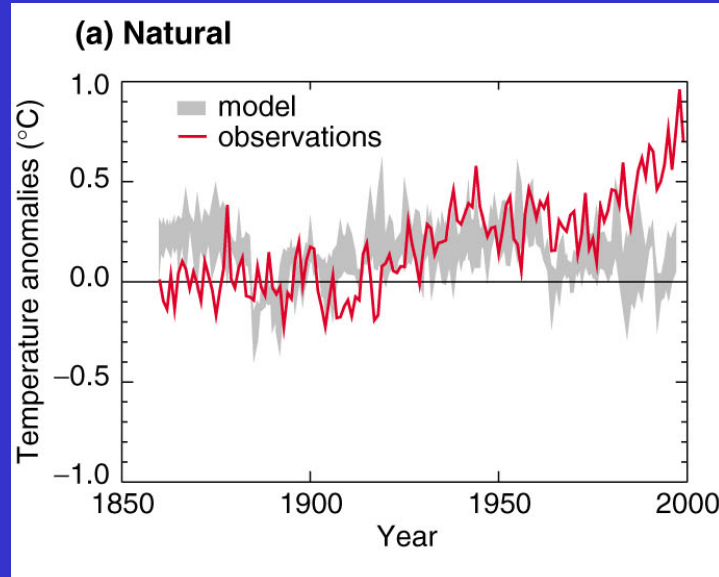
Natural

Solar

Cosmogenic Isotopes & Solar Irradiance



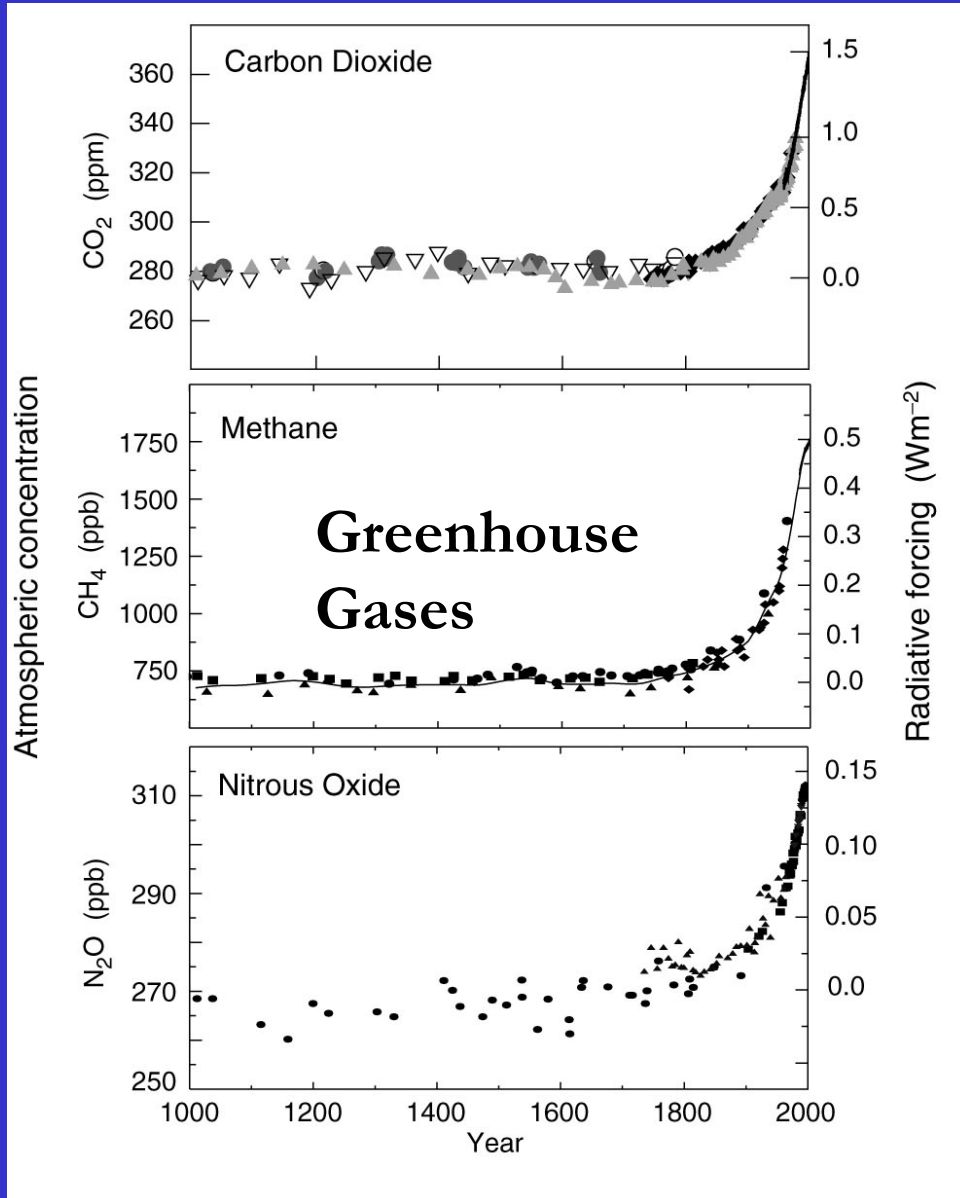
Simulated Annual Global Mean Surface Temperatures



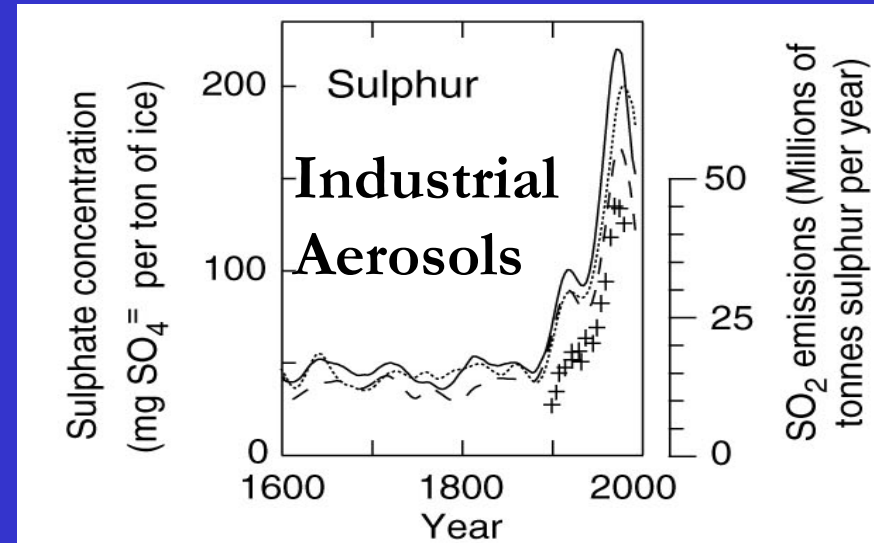
*Climate Change
2001: The
Scientific Basis,*
Houghton, J.T., et
al. (eds.),
Cambridge Univ.
Press, Cambridge,
2001

Forced Model
simulations

CLIMATE FORCINGS

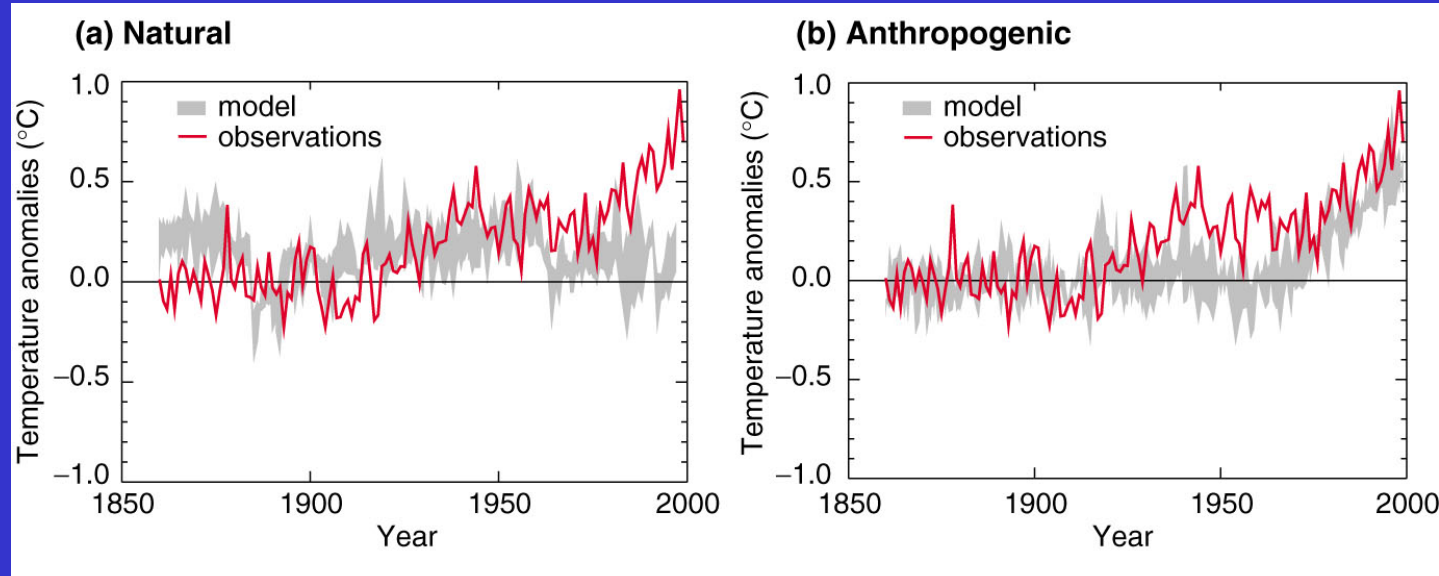


Anthropogenic



Simulated Annual Global Mean Surface Temperatures

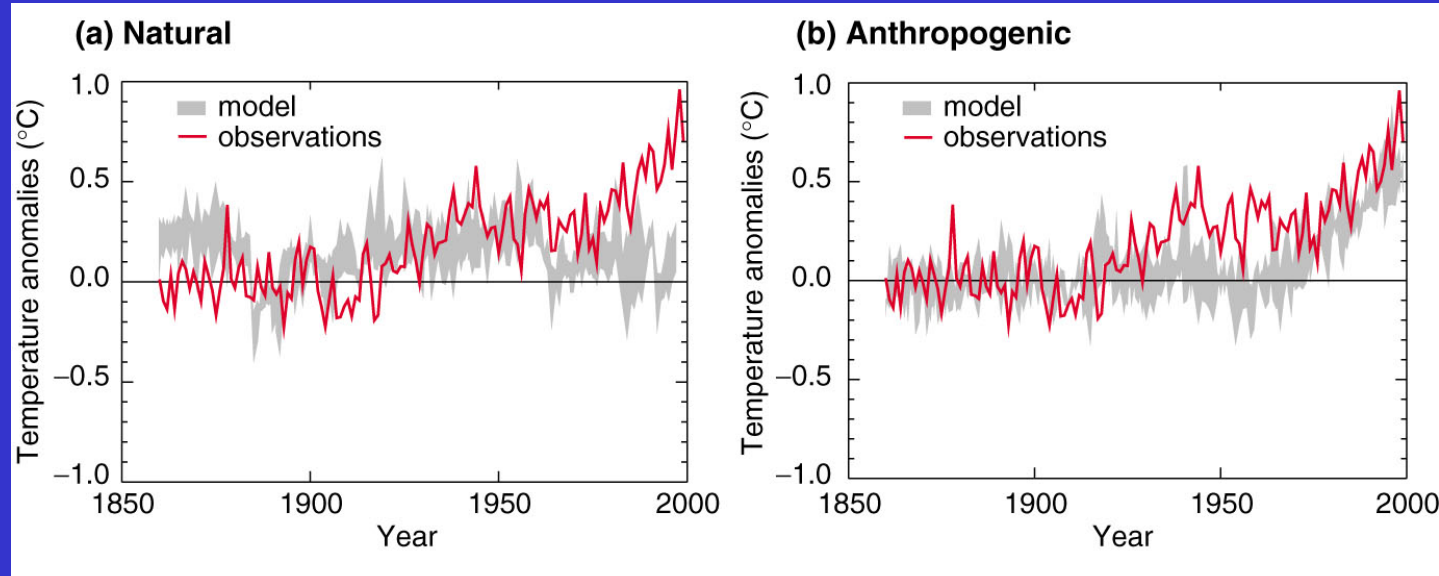
*Climate Change
2001: The
Scientific Basis,*
Houghton, J.T., et
al. (eds.),
Cambridge Univ.
Press, Cambridge,
2001



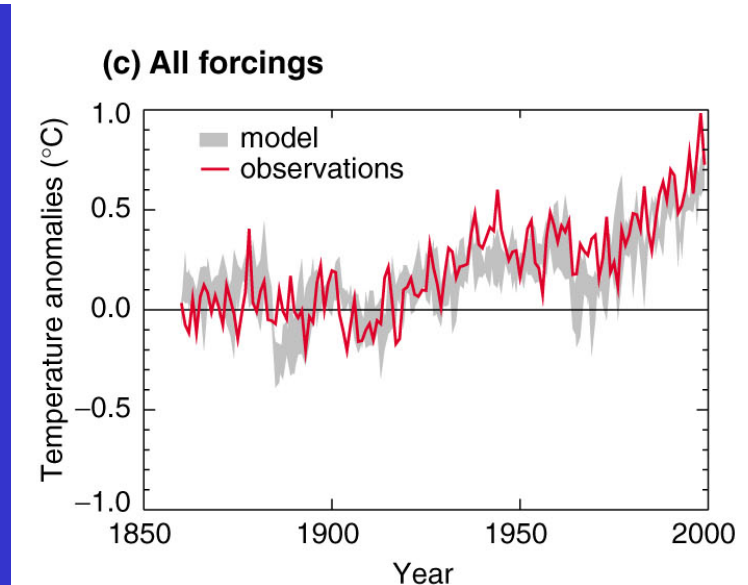
Forced Model
simulations

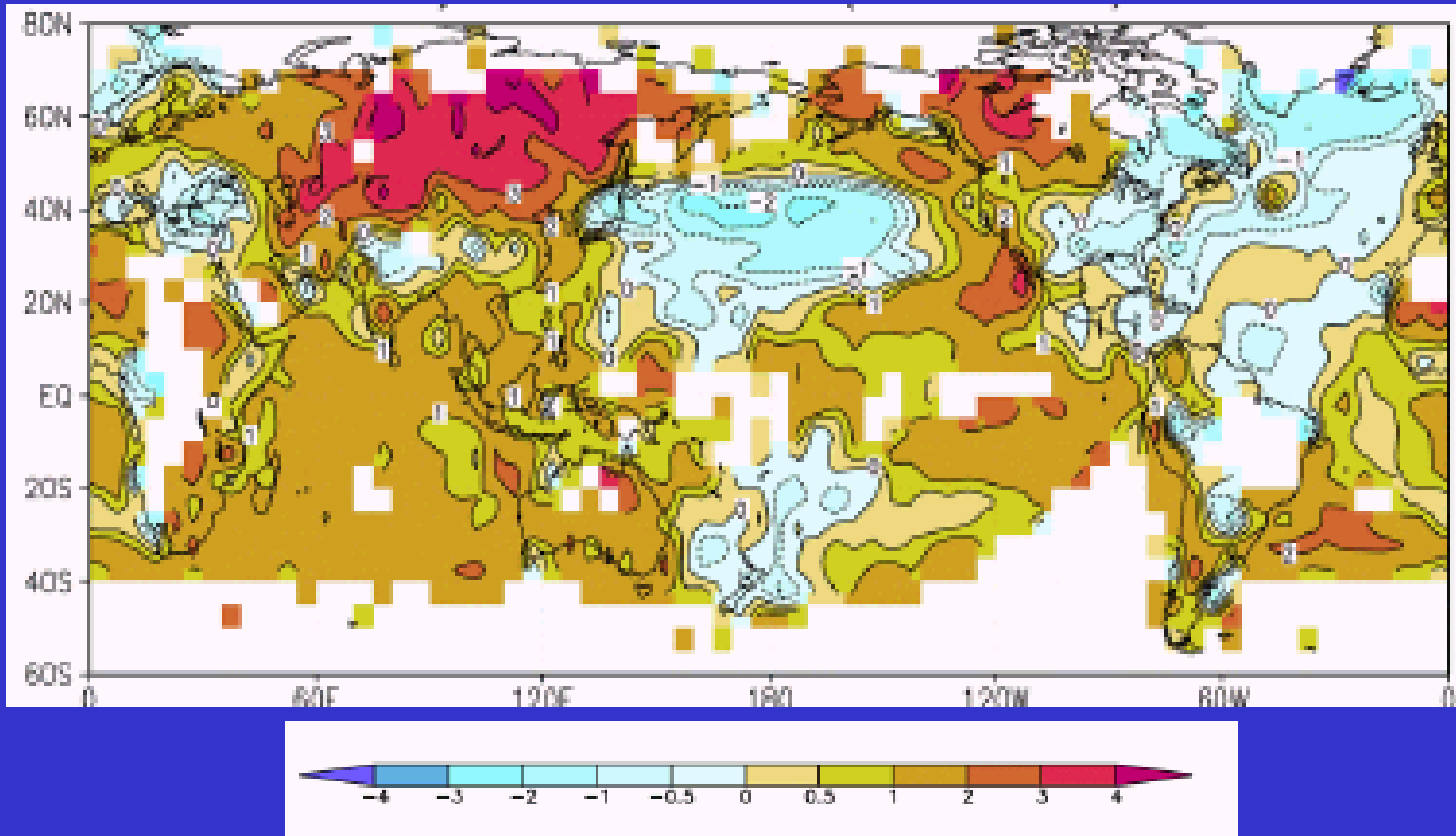
Simulated Annual Global Mean Surface Temperatures

*Climate Change
2001: The
Scientific Basis,*
Houghton, J.T., et
al. (eds.),
Cambridge Univ.
Press, Cambridge,
2001



Forced Model
simulations





OBSERVED ANNUAL MEAN TREND 1949-1997

Knutson, T.R., T.L. Delworth, K.W. Dixon, and R.J. Stouffer, Model assessment of regional surface temperature trends (1949-1997), *Journal of Geophysical Research*, 104, 30981-30996, 1999.

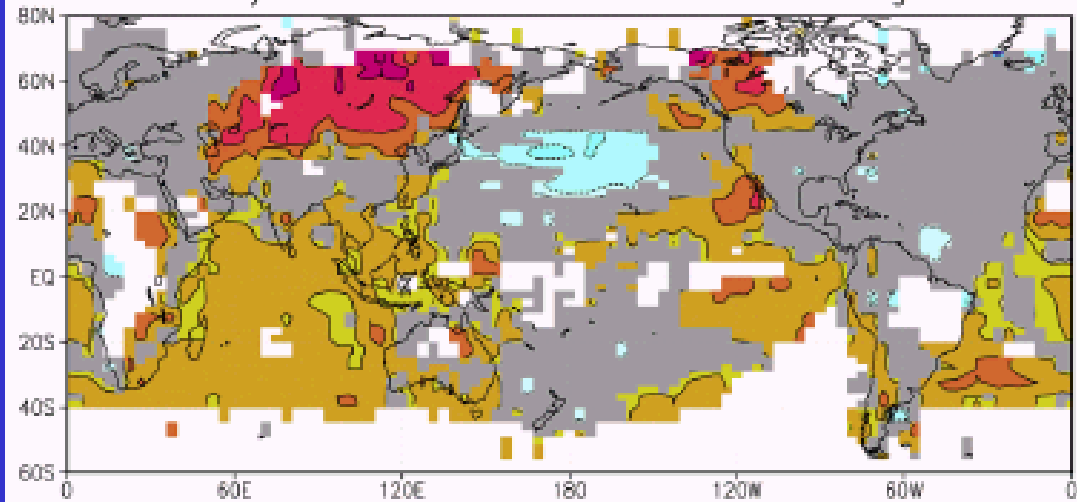
Inconsistent with
Natural *unforced*
Variability



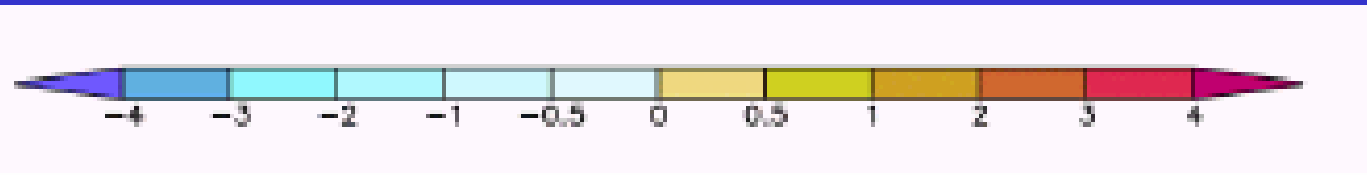
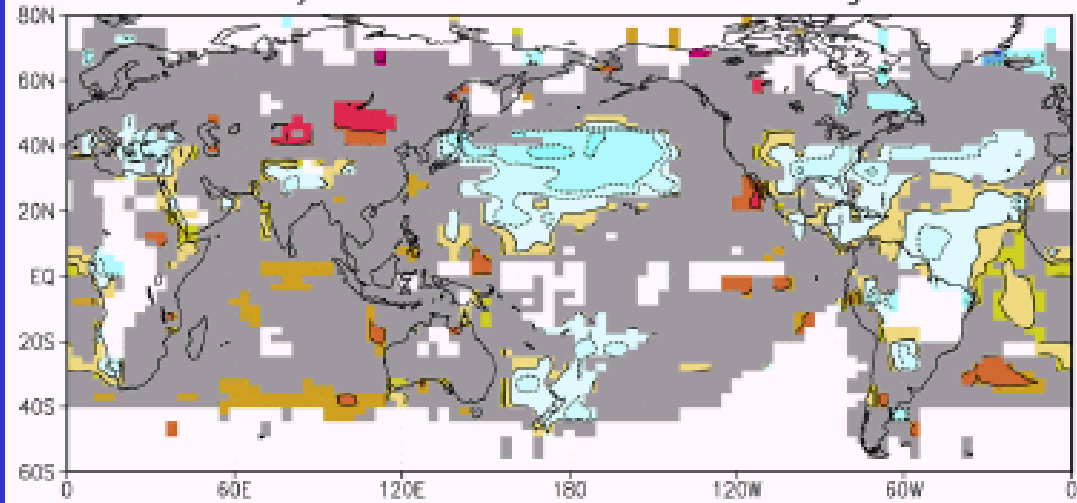
Inconsistent with
Greenhouse+
Sulphate Forcing

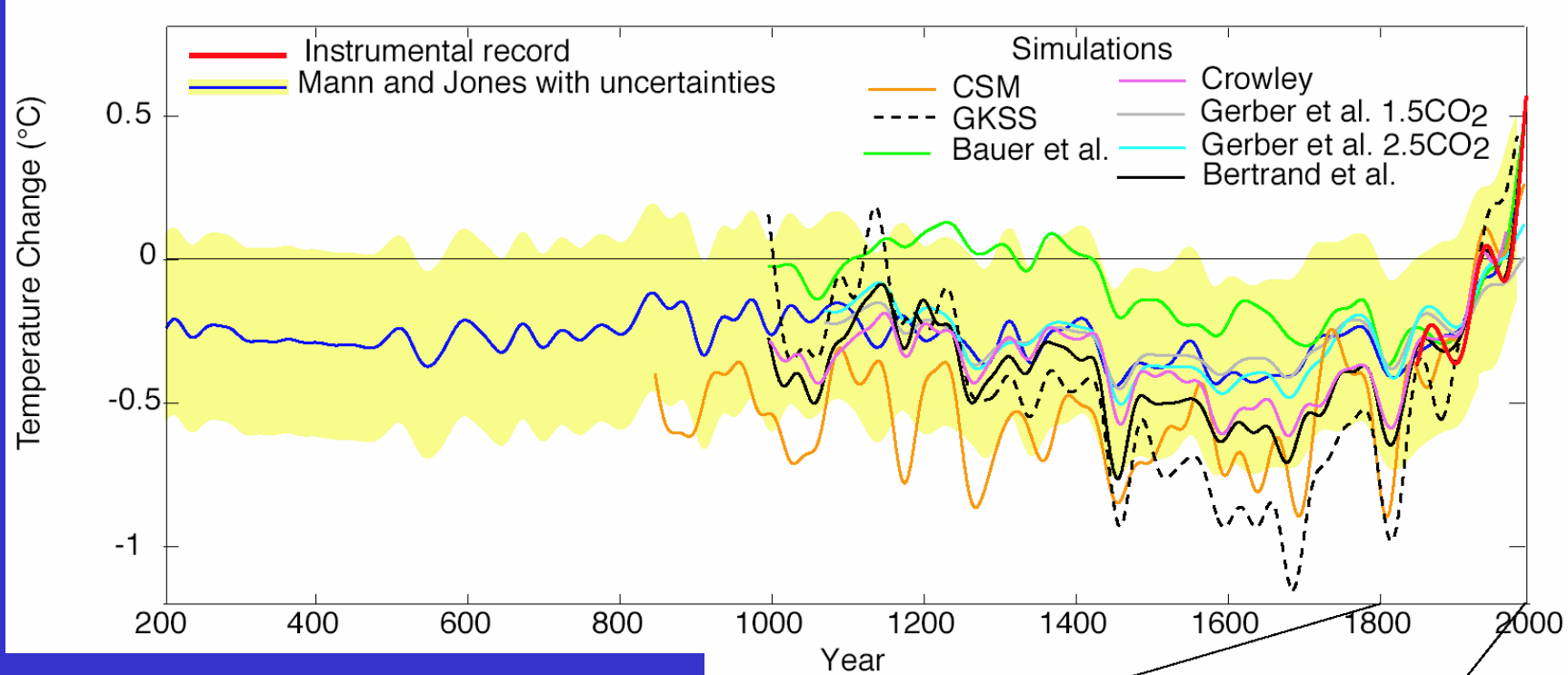


c) Trend Assessment: No external forcing

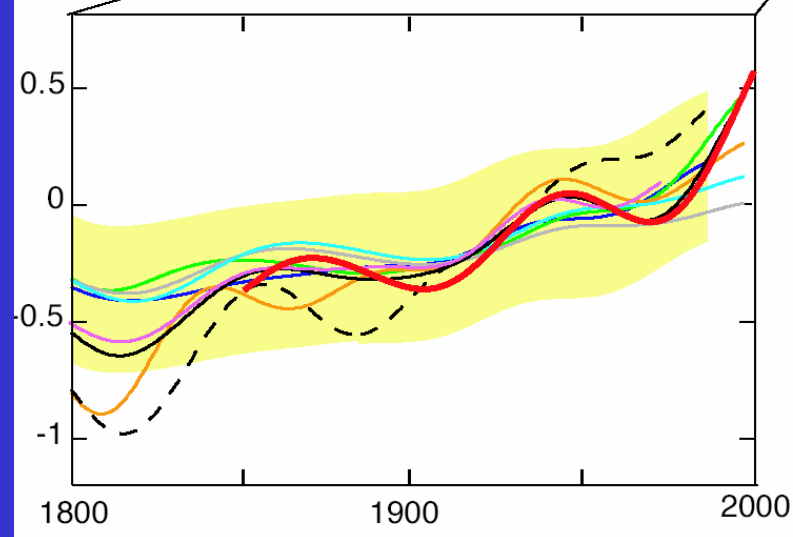


d) Trend Assessment: G+S Forcing



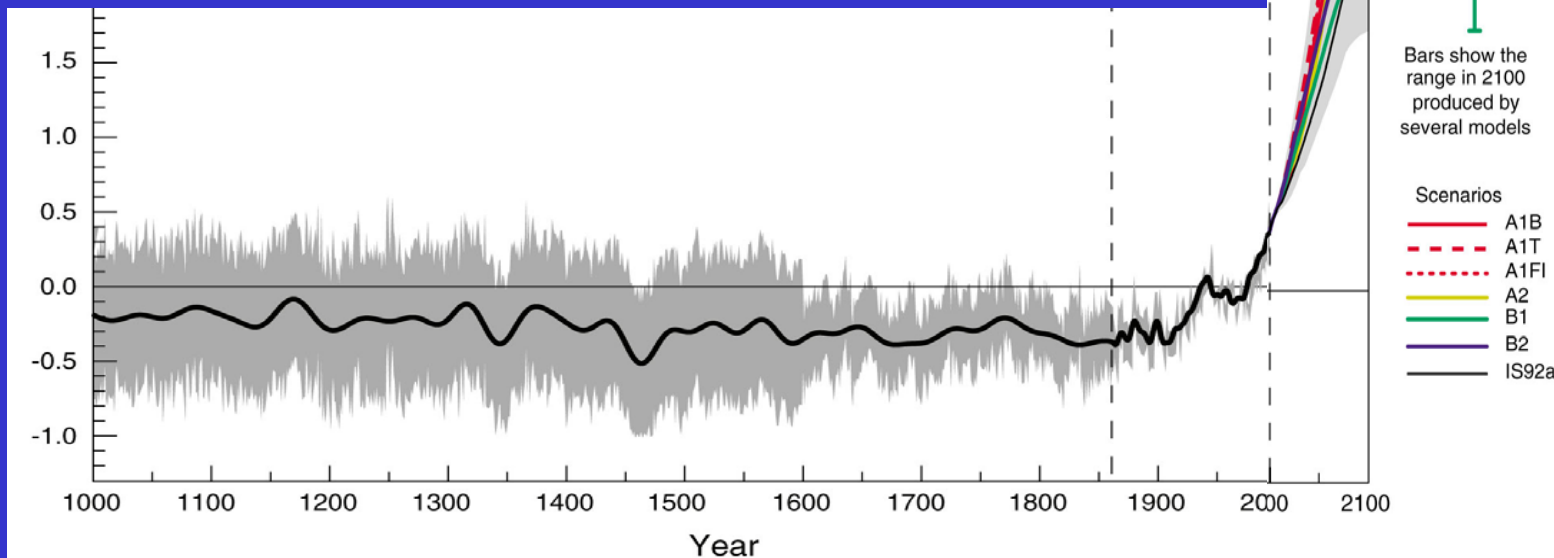


Jones, P.D., Mann, M.E., *Climate Over Past Millennia*, *Reviews of Geophysics*, 42, RG2002, doi:10.1029/2003RG000143, 2004.



Future Surface Temperatures Trends?

Climate Change 2001: The Scientific Basis,
Houghton, J.T., et al. (eds.), Cambridge Univ.
Press, Cambridge, 2001





RealClimate

RealClimate is a commentary site on climate science by working climate scientists for the interested public and journalists. We aim to provide a quick response to developing stories and provide the context sometimes missing in mainstream commentary.

Gavin Schmidt, Michael Mann

**Eric Steig, William Connolley, Ray Bradley, Stefan Rahmstorf,
Rasmus Benestad, Caspar Ammann, Thibault de Garidel**

CONCLUSIONS

- Recent global surface temperatures are unprecedented this century, and likely *at least* the past millennium
- It is difficult to explain the recent surface warming in terms of natural climate variability
- Recent surface warming *is* largely consistent with simulations of the effects of anthropogenic influence on climate
- Uncertainties remain regarding the precise sensitivity of the climate to forcing, and the regional details of expected climate changes