

Lecture 27

The long-term temperature record.

This lecture: How do we know that the 1990s was the warmest decade in the last 1000 years?

An important scientific issue is being able to distinguish natural variability (solar, volcanic forcing, ENSO) from anthropogenic influence. Coming next.

(Ch. 15: p.292, then p.296-315, skip p.293-295)

The Little Ice Age

Late 1500s - cooling that continued through to about 1850

Evidence:

- re-advance of glaciers
- wintertime freezing of rivers (Thames in London, Tagus in Spain/Portugal, canals of Amsterdam) and seas (Baltic Sea).

Been proposed that the low number of sunspots during the period 1400-1650 AD was somehow related to the cold climate. However, no satisfactory hypothesis has yet been developed to explain how solar sunspots would significantly affect climate.

Our best data (satellites since 1978) show that changes in solar flux are not significant over the 11-year solar sunspot cycle. Only very shortwave UV changes significantly but this only affects the temperature of the atmosphere above 85 km altitude.



Pieter Bruegel the Elder (1525–1569).
Bitter winter, Feb 1565, Holland

Proxy data used to reconstruct climate

- 1) Pollen
- 2) Tree rings
- 3) Corals
- 4) Ice cores (gases, isotopes)
- 5) Ocean sediments
(seen these before for glacial cycle record)

Pollen: (e.g. from lake sediments) tell us the past vegetation that lived.
For example, a pine forest might be followed by an oak forest, a pattern typical of a shift to a drier climate.
(**Palynology** - study of pollen)

Trees: Annual growth rings provide the age of a tree. The width of the growth ring can be related to the availability of water and the temperature in the growing season.

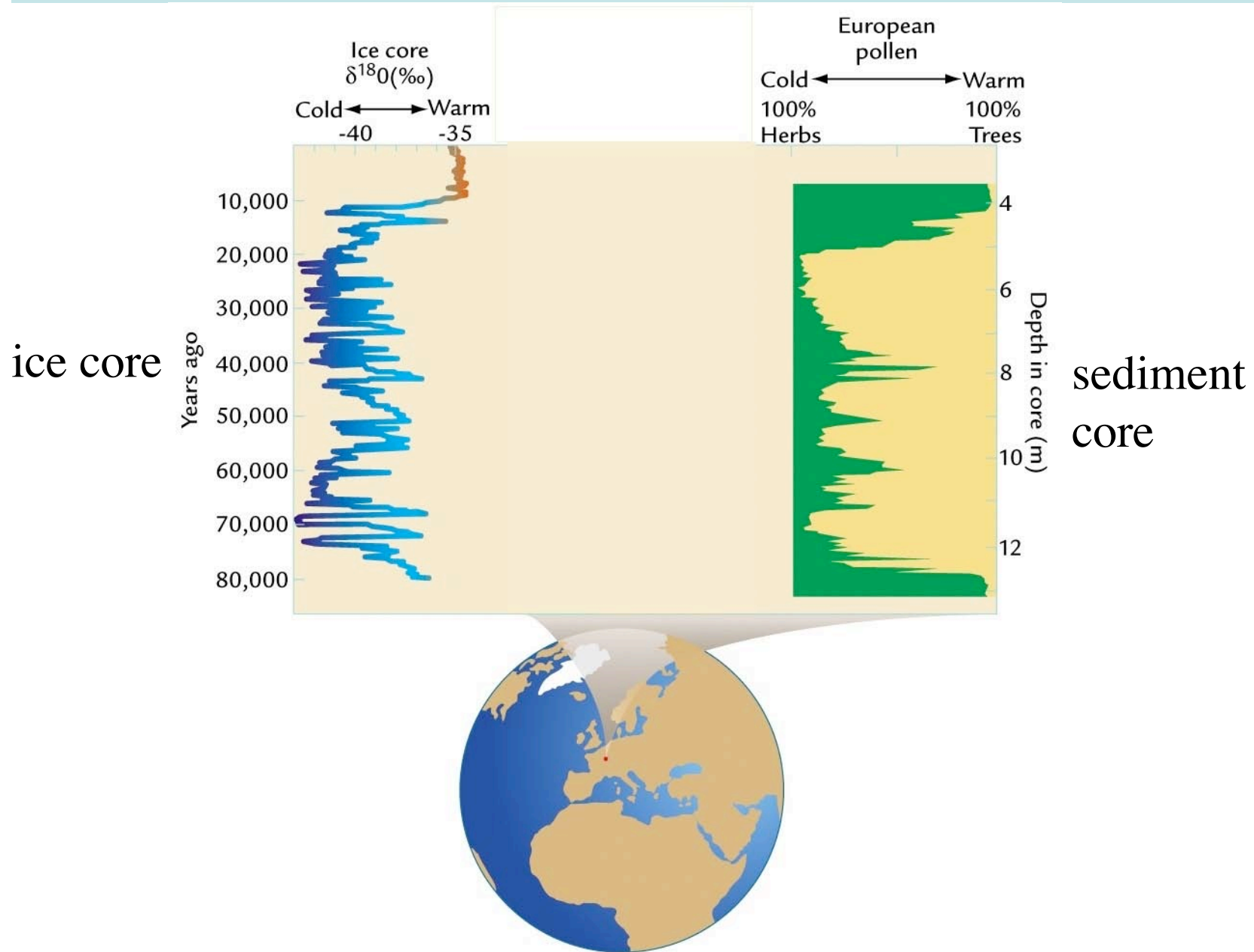
(Leonardo da Vinci: wet/dry years evident in tree rings.)

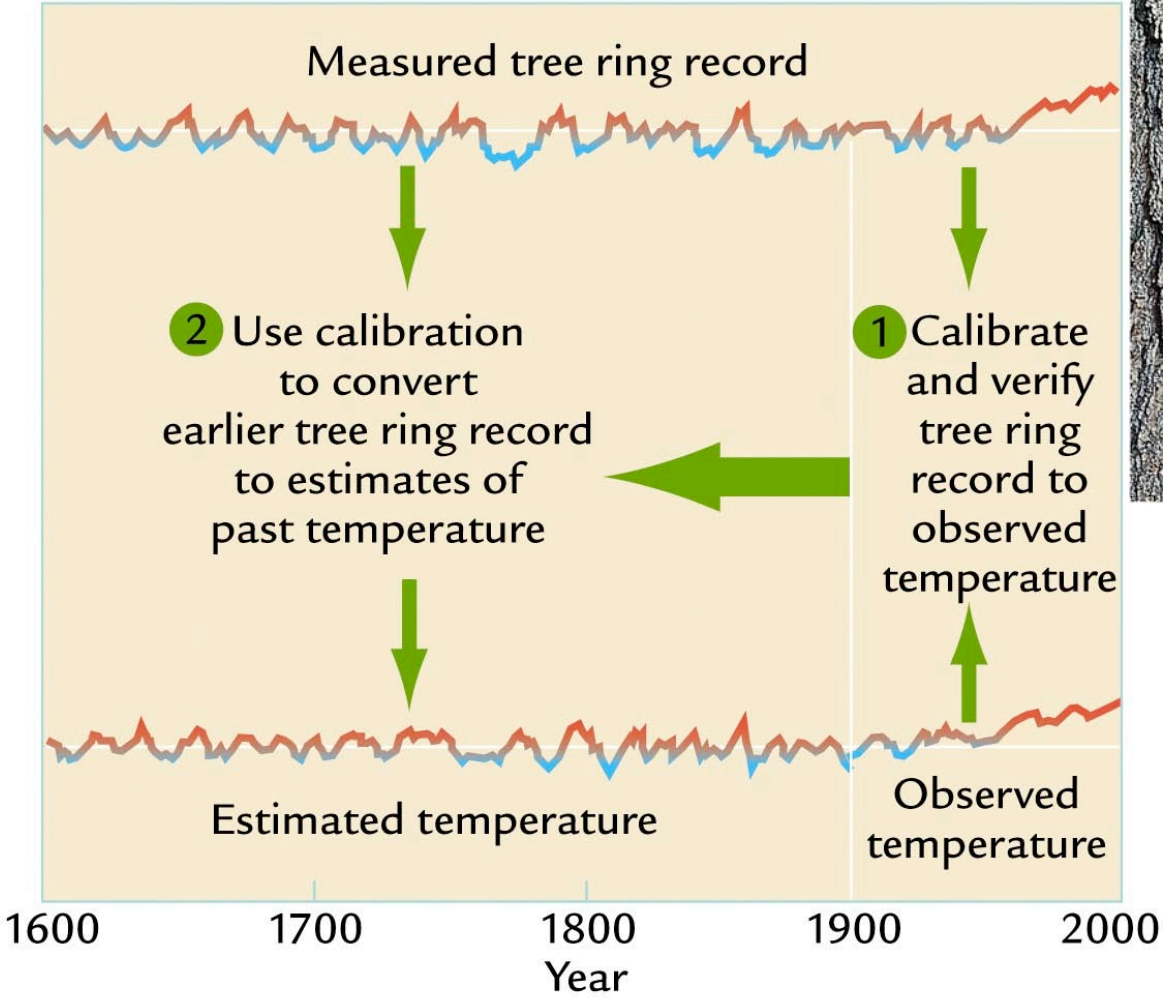
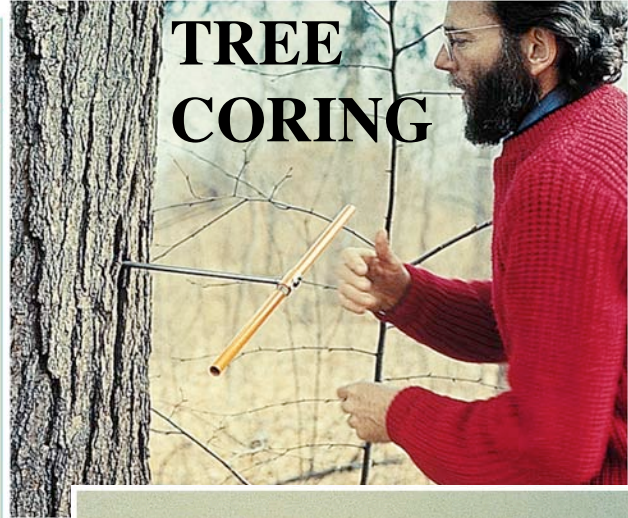
1837: Charles Babbage mentions tree rings for dating (**dendrochronology**)

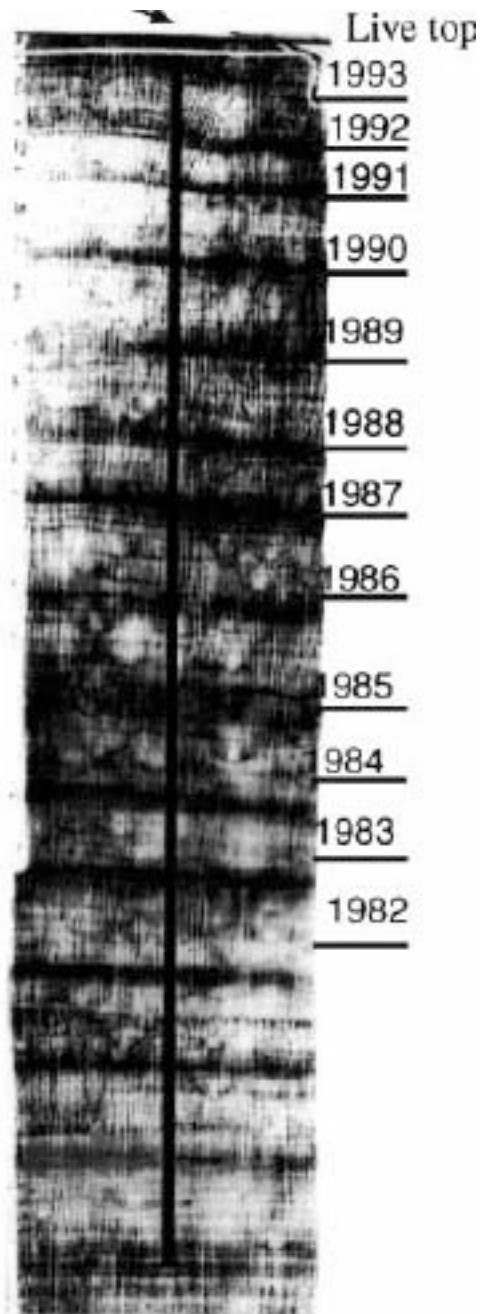
1928: Andrew Douglass (US astronomer) develops the technique.

Corals: Seasonal growth band and stable isotope variations in CaCO_3 skeleton.
 $\delta^{18}\text{O}$ decreases as temperature increases because of (a) more evaporation of ^{18}O , and (b) more direct incorporation of ^{16}O into the CaCO_3 (a kinetic effect).
Yields a reliable temperature record to $\pm 0.2^\circ\text{C}$ accuracy.
(**Summary: Low $\delta^{18}\text{O}$ = WARM , High $\delta^{18}\text{O}$ = COLD**)

Pollen correlation: glacial-to-Holocene







Annual coral bands

(from coral collected in 1994)

[Source:

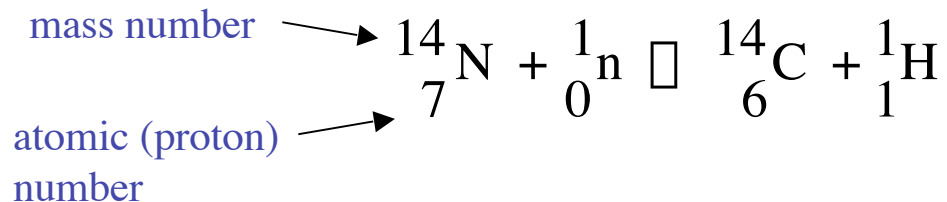
Linsley et al., (1999) *Coral Reefs*

18, 13-27.]

Carbon dating

Method by William Libby in 1949 (Nobel Prize in Chemistry, 1960)

In the upper atmosphere, cosmic ray neutrons interact with nitrogen and make carbon-14:



Radioactive ^{14}C gets oxidized to $^{14}\text{CO}_2$. This CO_2 is mixed by convection and winds to a near constant fraction in the atmosphere. CO_2 is cycled through vegetation. All living things contain some radioactive ^{14}C . Can calibrate past variations in solar cosmic rays, and hence atmospheric ^{14}C , using tree rings.

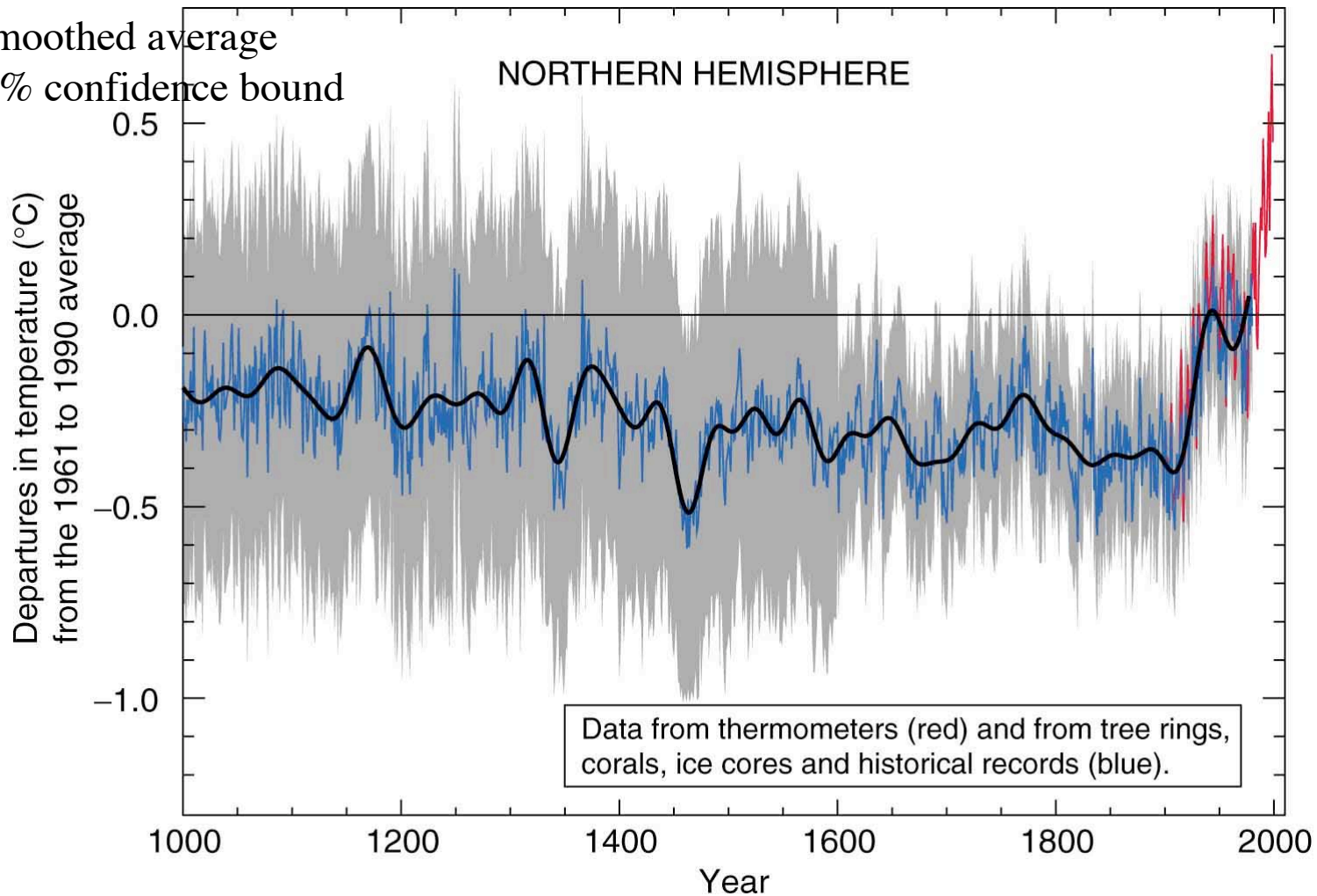
When organisms die, ^{14}C decays with a half-life of 5730 years to ^{14}N . This provides an age of shells, bones, dead wood, corals, etc.

“The 1990s are likely to have been the warmest decade of the millennium in the Northern Hemisphere” (IPCC 2001)

blue = data

black = smoothed average

gray = 90% confidence bound



What is the the largest, 50-year change in the pre-industrial era? What is the magnitude of this change (best-guess and upper bound)?

Recent climate changes - and natural variability

- Volcanoes and Climate (Kump 15:299-302)
- Sun and Climate (Kump 15:303-306)

Motive: context for assessing the question of future climate change

- Natural variability produces "noise" (ups and downs) in the temperature record
- Volcanoes provide a test of the theory that changes in energy balance cause changes in Global Annual Average Surface Temperature (GAAST)
- Solar changes are frequently invoked and emphasized by the so-called "skeptics" as an alternative explanation for the observed, global warming. Does it have any scientific credibility? Answer: No.

Natural Variability, Signal, and Noise

Any measurement in science contains signal, what we are trying to detect and quantify, and noise, anything that gets in the way of detecting and quantifying the signal.

When we examine the temperature record, we are trying to determine if it contains the signal of human-induced global warming. Two types of "noise" get in the way:

- errors in the measurements (discussed in Kump, Chap 1)
- natural variability

In essence, we need to be able to answer this question:

How large are natural changes in GAAST?

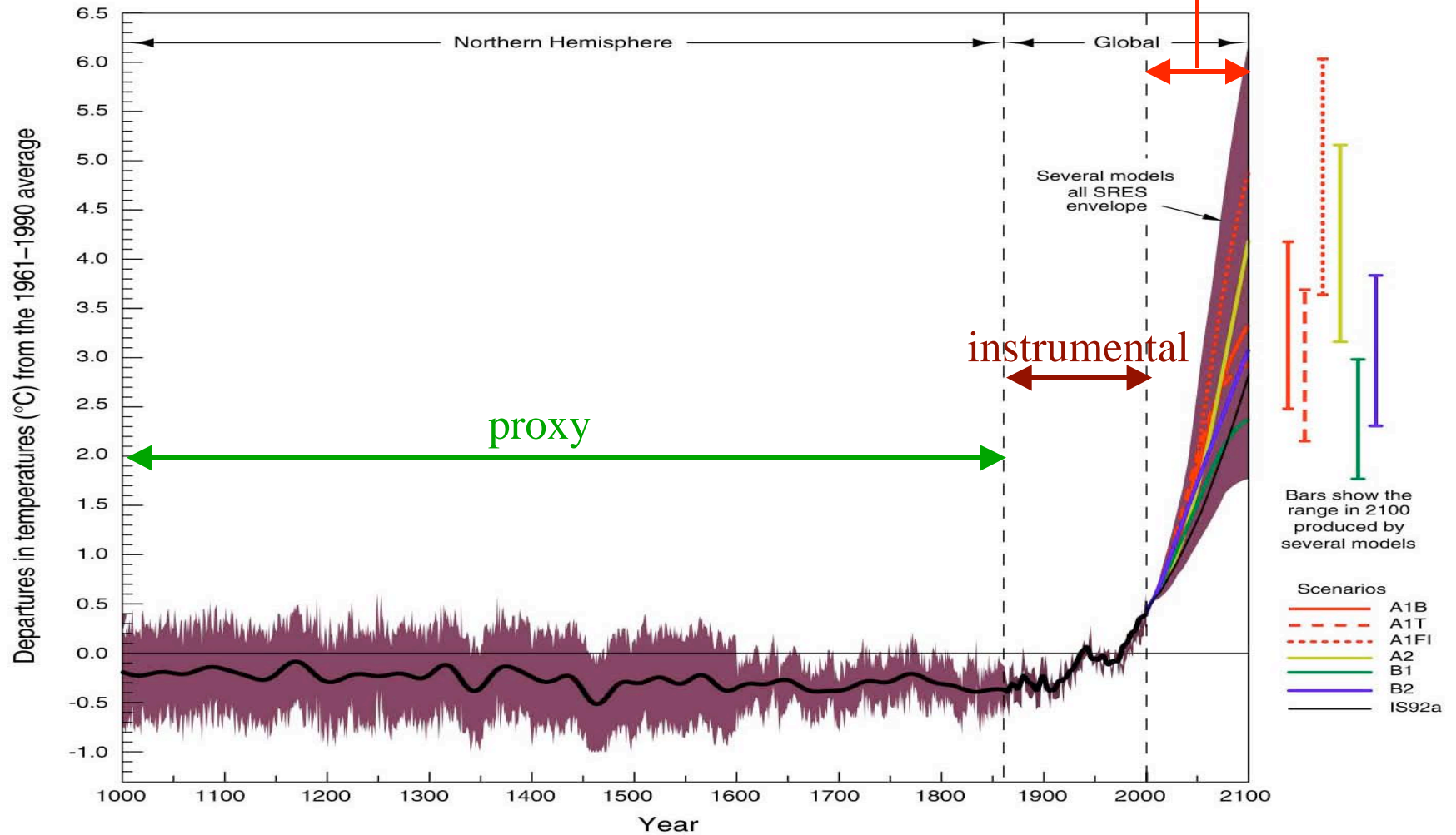
Given that information, we can assess the likelihood that the industrial-era changes in GAAST represent natural variation and not a human-induced effect.

(In a statistical analysis, natural variability would be the "null hypothesis".)

Does the "signal" of predicted global warming rise above the "noise" of natural variability in T-observations so far?

theory/
prediction

1000 to 1861, N.Hemisphere, proxy data; 1861 to 2000 Global, instrumental; 2000 to 2100, SRES projections



Natural climate variability due to Volcanoes and the Sun

Two types of natural variability of climate:

- 1) unforced change (**internal variability**)
- 2) change that is forced by natural causes:

Volcanoes and Solar changes are the two main mechanisms of natural, forced change.

Basis for historical research - proxy records

volcanoes: ash and sulfate in snow and ice-cores (many 1000s of years)

sun: sunspot observations (centuries to a few thousand years)

Forcing mechanism (physical basis of the forcing):

- well understood for volcanoes

- i. sulfur dioxide (SO_2) injected to the stratosphere forms sulfuric acid droplets
- ii. particles in the stratosphere reflect sunlight, increasing Earth's albedo
- iii. Pinatubo (1991): forcing and corresponding surface cooling were measured

- highly speculative for the sun

- i. changes in solar energy have been measured but are too small
- ii. therefore, exotic theories involving cosmic rays and clouds are invoked as "possible mechanisms". (To date, these appear implausible.)