Solar Variability and Earth’s Climate

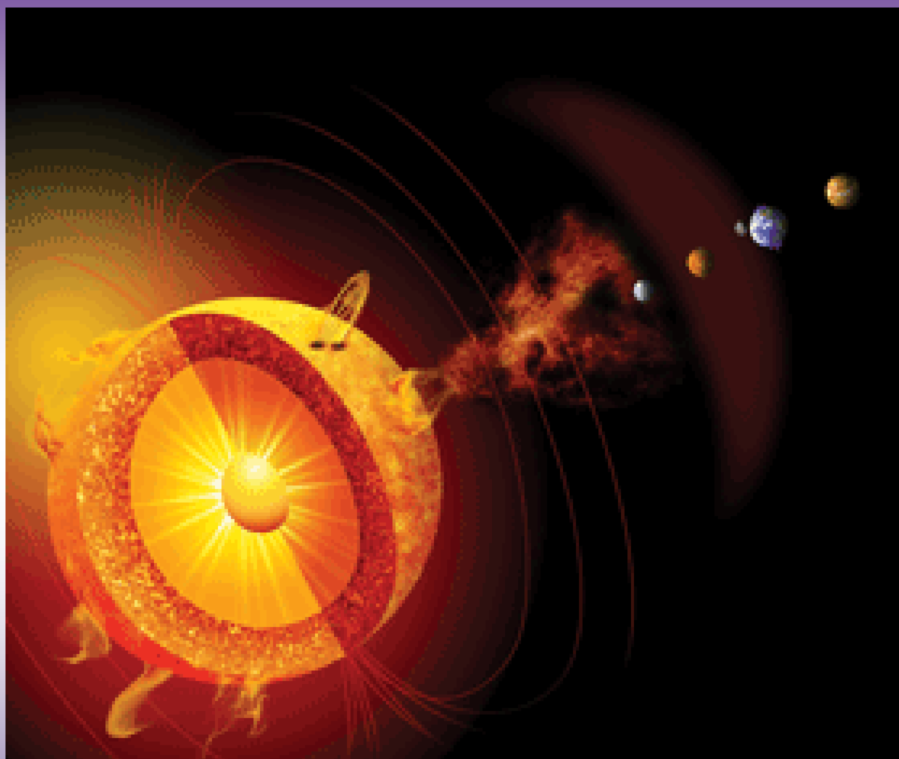
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Caspar M. Ammann

National Center for Atmospheric Research

Climate and Global Dynamics Division & High Altitude Observatory

Sun - Earth Connection

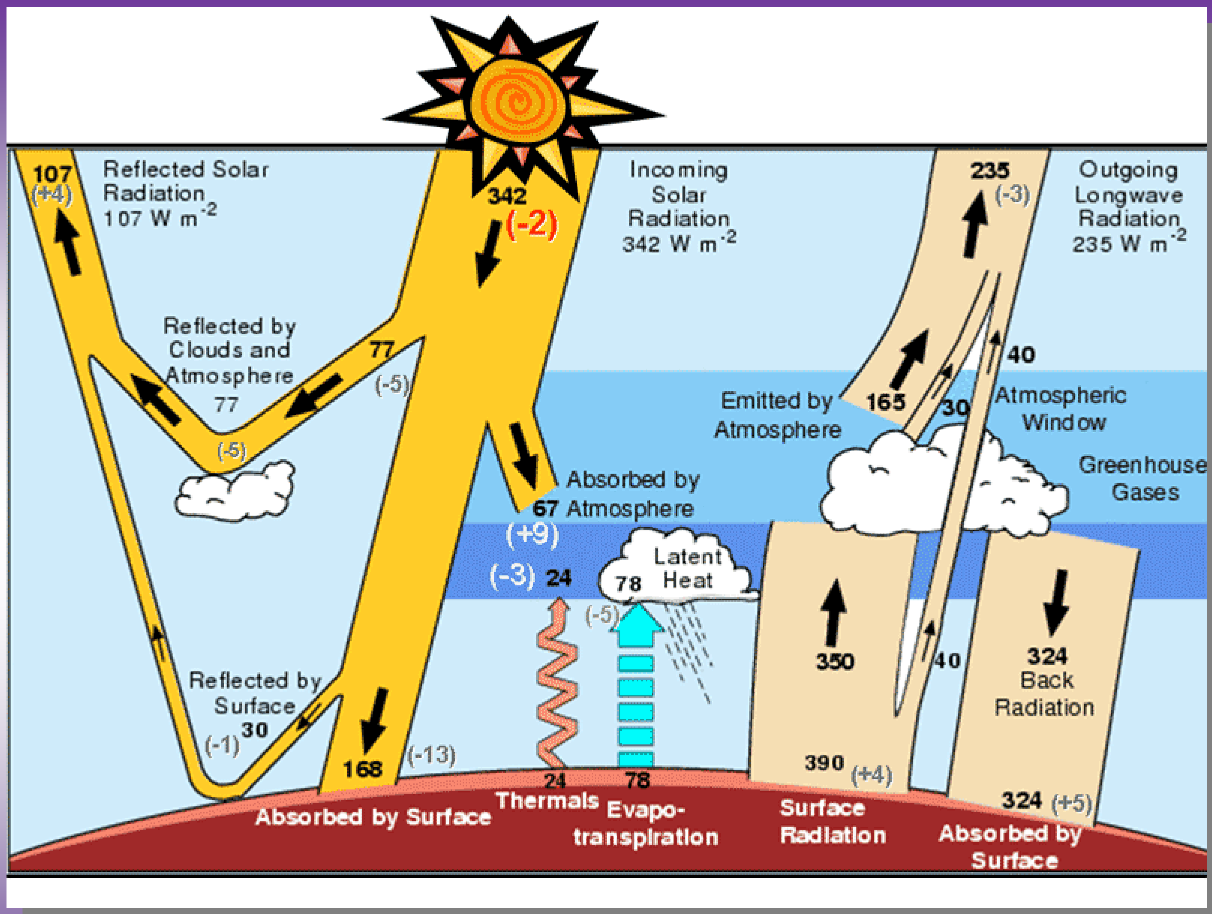


Solar Driver of the Earth System

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Climate Change: Sun vs Man?

Earth Radiative Balance



Kiehl & Trenberth

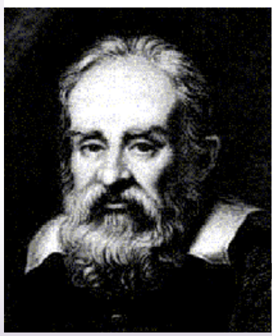
Overview

- Goal I: Indications of Change
  - Solar variability and its proxies
  - Climate records and signals from the solar variability?
- Goal II: The Uncertain Forcing
  - Spectral variations during high solar activity
  - Atmospheric profiles and trends
  - Historical consistency with the "*Medieval Warm Period*" and the *Little Ice Age*?
- Goal III: Next challenges in climate research
  - Climate sensitivity and global trends
  - An important role for the Sun-Earth connection for regional climate prediction

Records of Solar Variability and Climate

“Proxy-Archives” for Solar Activity

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Sunspots

Radio Isotopes

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

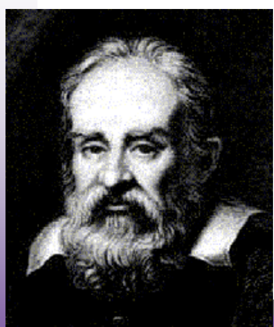
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

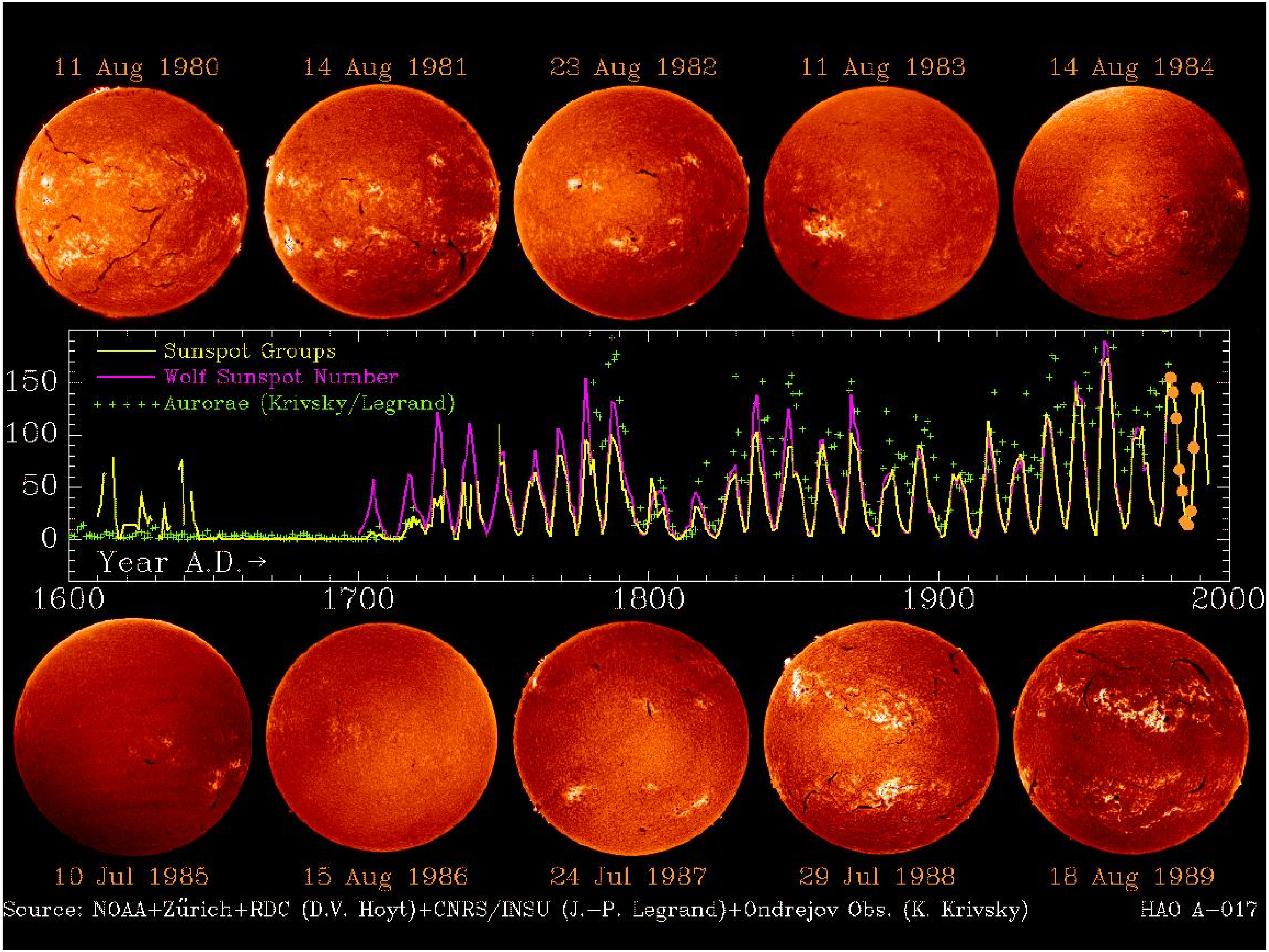
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Aurora

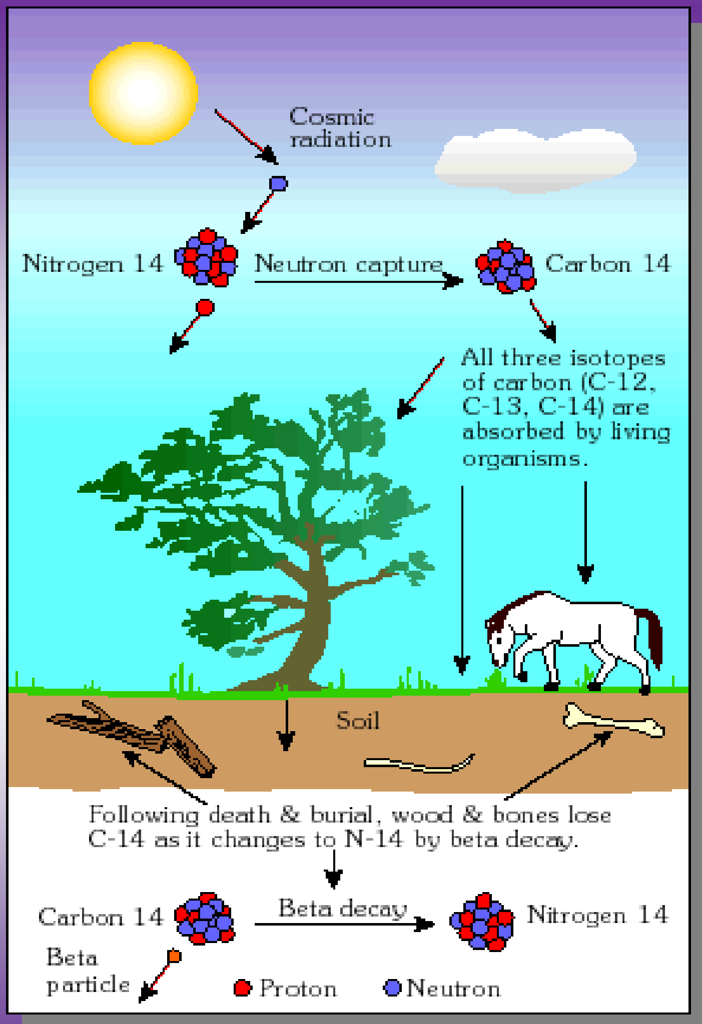
Sunspots : Galileo to Today

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.




11 Aug 1980
14 Aug 1981
23 Aug 1982
11 Aug 1983
14 Aug 1984
Sunspot Groups
Wolf Sunspot Number
+++++Aurorae (Krivsky/Legrand)
150
100
50
0
Year A.D.→
1600
1700
1800
1900
2000
10 Jul 1985
15 Aug 1986
24 Jul 1987
29 Jul 1988
18 Aug 1989
Source: NOAA+Zürich+RDC (D.V. Hoyt)+CNRS/INSU (J.-P. Legrand)+Ondrejov Obs. (K. Krivsky)
HAO A-017

Cosmic Radiation and Radio Isotopes



<u>Radio-Isotopes:</u>

^{14}Carbon

^{10}Beryllium

^{136}Chlorine

Solar activity indicators

Decay: useful for dating

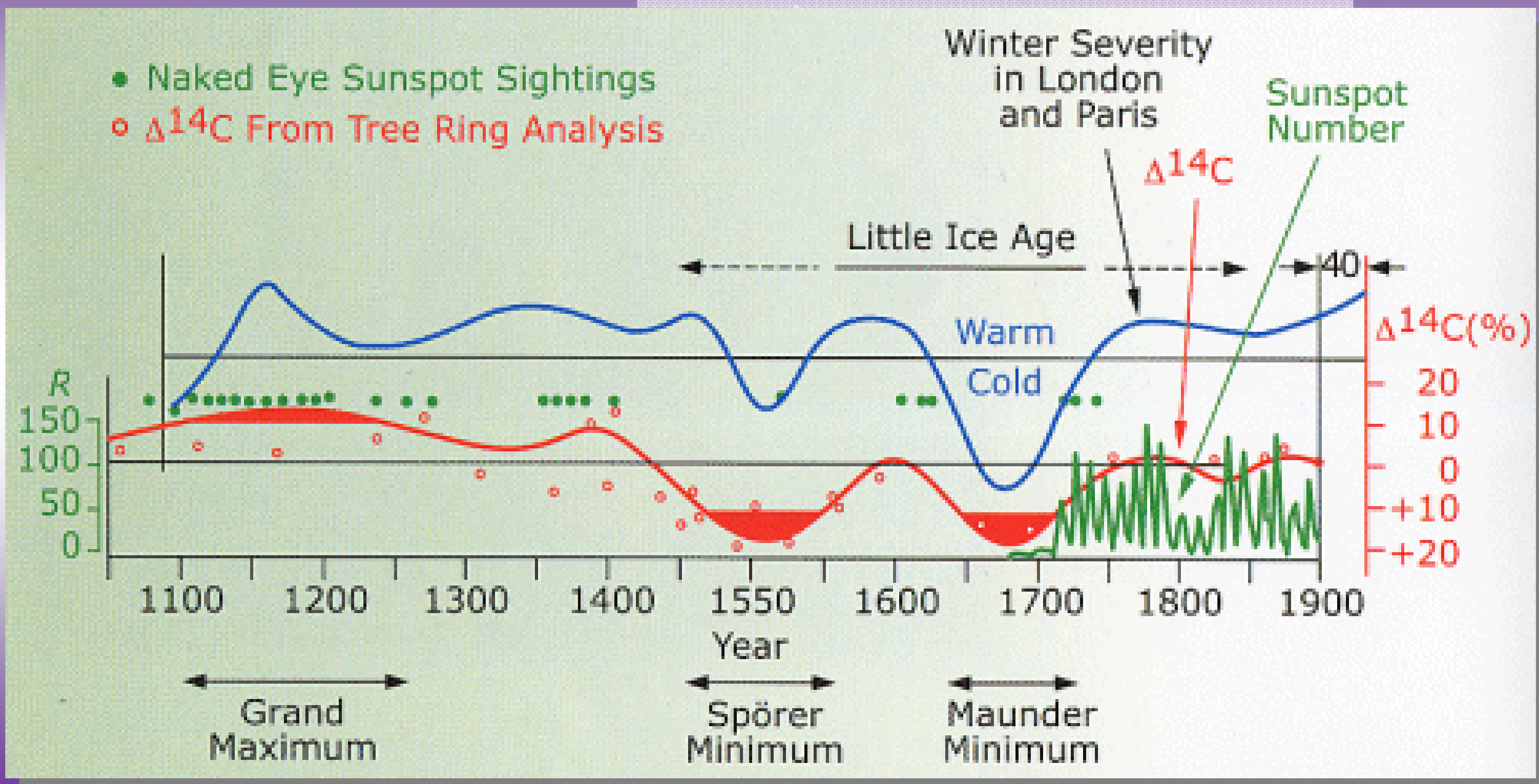
18 June 1976, Volume 192, Number 4245

SCIENCE

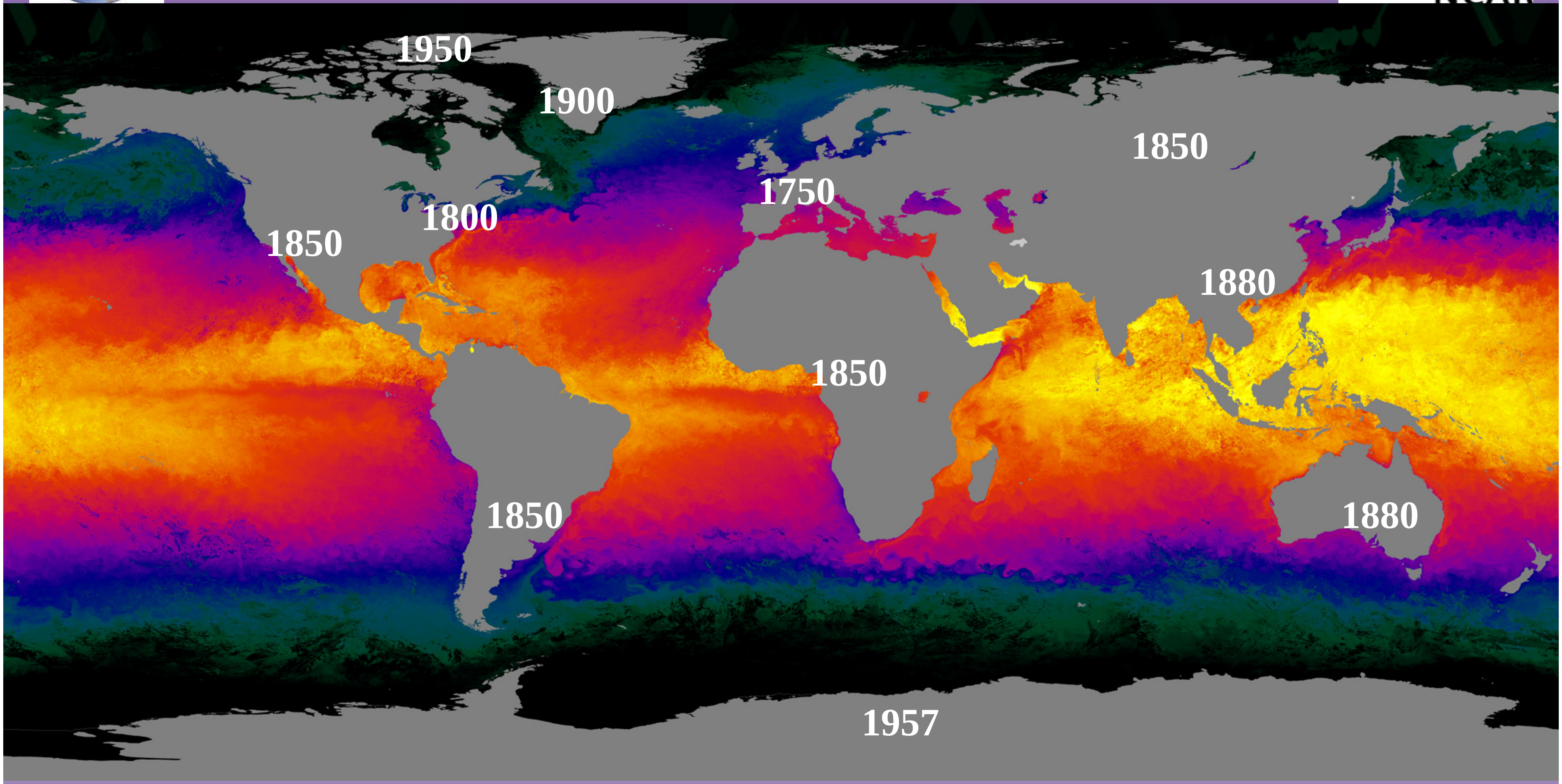
The Maunder Minimum

The reign of Louis XIV appears to have been a time of real anomaly in the behavior of the sun.

John A. Eddy



Earliest instrumental records on land



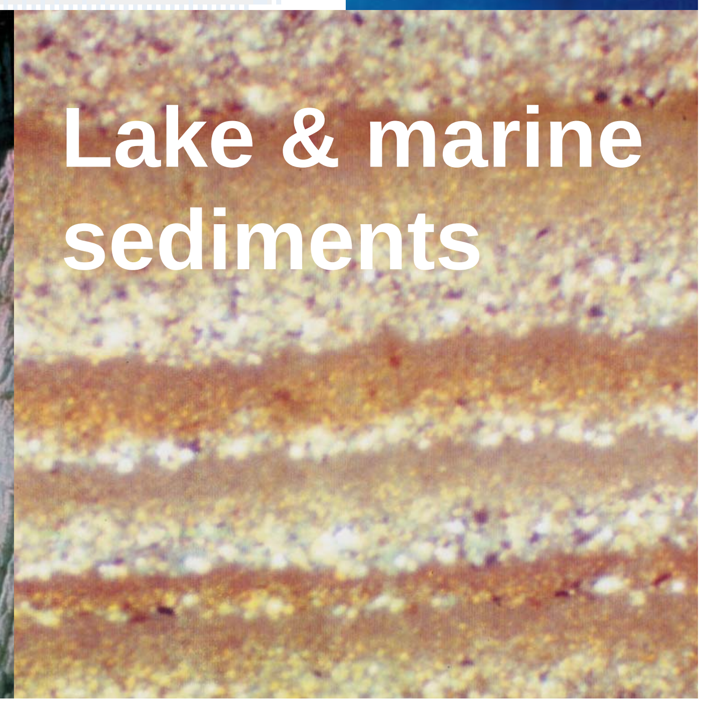

Stalagmites


Tree rings

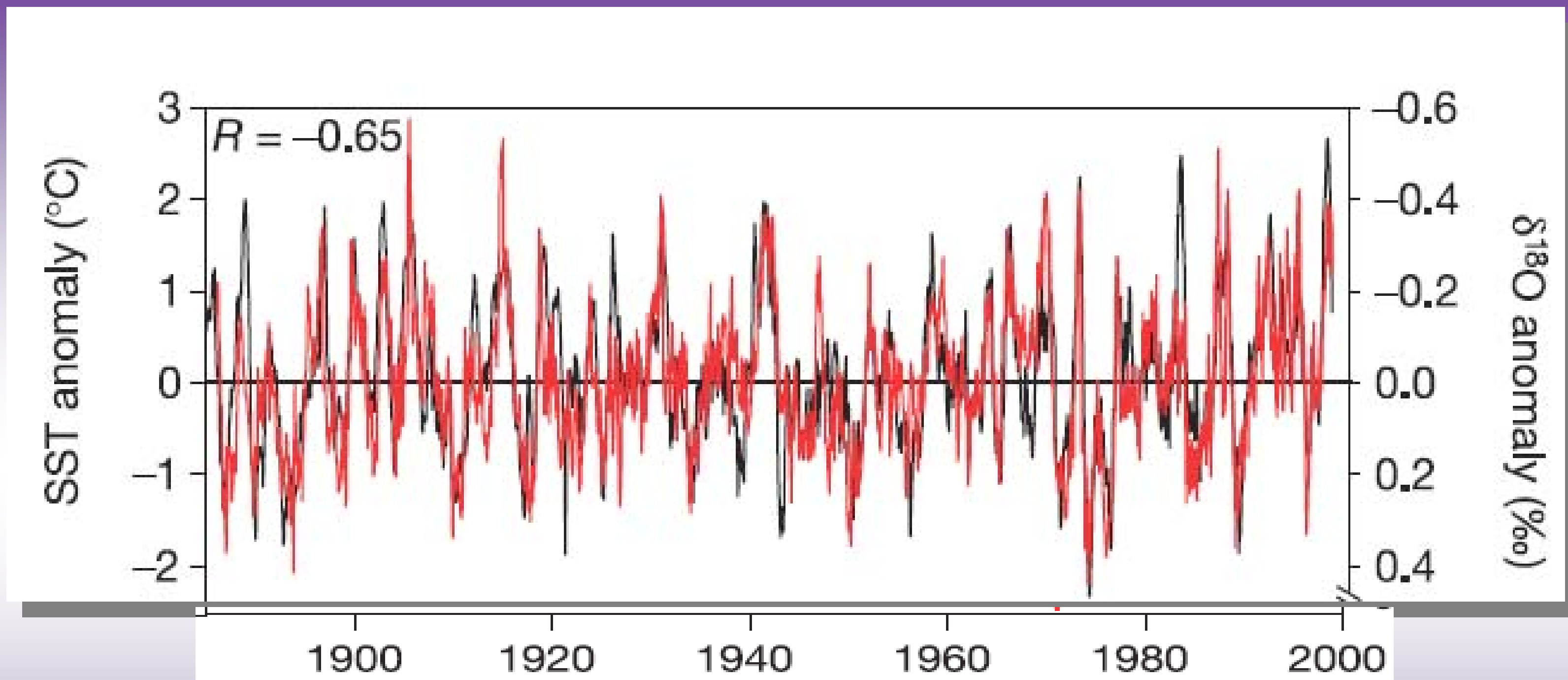

Corals


Historical documents


Ice


Lake & marine sediments

Calibration of Proxies



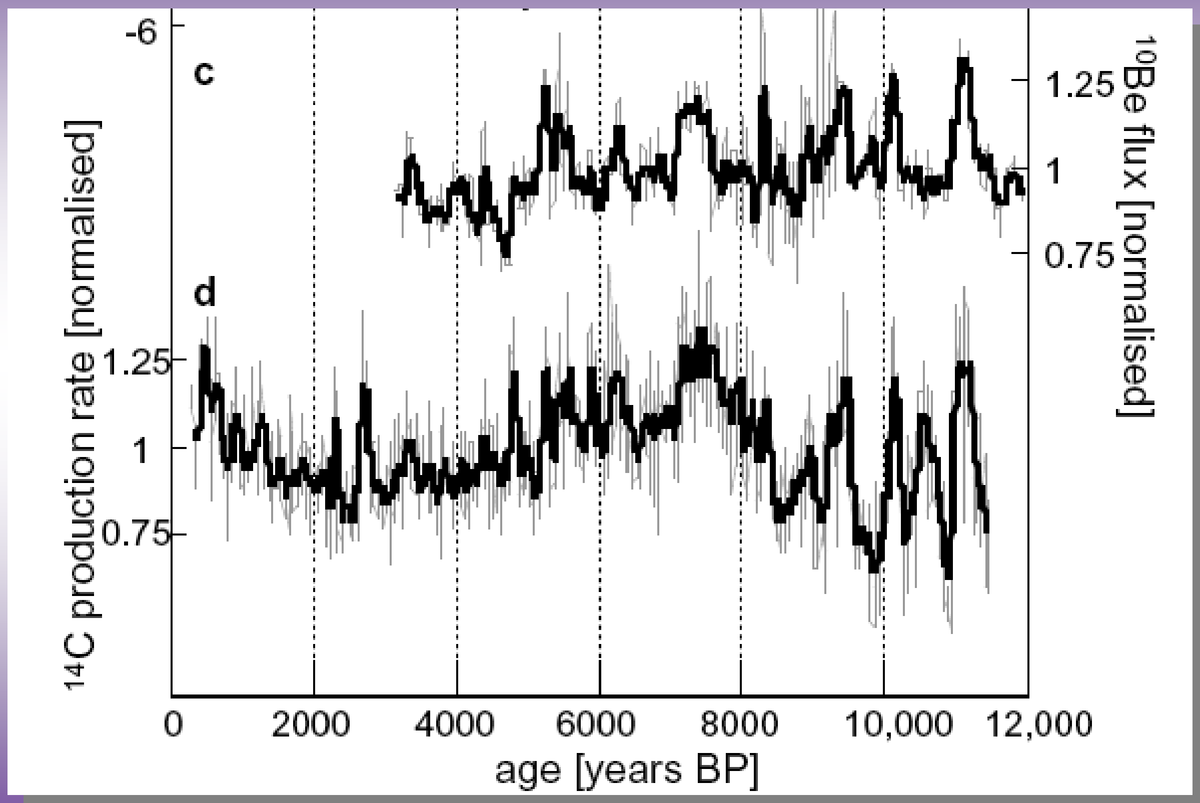
Modern coral $\delta^{18}O$ anomalies (red)
Sea surface temperatures (black)

Source: *Cobb et al., 2003*

Solar Forcing Timescales

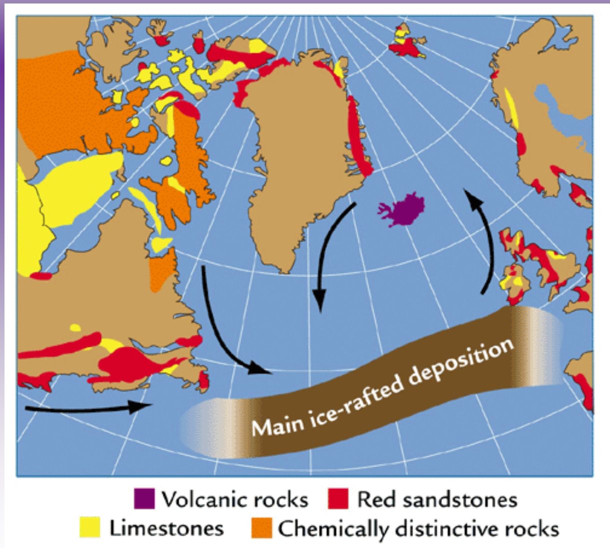
11/22-year Schwabe / Hale Cycle
~80-88-year Gleissberg

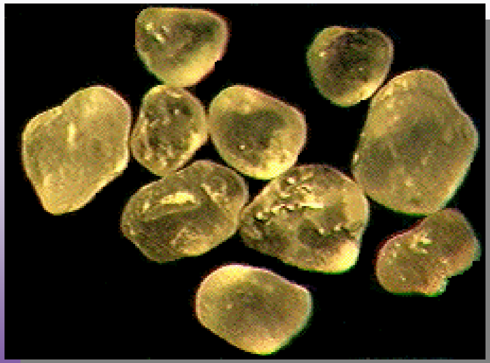
~207-year deVries
~1500-years?

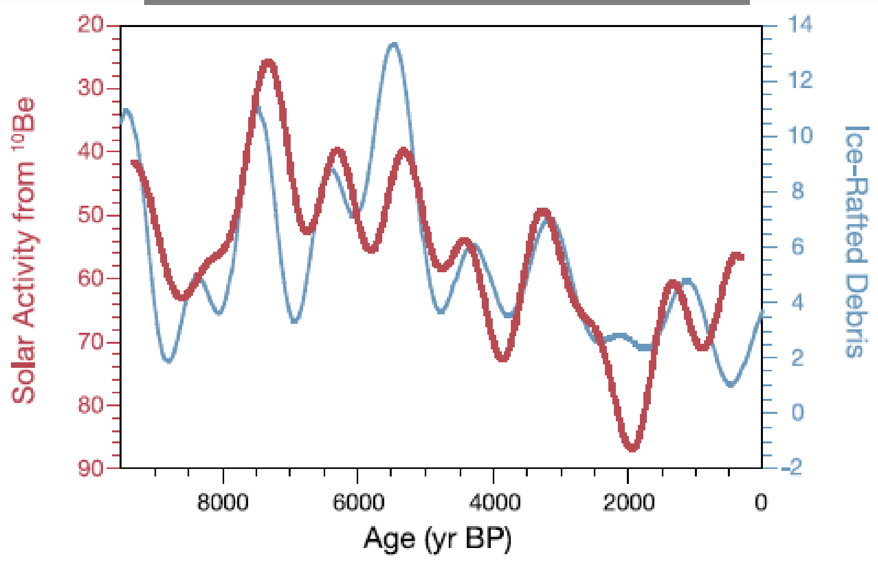


Muscheler et al., 2003

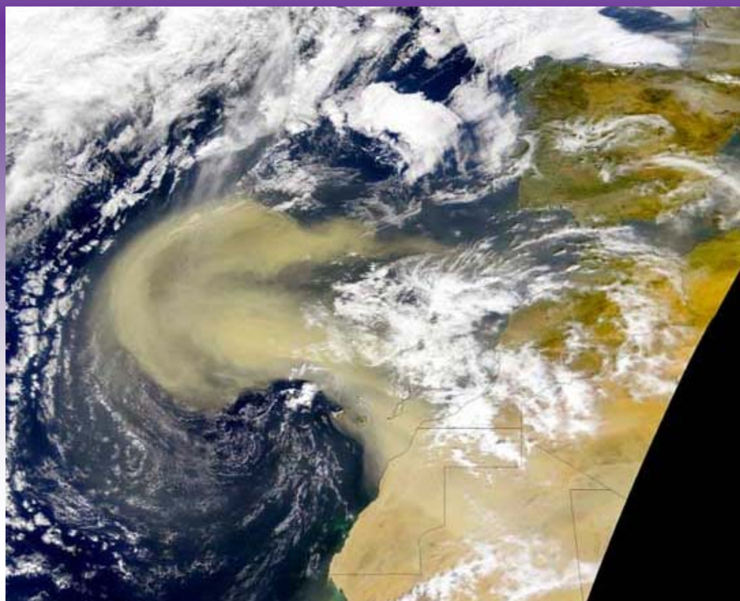
Solar signal in drift ice?



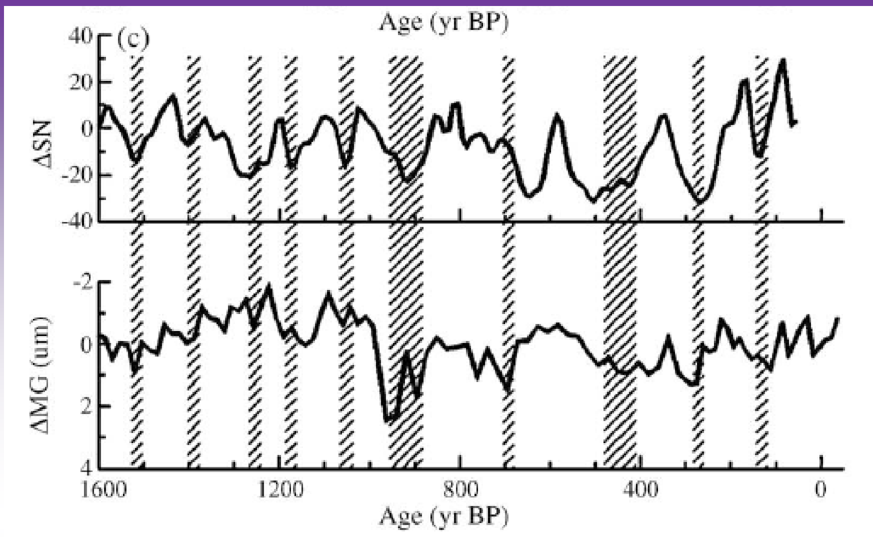




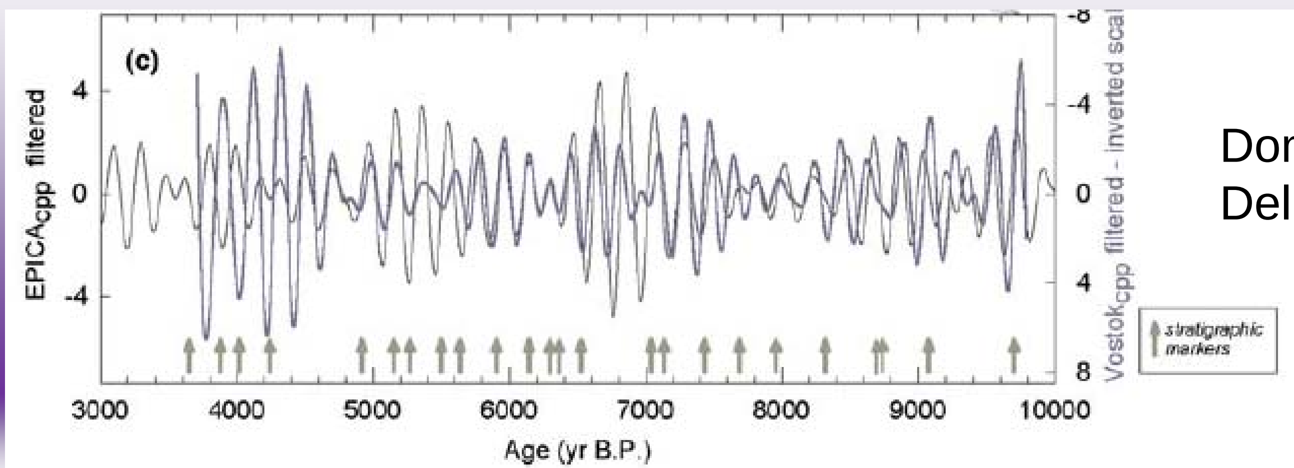
Centennial Dust Records (~200yrs)



Dust Records in mid- and high-latitudes



E-China Sea, Xiao et al., 2006

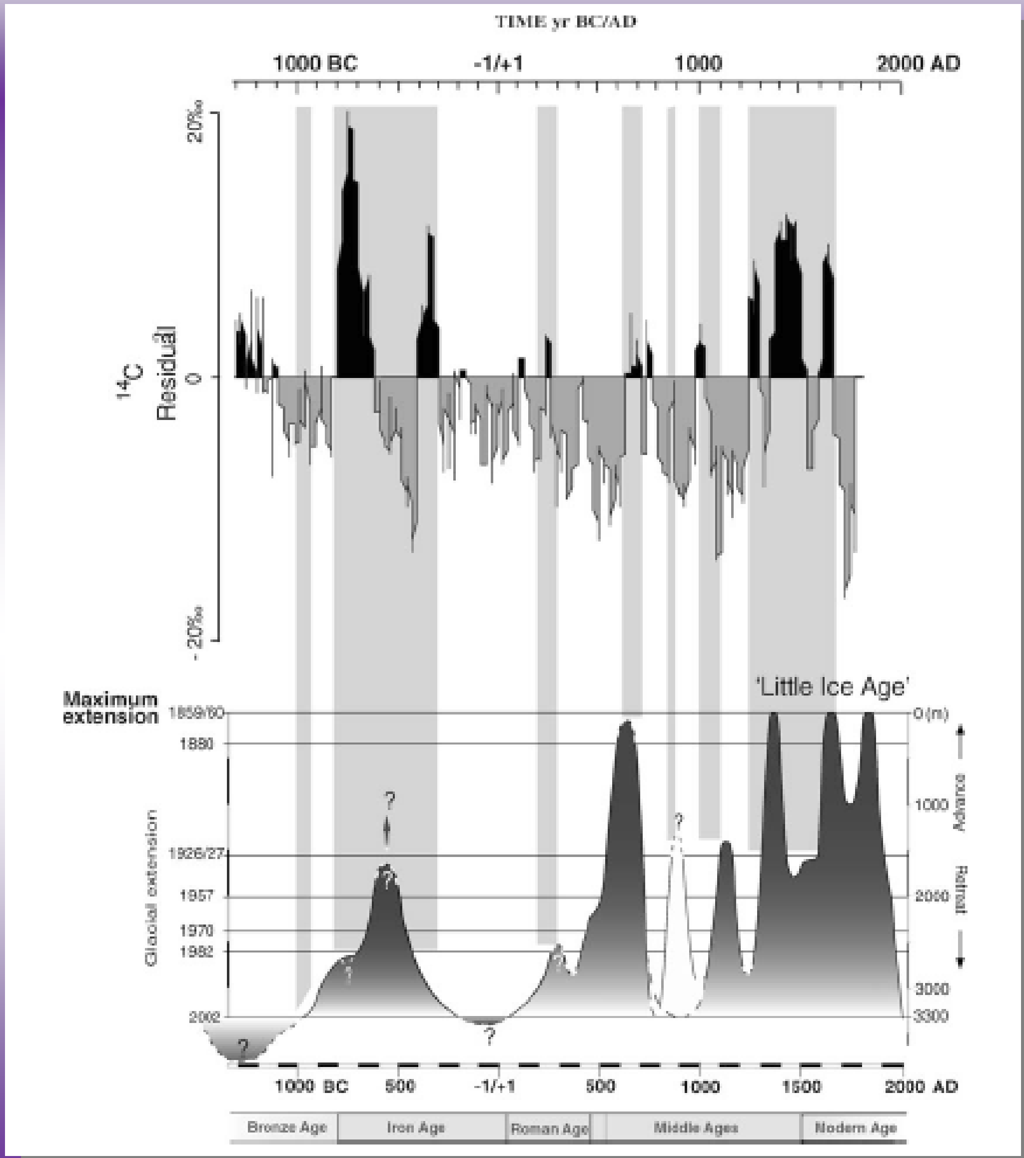


Dome C & Vostok, Antarctica
Delmonte et al., 2005

Unterer Grindelwald Gletscher

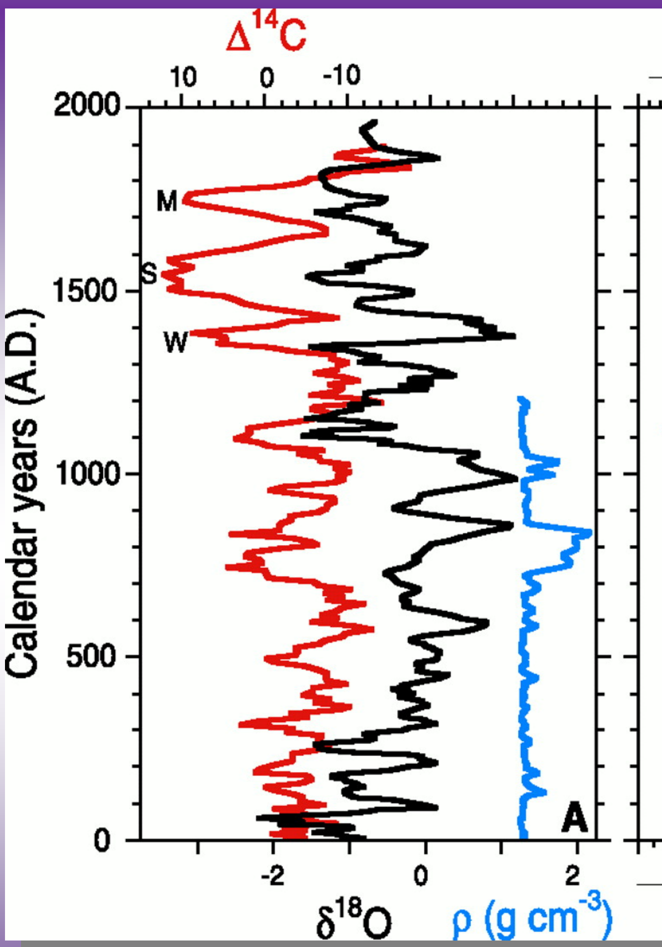
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

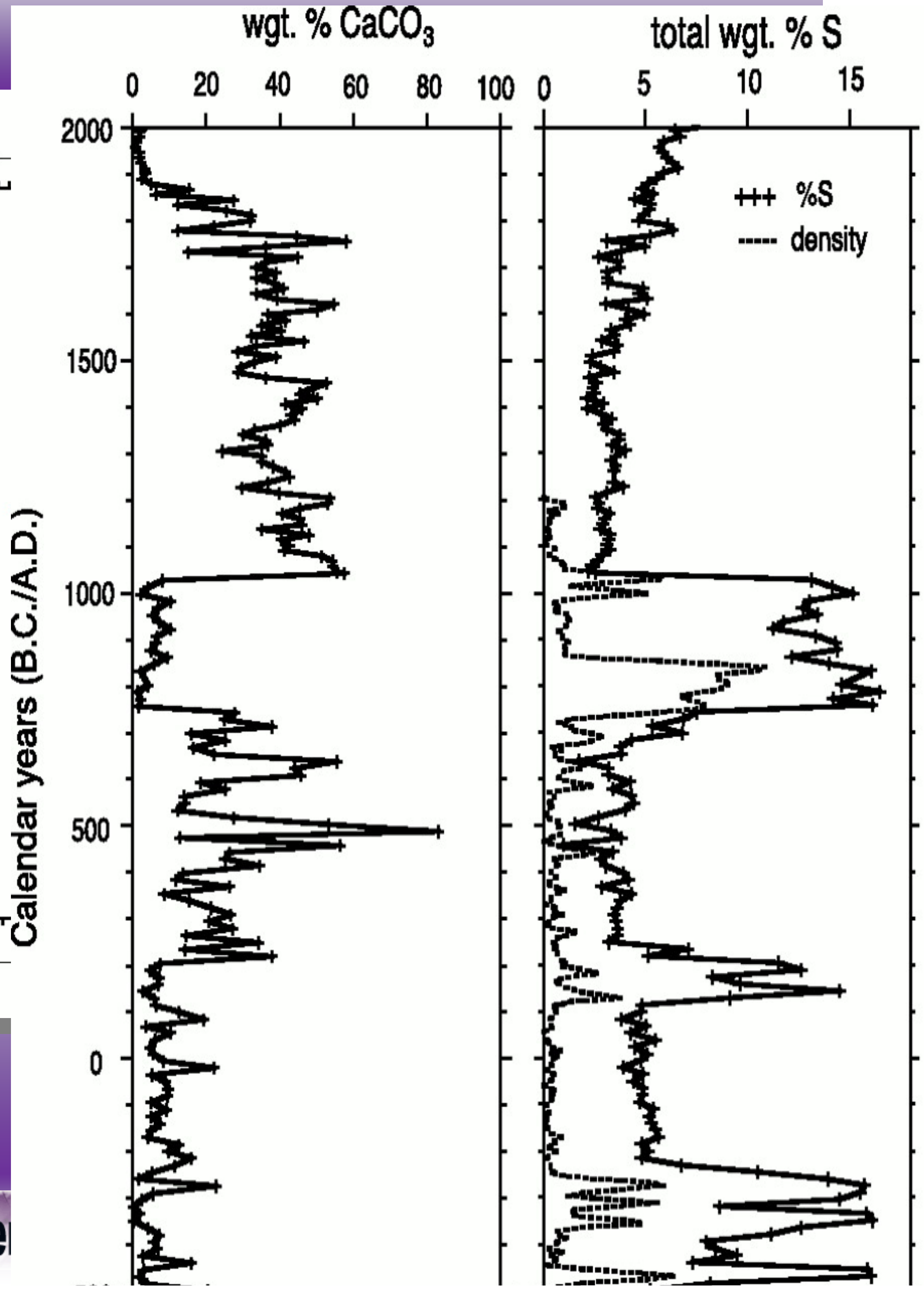
Alpine Glaciers and Solar Variations



Holzhauser et al. 2005

Hydrologic Indicators in the Tropics

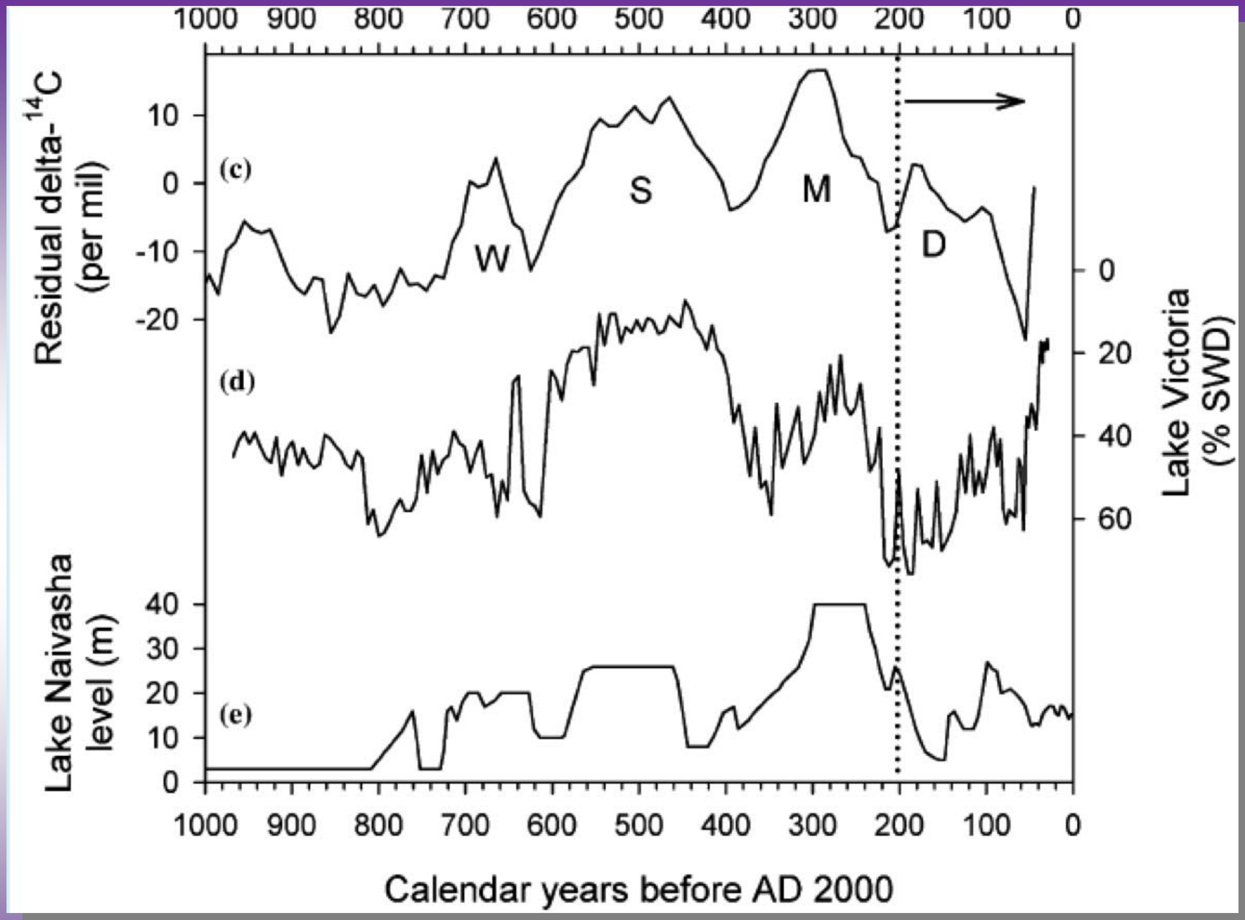




Punta Laguna, MX

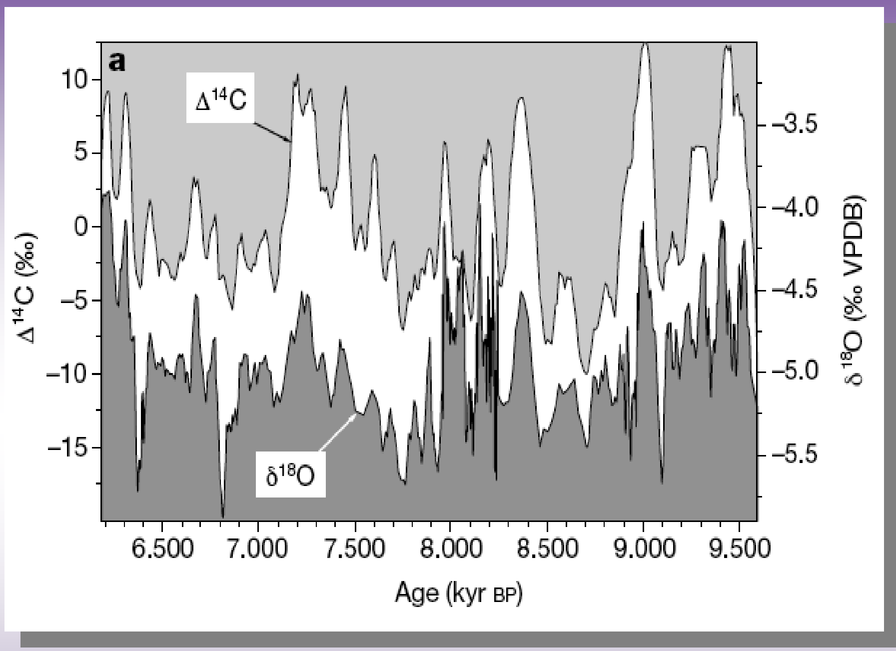
2001

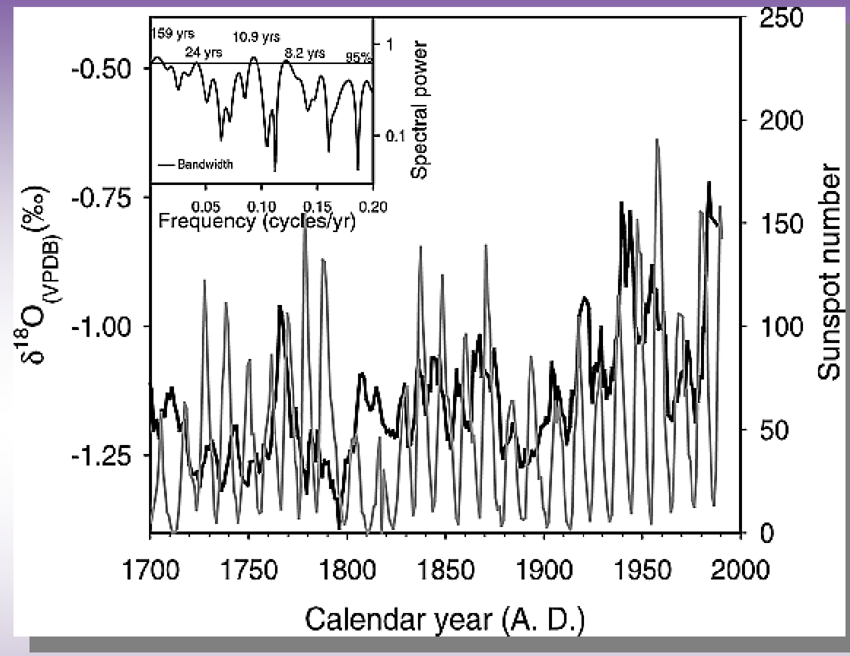
Hydrologic Indicators in the Tropics : Kenya lakes



Verschuren et al., 2000
Stager et al. 2005

Consistent (Multi-)Decadal Solar Signals?





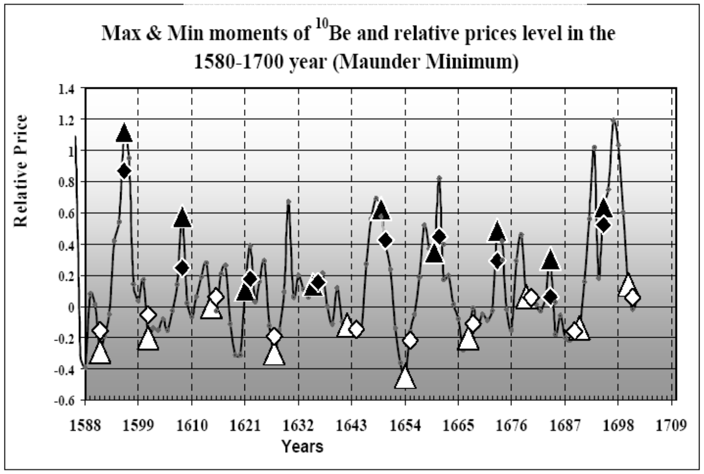
Neff et al., 2001

Black et al., 2004

Caution: Exact Dating necessary…

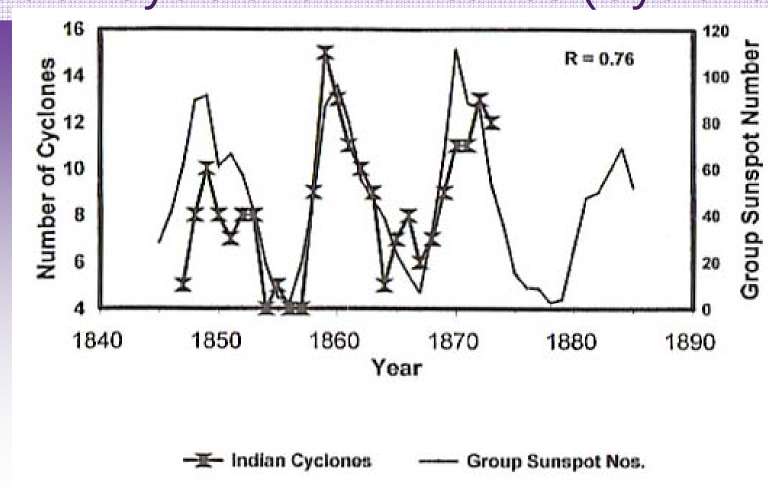
Solar Cycles and Climate

Price of Wheat

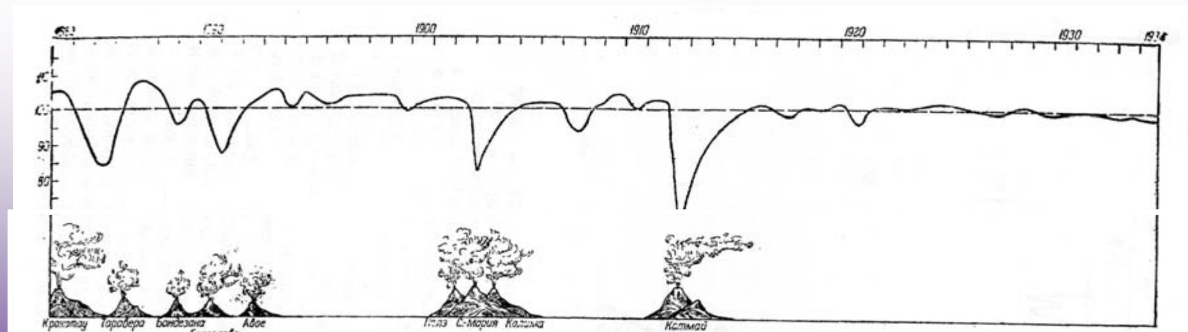


Herschel 1801 // Pustilnik and Din, 2003

Solar Cycle and Hurricanes (Cyclones)



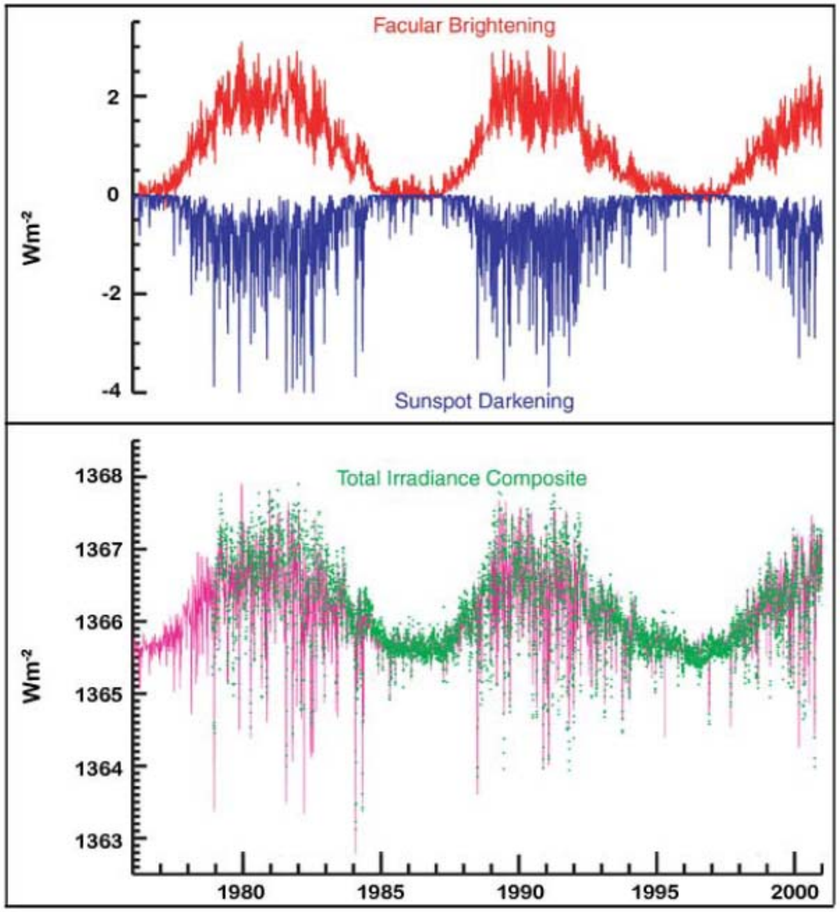
Lockyer, 1872

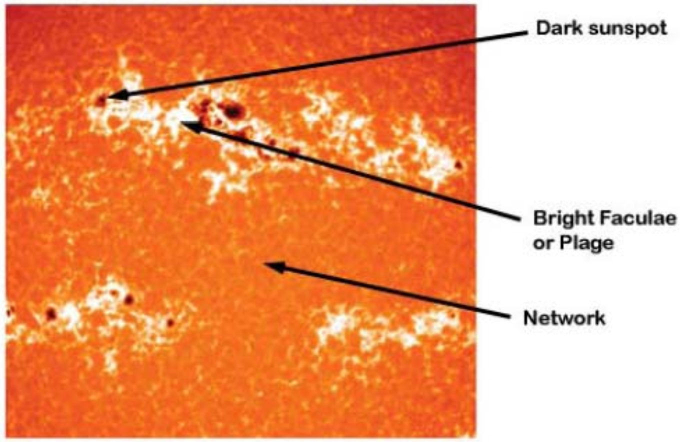


Фиг. 1. Влияние извержений вулканов на прозрачность атмосферы.

Kalitin, 1939
Solar Irradiance

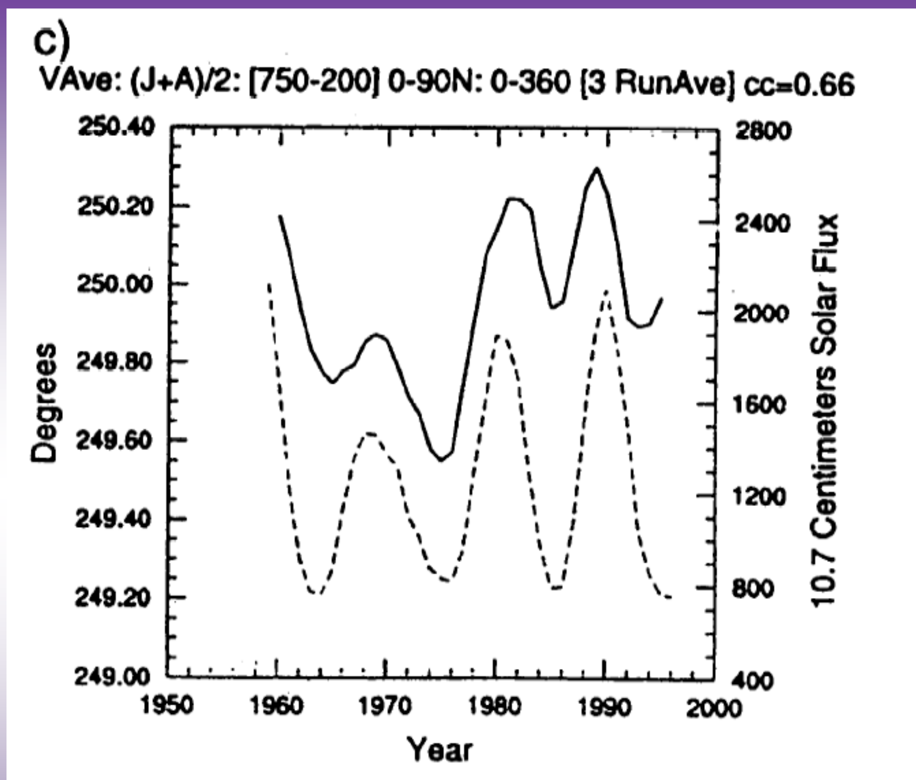
Recent Satellite Mesurements



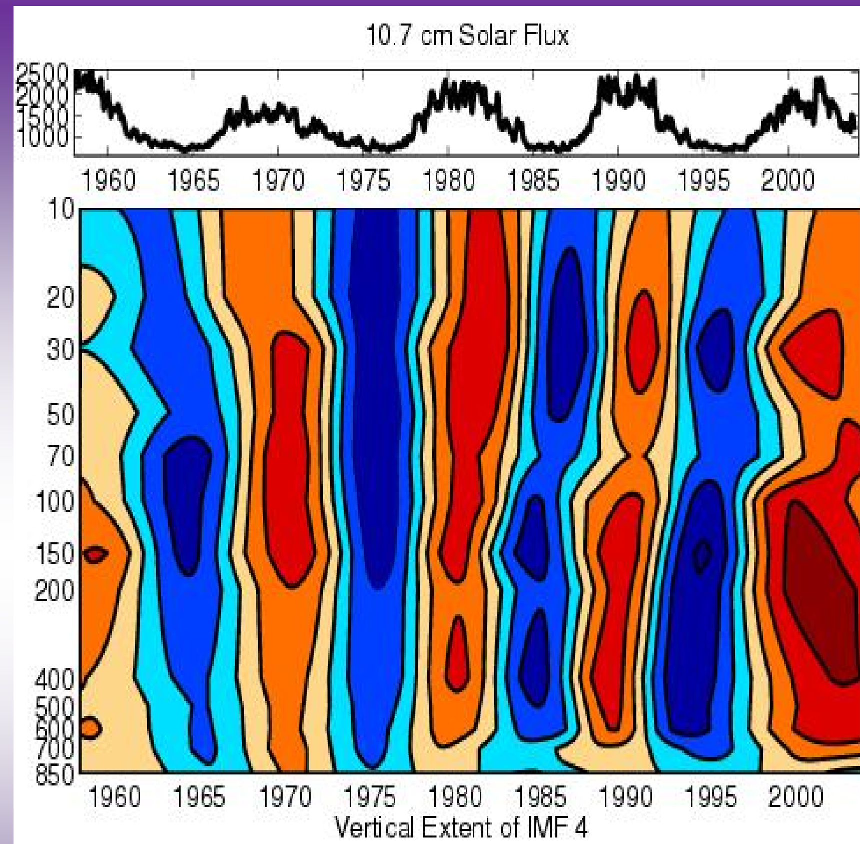


NASA LWS, 2003

Spatial Integration and Noise Reduction

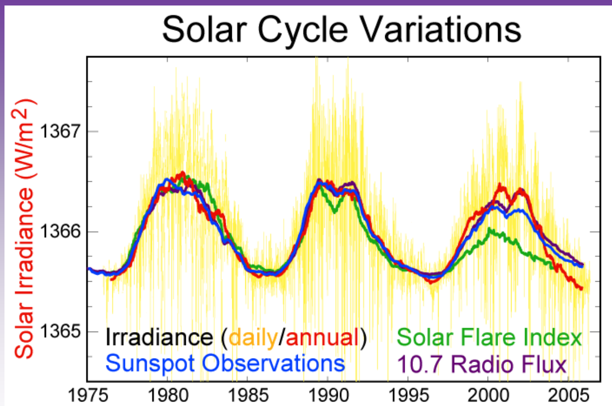


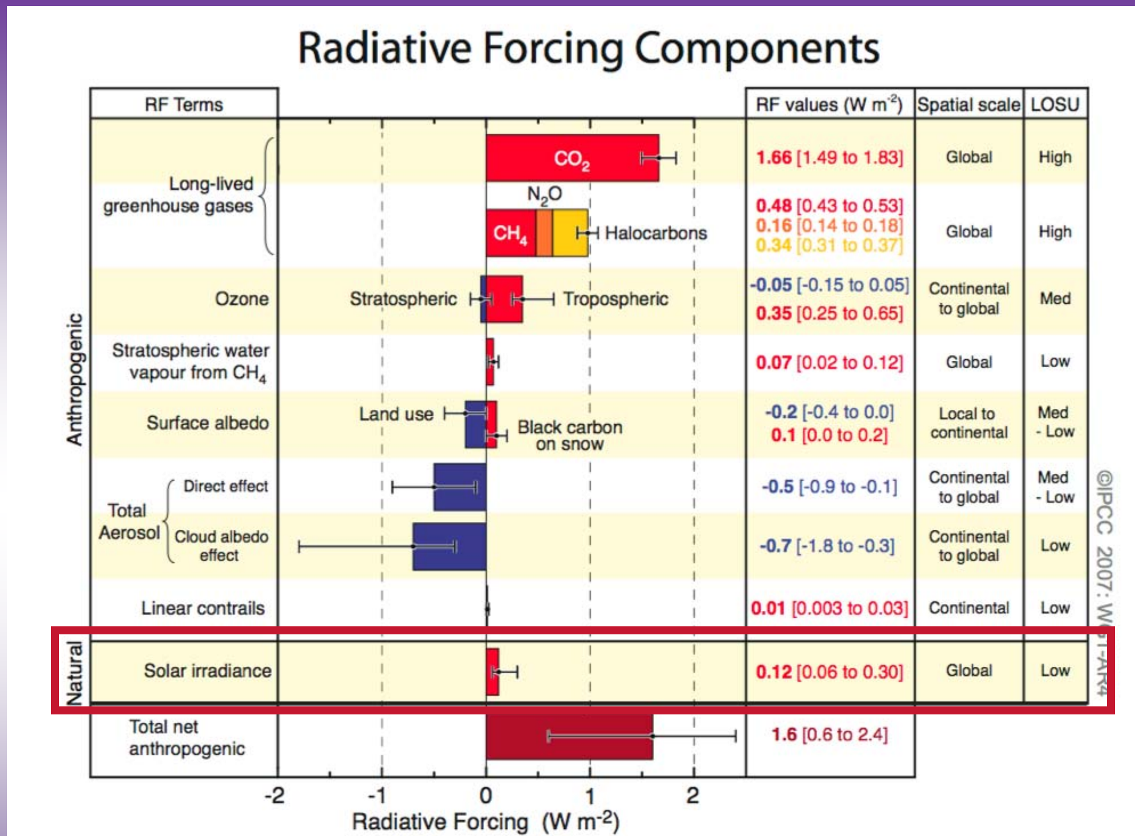
Van Loon & Shea. (1999)
QBO-filtered data



Coughlin & Tung (2004)
EMD decomposition

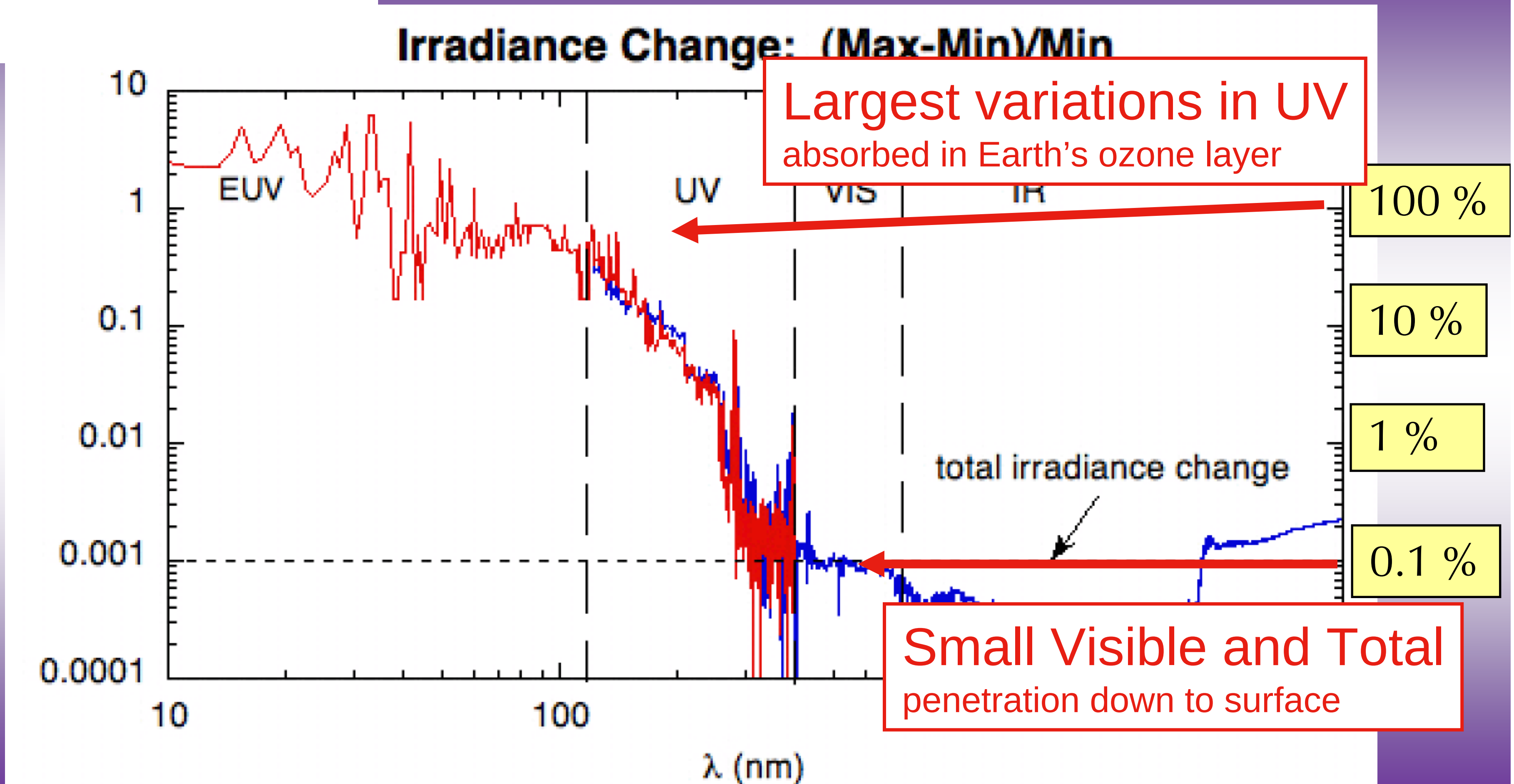
The Uncertain Forcing





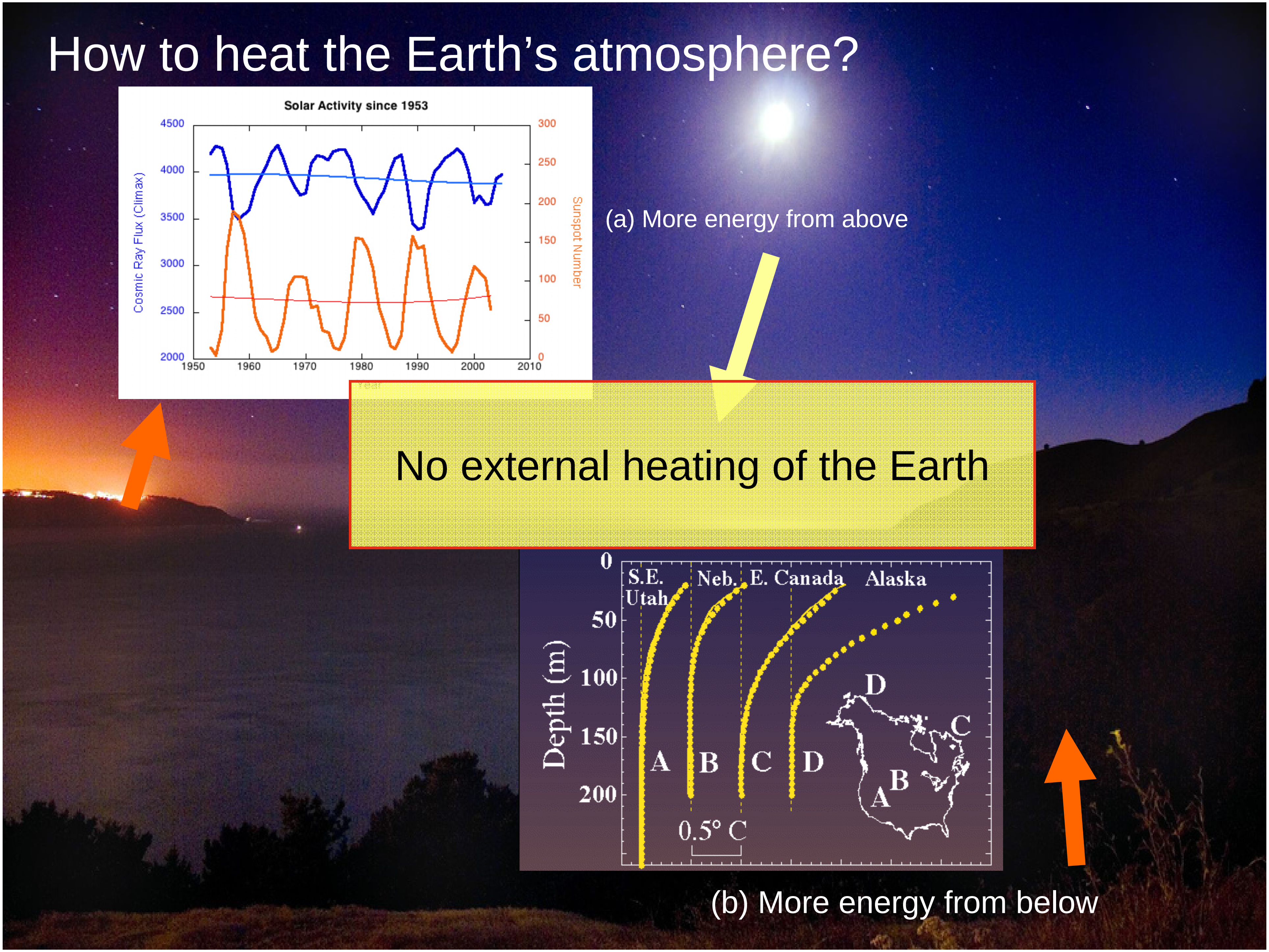
Solar Irradiance Variations

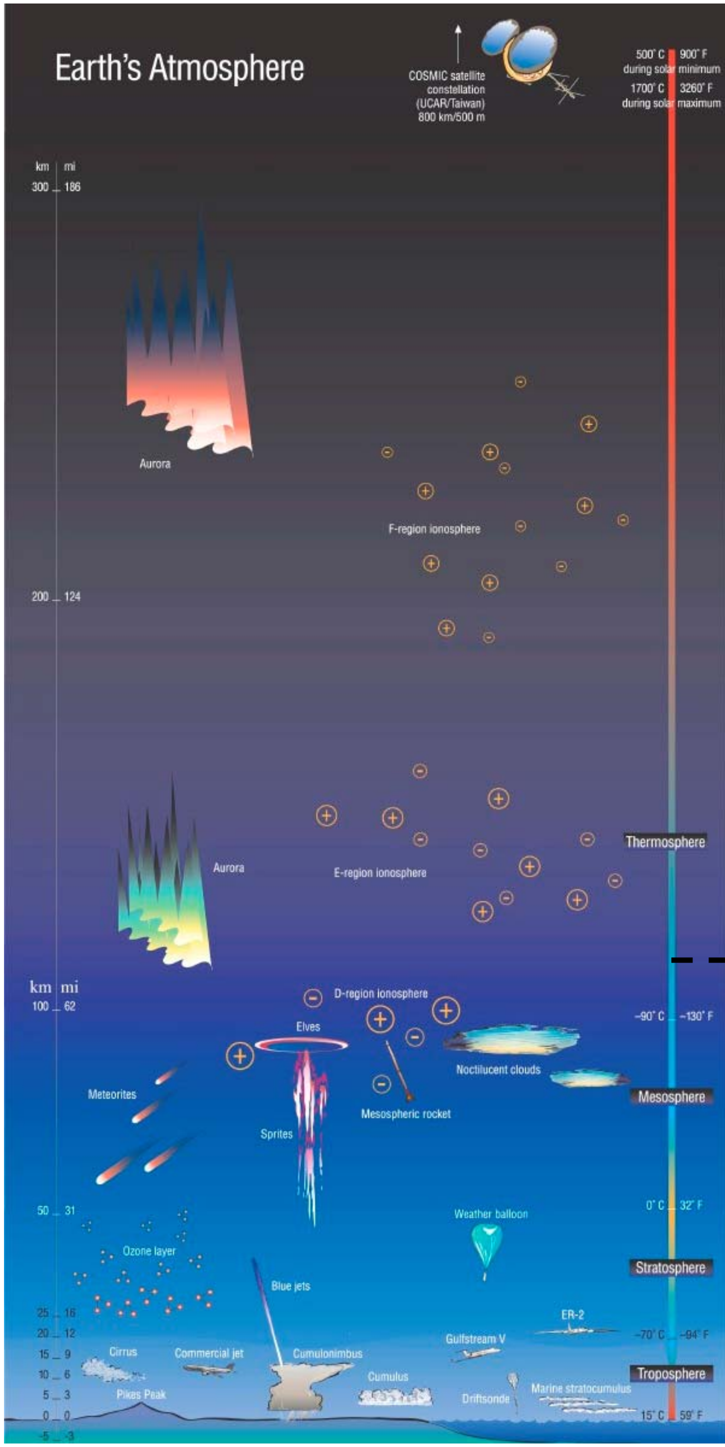
QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



Why Global Warming is not from the Sun

- No trends in solar energy input into climate system
- Vertical temperature trends not consistent with active sun
- Modeling studies suggest small solar forcing is detectable


How to heat the Earth's atmosphere?
Solar Activity since 1953
Cosmic Ray Flux (Climax)
Sunspot Number
4500
4000
3500
3000
2500
2000
300
250
200
150
100
50
0
1950
1960
1970
1980
1990
2000
2010
(a) More energy from above
No external heating of the Earth
Depth (m)
0
50
100
150
200
S.E. Utah
Neb.
E. Canada
Alaska
A
B
C
D
0.5° C
(b) More energy from below

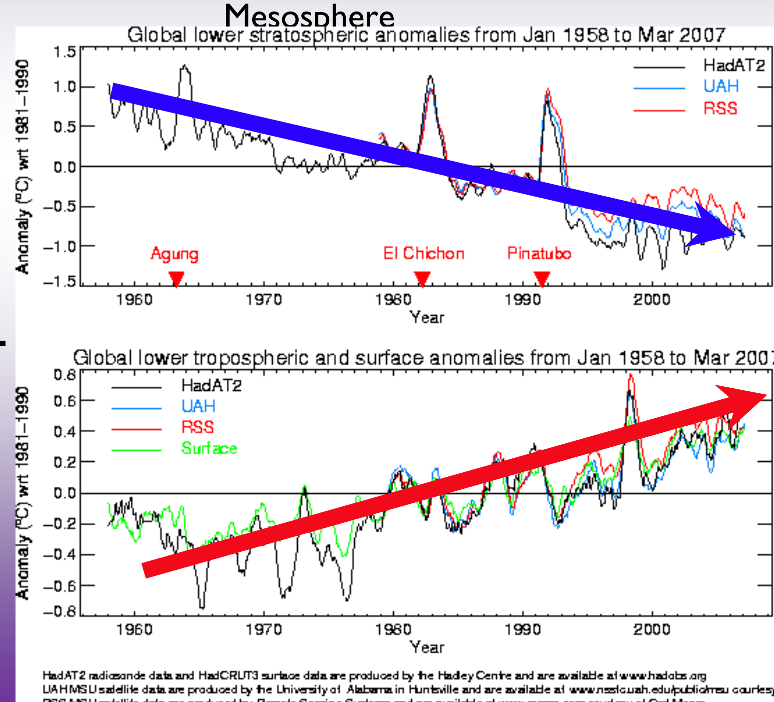


Temperature trends expected:

The Sun

Greenhouse Gases

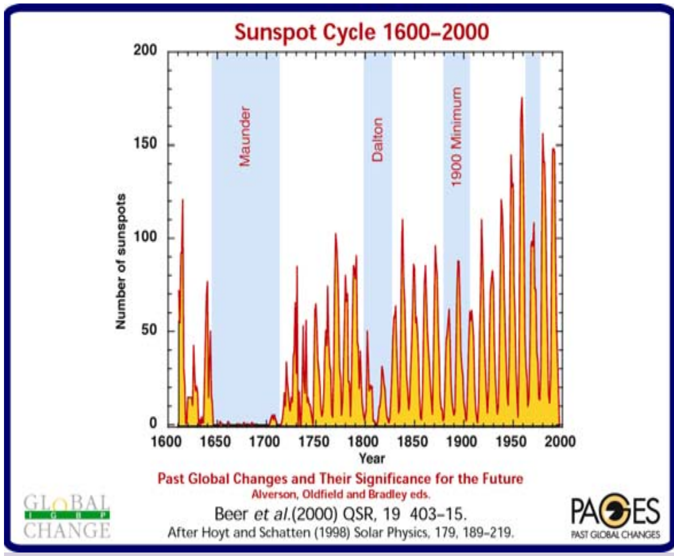
Mesosphere



Can Climate Models capture trends?

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

NCAR CCSM - Ammann 2005

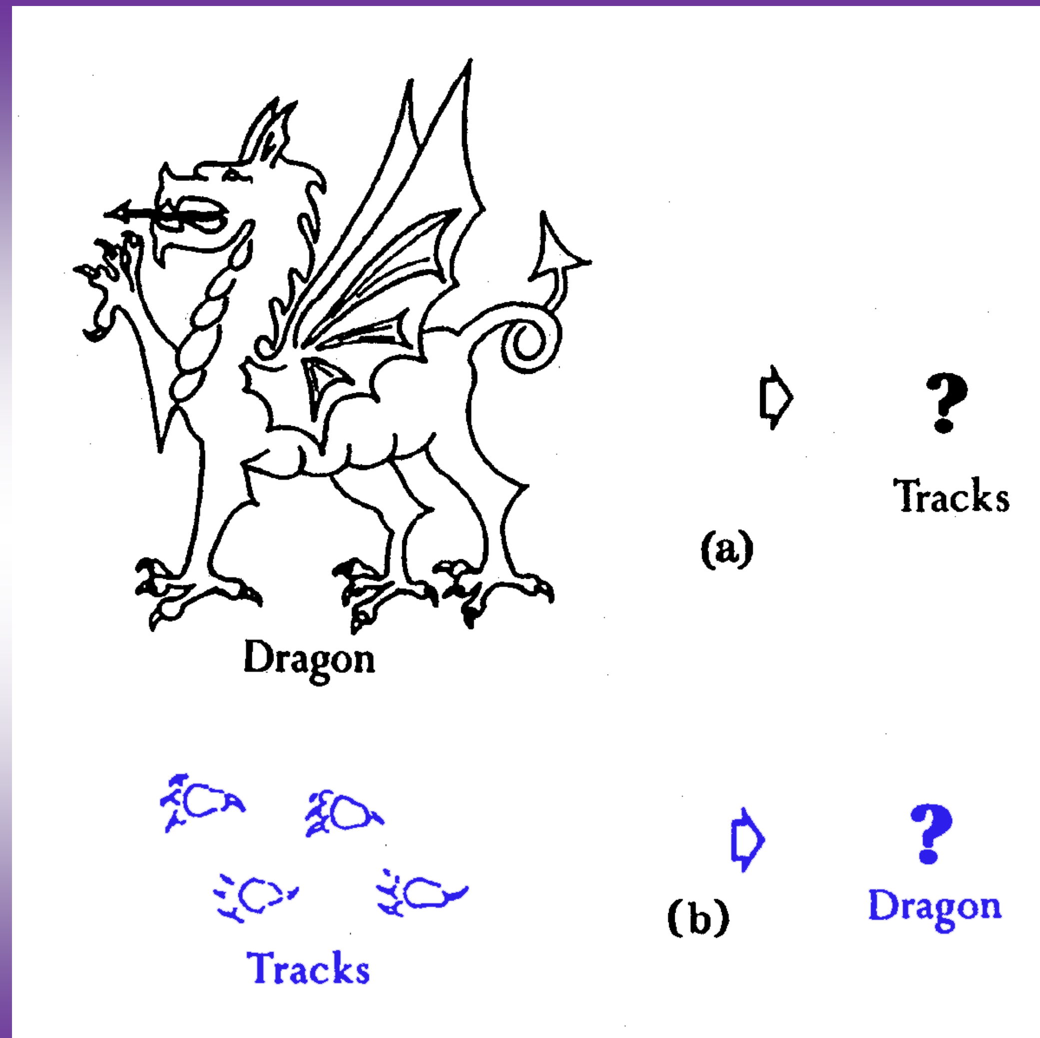


Model / Data Intercomparison

NCAR

Modeling

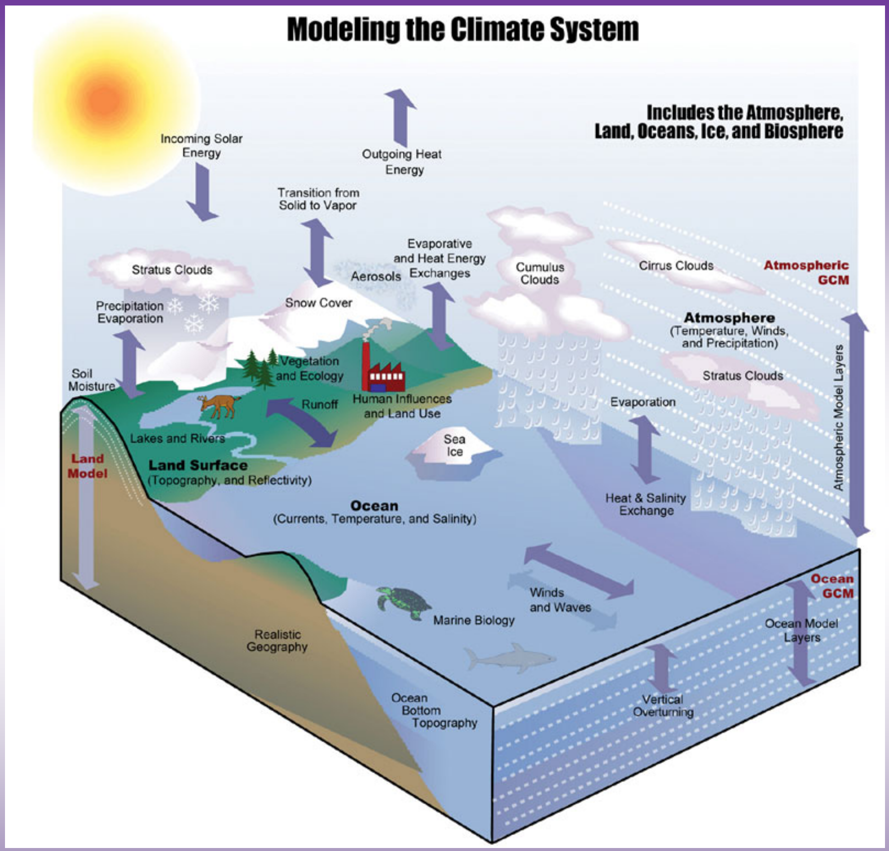
Strength:
- physically consistent
- full climate information

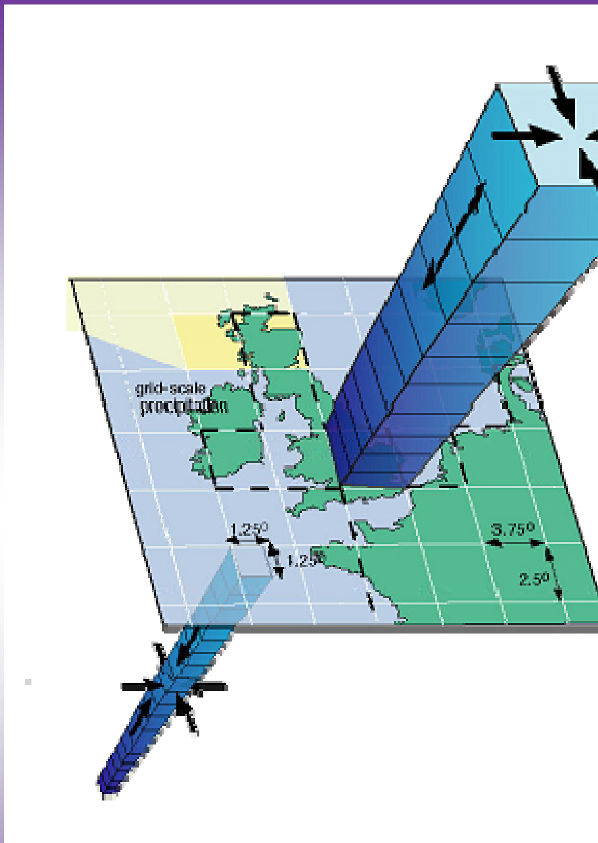


Climate Reconstruction

Strength:
- Real world (Not based on parameterization)
- long records
- spatial component

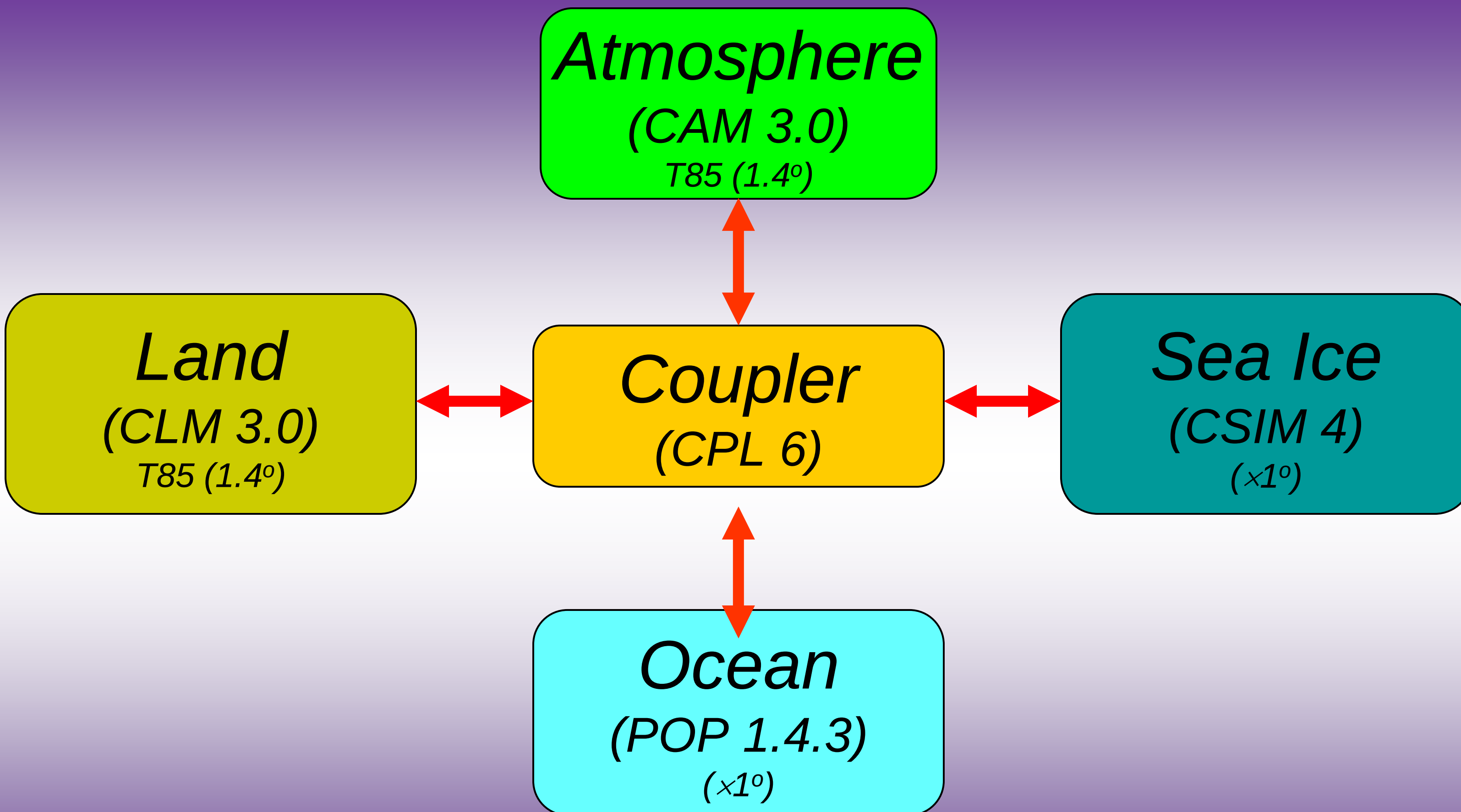
What are climate models?



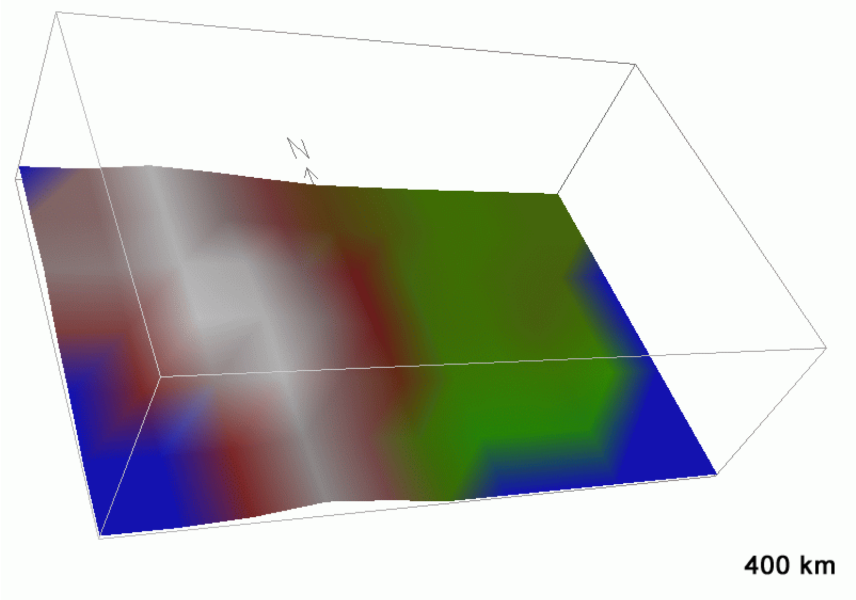


Viner (2002)

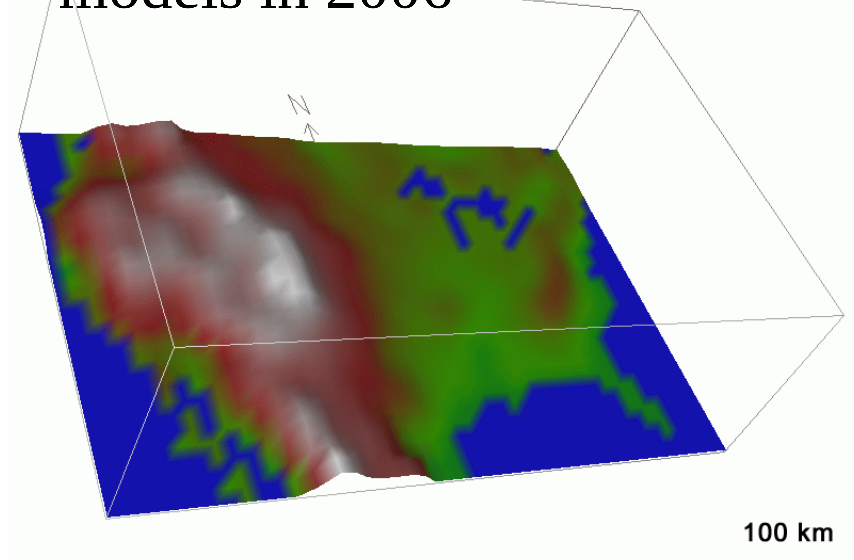
Configuration of NCAR CCSM3



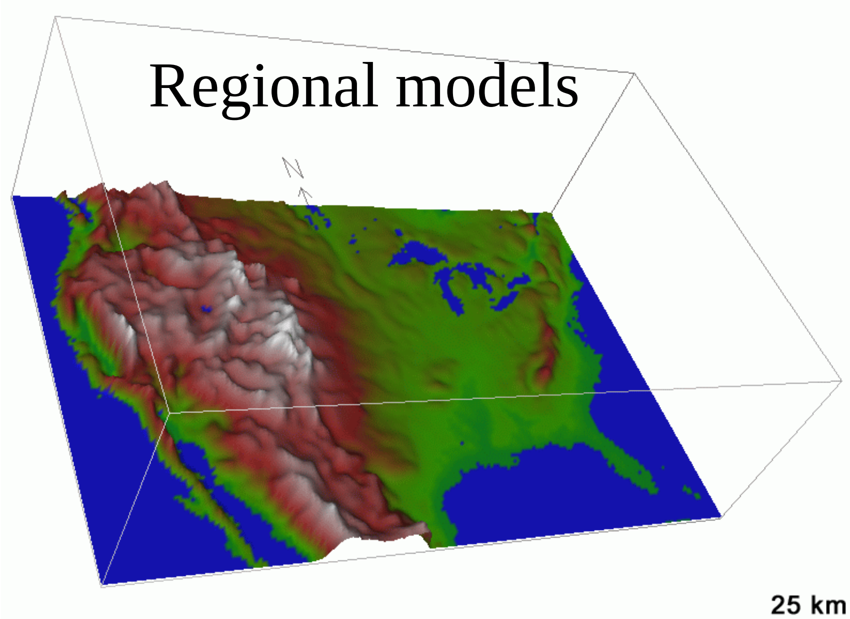
Climate Models circa early 1990s



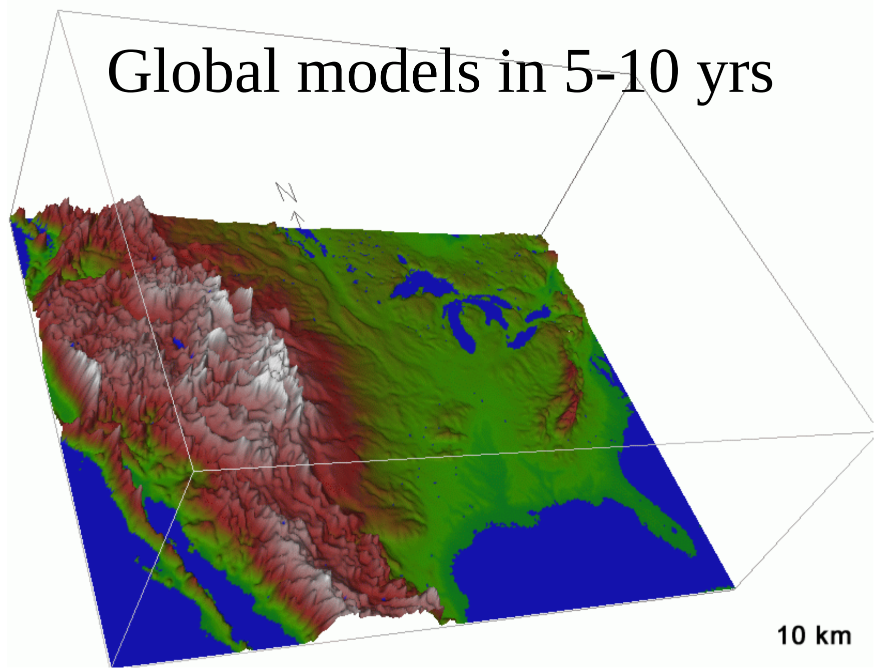
Global coupled climate models in 2006



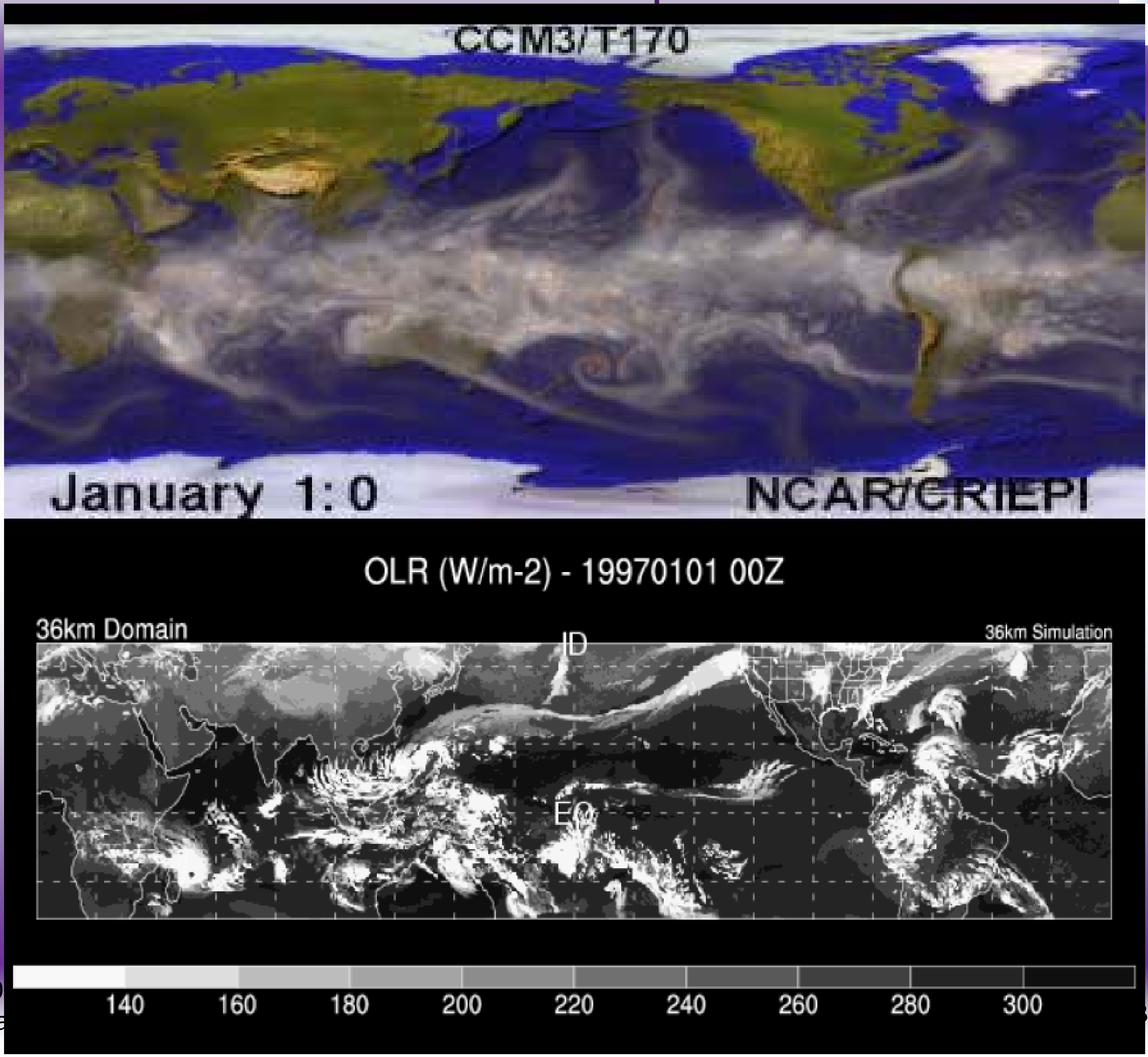
Regional models



Global models in 5-10 yrs



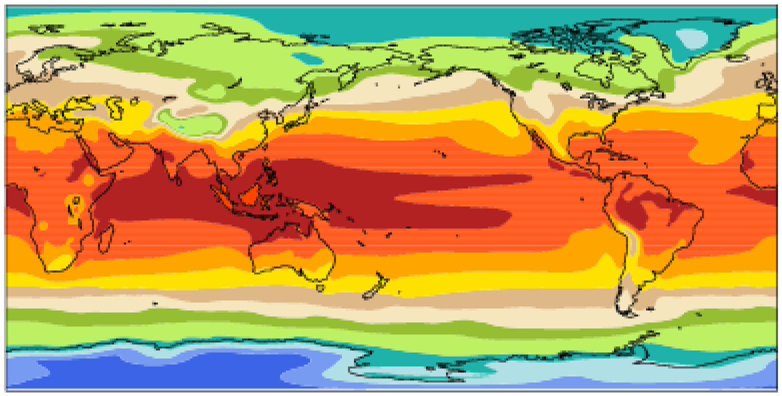
Global Atmosphere



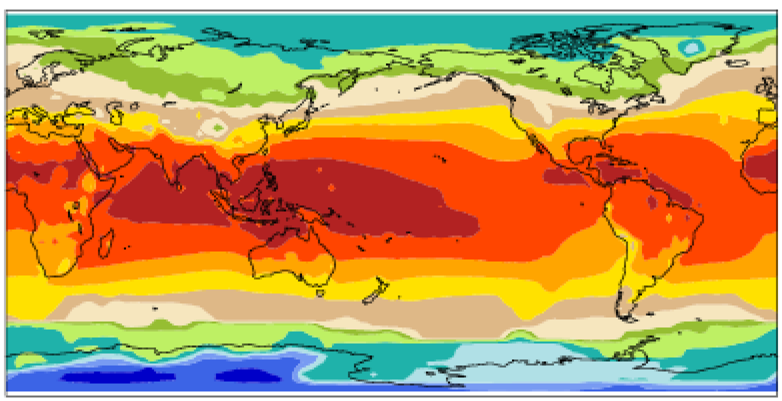
Performance of CCSM-3

Surface Air Temperature

Model

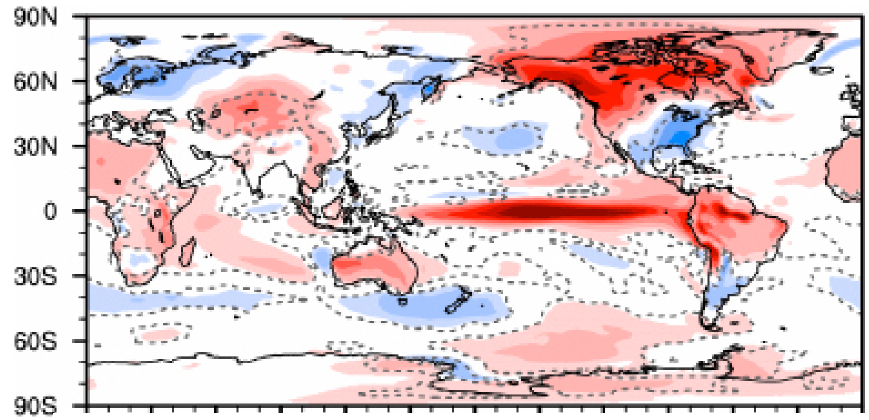


Observations

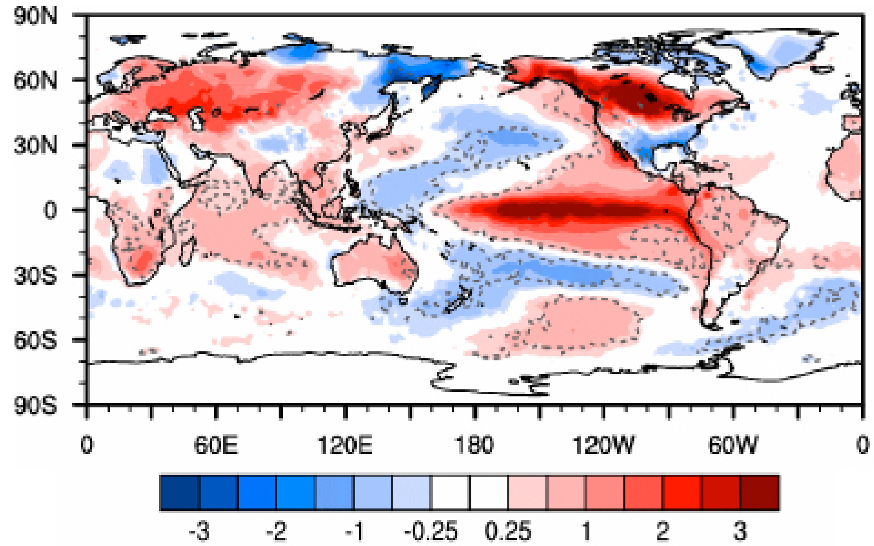


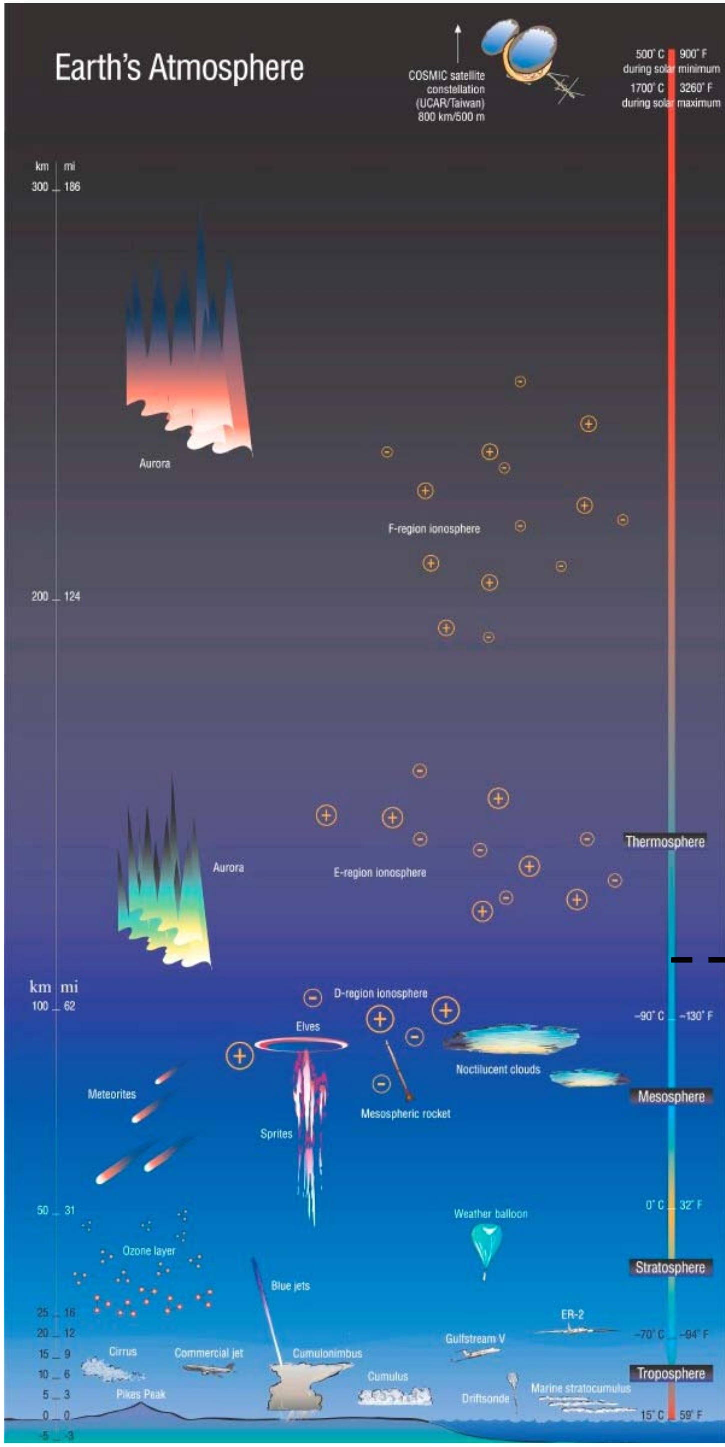
El Niño-Variability

Model



Observations



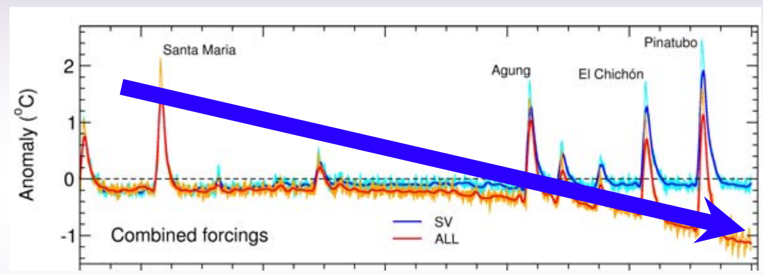


Model Simulated Trends 3D

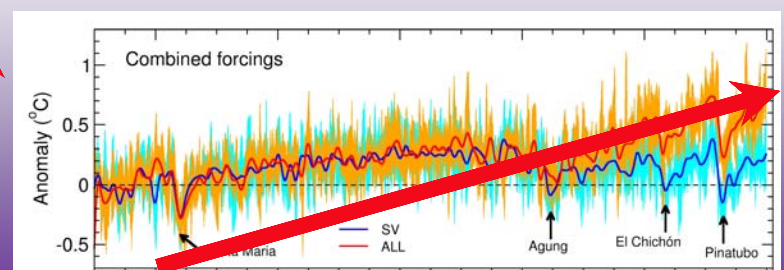
NCAR

The Sun

Greenhouse Gases



1900 1960 2000



1900 1960 2000

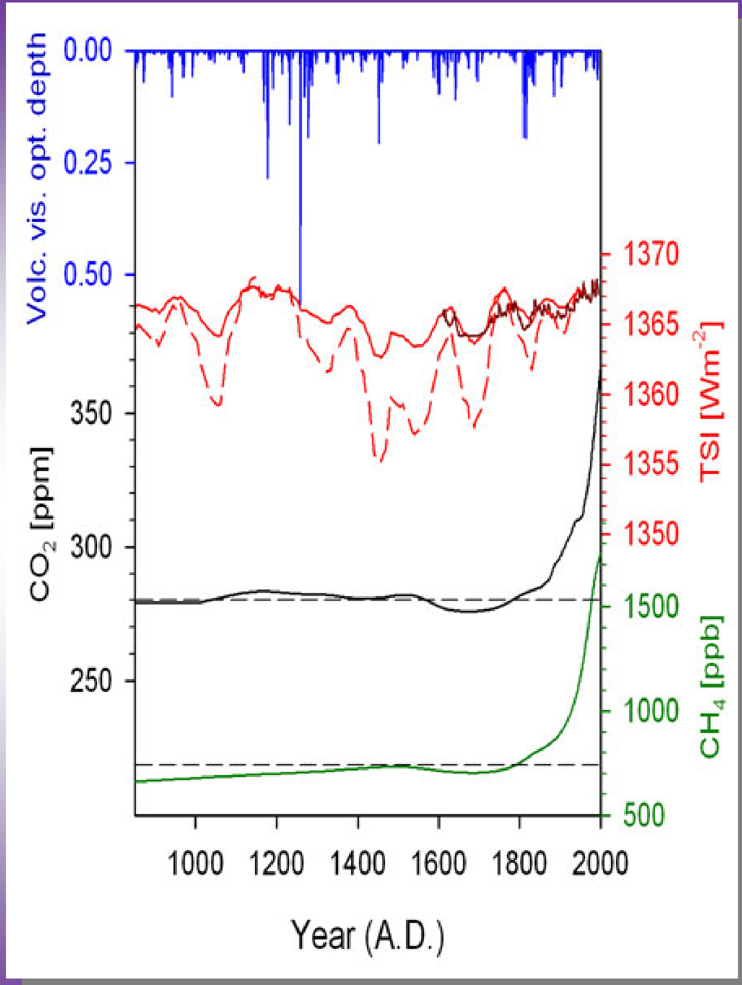
Summer School for Heliophysics

NCAR - Climate System Model 1.4

Coupled simulations
T31x3' model
for 850 AD - present

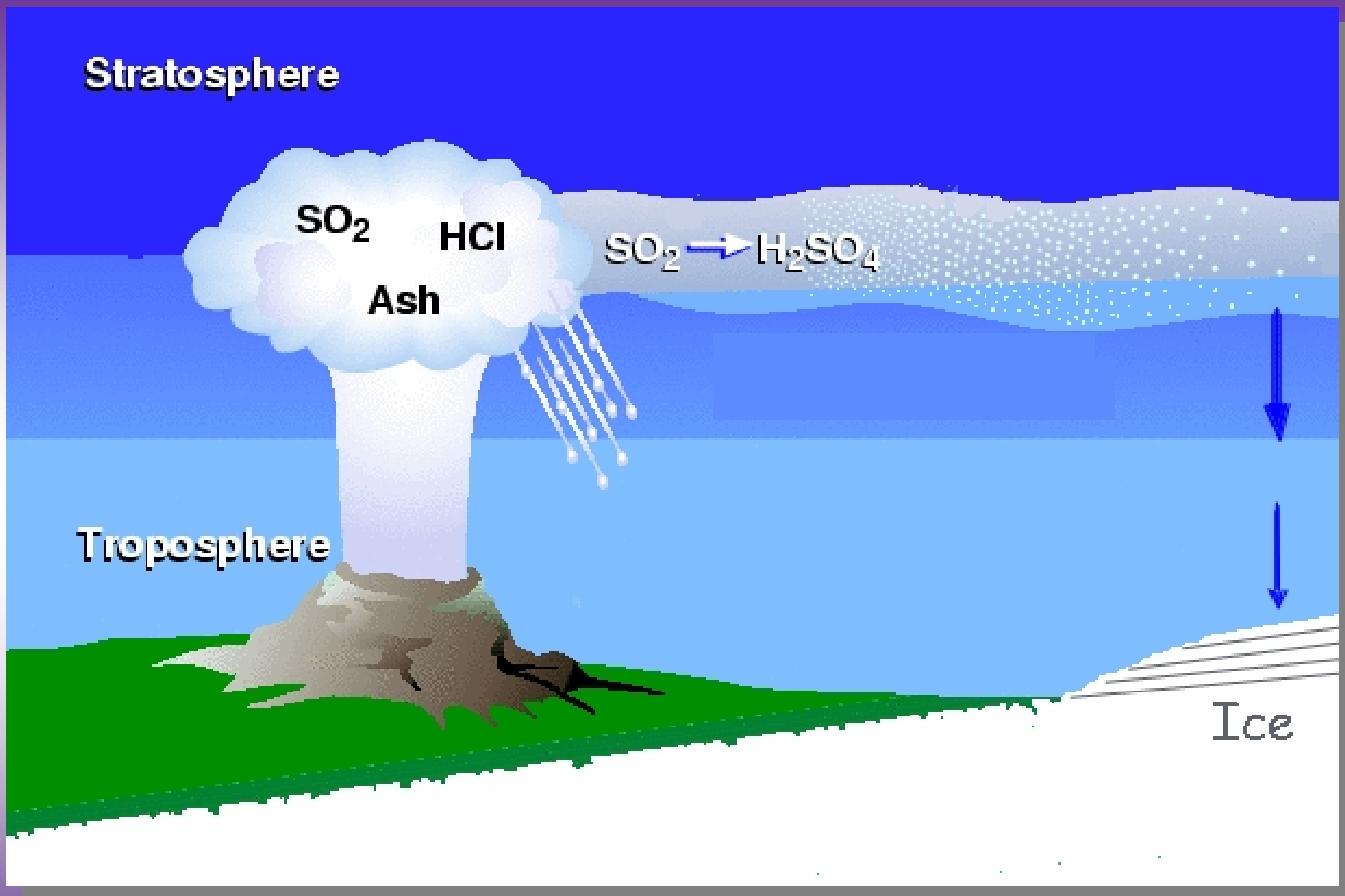
with :
Solar Forcing (various magnitudes)
Volcanic Forcing (ice core based history)
GHG (ice core based history)
Fixed Ozone and nat. Sulfate Climatology (12 months)

After 1870:
either natural only (GHG, sulfate fixed at 1870) or ramped after 'observations'



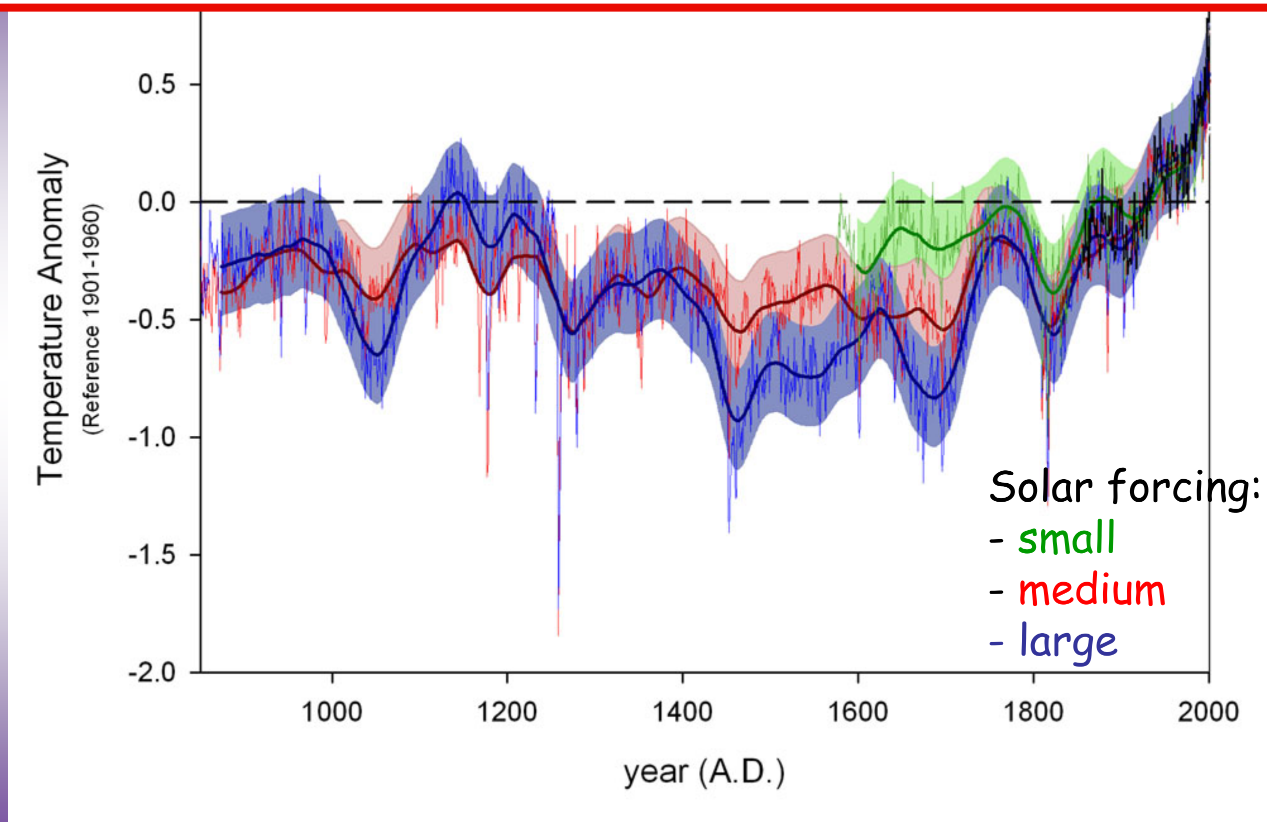
Ammann et al. (2007)

Volcanic Sulfur : Polar Ice Core Record



CSM 1.4: Global Surface Temperatures

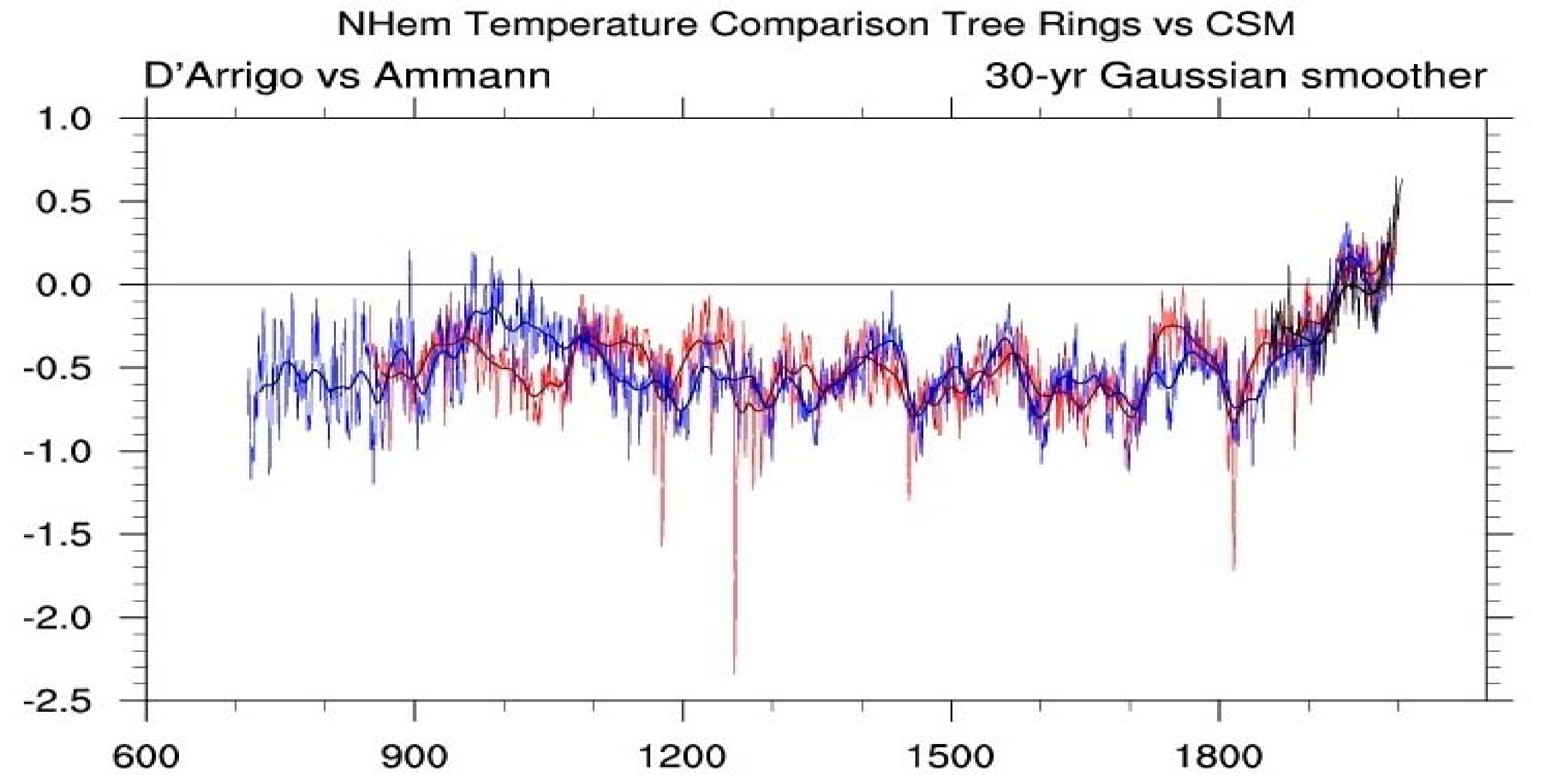
Medium Experiment is consistent with 20th Century Run and with most Simulations submitted to IPCC

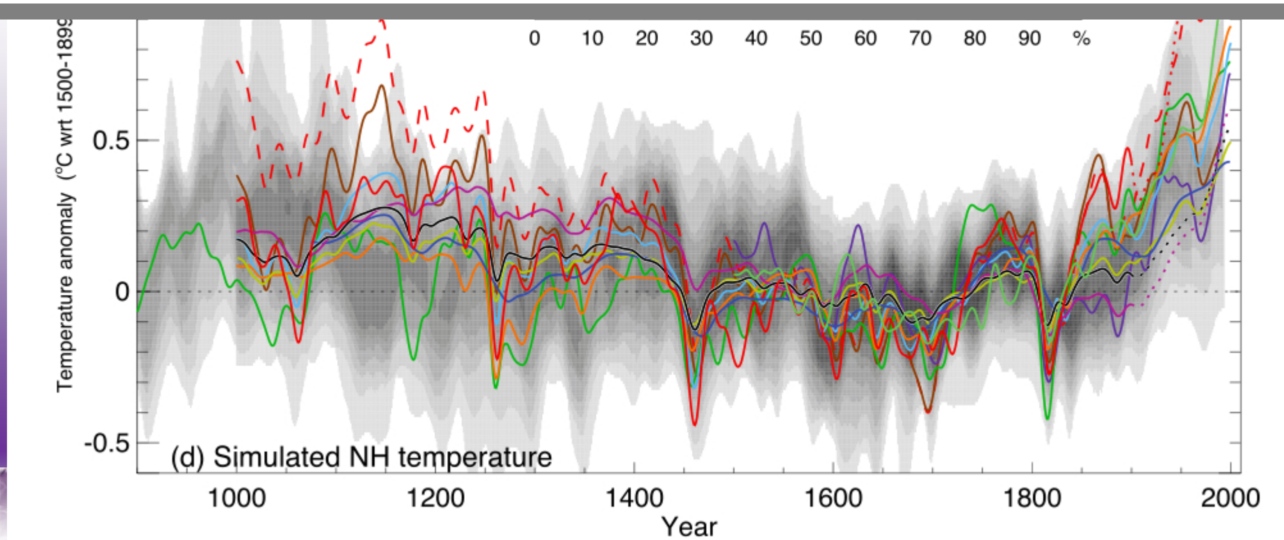


Ammann et al. (2007)

Forcing

Models
Vs
Recons

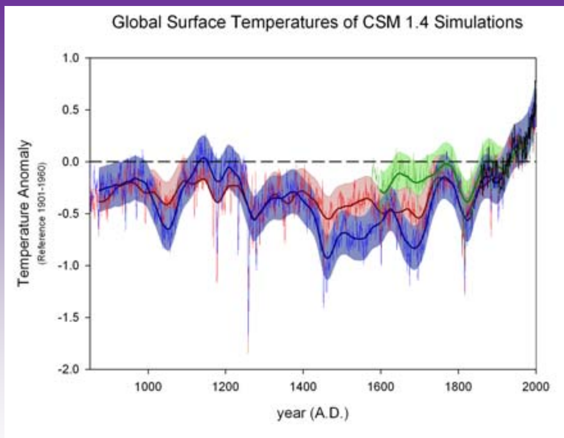


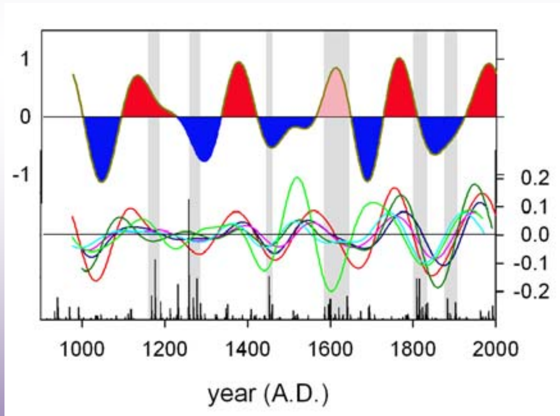


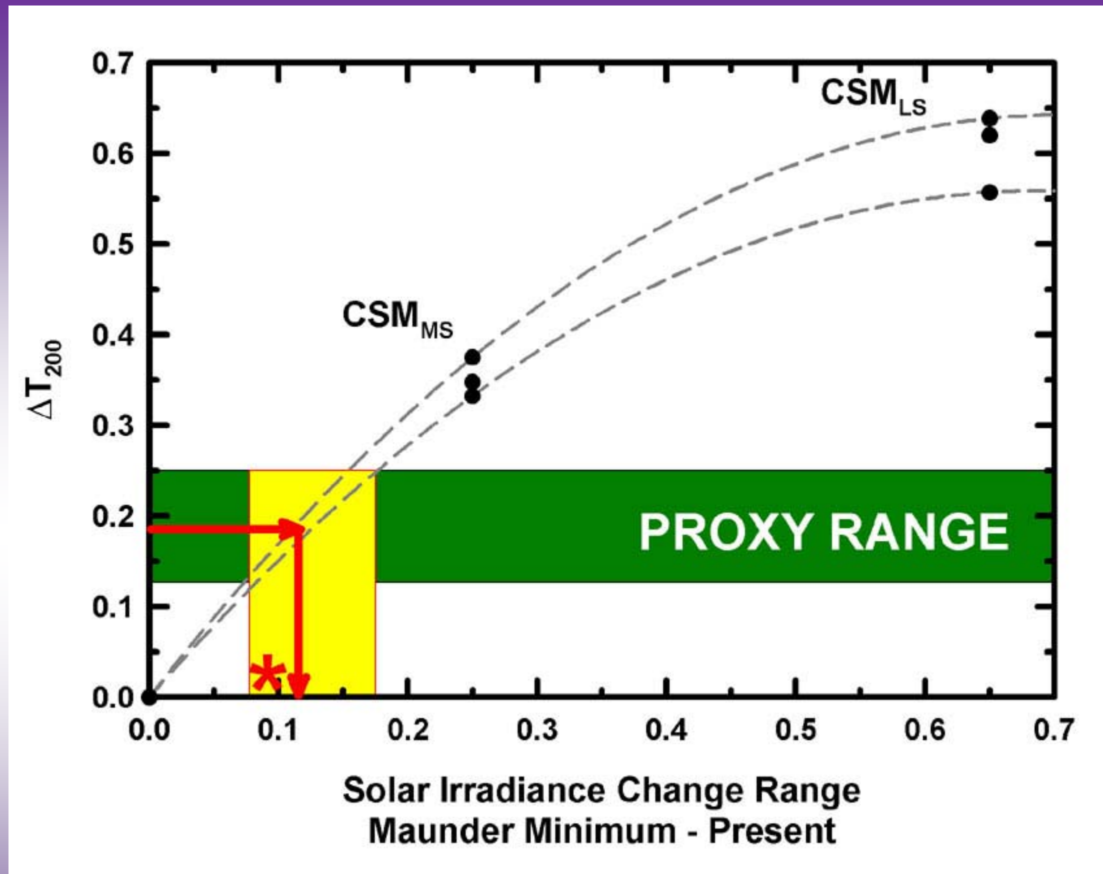
IPCC 2007

August 7, 2007
Caspar Ammann

Global/Hemispheric Signal of ~200-year Cycle





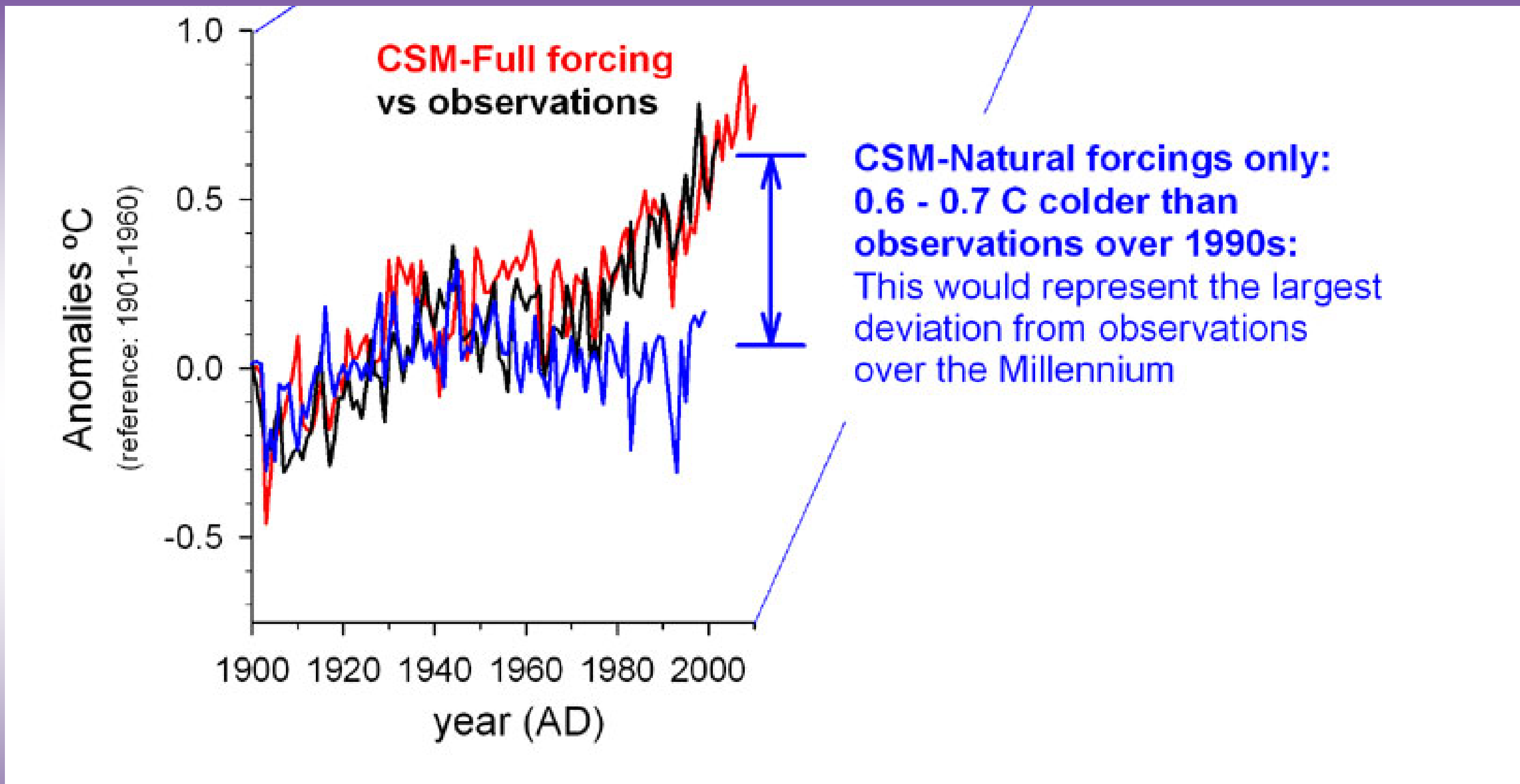


Ammann et al. (2007)

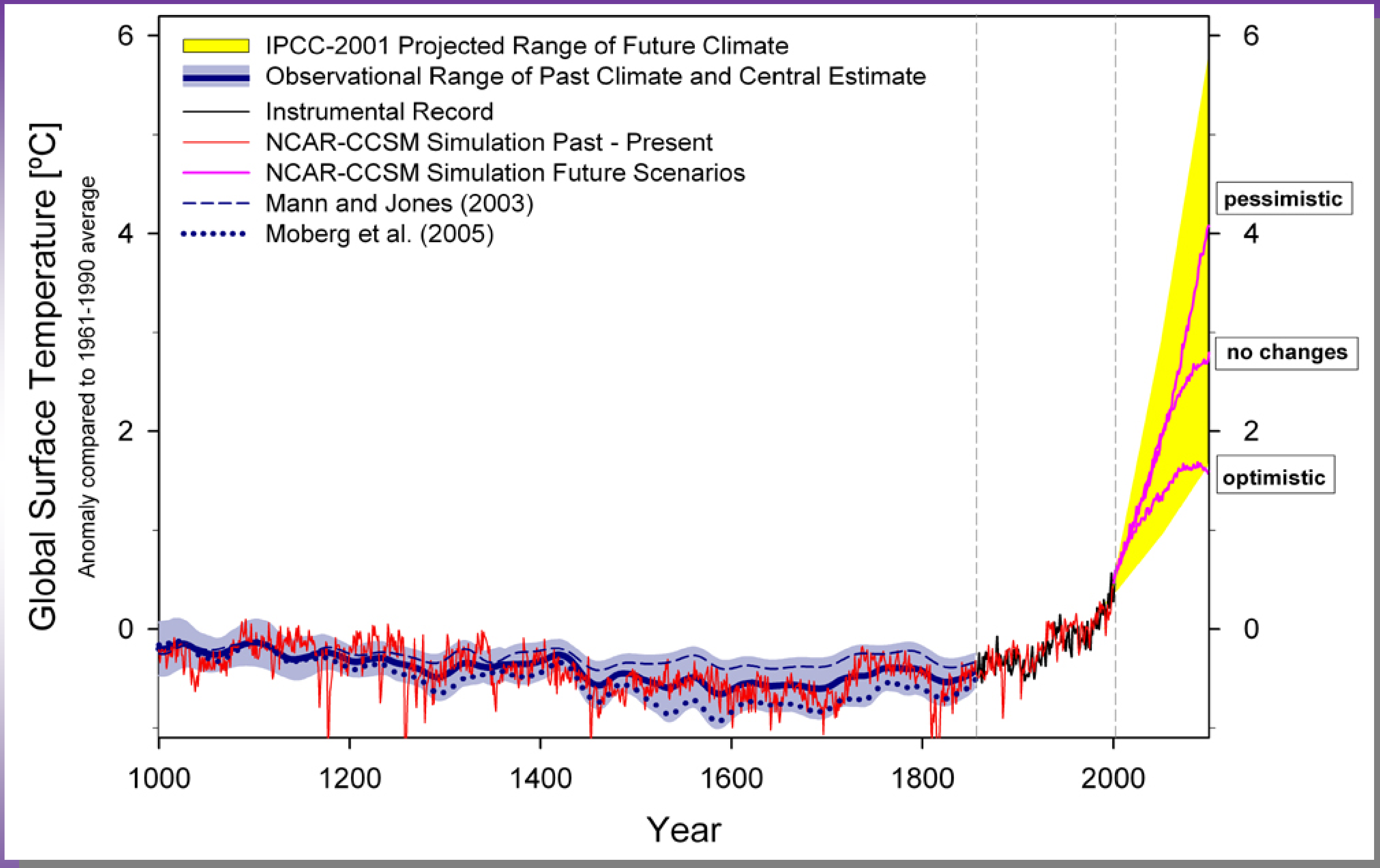
Ammann & Joos

Climate Model Simulations

20th Century without anthropogenic forcing?



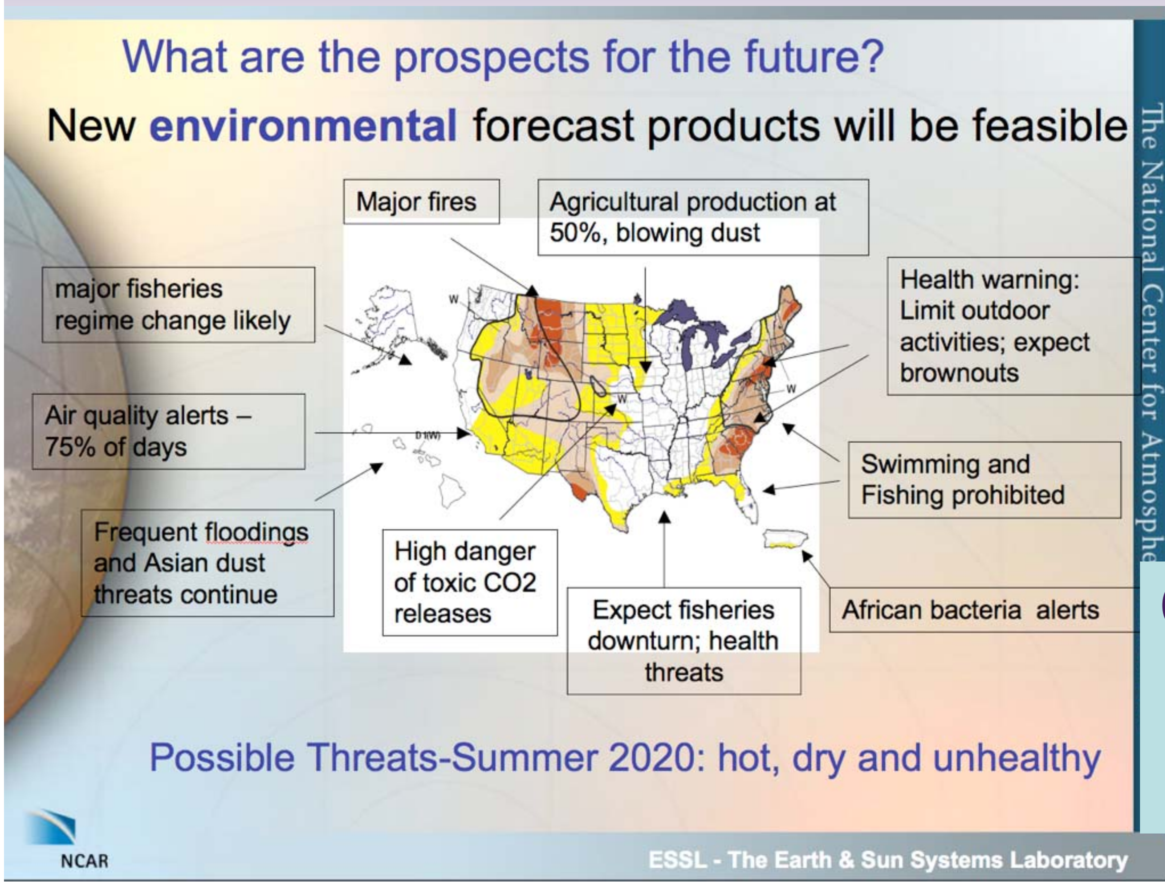
Surface Temperatures : Past - Present - Future



What's Next?

IPCC AR5 (~2013?)

(1) Long, multi-century projections to study Carbon Cycle Feedbacks, Sea Level Change



(2) Very high-resolution simulatioins of the next 20-30 years for regional climate change prediction

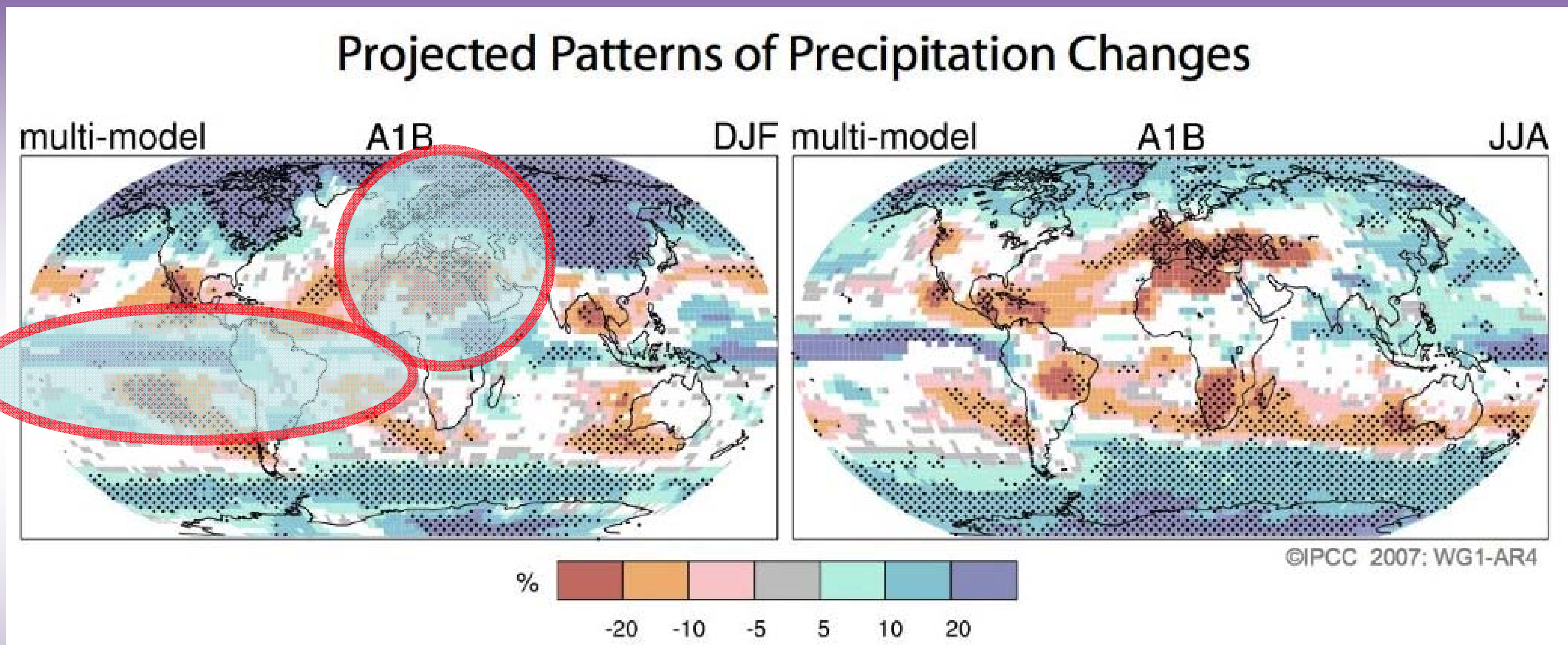
Next big questions (1)

- **Long-term trend and rate of change**: Faster than expected:
  - GHG
  - Sea ice loss
  - Glacier melting
  - Sea level change
  - Oceanic feedback to carbon cycle
  - Land feedback to carbon cycle

(Is PETM an analogue?)

Next big questions (2)

- Regional prediction of the next 20-30 years

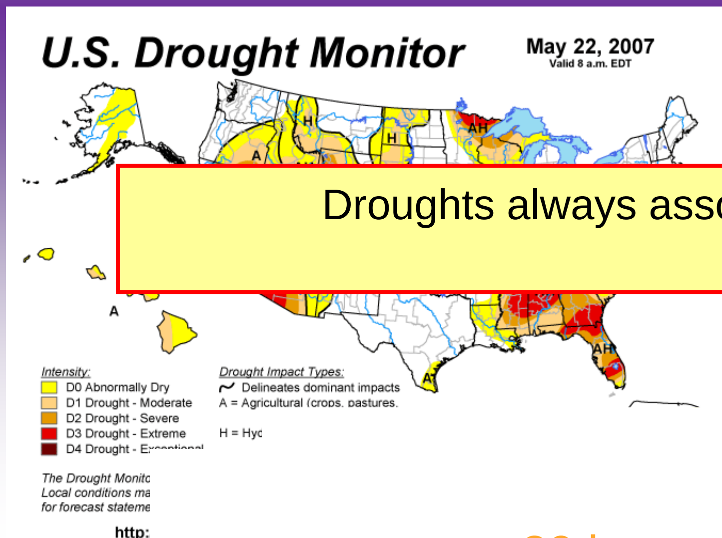


Key Questions:

- How realistic is the El Niño response to forcing in models?
- Lack of Blocking in atmospheric circulation (cold/heat waves)

US South West

Is the current drought just the start?



Droughts always associated with positive radiative forcing?

ressor
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20th century — 21st century

QuickTime™ and a
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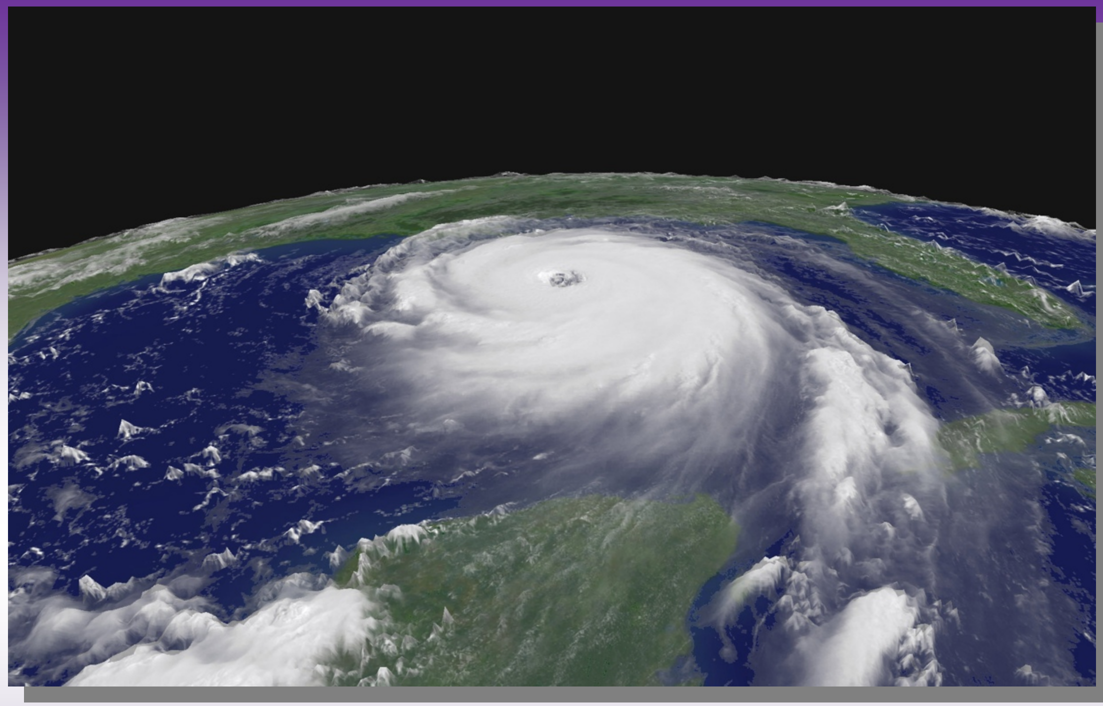
are needed to see this picture.

Seager et al. 2007

Intense Hurricanes controlled by El Nino and W-African Monsoon

Nature May 24, 2007

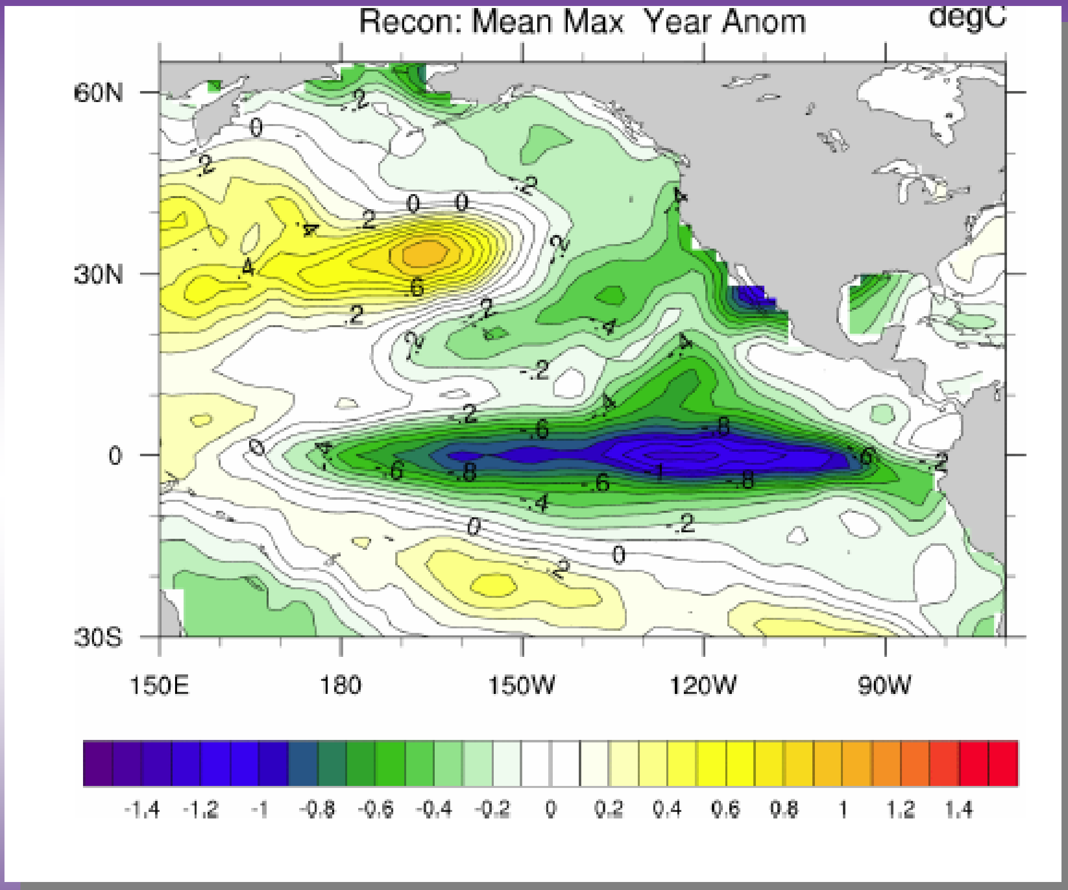
Donnelly and Woodruff



"… the findings pointed to the importance of figuring out an unresolved puzzle: whether global warming will affect the (El) Nino cycle one way or the other. More intense or longer Pacific warm-ups could stifle Atlantic and Caribbean hurricanes even with warmer seas, Dr. Donnelly said."

NY Times, May 24, 2007

Solar effects in the Pacific : 11-year Cycle Observations



SST anomalies during peak years of the solar cycle (1856-2004)

Van Loon & Meehl

Active Sun -> La Nina?

Pacific Signal on 11-year and Centennial?

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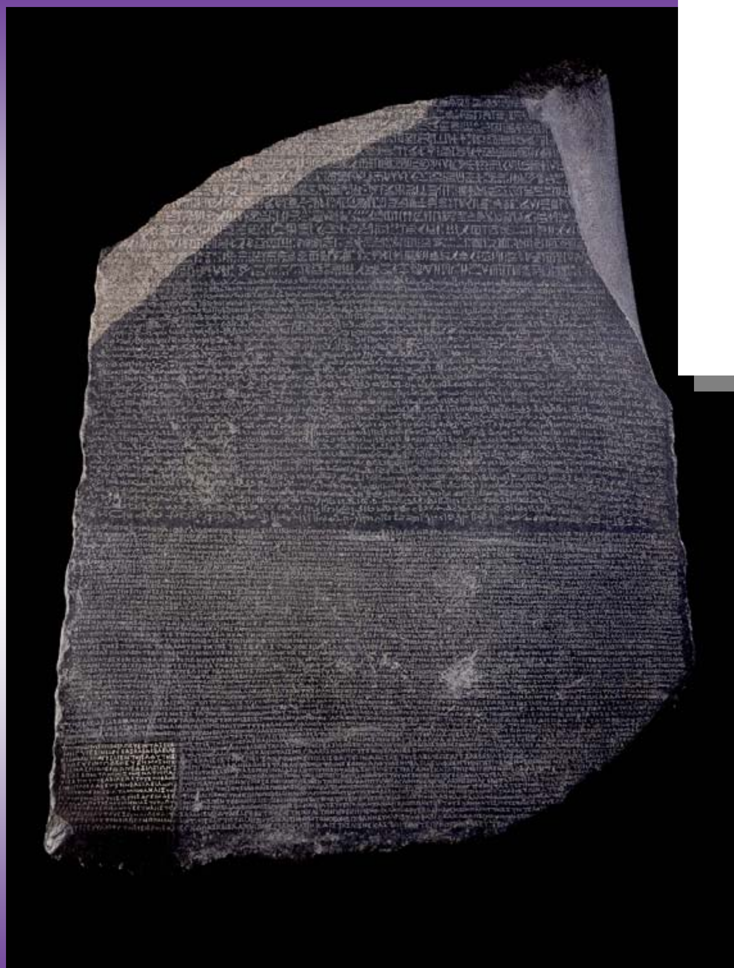
Solar Forcing : Rosetta Stone” to regional dynamics and a test for climate models?



QuickTime™ and a
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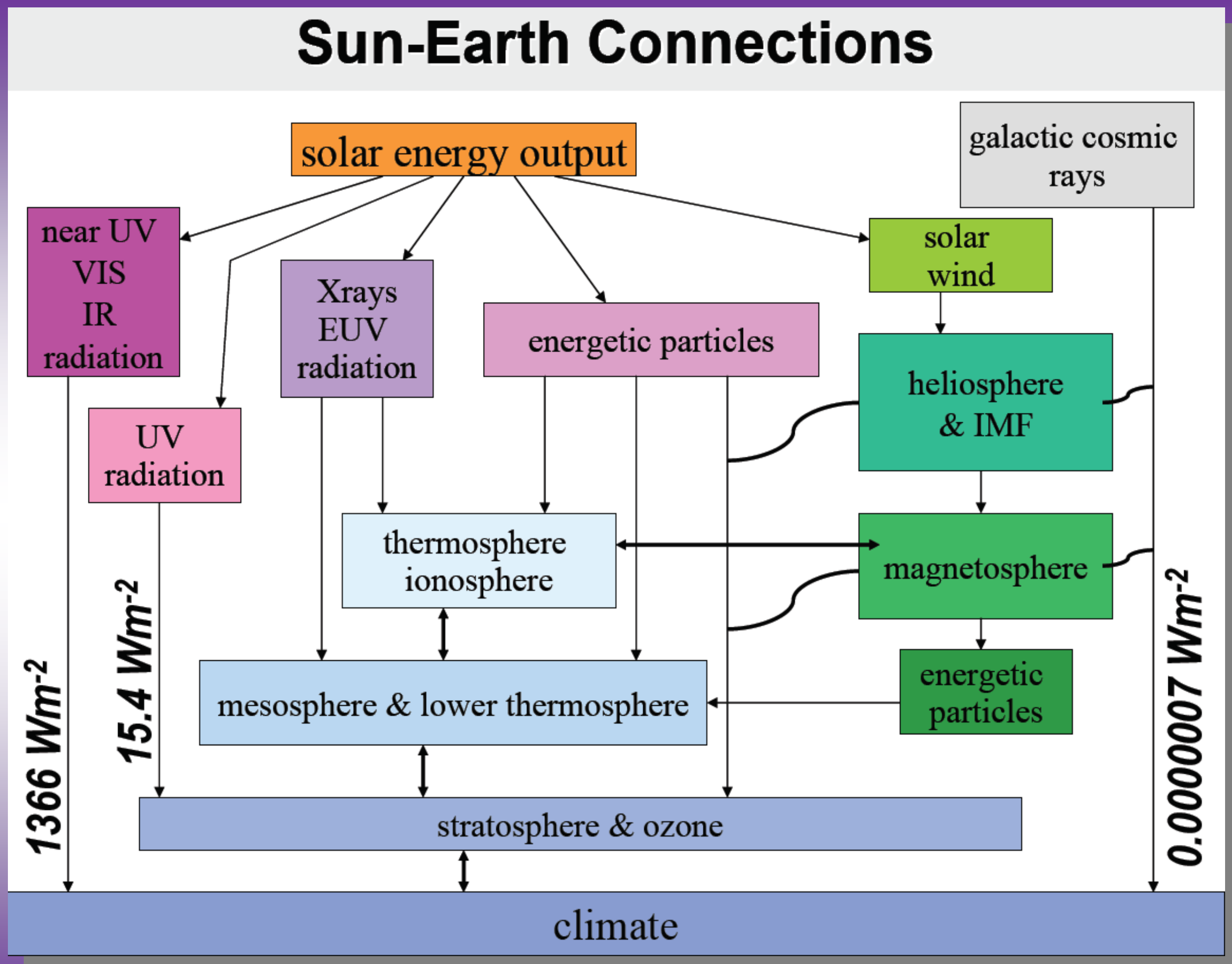
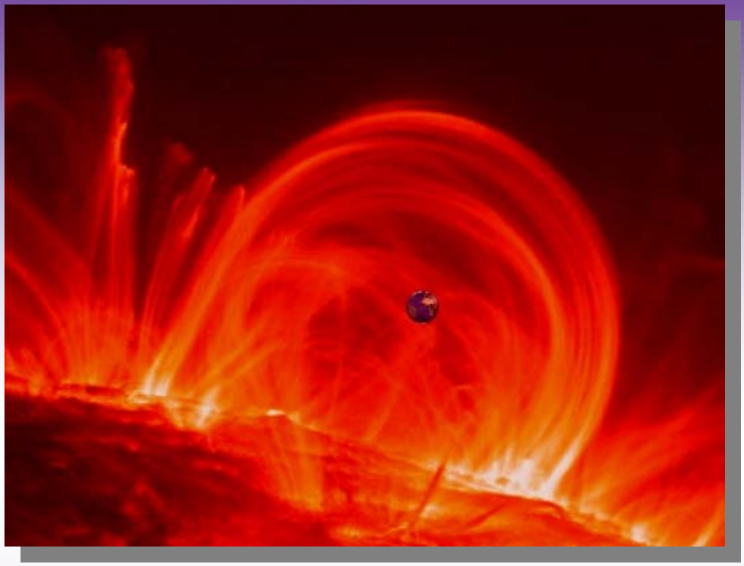
- Short observations and models: Greek
- Solar forcing and its impact in paleorecords: Demotic Text
- Geophysical Process: Hieroglyphs

More detailed simulations of Solar Influence on Atmosphere



NASA LWS

Summary



- There are small solar signals in regional climatic records at various time scales, and a clear but also small solar component can be detected at the hemispheric scale. (~0.1-0.2 degrees)
- No trends in any solar-related proxy (incl. cosmic rays) exist at present, thus little to no contribution is coming from the Sun to the current global warming
- Improved across-scale Sun-Earth links could be gained from historically recurring variations and the combination of observational, modeling and paleo- analyses could act as a “Rosetta Stone” for regional climate variability.