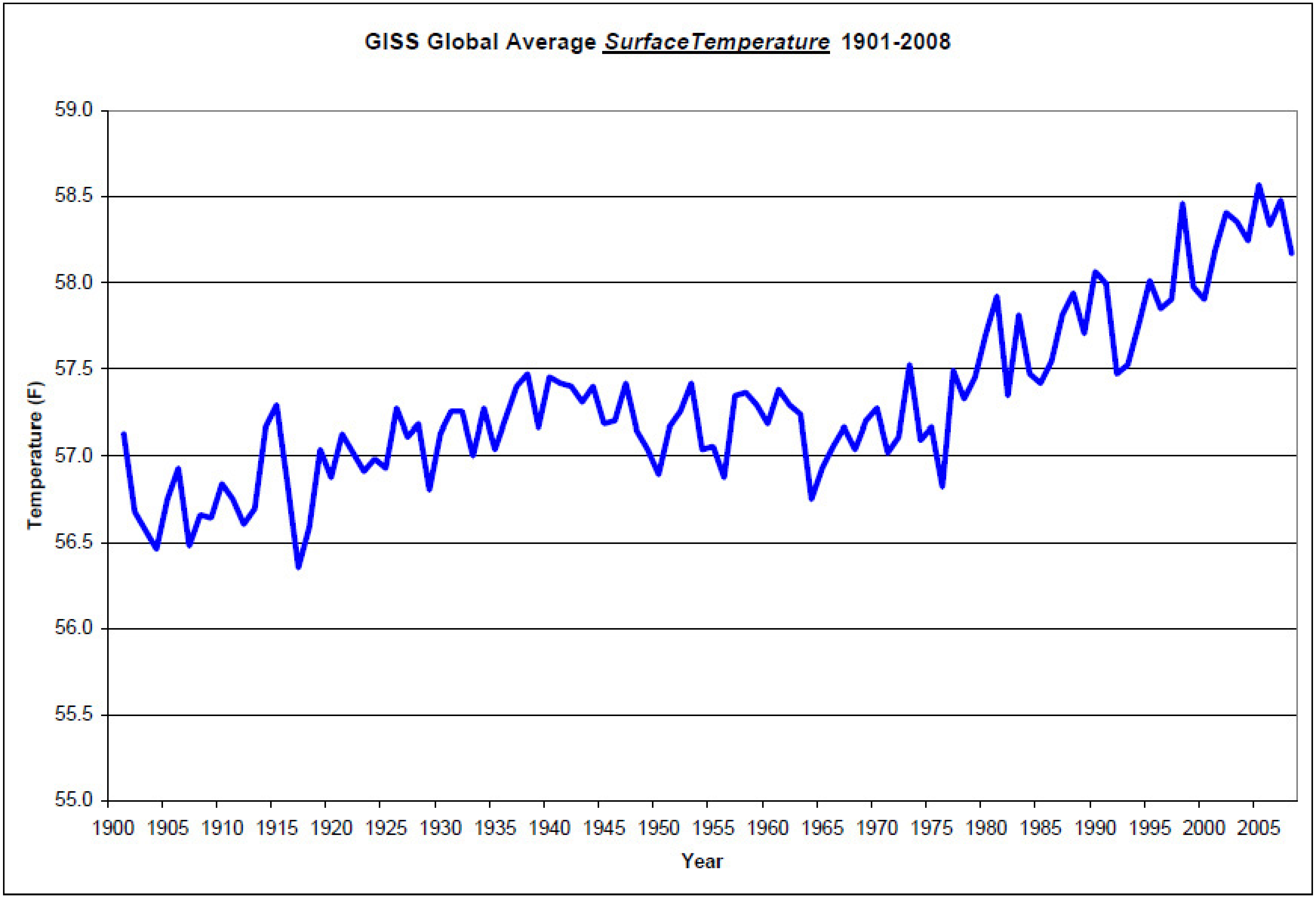
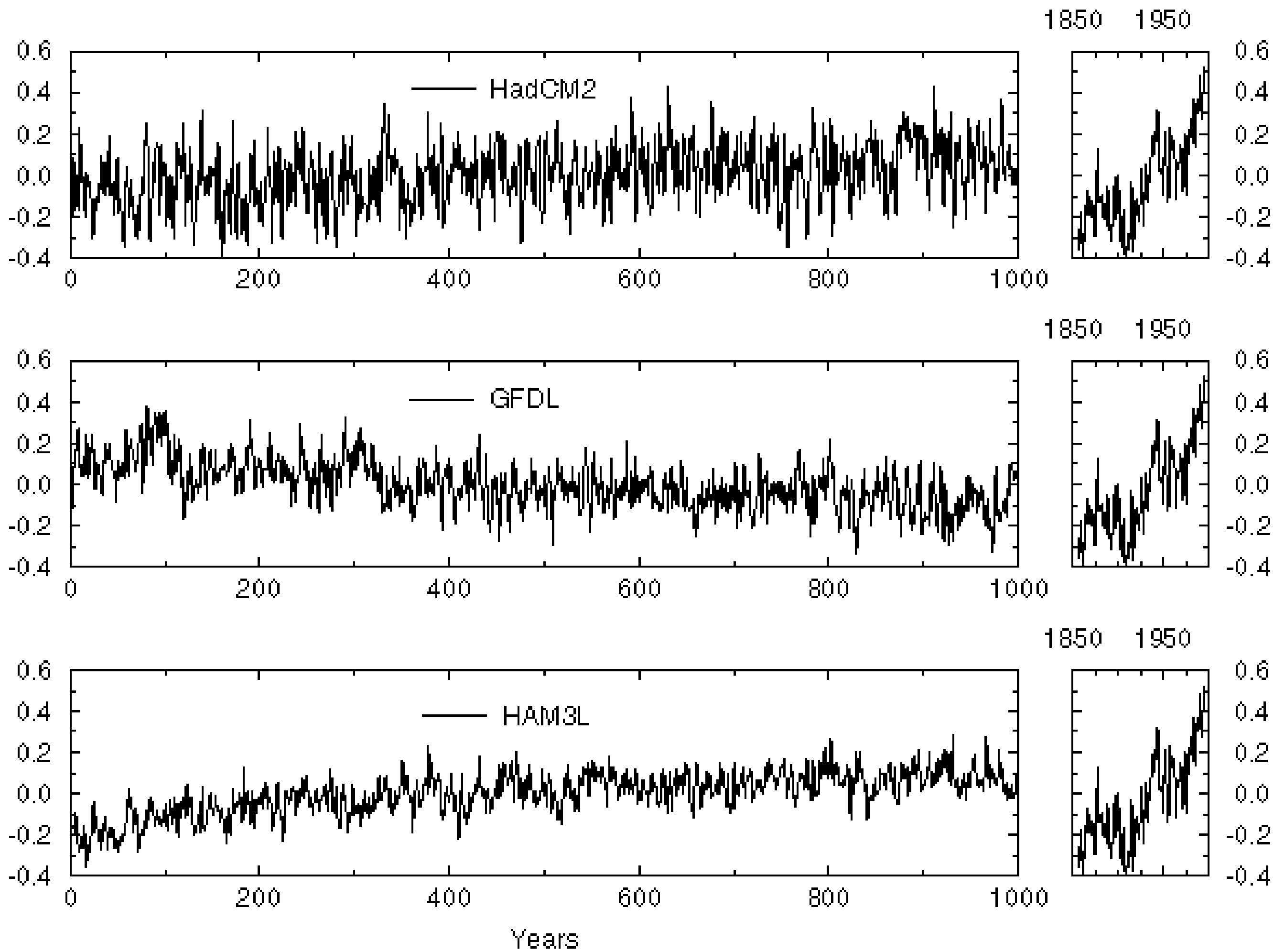
Natural Variability of the Climate System



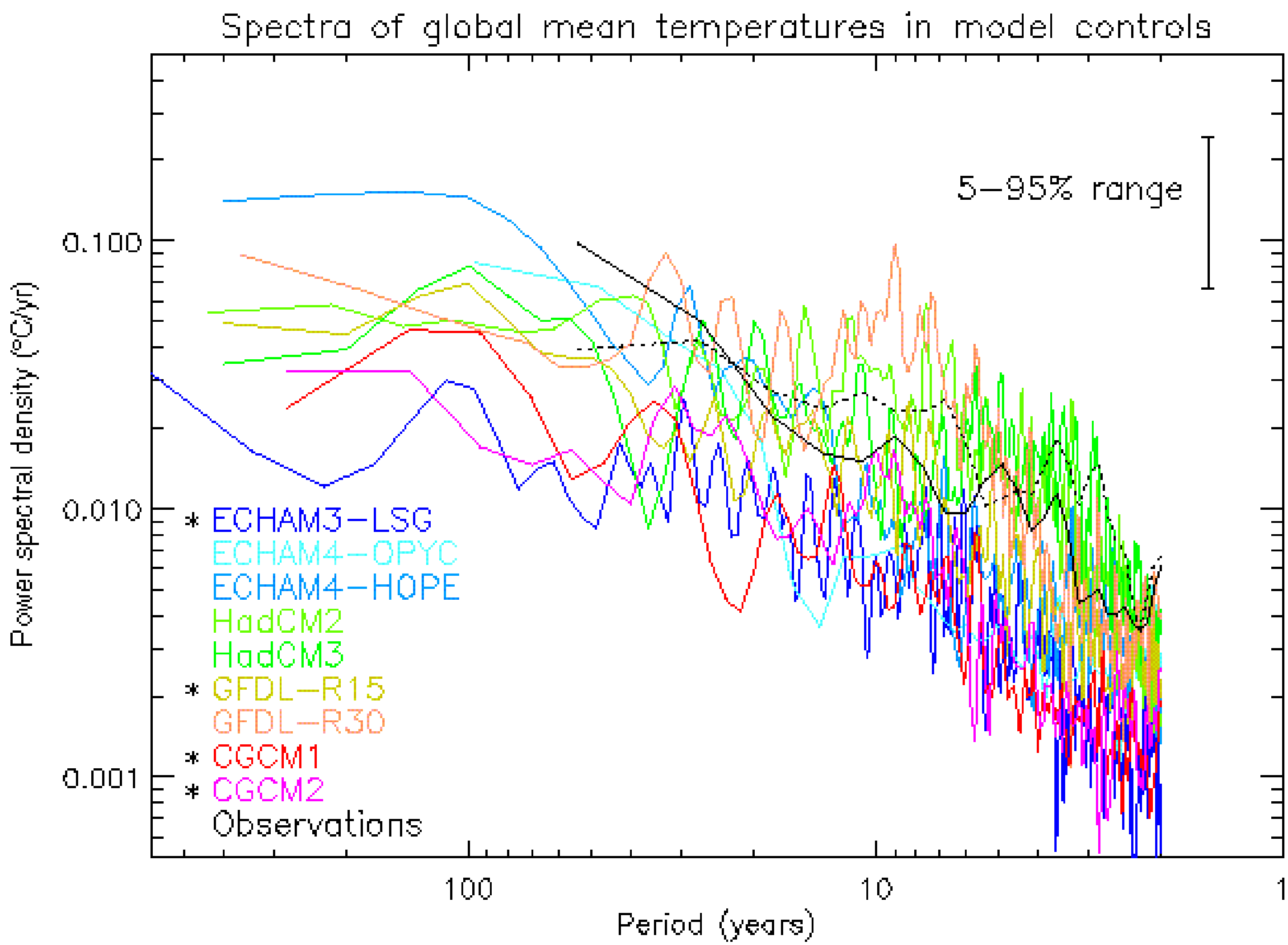
In examining a record like this one, how much of the observed variability is forced and how much of it is free?

Key Difficulties in Detection of Natural Climate Variability

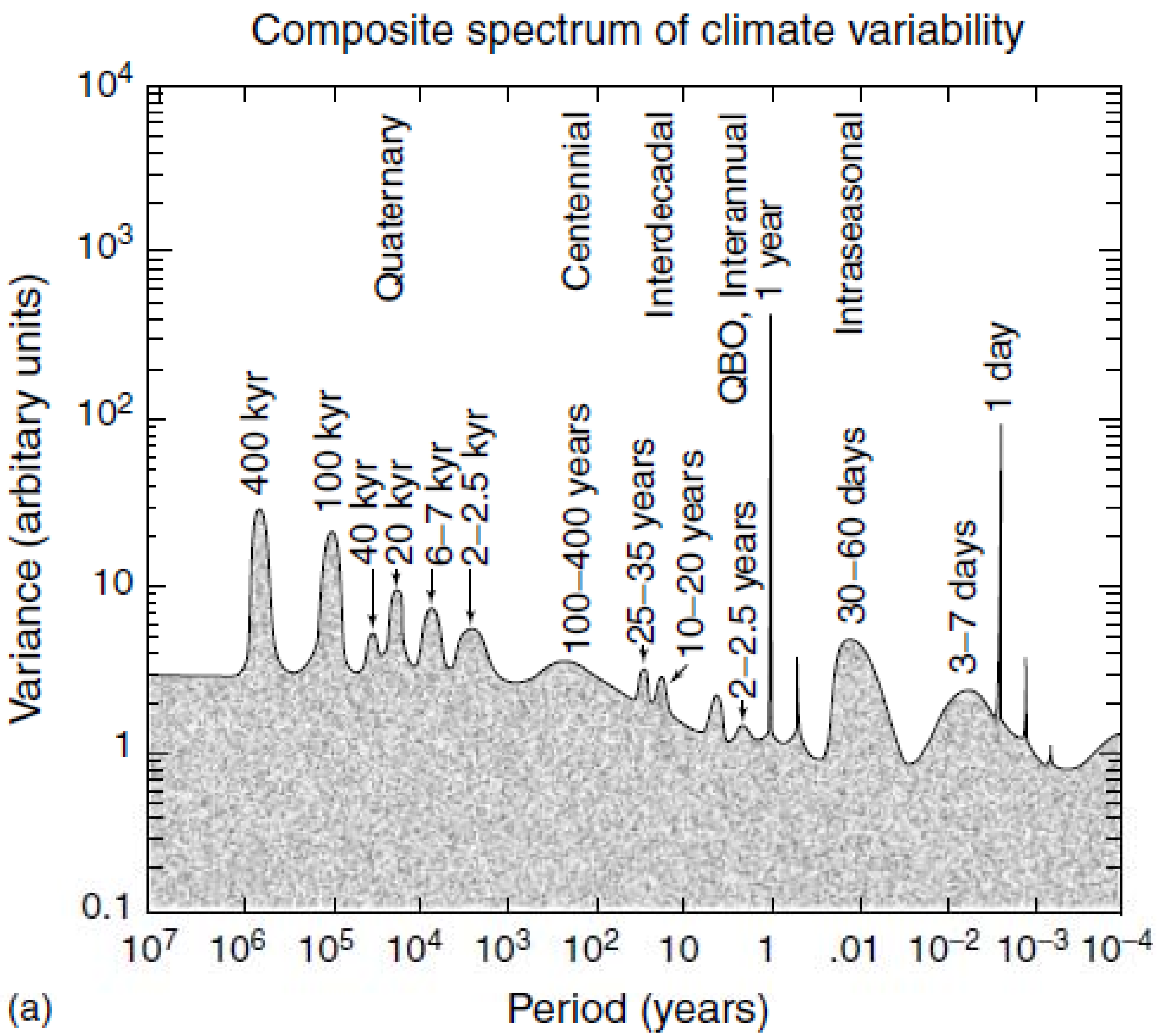
- Reliable instrumental records extend back only ~150 years and are spatially inhomogeneous
- Satellite records ~30 years
- Proxies at various time scales, but spatially inhomogeneous
- Potentially large and uncertain variations in forcings



Global mean surface air temperature anomalies from 1000-year control simulations with three different climate models, HadCM2, GFDL R15 and ECHAM3/LSG (labelled HAM3L), compared to the recent instrumental record.

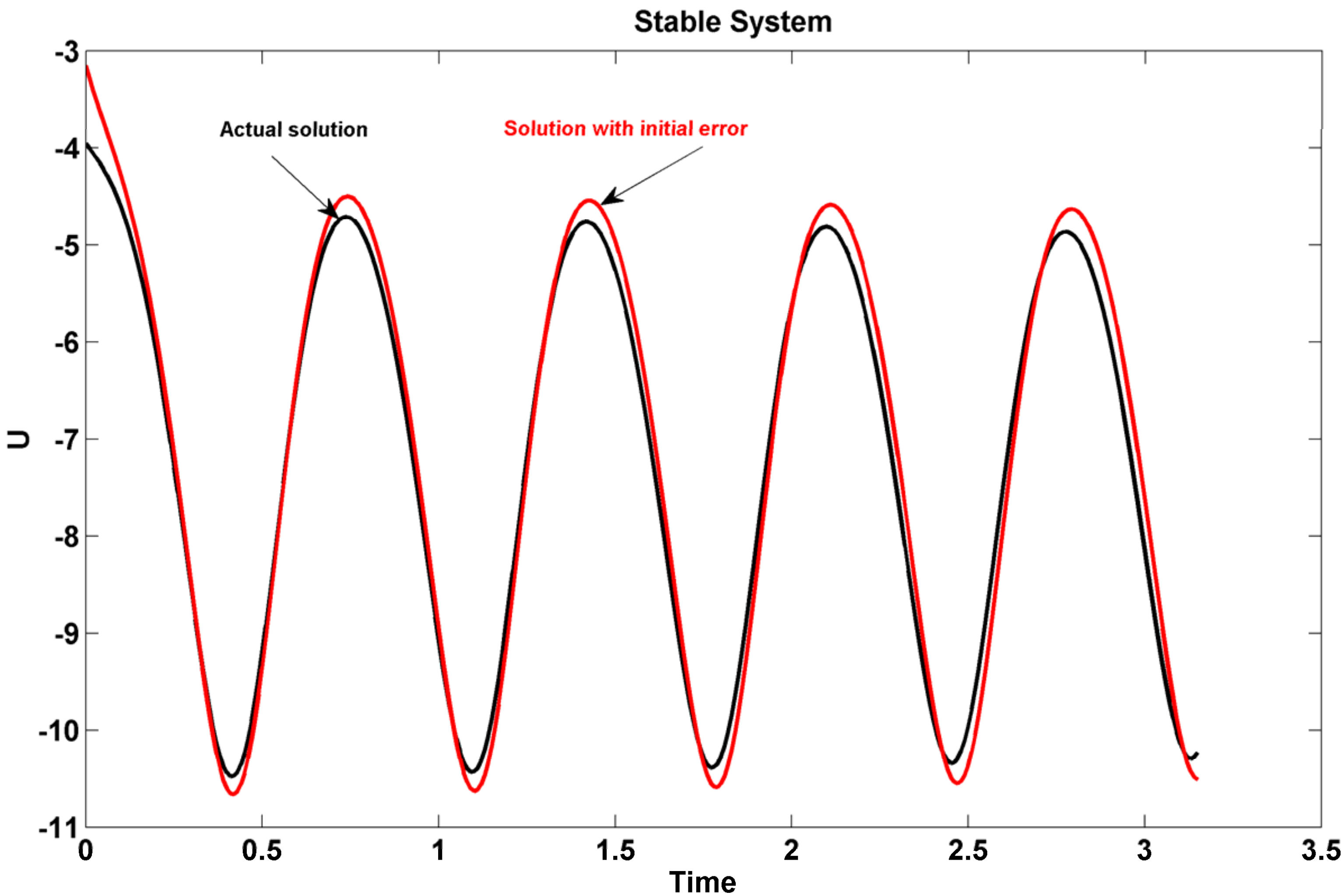


Colored lines: Power spectra of global mean temperatures in the unforced control integrations that are used to provide estimates of internal climate variability. Solid black line: spectrum of observed global mean temperatures over the period 1861-1998 after removing a best-fit linear trend. Dotted black line: spectrum of observed global mean temperatures after removing an independent estimate of the externally-forced response provided by the ensemble mean of a coupled model simulation. Asterisks indicate models whose variability is significantly less than observed variability on 10-60-year timescales after removing either a best-fit linear trend or an independent estimate of the forced response from the observed series.

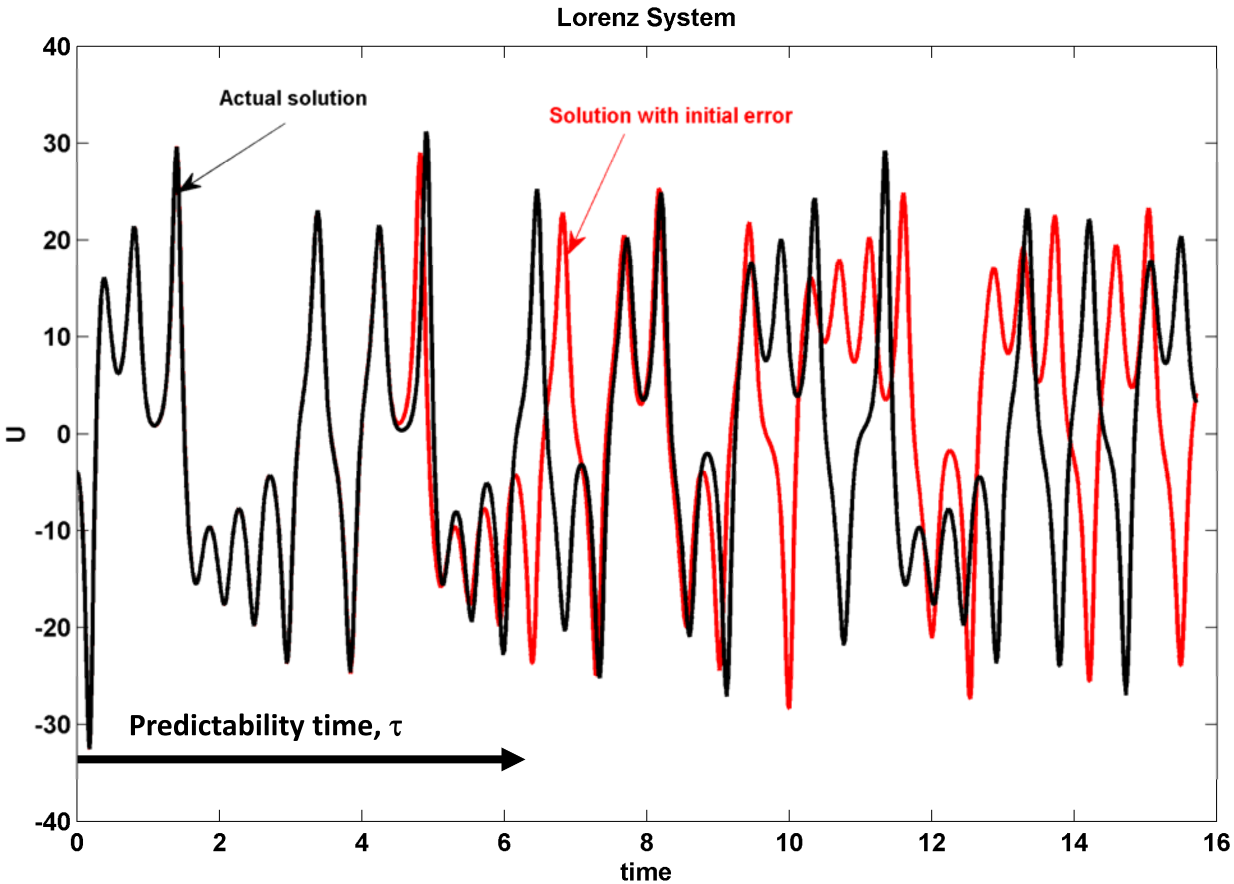

Composite spectrum of climate variability
Variance (arbitary units)
Period (years)
10^4
10^3
10^2
10
1
0.1
10^7
10^6
10^5
10^4
10^3
10^2
10
1
.01
10^-2
10^-3
10^-4
Quaternary
Centennial
Interdecadal
QBO, Interannual
1 year
Intraseasonal
1 day
400 kyr
100 kyr
40 kyr
20 kyr
6–7 kyr
2–2.5 kyr
100–400 years
25–35 years
10–20 years
2–2.5 years
30–60 days
3–7 days
(a)

Periodic vs. Chaotic Dynamics

Deterministic versus chaotic dynamics

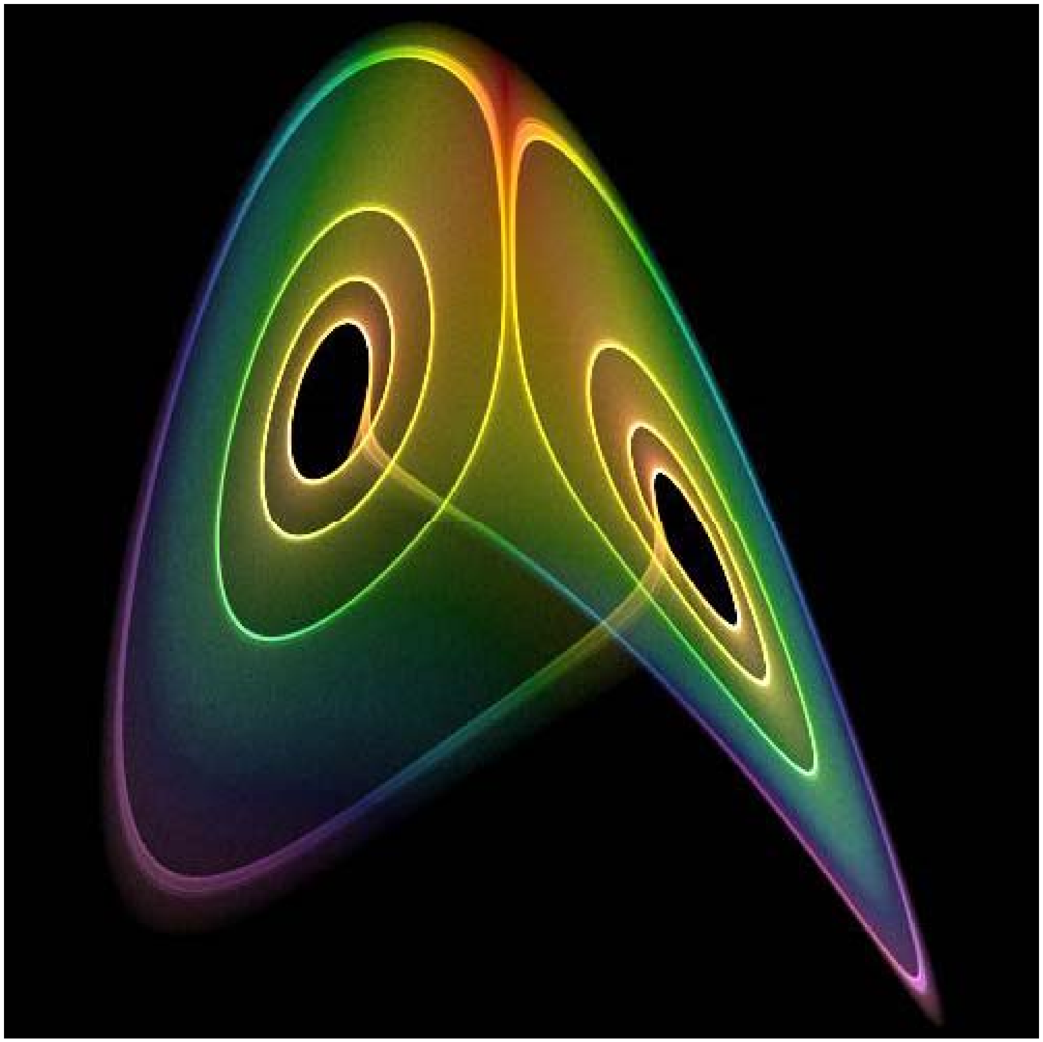


Chaotic Dynamics



$$Note: \quad \lim_{\varepsilon \to 0}(\tau) = \tau_{pre} \neq 0$$

lorenzgui in MATLAB



$$\frac{dx}{dt} = \sigma\left(y - x\right)$$

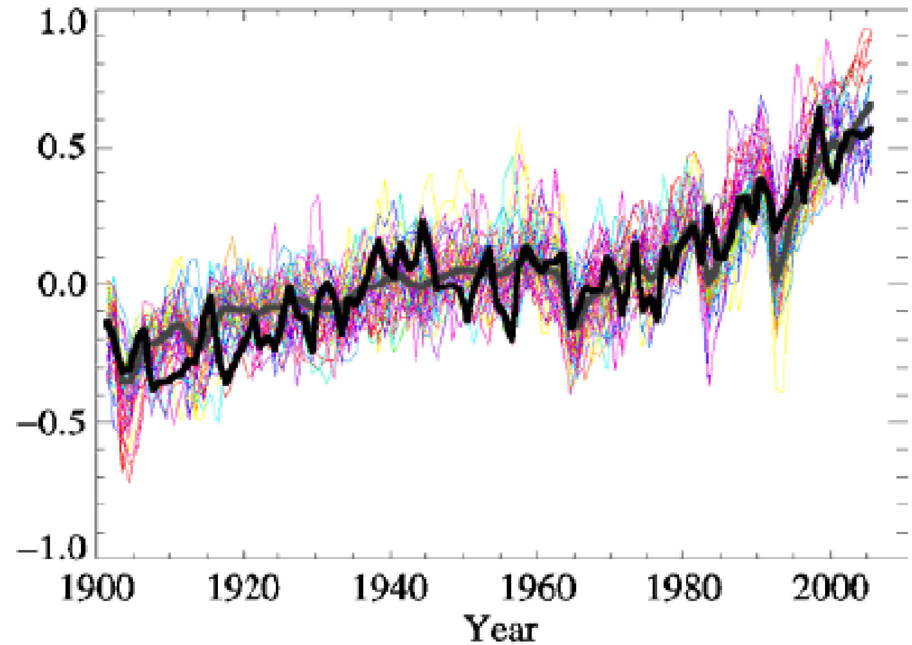
$$\frac{dy}{dt} = x\left(p - z\right) - y$$

$$\frac{dz}{dt} = xy - \beta z$$

Climate chaos

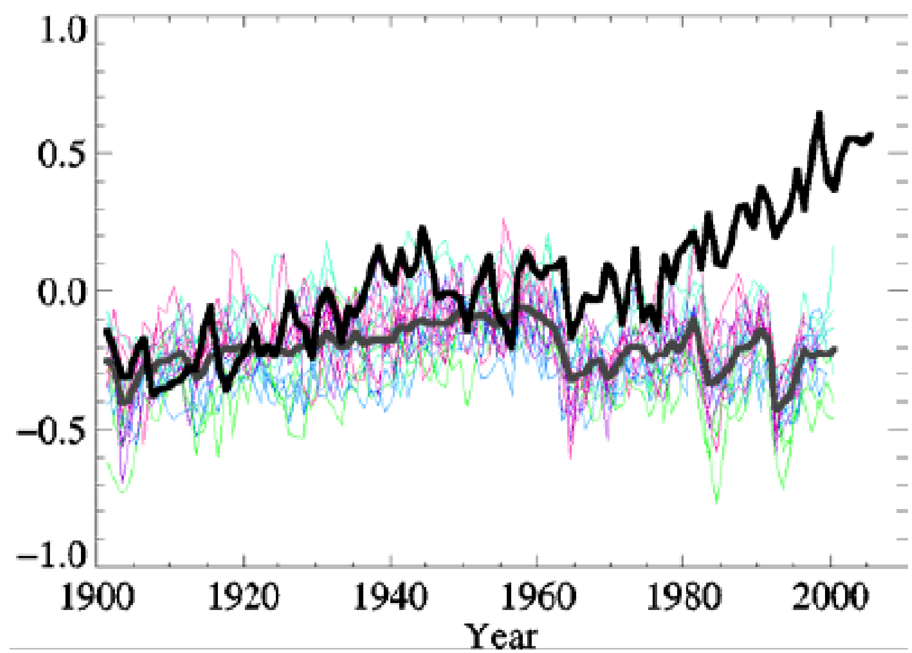
- Atmosphere known to be chaotic on time scales at least as large as several months
- Ocean known to be chaotic on time scales of at least 6 months and perhaps as long as hundreds of years
- Coupled atmosphere-ocean system may be chaotic on time scales as long as several thousand years

Global mean temperature (black) and simulations using many different global models (colors) including all forcings



To quantify natural, chaotic variability, necessary to run large ensembles

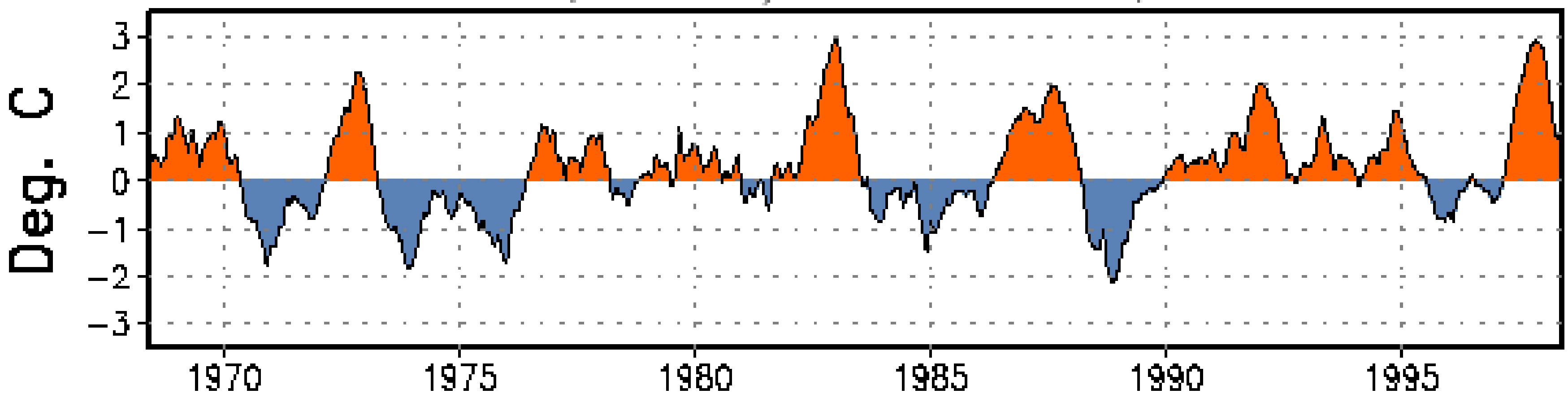
Same as above, but models run with only natural forcings



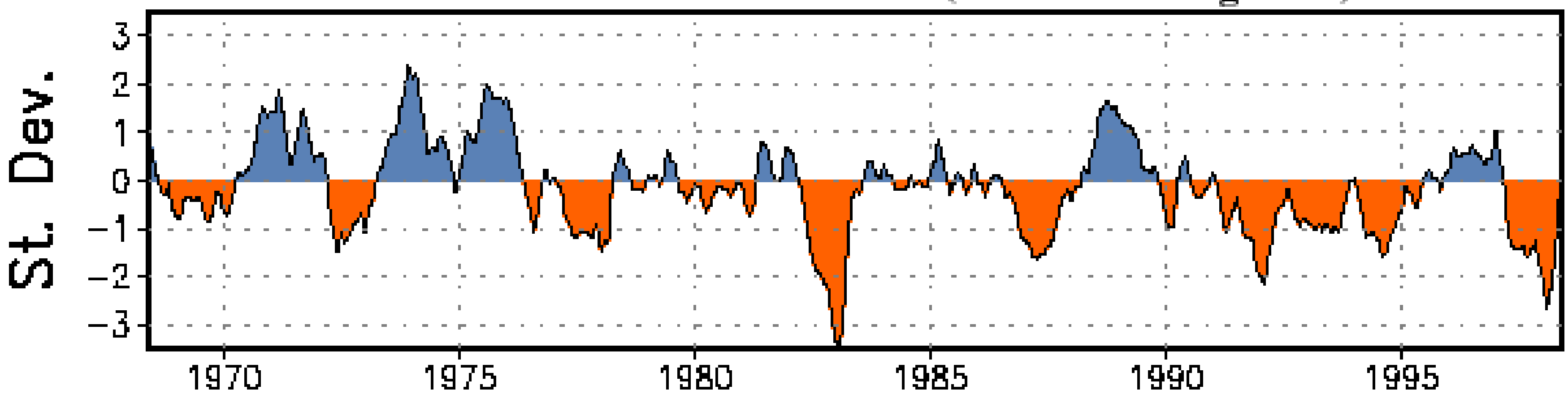
Quasi-Periodic Climate Fluctuations

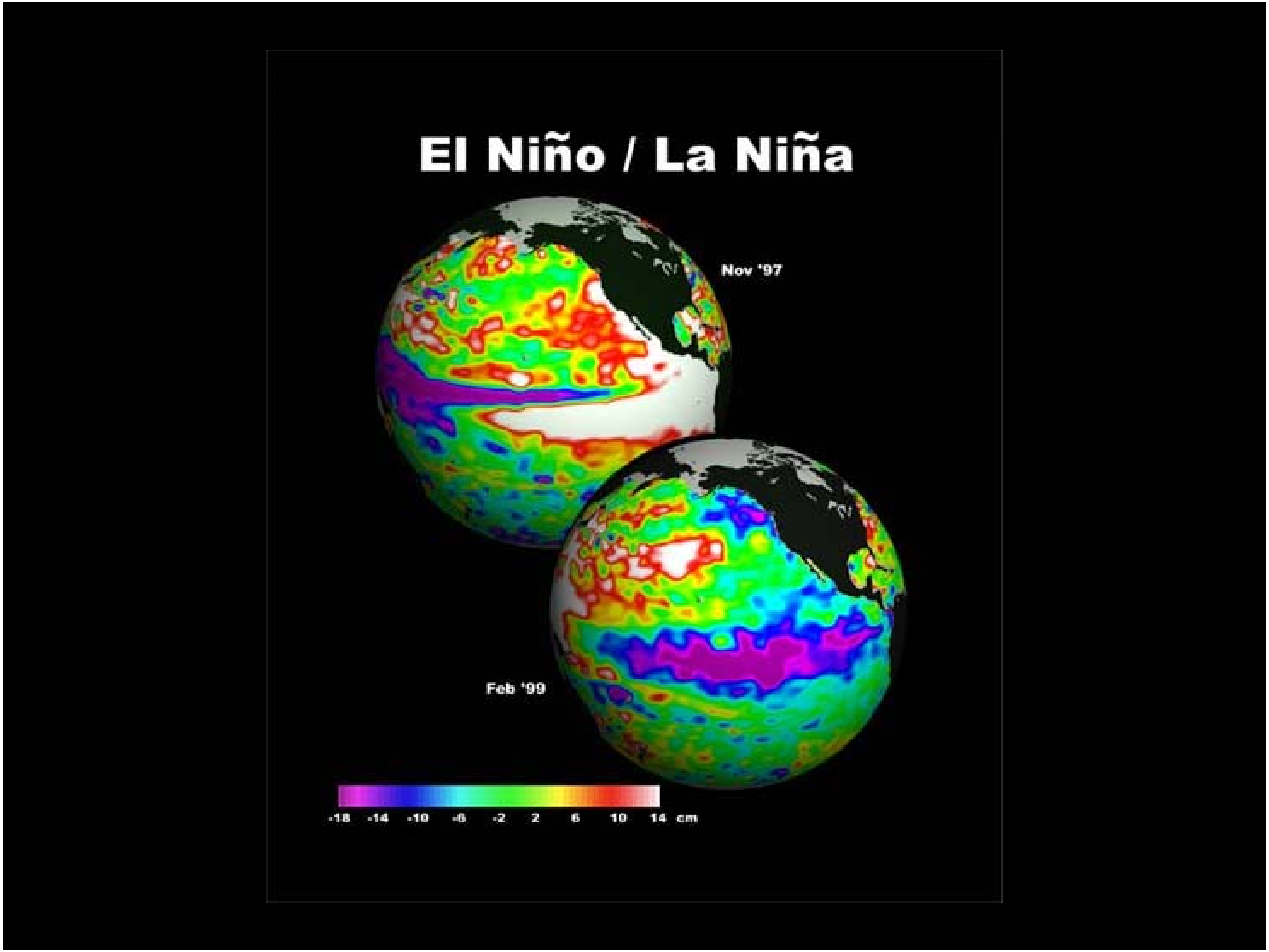
El Niño/Southern Oscillation (ENSO)

Ocean Temperature Departures (˚C) for Niño 3.4
(5˚N-5˚S, 170˚W-120˚W)

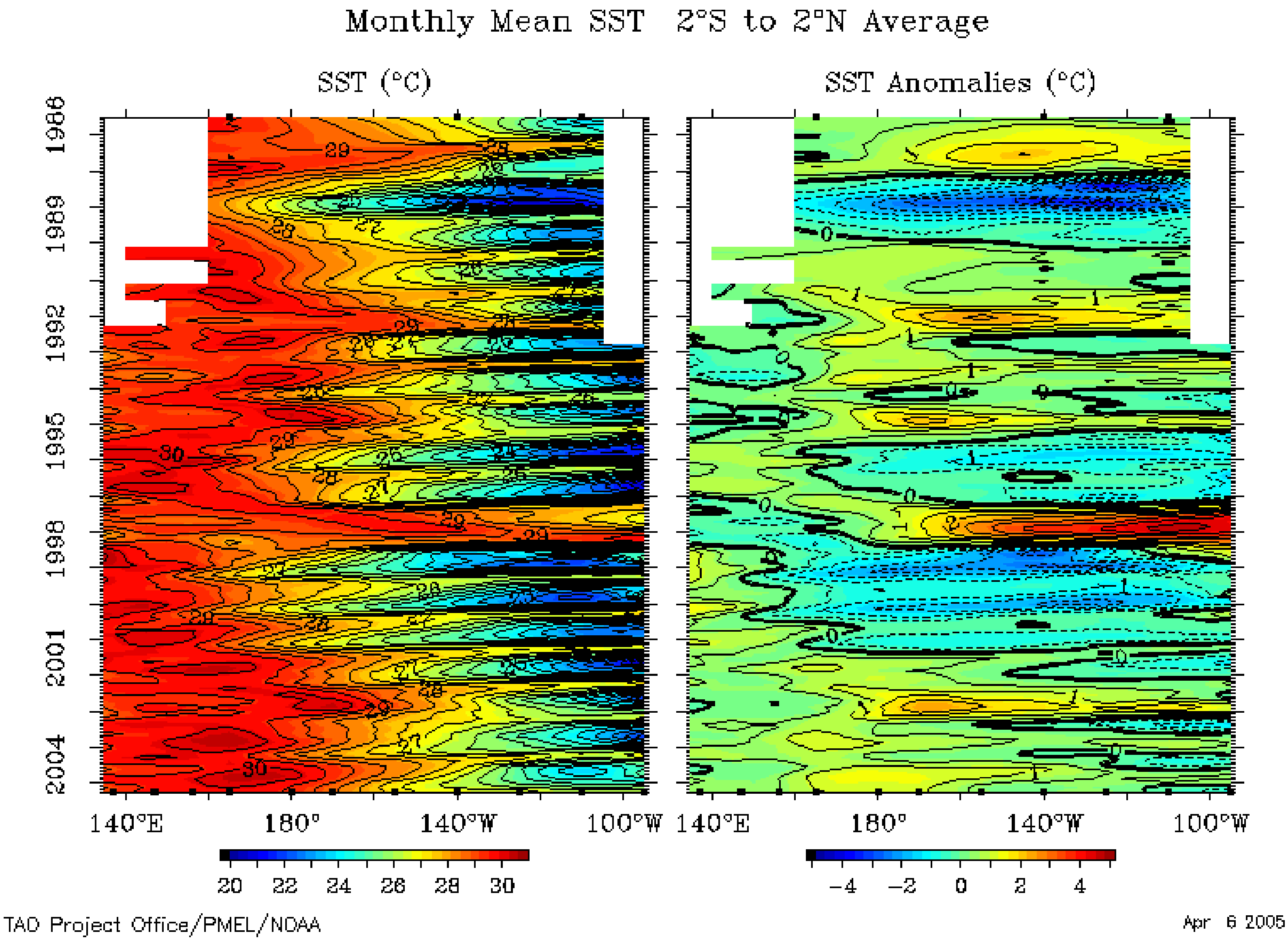


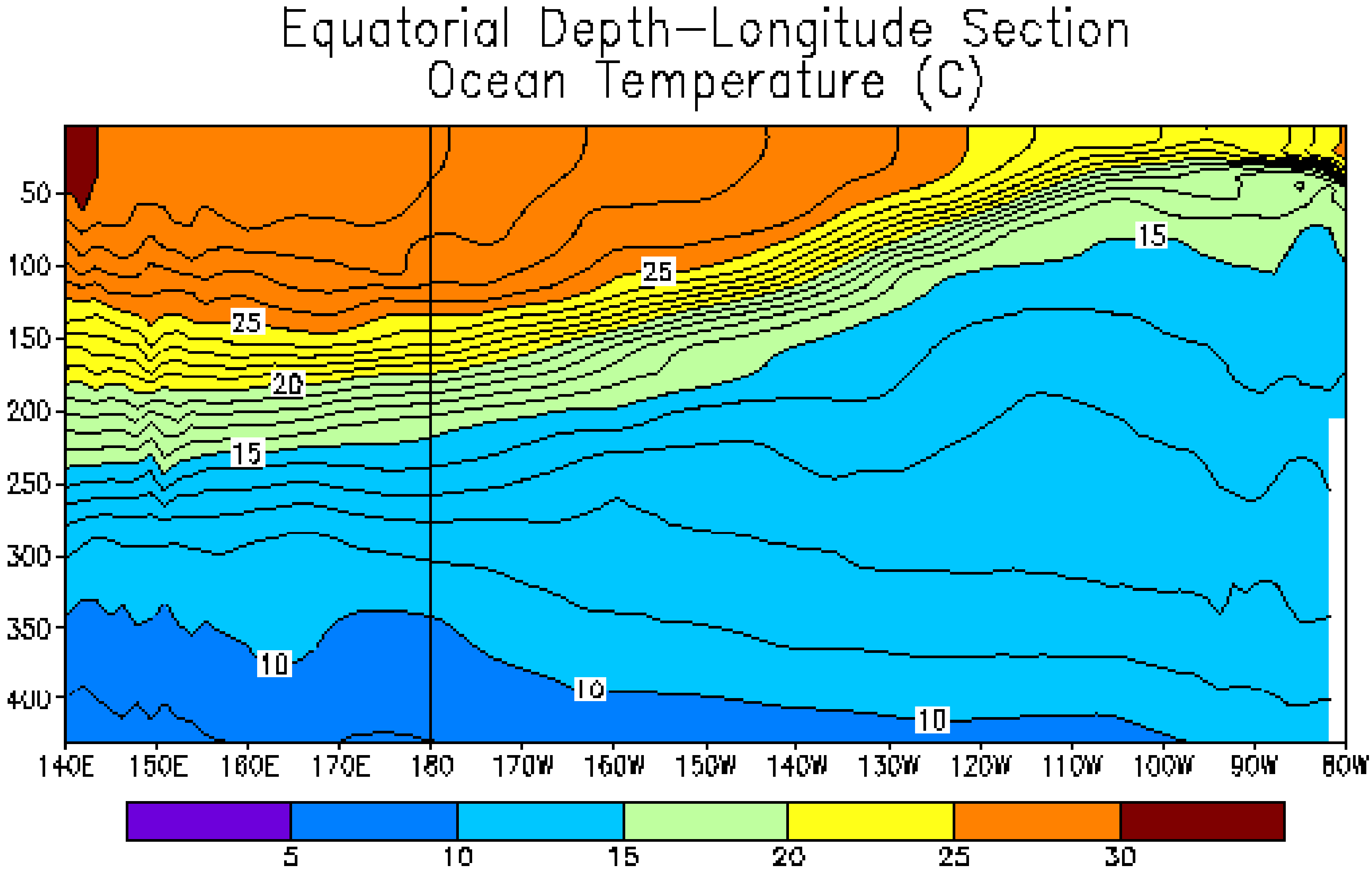
Tahiti - Darwin SOI (3 month-running mean)



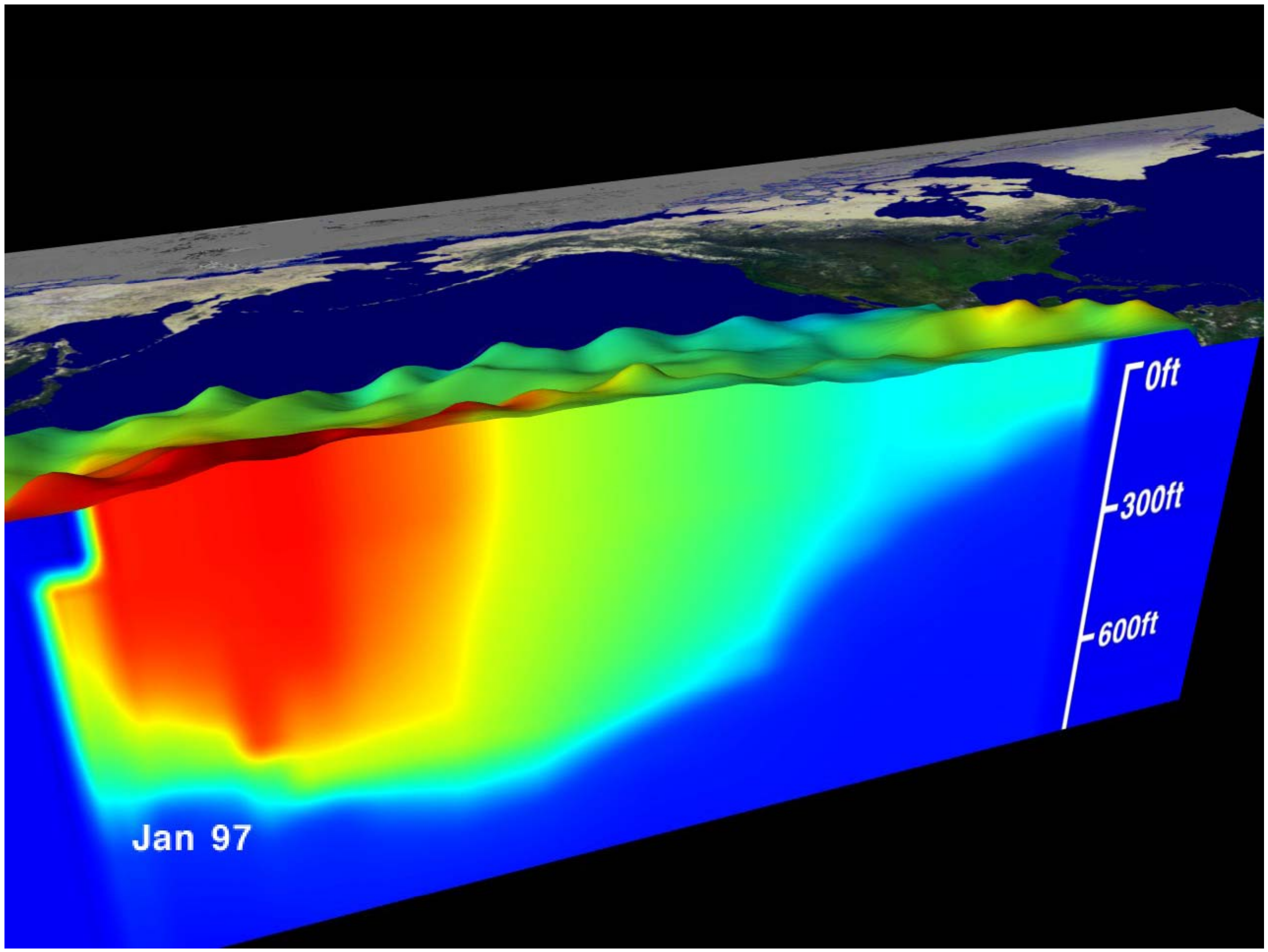

El Niño / La Niña
Nov '97
Feb '99
-18 -14 -10 -6 -2 2 6 10 14 cm

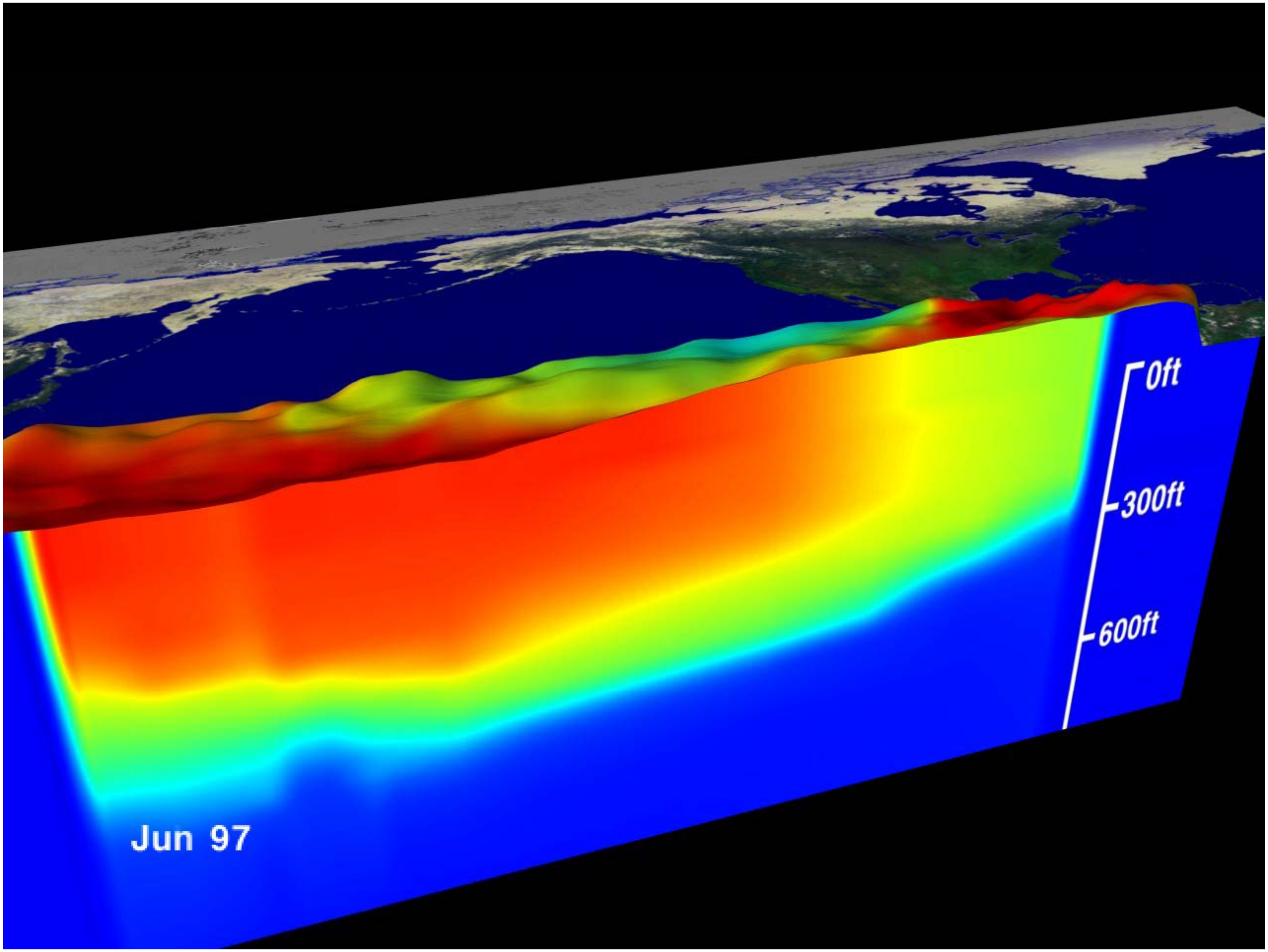
Large excursions of SST in central and eastern equatorial Pacific:



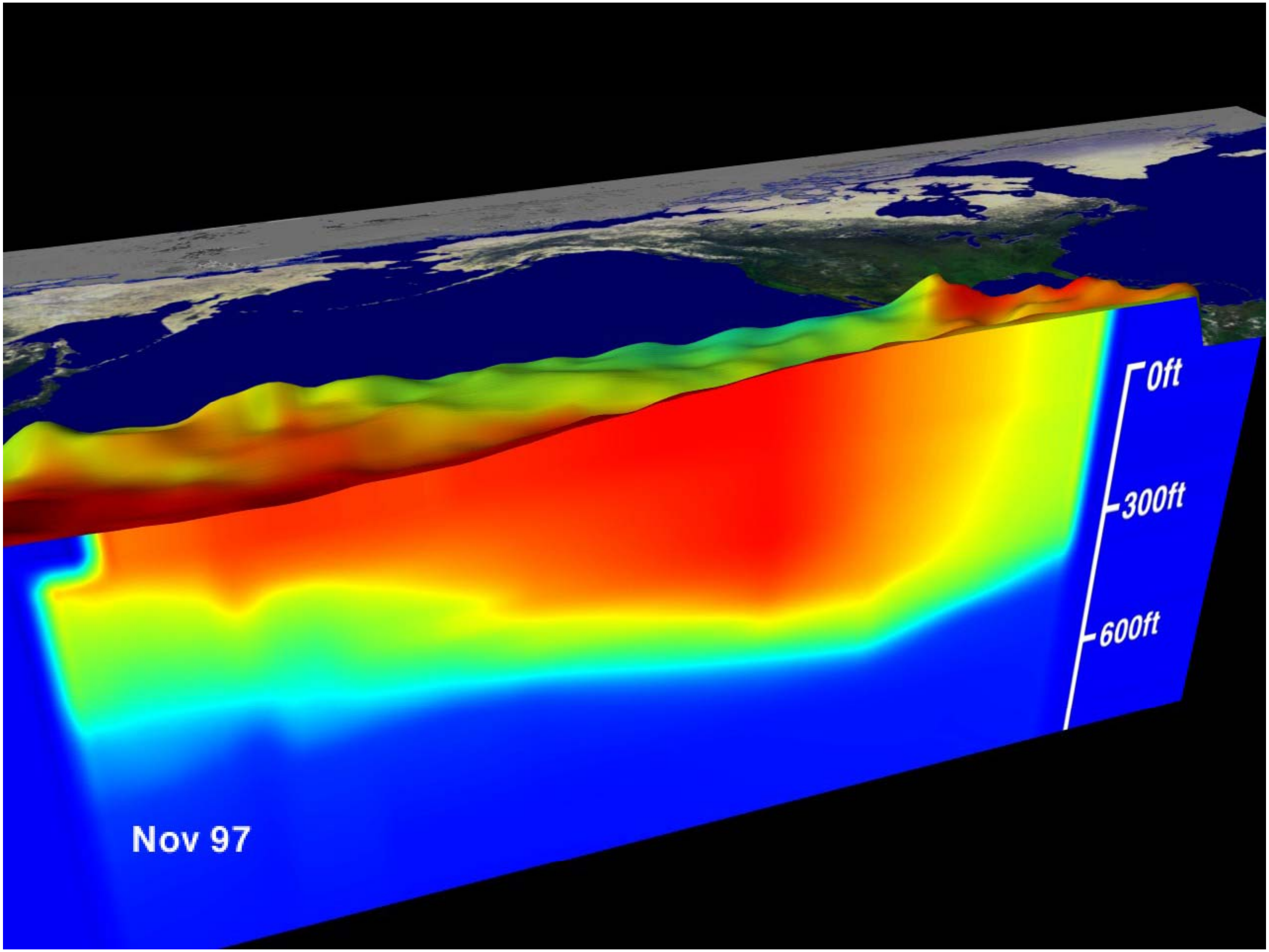

Equatorial Depth-Longitude Section
Ocean Temperature (C)
50
100
150
200
250
300
350
400
25
25
20
15
15
10
10
10
140E
150E
160E
170E
180
170W
160W
150W
140W
130W
120W
110W
100W
90W
80W
5
10
15
20
25
30

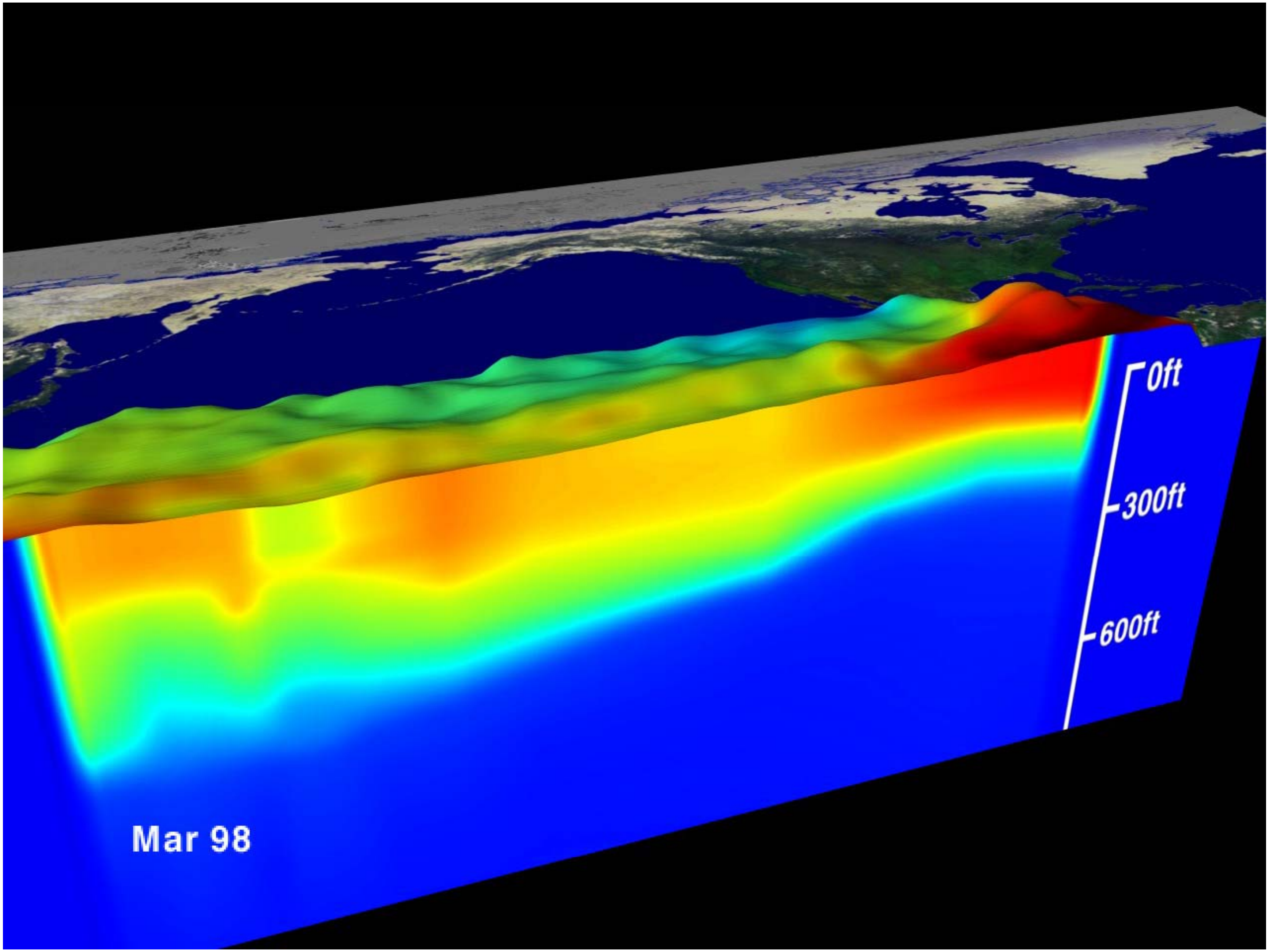
Accompanied by large excursions of equatorial thermocline:



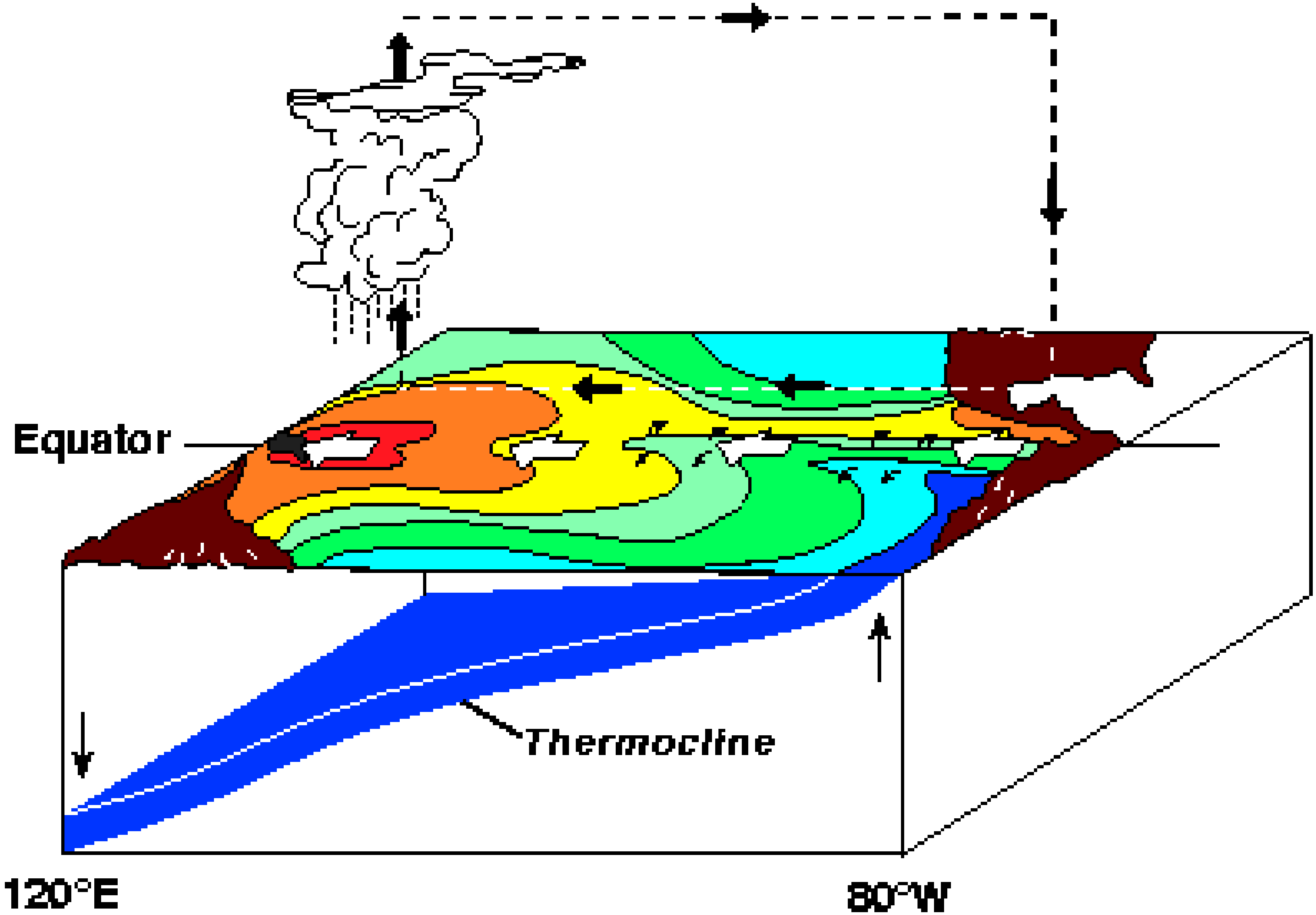


0ft
300ft
600ft
Jun 97

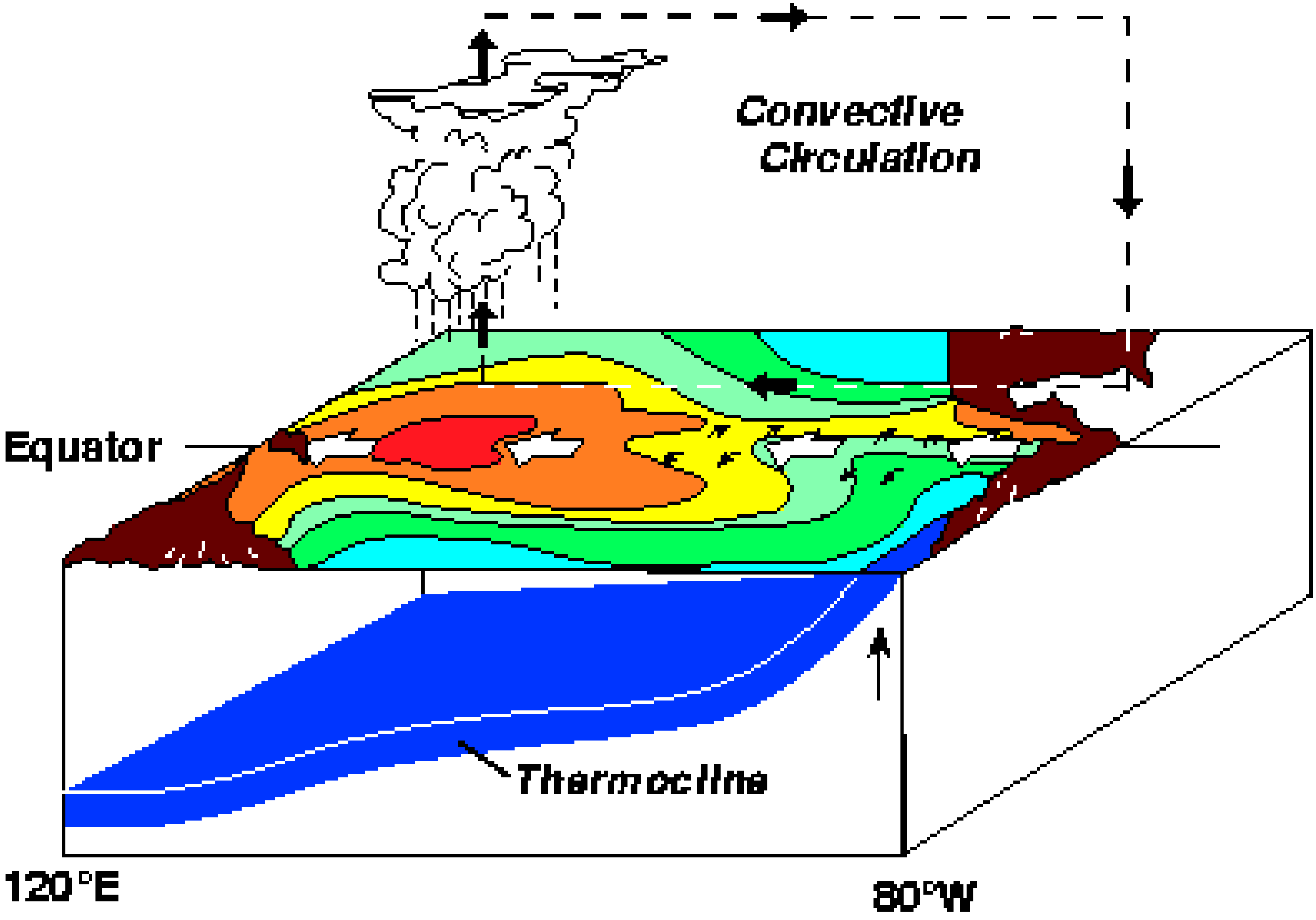

0ft
300ft
600ft
Nov 97


0ft
300ft
600ft
Mar 98

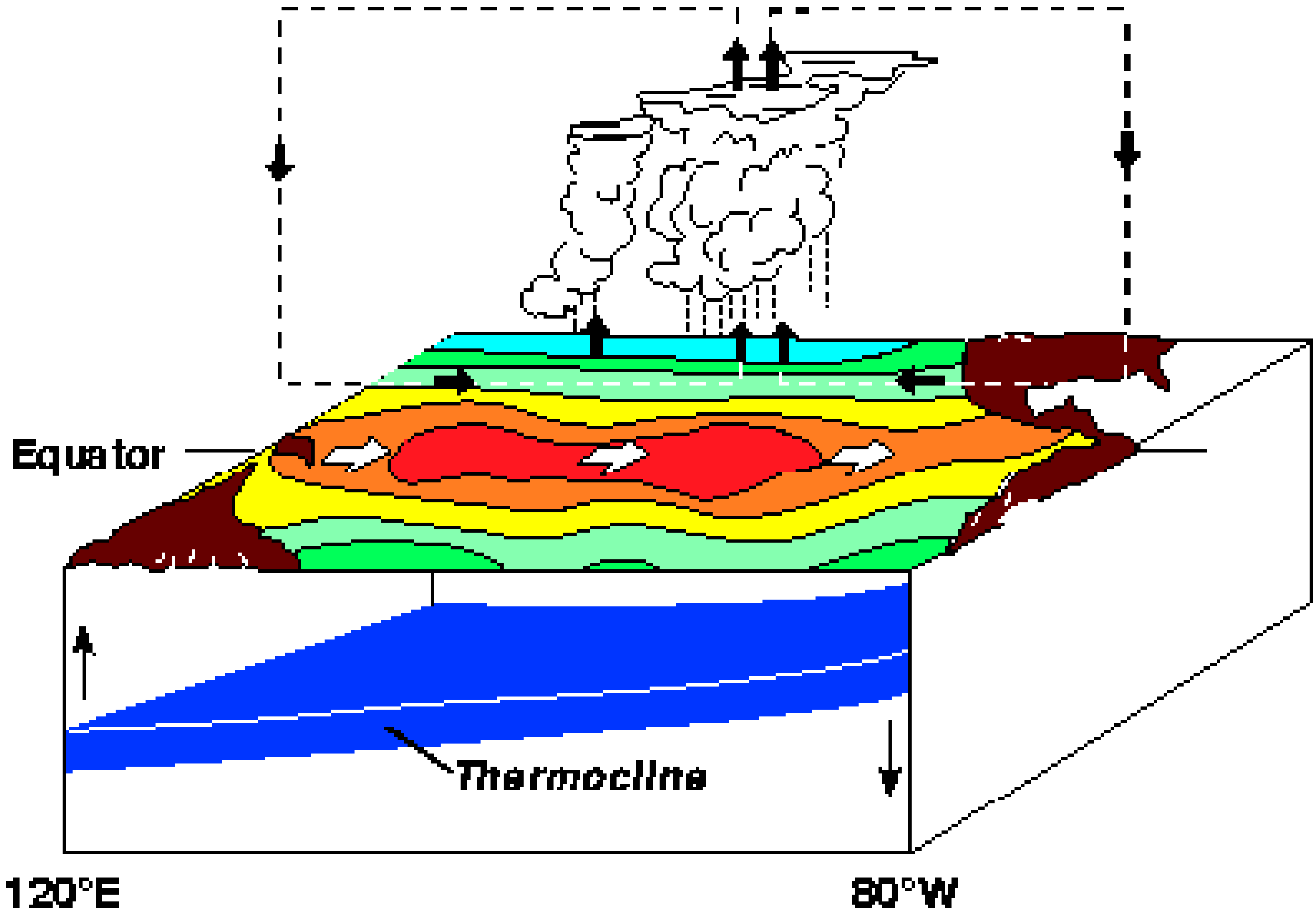
La Niña Conditions

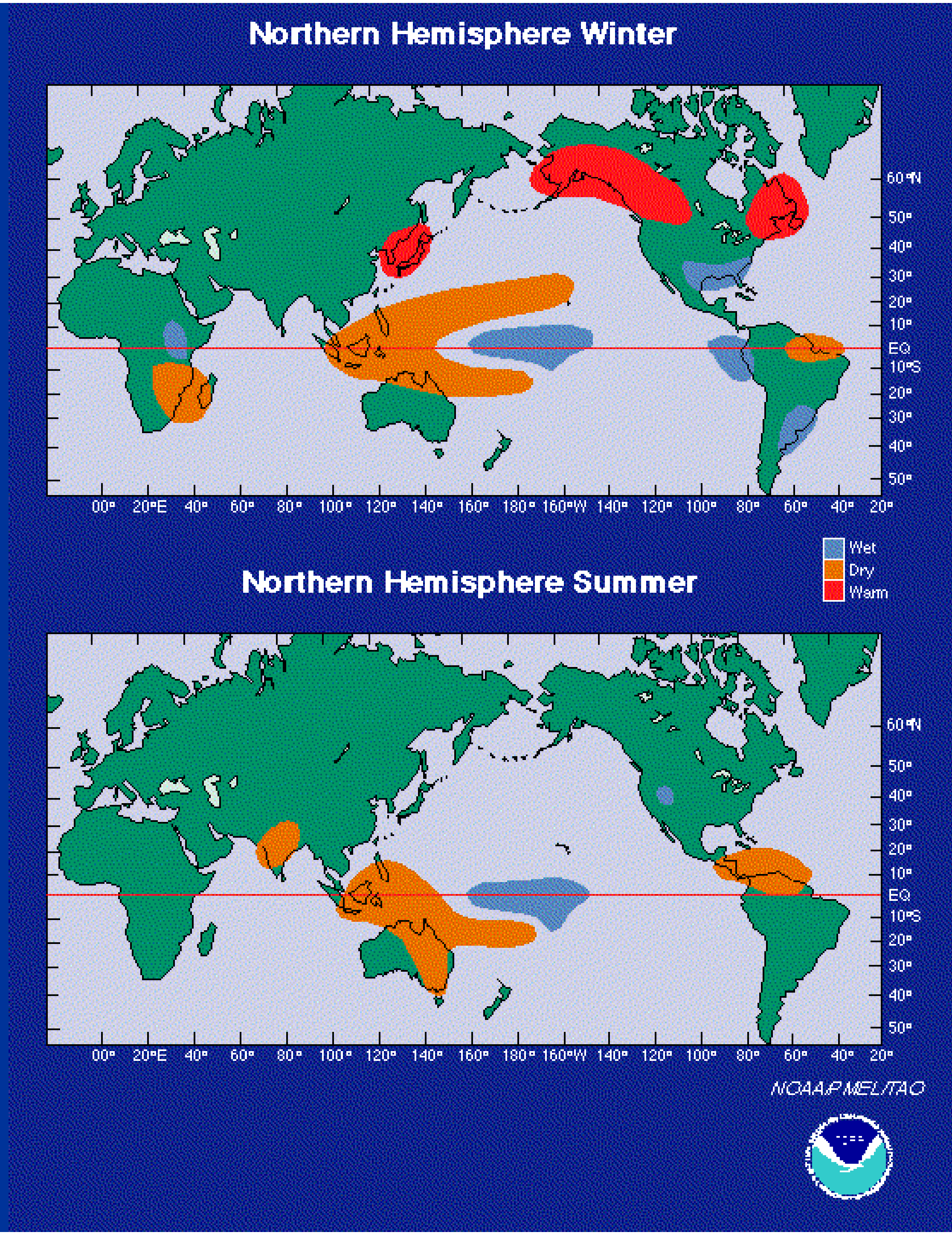


Normal Conditions



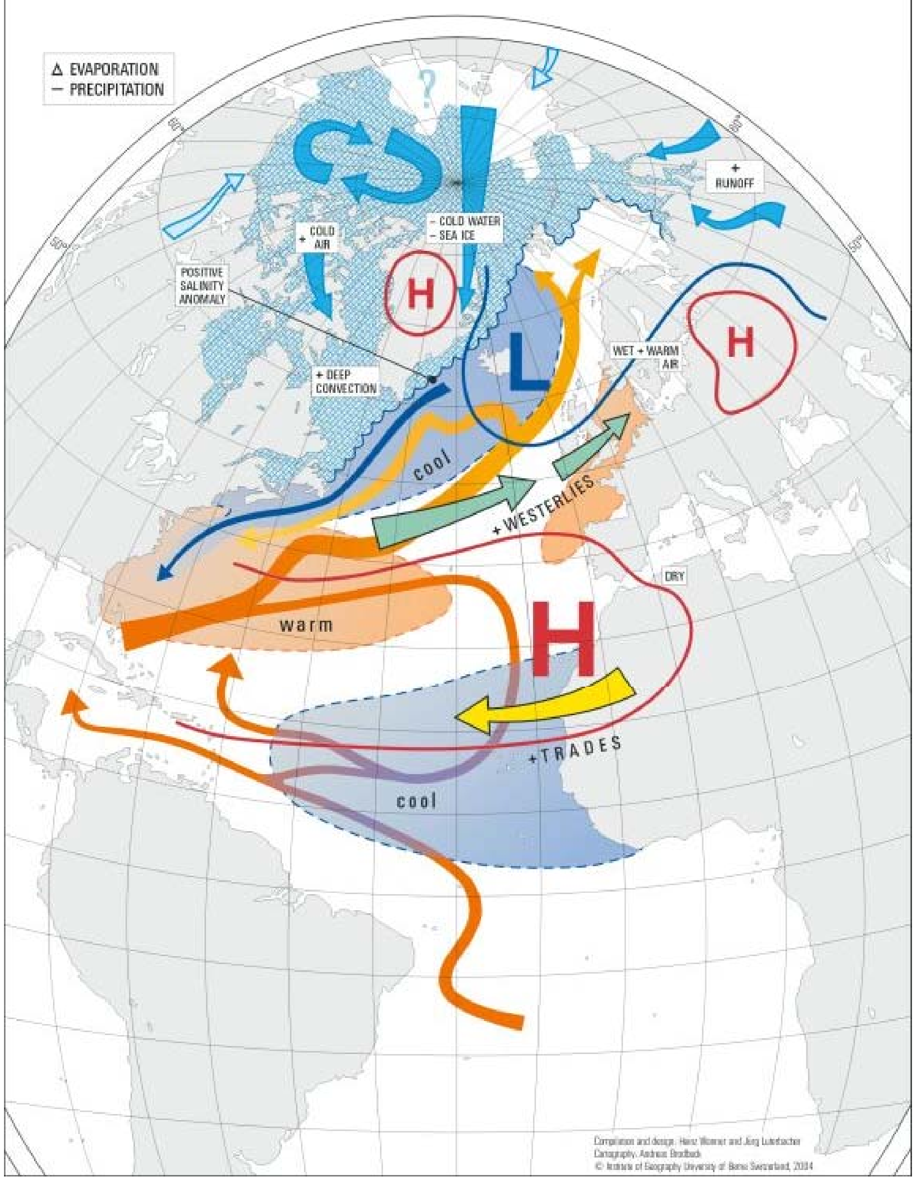
El Niño Conditions




Northern Hemisphere Winter
Northern Hemisphere Summer
Wet
Dry
Warm
60°N 50° 40° 30° 20° 10° EQ 10°S 20° 30° 40° 50°
00° 20°E 40° 60° 80° 100° 120° 140° 160° 180° 160°W 140° 120° 100° 80° 60° 40° 20°
NOAA/PMEL/TAO

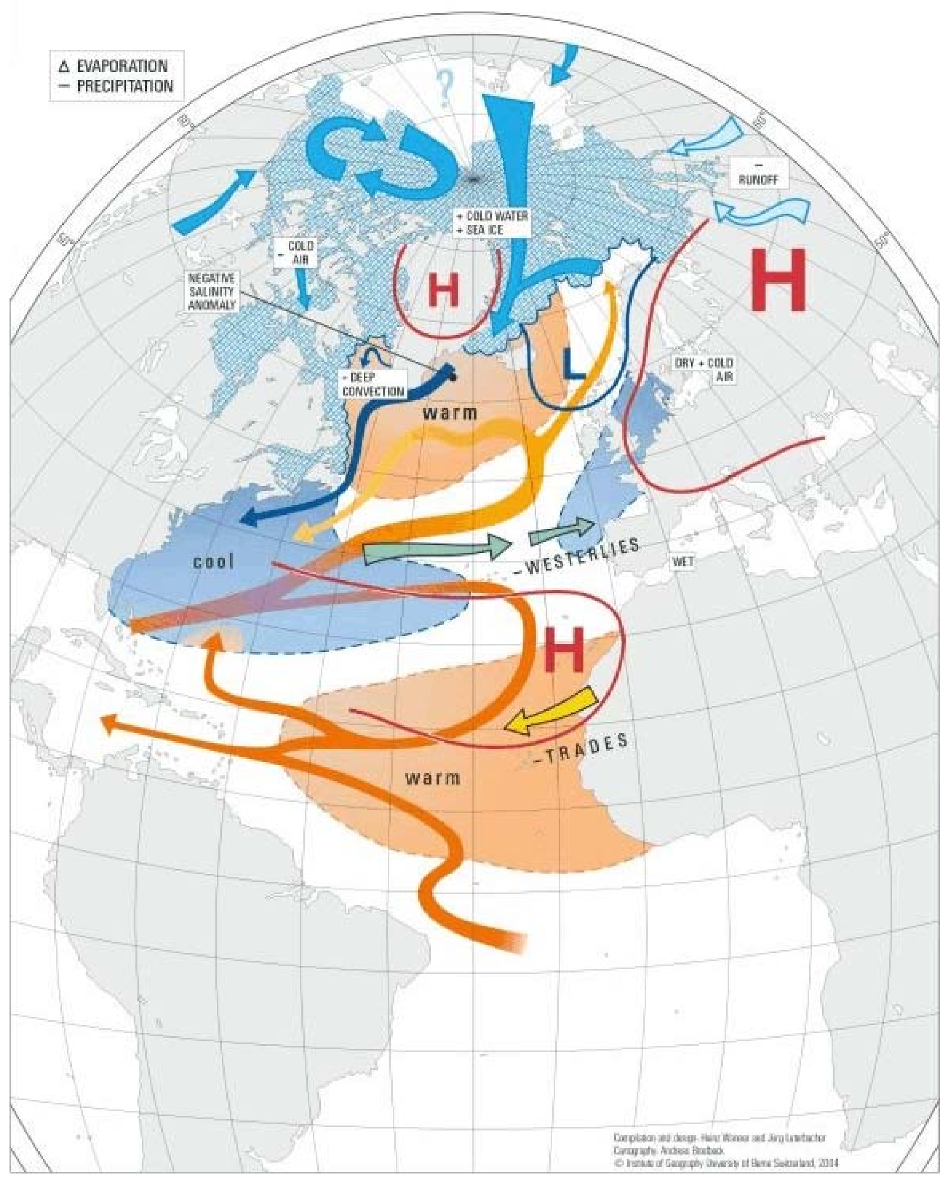
The North Atlantic Oscillation

NAO +



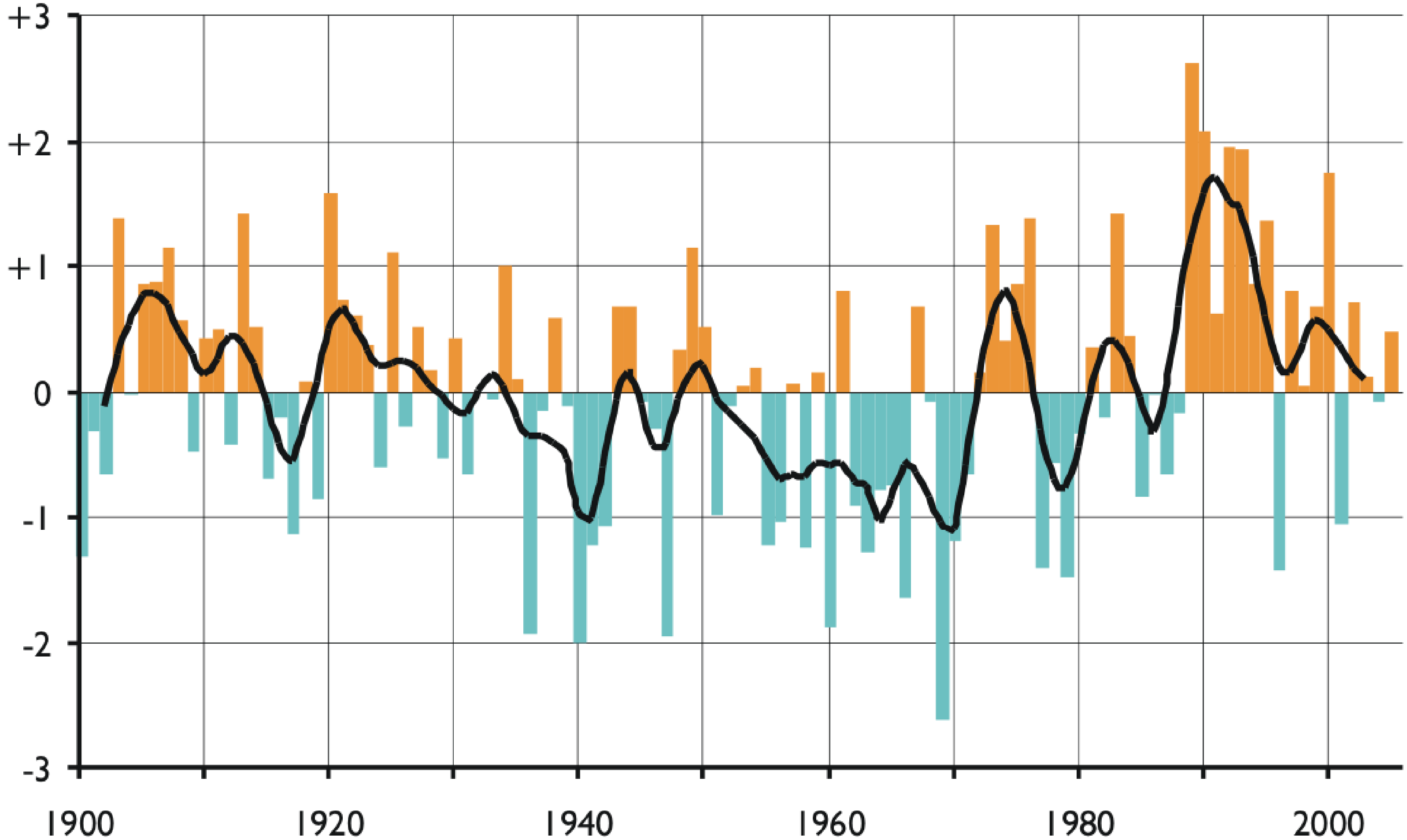
Δ EVAPORATION
— PRECIPITATION
?
+ RUNOFF
– COLD WATER
– SEA ICE
+ COLD AIR
POSITIVE SALINITY ANOMALY
H
L
H
+ DEEP CONVECTION
WET + WARM AIR
cool
+ WESTERLIES
DRY
warm
H
+ TRADES
cool
Compilation and design: Heinz Wanner and Jürg Luterbacher
Cartography: Andreas Brodbeck
© Institute of Geography University of Berne Switzerland, 2004

NAO -



Δ EVAPORATION
— PRECIPITATION
?
– RUNOFF
+ COLD WATER
+ SEA ICE
– COLD AIR
NEGATIVE SALINITY ANOMALY
H
H
L
– DEEP CONVECTION
warm
DRY + COLD AIR
cool
– WESTERLIES
WET
H
– TRADES
warm
Compilation and design: Heinz Wanner and Jürg Luterbacher
Cartography: Andreas Brodbeck
© Institute of Geography University of Berne Switzerland, 2004

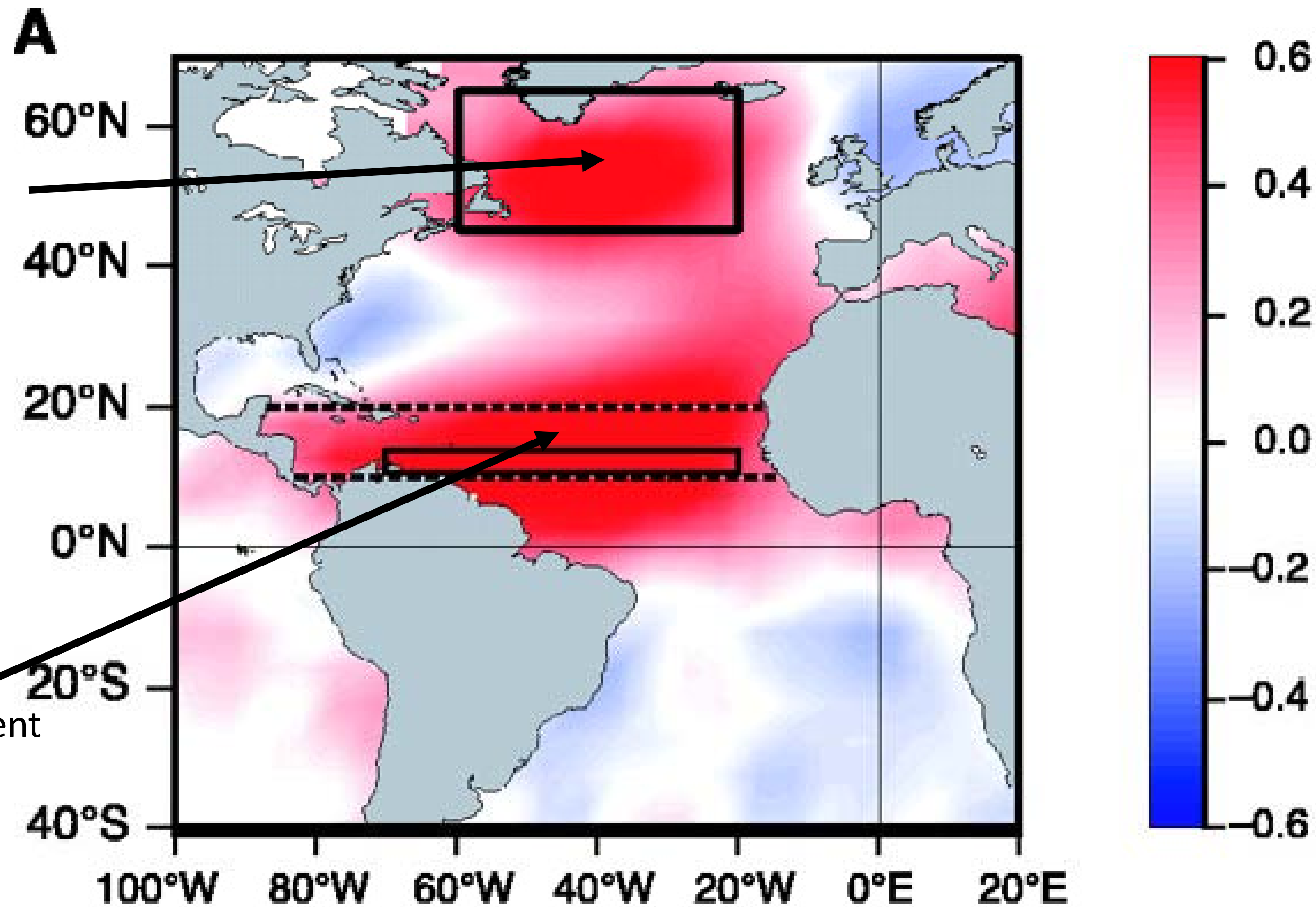
NAO Index (Principal Component)



The Atlantic Multidecadal Oscillation: The Dangers of Overinterpreting Data

Third rotated EOF of the non-ENSO residual 1856-1991 de-trended SST data. From Goldenberg et al., 2001, adapted from Enfield et al., 1999, *J. Climate*

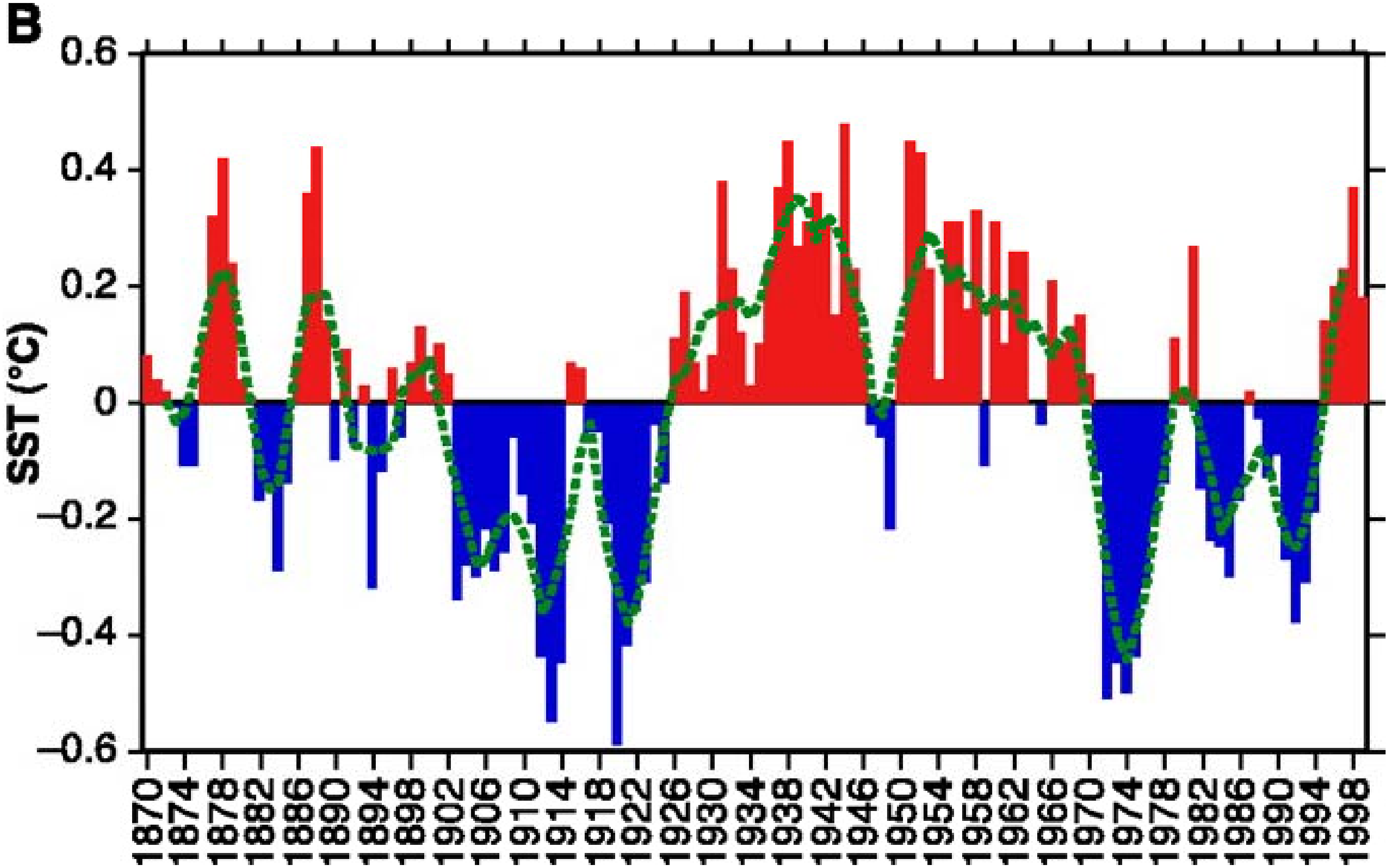
High-latitude North Atlantic



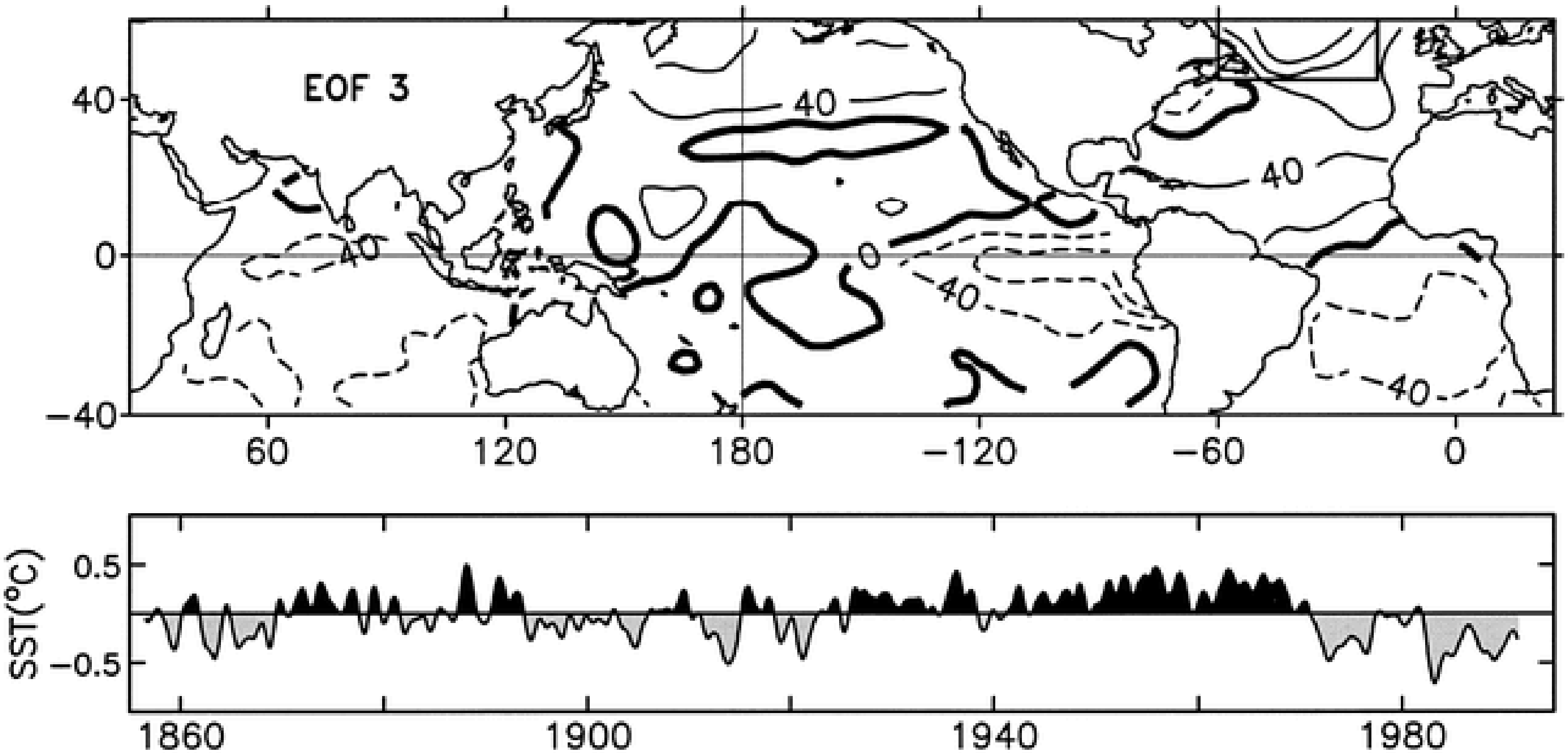
"Main development region"

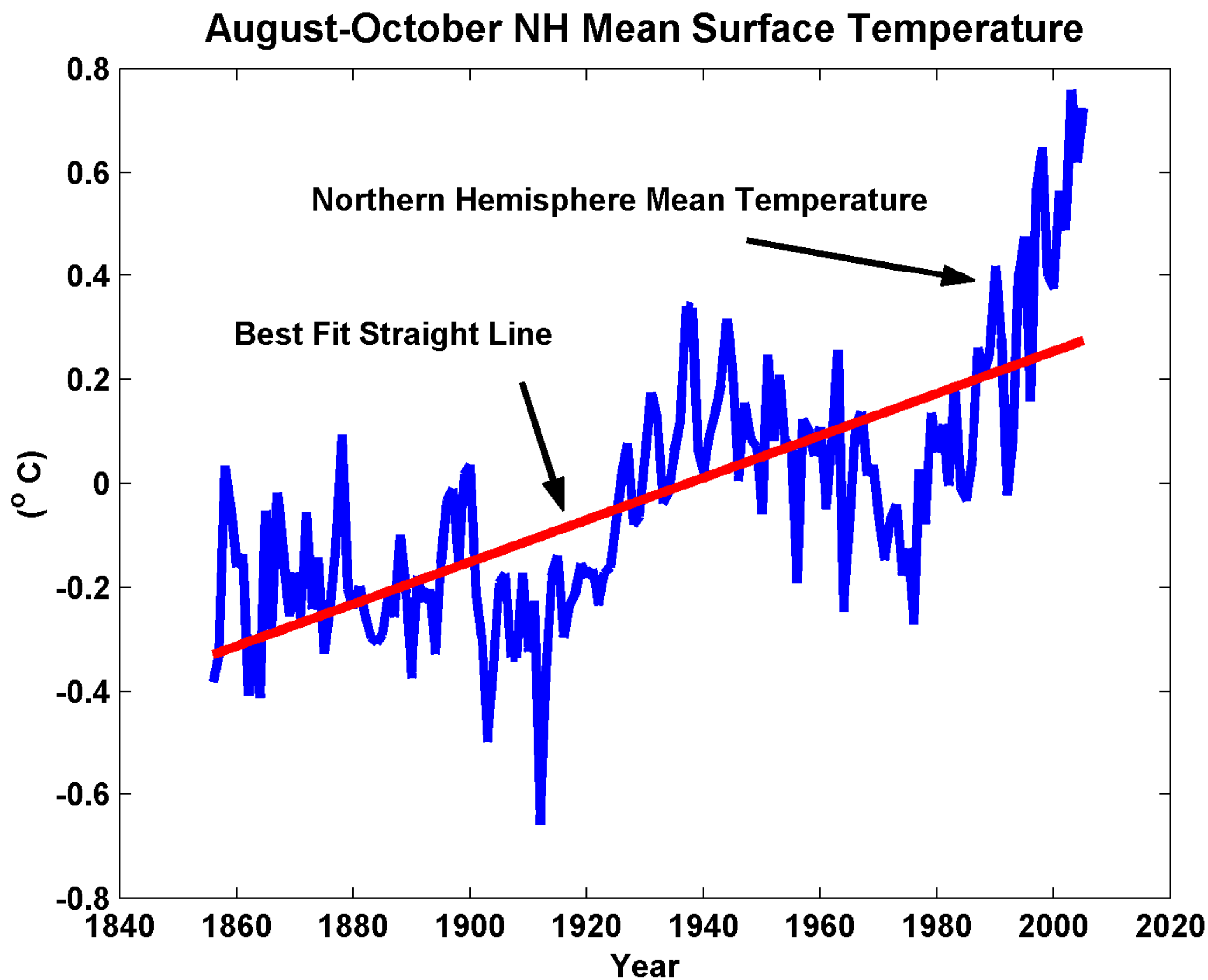
S. B. Goldenberg et al., Science 293, 474 -479 (2001)

Variation with time of amplitude of third rotated EOF of the non-ENSO residual 1856-1991 de-trended SST data



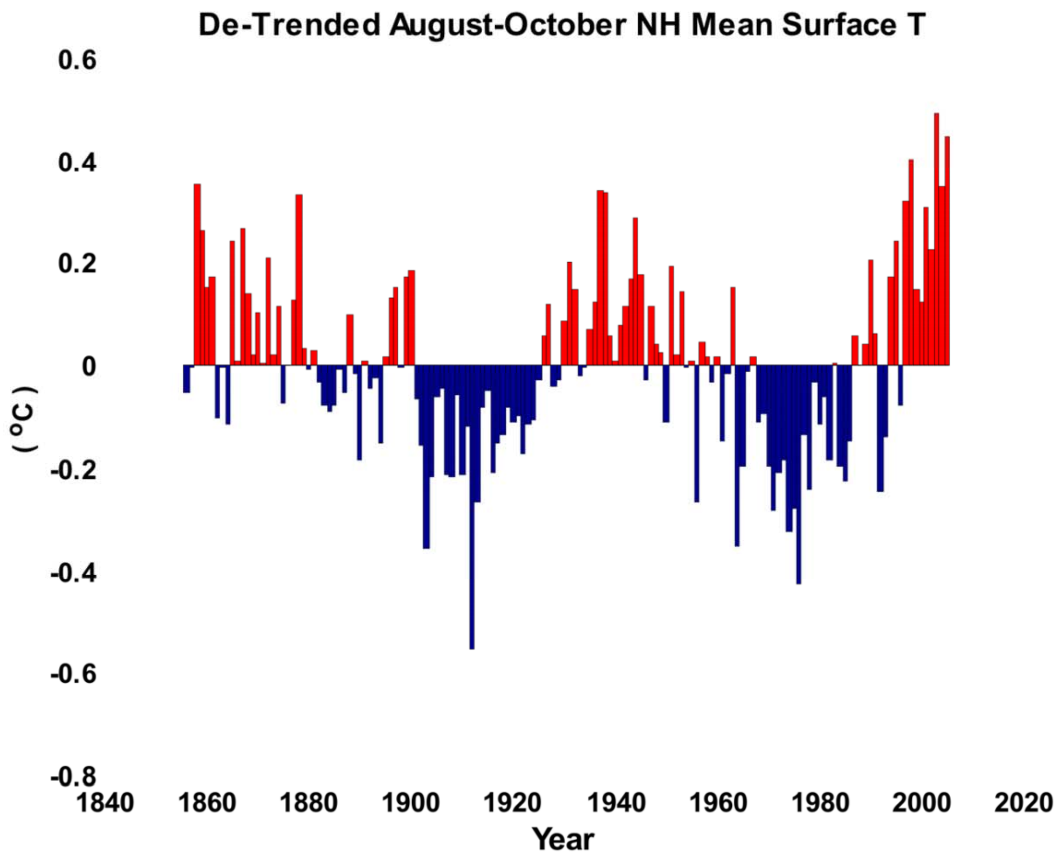
Same, but showing global distribution. From Enfield et al., 1999



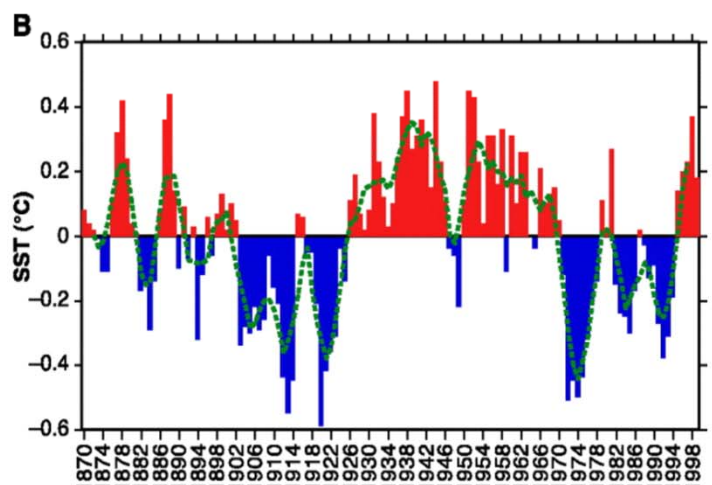


Source: Hadley Centre Global Surface Temperature Data

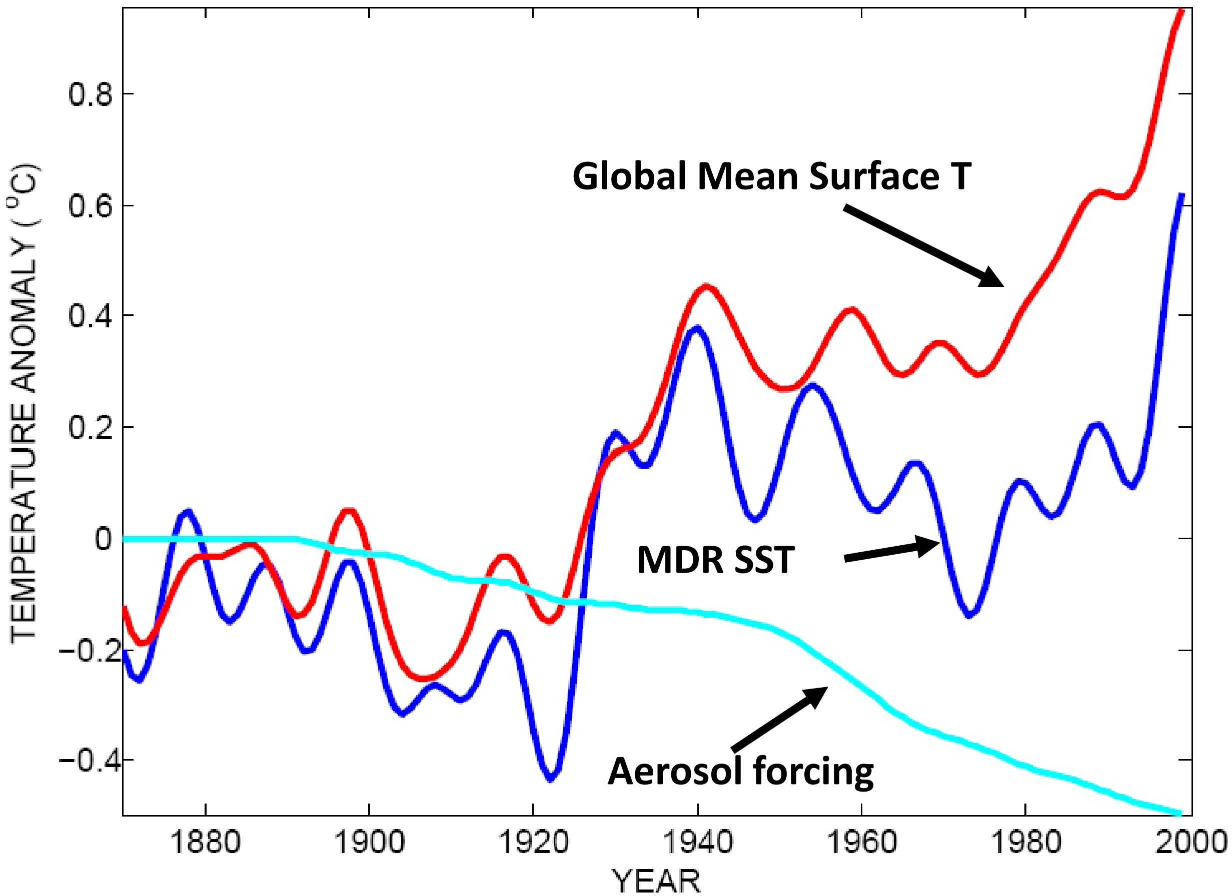
De-trended Aug-Oct NH surface T



Goldenberg et al. AMO index

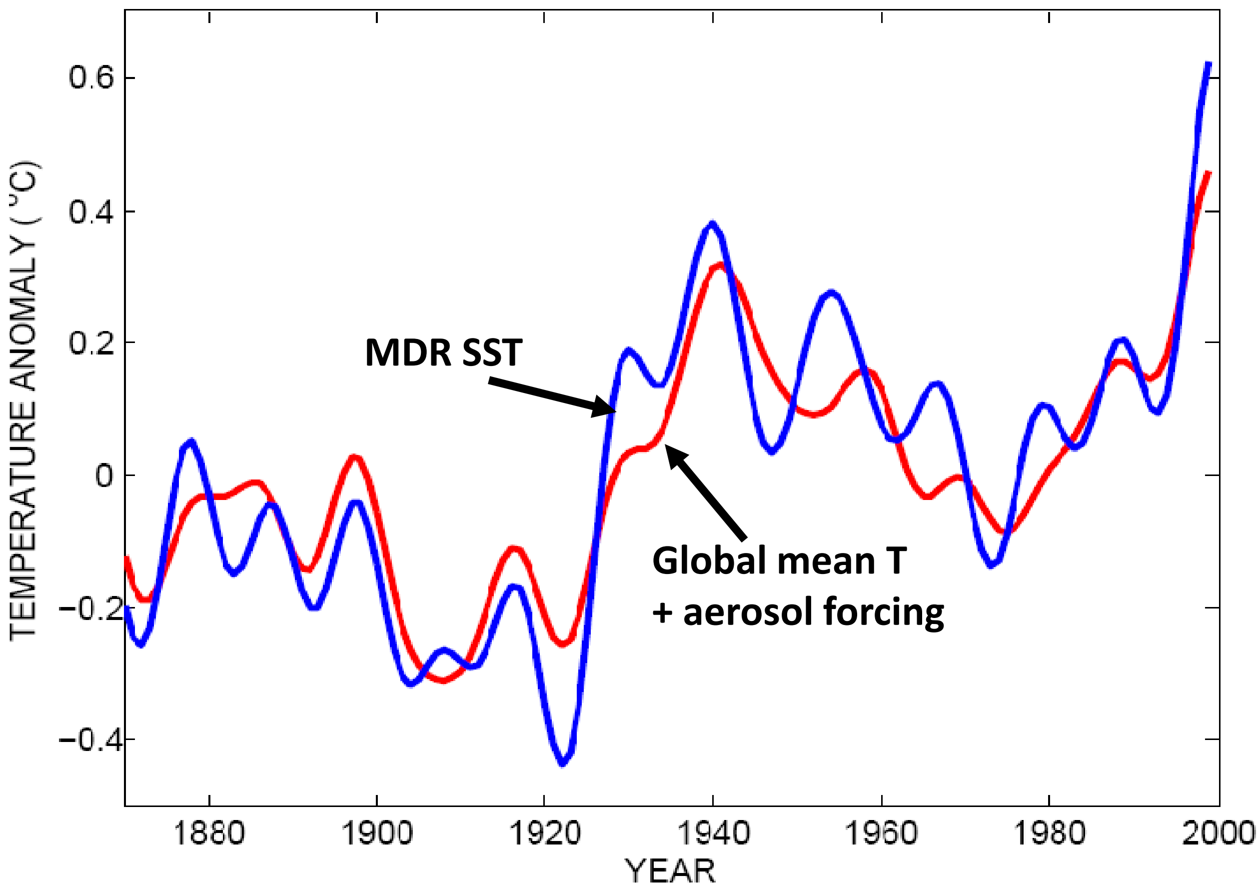


Tropical Atlantic SST(blue), Global Mean Surface Temperature (red), Aerosol Forcing (aqua)



Mann and Emanuel (2006)

Best Fit Linear Combination of Global Warming and Aerosol Forcing (red) versus Tropical Atlantic SST (blue)



Mann and Emanuel (2006)

Attribution of Climate Change to Forcing Versus Natural Variability

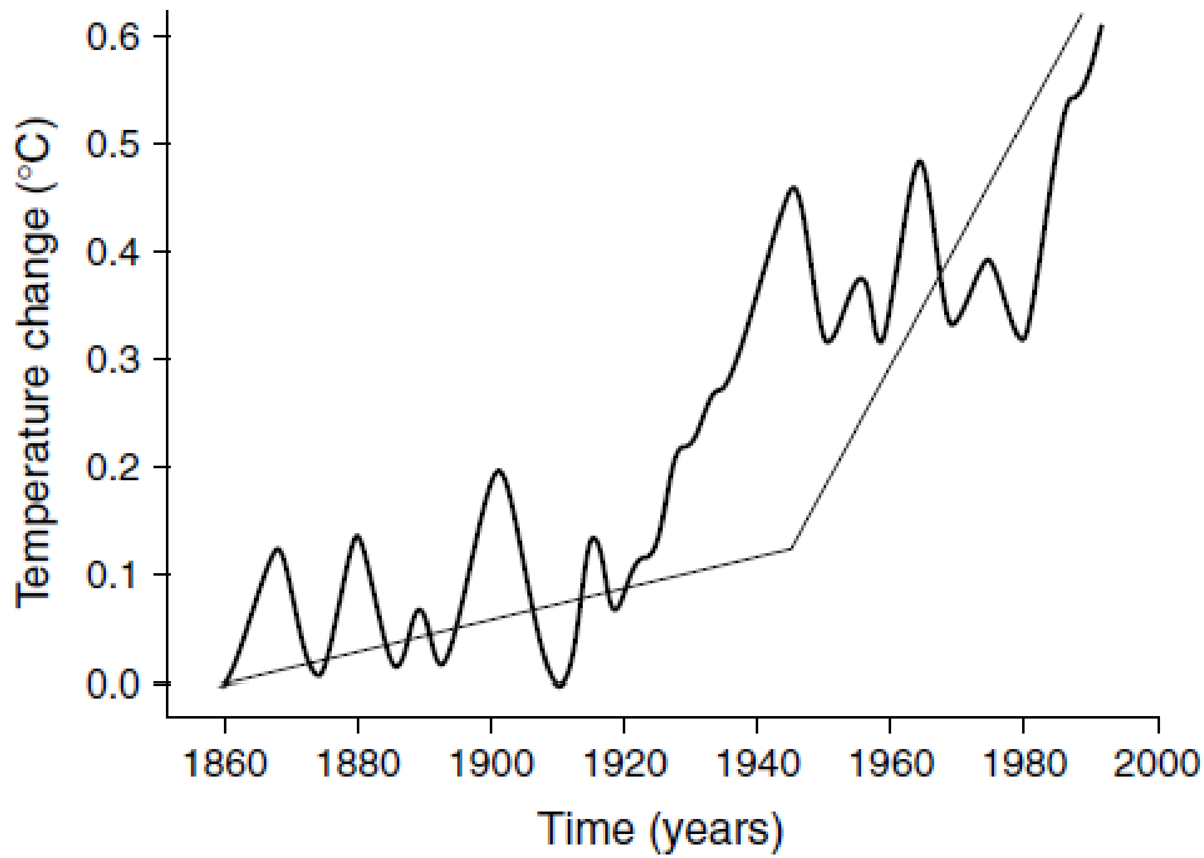
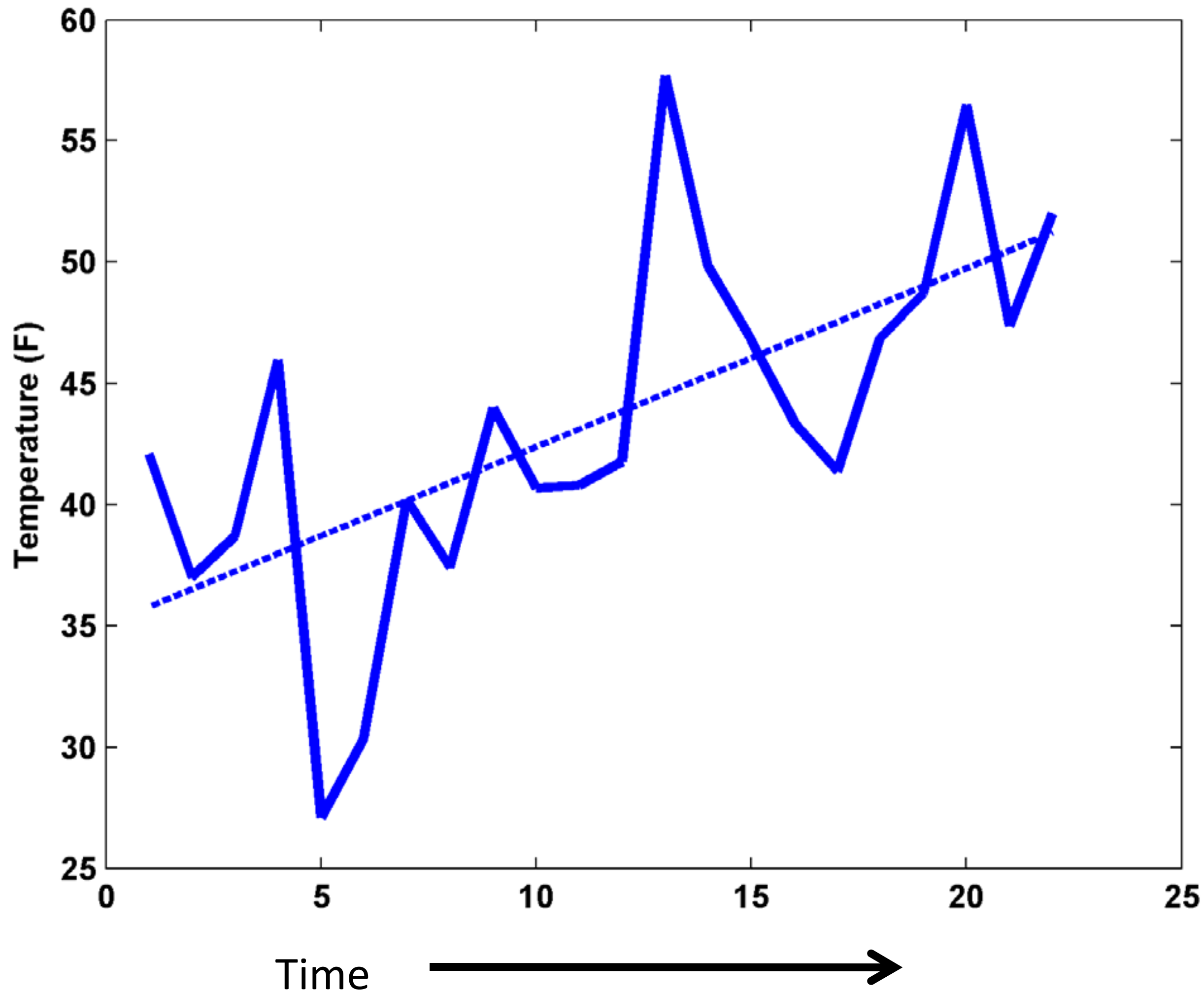
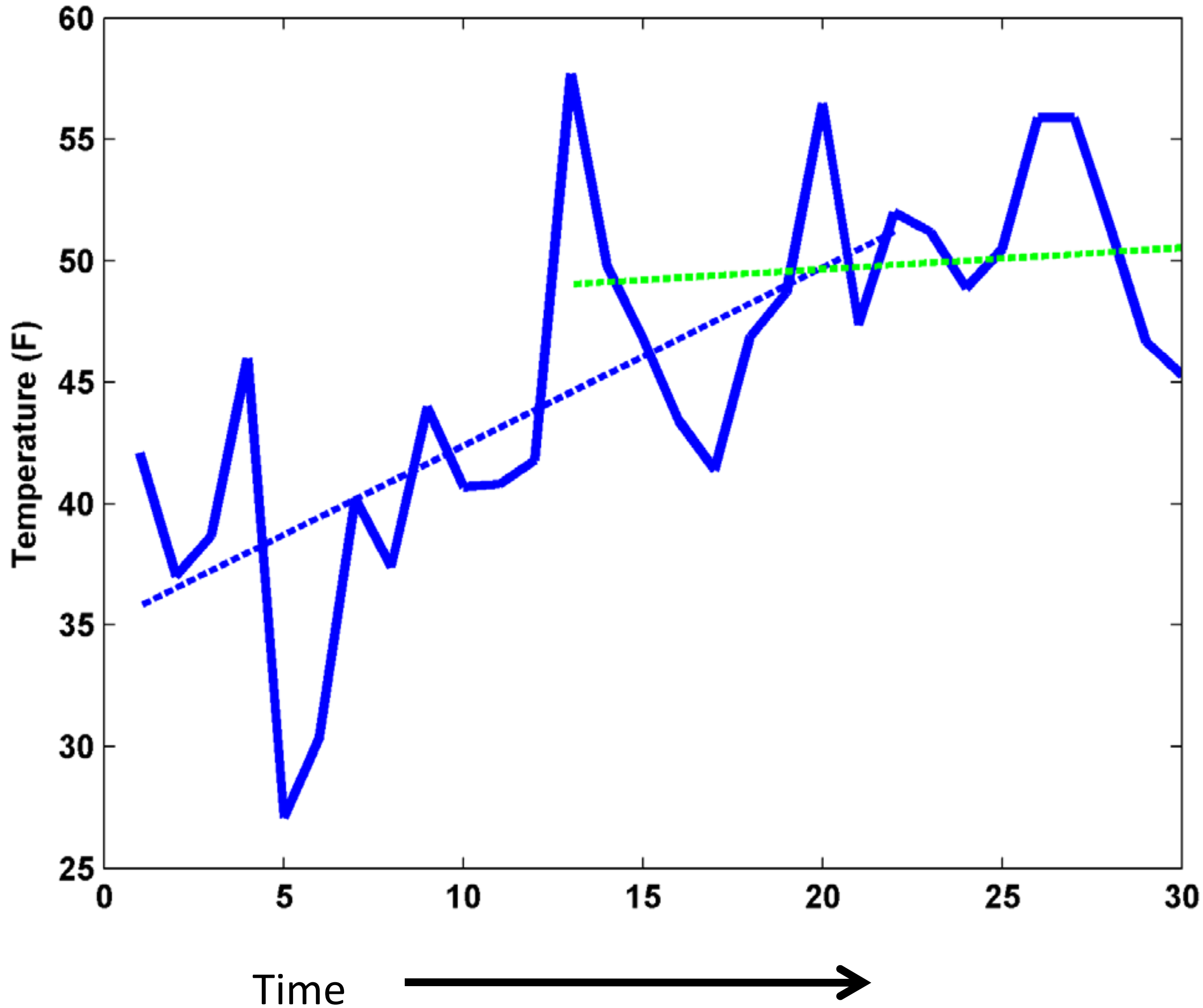


Figure 4 The role of natural variability in climate-change detection and attribution: equilibrium response of global temperatures to changes in aerosols and trace gases (light solid line) vs. observed temperature variations (heavy solid)

An example

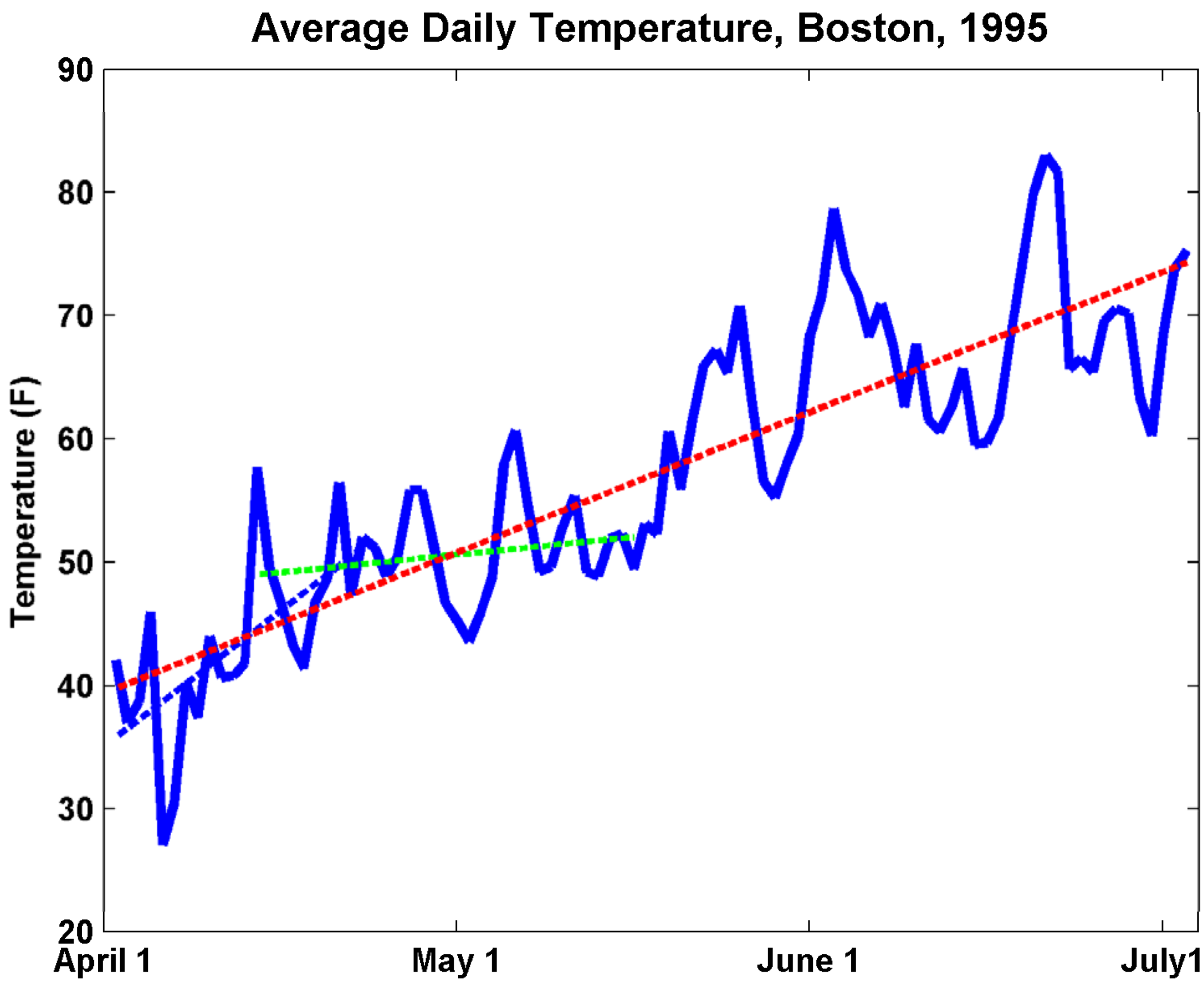


It's getting warmer!....



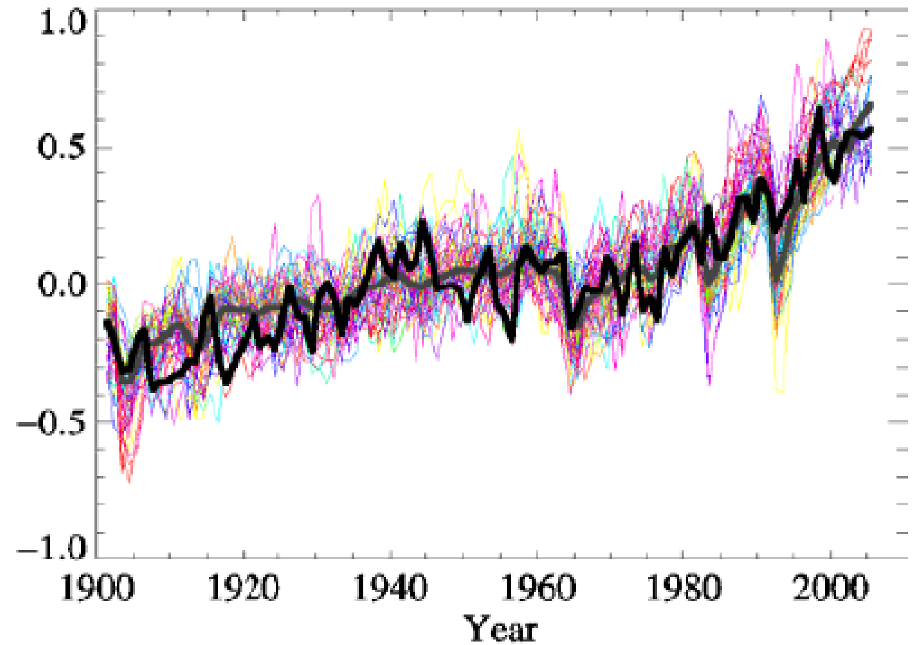
It's getting warmer!....

No, it's not! Warming stopped at 13! In fact, 13 was warmer than at any time since then!



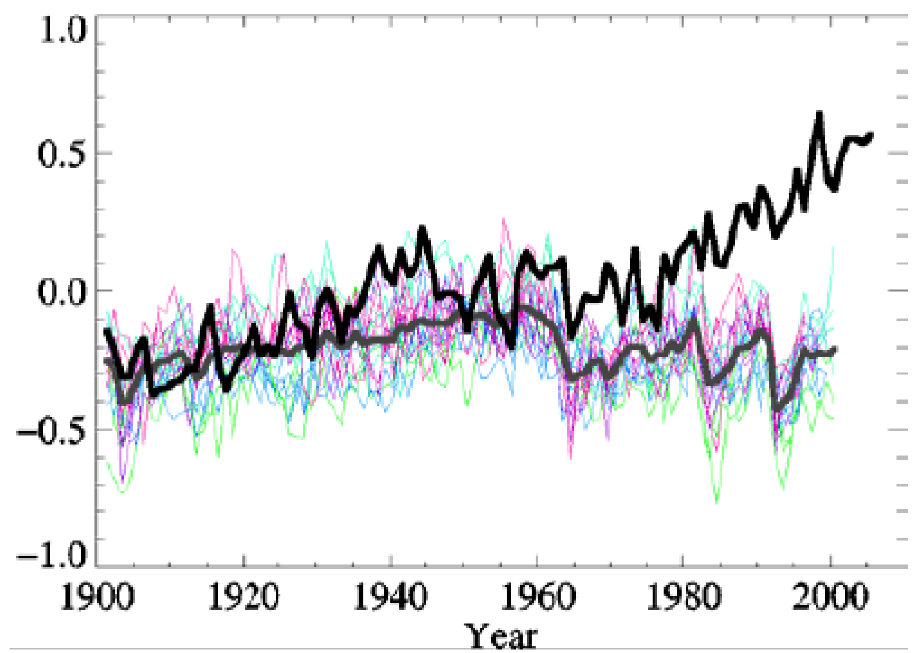
Note: We can forecast that summer will be warmer than winter, even though we cannot forecast the weather beyond a few days

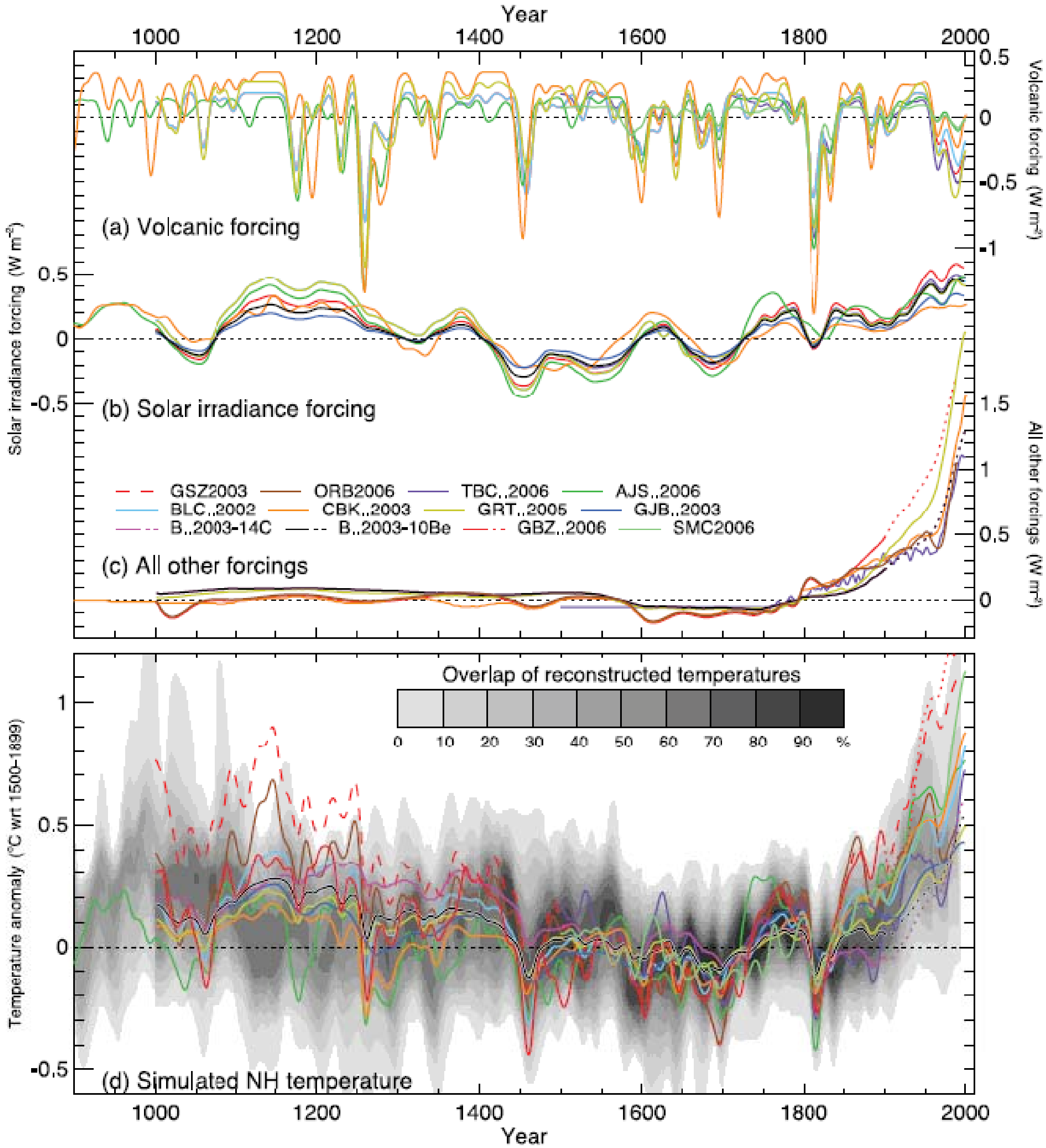
Global mean temperature (black) and simulations using many different global models (colors) including all forcings



To quantify natural, chaotic variability, necessary to run large ensembles

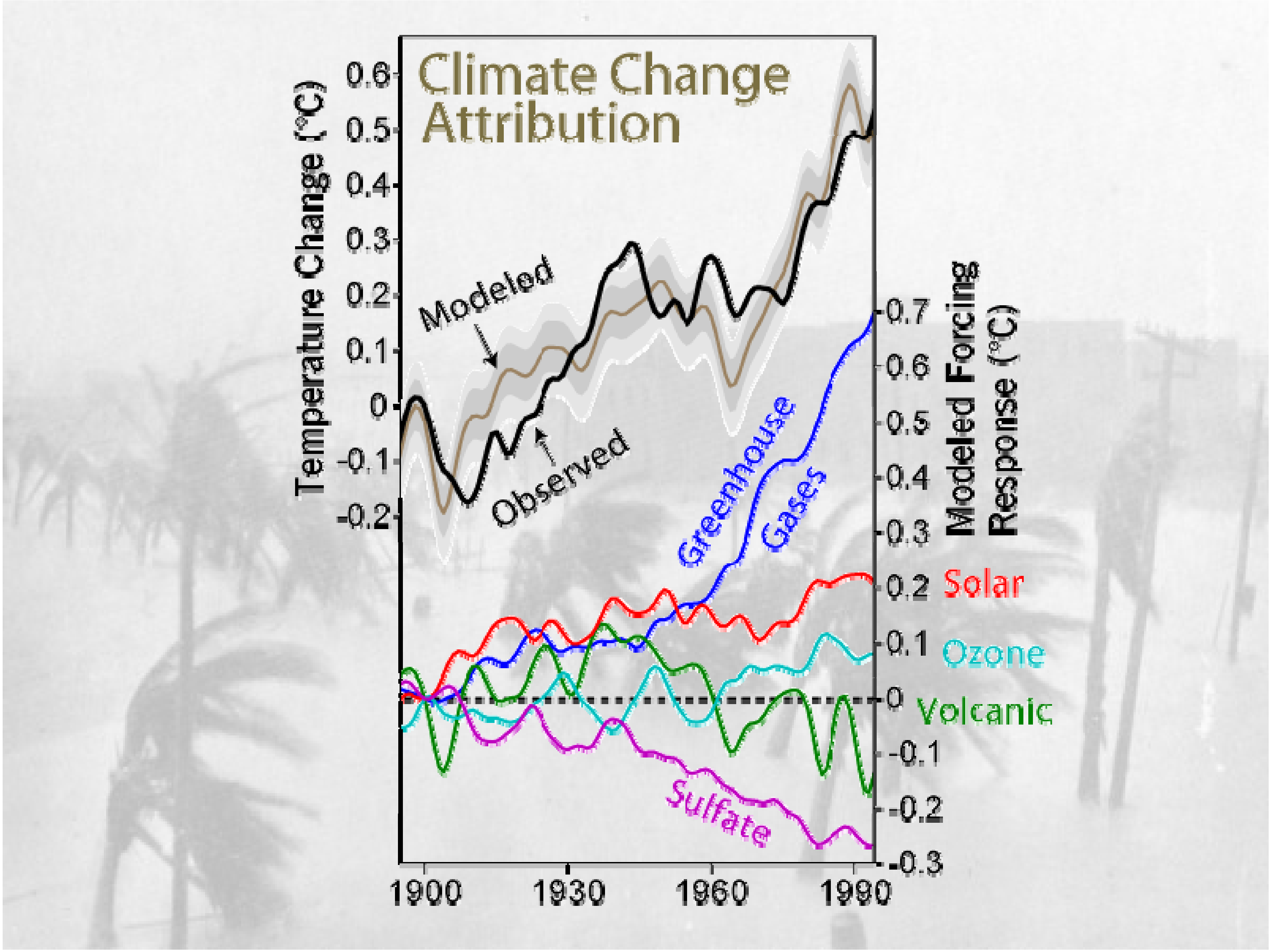
Same as above, but models run with only natural forcings





Contributions to Radiative Climate Forcing

Proxy Temperature Reconstructions



Climate Change Attribution
Temperature Change (°C)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
Modeled
Observed
Greenhouse Gases
Solar
Ozone
Volcanic
Sulfate
Modeled Forcing Response (°C)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1900
1930
1960
1990

Contributions to net radiative forcing change, 1750-2004: