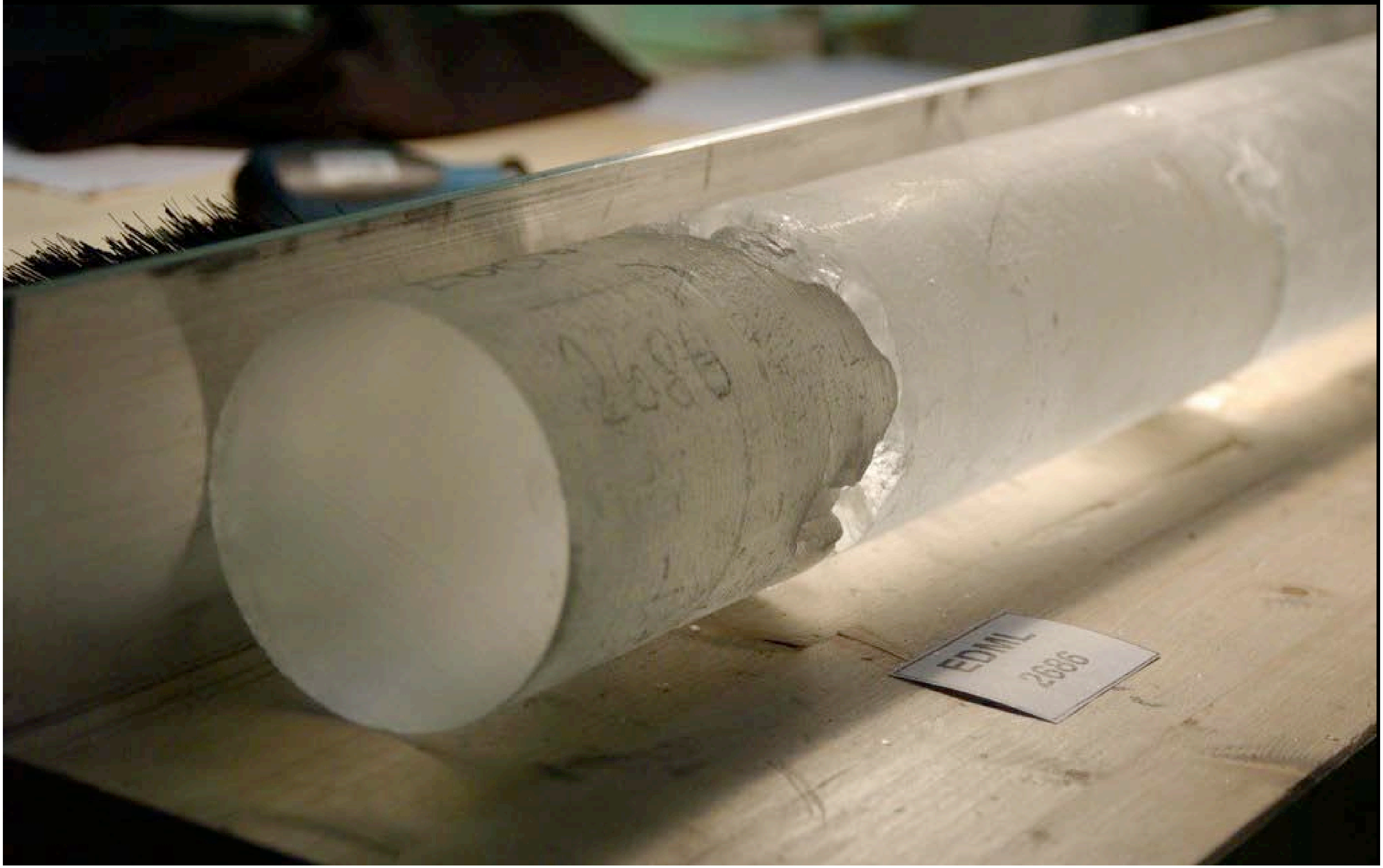
XV. Understanding recent climate variability

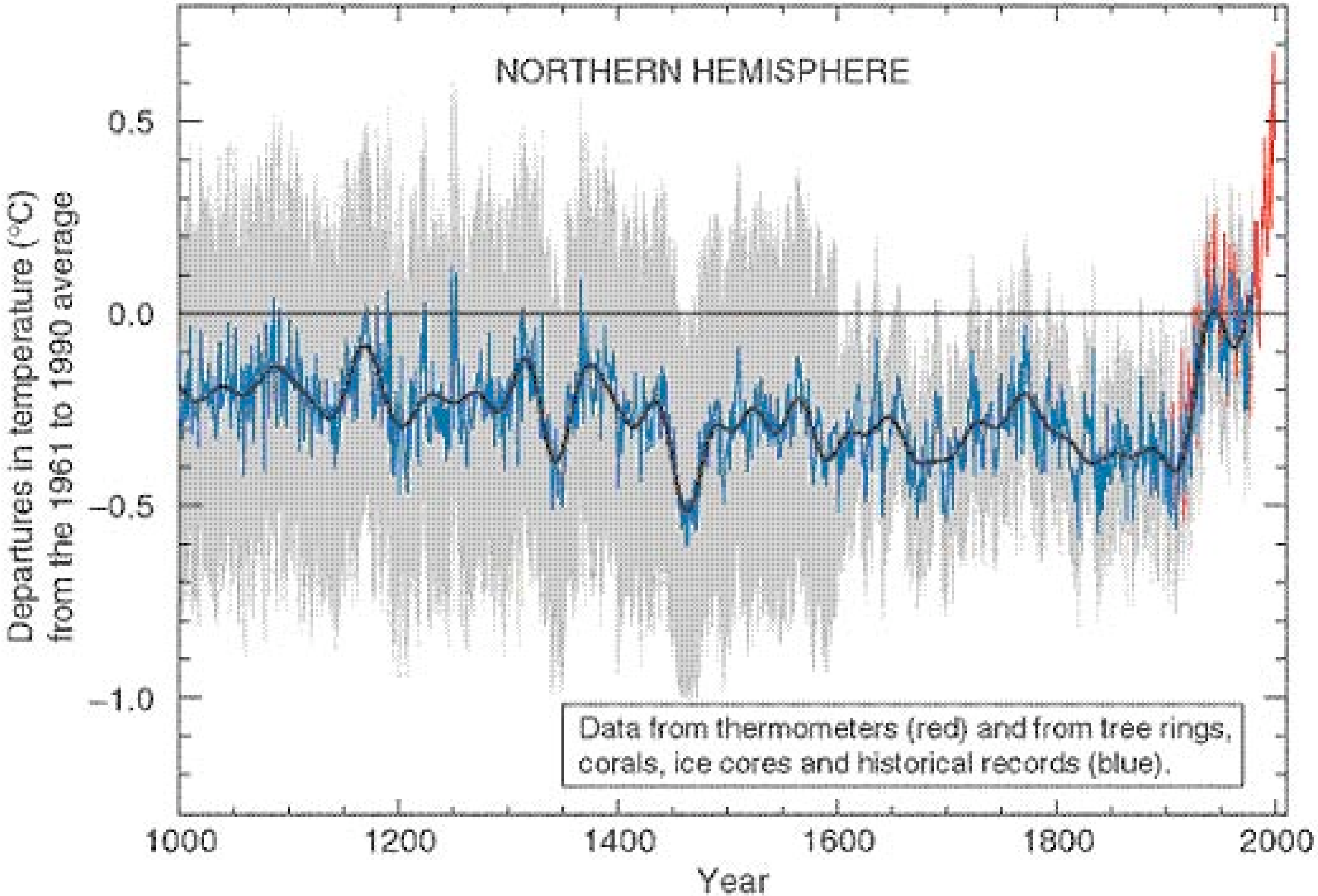


review

- temperature from thermometers, satellites, glacier lengths and boreholes all show significant warming in the 20th C+

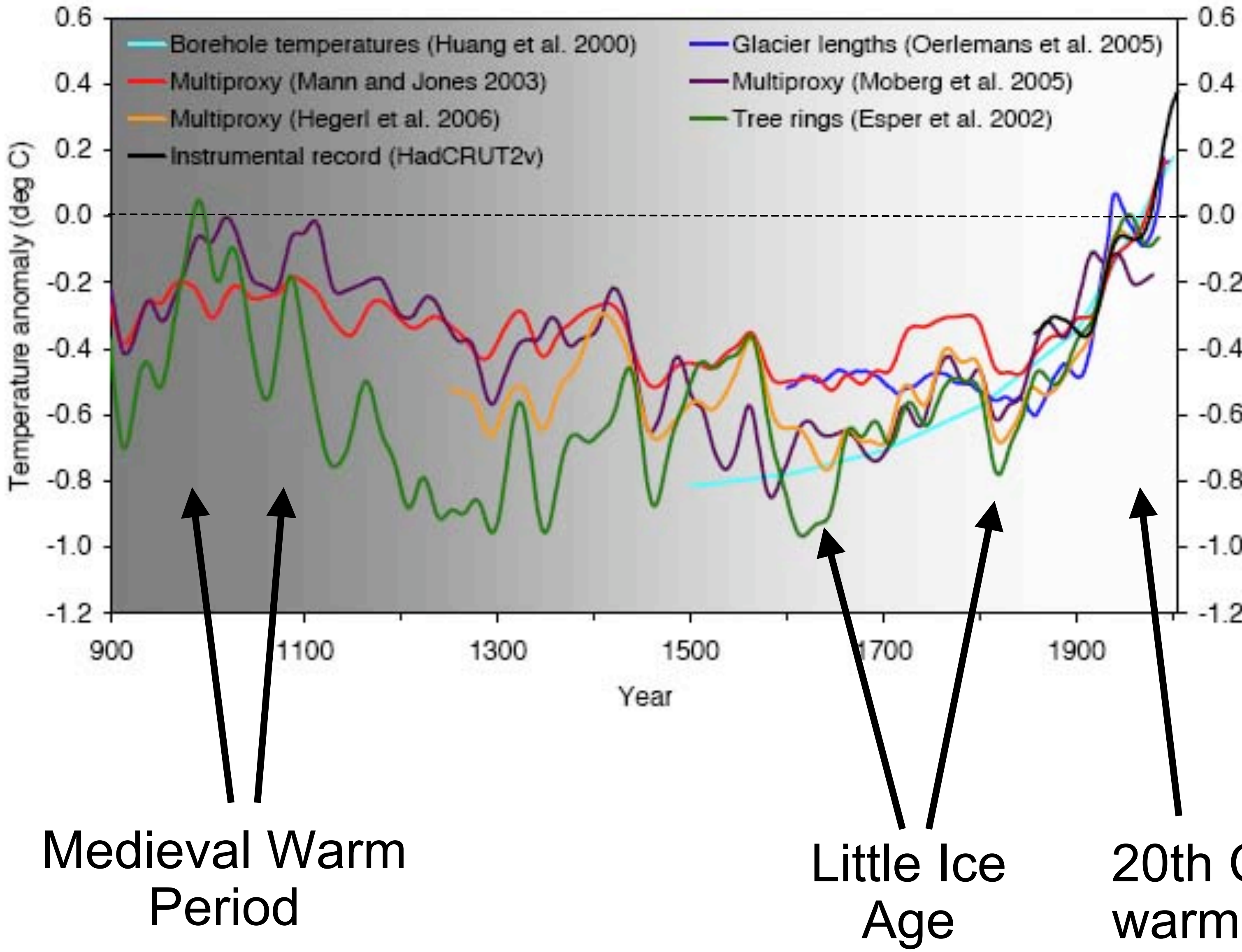
- reconstruction of past temperatures from corals, tree rings, and ice cores indicate that the 20th C+ warming is *anomalous* in the last 1000 years

infamous "hockey stick"



the details of this reconstruction by Penn State climatologist Michael Mann and others (1998) have been questioned by US policy makers and some scientists- a recent comprehensive review finds it to be largely correct within the stated errors (in gray)

recall temperature records compared



from recent review and compilation by the NAS (NRC 2007)

what factors influence climate?

what factors might influence the amount of energy received or retained by the climate system?

- solar variations
- volcanic activity
- change in atmospheric composition
  - GHG's
  - aerosols
  - clouds (as feedback or "forced" by aerosols)
- change in albedo
  - vegetation (as climate-vegetation feedback or "forced" by land-use change)
  - snow and ice (as feedback)

recall

- **climate forcing** - any mechanism that influences the amount of energy received or retained by the climate system, often expressed as a *radiative forcing* in W/m^2

- **climate response** - the response of the climate system to a particular forcing (or forcings), where the response may include climate *feedback* processes (*example: the climate response to CO_2 forcing is dominated by water vapor feedback*)

- **climate sensitivity -** the ratio of response to forcing at equilibrium, often therefore expressed as temperature change per W/m^2 (or per "CO_2 doubling")

recall concept of energy balance

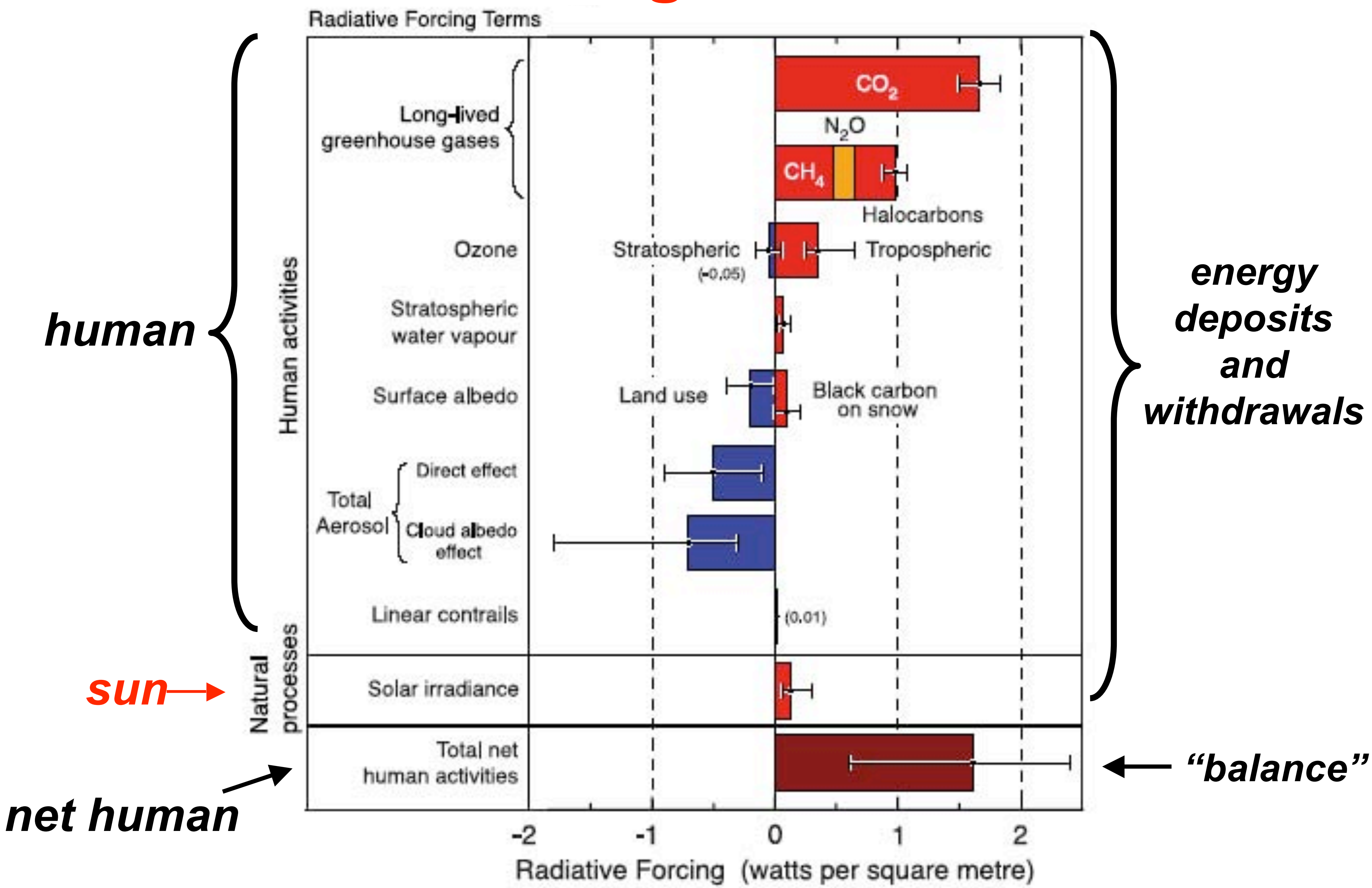
- what must happen if the received radiation (or the *radiative forcing*) changes?

- the *temperature* must adjust so that emitted radiation balances received radiation

- when the *radiative forcing* is changing the system still seeks but will not necessarily achieve equilibrium or radiative balance

$$F = \sigma T^4$$

est. radiative forcing of climate 1750-2005



radiative forcings are simply additive

IPCC AR4

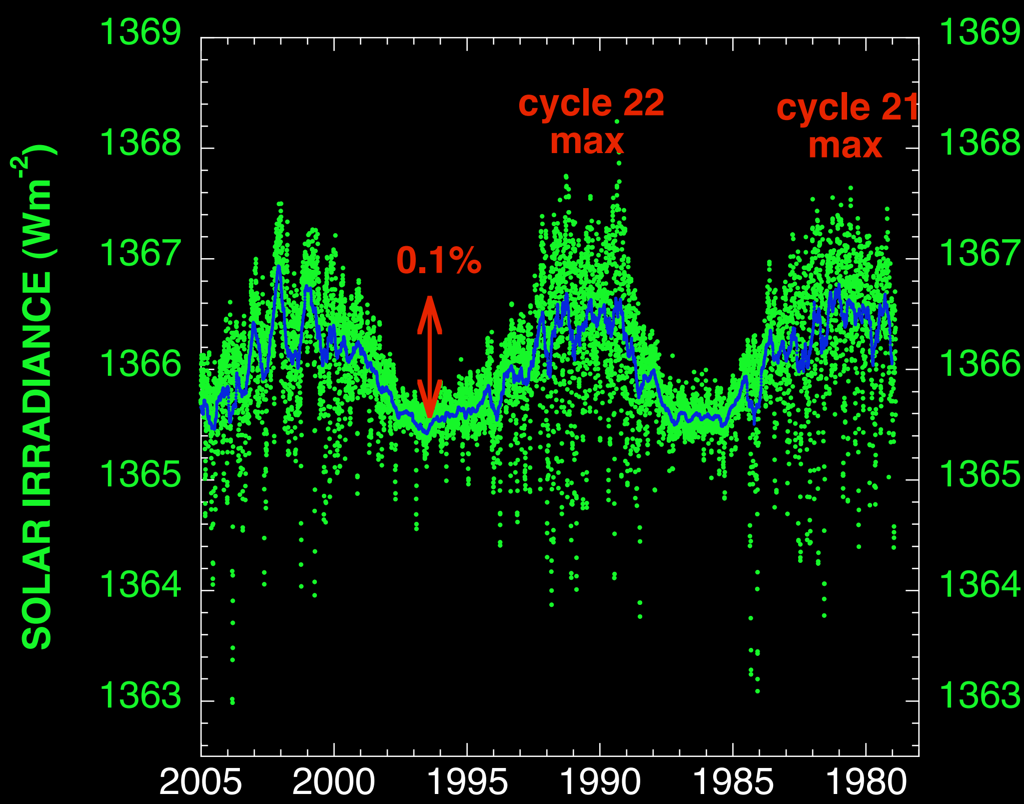
climate variation of the last 1000 yr

we might expect climate of the last 1000 years to have been influenced by factors that alter the *radiative forcing*, such as:

- solar variability
- volcanoes
- greenhouse gases
- aerosols

let's look at them one at a time.....

Total Solar Irradiance from satellites



- 11-yr solar cycle amplitude ~0.1% (so-called sunspot cycle)
- *longer-term variations not yet detectable*

± 0.1%TSI (1-0.3)/4

↓

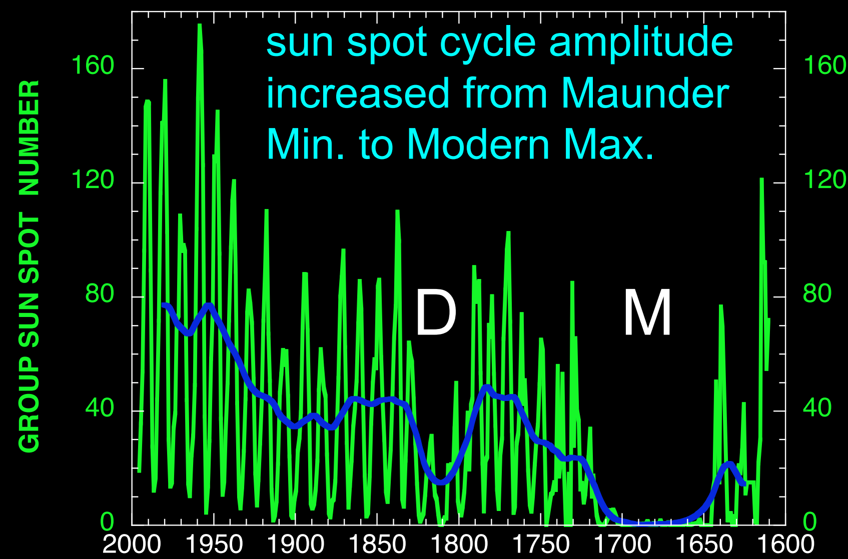
± ~0.25 Wm^{-2}

↓

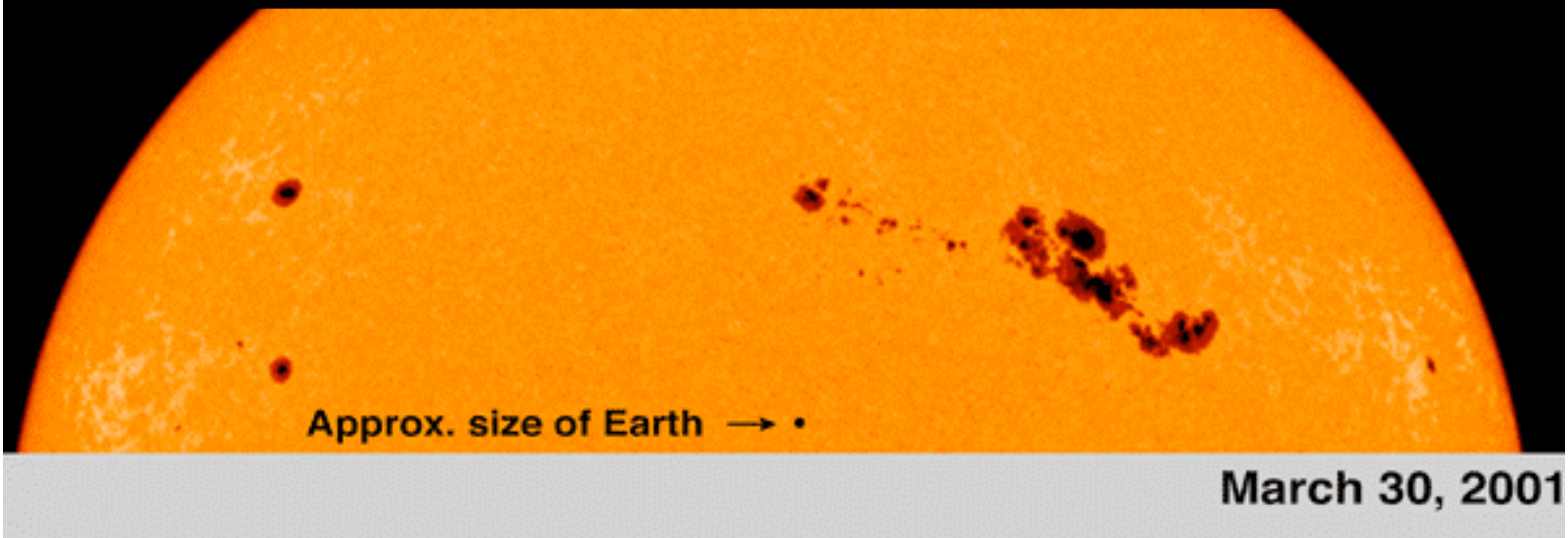
CLIMATE

data: Froehlich & Lean '98 & www.pmodwrc.ch

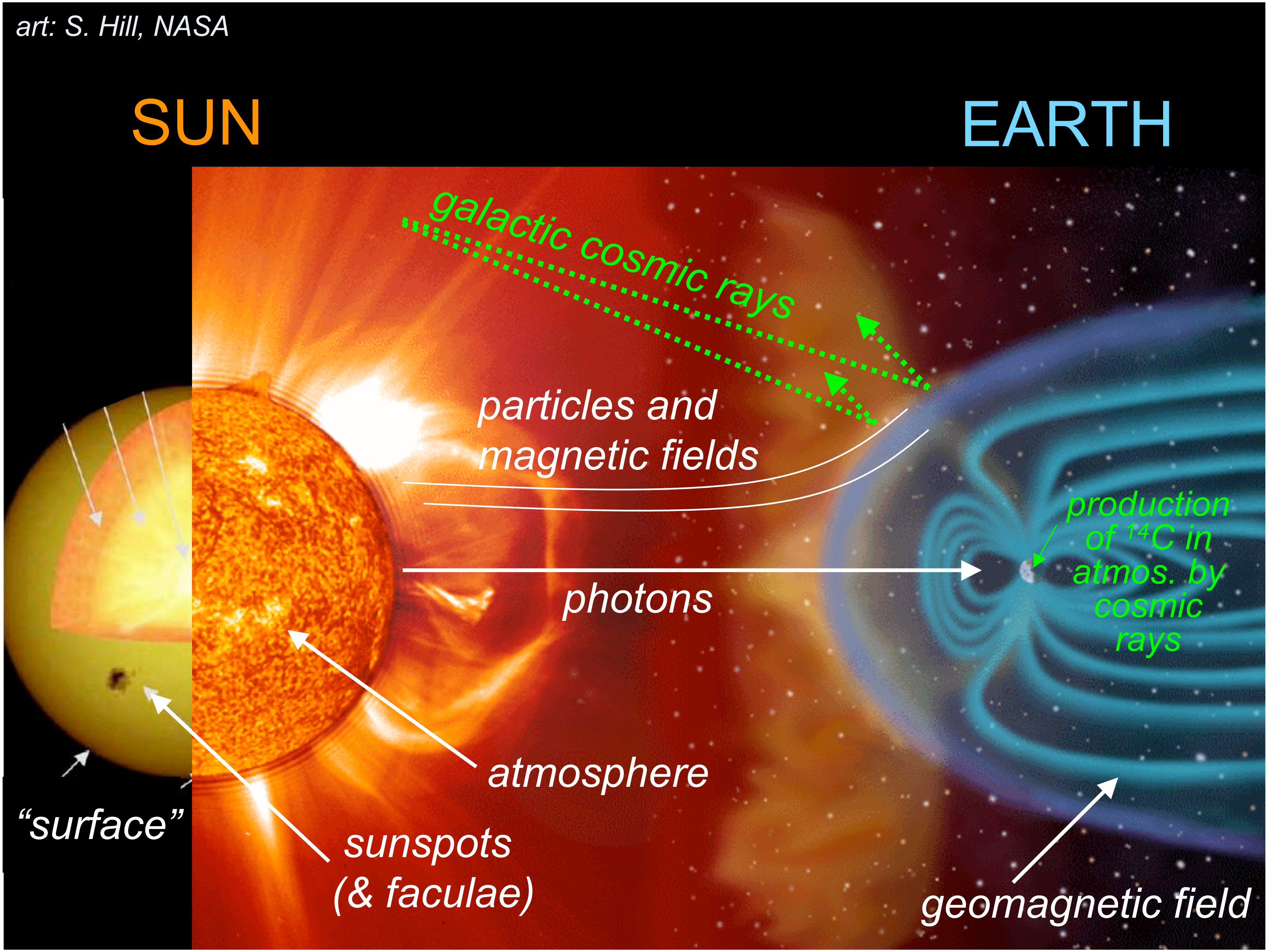
Sun Spots from telescopes



- Galileo's telescope, 1611
- telescopes record periodic changes in sun spot abundance
- *fewer spots, lower irradiance*
- <u>M</u>aunder and <u>D</u>alton Minima (~ Little Ice Age)
- followed by Modern Maximum



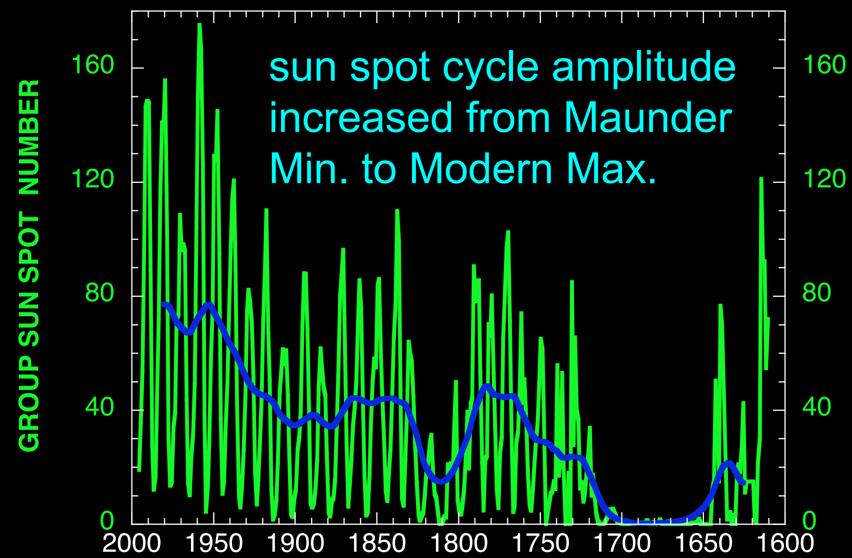
data: Hoyt & Schatten '98


art: S. Hill, NASA
SUN
EARTH
galactic cosmic rays
particles and
magnetic fields
photons
production
of 14C in
atmos. by
cosmic
rays
atmosphere
"surface"
sunspots
(& faculae)
geomagnetic field

“cosmogenic” isotopes and the sun

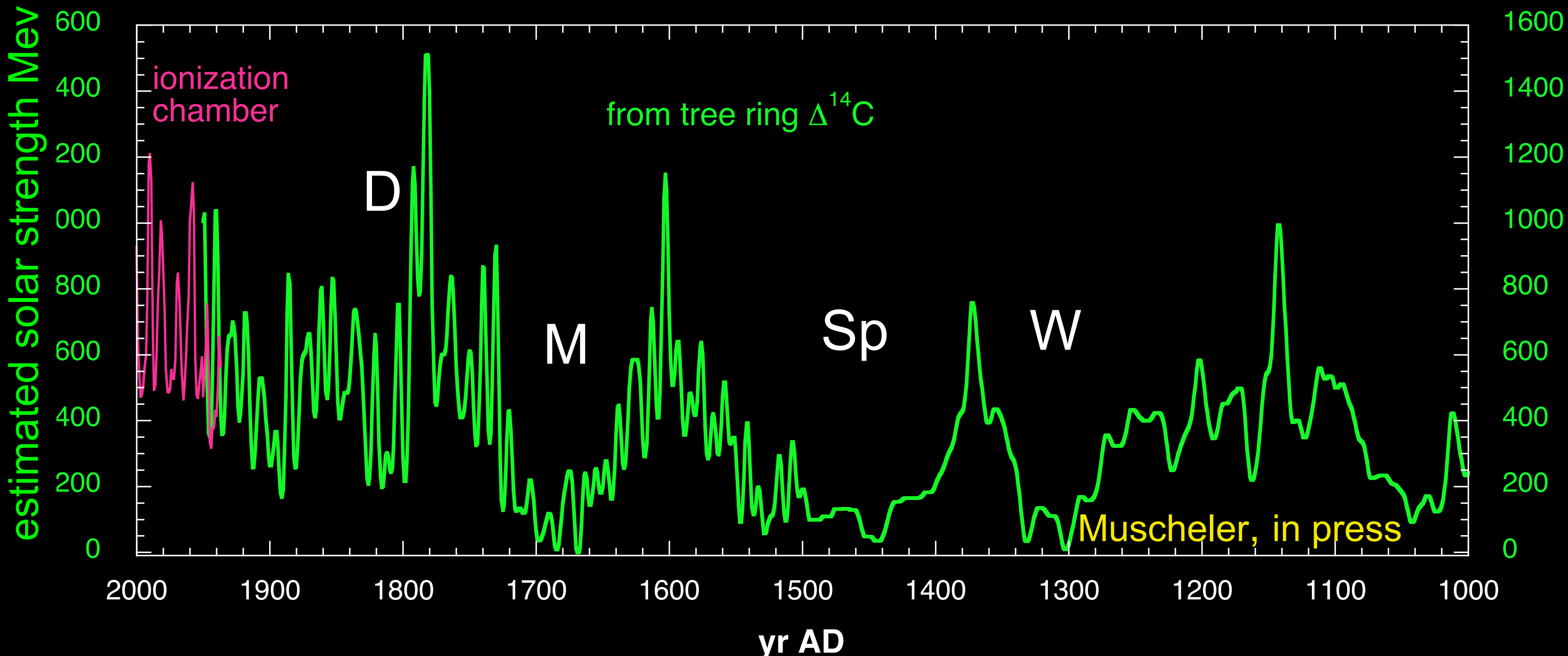
- in our discussion of the previous slide, we noted that when the sun is more active, the *solar wind* (containing particles and magnetic fields) increases, adding to the total *magnetic field* near Earth
- when this happens fewer galactic cosmic rays penetrate the magnetic field
- “cosmogenic” isotopes are formed by the interaction of cosmic rays with other elements, for example by bombardment of common nitrogen to produce ^{14}C in the atmosphere
- since ^{14}C is taken up into plant material along with common carbon, we can use its abundance in tree rings to estimate past solar activity (as shown on the next slide)

Longer Term Solar Variability from "cosmogenic isotopes" like ^{14}C



Wolf
Sporer
Maunder
Dalton

minima



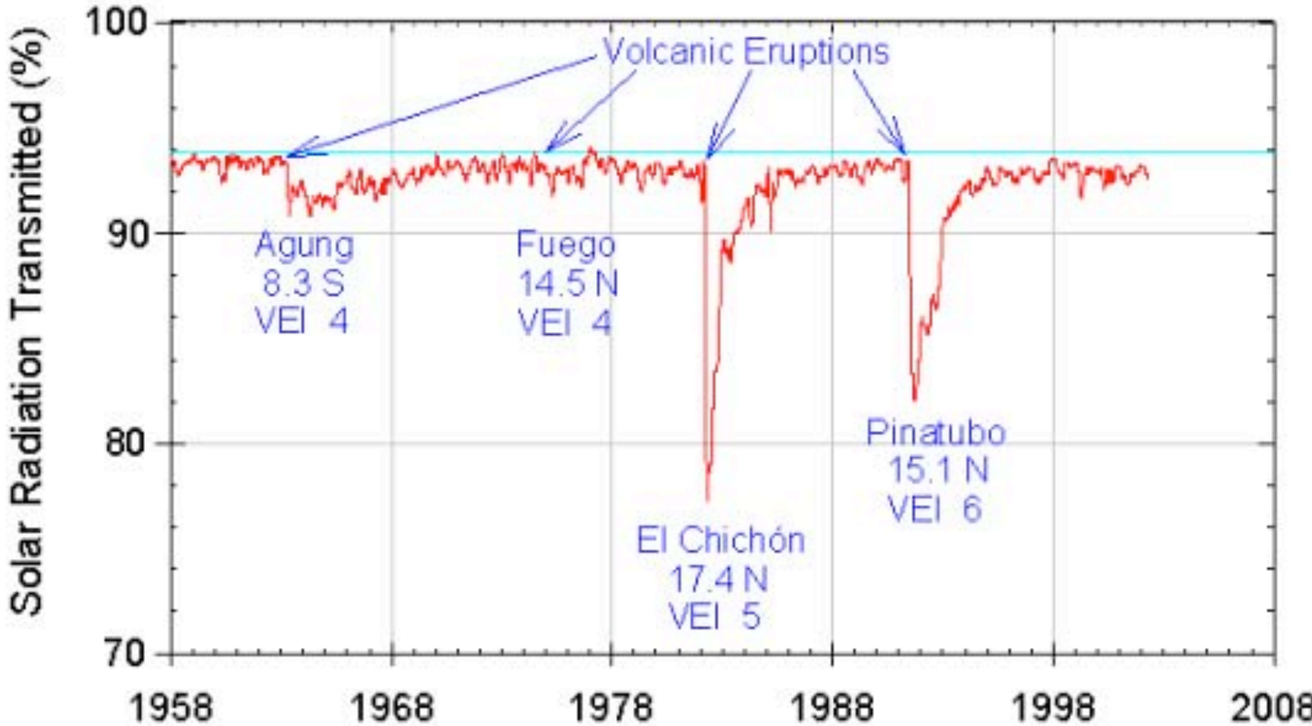
solar variability

- satellites record changes in total solar irradiance since 1978 revealing an 11-yr cycle with an amplitude of ~0.1%
- sunspots and “cosmogenic” isotopes (like ^{14}C) suggest bigger solar variations in the past (i.e. the Wolf, Sporer, Maunder and Dalton Minima) but these *relative* changes are difficult to scale to *absolute* changes in irradiance
- irradiance changes during past solar minima are thought to be in the range of -0.1 to -0.4 %

volcanoes

- inject aerosols into atmosphere
  (soot, dust, gases)
- can block out sun directly
  (higher albedo, cools planet)
- but also can change properties of clouds
  (higher cloud albedo)

atmospheric transmission at MLO



reduced transmission of solar radiation is a negative radiative forcing

Agung 1963, Indonesia
Fuego 1974, Guatemala
El Chichon 1982, Mexico
Pinatubo 1991, Philippines

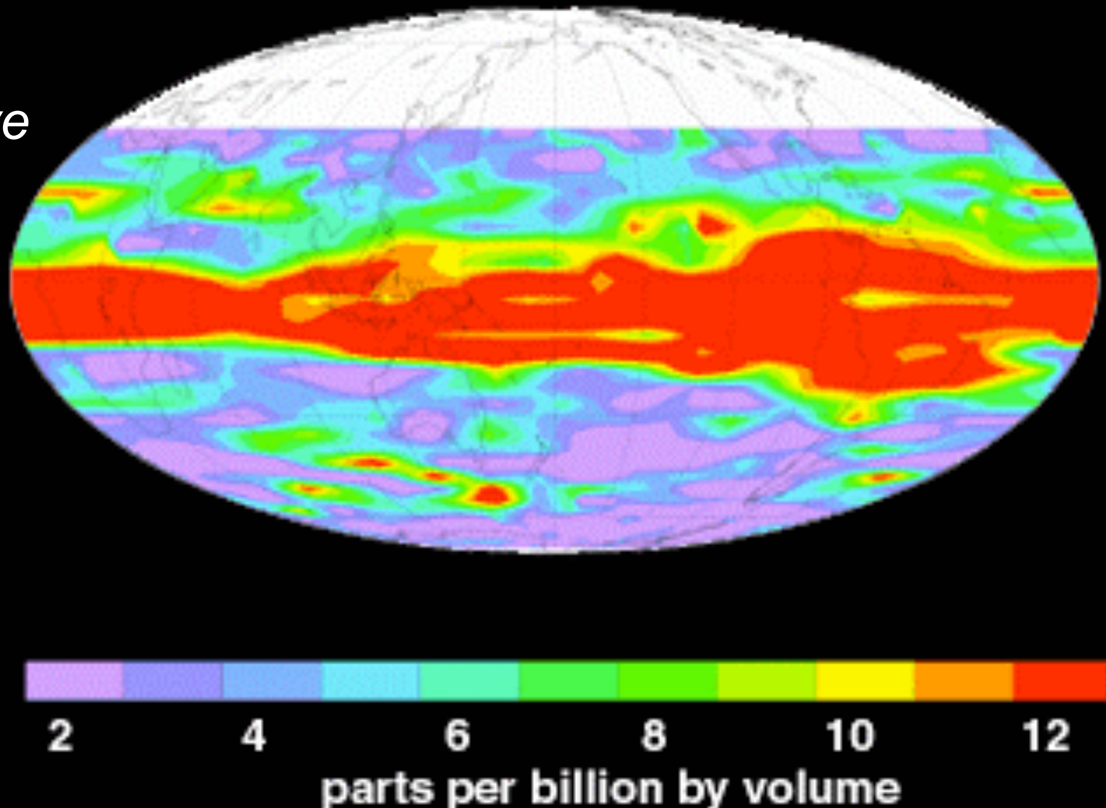
VEI= Volcanic Explosivity Index

comprehensive list of large eruptions last 10 kyr can be found at
http://www.volcano.si.edu/world/largeeruptions.cfm
(Global Volcanism Program)

sulfur aerosol

sulfur aerosol in stratosphere following injection by Pinatubo
(for layer at 26 km)

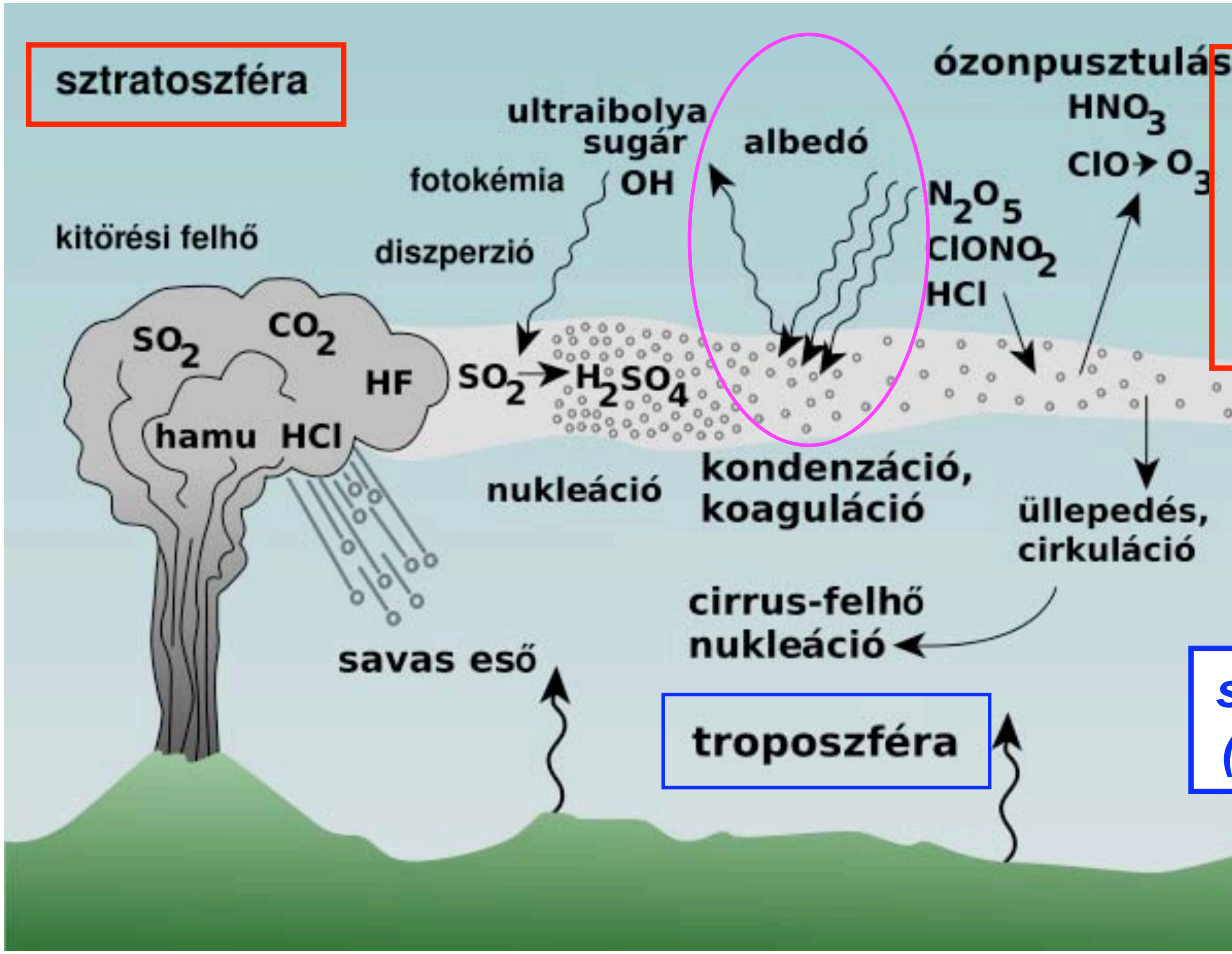
large explosive eruptions punch ash and gases into stratosphere



aerosols can spread out before destruction and removal

Read et al., 1993

radiative (and chemical) effects



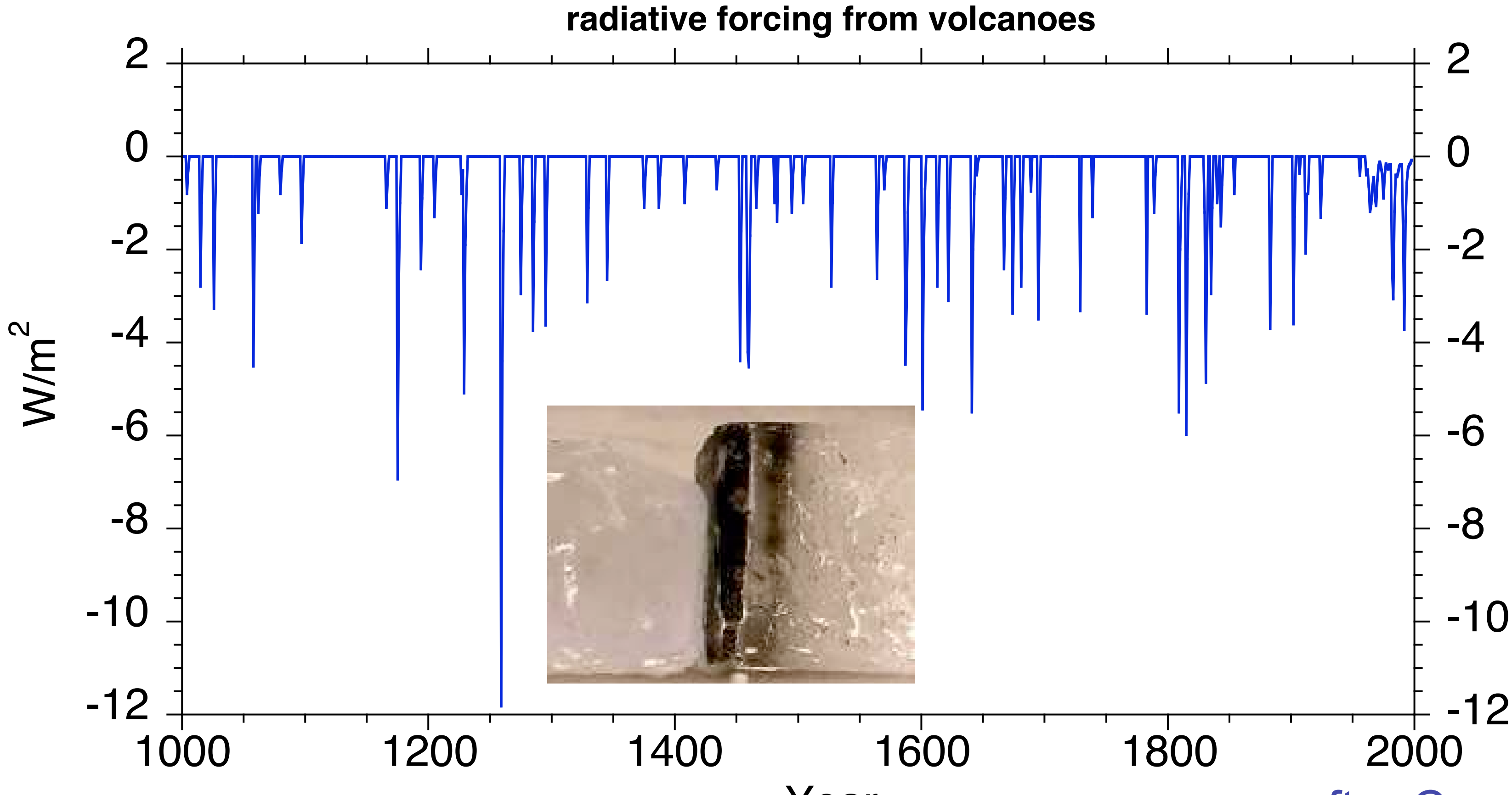
stratospheric warming (energy incr.)
"white house effect"

surface cooling (energy deficit)

adapted (by a Hungarian?) from Robock 2000

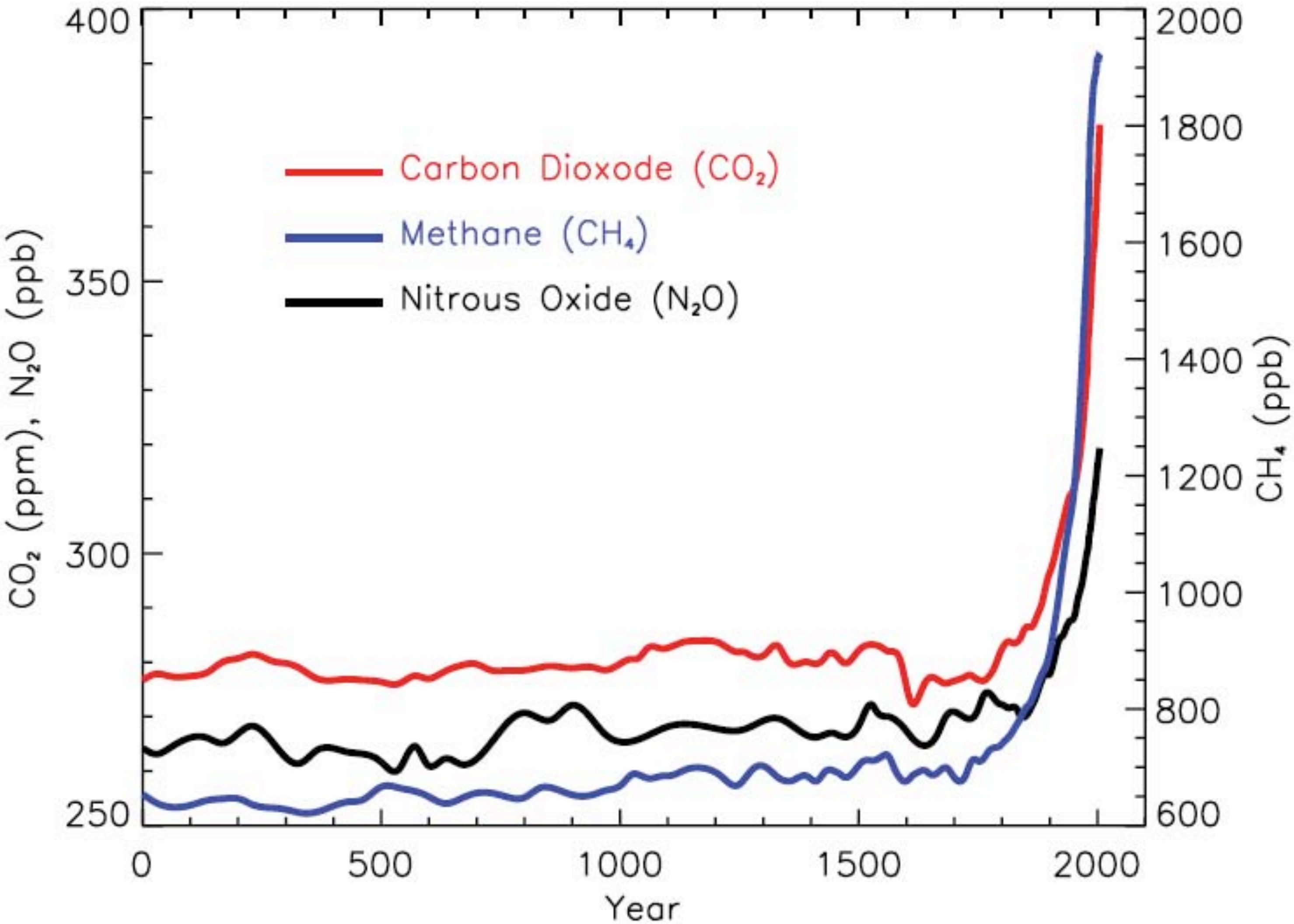
volcanoes

history and size of major eruptions from historic records and volcanic ash in ice cores, last 1000 years (expressed here in terms of impact on radiation balance at top of troposphere)



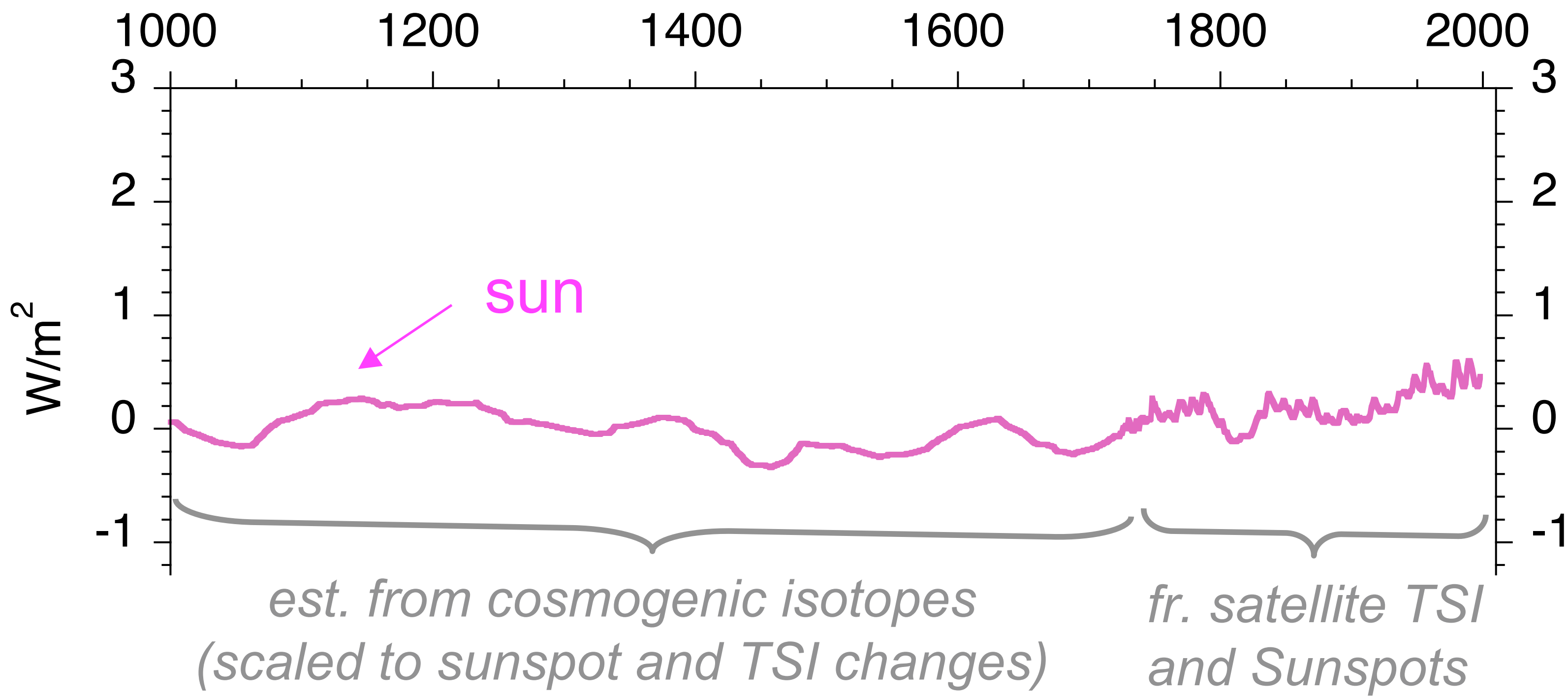
after Crowley ‘00

greenhouse gases 0-2005 AD



IPCC AR4

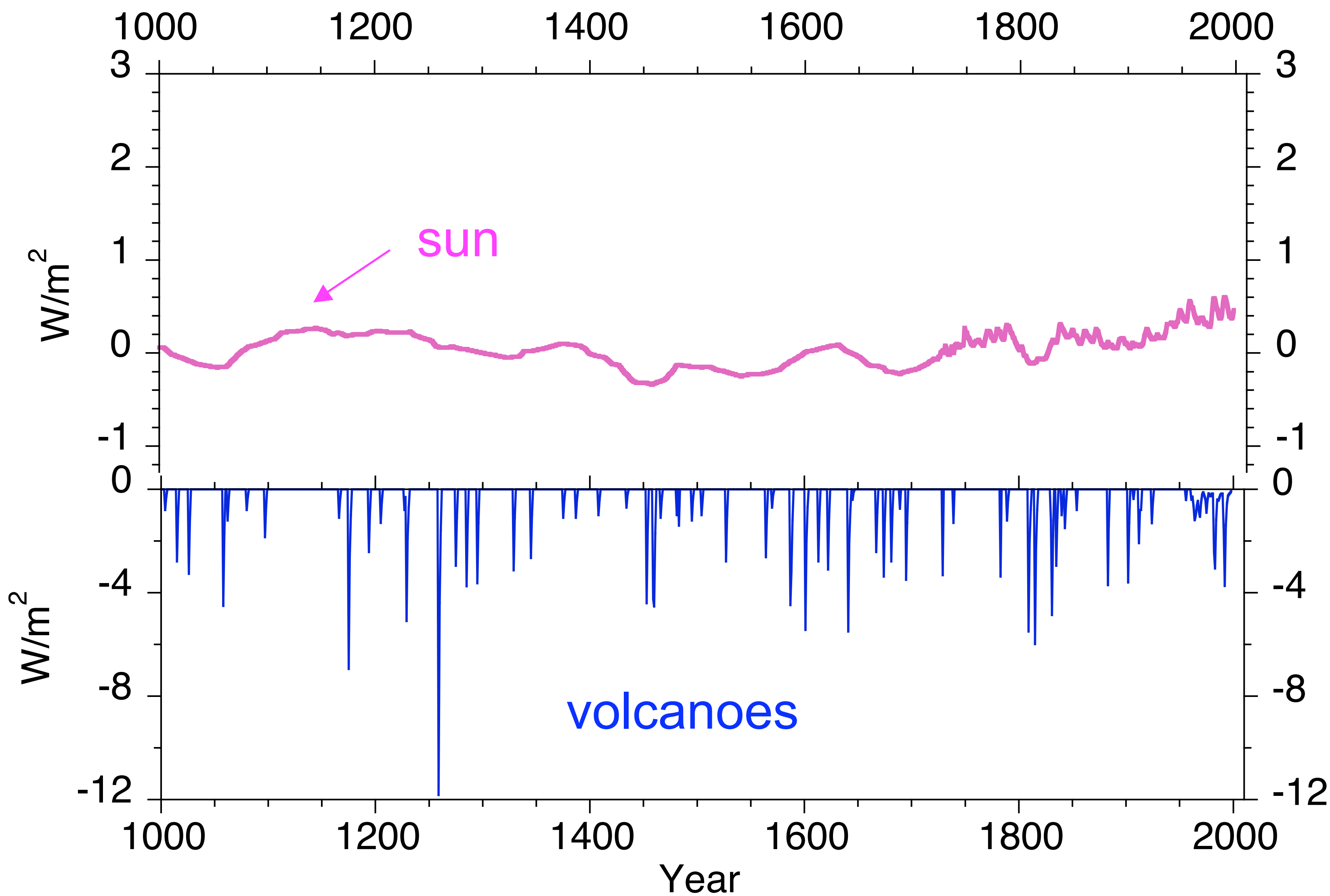
estimated forcings, last 1000 yr



small overall increase since 1750
(range: a few tenths W/m²)

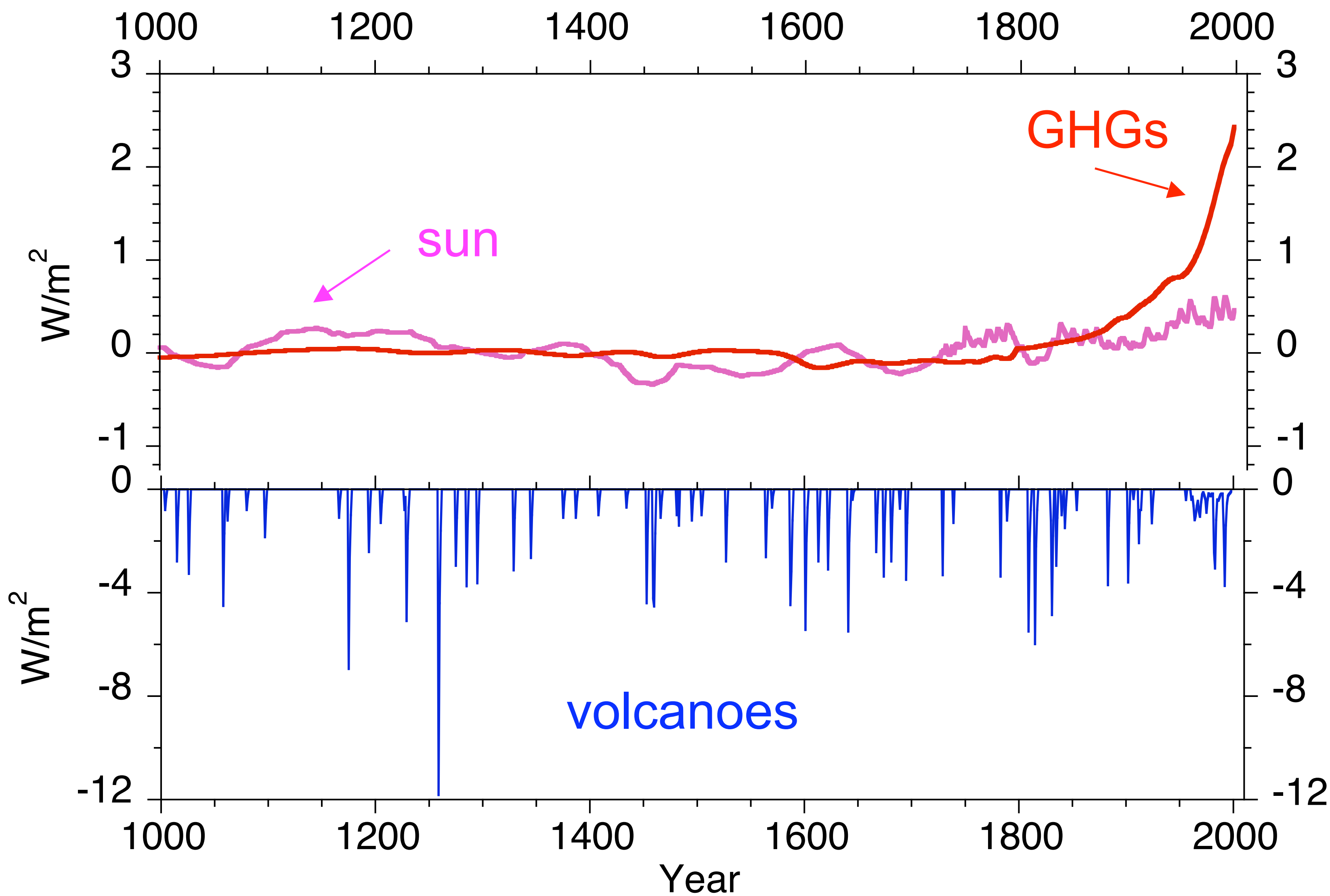
after Crowley '00

estimated forcings, last 1000 yr



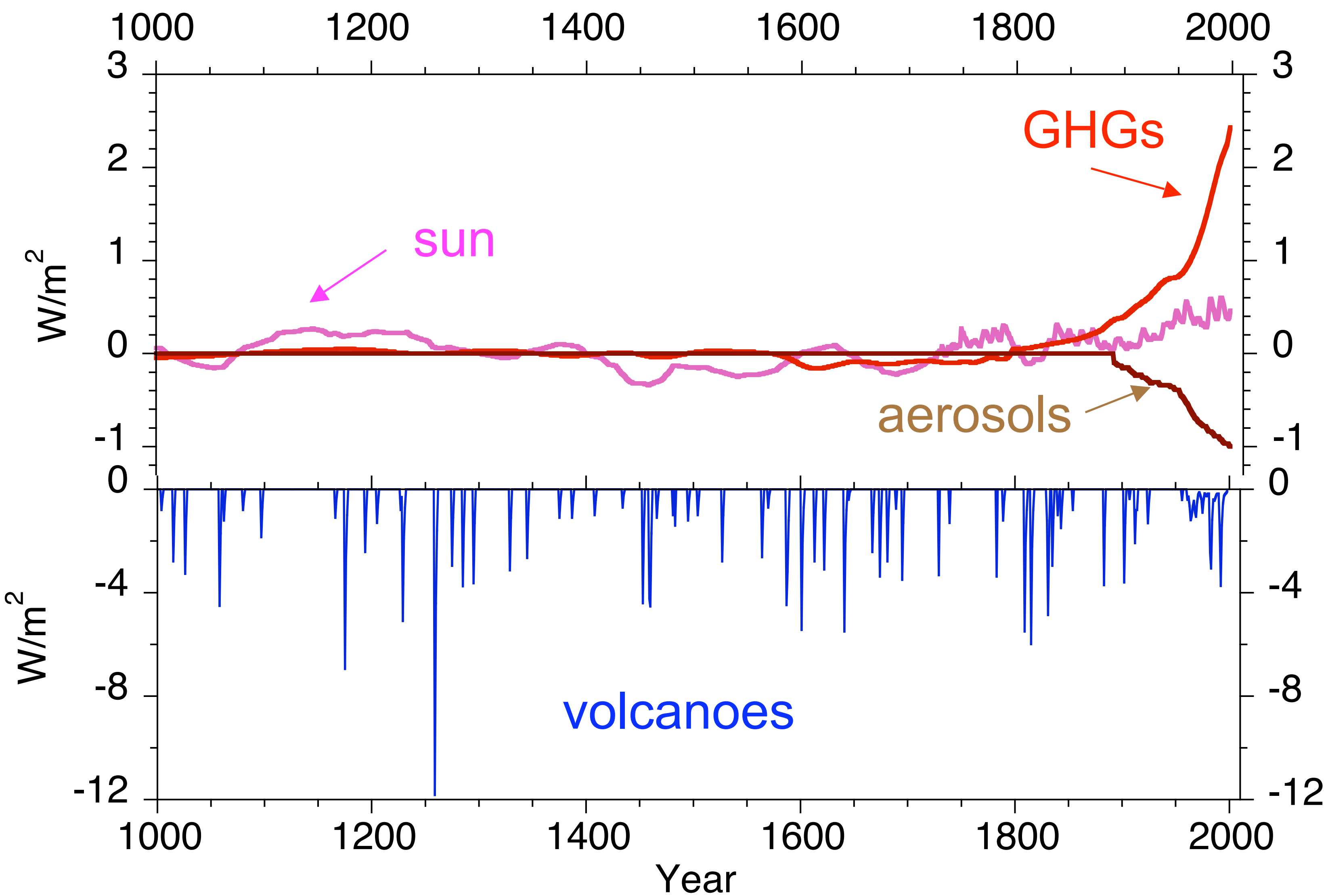
after Crowley '00

estimated forcings, last 1000 yr



after Crowley '00

estimated forcings, last 1000 yr



which forcing is now dominant?

after Crowley '00

a test of our understanding

- how might we use information about *radiative forcing* to evaluate our understanding of past climate change?

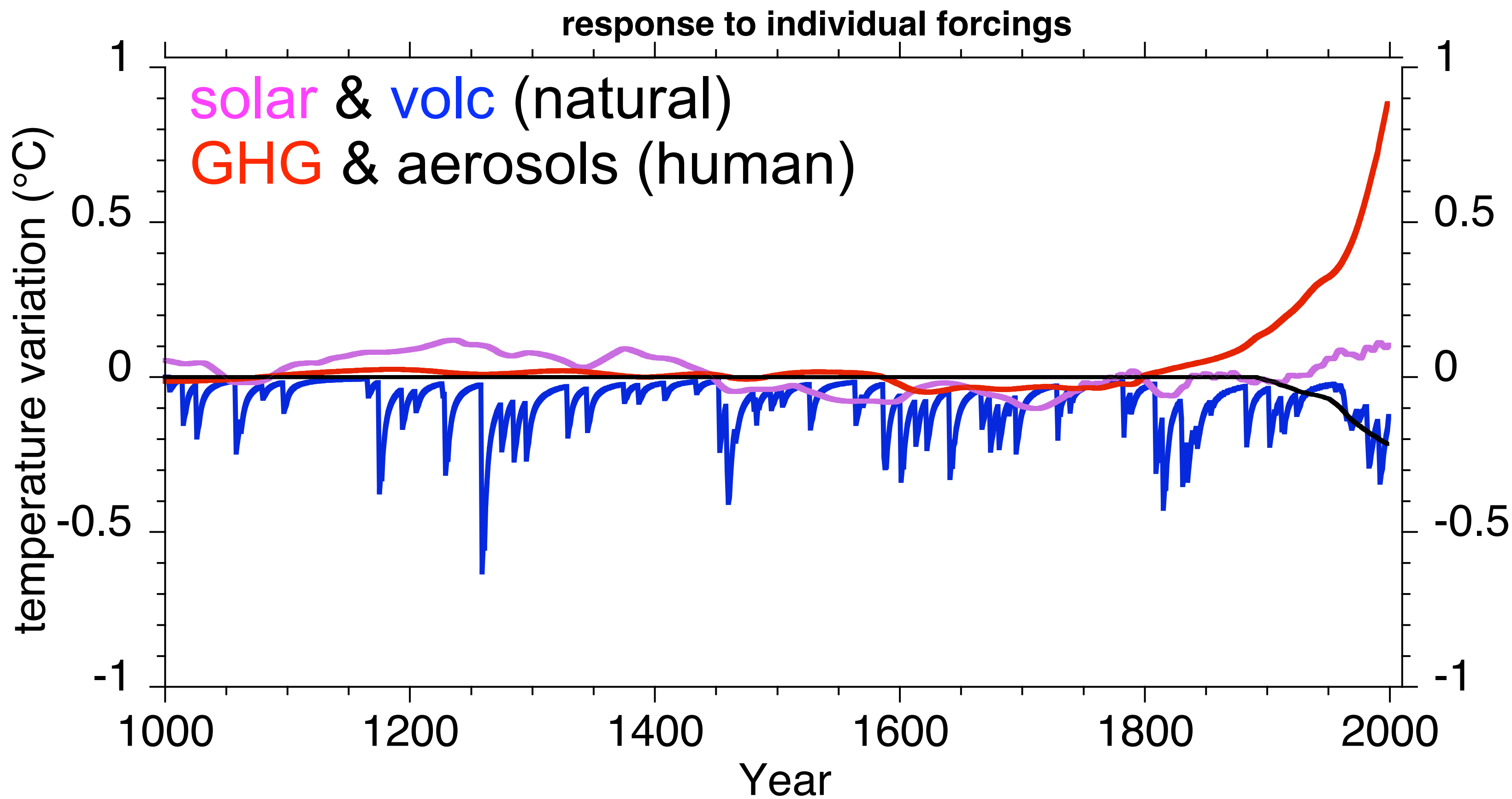
- use model (or understanding or *climate sensitivity*) to calculate *climate response* to *radiative forcings*

- compare to observations and reconstructions

- *and …..*

estimated temperature response

from a simple “Energy Balance Model”

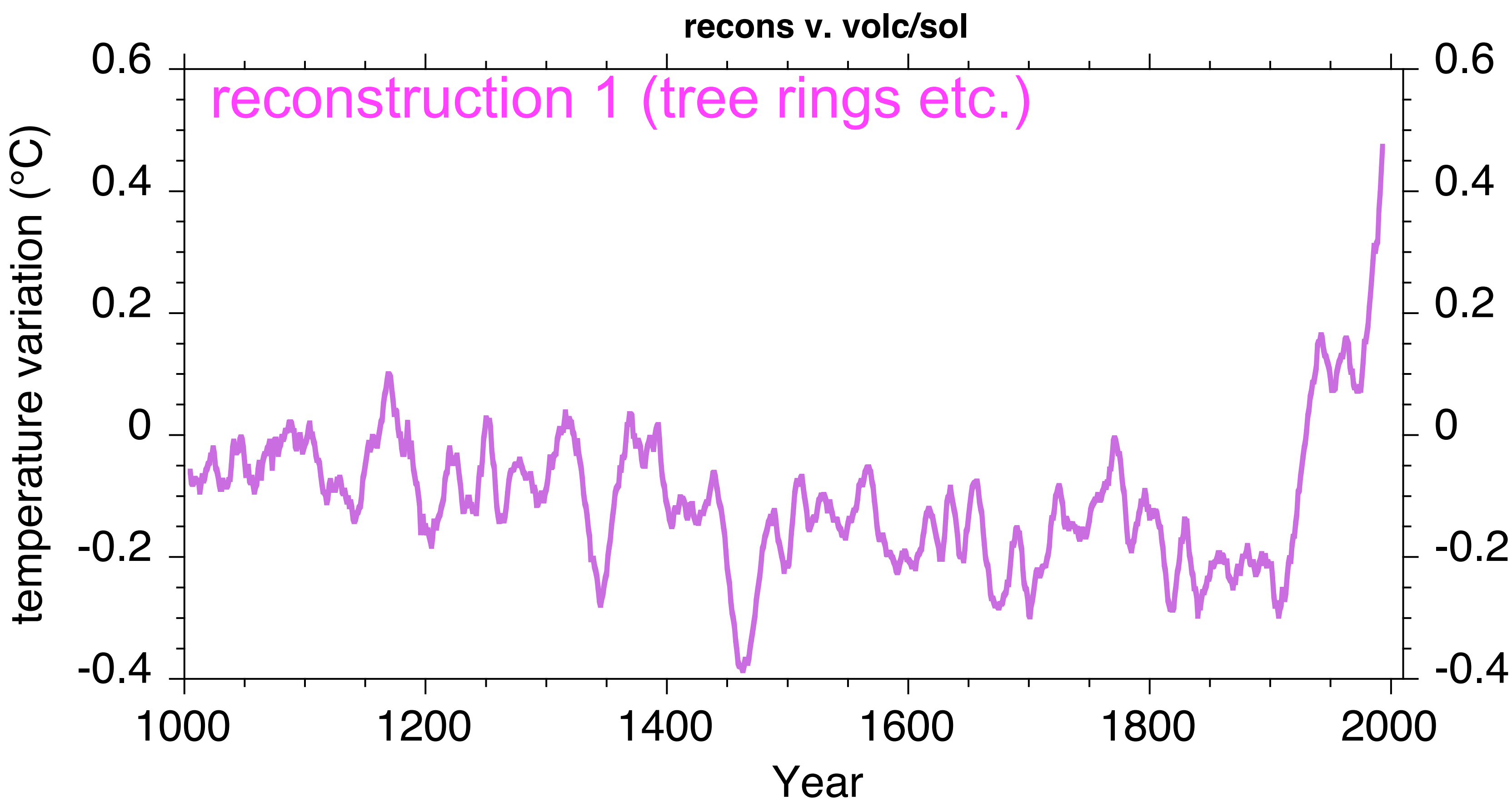


estimated temperature response to individual forcings

now let’s compare responses to observed and reconstructed temperatures

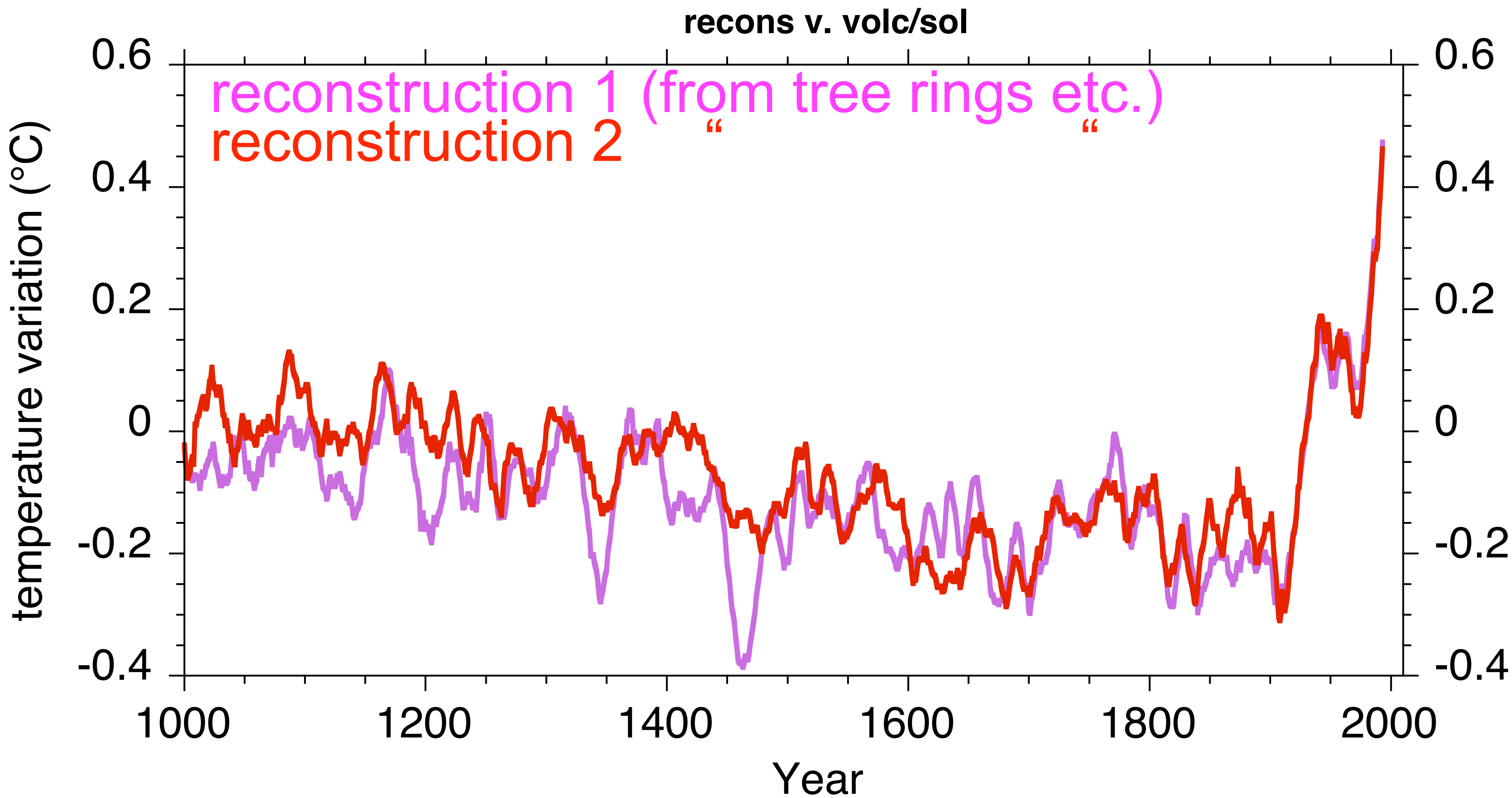
after Crowley ‘00

reconstructed temperature vs. response to natural forcings



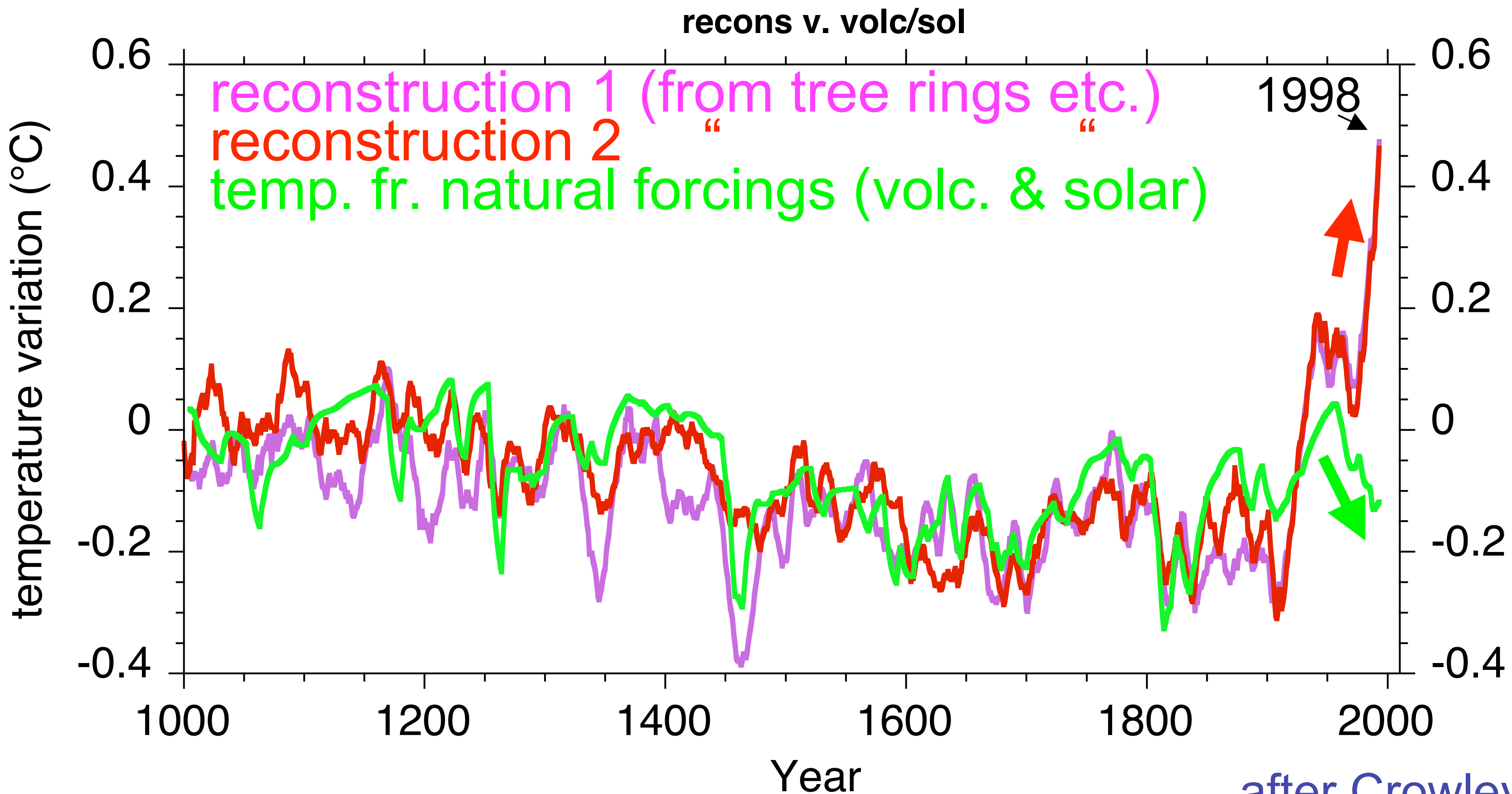
after Crowley '00

reconstructed temperature vs. response to natural forcings



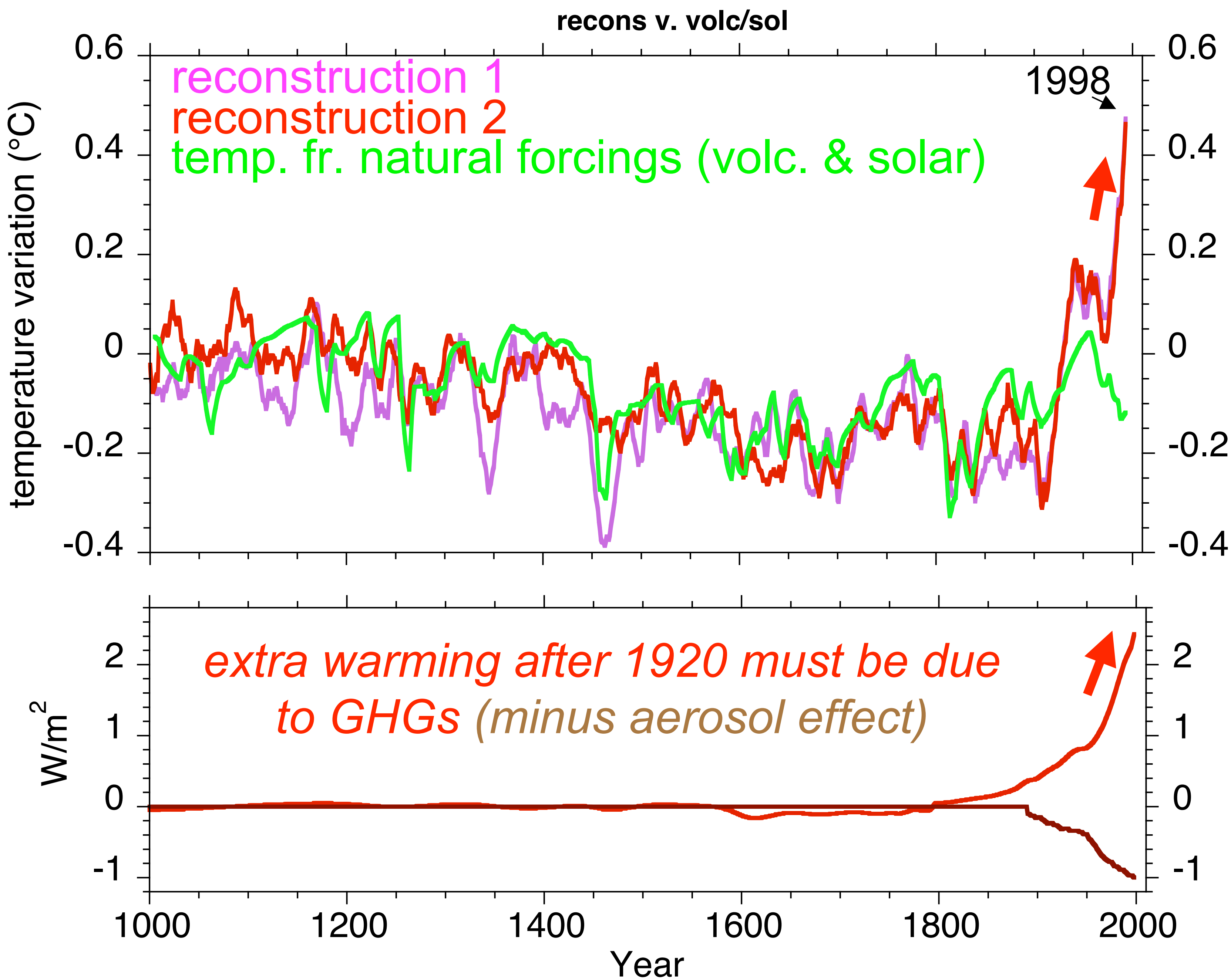
after Crowley '00

reconstructed temperature vs. response to natural forcings



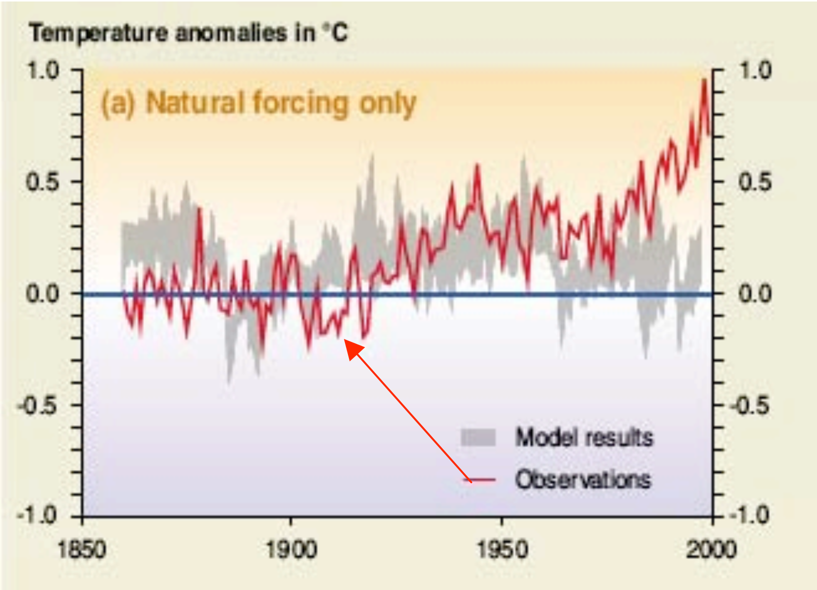
after Crowley '00

temperature variability prior to 20th C+ well explained by natural forcings, but not after!
(temperatures have now reached ~0.7 on this scale)



after Crowley '00

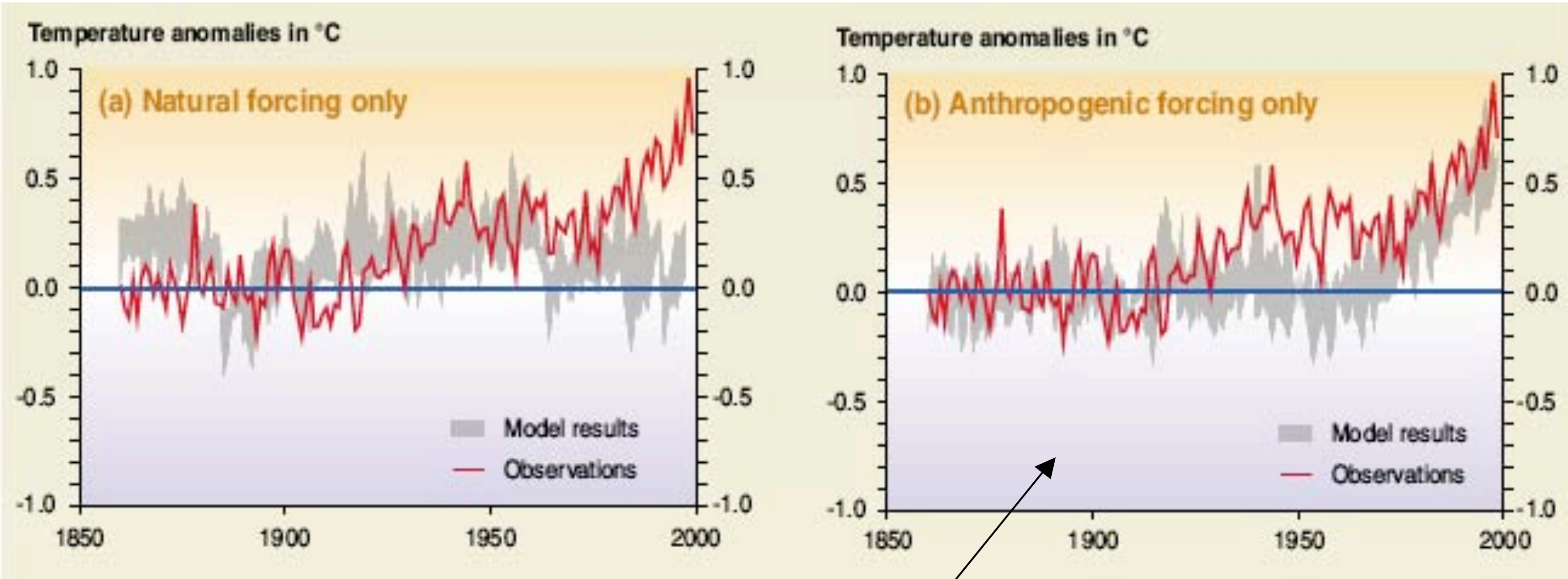
global temperature change since 1860



climate model "hindcast": natural forcings only

IPCC TAR (2001)

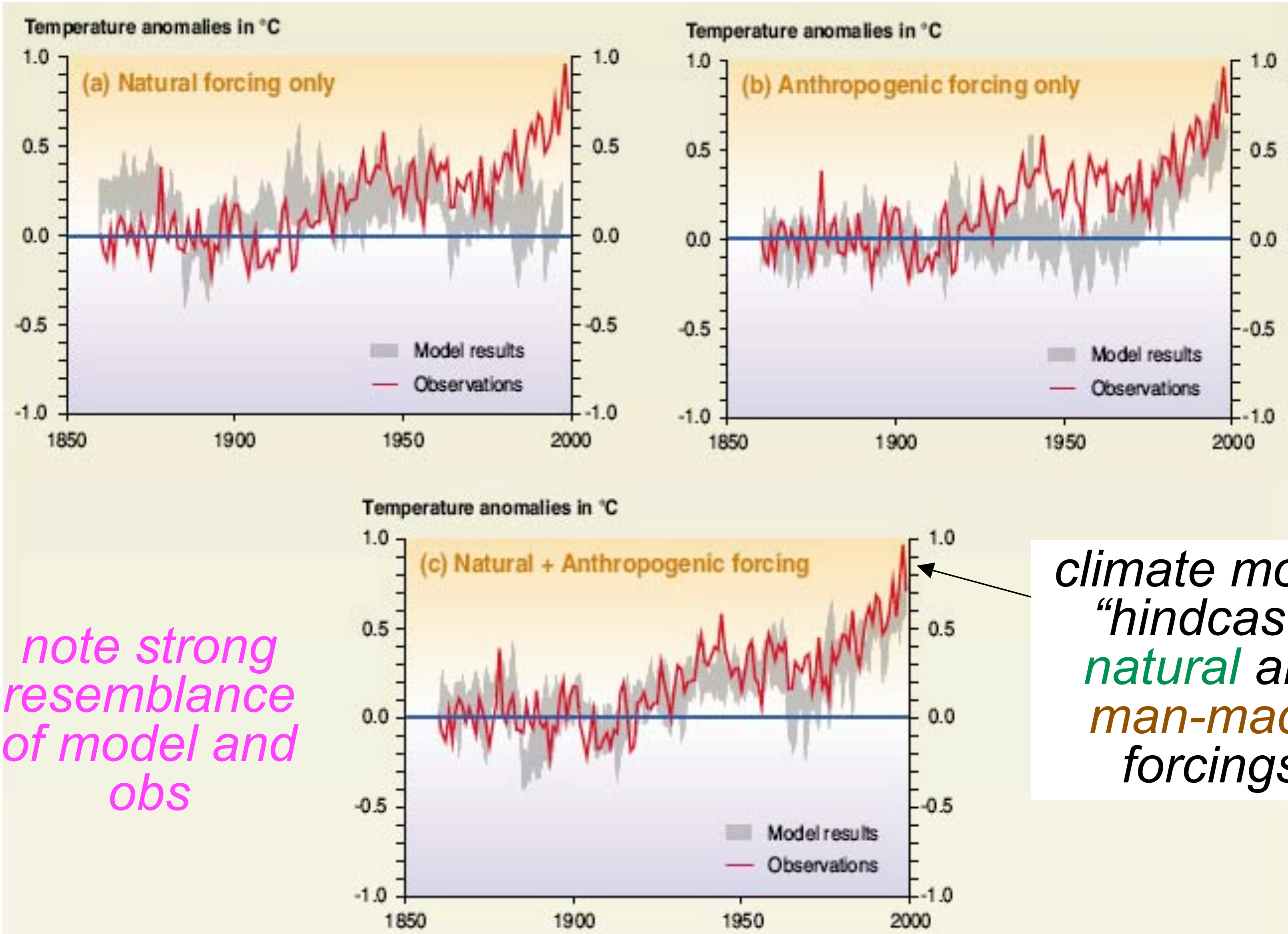
global temperature change since 1860



climate model
"hindcast"
man-made
forcings only

IPCC TAR (2001)

global temperature change since 1860

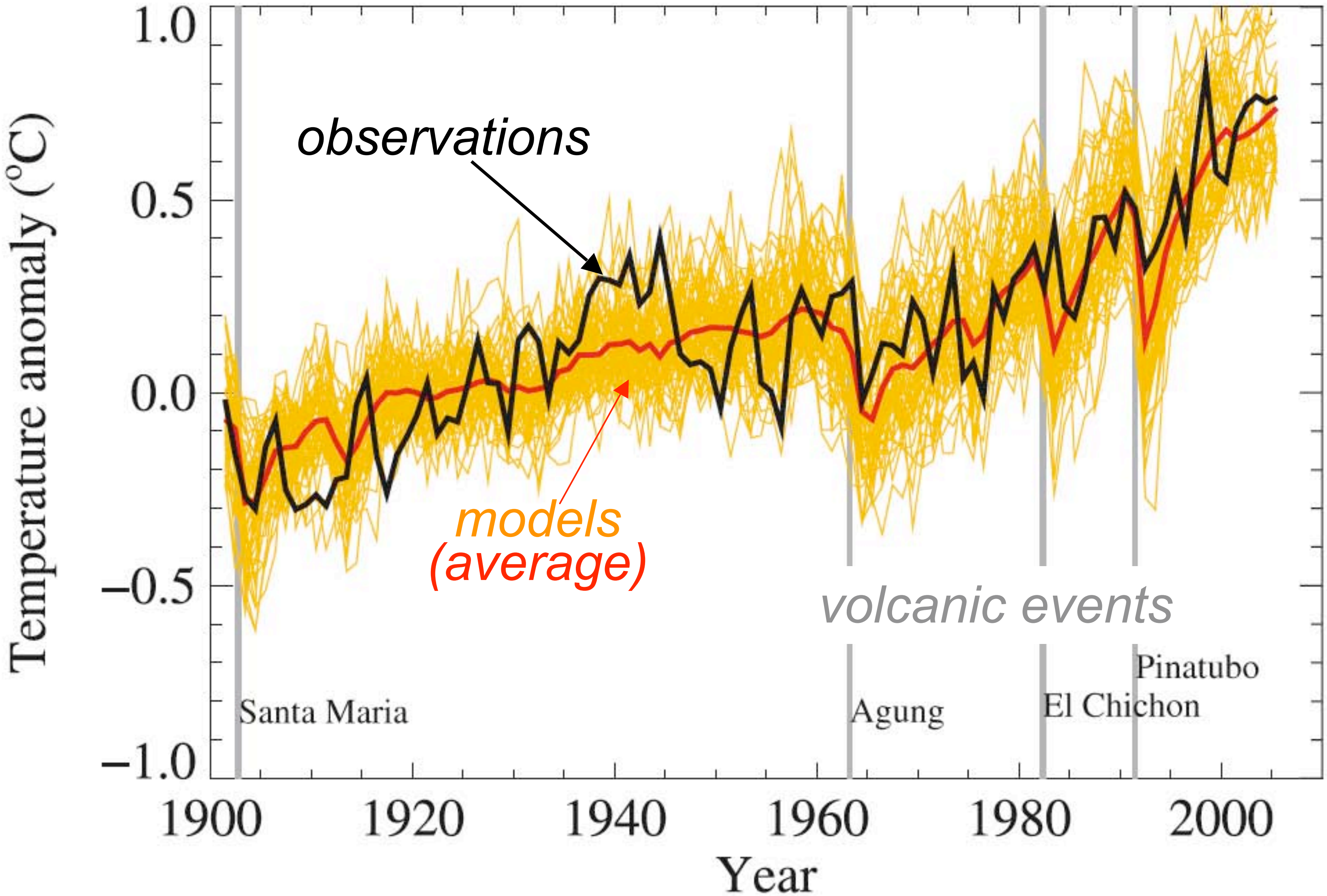


note strong resemblance of model and obs

climate model "hindcast": natural and man-made forcings

IPCC TAR (2001)

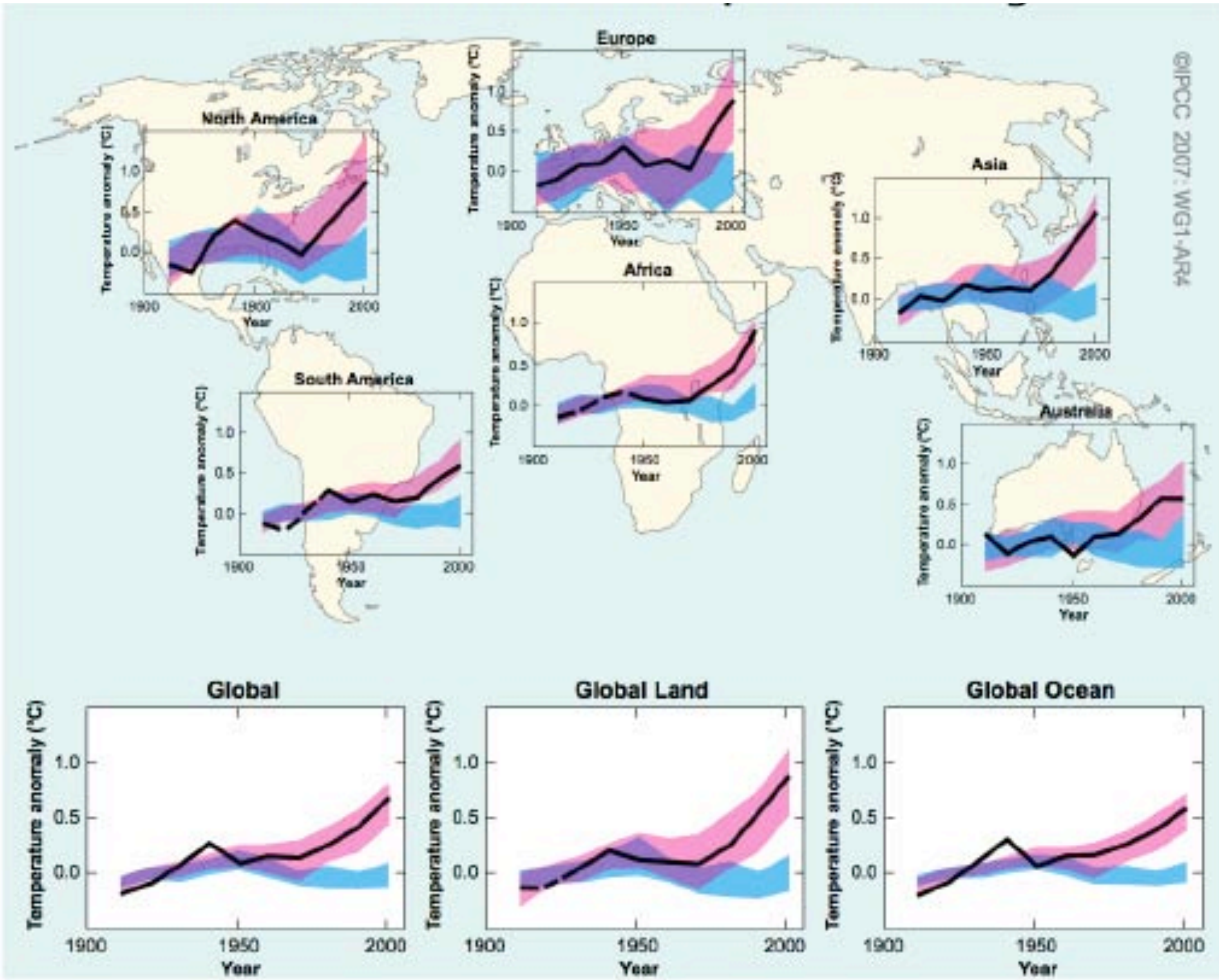
global temperature change since 1900



58 simulations (fr. 14 models) vs. observations

IPCC AR4 (2007)

temperature change since 1900



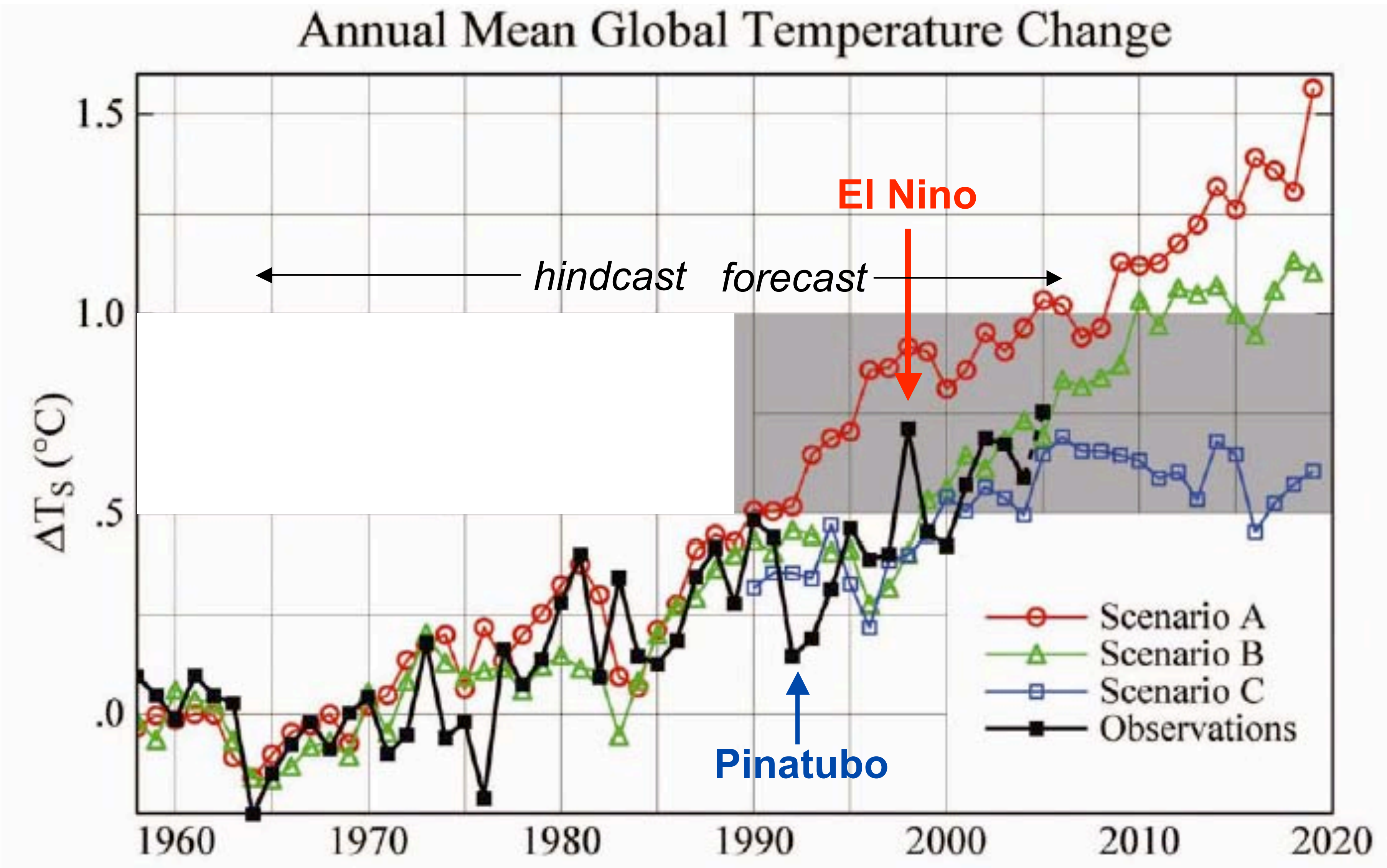
model "hindcasts" considering all factors (incl. GHG's),
natural factors only, black is ***observed temperatures***

source: IPCC '07

Hansen's bold prediction

In 1988 NASA's Jim Hansen testified to the US Congress. He showed a yearly forecast (and hindcast) of global surface temperature change in the NASA-GISS model due to past and projected GHG emissions (and other forcings). He modeled 3 scenarios, A for fast burning, B for "business as usual", and C for slow burning. He suggested scenario B was most likely. For realism, he sprinkled volcanoes into the future record at mid-decade. This is what he showed, but with the 20 years of observations since now added.......

Hansen's bold prediction



volcanic eruption occurred in 1991, not mid-decade...

large El Nino in 1998

Hansen's bold prediction

Most scientists are uneasy making predictions.

Jim Hansen understood the limitations of models, but he also understood that *radiative forcing* was ever increasing due to GHG's and would soon dominate all sources of natural variation, giving him confidence in his predictions.

Jim Hansen is a national science hero!

summary points

- natural variation in estimated *radiative forcing* from solar changes and volcanoes explains much of the variability in reconstructed temperature prior to ~1900
- after that, *radiative forcing from increasing GHG's* is required to explain observed temperatures
- we have already reached the point where radiative forcing from GHGs (minus that from aerosols) is larger than the natural variation in radiative forcing during the past millennium

six easy pieces

- there is a natural greenhouse effect
- radiatively important trace gases contribute to the natural greenhouse effect
- radiatively important trace gases have increased markedly due to human emissions
- radiative forcing is a useful diagnostic and can be easily estimated (and individual radiative forcings are simply additive)
- climate sensitivity is somewhere around 3/4 °C per W/m^2 (i.e. ~3 °C for CO_2 doubling)
- the product of the altered radiative forcing and the climate sensitivity is a significant number

lecture 16 learning goals

- be able to describe the factors that may have influenced global temperature over the last millennium
- use the concept of *radiative forcing* and *climate response* in an attempt to explain the temperature history of the last 1000 yrs as reconstructed from geologic proxies (tree rings, etc.) and thermometers
- consider how well estimated changes in *radiative forcing from natural factors* explain reconstructed temperatures of the last millennium v. the anomalous warming of the 20th Cent.+
- be familiar with Jim Hansen’s 1988 prediction and the observed outcome

next class:

- sea level change
- reading: Ch. 11
- HMWK due today