FACULTY OF SCIENCE
Institute for Biodiversity and Ecosystem Dynamics

Environmental monitoring based on paleo-records

marine sediments, lake and peat deposits, ice cores

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TERENO International Conference, Bonn
Session: **Crossing Time Scales: From Paleo Records to Present Day Change**
1 October; 8.30-8.50

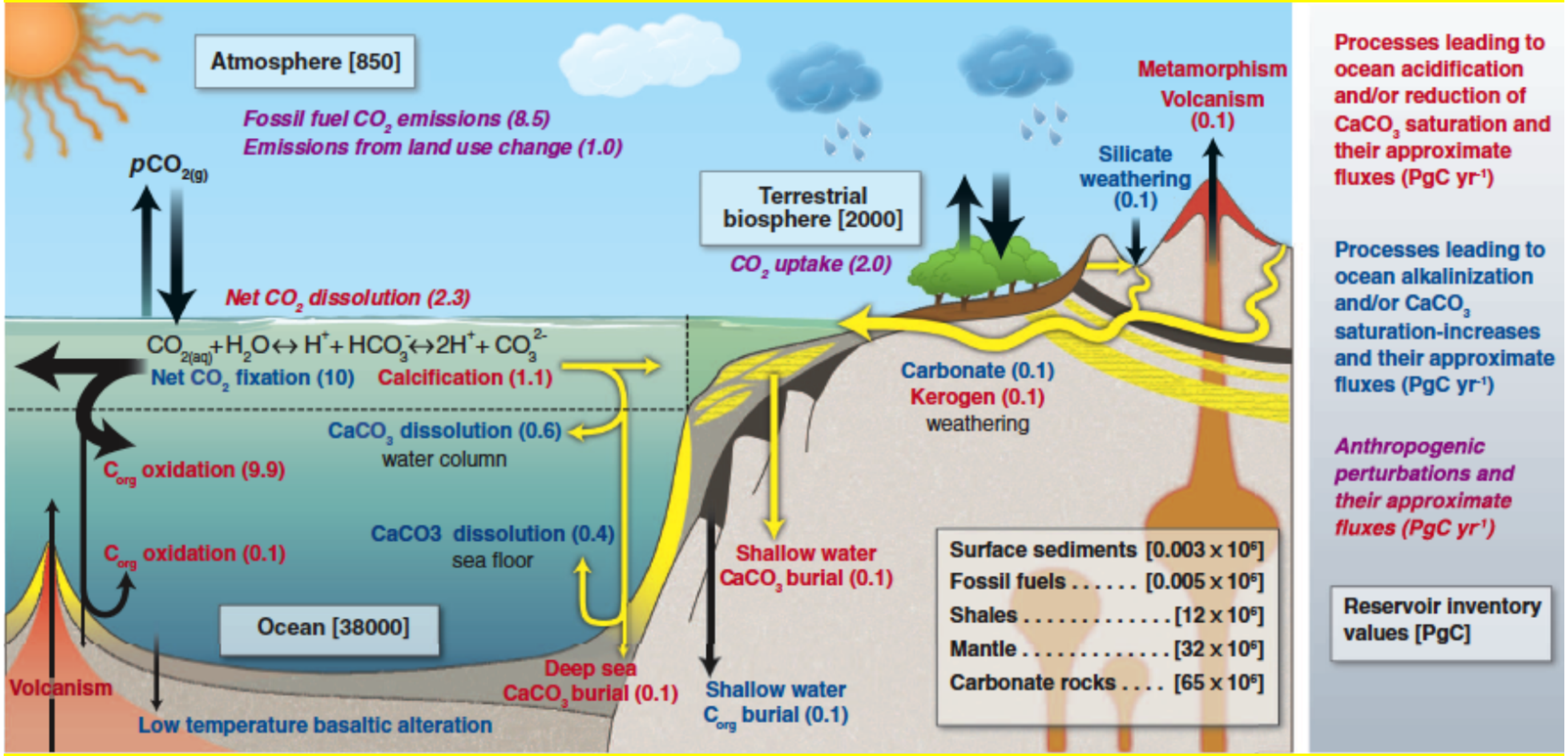
TERENO: an interdisciplinary and ***long-term*** research program.

TERENO aims to catalogue the ***long-term*** ecological, social and economic impact of global change at regional level.

How long is long-term?

We can learn from paleo-records about effects of increasing CO_2 levels, orbital forcing, and about the role of the Sun upon climate change!

Nowadays: rapid CO_2 release, causing climate and ecosystem change



Hönisch, B. et al., 2012. The geological record of ocean acidification. Science 335: 1058-1063.

TERENO: monitoring of terrestrial sites

Paleo-studies (carbon cycle): most cores from marine sediments

'**Future-relevant**' paleo-ocean acidification events;
massive GHG release, pH decline and $CaCO_3$ saturation decline, biotic responses, climate change.

One of the research goals of studies of marine sediments:
Future projections in terms of disrupting the balance of ocean carbonate chemistry.

What may happen in the future?

Alkalinity released by rock weathering on land must be balanced by the burial of $CaCO_3$ in marine sediments which is controlled by the saturation state of the ocean.

Present CO_2 increase:
weathering and sinks ($CaCO_3$ burial) are no longer balanced.

Example (natural): transition Weichselian to Holocene:
There was a 30 % CO_2 rise (to pre-industrial levels)
-> 0.15 pH decrease
-> Foram shells weights decreased 40-50%
-> Coccolith mass decreased by 25%

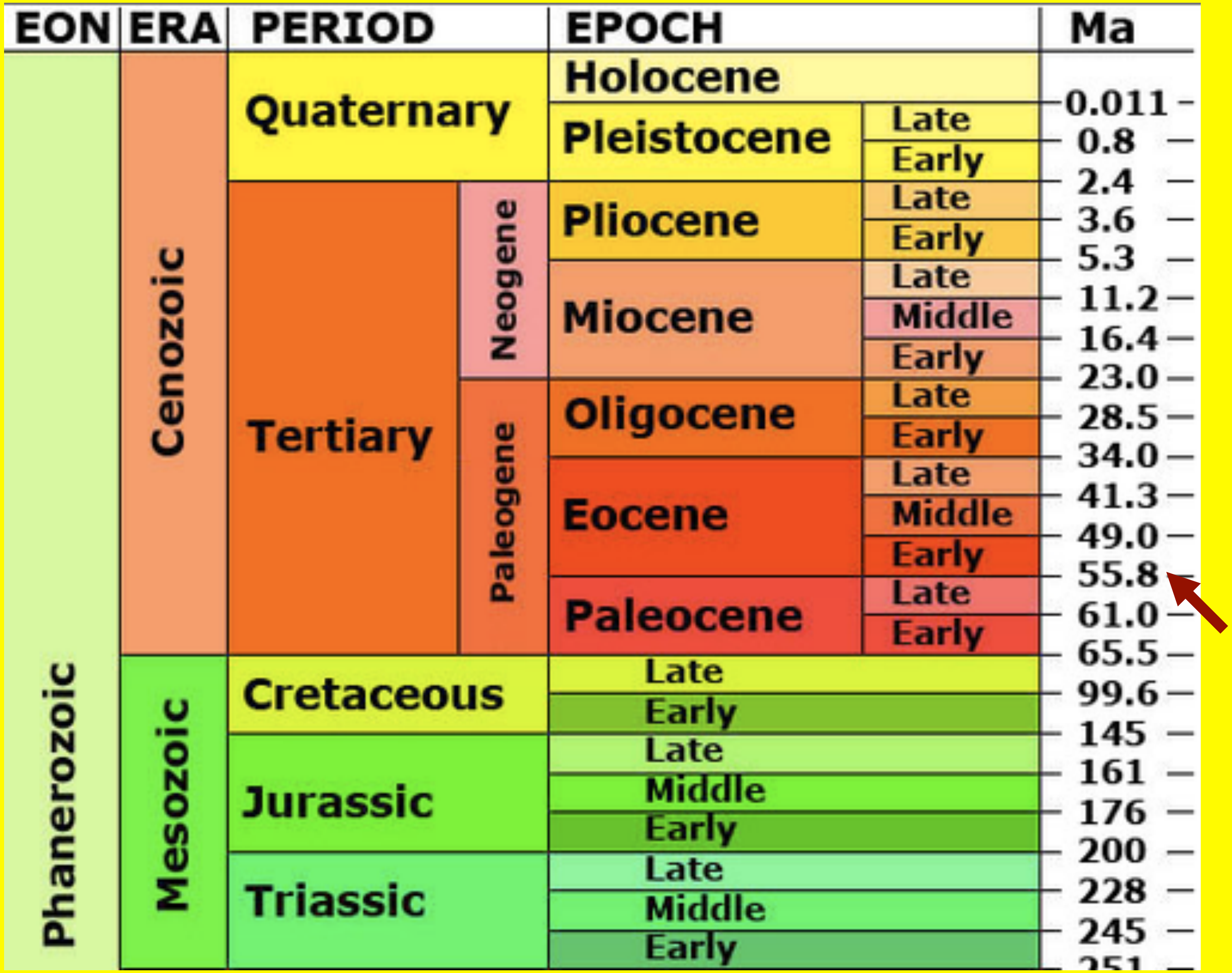
Trace elements and isotopic tools to infer past seawater carbonate chemistry:

- Boron isotopic composition (∂^{11}B): **pH changes**
- B, U and Zn to Calcium ratio of foram shells: ambient $\mathbf{CO_3^{2-}}$
- ∂^{13}C of organic molecules: ocean $\mathbf{CO_2}$

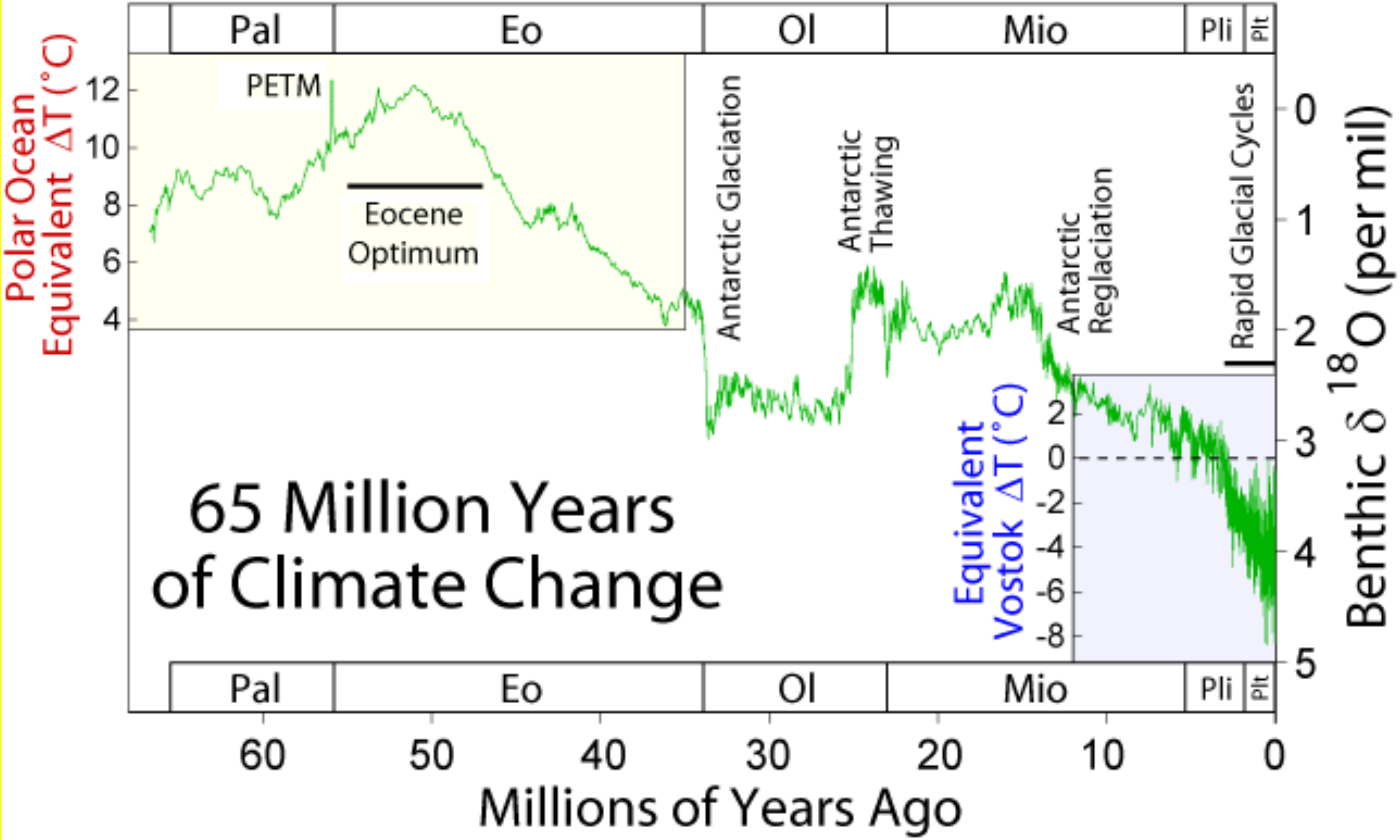
Elevated dissolved CO_2 -> decreased pH: 'ocean acidification'
Decreased saturation with $CaCO_3$

$CaCO_3$, a compound widely used by marine organisms for the construction of their shells and skeletons.

ca 60-50 million years ago was the warmest interval of the last 66 million years (Cenozoic)



PETM: Paleocene-Eocene Thermal Maximum: ca 55 million years ago



Source of the carbon during PETM:

Thermal dissociation of methane hydrates (unstable clathrates → methane)

or

Volcanism (kimberlite pipes: magma flows through deep fractures in the Earth)

PETM: extreme climatic warming after massive atmospheric greenhouse gas input.

Rapid injection of CO_2
Concentrations were similar to those expected in the next centuries.

Temperature information based on (a.o.) sea surface temperature proxy TEX86, and oxygen isotope data.

PETM (56 million years ago): focal point of research. Probably the best past analog to understand impacts of future global warming and massive carbon input to ocean and atmosphere, including ocean acidification.

PETM carbon addition estimated 2000-6000 Gt. Comparable to projected anthropogenic emissions (2000 Gt).

Global temperatures rose about 6^{o}C within about 20,000 years. pH decline: 0.25 - 0.45

Arctic temperatures rose from 17 to 23^{o}C

PETM effects (a.o.):
Largest Cenozoic extinction of calcareous deep marine foraminifera (deep-sea anoxia)

Collapse of coral/algal reefs

and

Poleward migration of (sub)tropical marine plankton, terrestrial plant species and mammals; sudden appearance of modern mammal orders in Europe and N-America

In addition:

ca 5 m sea-level rise (thermal expansion)

Extreme global warming in the absence of ice-albedo effects

Is this a geological analog for the future?

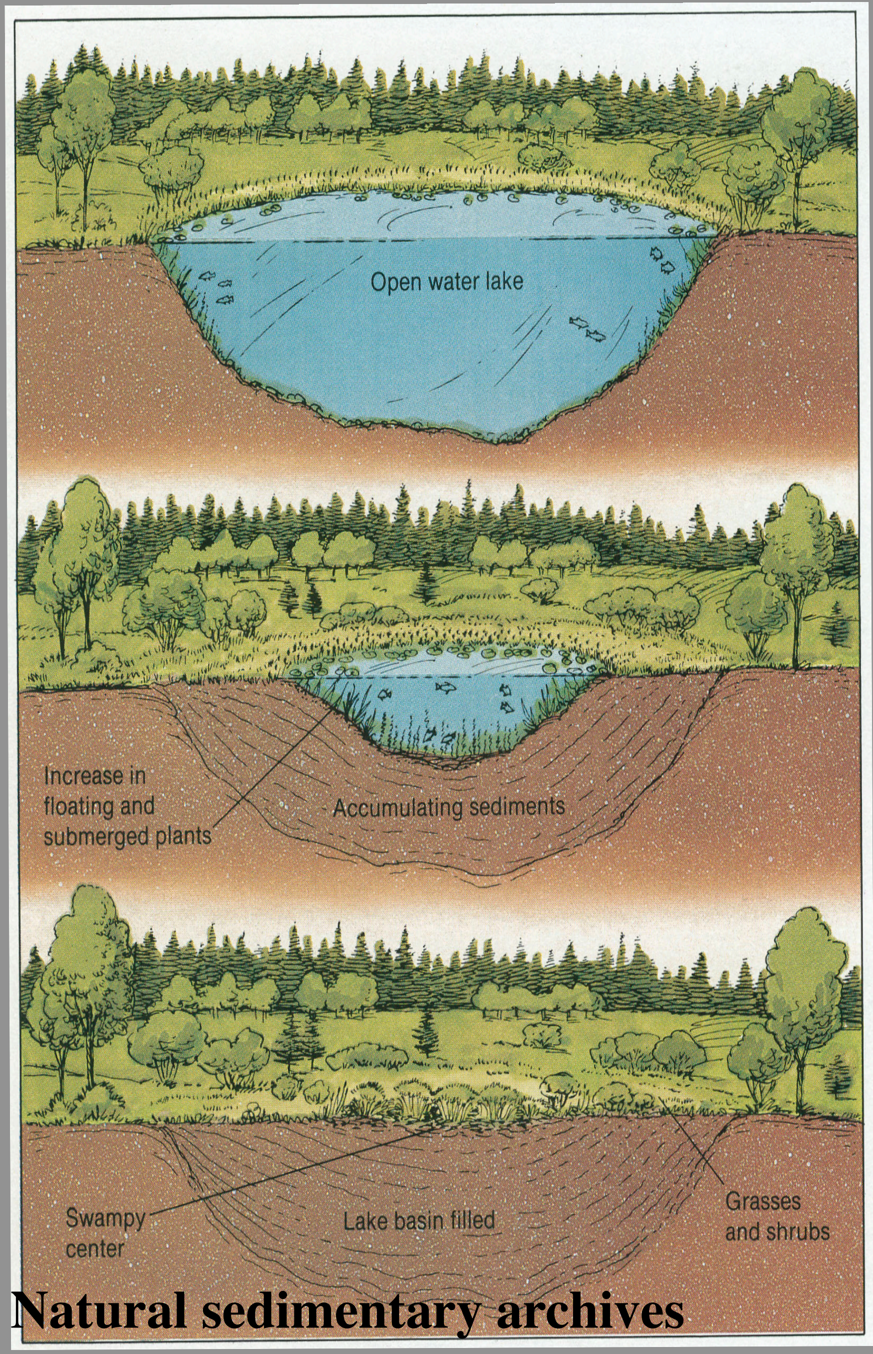
Rapid Acidification of the Ocean during the Paleocene-Eocene Thermal Maximum
Zachos et al., 2005. **SCIENCE** 308: 1611-1615.

Subtropical Arctic Ocean temperatures during the Palaeocene/Eocene Thermal Maximum
Sluijs et al., 2006. **NATURE** 441: 610-613.

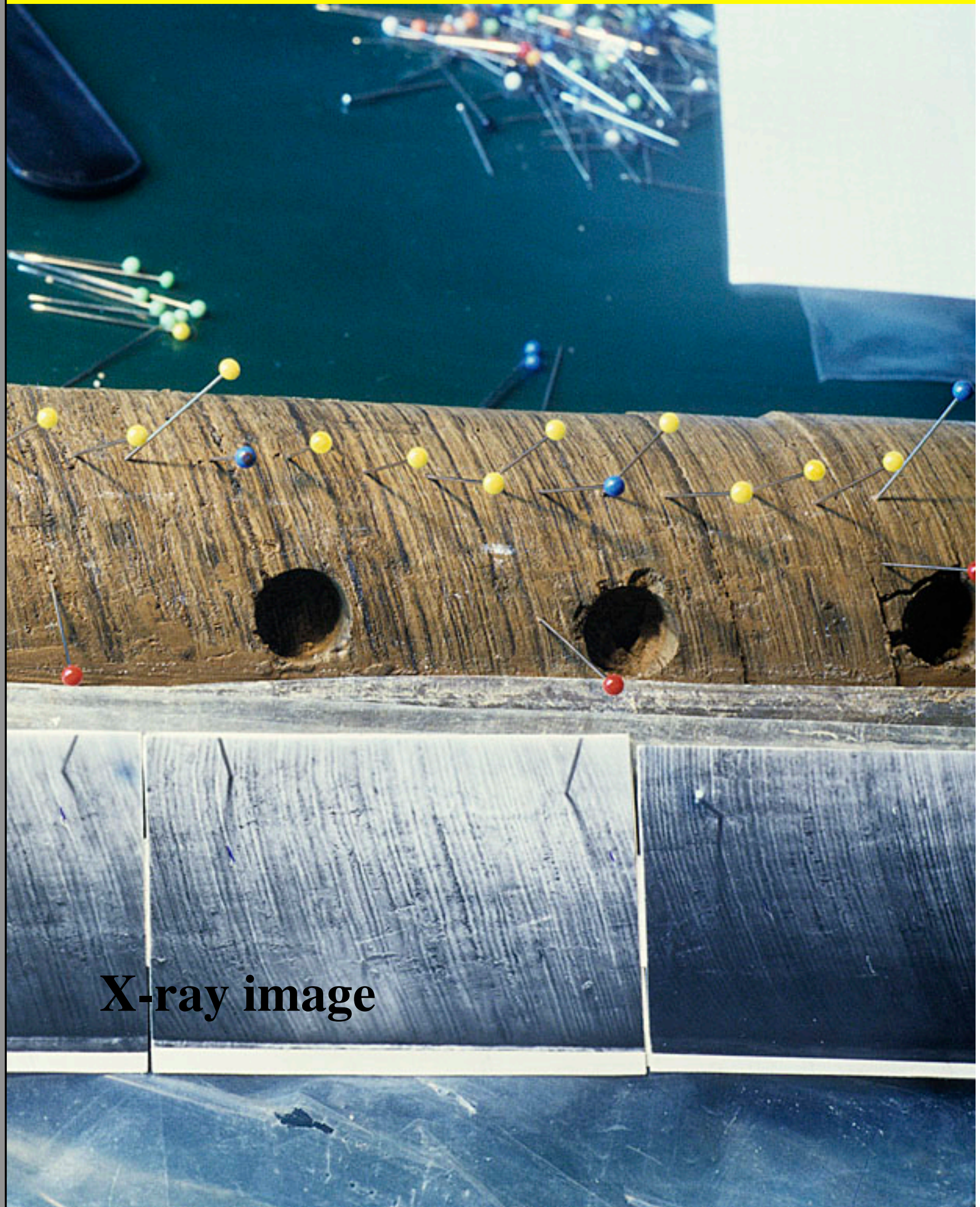
Extreme warming of mid-latitude coastal ocean during the Paleocene-Eocene Thermal Maximum: Inferences from TEX_{86} and isotope data.
Zachos et al., 2006. **GEOLOGY** 34: 737-740.

The geological record of ocean acidification.
Hönisch et al., 2012. **SCIENCE** 335: 1058-1063.

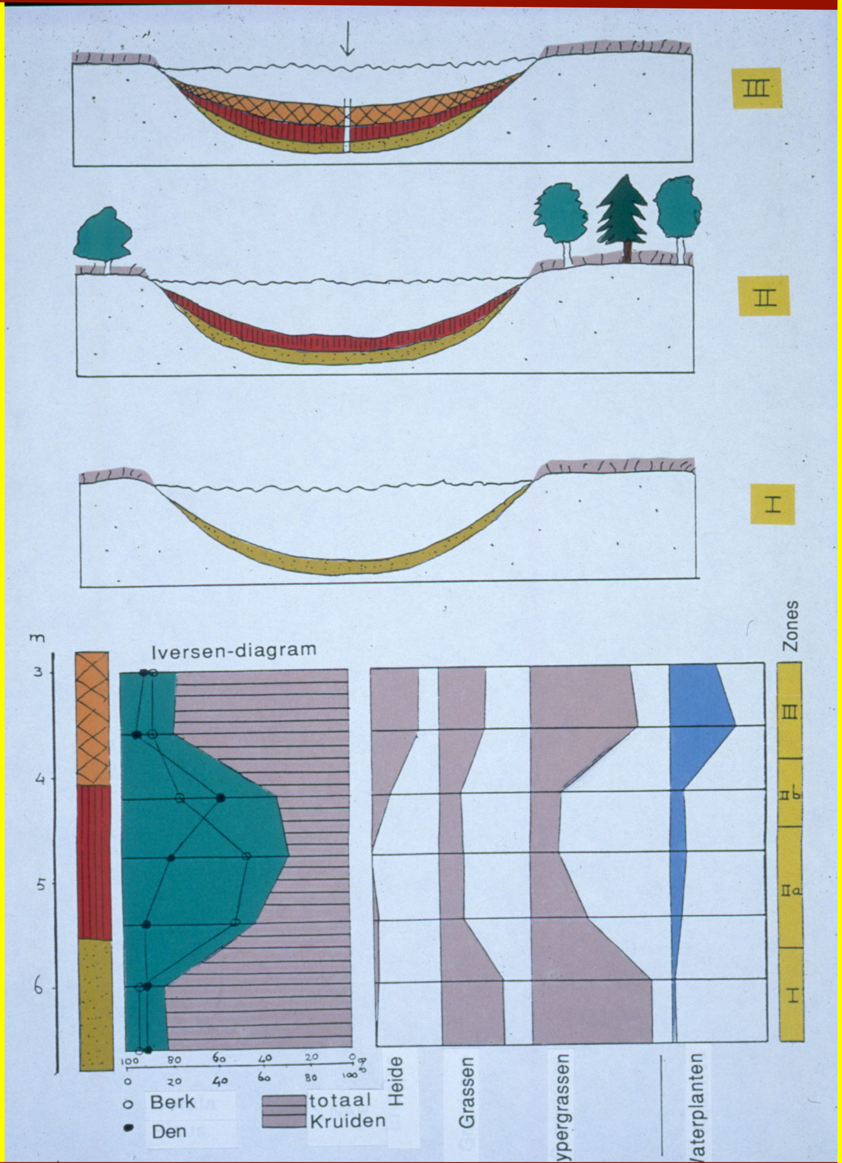
Terrestrial archives



Natural sedimentary archives

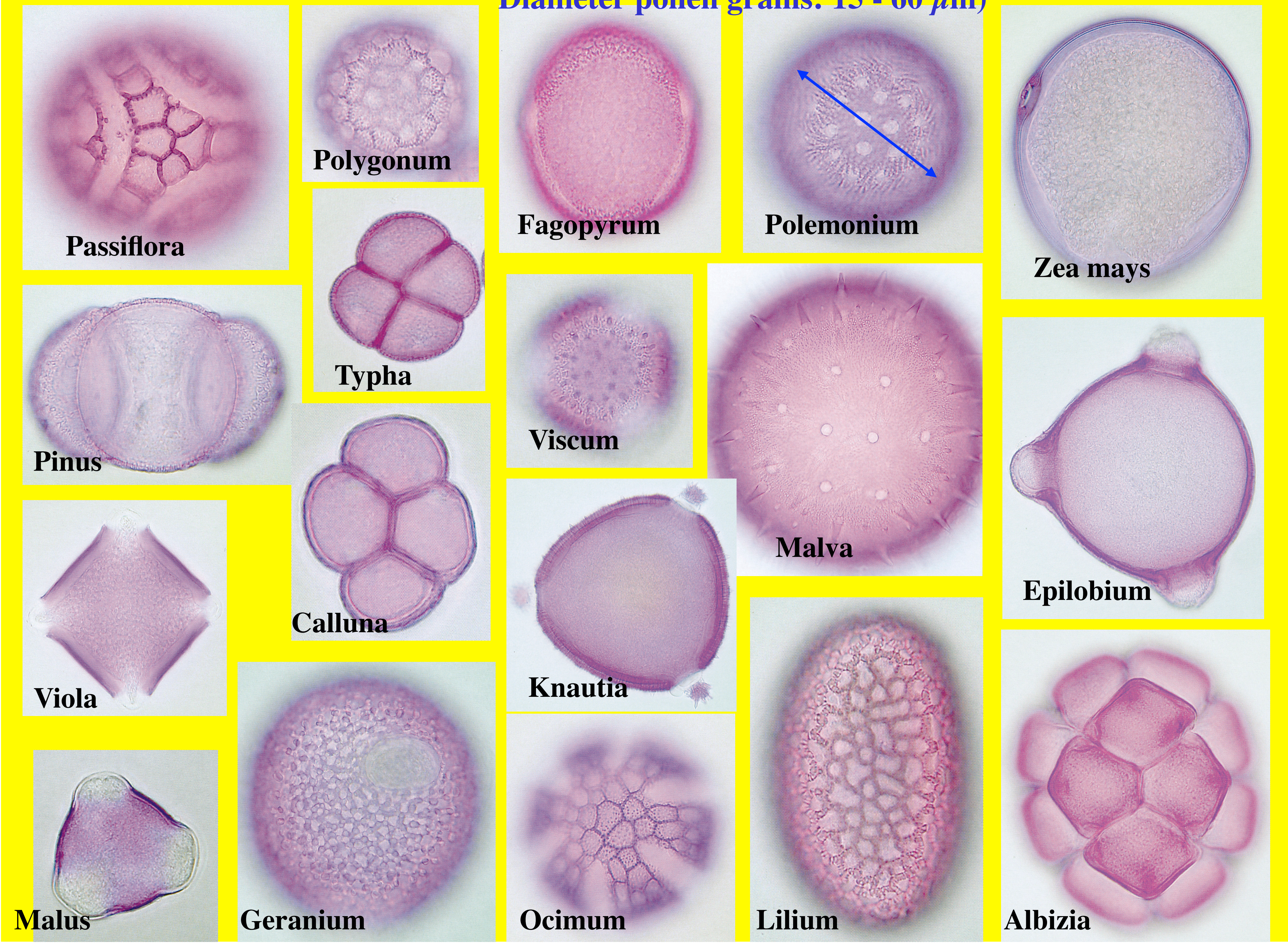


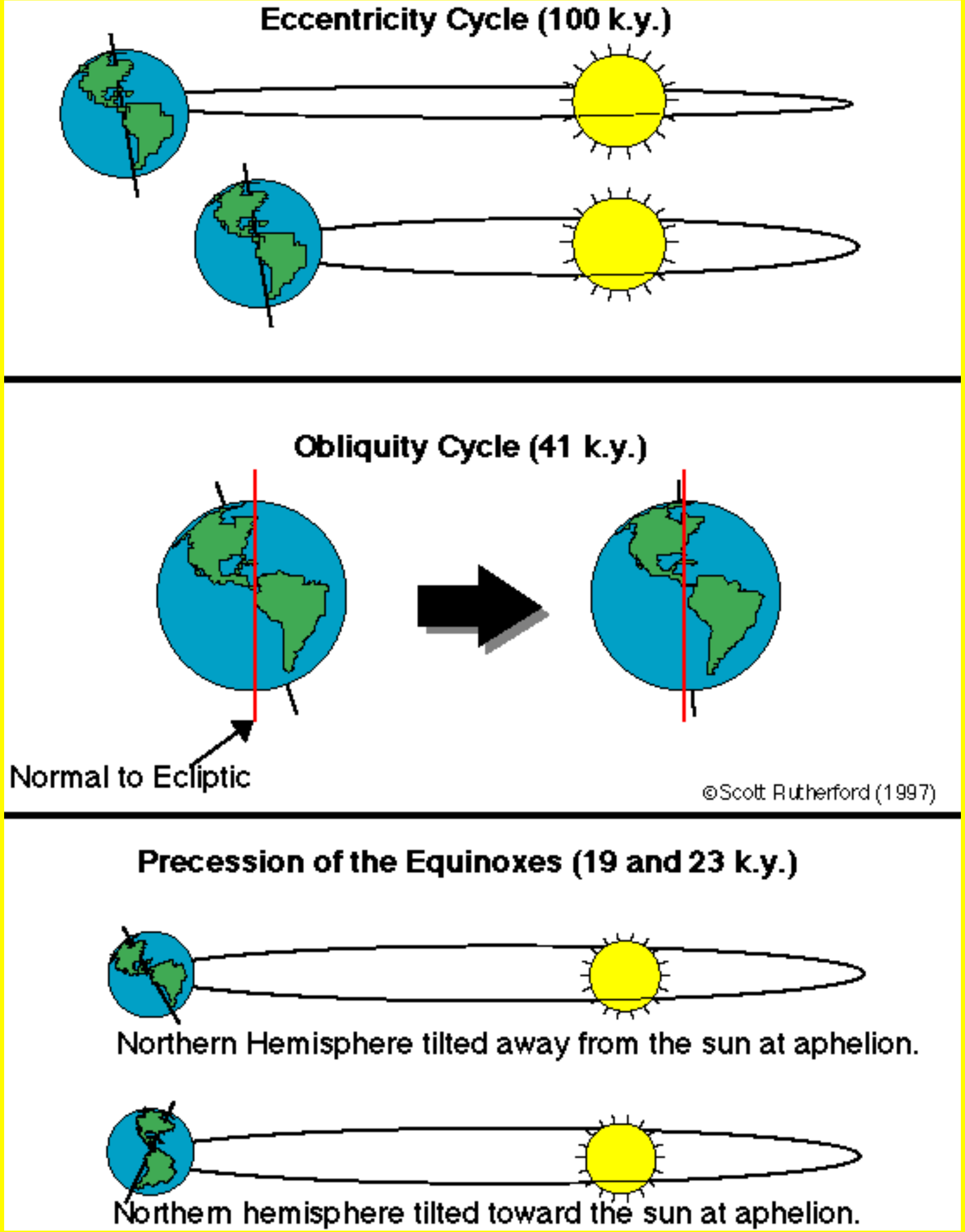
annually laminated sediment
(Lake Gosciaz, Poland)



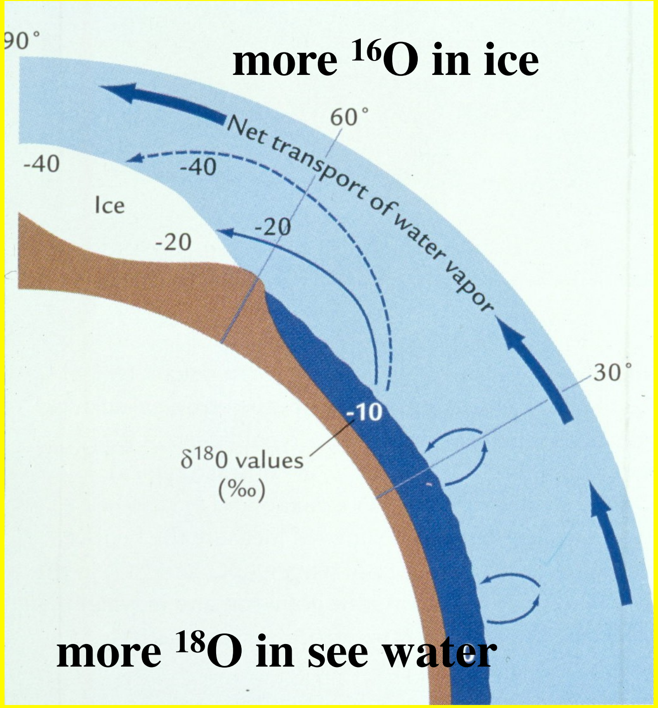
Sampling a raised bog deposit

Diameter pollen grains: 15 - 60 μm)

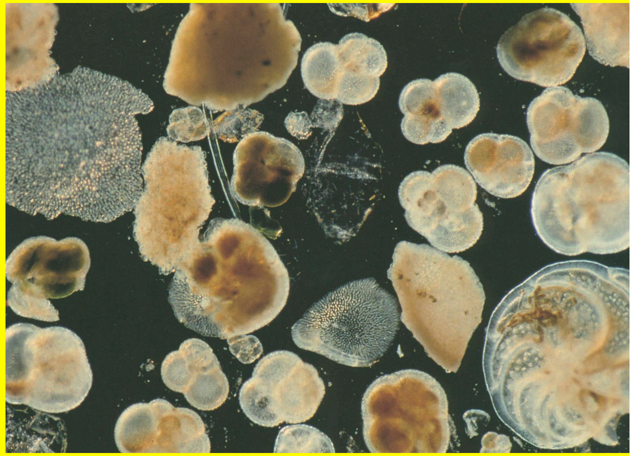




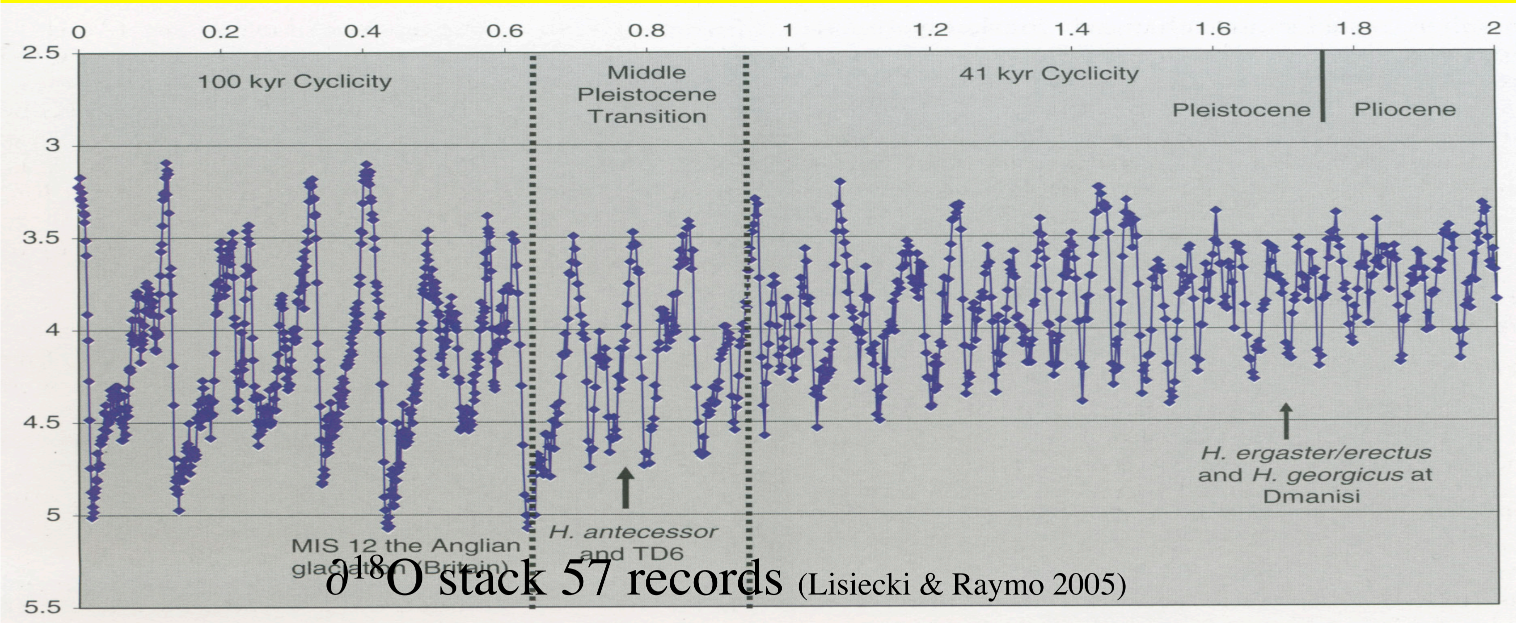
Orbital forcing
(Milankovitch)



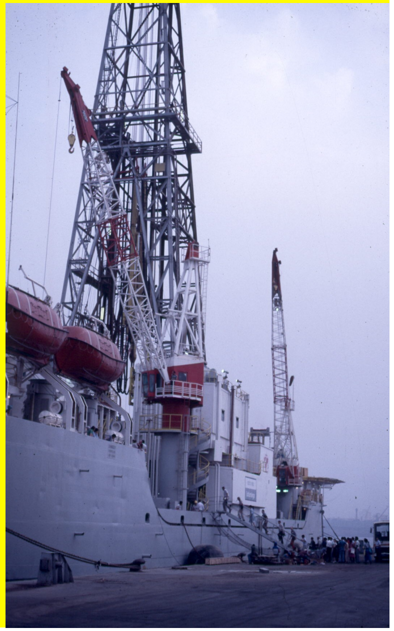
Foraminiferae in ocean cores

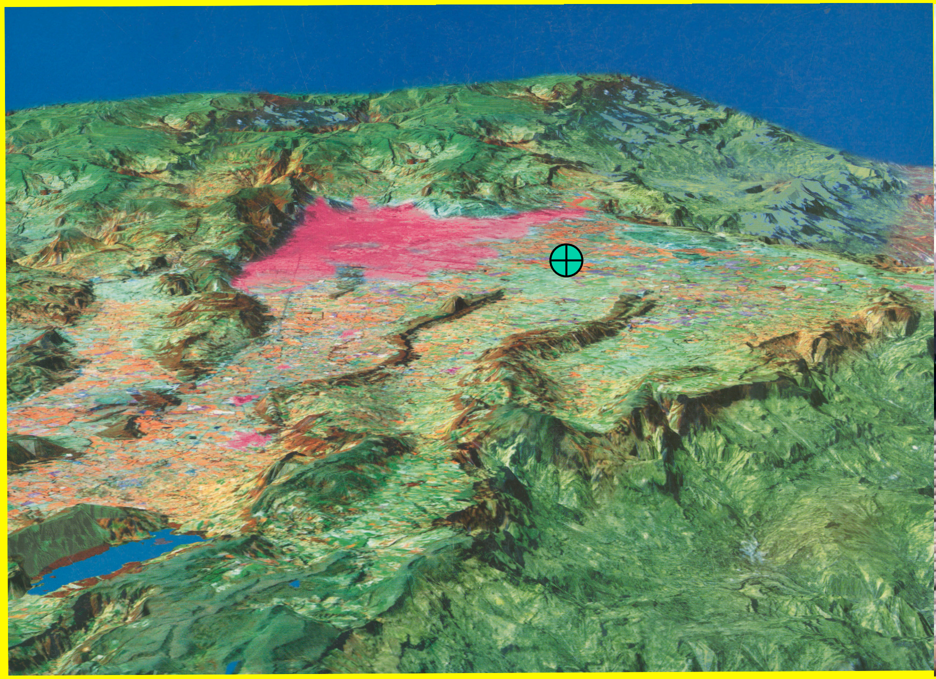


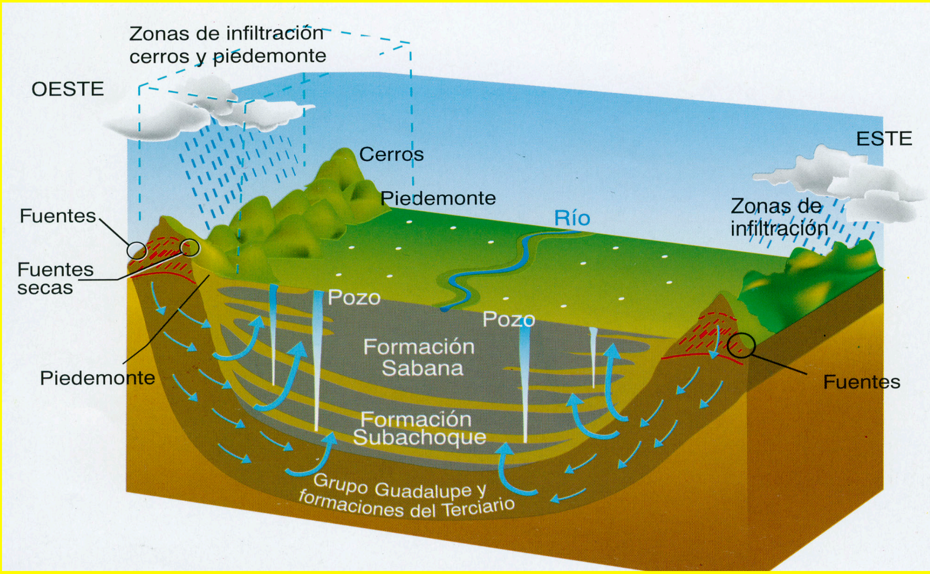
$^{16}O/^{18}O$: $\partial^{18}O$



$\partial^{18}O$ stack 57 records (Lisiecki & Raymo 2005)

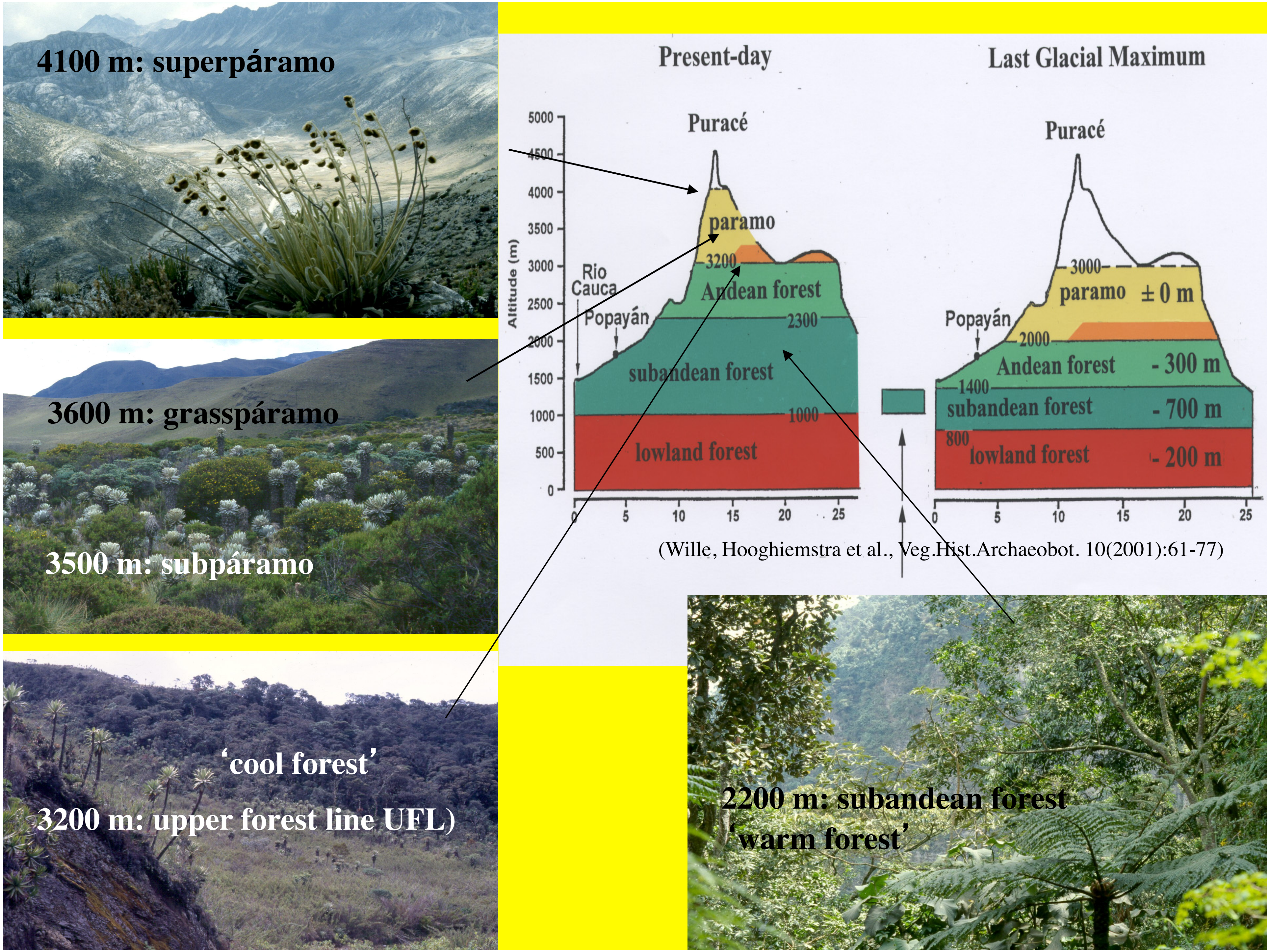


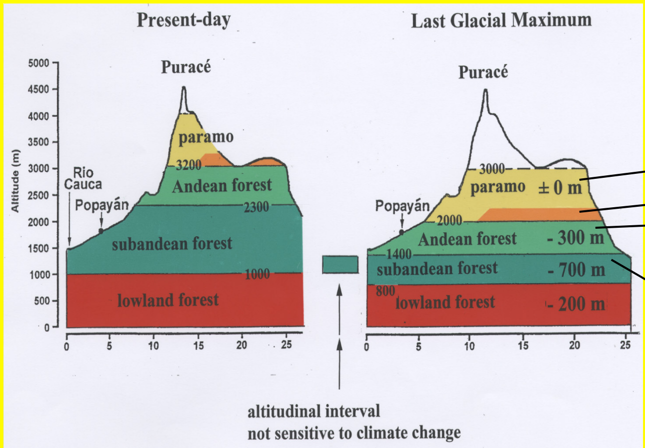




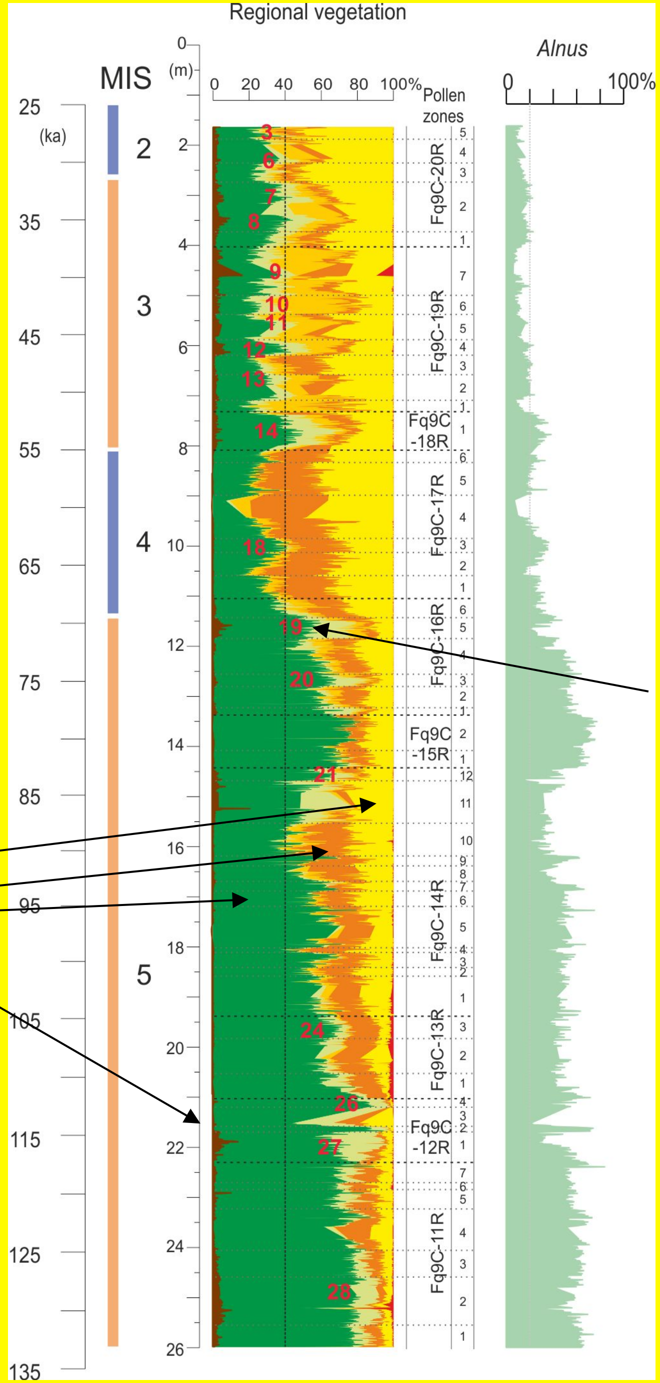
Sabana de Bogotá ~4°N, 2550 m asl

core 1: 357 m
core 2: 586 m until bedrock


4100 m: superpáramo
3600 m: grasspáramo
3500 m: subpáramo
'cool forest'
3200 m: upper forest line UFL)
Present-day
Last Glacial Maximum
Puracé
Puracé
Altitude (m)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
paramo
3200
Rio Cauca
Andean forest
Popayán
2300
subandean forest
1000
lowland forest
0
5
10
15
20
25
Popayán
3000
paramo ± 0 m
2000
Andean forest - 300 m
1400
subandean forest - 700 m
800
lowland forest - 200 m
(Wille, Hooghiemstra et al., Veg.Hist.Archaeobot. 10(2001):61-77)
2200 m: subandean forest
'warm forest'



vegetation distribution
Modern vs. LGM

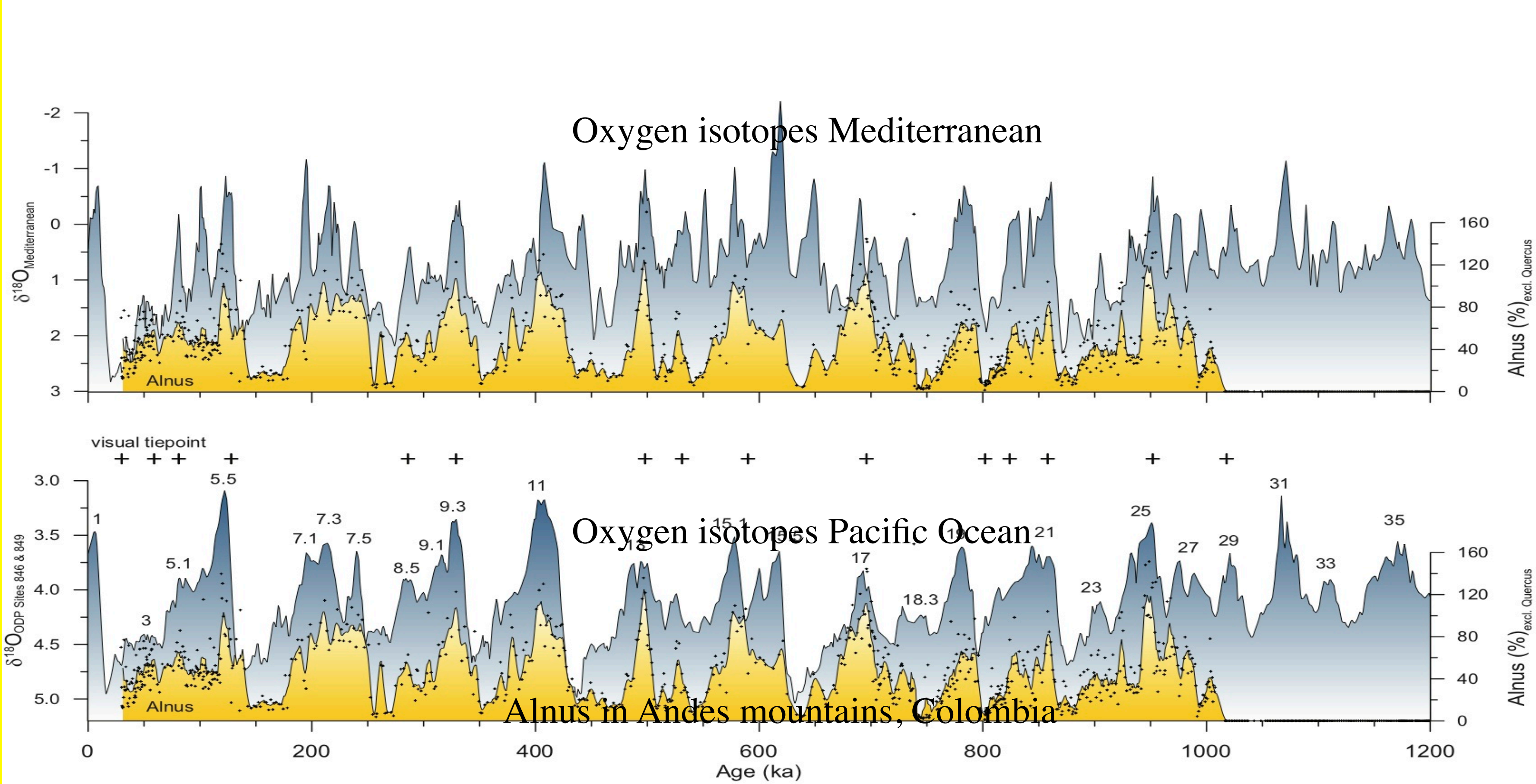


Lake Fúquene

133,000 - 27,000 yr BP

26 - 1.6 m

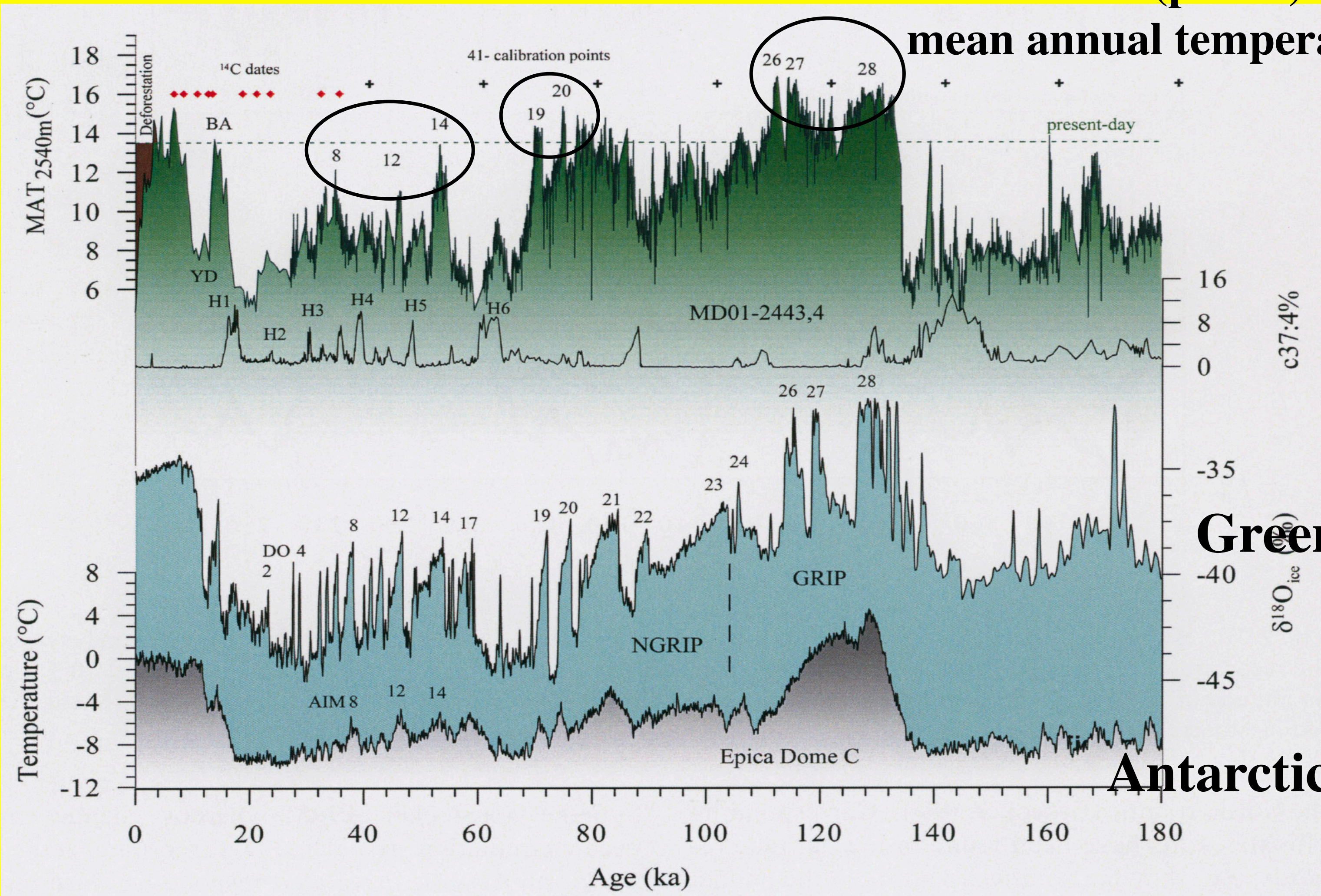
millennial-scale Dansgaard-Oeschger-cycles #3 - #28



Torres, Hooghiemstra, Lourens, Tzedakis, QSR 63, 59-72, 2013

Greenland climate variability reflected in the tropical Andes:

Colombia (pollen):
mean annual temperature (MAT)



Greenland ($\partial^{18}O$)

Antarctica (deuterium)

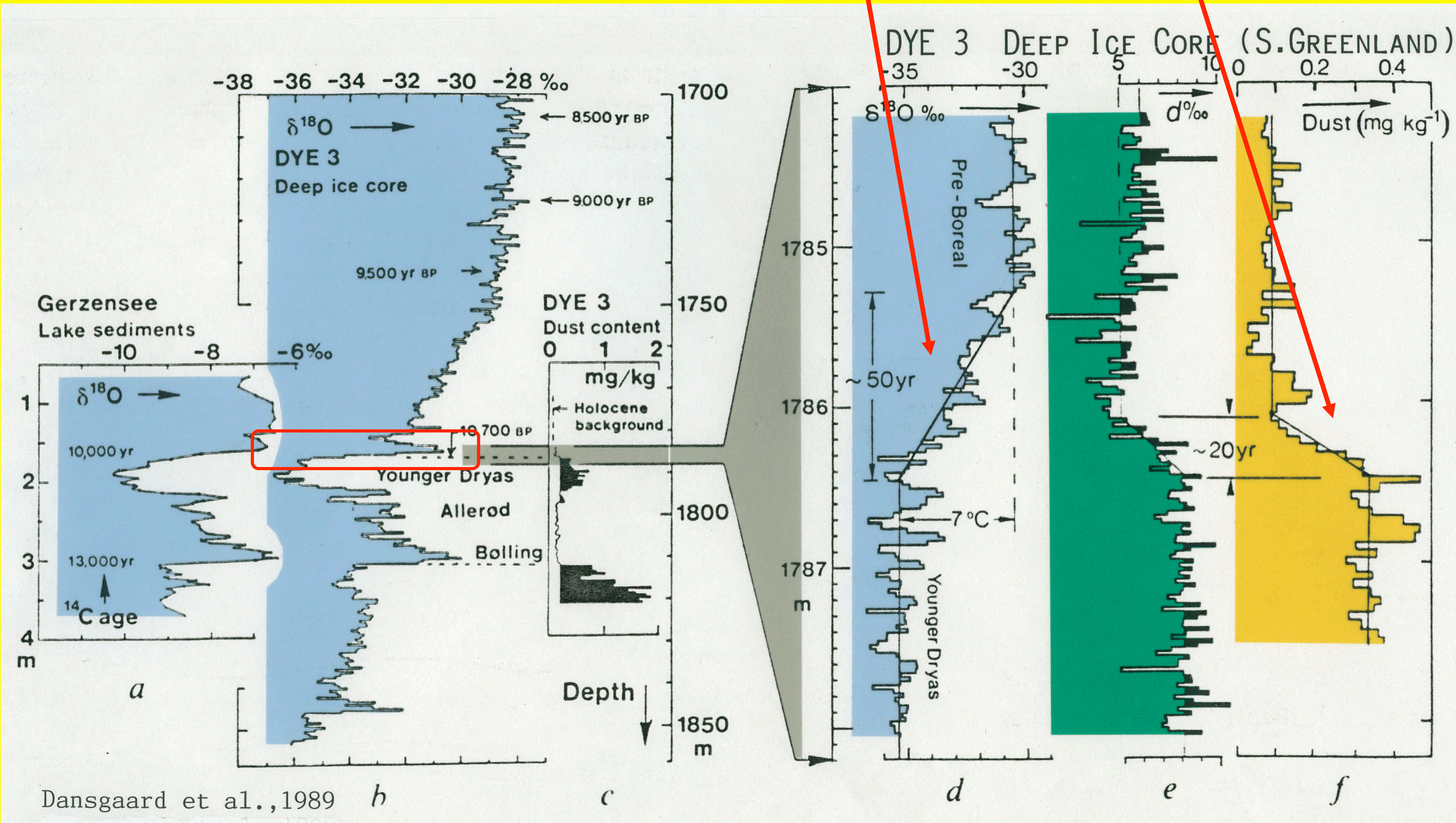
rates of Temp. change tropical Andes: 2 - 3.5°C / 100 yr, up to 10°C/~100 yr

(Groot, Bogotá, Lourens, Hooghiemstra et al., CoP 7 (2011): 299-316)

Fast climate change

Major change in 50 years

Atmosphere reacted in 20 years



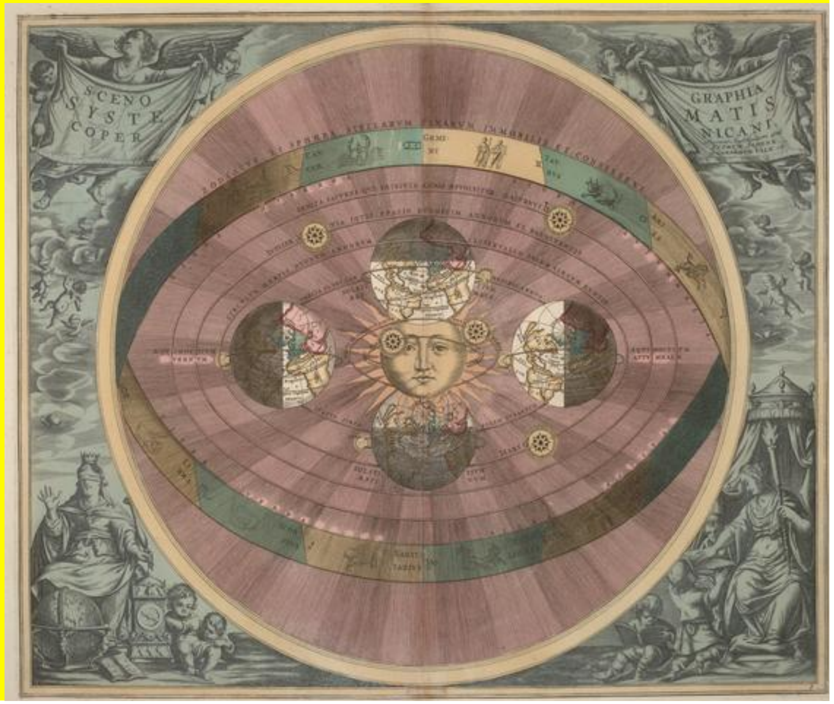
Glacial-cycle on Groenland >30°C

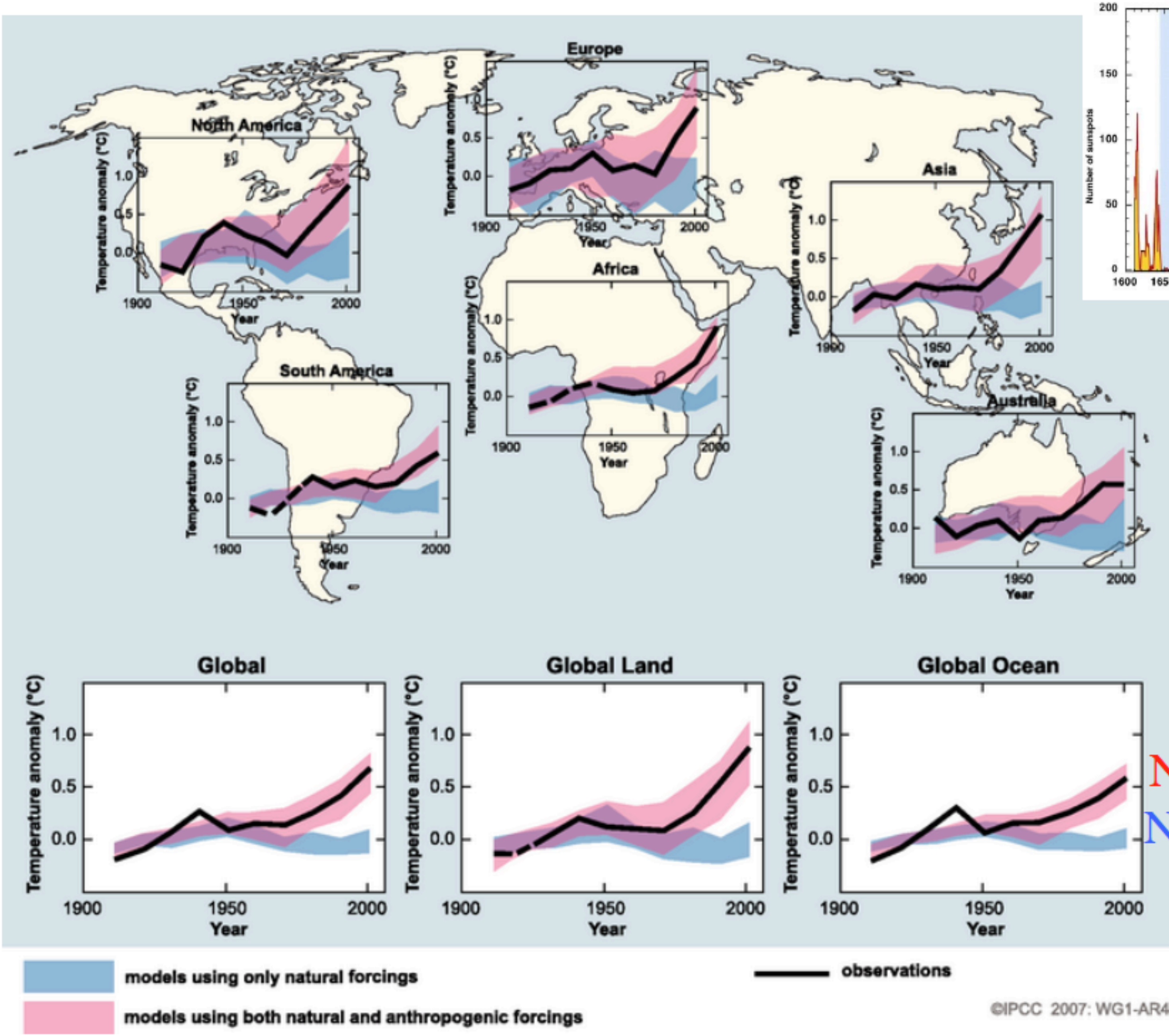
Glacial-cycle in W-Europa 8°-9°C

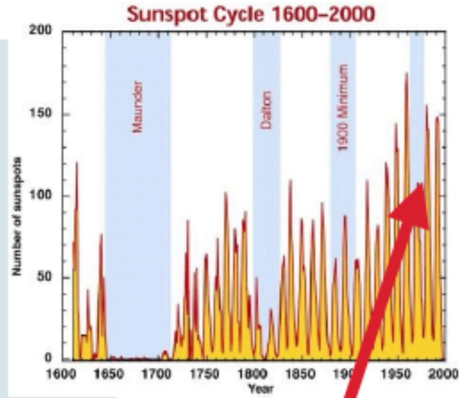
Climate change after the last Ice Age:

How important was the role of the Sun in the past?

Which part of the worldwide temperature rise of the second half of the last century was anthropogenic and which part was natural?





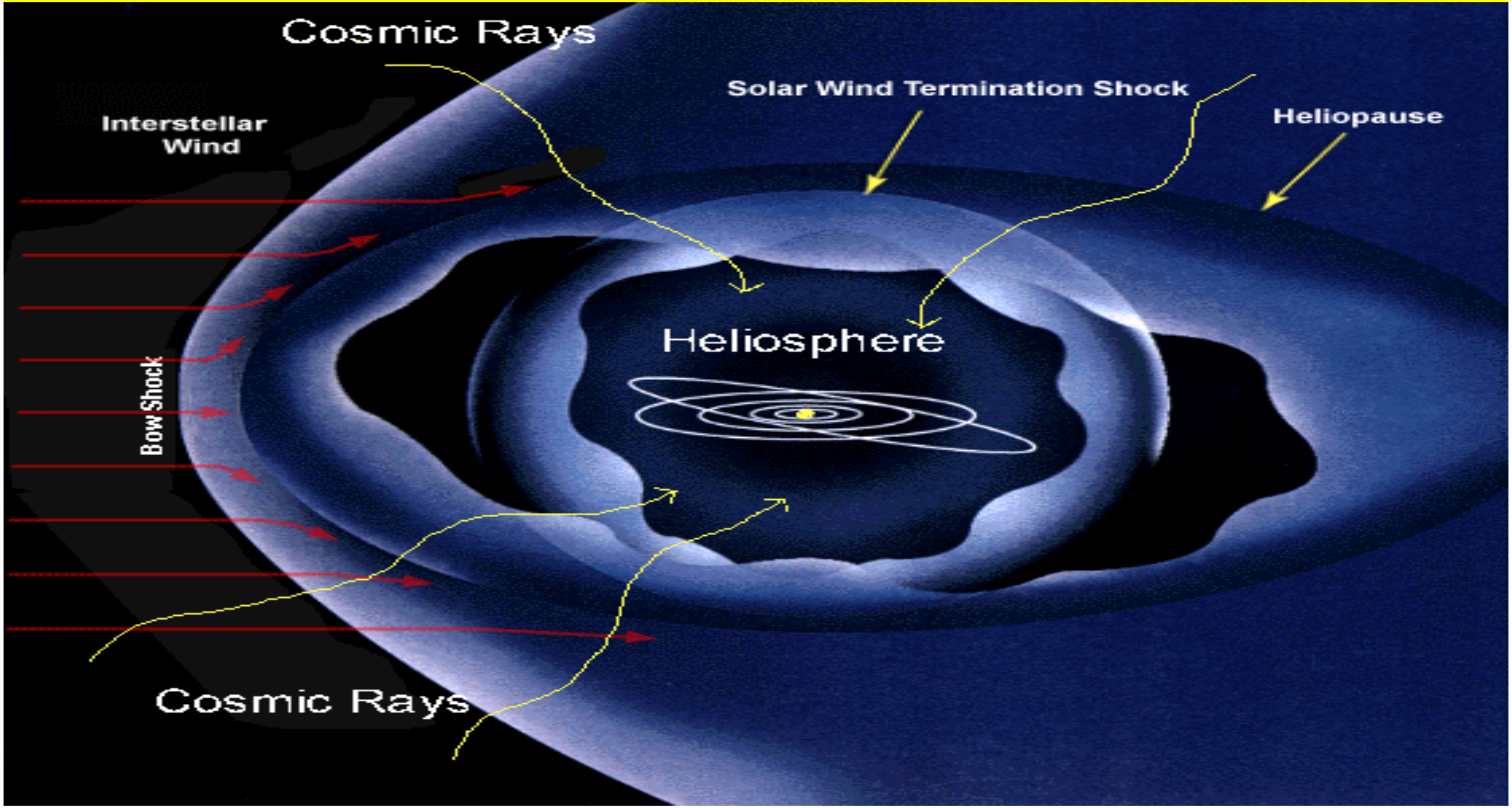


Grand
Modern
Solar
Maximum

Natural + anthr

Natural

Cosmic ray flux, modulated by sun-ejected magnetized plasma clouds (solar wind), affects production of cosmogenic isotopes ^{14}C and ^{10}Be in Earth's atmosphere



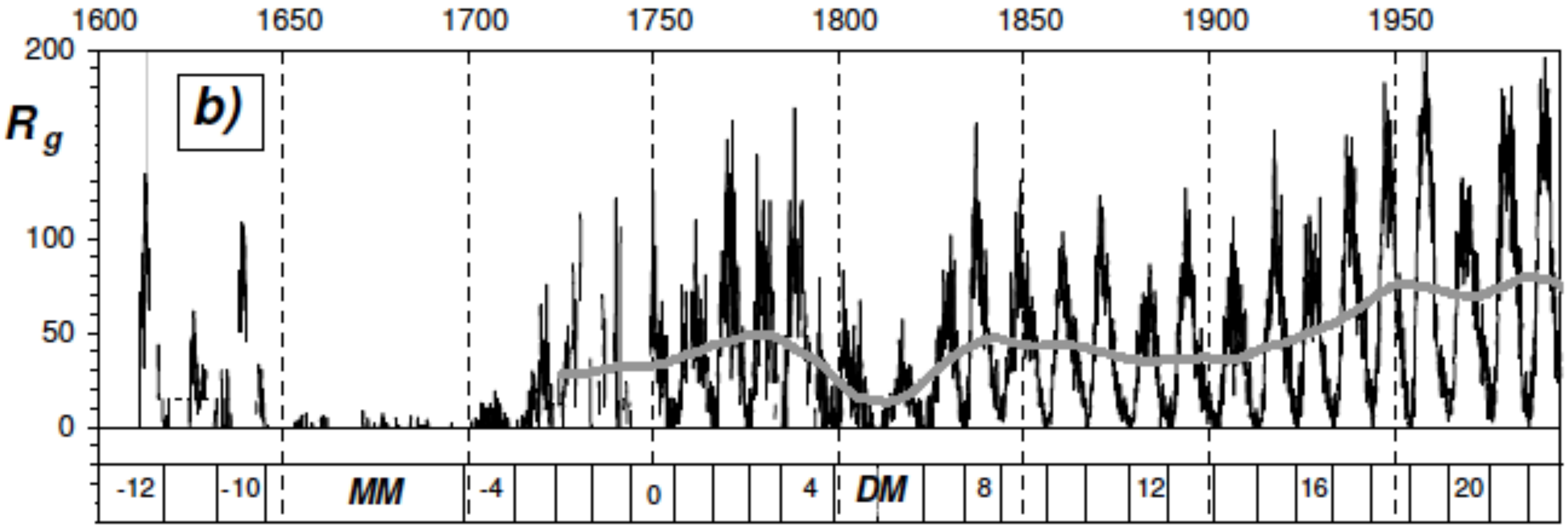
Cosmogenic isotopes in natural archives show changing solar activity in the past:

^{14}C (Radiocarbon) in tree rings

en

^{10}Be (Beryllium-10) in ice cores

Schwabe cycle: quasi-periodicity of about 11 (9-14) years
Hale magnetic polarity cycle: ca. 22 years
Grand minima: e.g., Maunder minimum (MM) and Dalton minimum (DM)



Living Rev. Solar Phys., **5**, (2008), 3
http://www.livingreviews.org/lrsp-2008-3

LIVING REVIEWS
in solar physics

A History of Solar Activity over Millennia

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Abstract

Presented here is a review of present knowledge of the long-term behavior of solar activity on a multi-millennial timescale, as reconstructed using the indirect proxy method.

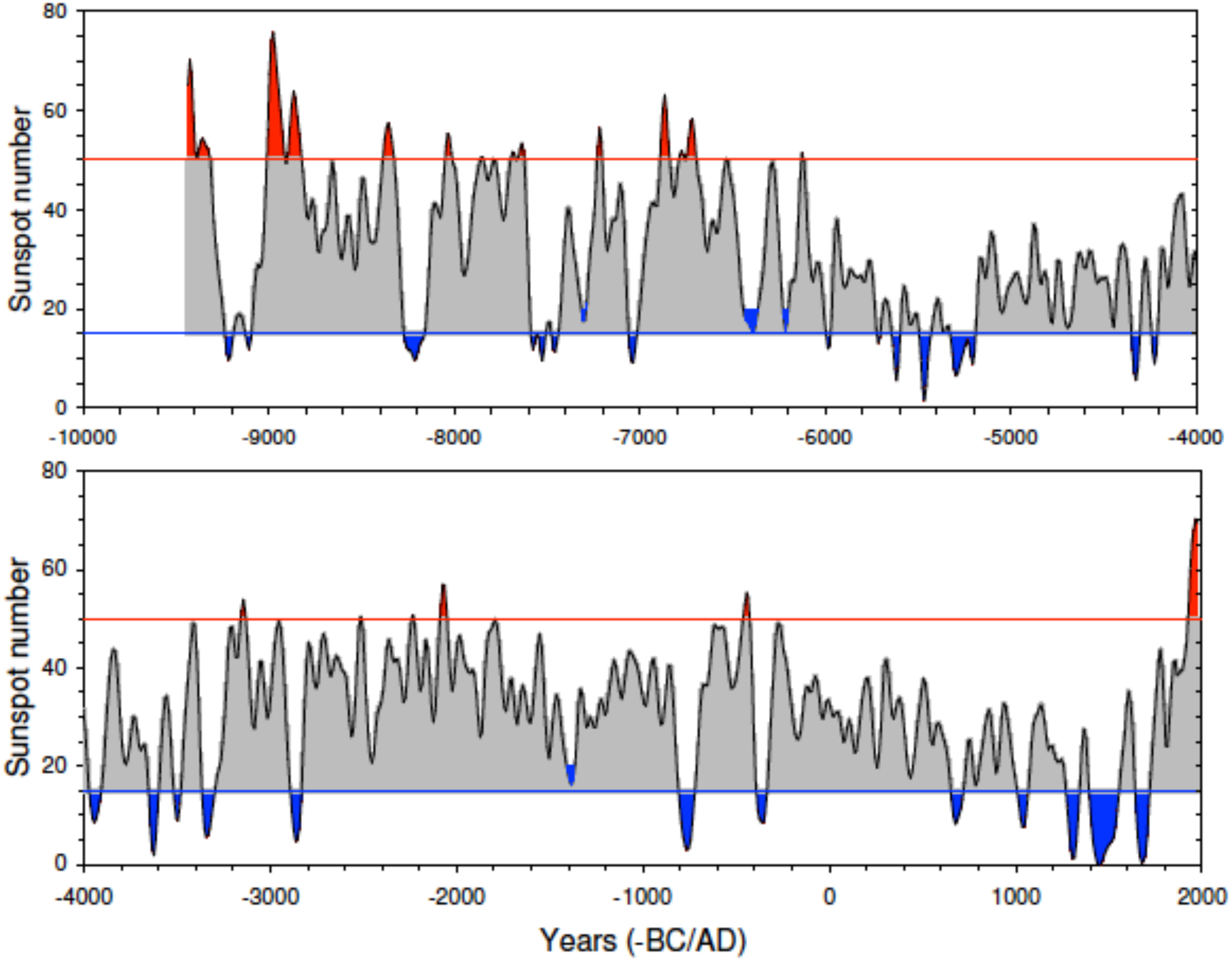
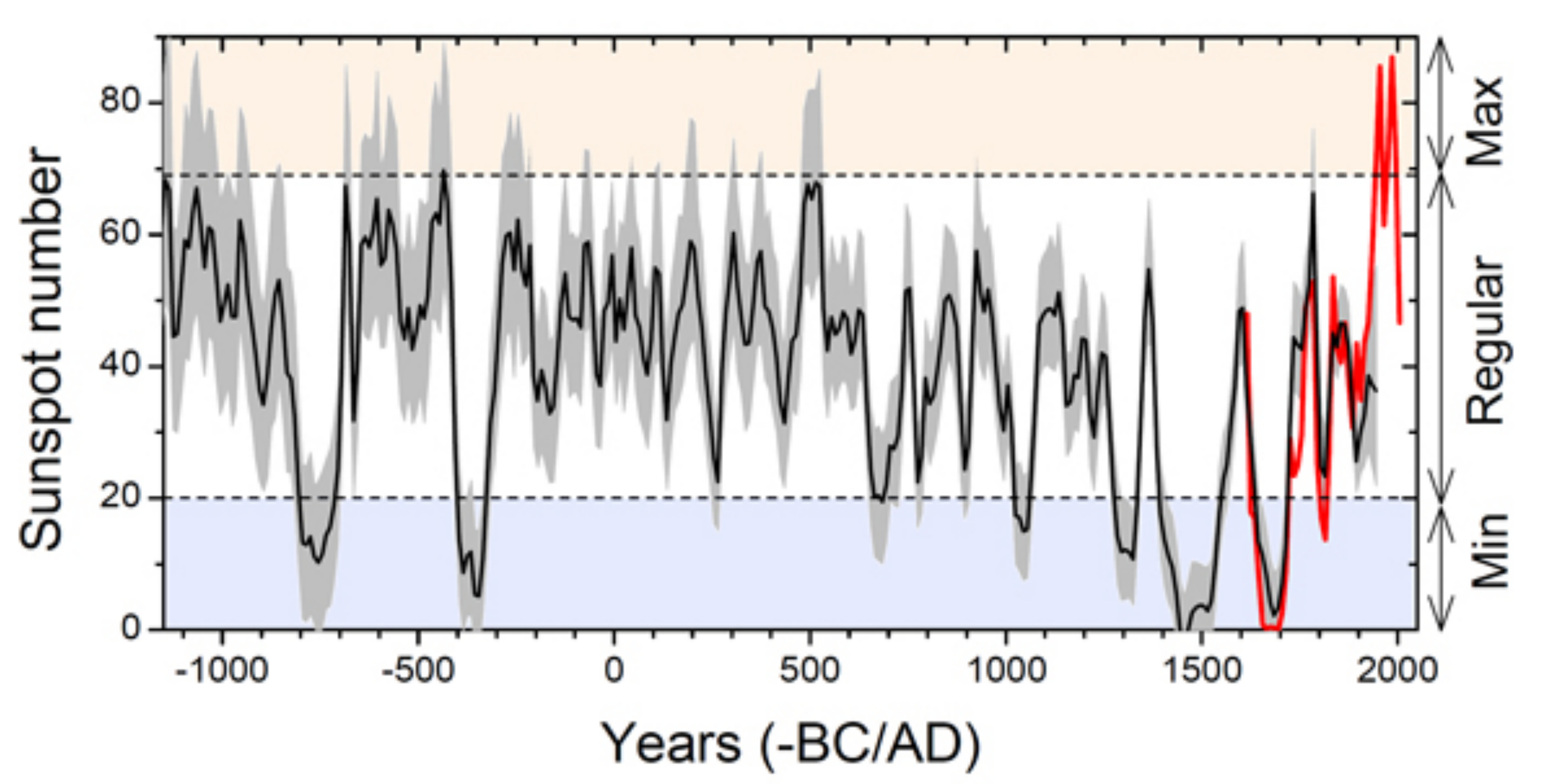


Figure 17: Sunspot activity (over decades, smoothed with a 12221 filter) throughout the Holocene, reconstructed from ^{14}C by Usoskin *et al.* (2007) using geomagnetic data by Yang *et al.* (2000). Blue and red areas denote grand minima and maxima, respectively.

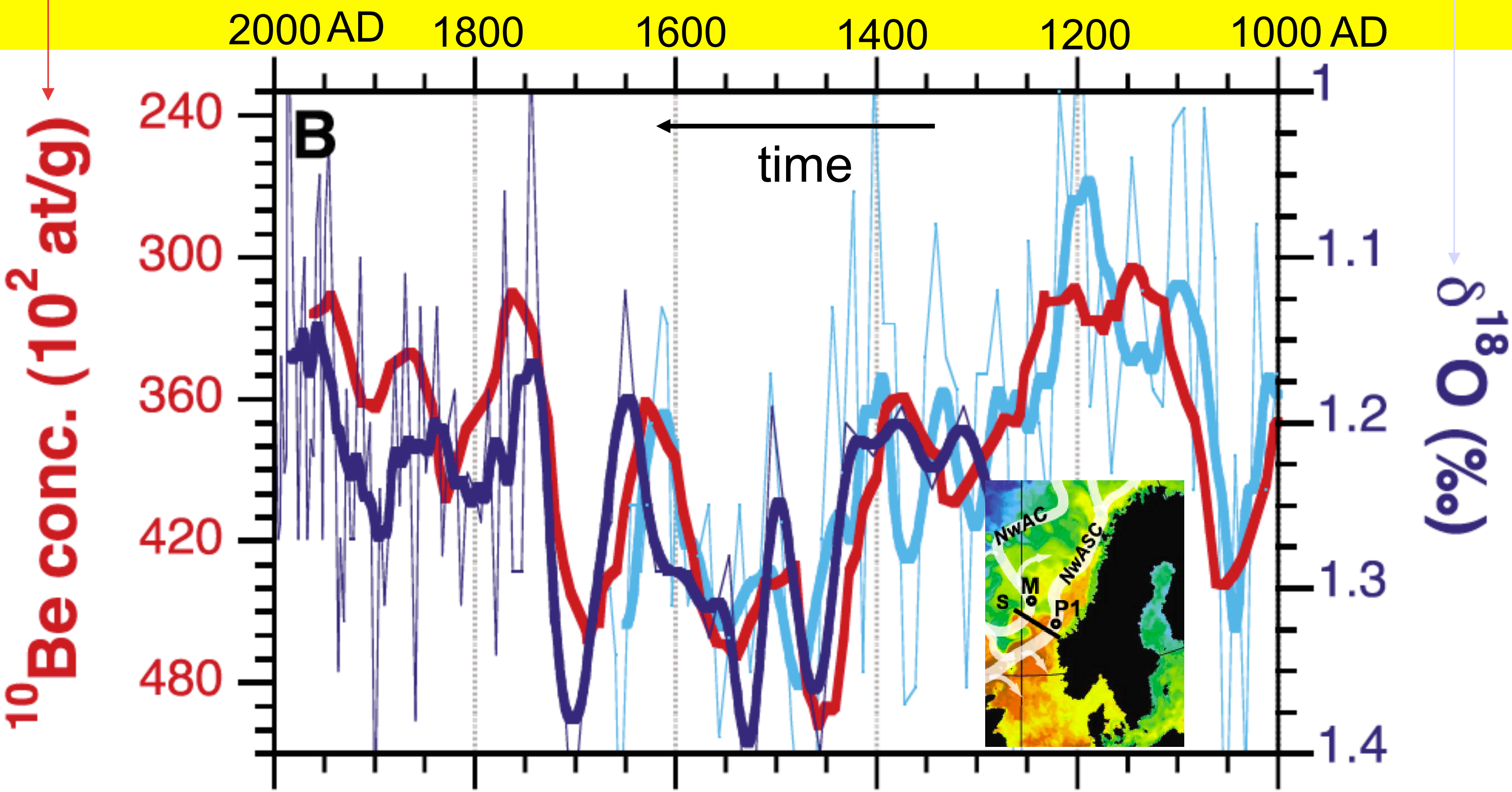
What was the effect of the Grand Maximum of solar activity (1950 -2009) on the Earth's climate?



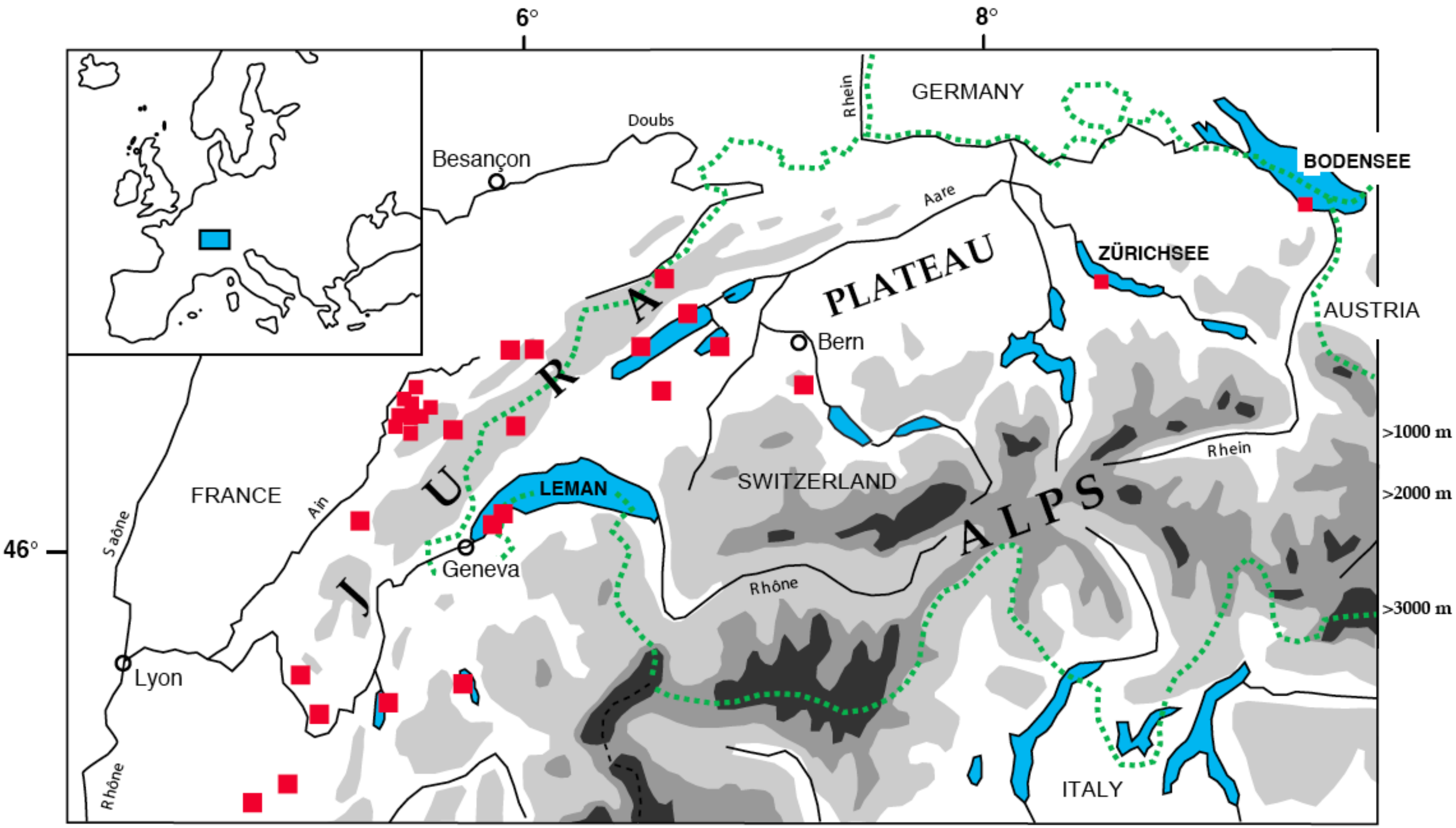
Usoskin: a rare, unique event in the past millennia.

from Antarctic ice core

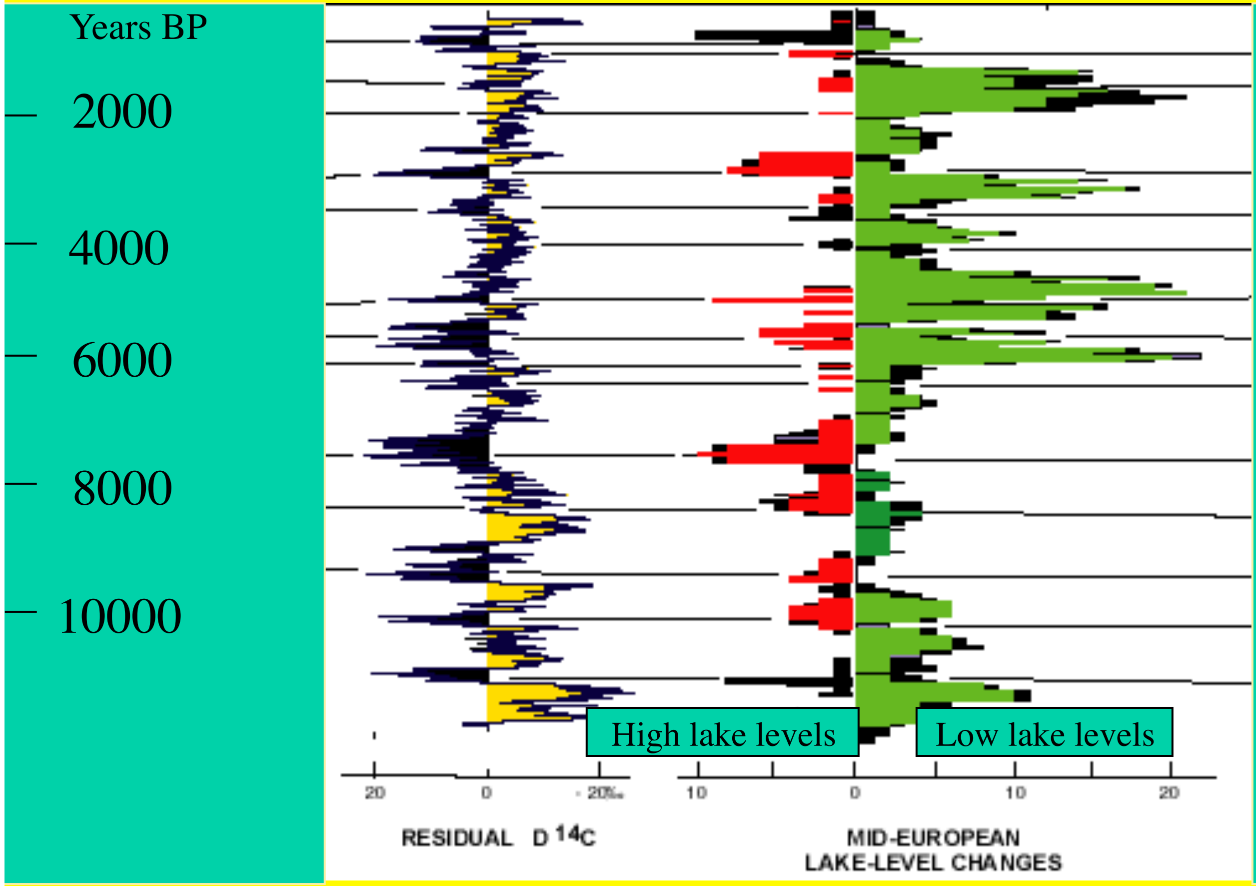
Sediment cores from Norwegian Sea



Sejrup et al., 2010. Response of Norwegian sea temperature to solar forcing. Journal of Geophysical Research, vol.115, C12034



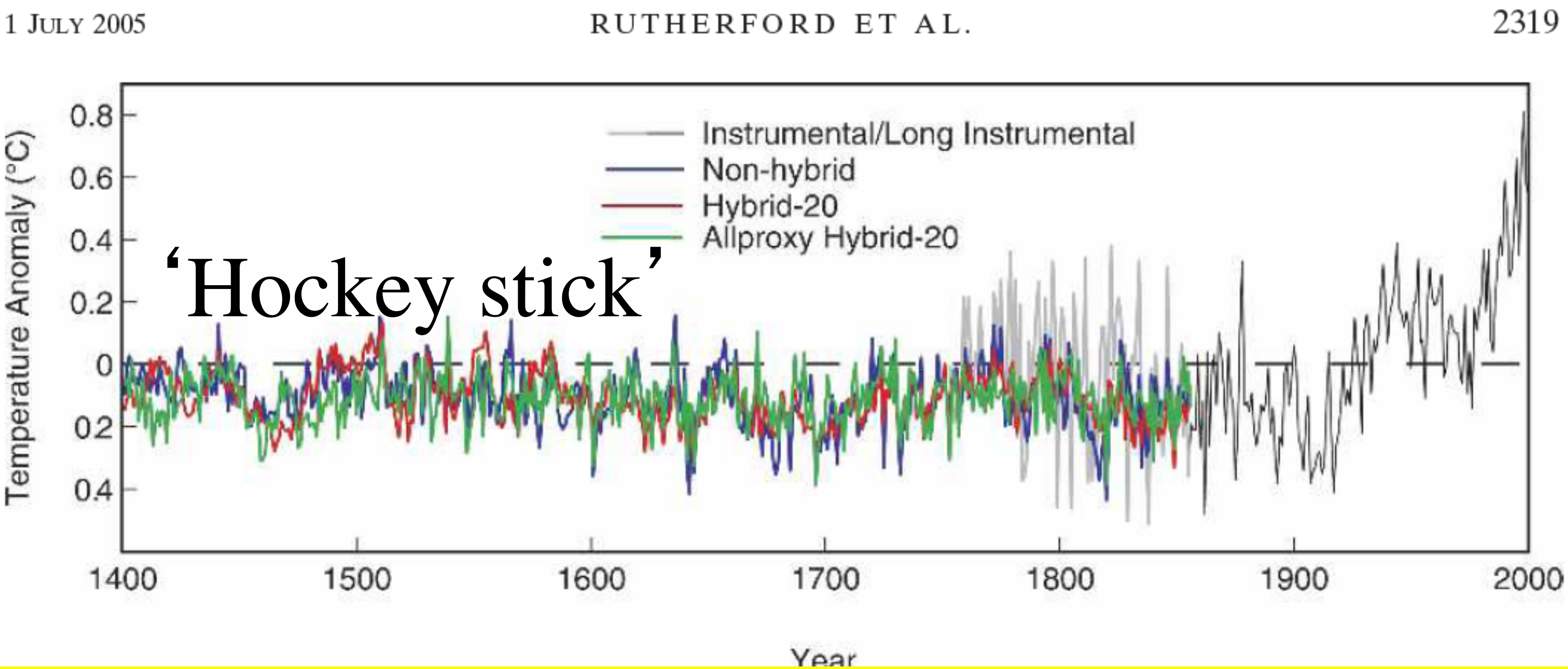
M. Magny, 2007, in Encyclopedia of Quaternary Science, Elsevier



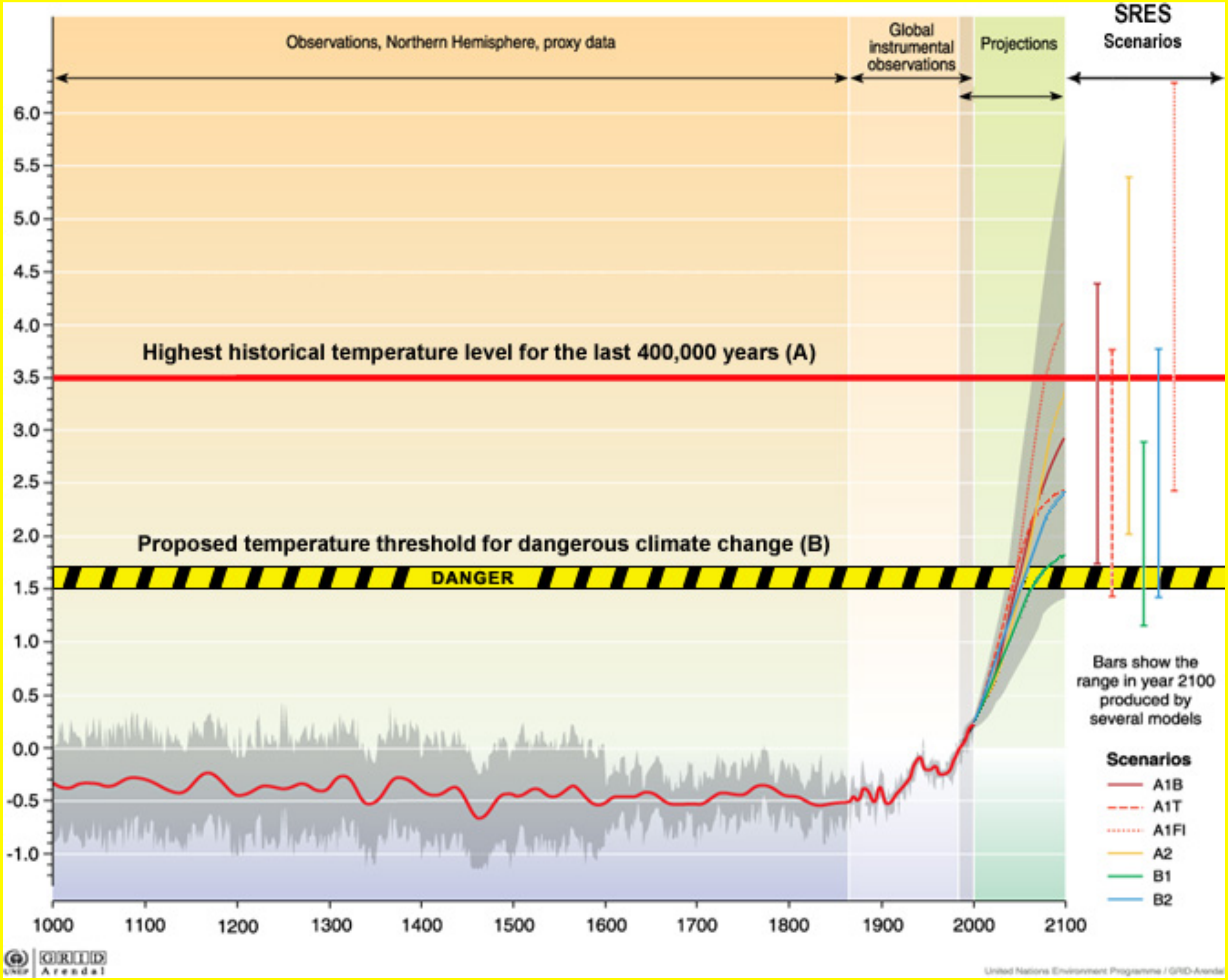
Evidence for 'solar forcing' of climate change based on Mid-European lake sediments

M. Magny, Encyclopedia of Quaternary Science, 2007

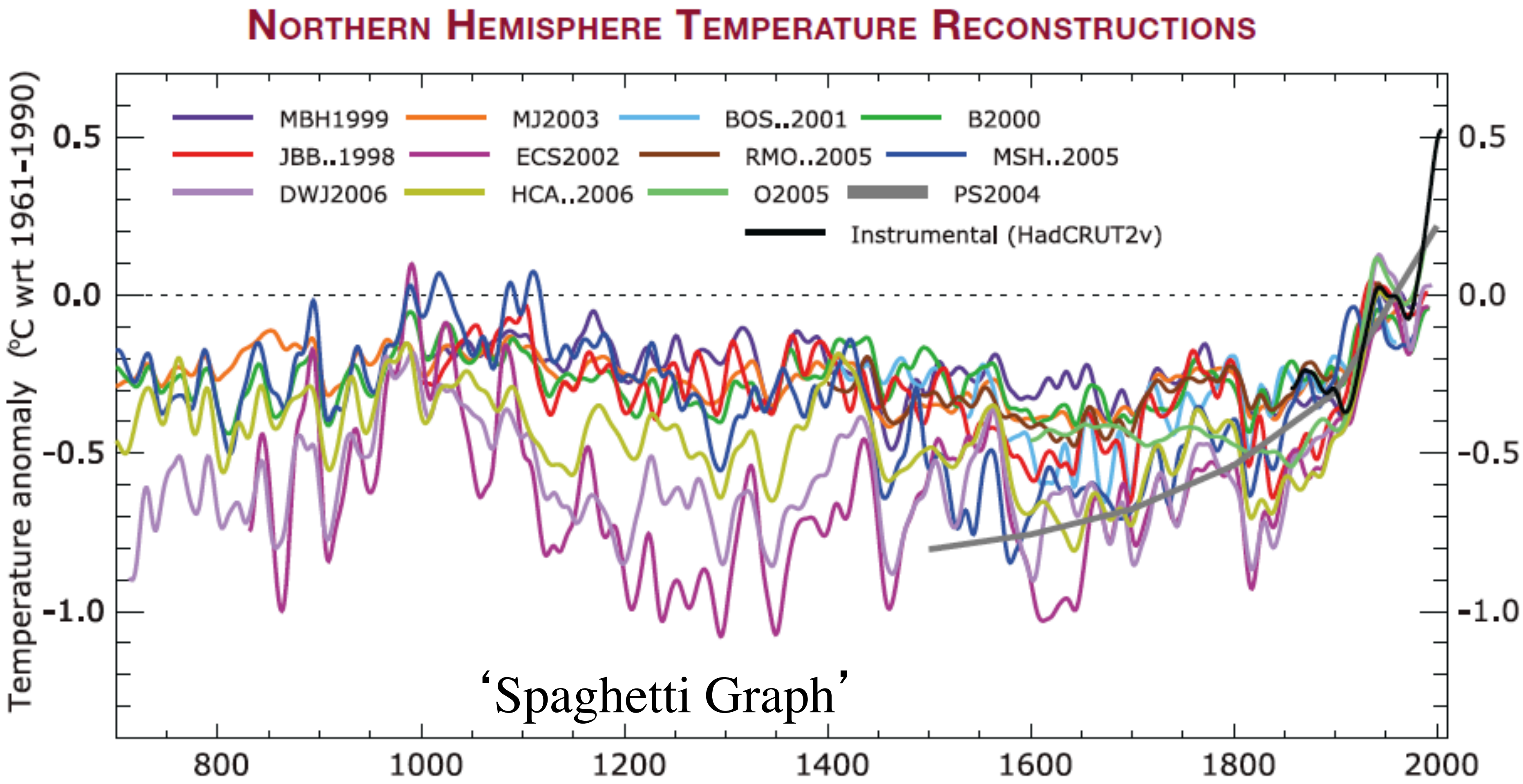
Journal of Climate 18: 2308-2329



Fortunately not correct!



Observations, Northern Hemisphere, proxy data
Global instrumental observations
Projections
SRES Scenarios
Highest historical temperature level for the last 400,000 years (A)
Proposed temperature threshold for dangerous climate change (B)
DANGER
Bars show the range in year 2100 produced by several models
Scenarios
A1B
A1T
A1FI
A2
B1
B2
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
GRID Arendal
UNEP
United Nations Environment Programme / GRID-Arendal


NORTHERN HEMISPHERE TEMPERATURE RECONSTRUCTIONS
MBH1999
MJ2003
BOS..2001
B2000
JBB..1998
ECS2002
RMO..2005
MSH..2005
DWJ2006
HCA..2006
O2005
PS2004
Instrumental (HadCRUT2v)
Temperature anomaly (ºC wrt 1961-1990)
0.5
0.0
-0.5
-1.0
800
1000
1200
1400
1600
1800
2000
'Spaghetti Graph'

IPCC 2007

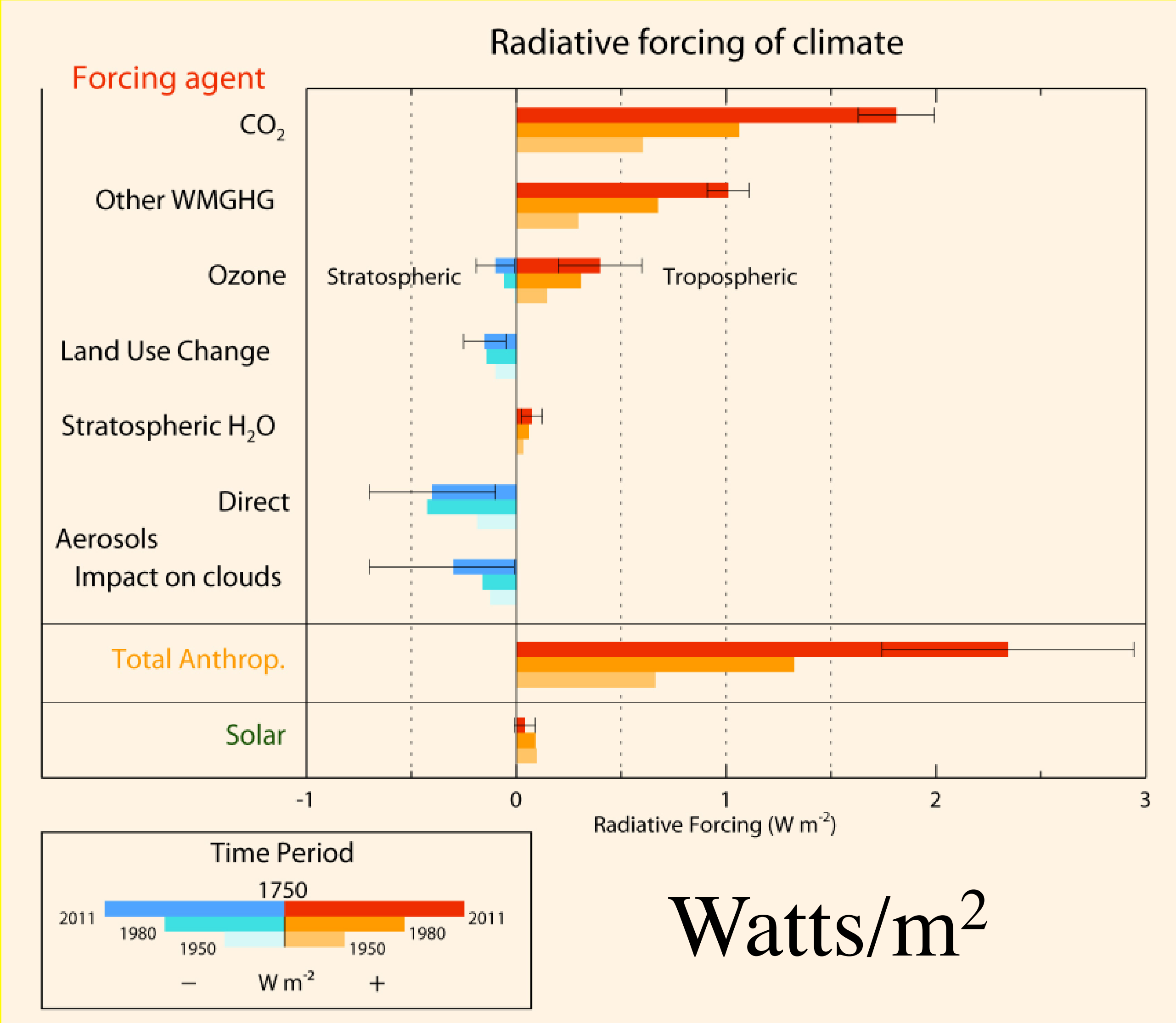
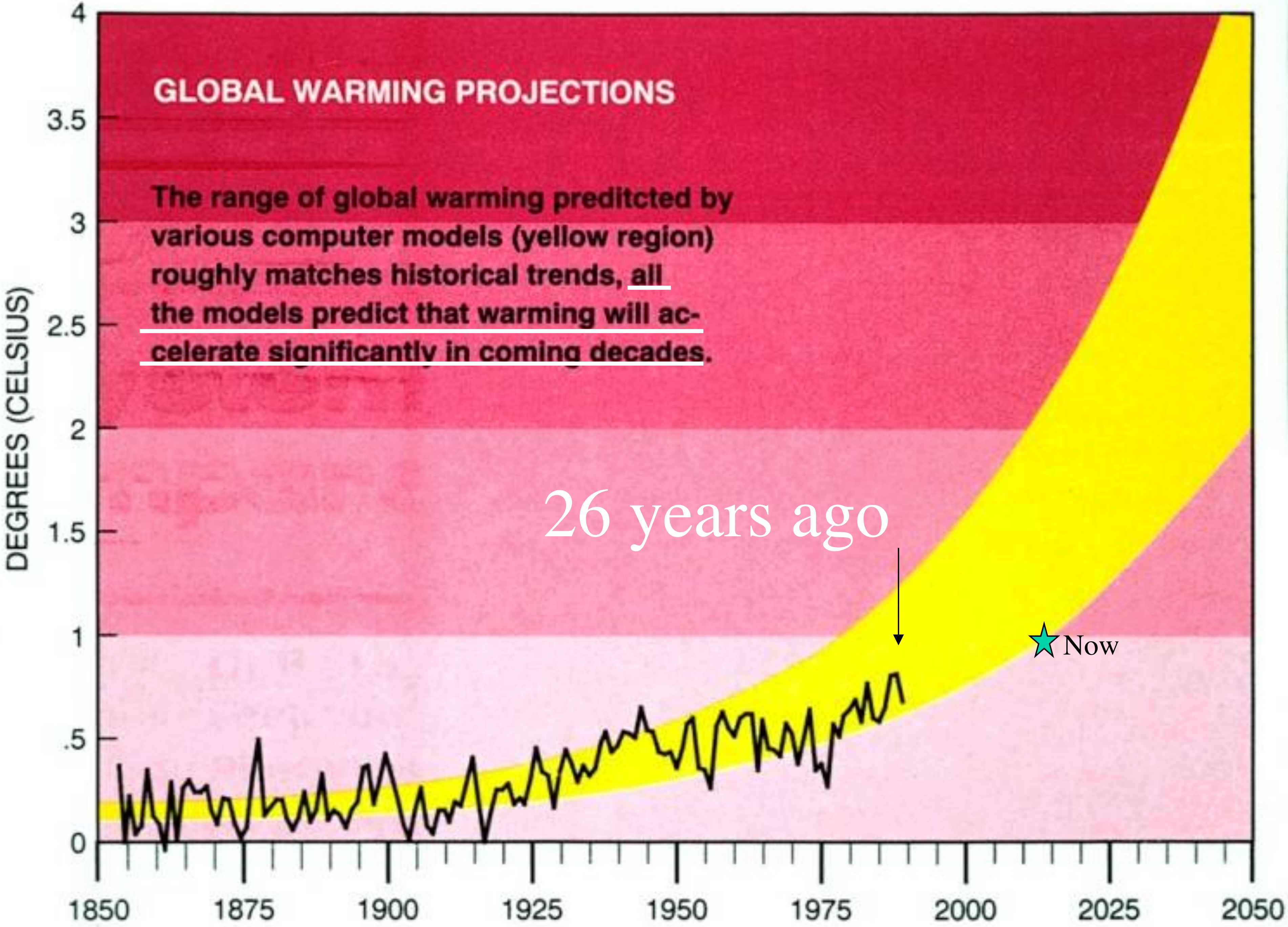
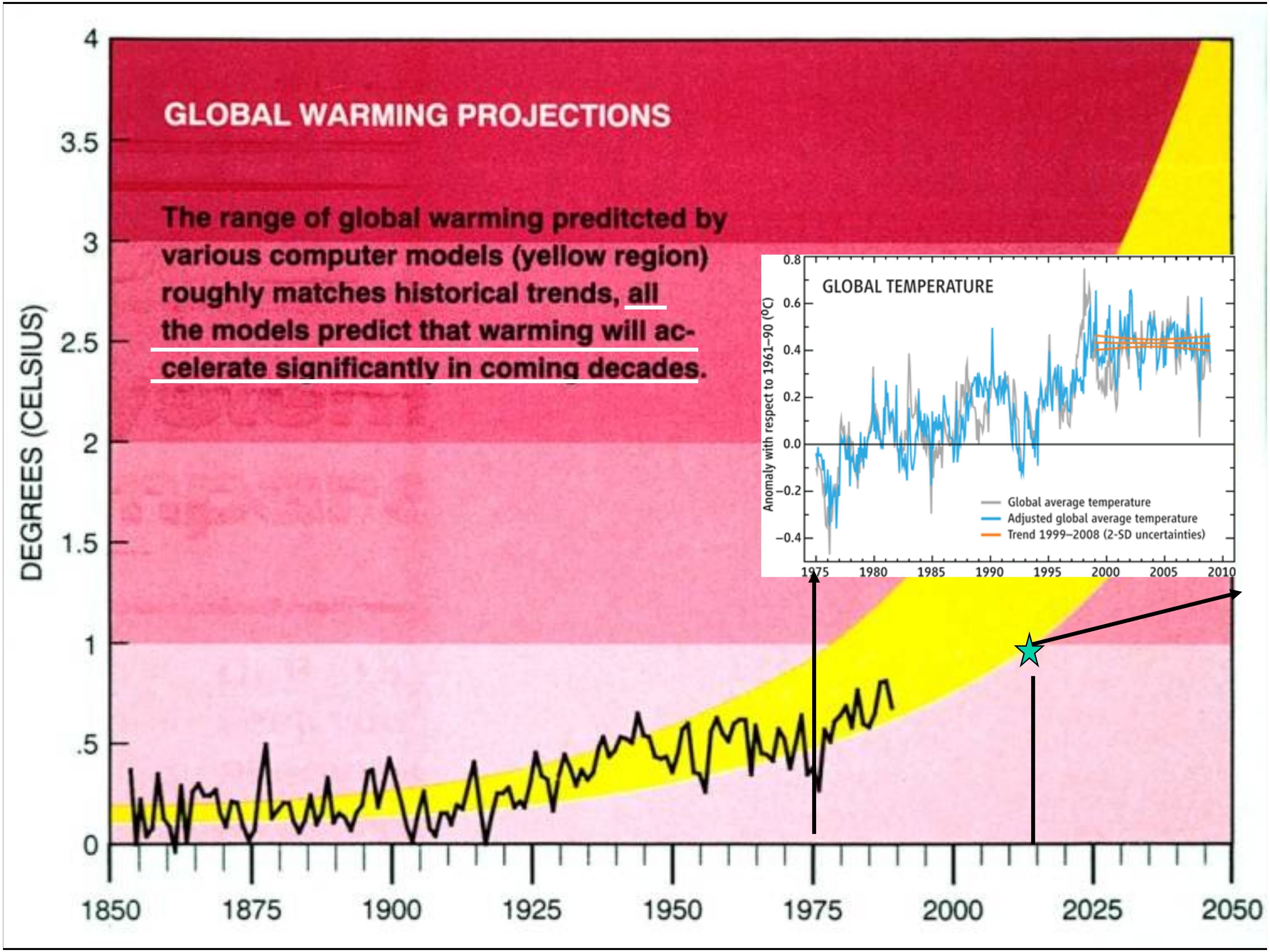
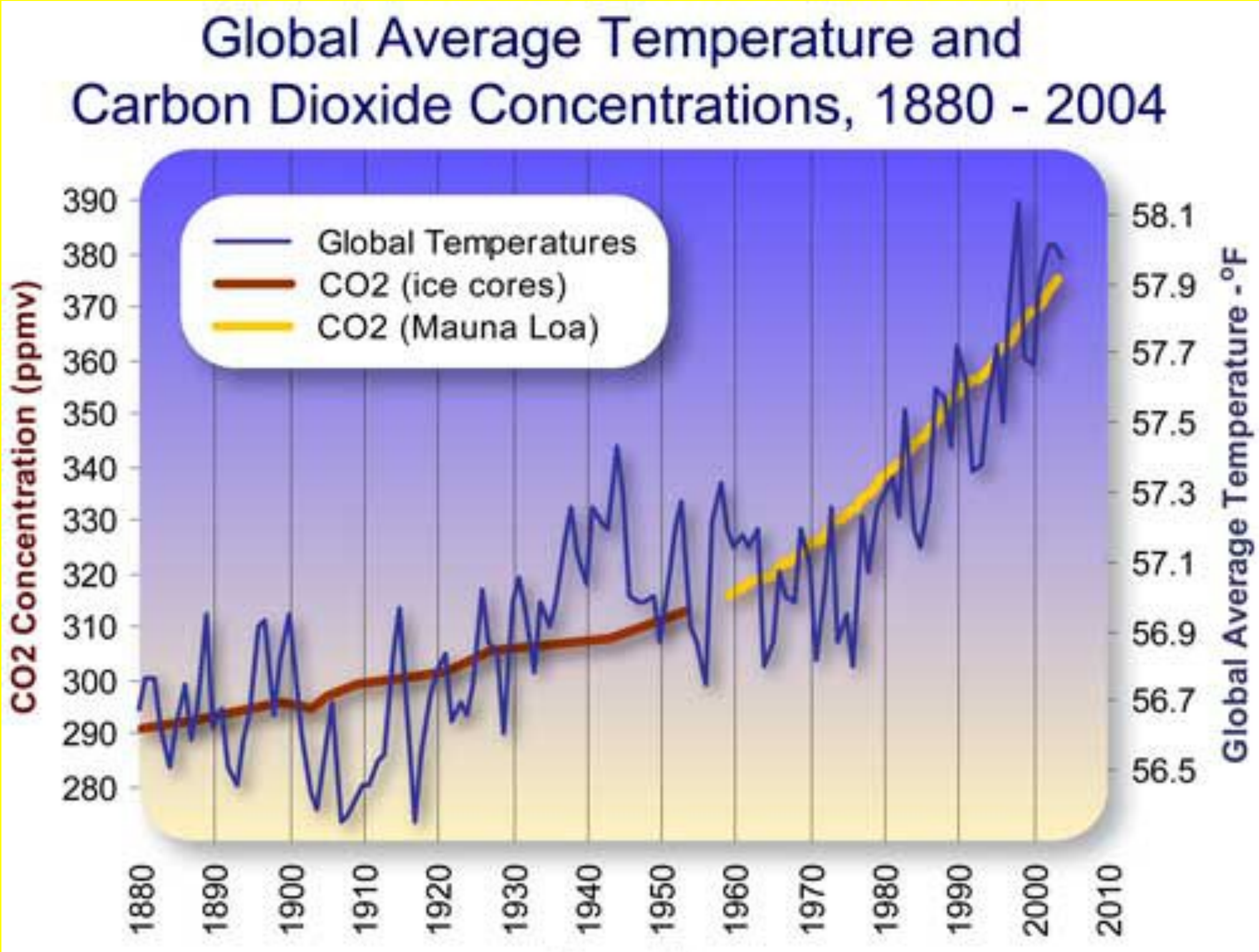


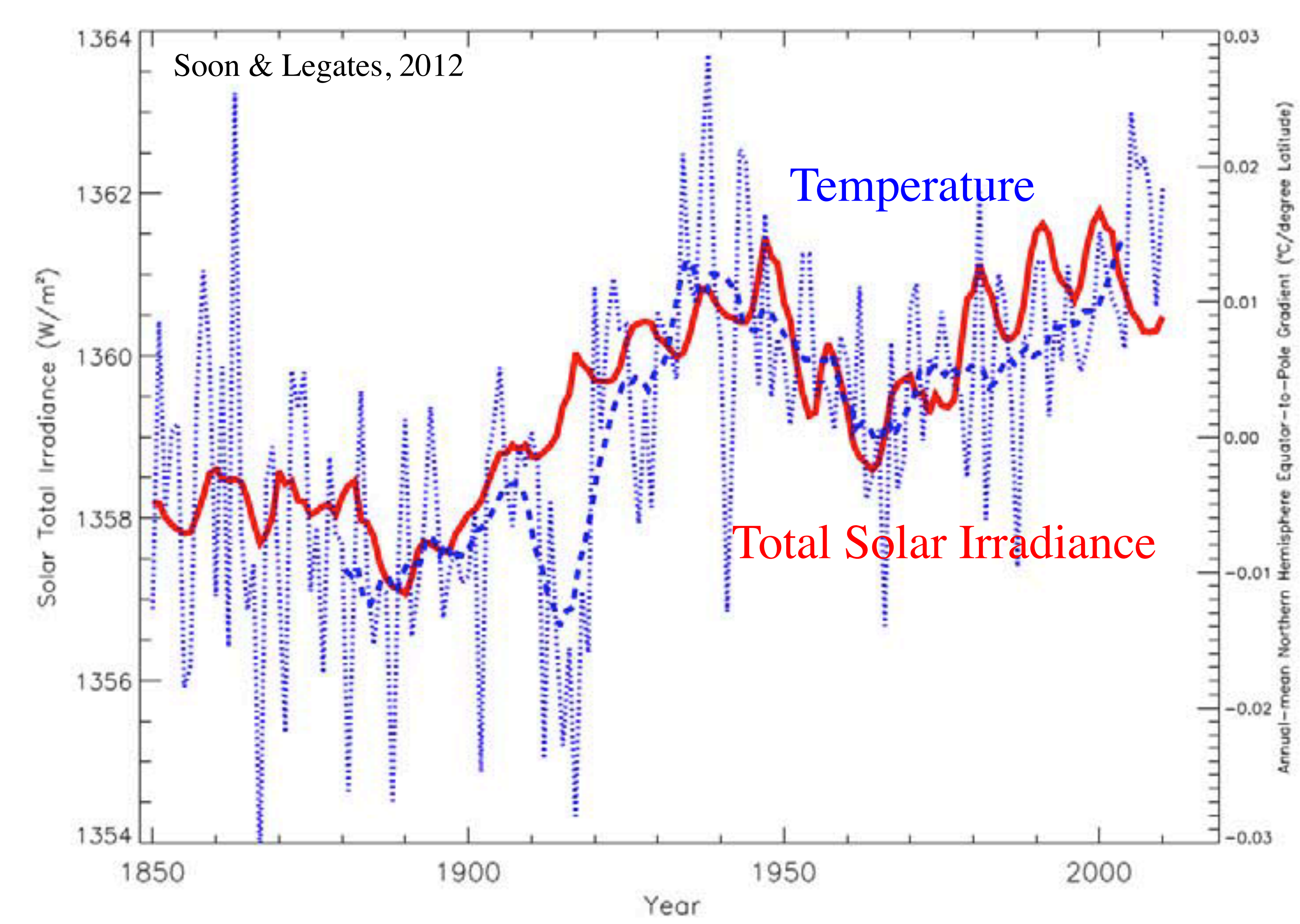
Figure SPM.3: Global average radiative forcing (RF) estimates and ranges for various drivers and three successive time periods; 1750_1950, 1750_1980, 1750_2011. The anthropogenic drivers are carbon dioxide (CO_2), other well-mixed greenhouse gases (CH_4, N_2O, and others), ozone, land use change, statospheric water vapour, and aerosols, with the sum of all contributions indicated. Assessed uncertainty ranges are given by black intervals. The RF of solar irradiance, a natural driver, is also estimated for the three time periods. {Figure 8.17}


GLOBAL WARMING PROJECTIONS
The range of global warming preditcted by various computer models (yellow region) roughly matches historical trends, all the models predict that warming will accelerate significantly in coming decades.
26 years ago
Now
DEGREES (CELSIUS)
4
3.5
3
2.5
2
1.5
1
.5
0
1850
1875
1900
1925
1950
1975
2000
2025
2050

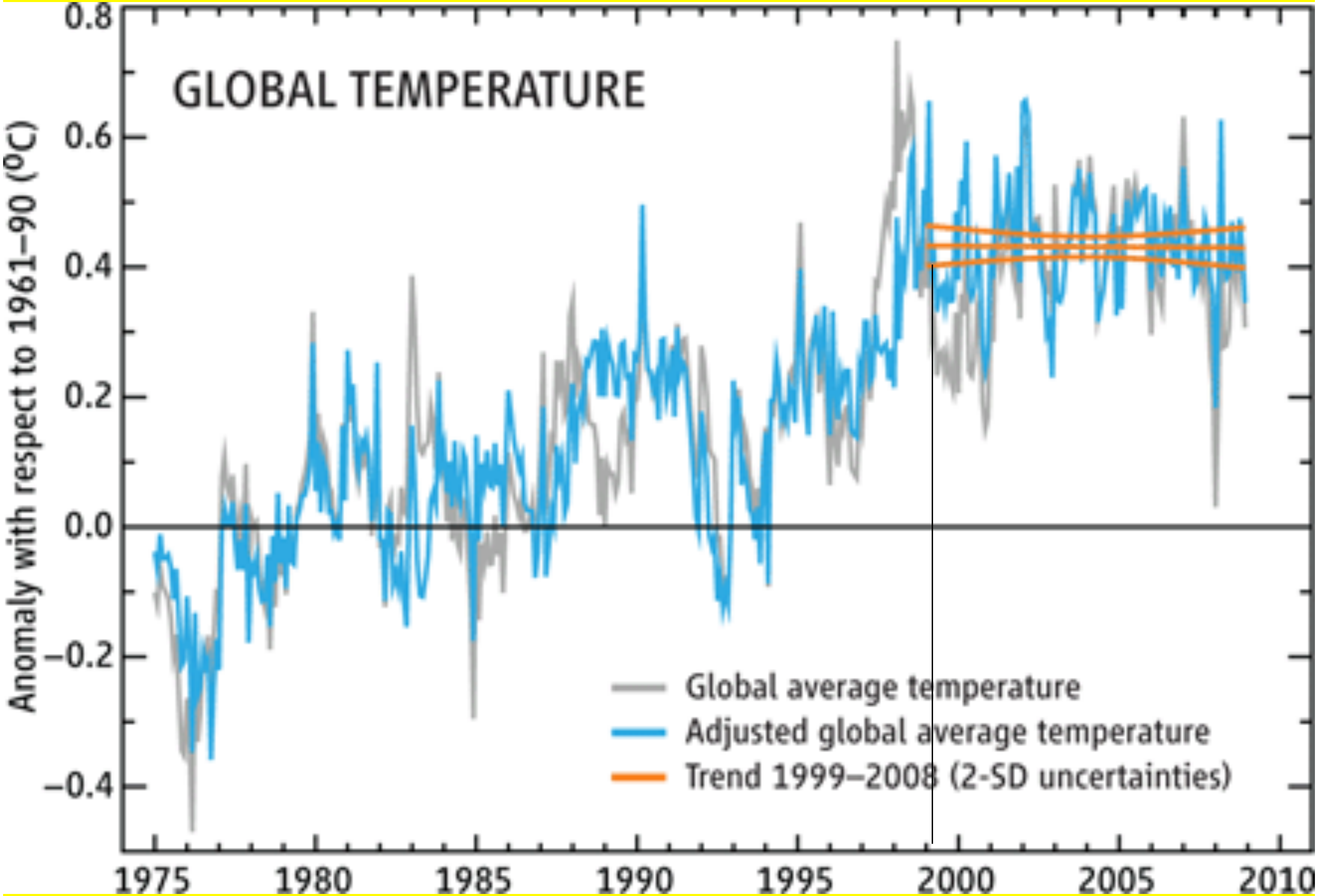

GLOBAL WARMING PROJECTIONS
The range of global warming preditcted by various computer models (yellow region) roughly matches historical trends, all the models predict that warming will accelerate significantly in coming decades.
DEGREES (CELSIUS)
4
3.5
3
2.5
2
1.5
1
.5
0
1850
1875
1900
1925
1950
1975
2000
2025
2050
GLOBAL TEMPERATURE
Anomaly with respect to 1961–90 (ºC)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
1975
1980
1985
1990
1995
2000
2005
2010
Global average temperature
Adjusted global average temperature
Trend 1999–2008 (2-SD uncertainties)

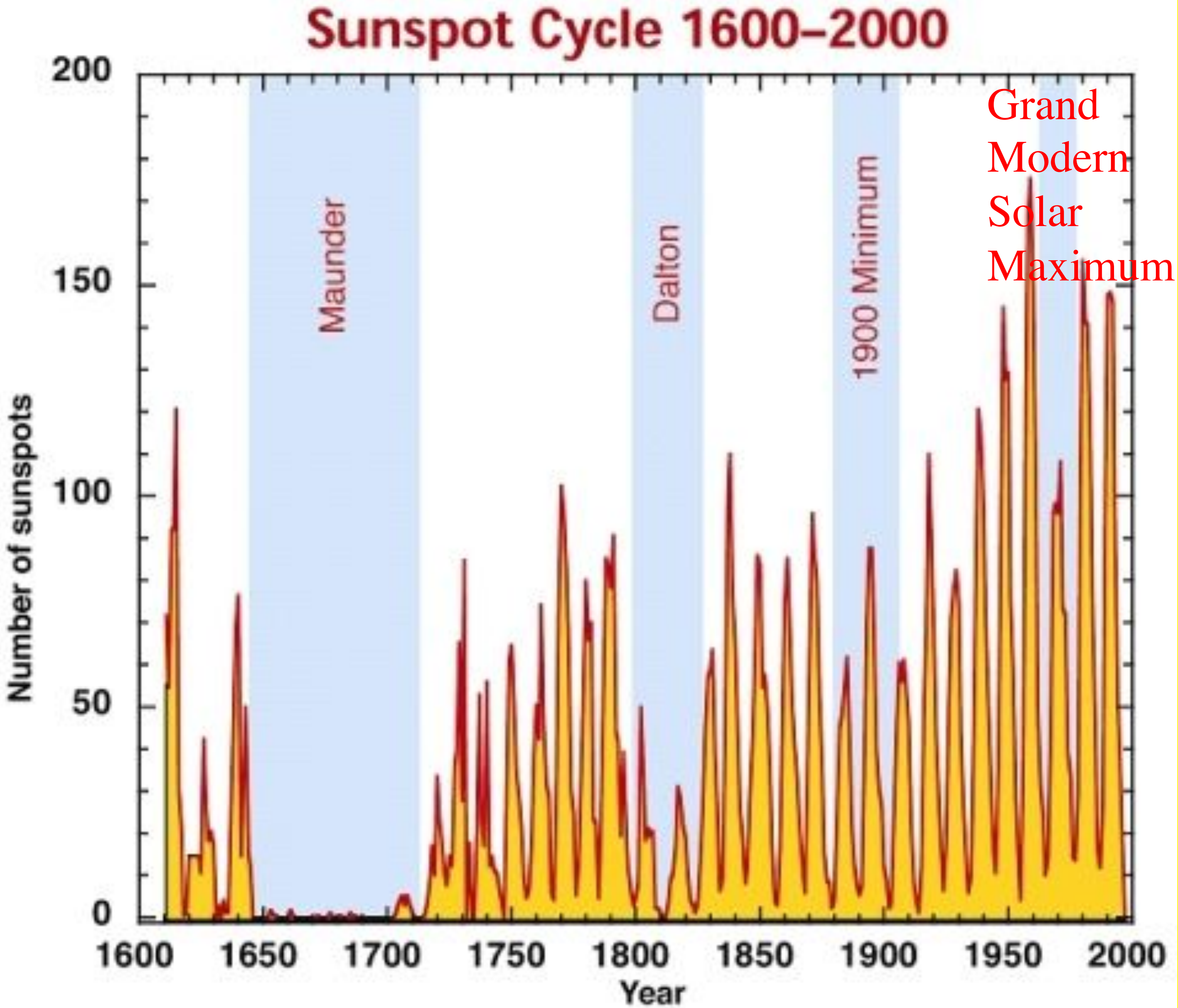


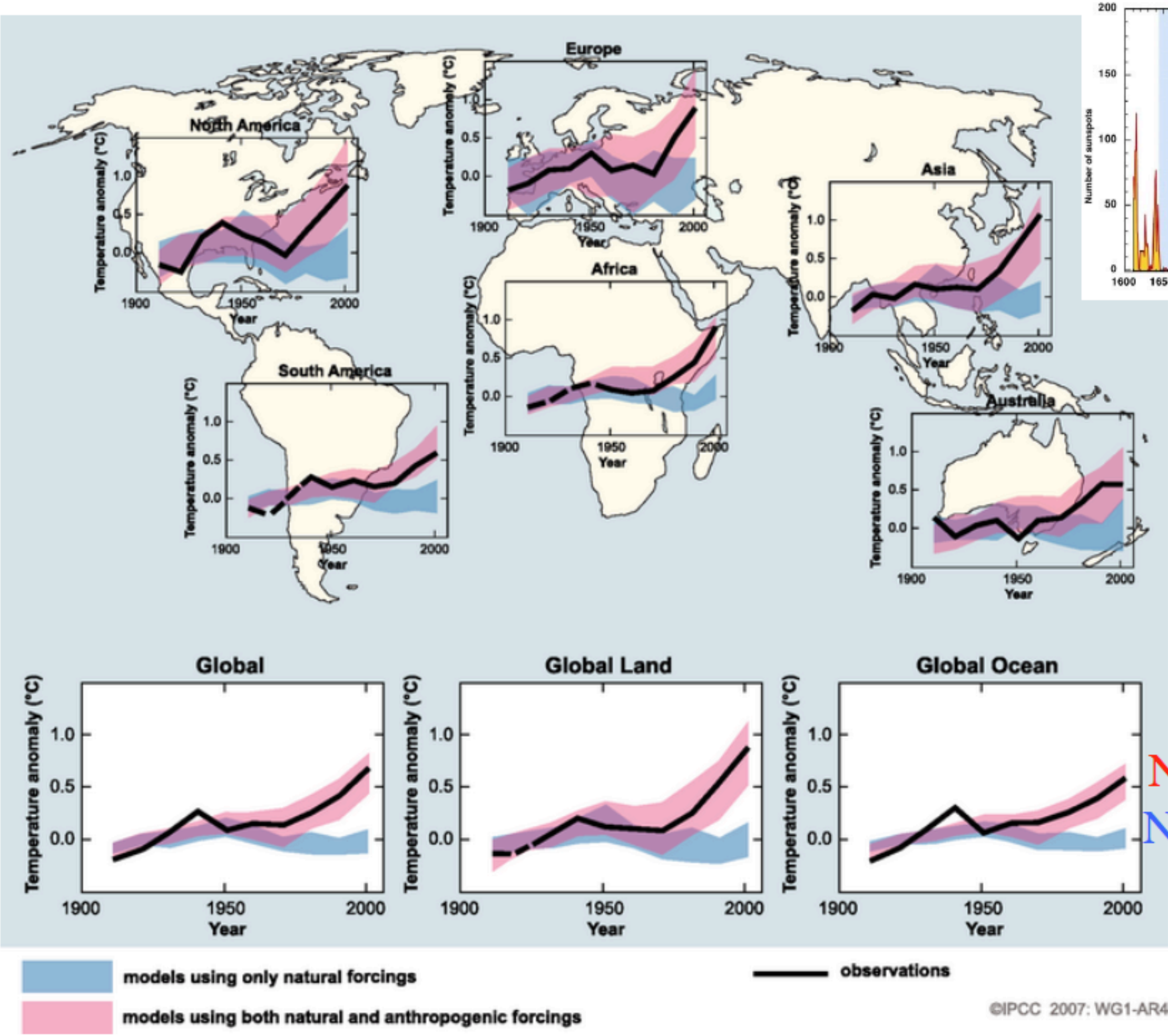
Global Average Temperature and
Carbon Dioxide Concentrations, 1880 - 2004
Global Temperatures
CO2 (ice cores)
CO2 (Mauna Loa)
CO2 Concentration (ppmv)
390
380
370
360
350
340
330
320
310
300
290
280
Global Average Temperature -°F
58.1
57.9
57.7
57.5
57.3
57.1
56.9
56.7
56.5
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

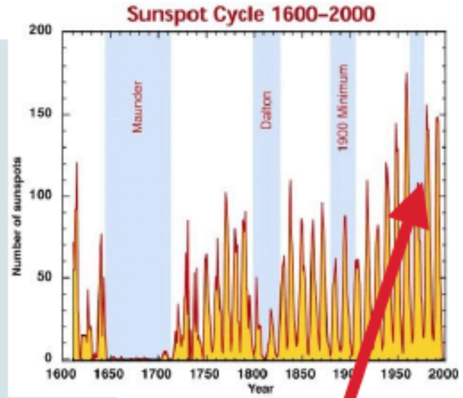


Annual-mean EPTG over the entire Northern Hemisphere (◦C/degree latitude; dotted blue line) and smoothed 10-year running mean (dashed blue line) versus the estimated total solar irradiance TSI (Wm-2; solid red line) of Hoyt and Schatten (1993; with updates by N. Scafetta) from 1850 to 2010.


GLOBAL TEMPERATURE
Anomaly with respect to 1961–90 (°C)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
1975
1980
1985
1990
1995
2000
2005
2010
Global average temperature
Adjusted global average temperature
Trend 1999–2008 (2-SD uncertainties)


Sunspot Cycle 1600–2000
Number of sunspots
200
150
100
50
0
Maunder
Dalton
1900 Minimum
Grand Modern Solar Maximum
1600
1650
1700
1750
1800
1850
1900
1950
2000
Year



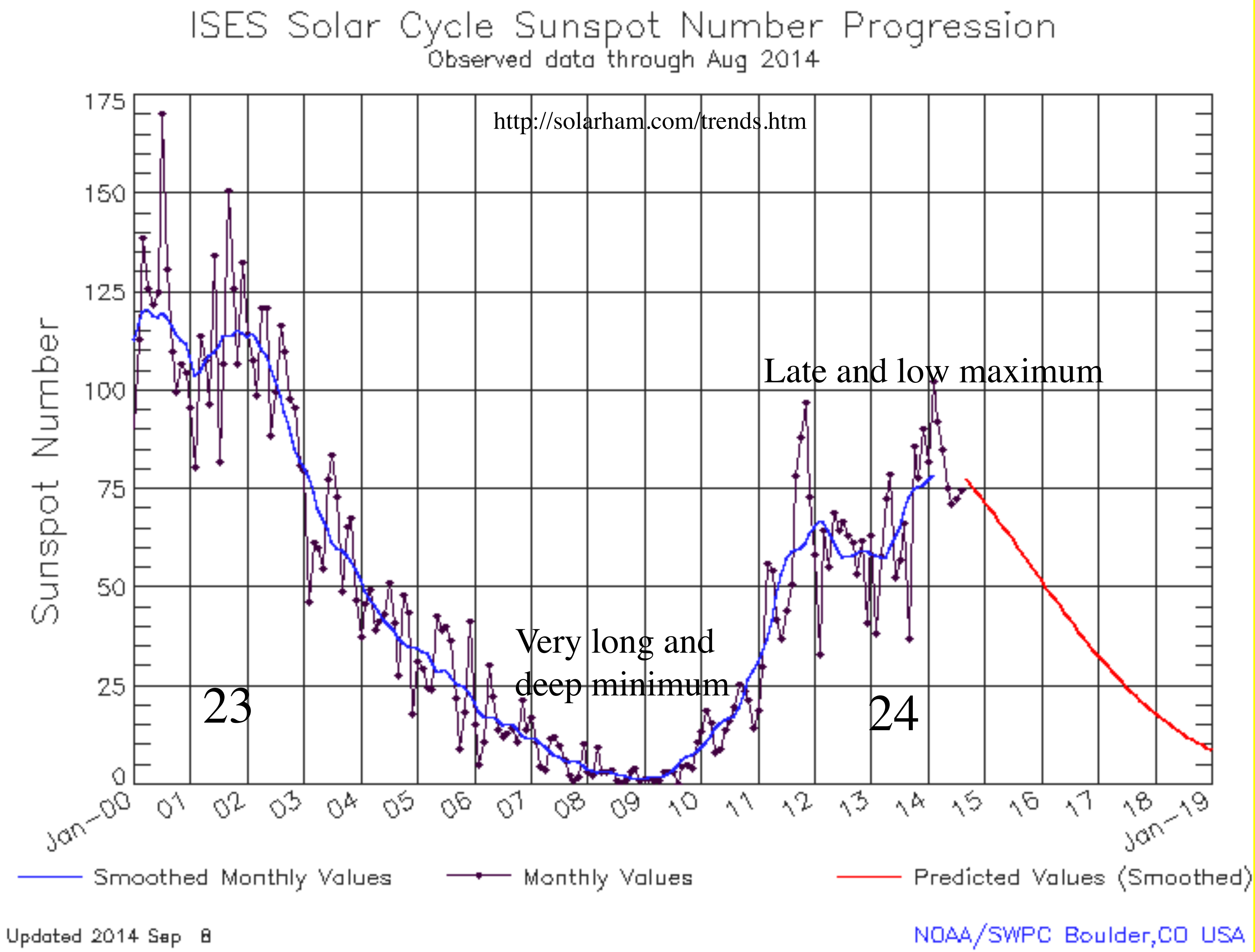


Grand Modern Solar Maximum

Natural + anthr

Natural

GMSM: impossible without temperature rise


ISES Solar Cycle Sunspot Number Progression
Observed data through Aug 2014
http://solarham.com/trends.htm
Sunspot Number
175
150
125
100
75
50
25
0
Late and low maximum
Very long and
deep minimum
23
24
Jan-00
01
02
03
04
05
06
07
08
09
10
11
12
13
14
15
16
17
18
Jan-19
Smoothed Monthly Values
Monthly Values
Predicted Values (Smoothed)
Updated 2014 Sep 8
NOAA/SWPC Boulder,CO USA

Habibullo I. Abdussamatov (2012) Bicentennial decrease of the Total Solar Irradiance leads to unbalanced thermal budget of the Earth and a Little Ice Age. Applied Physics Research 4 (1): 178-184.

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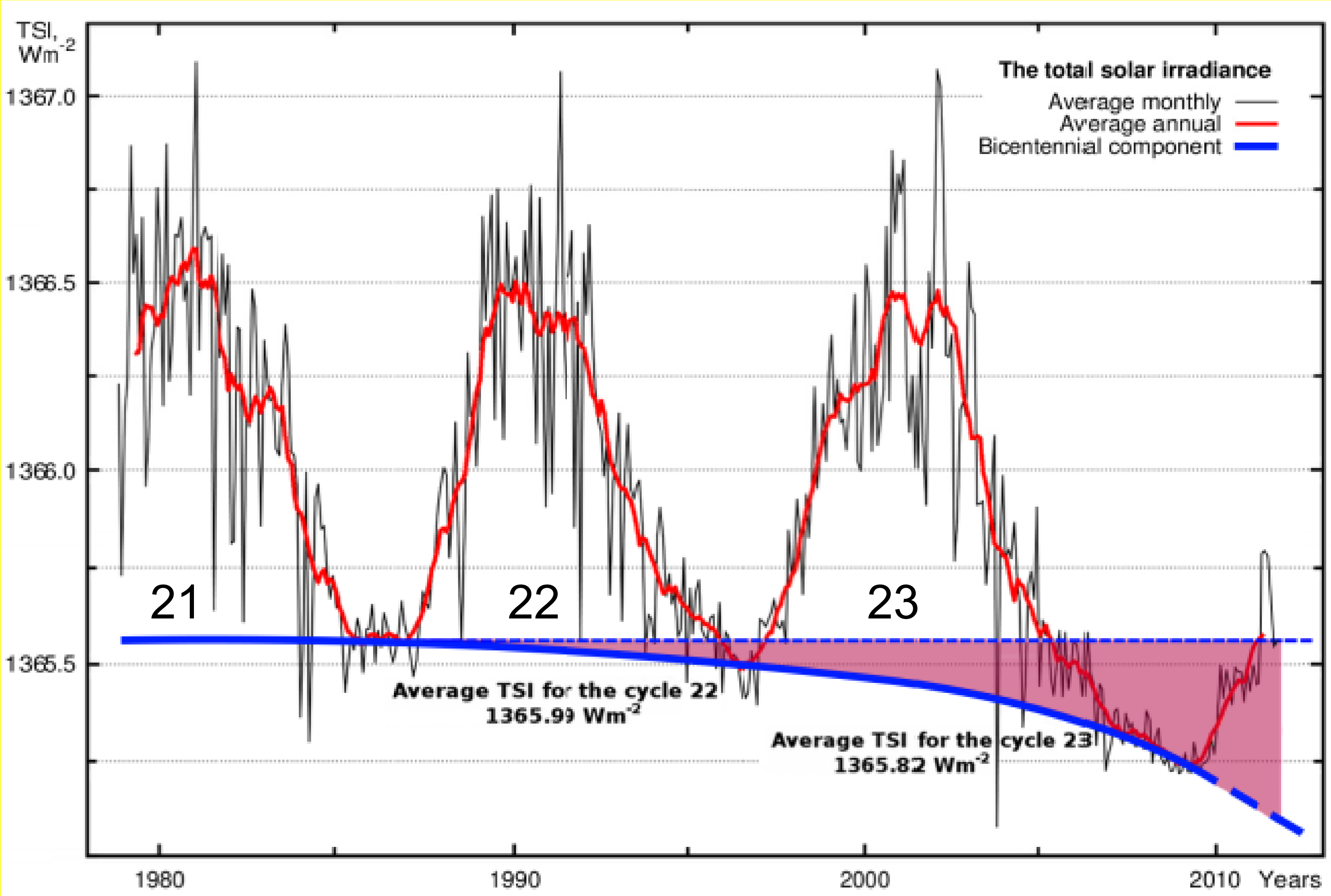


Figure 2. Variations of the TSI in 1978-2011 and deficit of the TSI since 1990

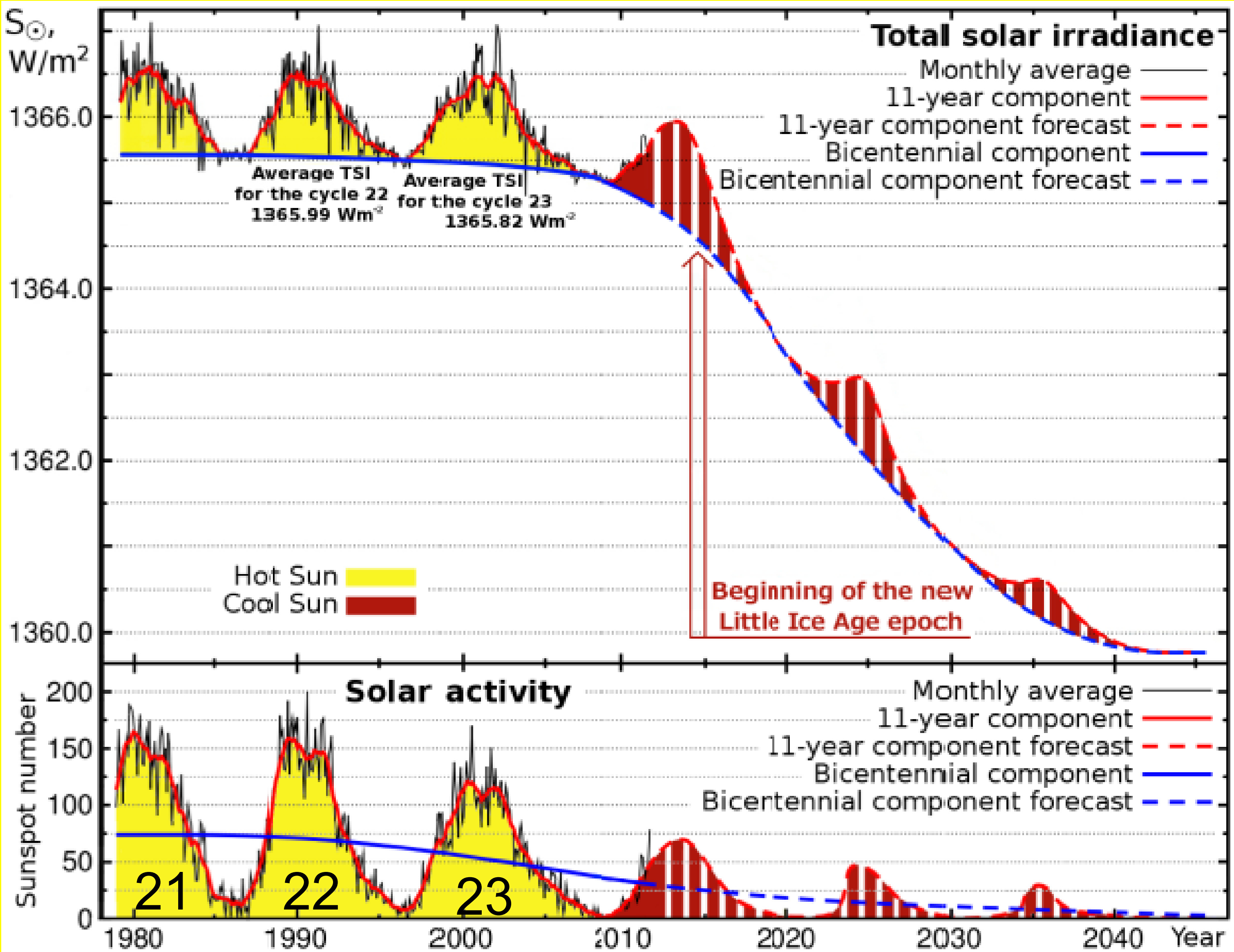


Figure 3. Variations of both the TSI and solar activity in 1978-2011 and a forecast of their variations in cycles 24-26 (up to the year 2045)

Friedhelm
Steinhilber

STEINHILBER AND BEER: PREDICTION OF SOLAR ACTIVITY

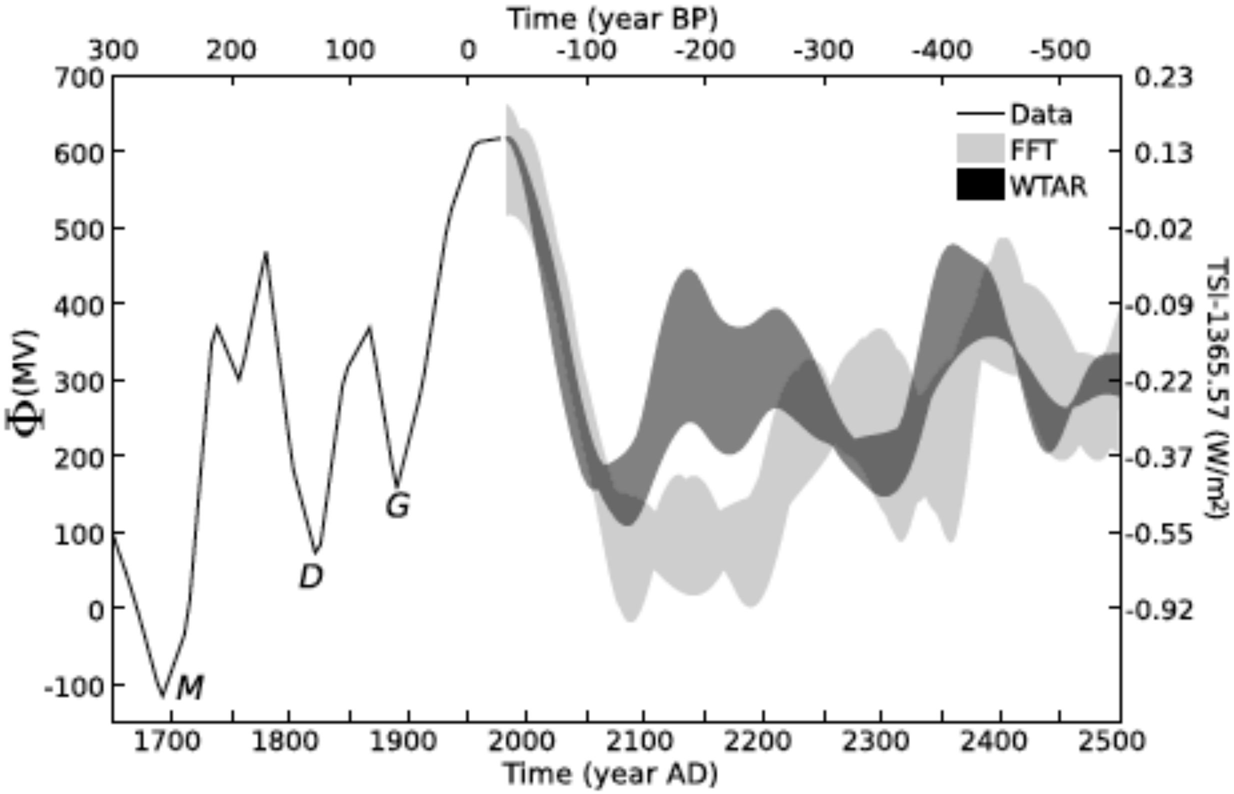


Figure 4. Prediction of solar activity (Φ on the left *y* axis and total solar irradiance (TSI) on the right *y* axis) for the next 500 years using the same parameters as for the tests with data of the past. The black curve depicts the solar activity reconstruction. Bright grey band: FFT method results using different numbers of lines and calibration windows with a length of 4000 and 6000 years. Dark grey band: WTAR method results using different combinations of scales and AR model orders and the two calibration windows (4000 and 6000 years). Grand solar minima in the past known from sunspot numbers are marked with capital letters (M: Maunder, D: Dalton, G: Gleissberg).

Jürg
Beer

Climate change (major questions):

How important was the role of the Sun in the past?

Which part of the worldwide temperature rise of the second half of the last century was anthropogenic and which part was natural?

IPCC Summary for Policymakers (2013)

Globally, CO_2 is the strongest driver of climate change.
Its relative contribution has further increased since the 1980s and by far outweighs the contributions from natural drivers.

It is *very likely* that early 20th century warming is due in part to external forcing, including greenhouse gas concentrations, tropospheric aerosols, and solar variations.
Climate model simulations that include only natural forcings (volcanic eruptions and solar variations) can explain a substantial part of the pre-industrial temperature variability since 1400 but fail to explain more recent warming since 1950.

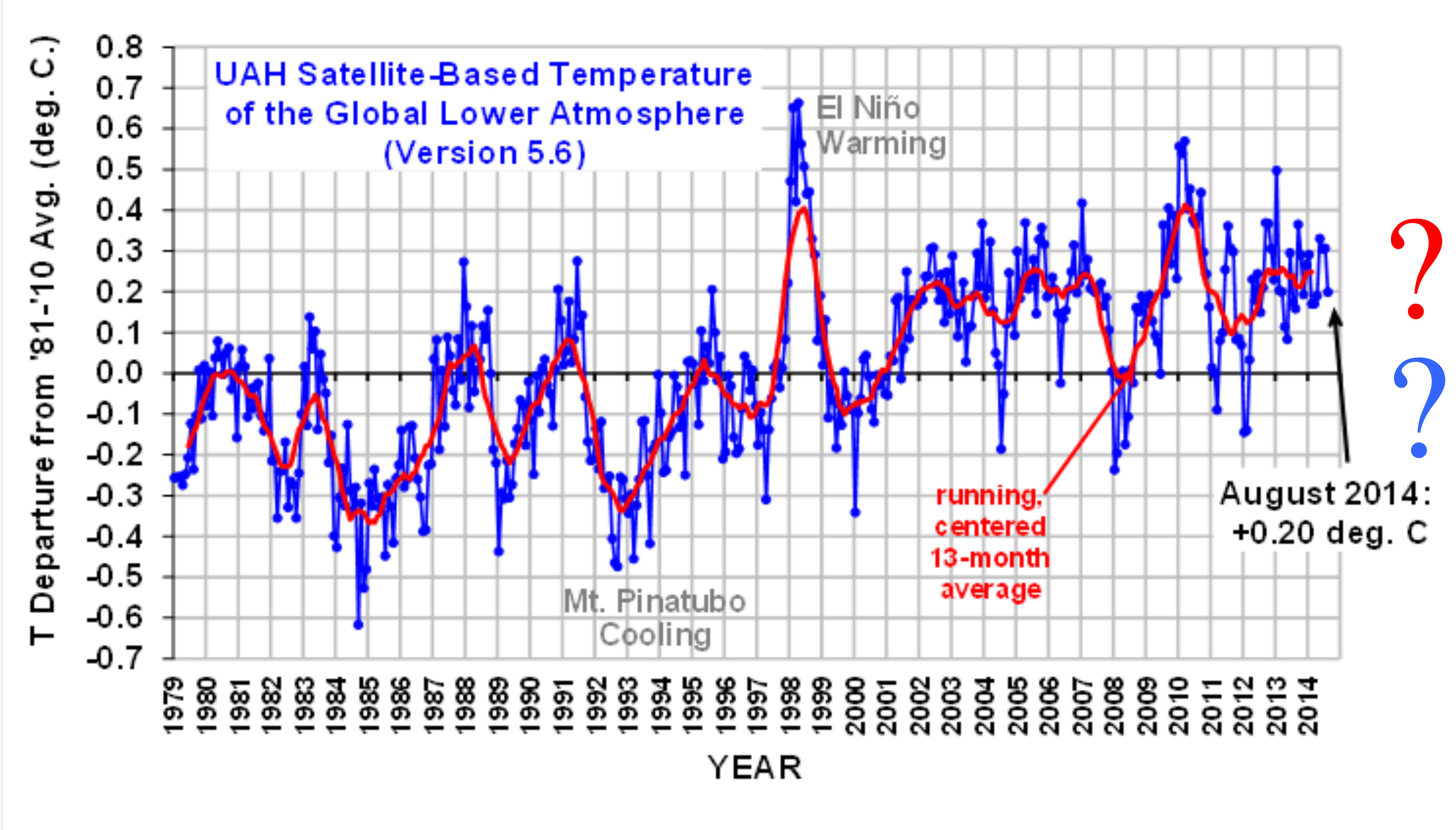
Many paleo-records show the hypersensitivity of the climate for relatively small changes of solar activity.

There must be amplification mechanisms.

W/m^2 does not make sense!

Good reasons to reduce the use of fossil fuels:

- geopolitical reasons
- acidification of oceans
- improve air quality
- use oil for making products instead of burning it
- avoid climate change



14 years of stagnating 'global warming'

(equilibrium with Grand Solar Maximum?)

GEOPHYSICAL RESEARCH LETTERS, VOL. 37, 2010

On the effect of a new grand minimum of solar activity on the future climate on Earth

Georg Feulner and Stefan Rahmstorf (Potsdam)

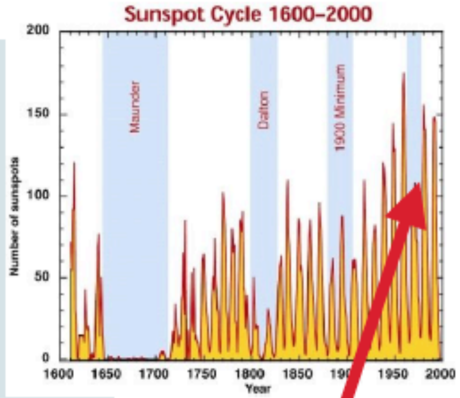
The current exceptionally long minimum of solar activity has led to the suggestion that the Sun might experience a new grand minimum in the next decades, a prolonged period of low activity similar to the Maunder minimum in the late 17th century.

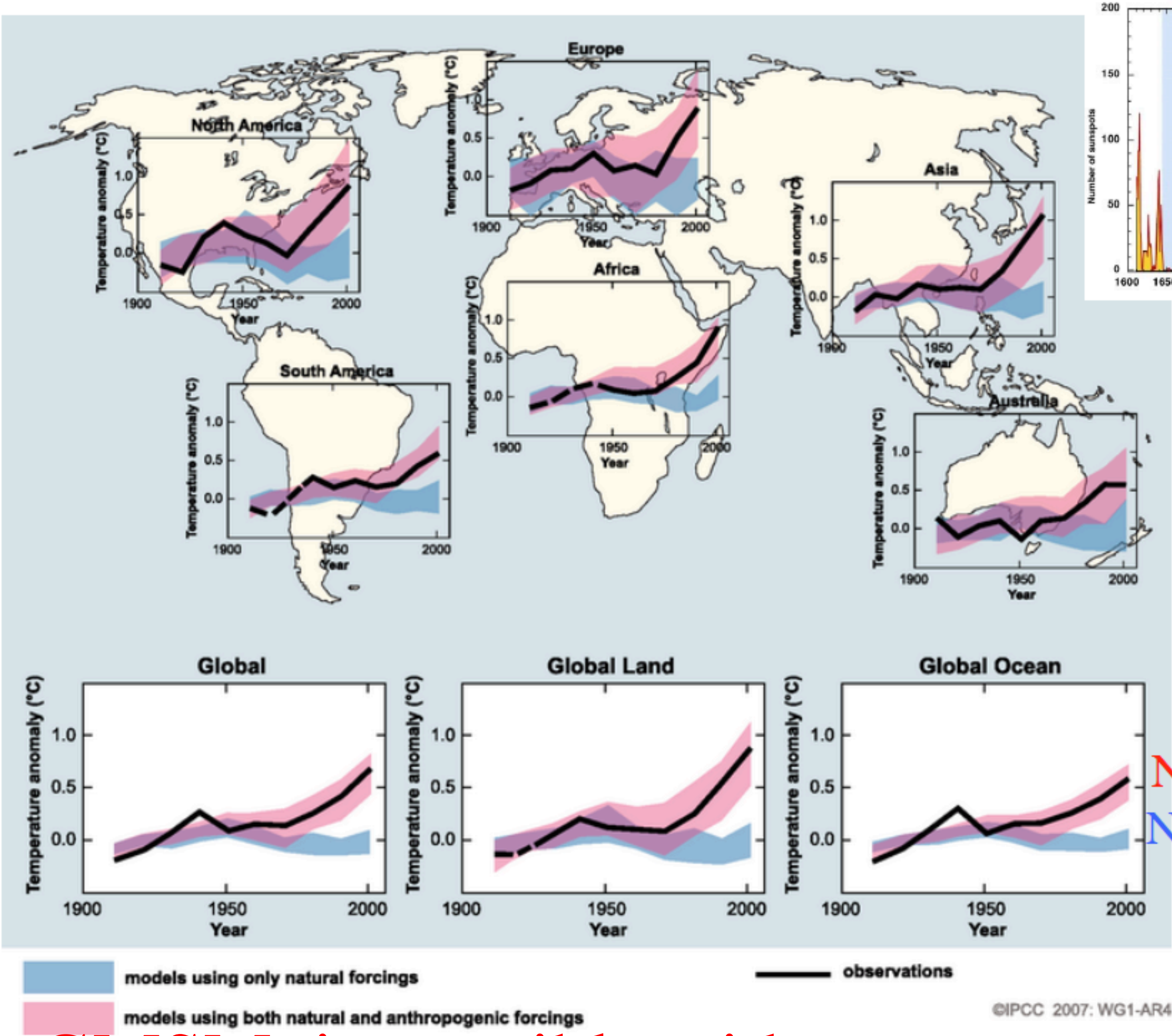
Here we use a coupled climate model to explore the effect of a 21st-century grand minimum on future global temperatures, finding a moderate temperature offset of no more than -0.3°C in the year 2100 relative to a scenario with solar activity similar to recent decades. This temperature decrease is much smaller than the warming expected from anthropogenic greenhouse gas emissions by the end of the century.

IPCC:

The Sun is not a major driver of the climate changes over the past 40 years because instrumental TSI and SSI records contain no significant trend, whereas records of global mean temperature and greenhouse gas concentrations contain significant trends of increasing values.

This lack of agreement in trends demonstrates that the Sun did not play a role during this period.





Grand
Modern
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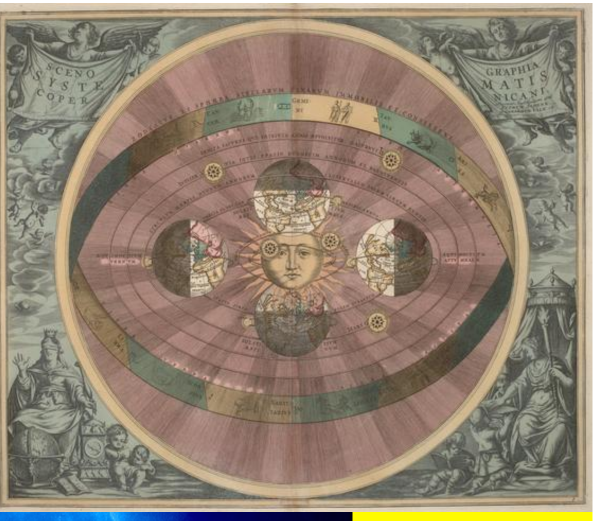
GMSM: impossible without temperature rise

Do we know enough about solar forcing of climate change?

Probably not: we do not even know the amplification mechanisms.

Role of the sun cannot be quantified in climate models.

My opinion: underestimation of solar forcing; overestimation of enhanced greenhouse effect and the role of humans.



Thank you for your attention!

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