

Solar variability and Climate Change

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T. Spangehl, S. Wagner

Sponsored by SPP CAWSES, DFG Germany

outline

- Introduction
- Orbital influences
- Direct influences
- Indirect influences
- Summary

CAWSES in Germany:
priority programme
of the DFG
(German Science Foundation)

6 years (3 x 2): 2005-2011
~17 Million US-\$
~30 institutes involved
(~120 scientists + PhD)

National programme with strong
encouragement for international cooperation

Free University Berlin

- Inst. for Meteorology
- Inst. for Experimental Physics

University Bochum

University Bremen

University Frankfurt

Max-Planck-Institut for Meteorology, Hamburg

University Heidelberg

University Ilmenau

Research Center Jülich

Research Center Karlsruhe

University Karlsruhe

Max Planck Inst. for Solar System Research, Katlenburg-Lindau

University Kiel

Leibniz Institute for Atmospheric Physics, Kühlungsborn

University Leipzig

Max-Planck-Institute for Chemistry, Mainz

University Munich

- Inst. for Atmospheric Physics
- Inst. for Astronomy and Astrophysics

German Space Agency, Neustrelitz

German Space Agency, Oberpfaffenhofen

University Osnabrück

GeoResearch Center Potsdam

University Wuppertal

blue: universities

red: research organisations

Topics covered within the priority programme:

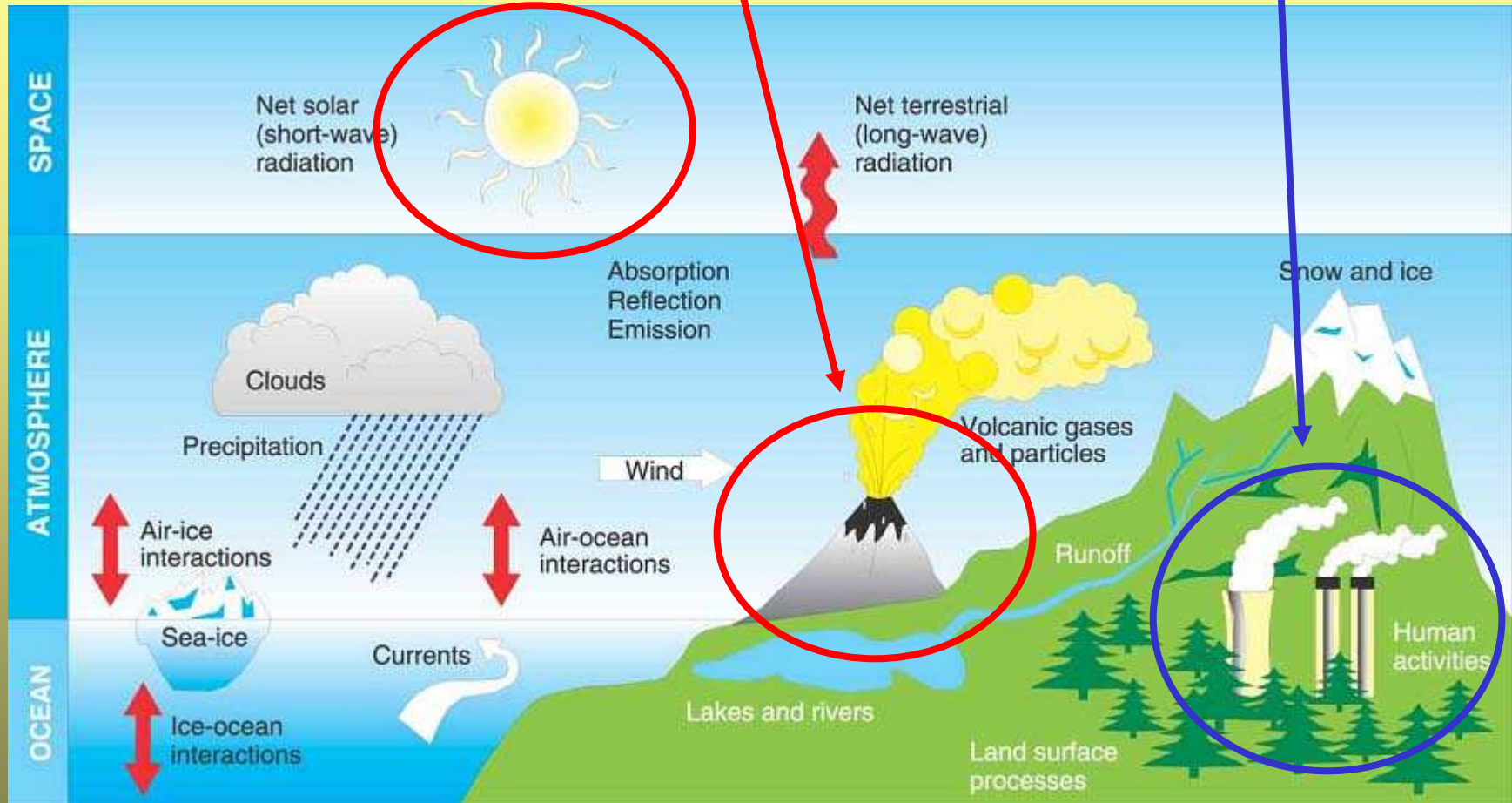
- Characterization of solar forcing and variability
- Influence on temperatures, trace gases, ice layers, ...
 - ... from the ground to the thermosphere
 - ... time scales: hours to centuries
- Coupling mechanisms (mainly by waves)
- Compare solar induced/ anthropogenic trends

(not covered: technical aspects of space weather)

Introduction

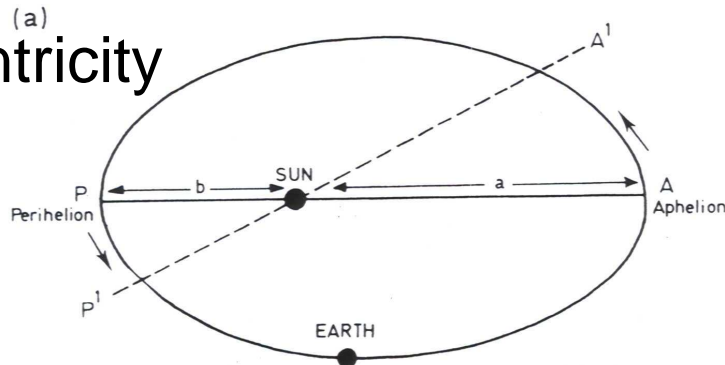
External Forcing

Anthropogenic Forcing



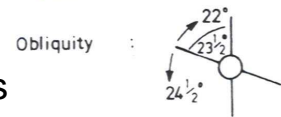
The climate system

excentricity



Eccentricity : $E = \frac{\sqrt{a^2 - b^2}}{a}$

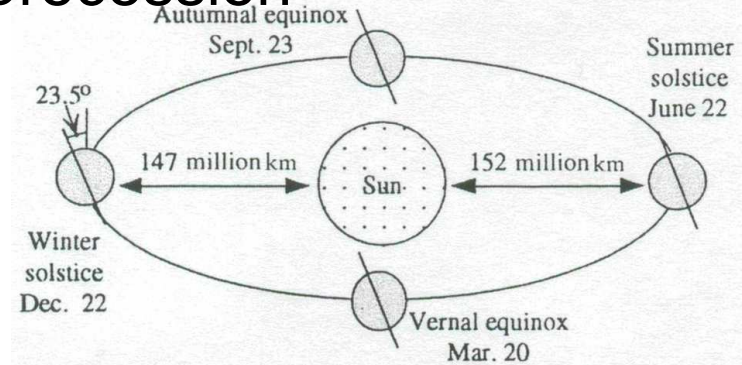
Precession of the location of the perihelion : $P \rightarrow P'$ and $A \rightarrow A'$



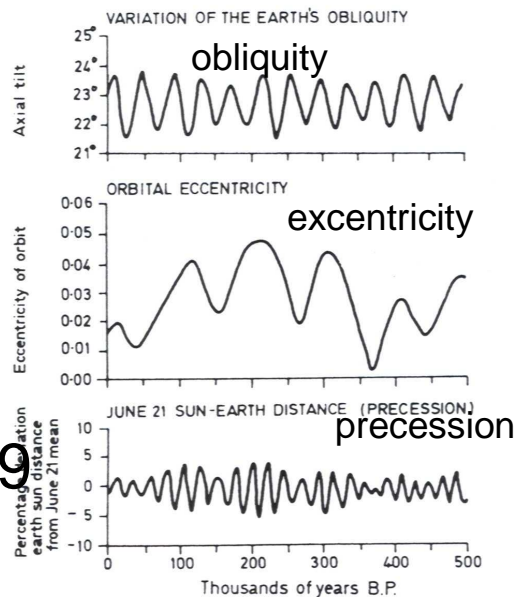
Oblivity :

excentricity
precession
obliquity
↔ tilt of the earth axis

precession



(b)



~41 ky

~100 ky

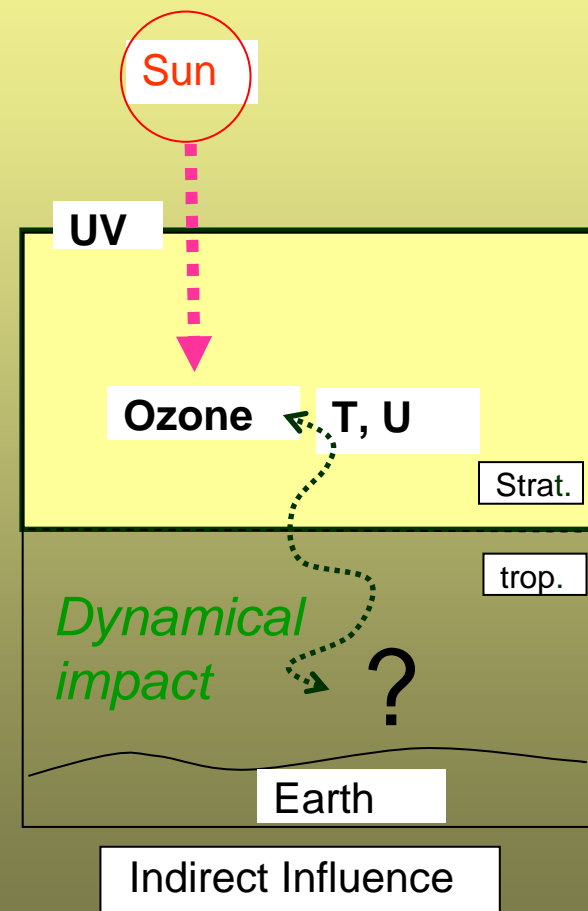
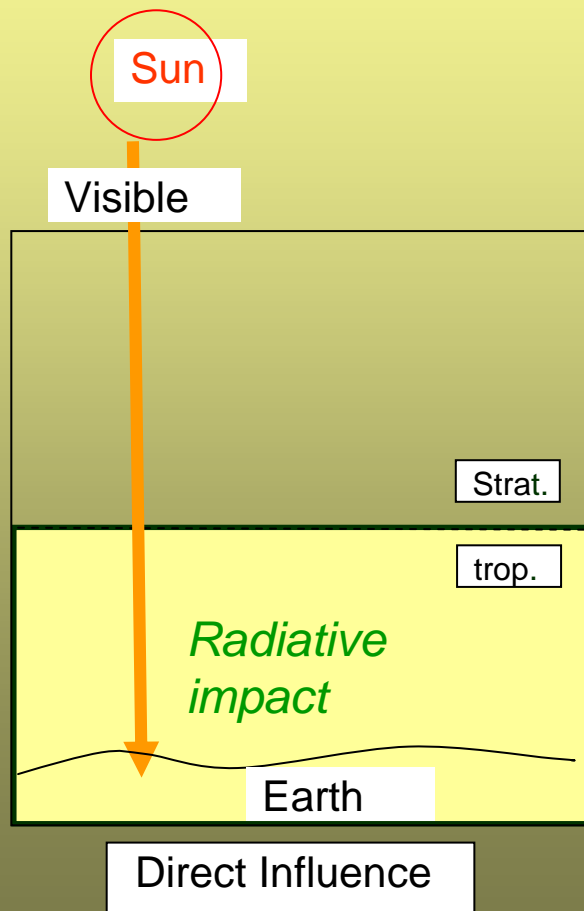
~ 23 und 19

ky

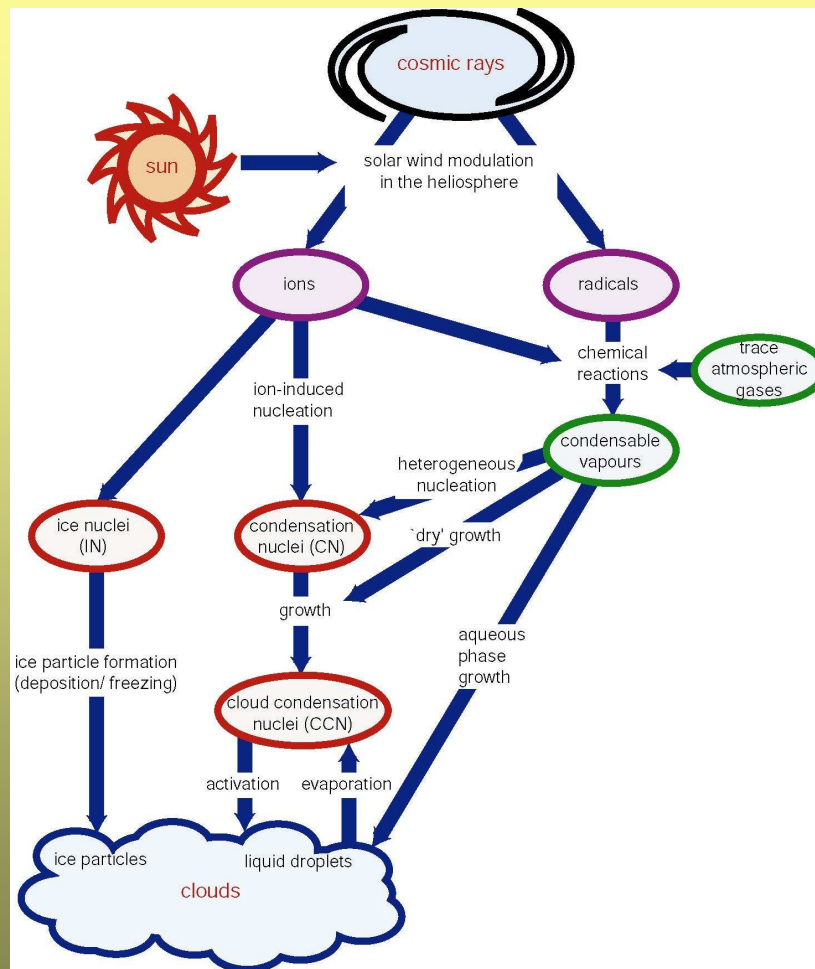
Figure 1.9 (a) Schematic diagram showing the variations in the three orbital components: obliquity (axial tilt), orbital eccentricity and precession of perihelion. (b) Variations in these three components, from 500 000 years ago to the present, as a function of time (reproduced by permission from Broecker and Van Donk (1970) *Rev. Geophys.*, 8, 169–196. Copyright by the American Geophysical Union)

Change of solar input by orbital parameters

Possible Ways for Solar Influence on Climate

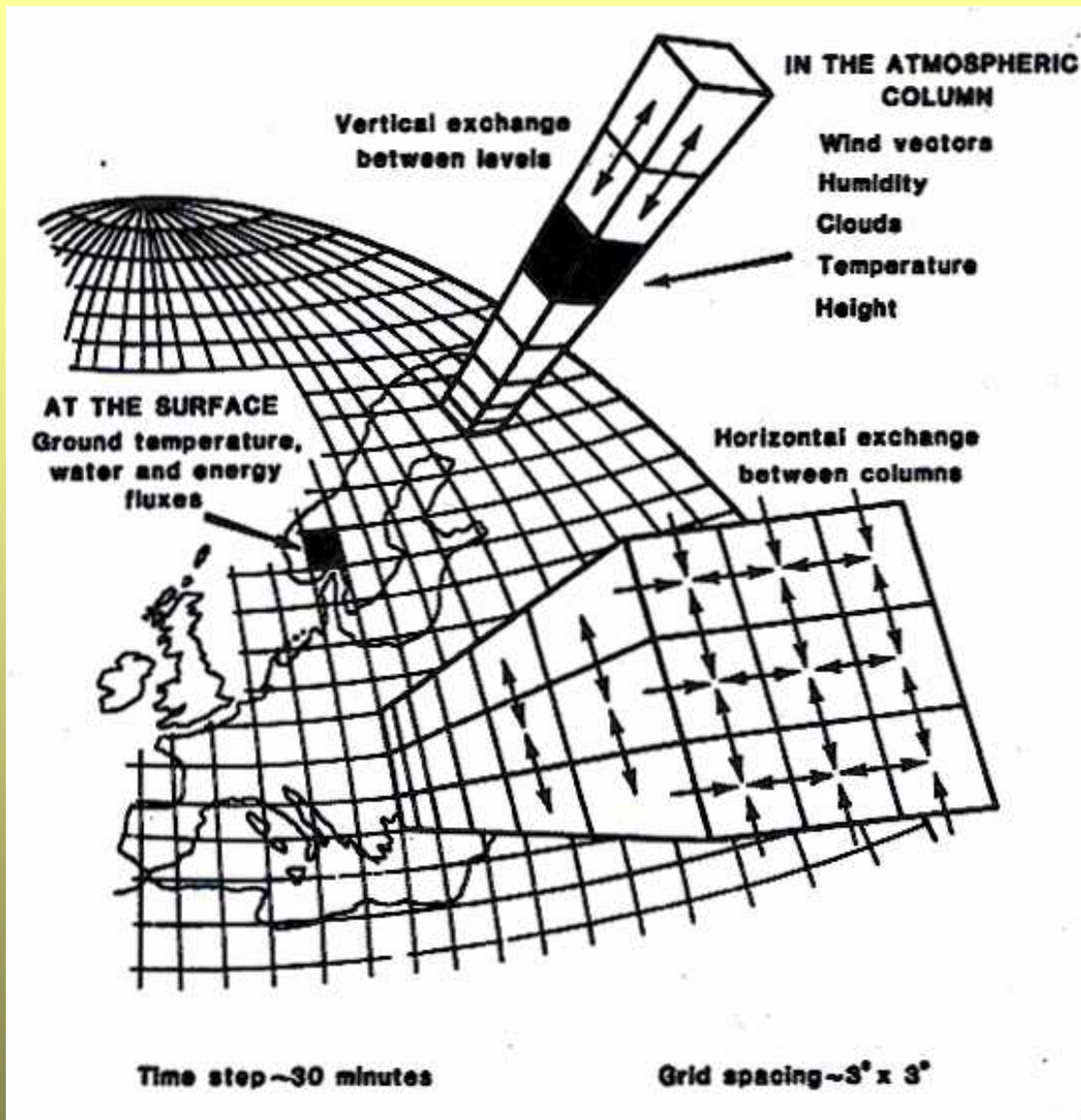


Possible Ways for Solar Influence on Climate

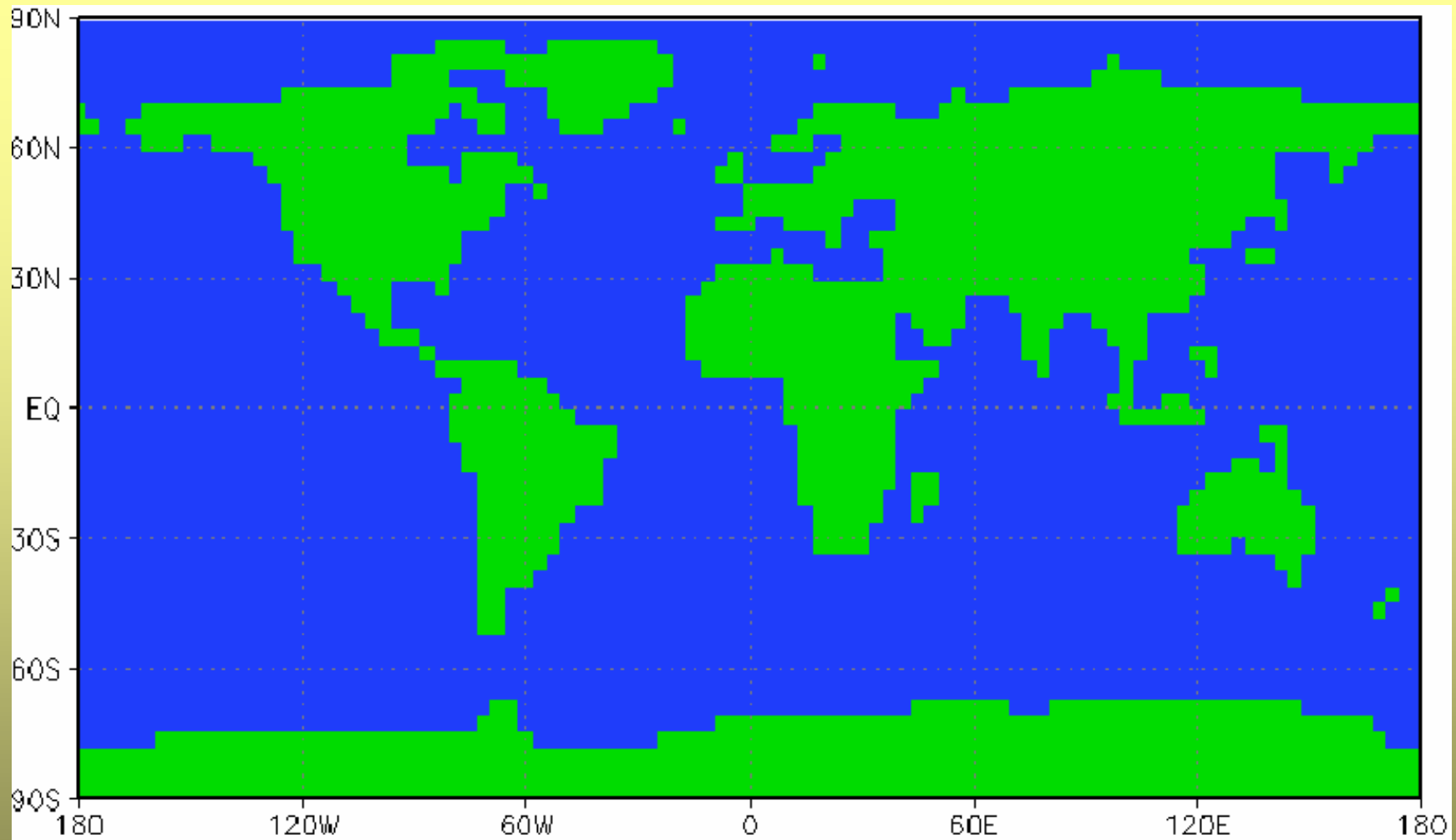


The influence of cosmic rays on clouds

Not yet quantified and not yet modelled!



A climate model



The land-sea mask of a typical climate model used in long simulations (ca. 3.75 x 3.75 deg)

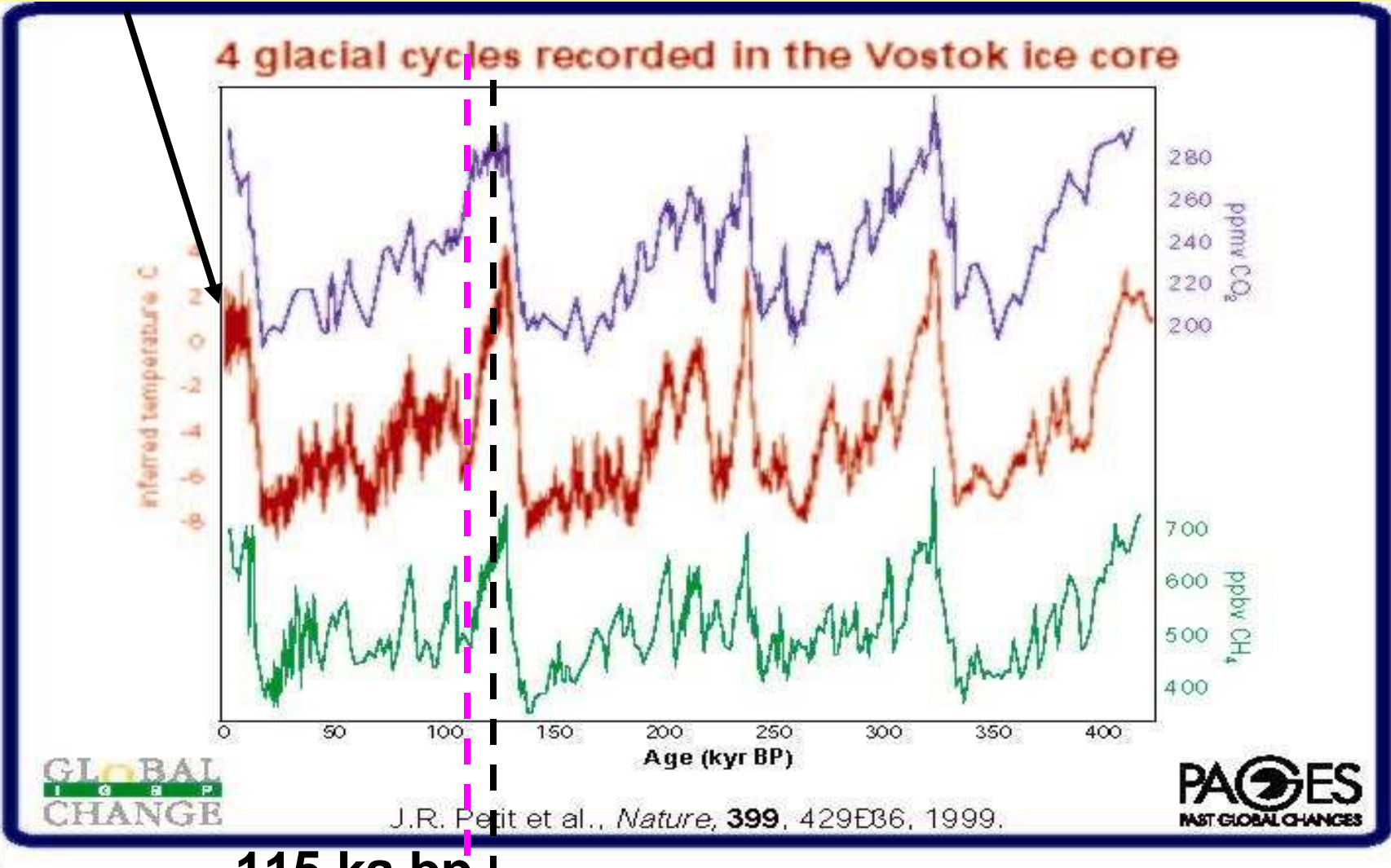
Orbital forcing

Simulations of 125 ky BP and 115 ky BP (Eem and its end)

known: orbital parameter

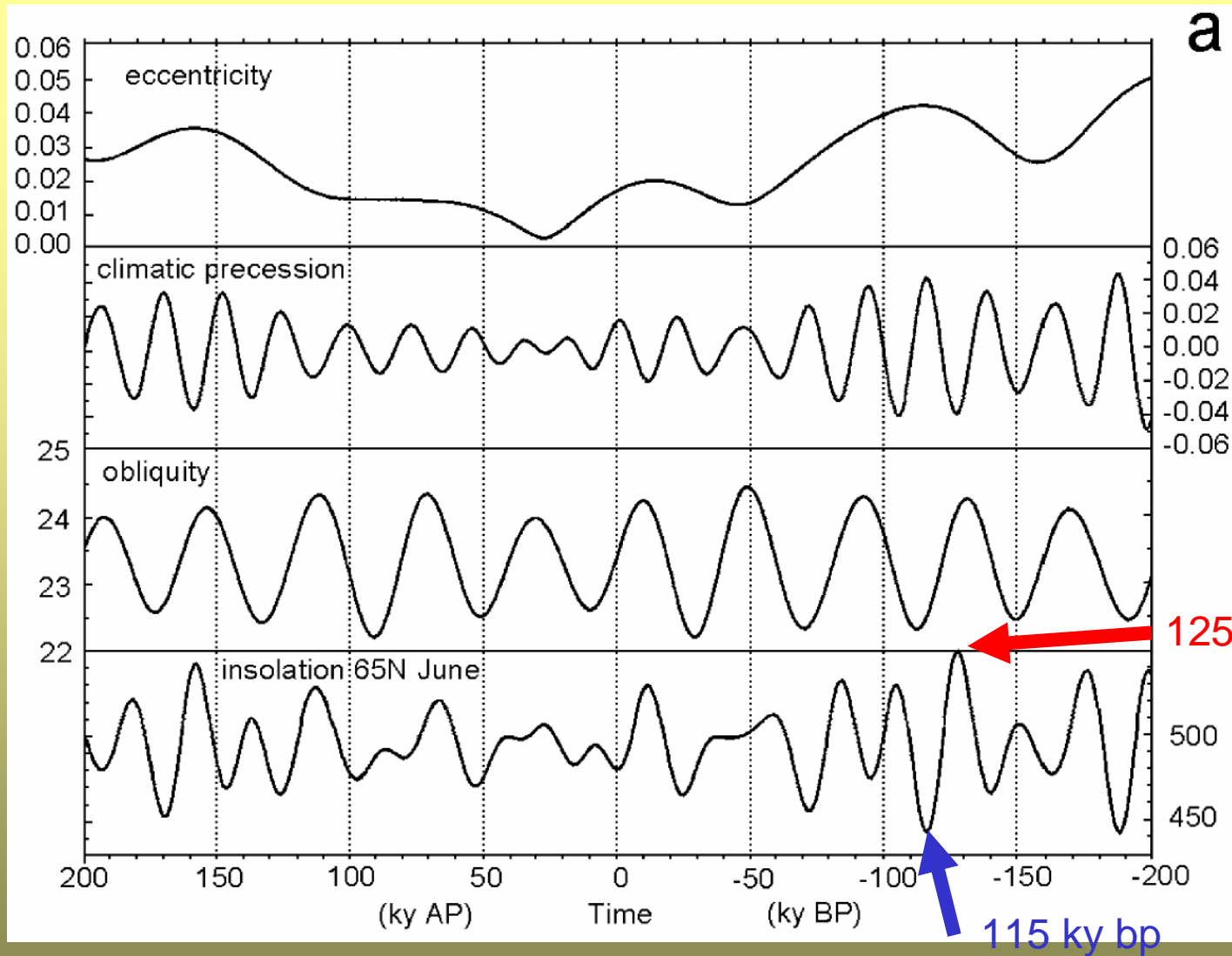
known: greenhouse gas
concentration

You are here



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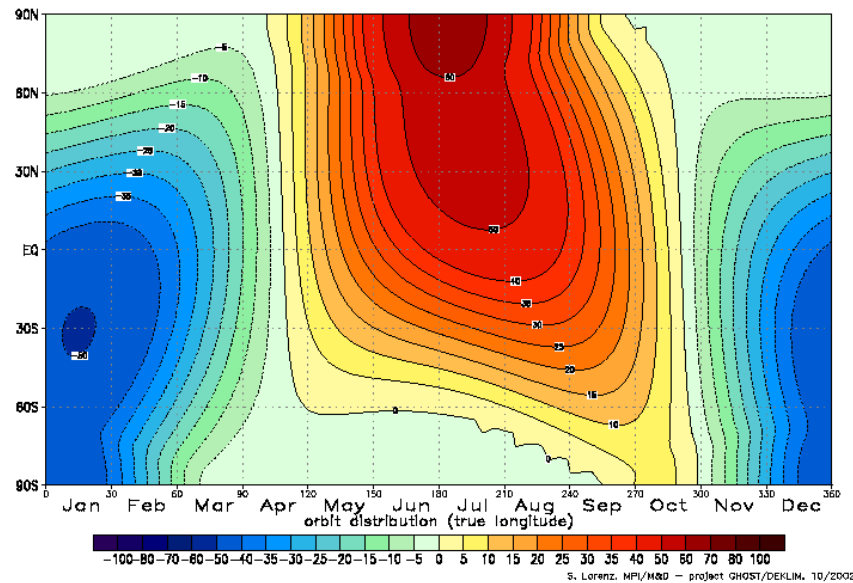
115 ka bp |
125 ka bp



Periodicity of the orbital parameter

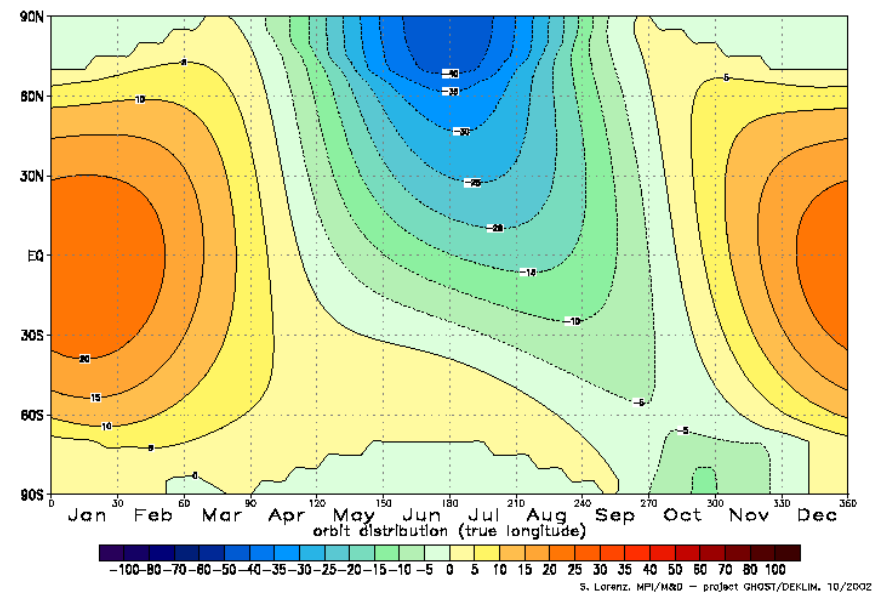
125 ky BP

Insolation (Berger 1978): latitude/orbit distribution [Wm^{-2}]
time = 125 ky BP (anomaly from today)



115 ky BP

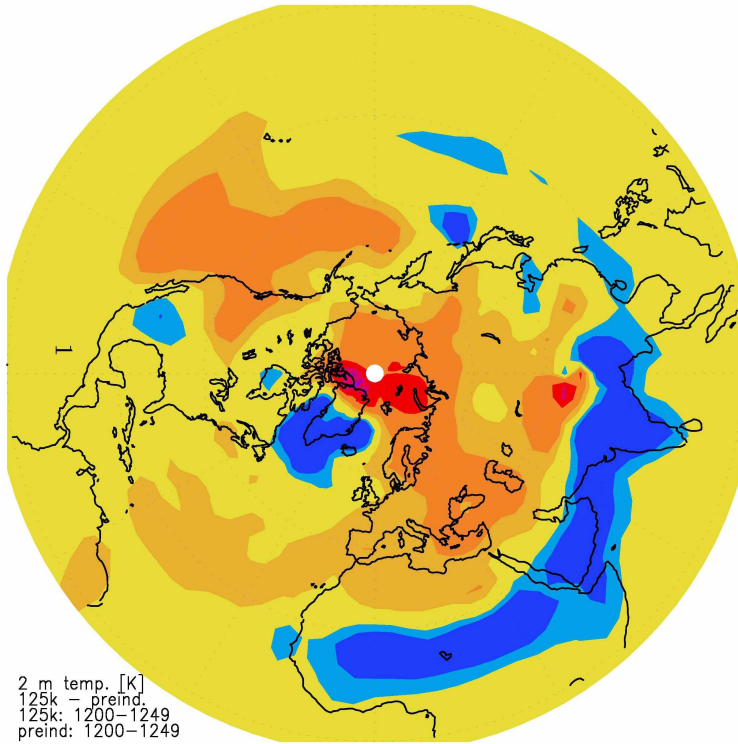
Insolation (Berger 1978): latitude/orbit distribution [Wm^{-2}]
time = 115 ky BP (anomaly from today)



The radiation anomaly compared to present day

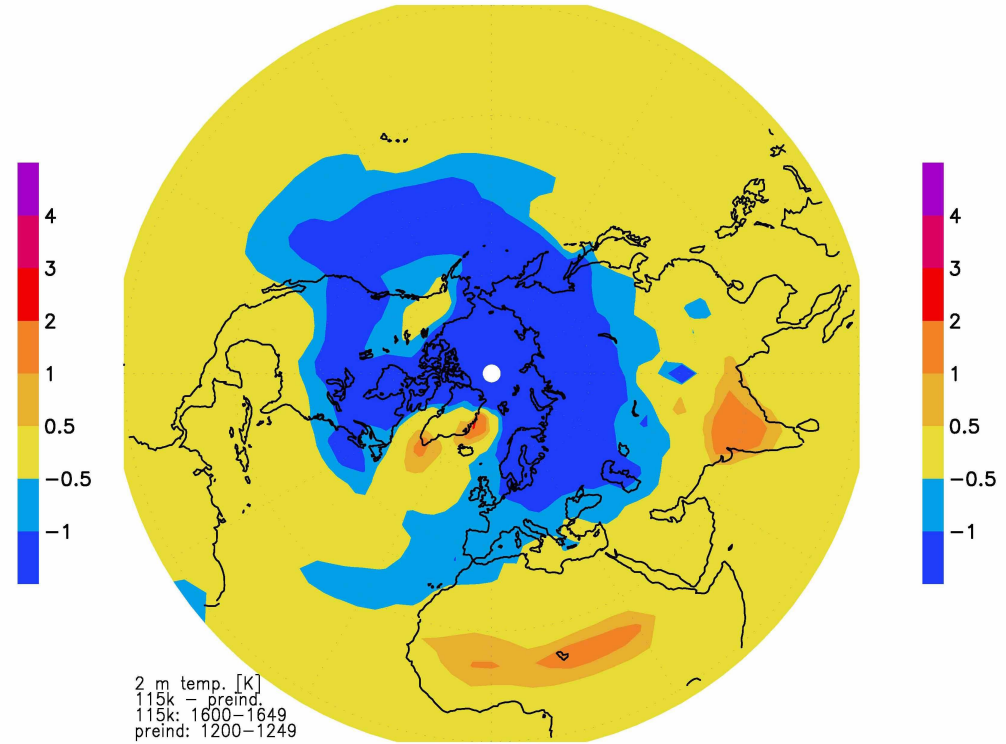
125 ka bp

2m temperature (Eemian – preind. [K])



115 ka bp

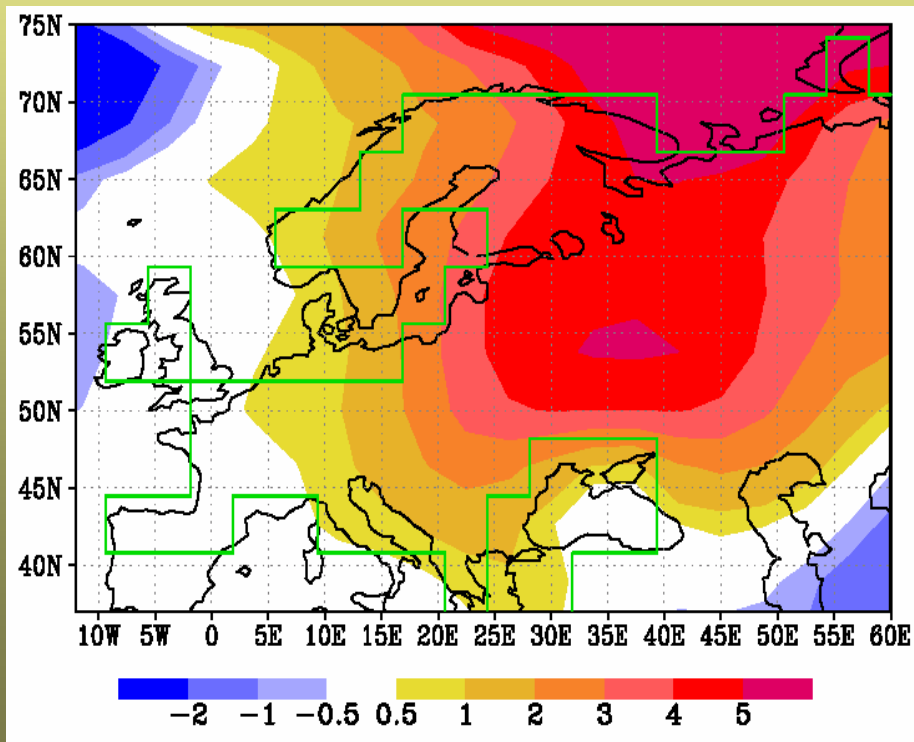
2m temperature (115k – preind. [K])



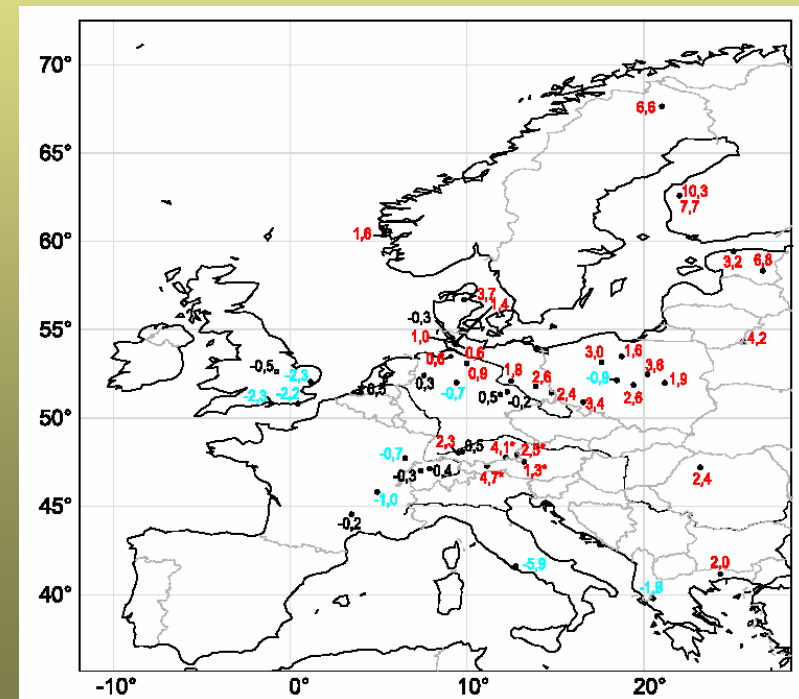
The near-surface temperature

January temperatures of the early Eemian (Corylus-phase) (difference to observed present-day values)

modelled

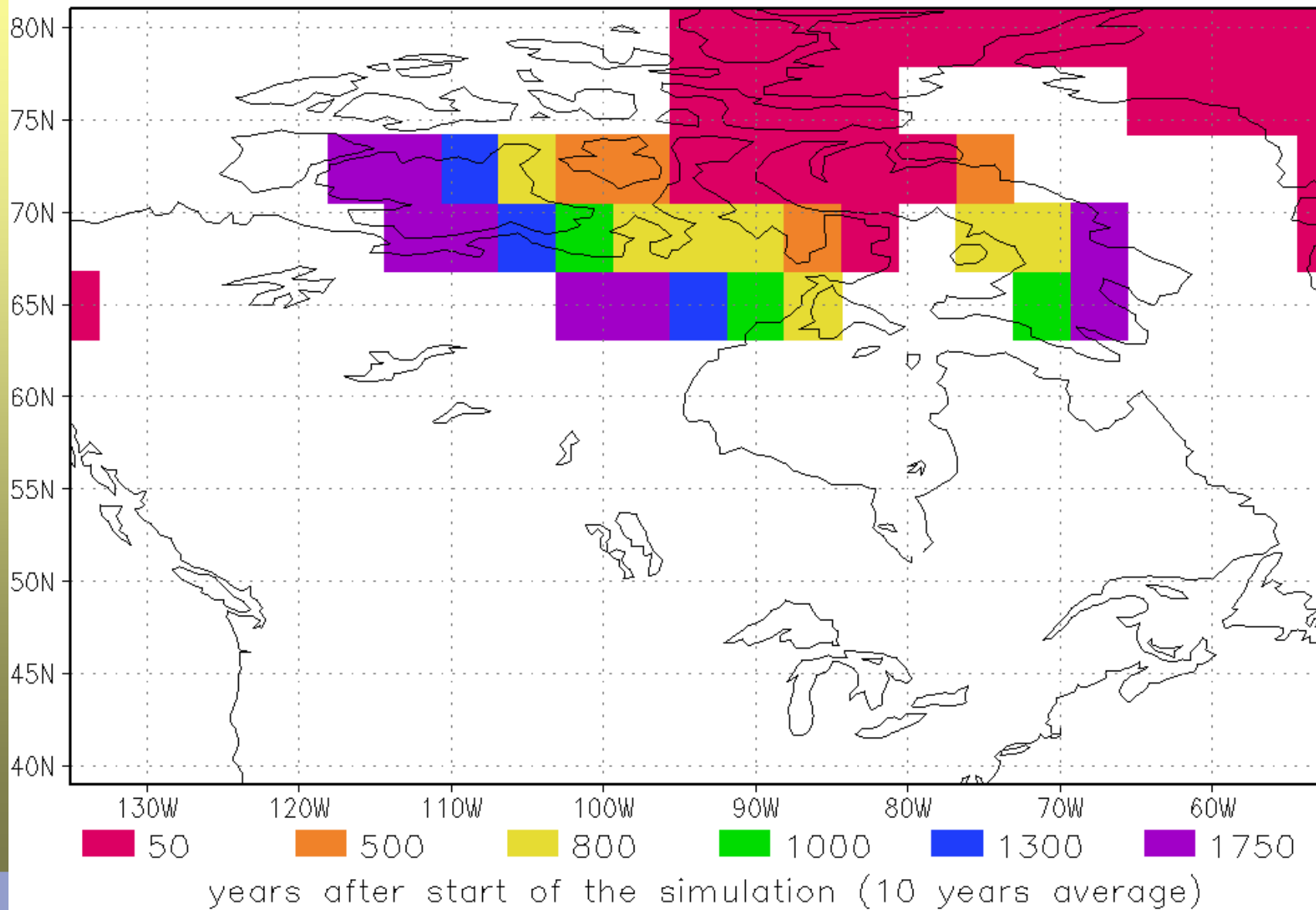


reconstructed

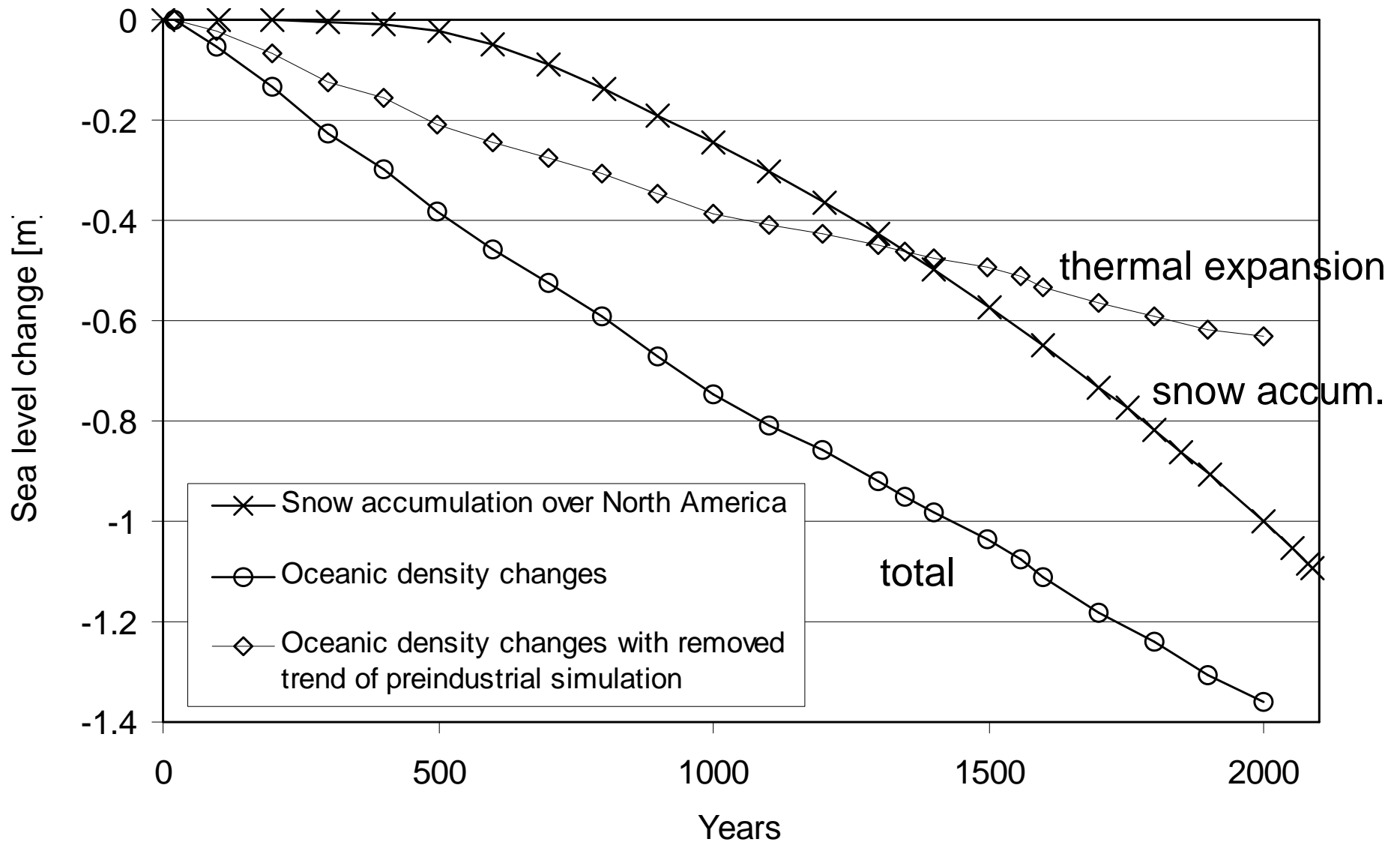


Transition to the cold phase

Permanently snow-covered areas in the simulation for 115 kyr BP



Sea level changes

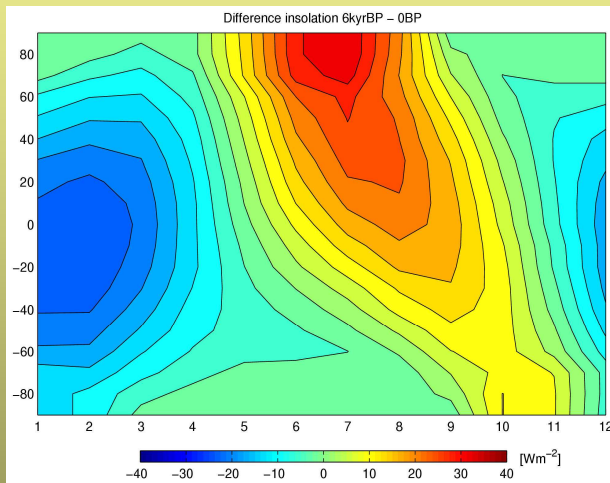


Simulations for the Holocene climate optimum

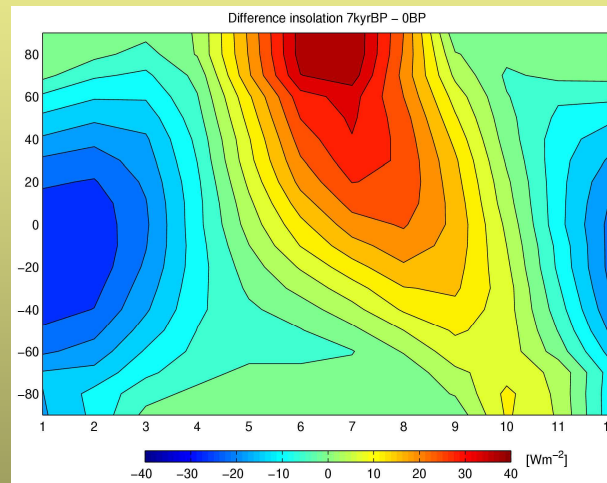
Forcings

Orbital Forcing (Berger, 1978)

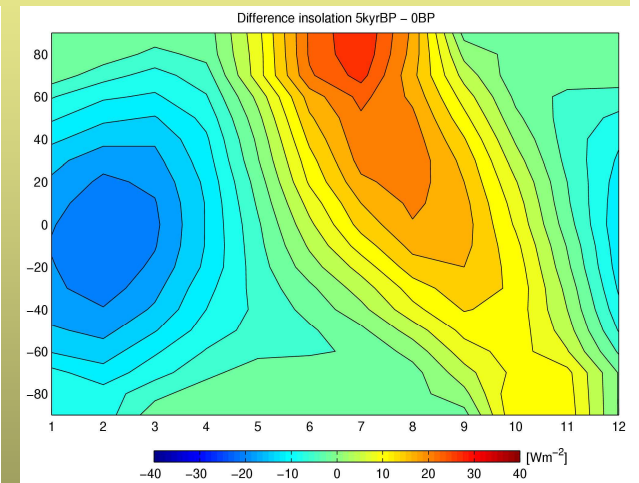
7 ka BP-present



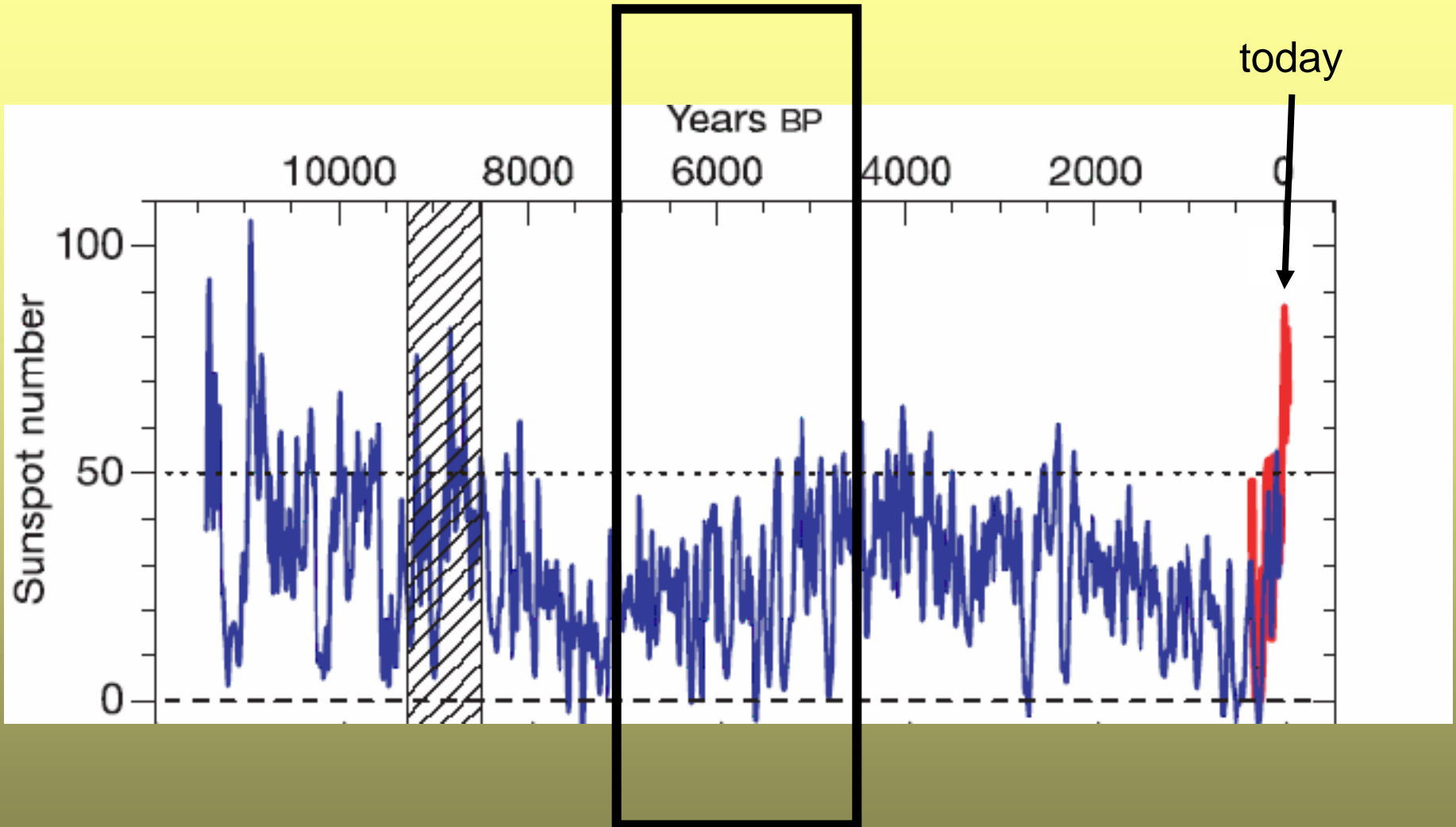
6 ka BP-present



5 ka BP-present



Selected time interval



Solar forcing: based on ^{14}C production rate (Solanki et al., 2004)

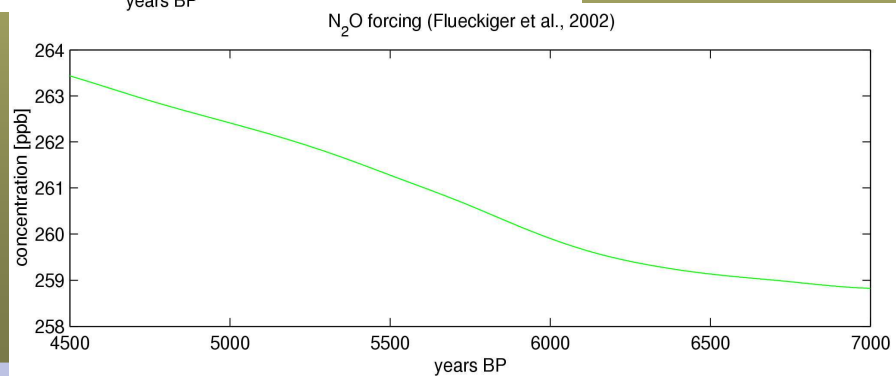
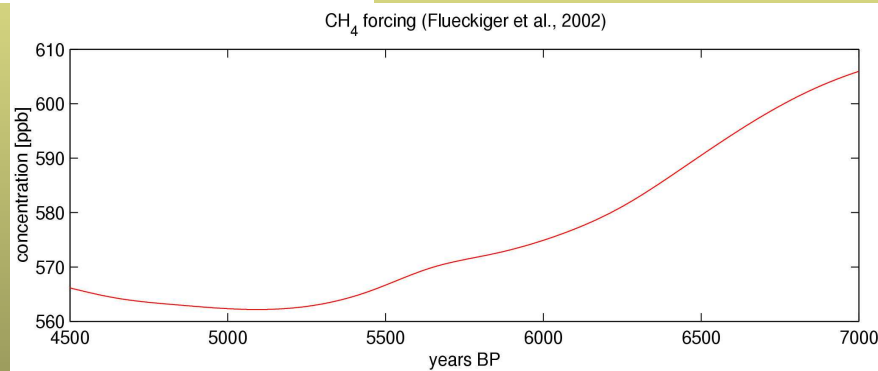
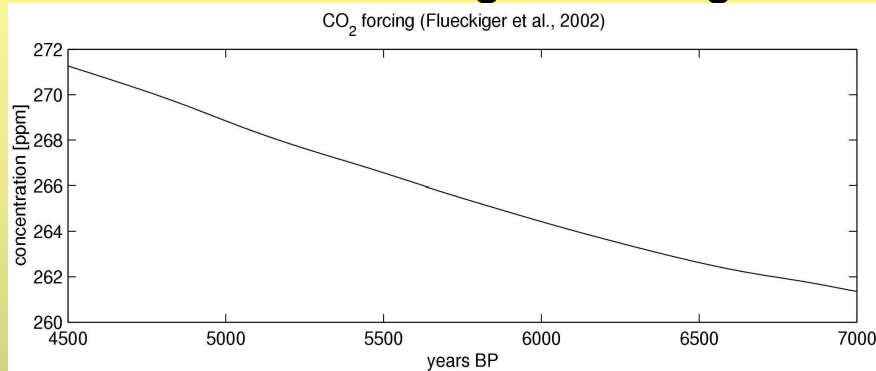
Scaling corresponds to 0.30% insolation difference present day- Maunder Minimum

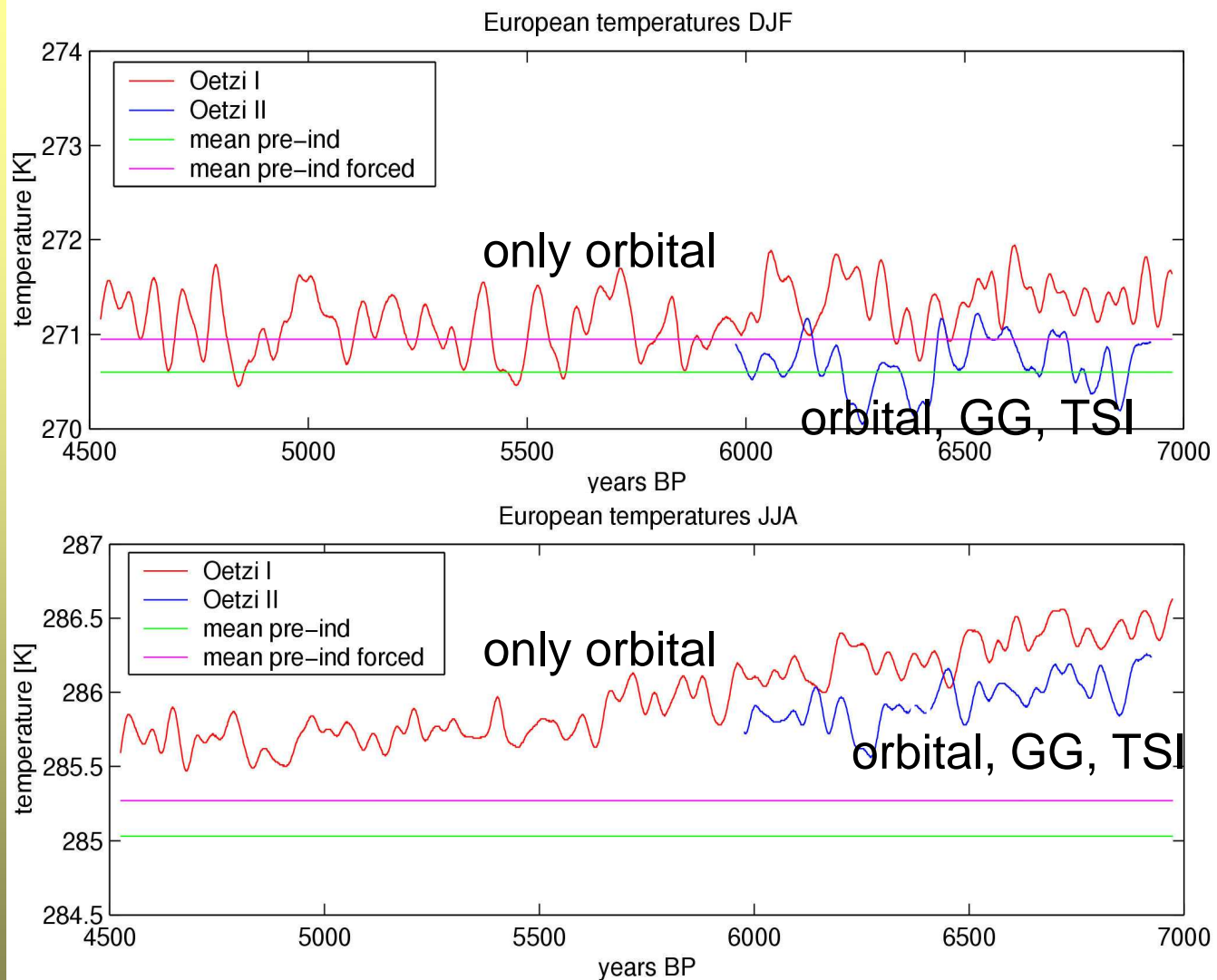
S. Wagner

25

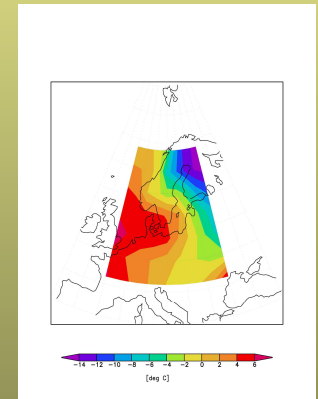
Forcings

Greenhouse gas forcings: Antarctic ice cores (Flueckiger et al., 2002)





„Europe“:
0 - 30°E
45°N - 70°N

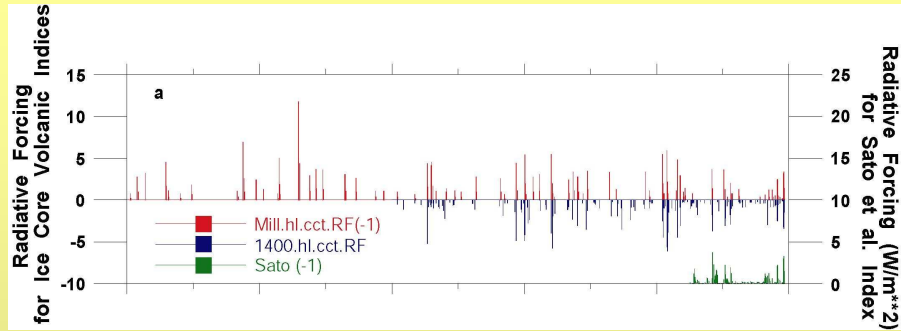


European temperatures

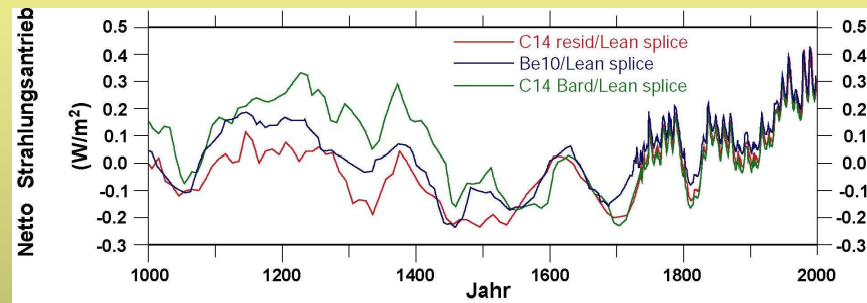
Direct influence

How was the climate variability
before industrialization?

Volcanisms

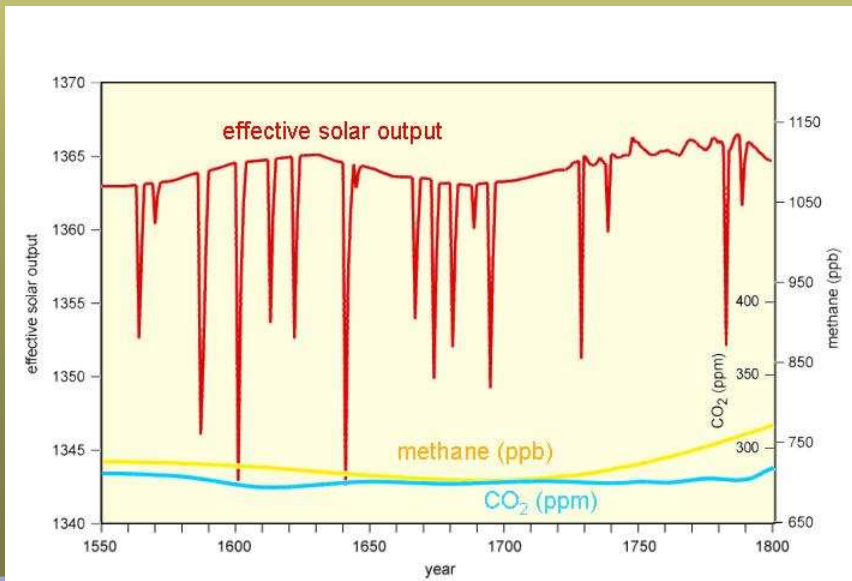


solar radiation



+

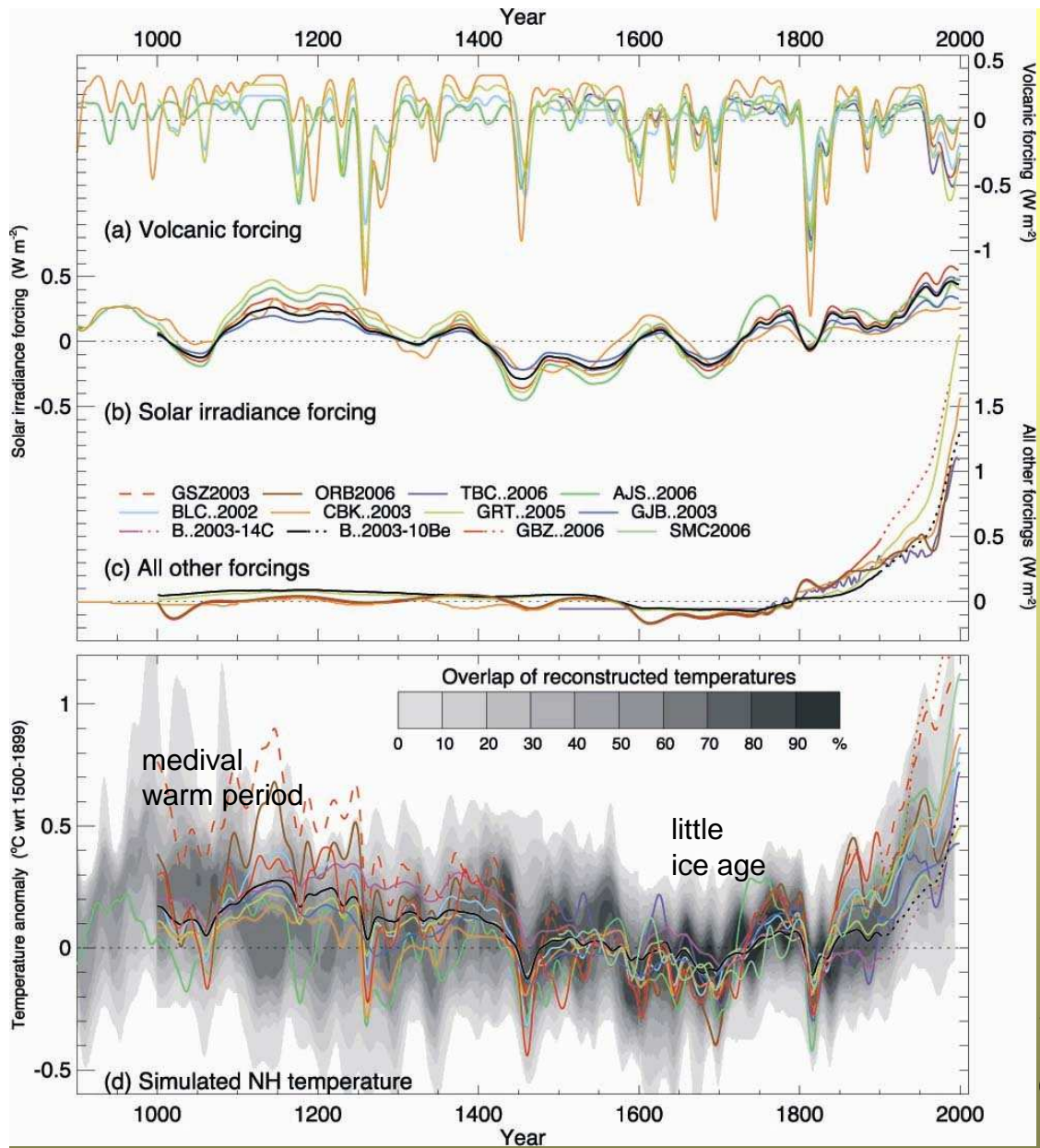
=



Forcing

solar variability

- 11-year cycle (Schwalbe-cycle):
ca. 0.1 % ~ 0.24 W/m² at the surface
- 80-year cycle (Gleissberg-cycle): ca.
0.24 - 0.3 % 0.5-0.75 W/m² at the
surface
- many more.....?



Volcanism

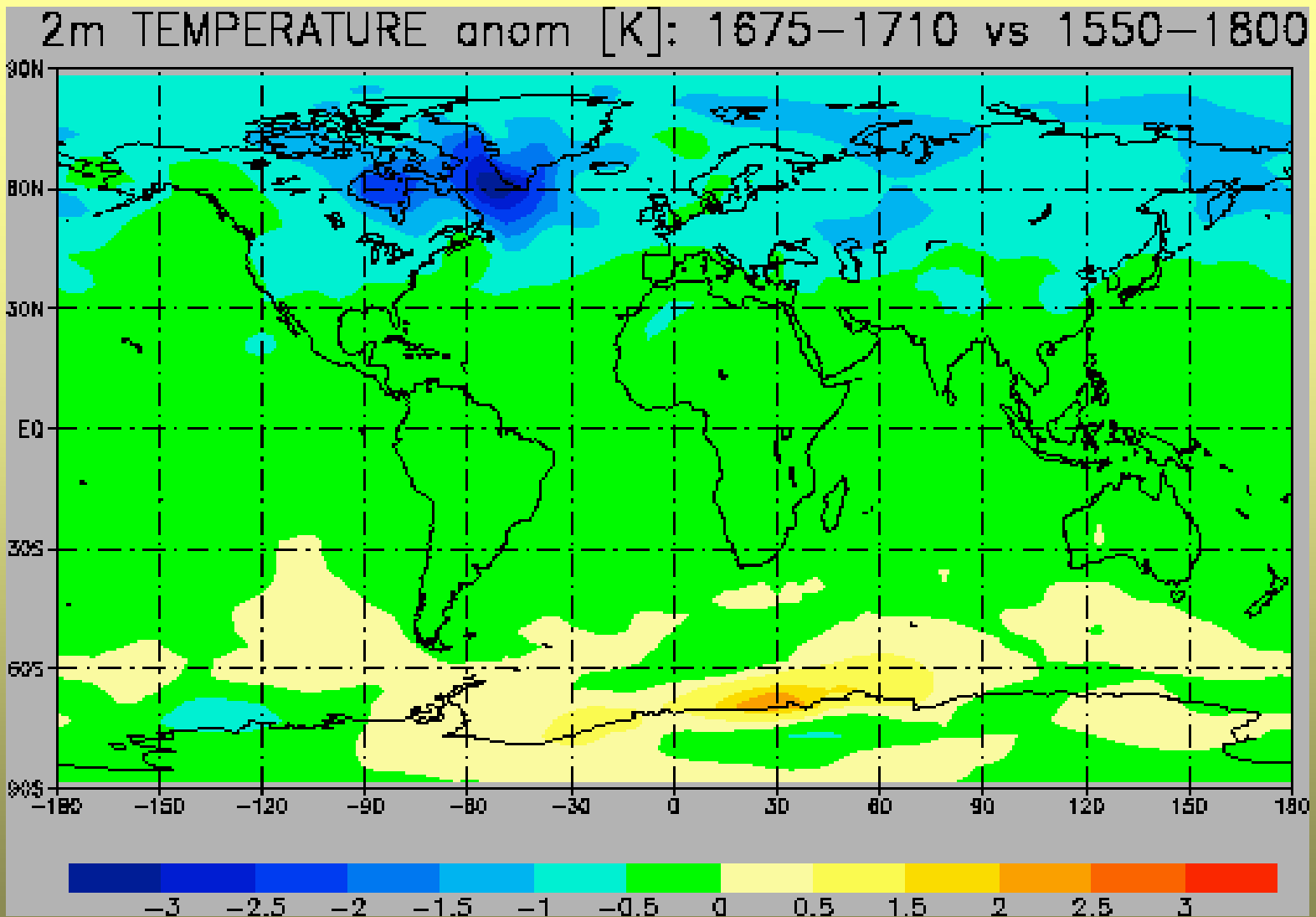
Solar variability

Greenhouse Gases

Temperature

Simulations of the climate of the last century

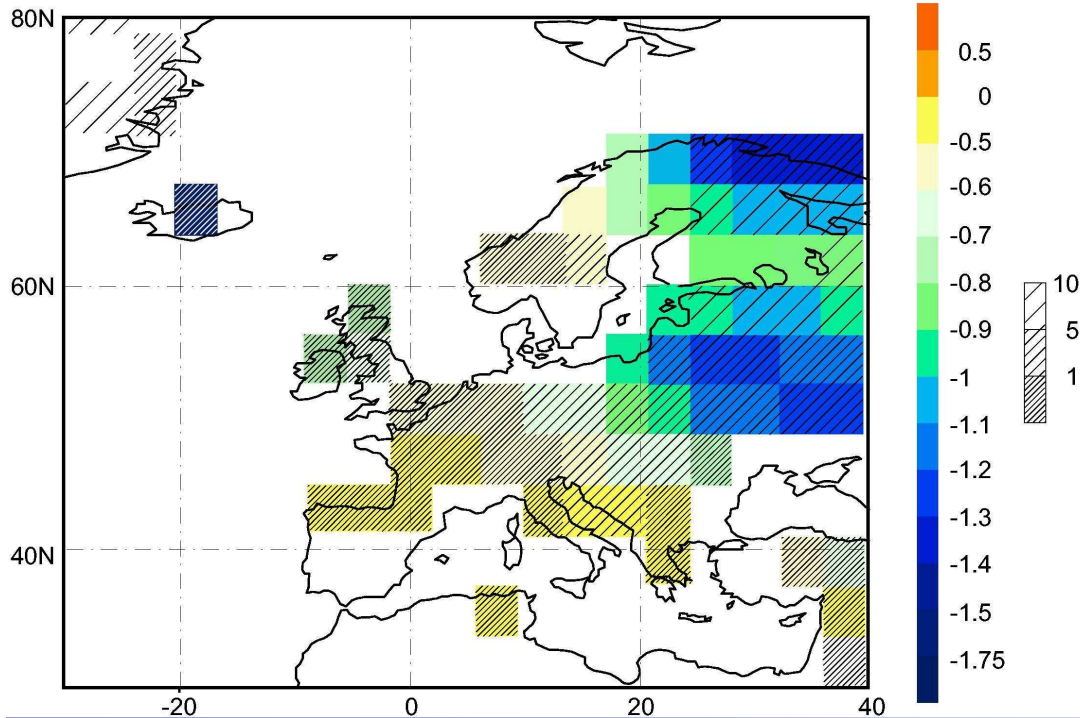
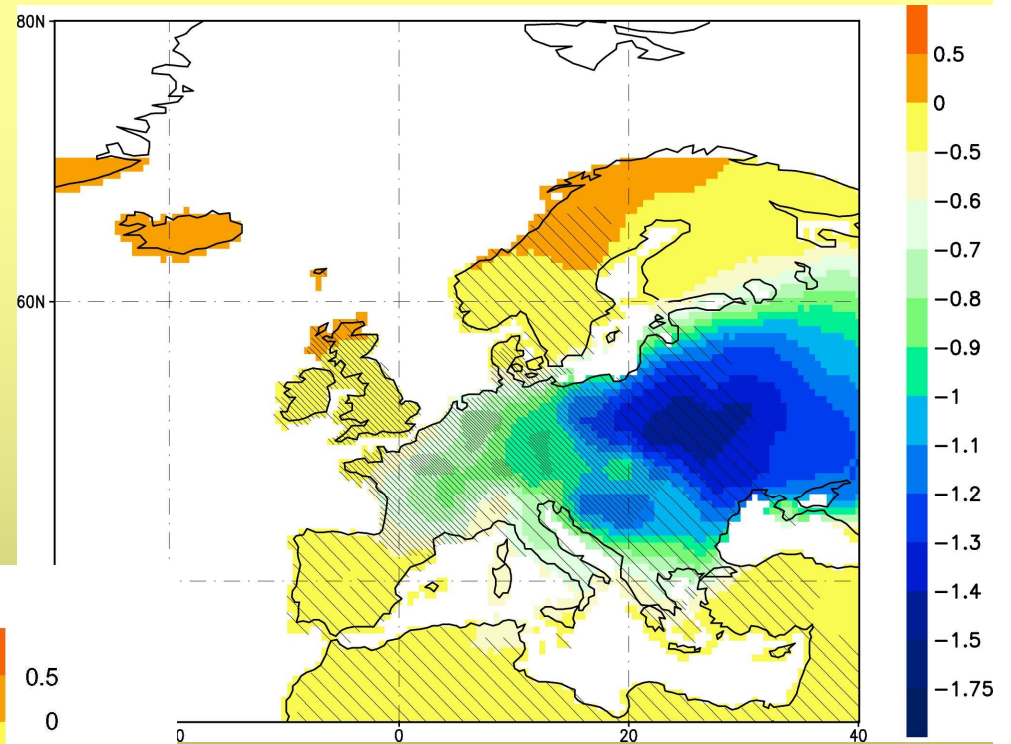
IPCC, 2007



**Simulated near surface-temperature anomaly
1675-1710**

Late Maunder Minimum

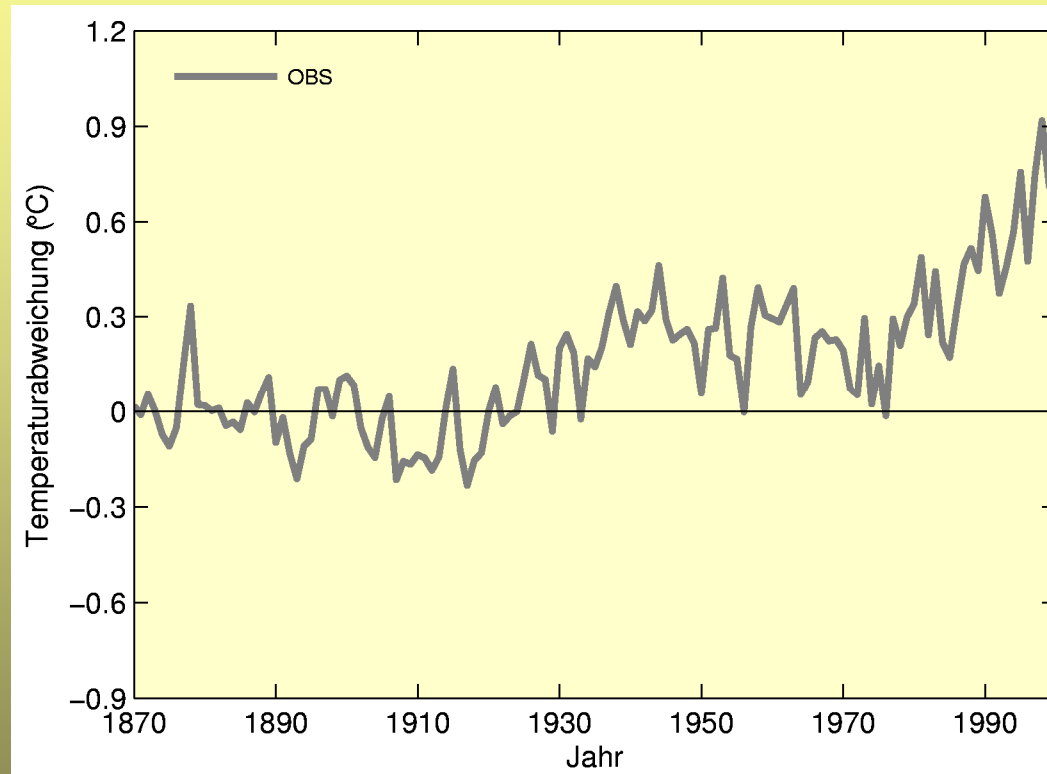
Model-Simulation



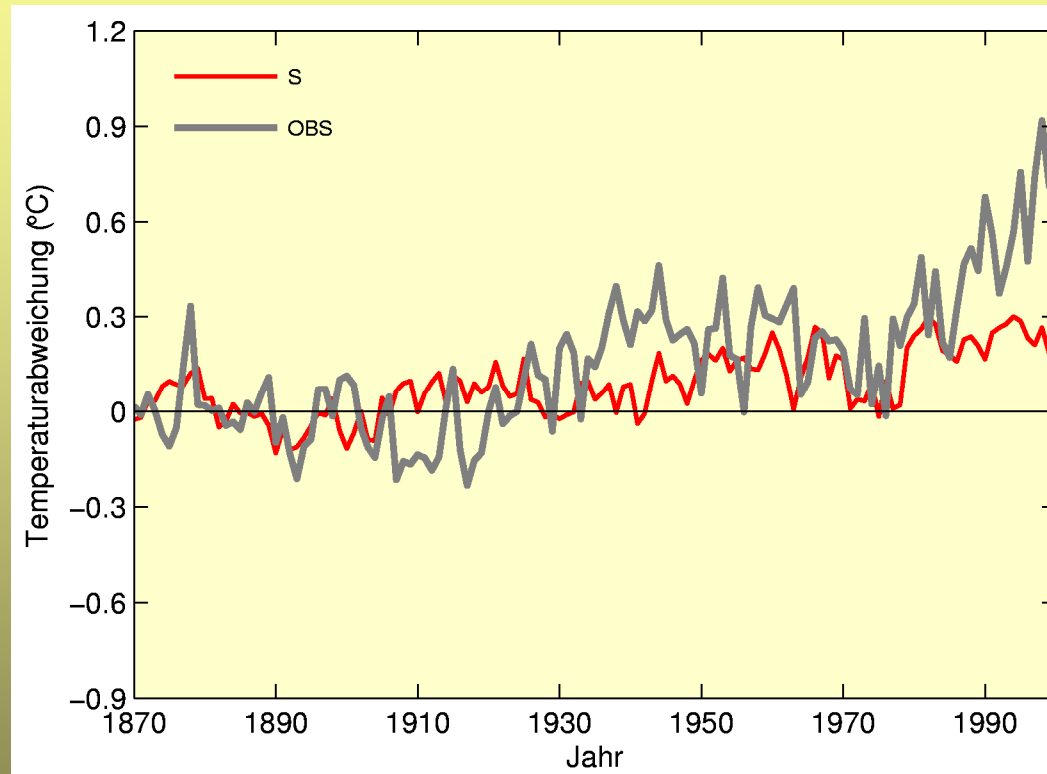
Reconstruction from historical evidence, from Luterbacher et al.

1675-1710
vs. 1550-1800

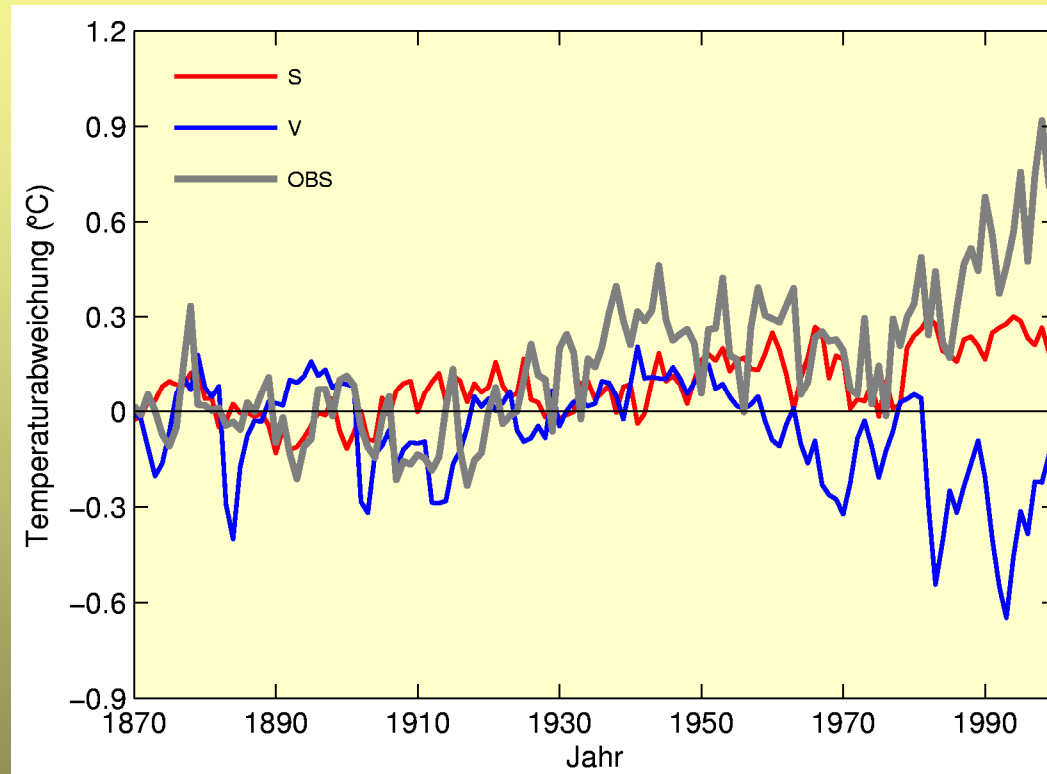
What part of the climate variability is anthropogenic, what part natural?



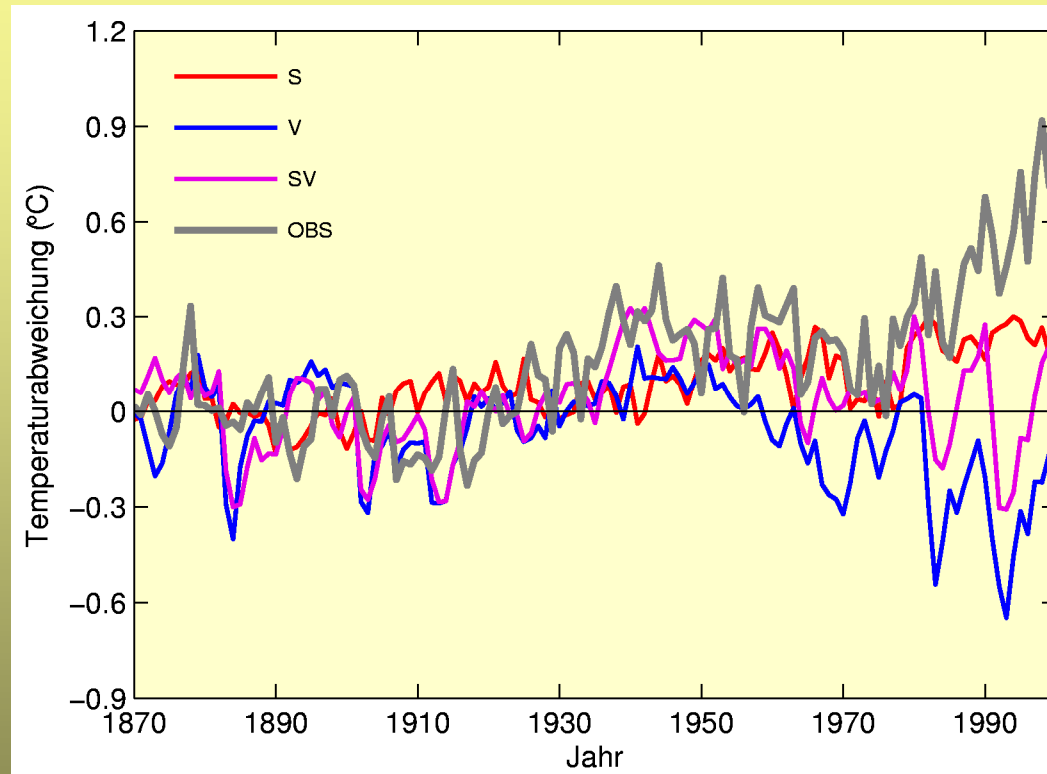
**The observed near-surface temperature change,
averaged over the northern hemisphere**



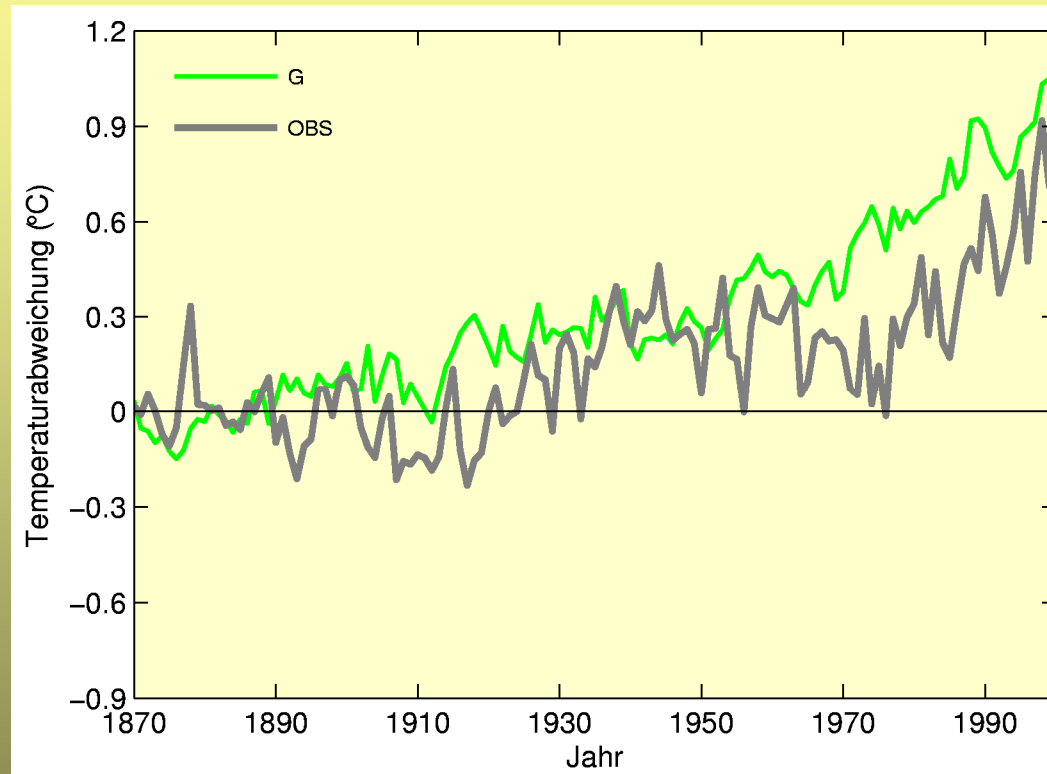
The observed and modelled (solar only) near-surface temperature change, averaged over the northern hemisphere



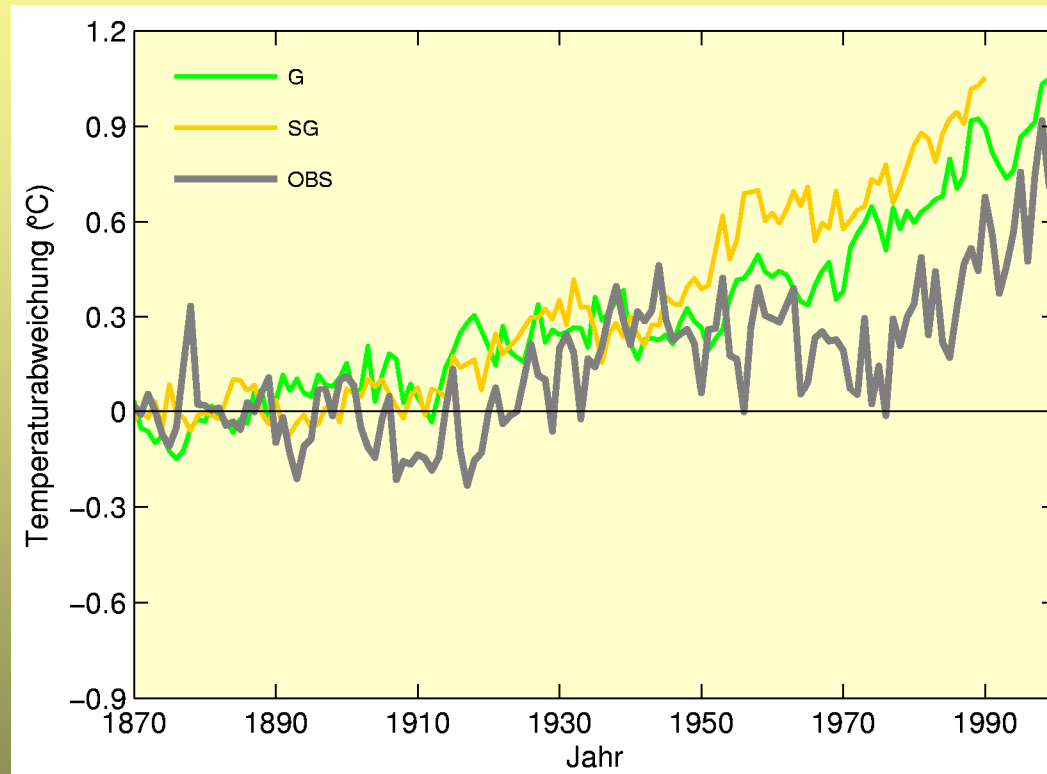
The observed and modelled (solar only, volcanoes only) near-surface temperature change, averaged over the northern hemisphere



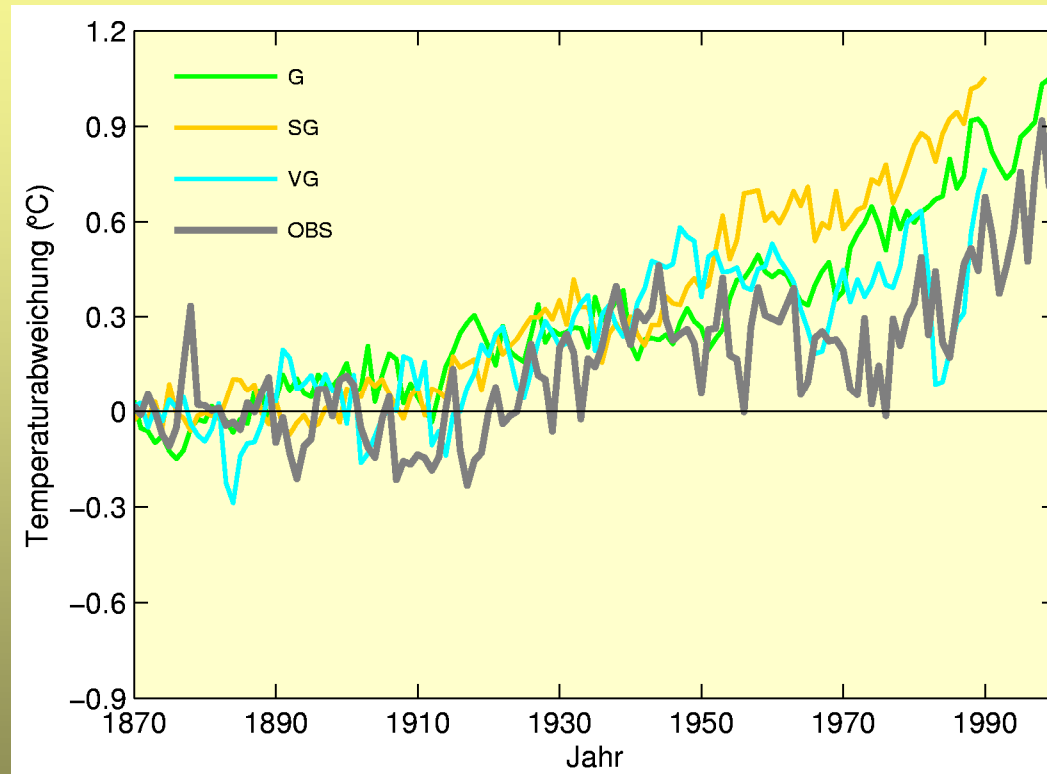
The observed and the modelled (solar, volcanic, solar&volcanic) near-surface temperature change, averaged over the northern hemisphere



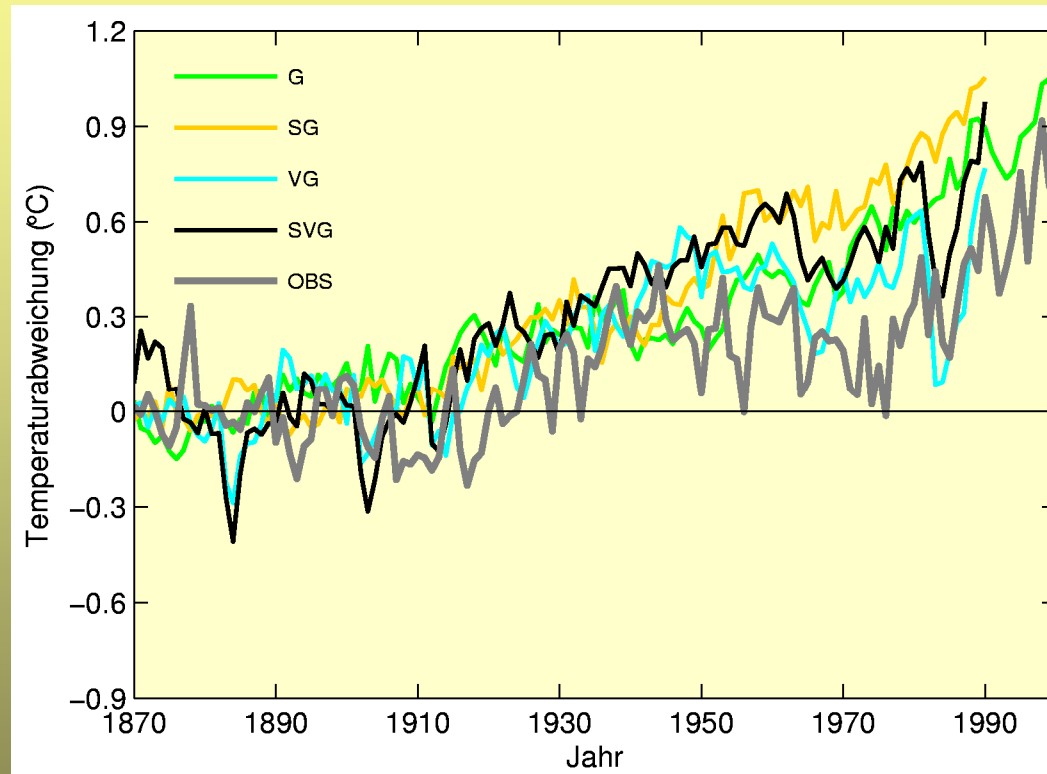
The observed and the modelled (greenhouse gases) near-surface temperature change, averaged over the northern hemisphere



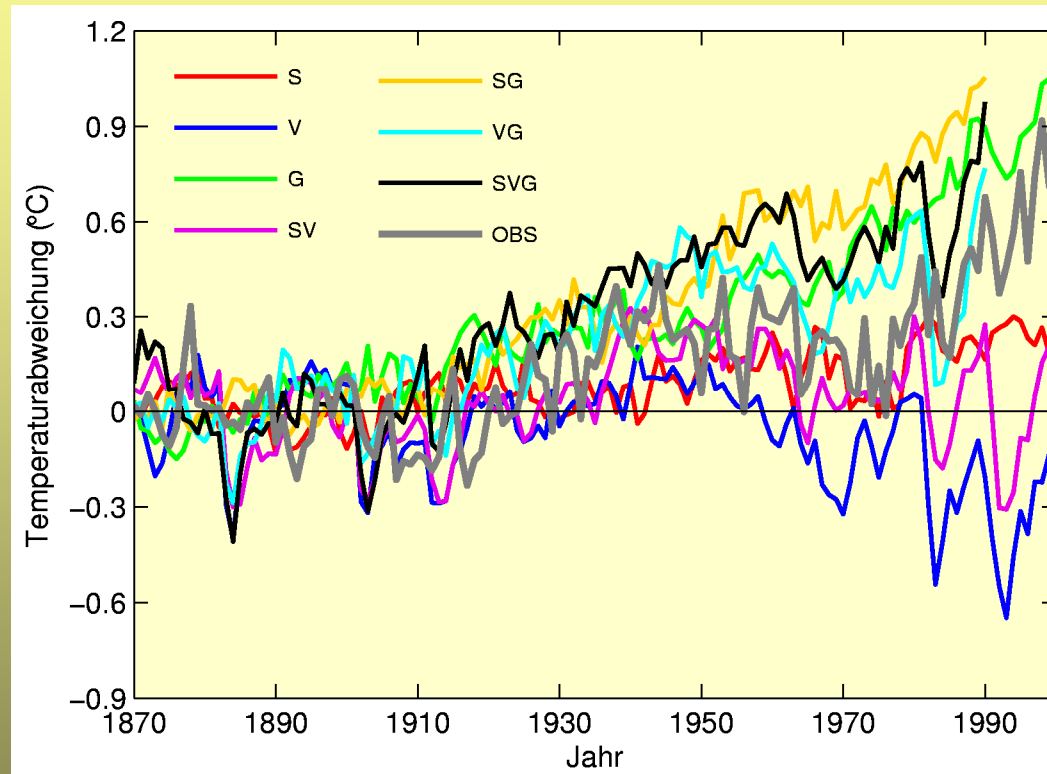
The observed and the modelled (greenhouse gases&solar) near-surface temperature change, averaged over the northern hemisphere



The observed and the modelled (greenhouse gases&volcanoes) near-surface temperature change, averaged over the northern hemisphere

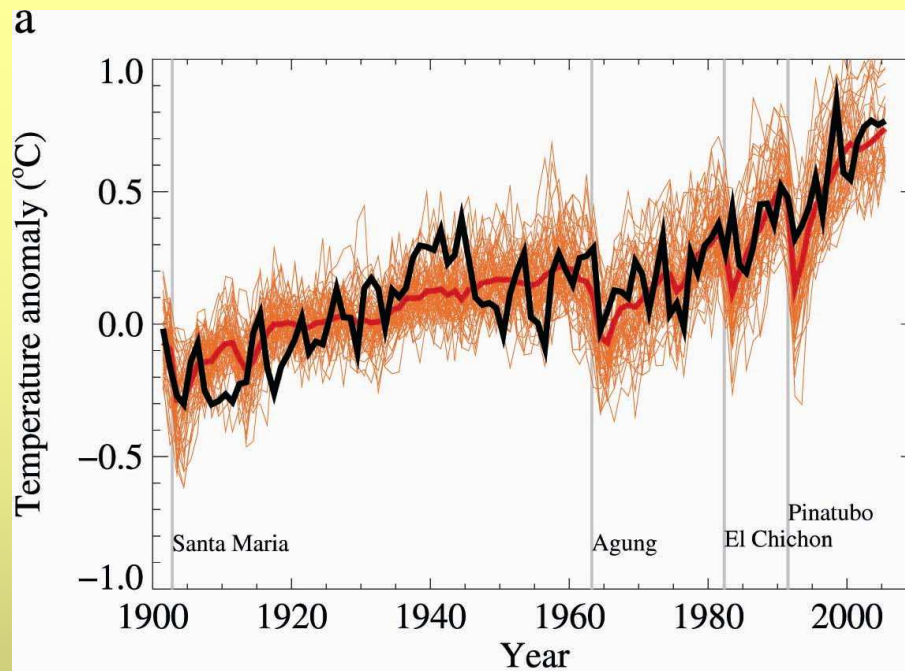


The observed and the modelled (greenhouse gases in connection with solar, volcanic, solar&volcanic) near-surface temperature change, averaged over the northern hemisphere

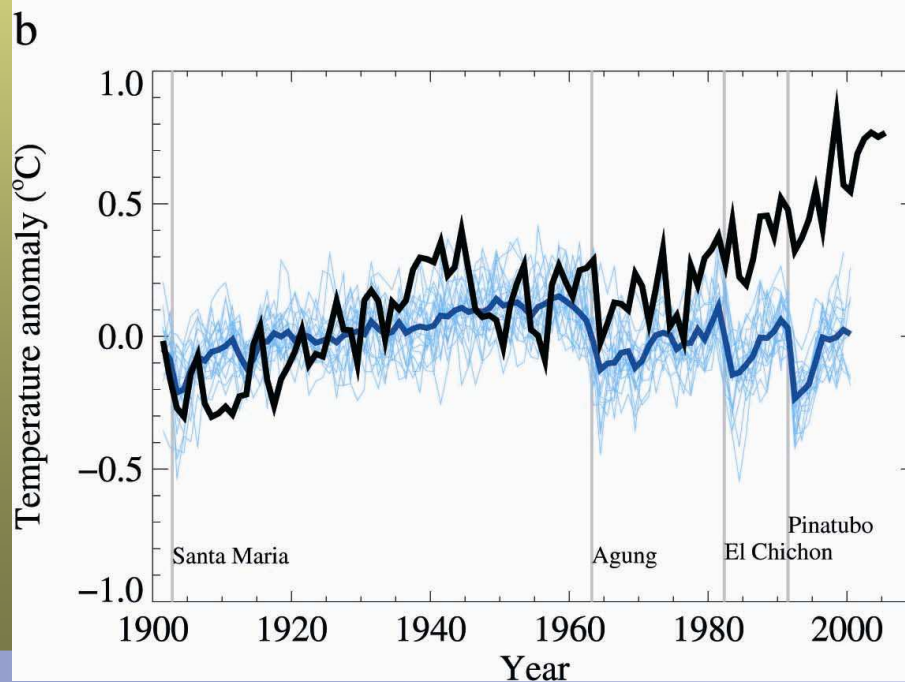


observations

The observed and the modelled (greenhouse gases, dto. in connection with solar, volcanic, solar&volcanic) near-surface temperature change , averaged over the northern hemisphere



natural and anthropogenic forcing



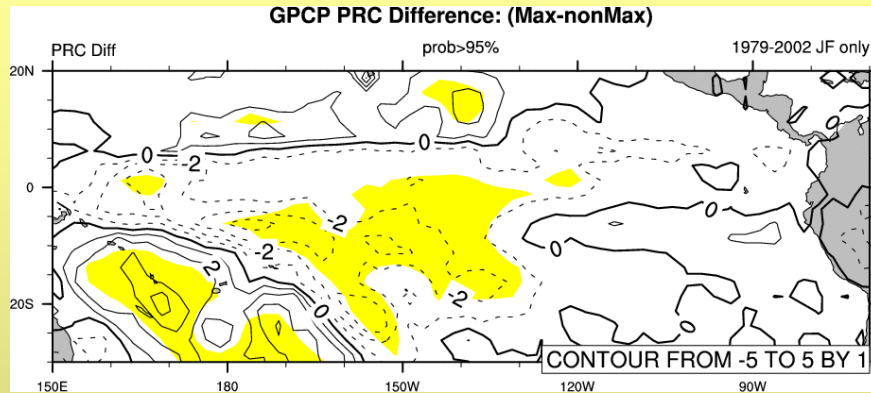
observations

natural forcing

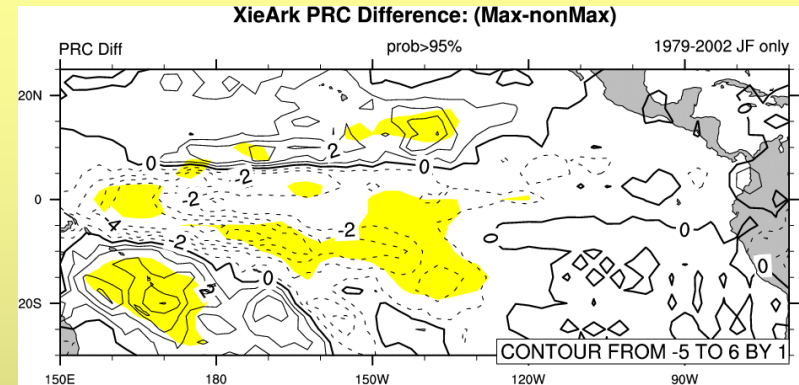
The AR4 modelling results

Can we see the 11-year solar cycle in the troposphere/ocean?

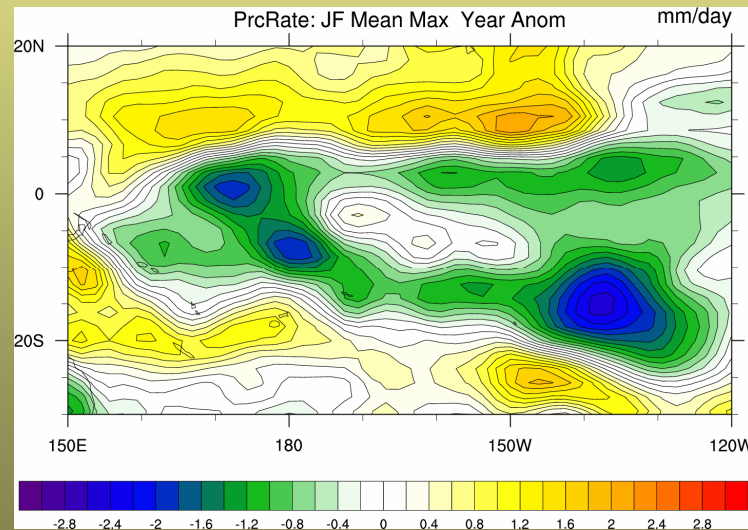
GPRC



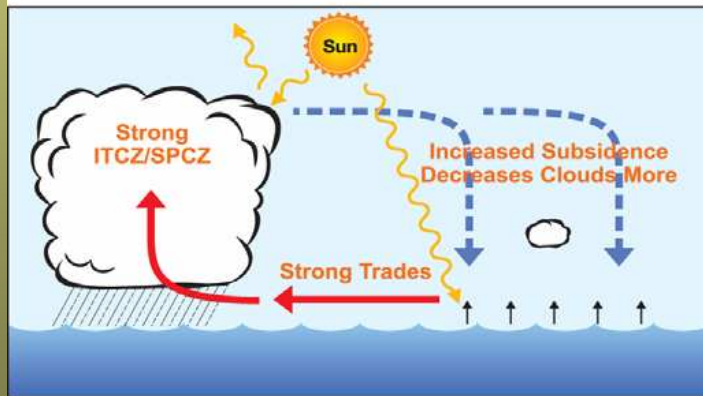
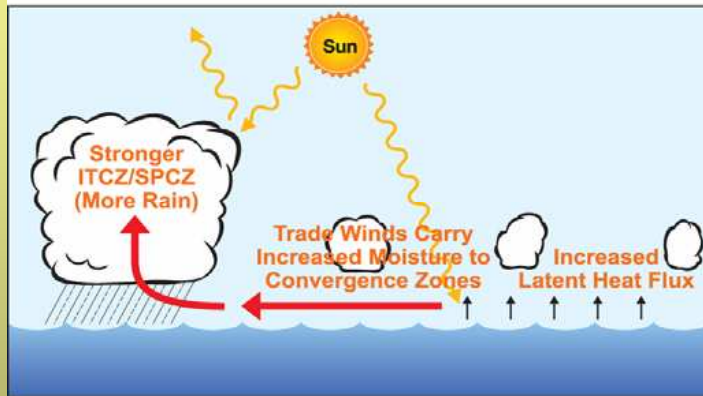
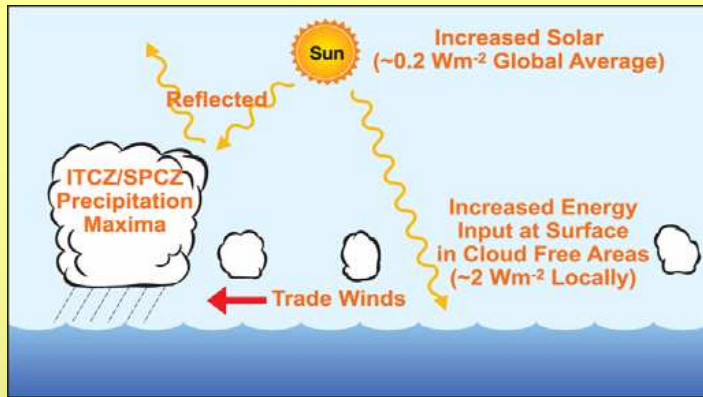
Xie & Arkin



NCEP-reanalysis



The precipitation anomaly in the tropical Pacific during solar maximum

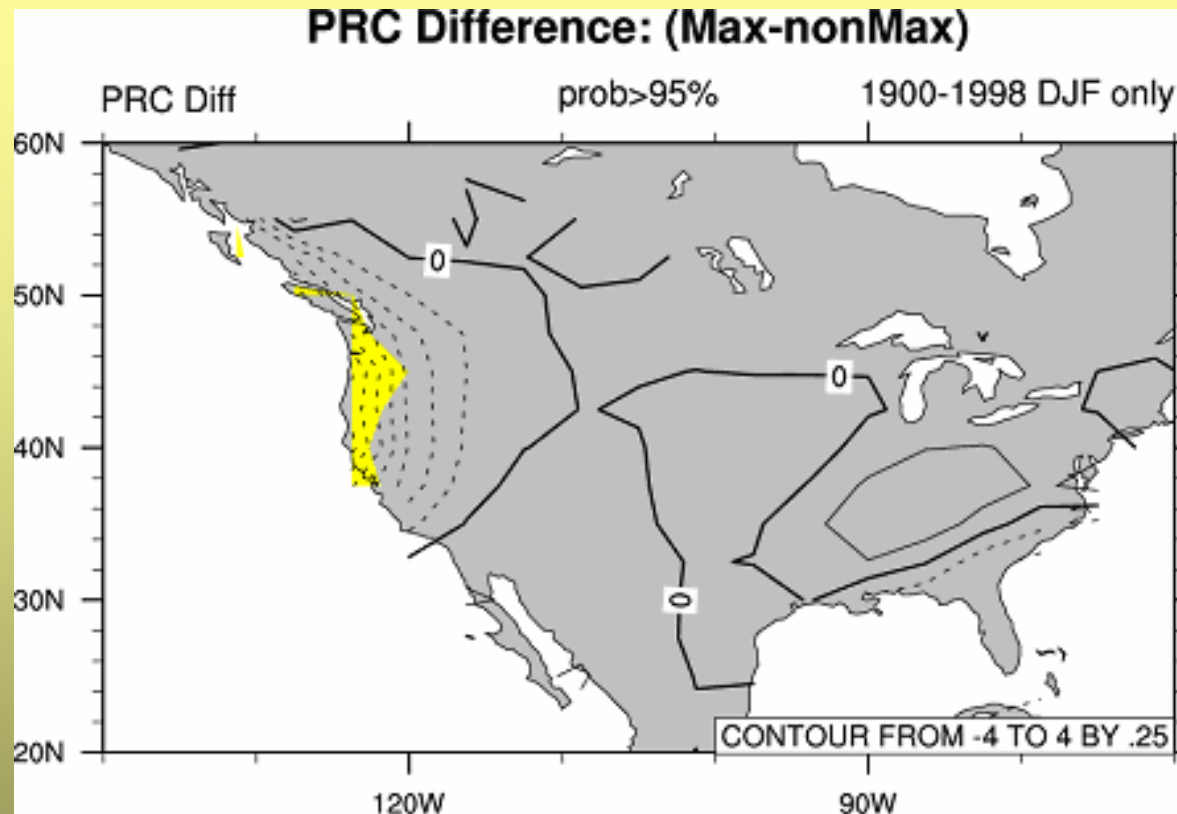


Meehl et al. (in press)

scheme for solar max

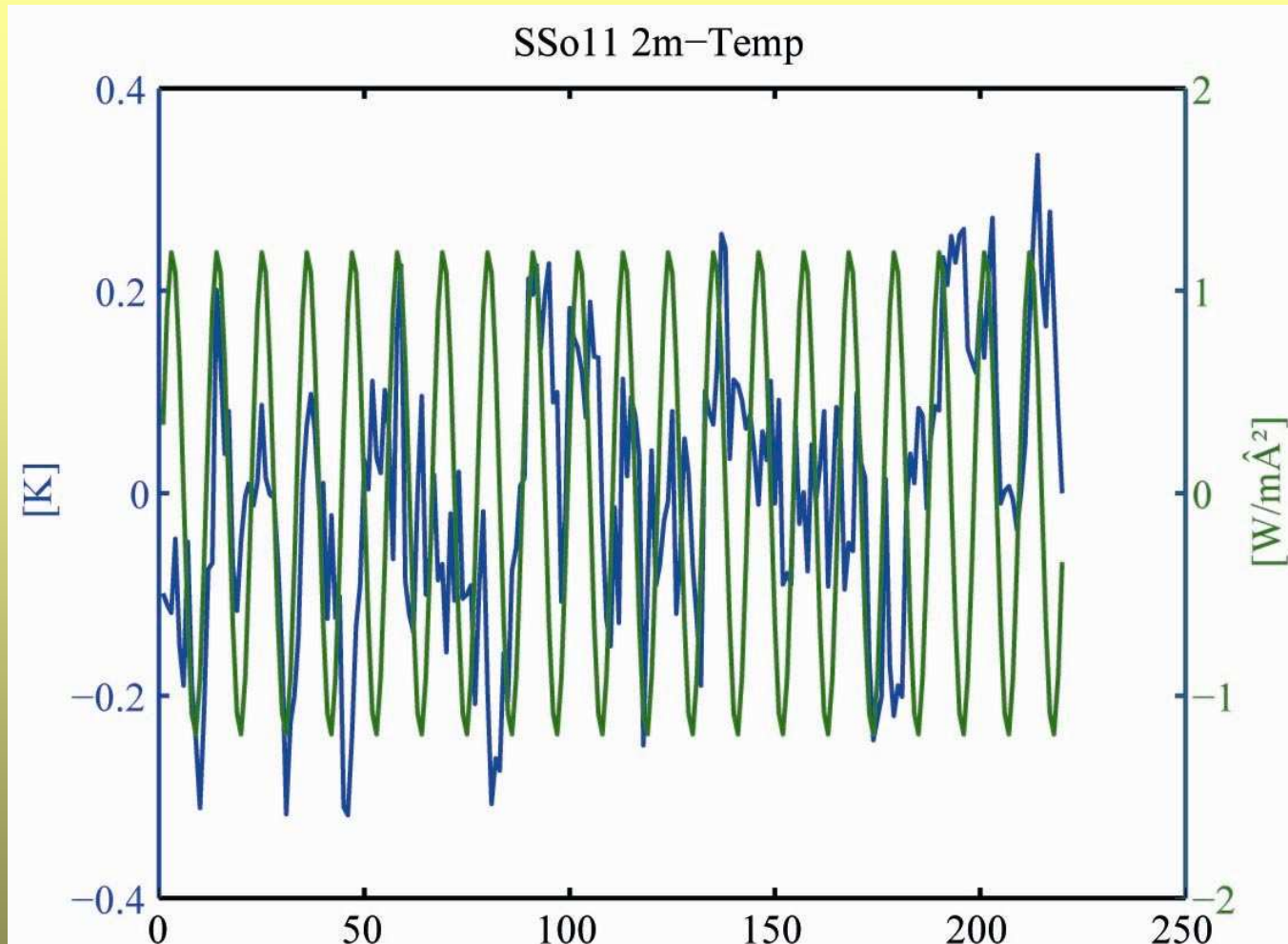
- solar forcing is spatial heterogeneous, strongest in the cloudless subtropics
- increased solar radiation enhances the evaporation in the subtropics
- intensified moisture transport reinforces the main precipitation regimes
- increased subsidence decreases cloud cover in the subtropics
- stronger trade winds enforce upwelling and trigger a La Nina like situation

observed



The precipitation anomaly during solar maximum

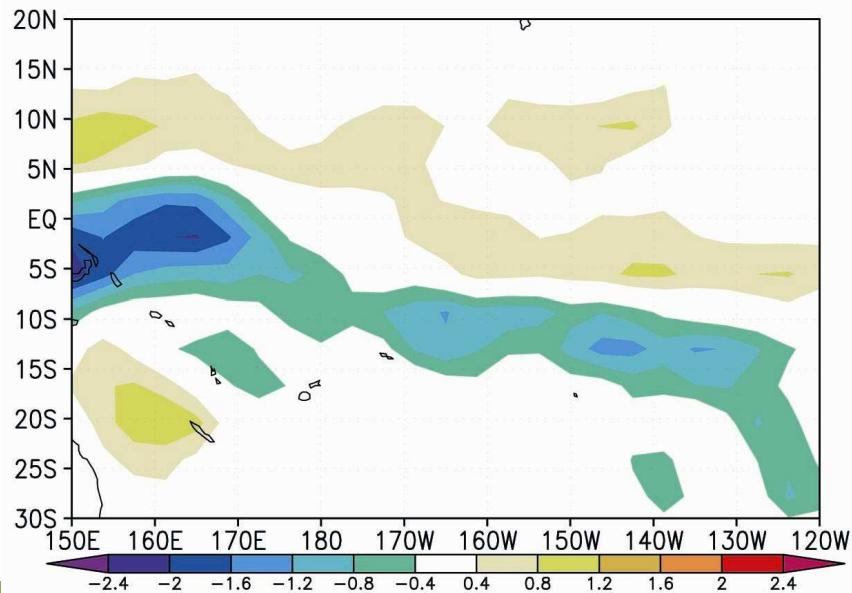
When I know the state of the solar cycle, I can predict ENSO and with it the rain in California for the next 10 years!?but ENSO has no 11-year cycle!



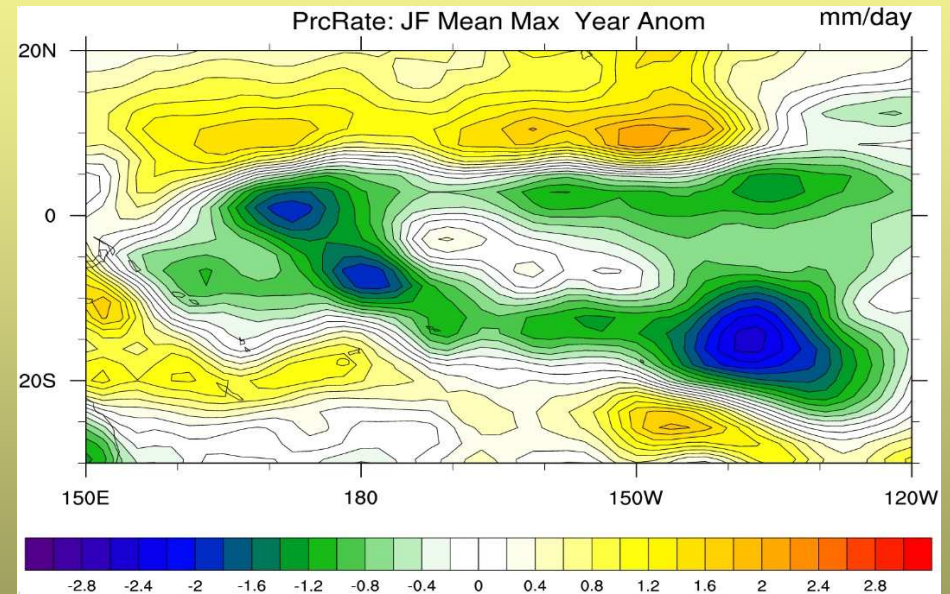
**The idealized forcing and
the response of the near surface temperature**

Precipitation pattern

Modelled: January/February max-min composite of 60 years



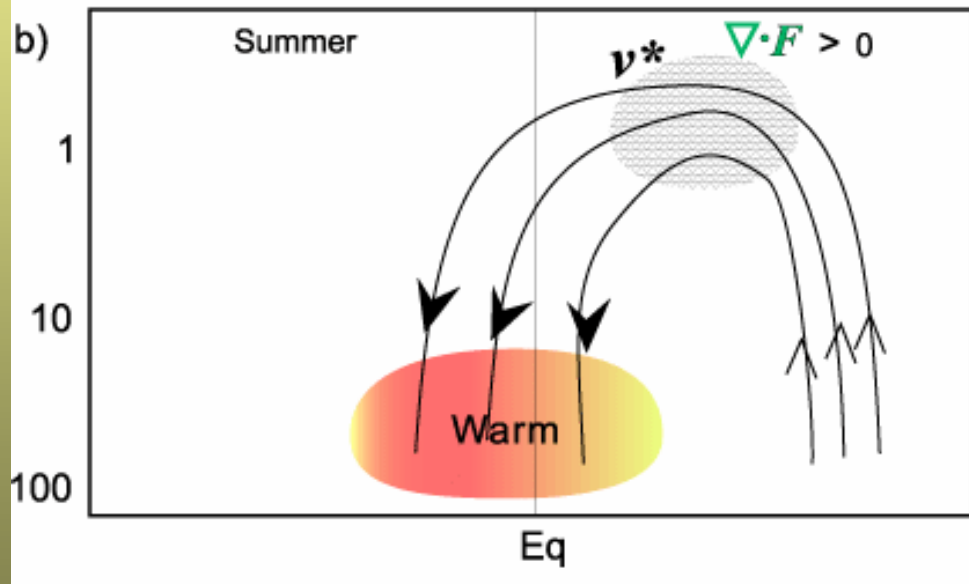
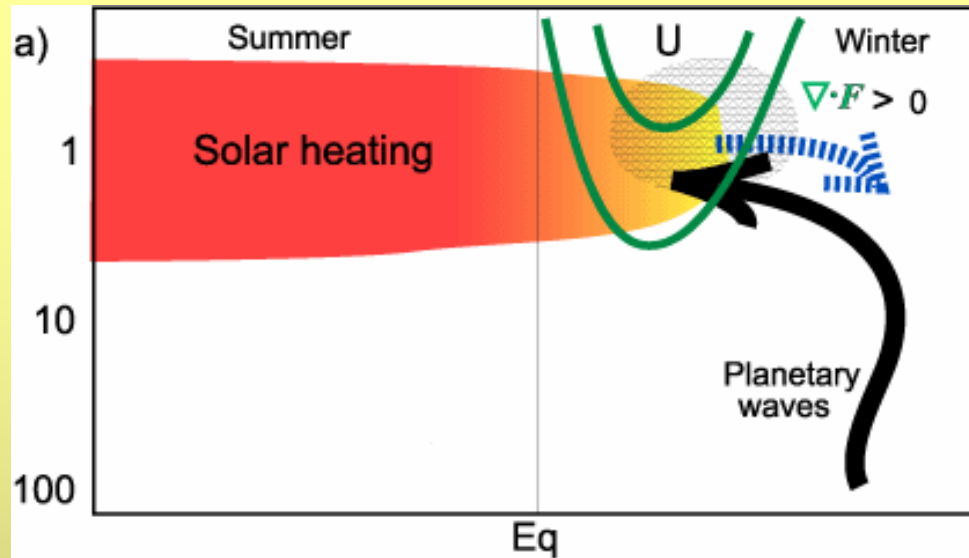
Observed: J/F mean max year anomaly (van Loon et al. 2006)



- precipitation declines along the equator with pos. changes northward and southward during solar maximum

- **The 11-yr signal in Sun's irradiance appears to excite a damped resonant response (i.e. the QDO) in the Earth's climate system. (White + Liu, 2008) with a lag of 3-5 years.**
- **The direct forcing appears to be insufficient to explain the size of the response (Meehl et al, in press), therefore both, the direct and the indirect response have to work together.**

Indirect influence



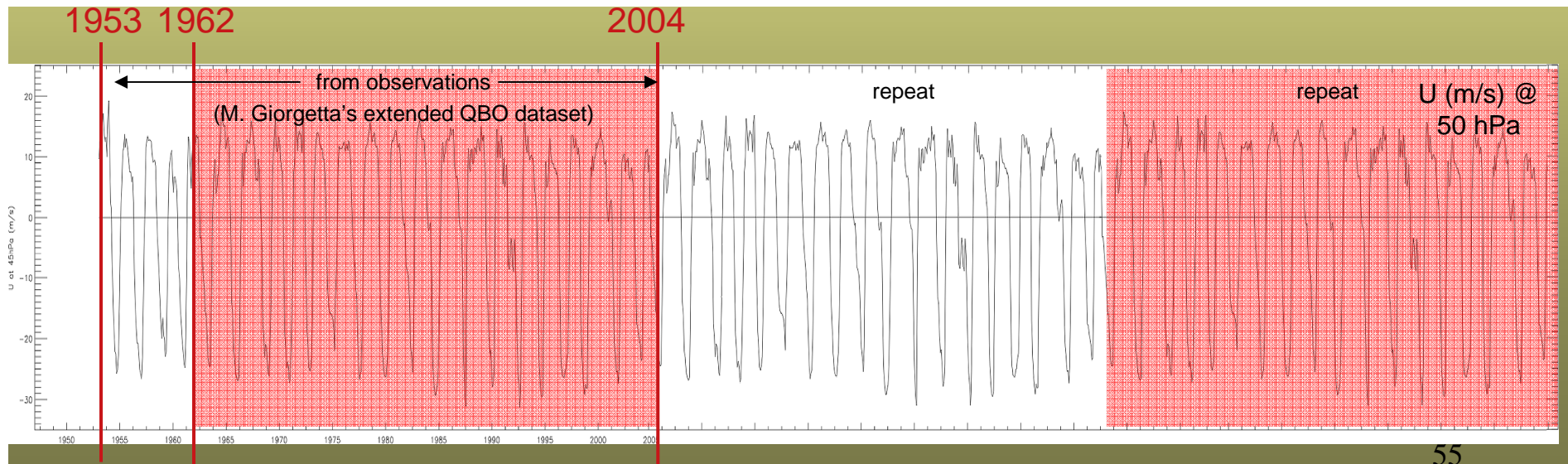
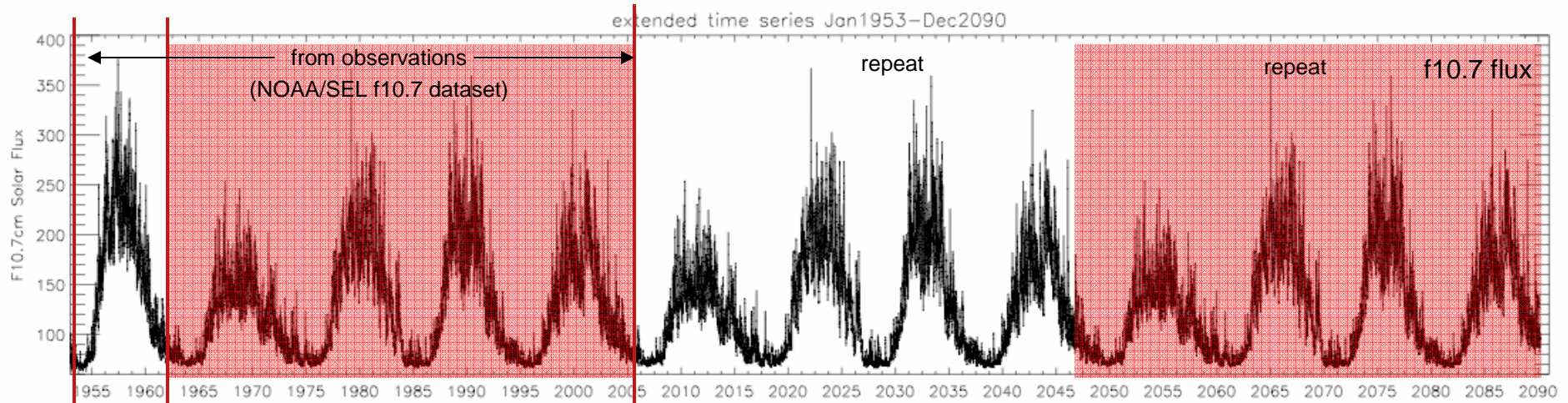
Solar effect in the stratosphere

- Solar heating modulates temperature gradients in the upper stratosphere/ lower mesosphere
- reinforcement of zonal winds deflects planetary waves, which creates positive divergence of Eliassen-Palm-flux
- this results a weakening of the Brewer-Dobson-circulation aligned with positive temperature anomalies in the lower tropical stratosphere

Kodera and Kuroda 2002

Forcing of 110 year run

Composite (1953 to 2004) + repeat (1962-2004)

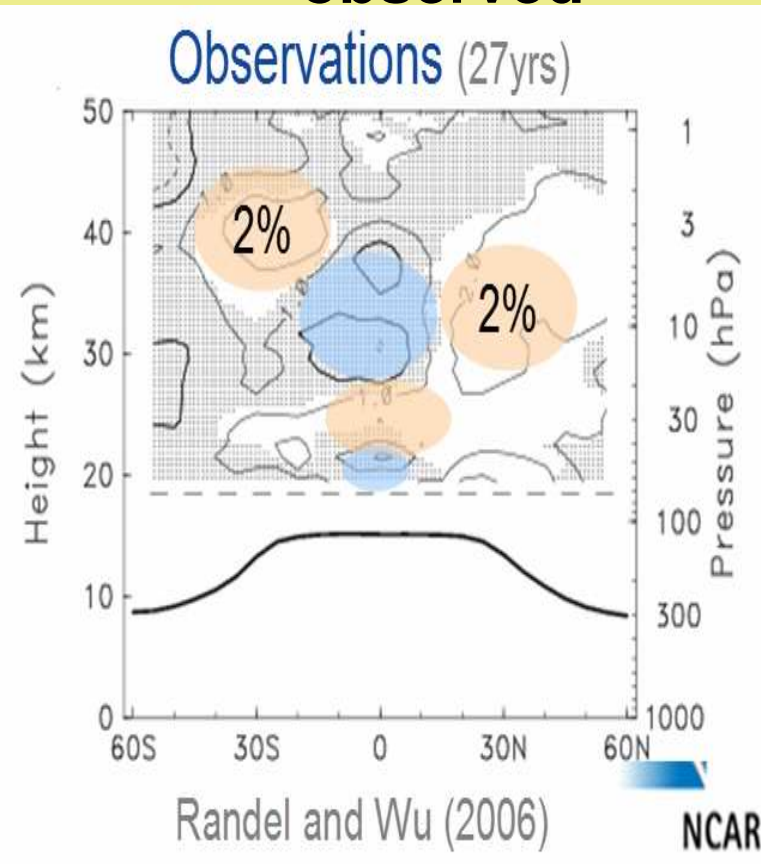
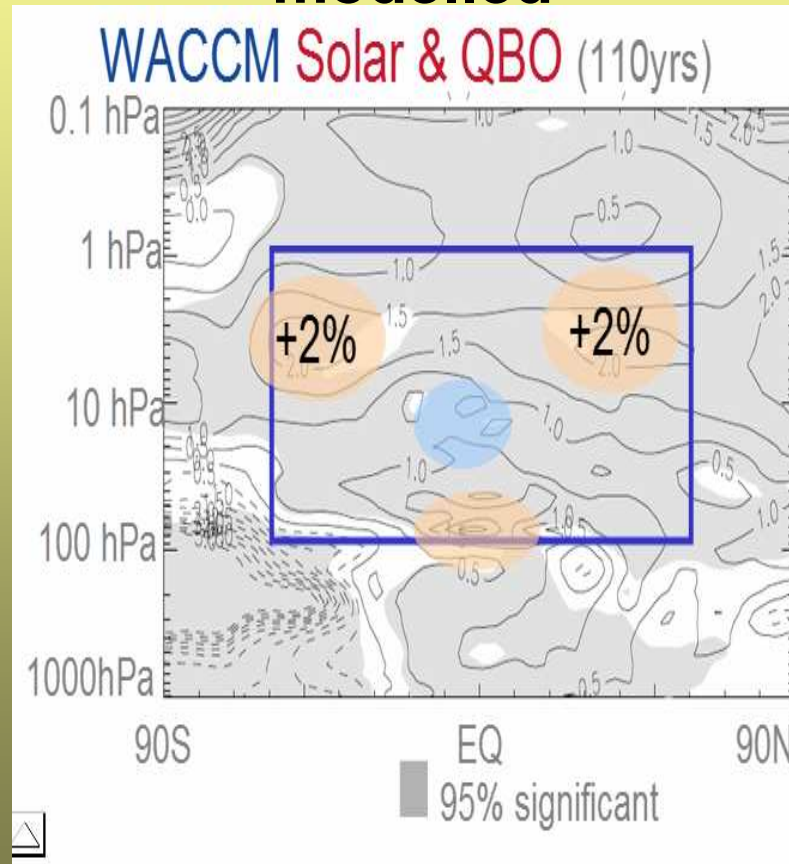


Solar Signal in Ozone (%/100 f10.7)

WACCM vs. Observations

modelled

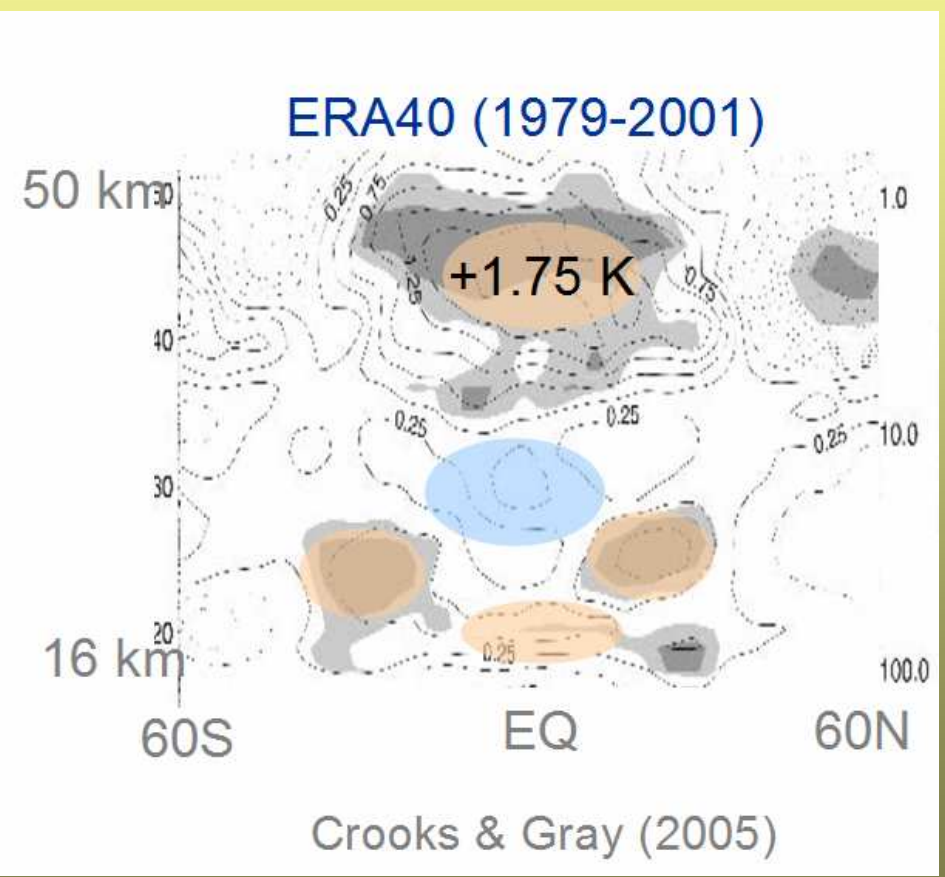
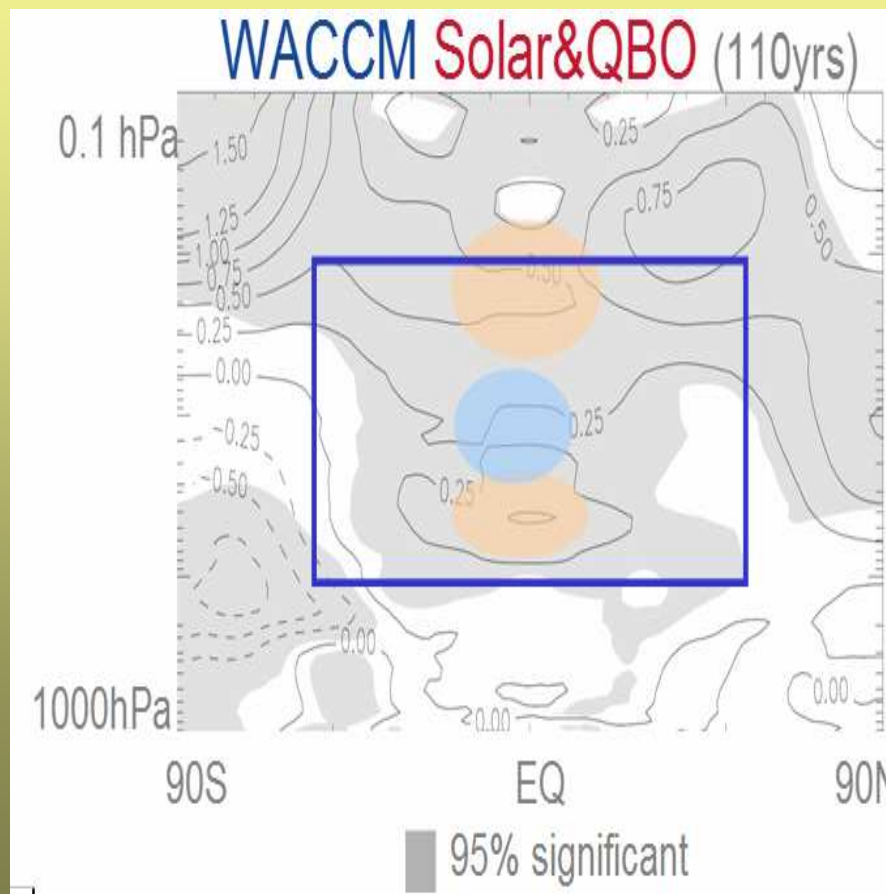
observed



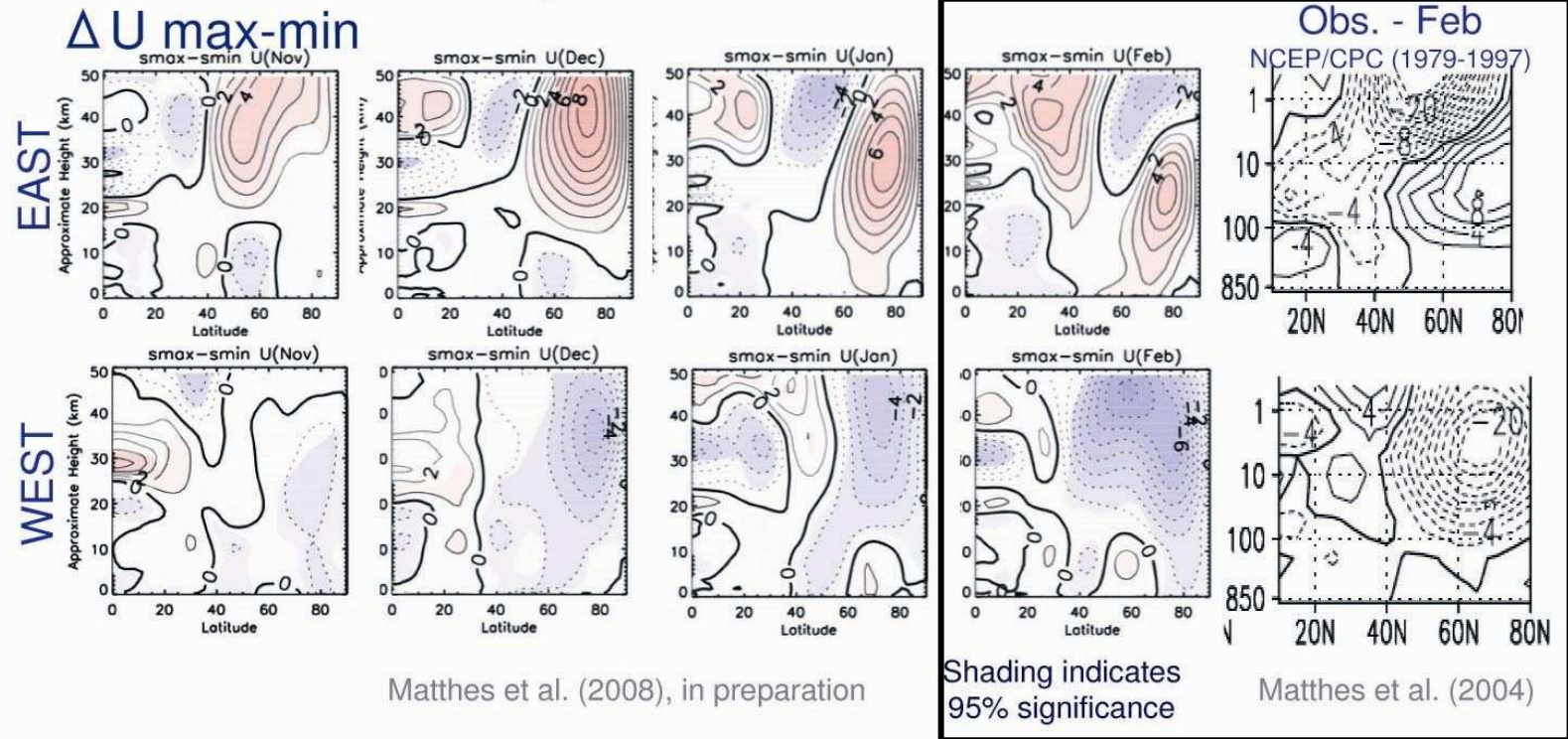
Solar Signal in Temperature (K/100 f10.7)

modelled

observed



QBO Impact – WACCM vs. Obs.



- poleward-downward propagation (Kodera and Kuroda, 2002)
- out-of-phase signal for QBO East and West
- qualitative agreement with observations and other mechanistic model studies (Labitzke and van Loon, 1988; Yoden, pers. comm., 2007)

Summary

- The sun influences the climate on various time-scales by orbital variations, TSI and UV-shift
- However, its influence is not sufficient to explain the recent warming.
- The 11-year solar signal in the upper stratosphere leads to circulation changes in the lower stratosphere and down to the troposphere at polar and equatorial latitudes.
- There are indications that it has some influence in the Pacific region, which might give some potential for decadal weather prediction.
- The interplay between direct and indirect effect is not clear.
- The interstellar partical flux and its influence on climate are not yet quantified and can therefore not be modellled.