Mon Nov 17

Where we're going:

This week: recent climates and climate variability

KKC Chaps 11,12 (selected)

Today:	Astronomical theory of ice-ages
Tues:	Evidence of ice-ages (movie and in-class exercise)
Wed:	Volcanic and Solar Influences on climate (Patrick Zahn)
Thurs:	HW#5 DUE El Nino / Southern Oscillation (Dr. Nate Mantua)
Fri:	*review, tutorial*

upcoming talks

TUESDAY 18 November

12:30 ATG 310c, Weather discussion, Mark Stoelinga

2:30 A-118 PAA (physics/astronomy auditorium), Prof Peter Ward, Why there were dinosaurs, Why there are birds

FRIDAY 21 November

3:30 14 OTB (Oceanography Teaching Bldg)

Dr. David Archer, U. Chicago, Deep-sea argon as a carbon-cycle indicator

Paleoclimate: why study?

We address questions like…

Has climate changed in the past?

How much?

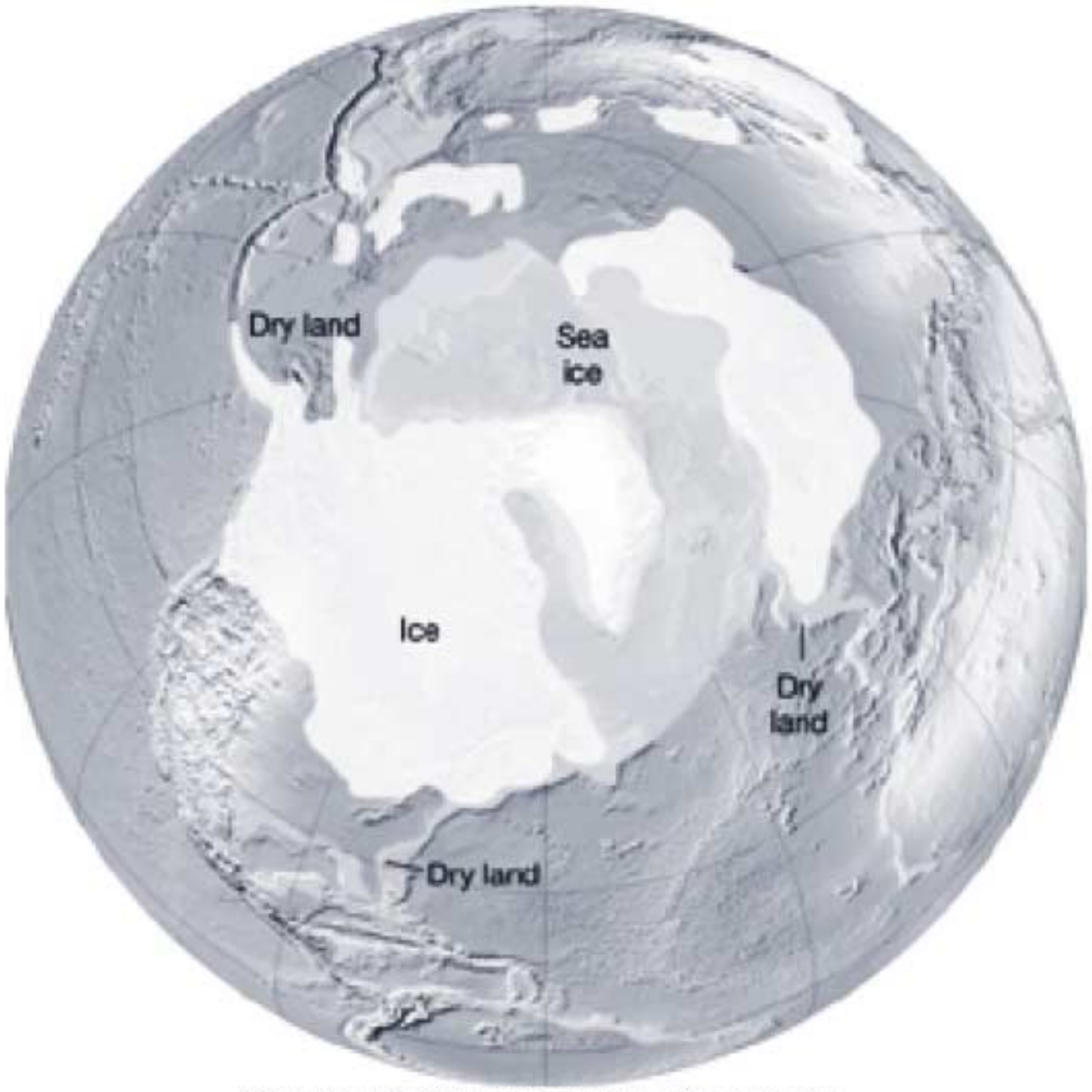
How fast?

The answers provide a context for assessing potential climate changes in the future.

Paleoclimate studies may give us insights into

- mechanisms of climate change
- functioning of the Earth system
- stabilizing or amplifying feedbacks

Glaciation Map



Pleistocene Glaciations:
OVERVIEW

Geological evidence
- abundant, overwhelmingly convincing
- timing info is not precise (see Ahrrenius, 1896)

Ocean sediments
- ^{18}O provides record of glacial ice amount
- detailed, precise timing information
- timing seems to correspond to orbital parameters

Ice-core record
- ^{18}O provides record of local temperature
- air bubbles provide record of CO_2 and other gases
- remarkable correlation between temperature and CO_2

Orbital parameters
- precession (23 k.y.), tilt (41 k.y.), eccentricity (100 k.y.)

Cause of glacial oscillations (theory)
- orbital trigger involving N. Hem. Summer
- ice-albedo feedback
- CO2 as contributing driver

Problems
- eccentricity: tiny trigger but dominant oscillation
- timing not always logical for specific events
- lapse rate in the Tropics

Pleistocene Glaciations:
LESSONS

1. Current climate is not the only possible one for Earth
   (indeed, glacial conditions seem to be preferred)

2. A change in surface temperature of about -5C is associated with a massive climate shift

3. Global climate and CO_2 appear to be intimately intertwined

4. If the orbital parameter theory is right, small triggers can produce major climate changes under some conditions

5. But… there are many remaining questions and enigmas

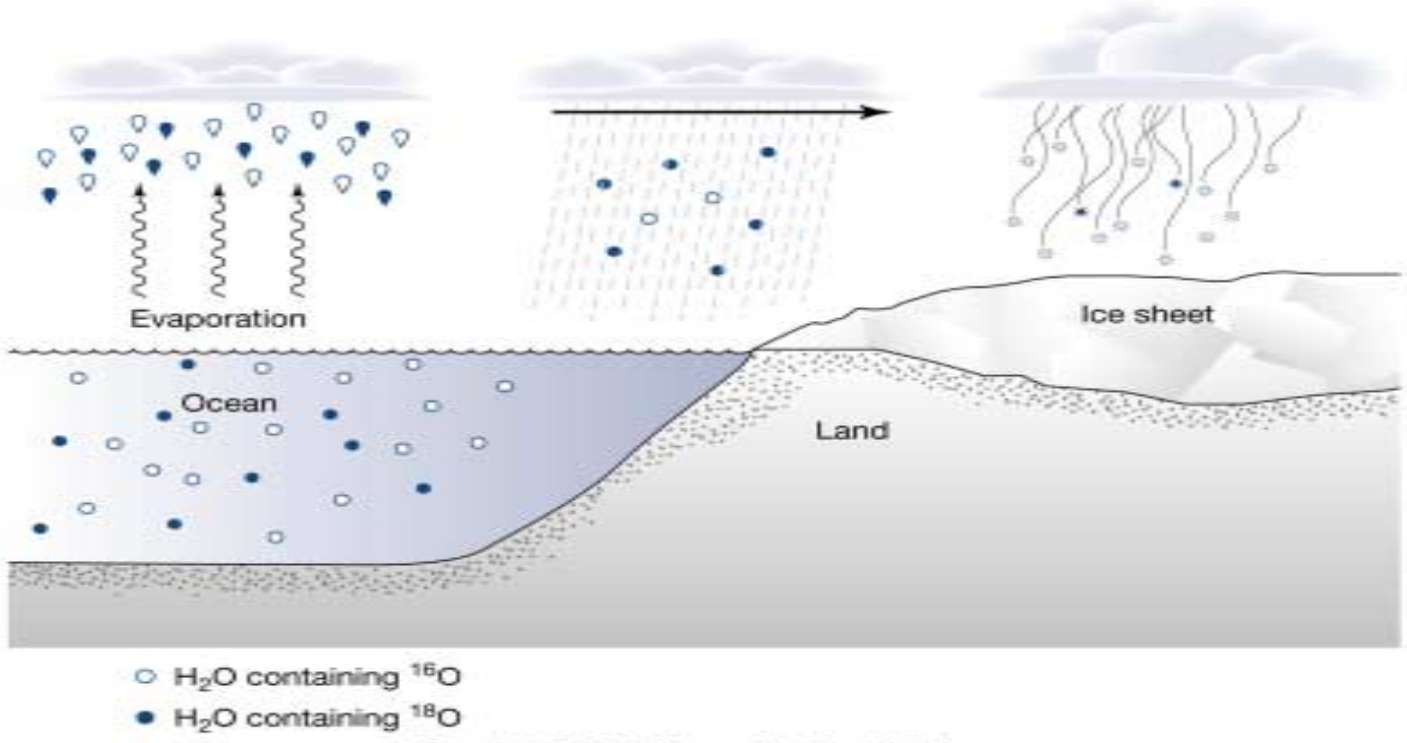
Isotopic Evidence (updated version of Fig 11-3)

^{16}O vs ^{18}O

"light" (normal)

"heavy"

- evaporation selects for "light"
- condensation (precipitation) selects for "heavy"



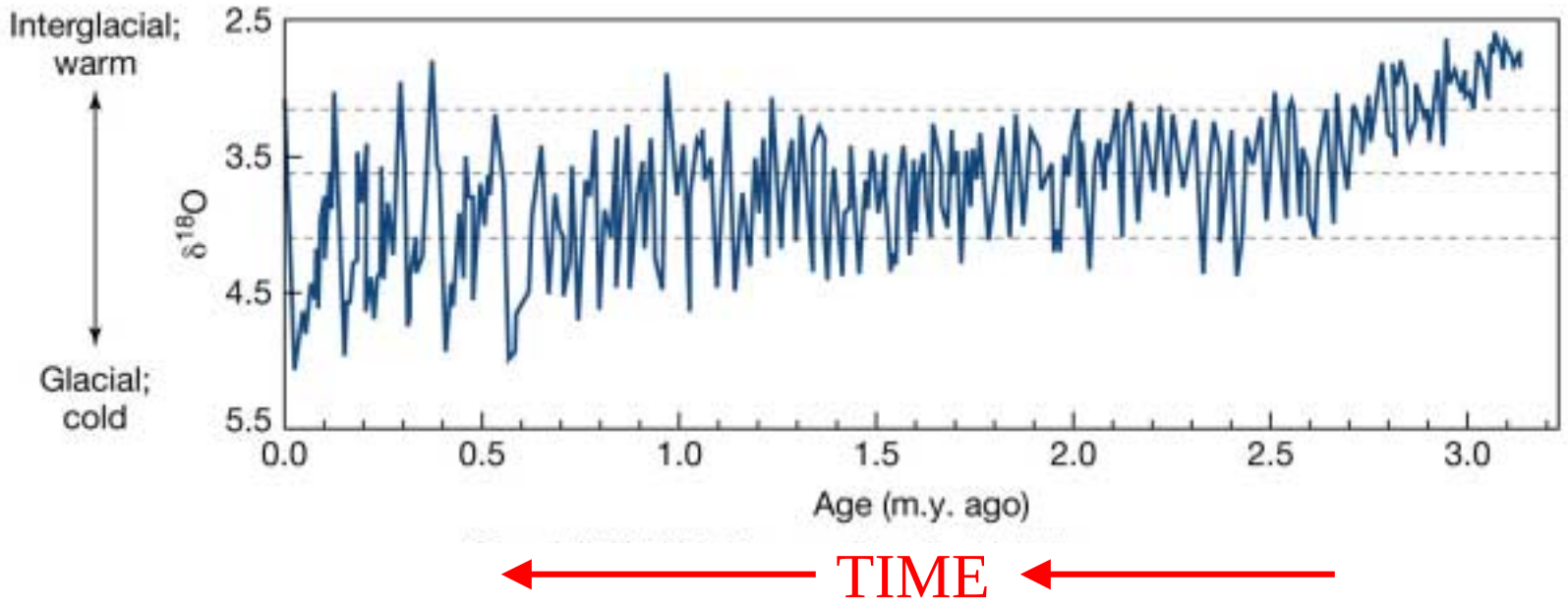
^{18}O in ocean sediments records glacial ice volume:

More "light" water in ice-sheets means remaining ocean water is "heavier".

^{18}O in ice-cores indicates local temperature:

Colder conditions means more precipitation en route so "lighter" snow.

3.5 Million Year Record of Global Ice Volume

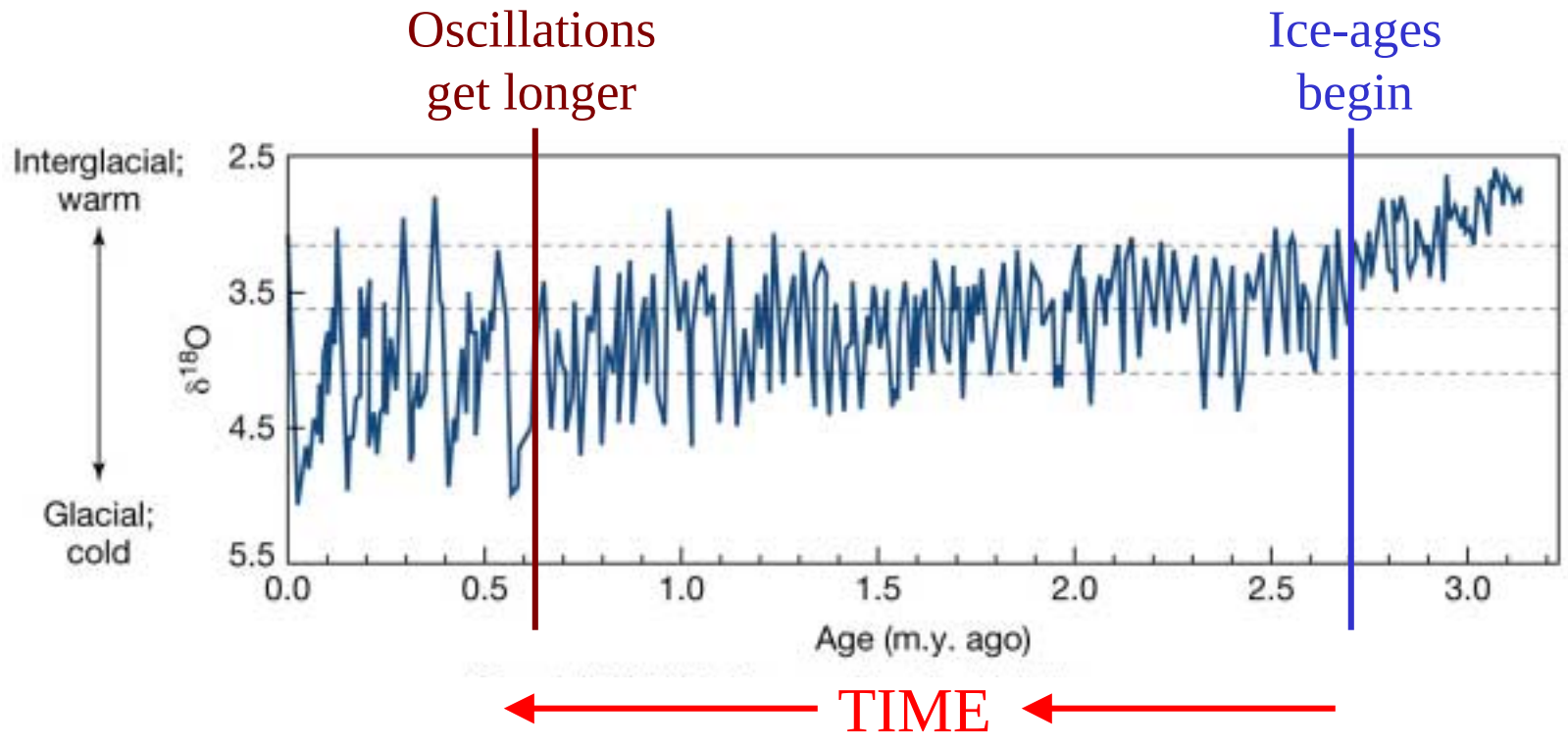


Questions:

1. **Is this an ocean sediment record or a polar ice-core record?**
2. **Which way does time go on this plot (left-to-right or right-to-left)?**

1. **Ocean sediments record ice volume. Ice-core records only extend back to about 500,000 years at most.**

3.5 Million Year Record of Global Ice Volume



Questions:

3. What two major transitions do you see in this record?

4. Was sea-level lower or higher than today during the three most prominent previous interglacial periods?

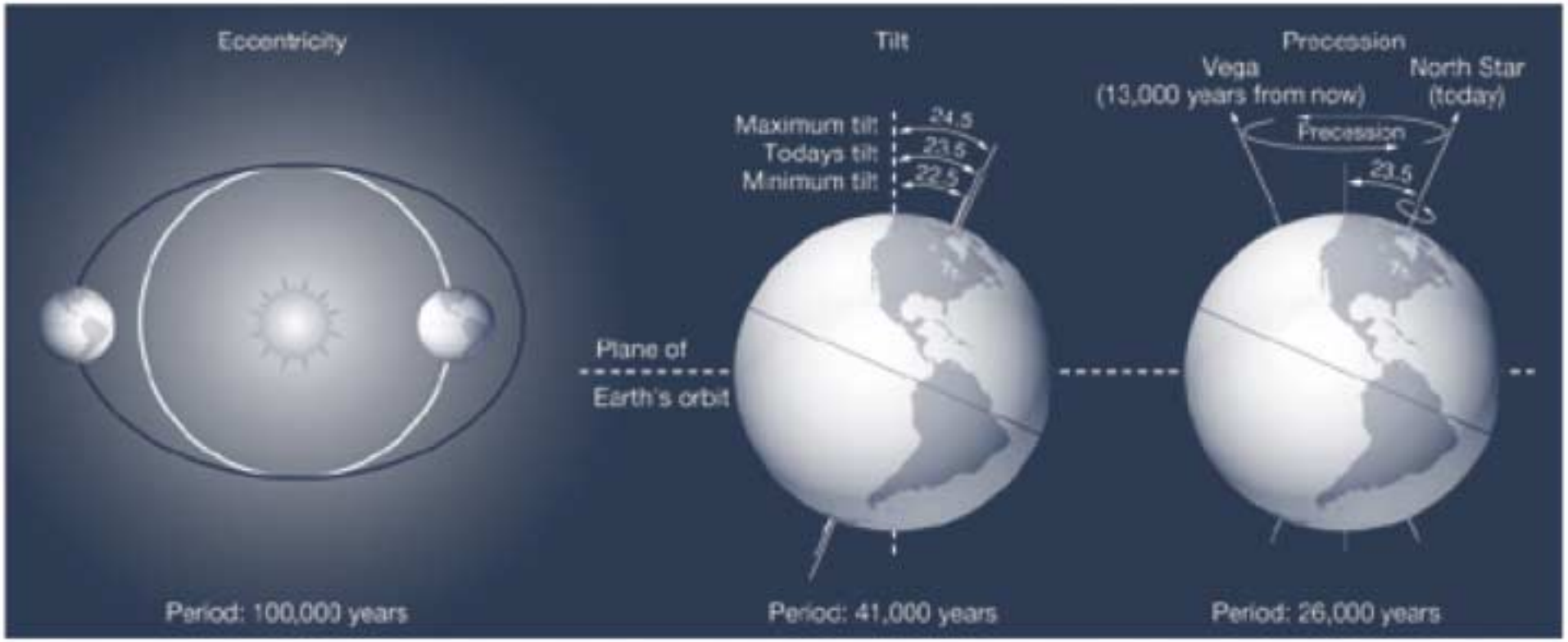
4. Less ice-volume, therefore higher sea level. (May have been warmer than today as well.)

Orbital Parameters

Eccentricity
100,000 years

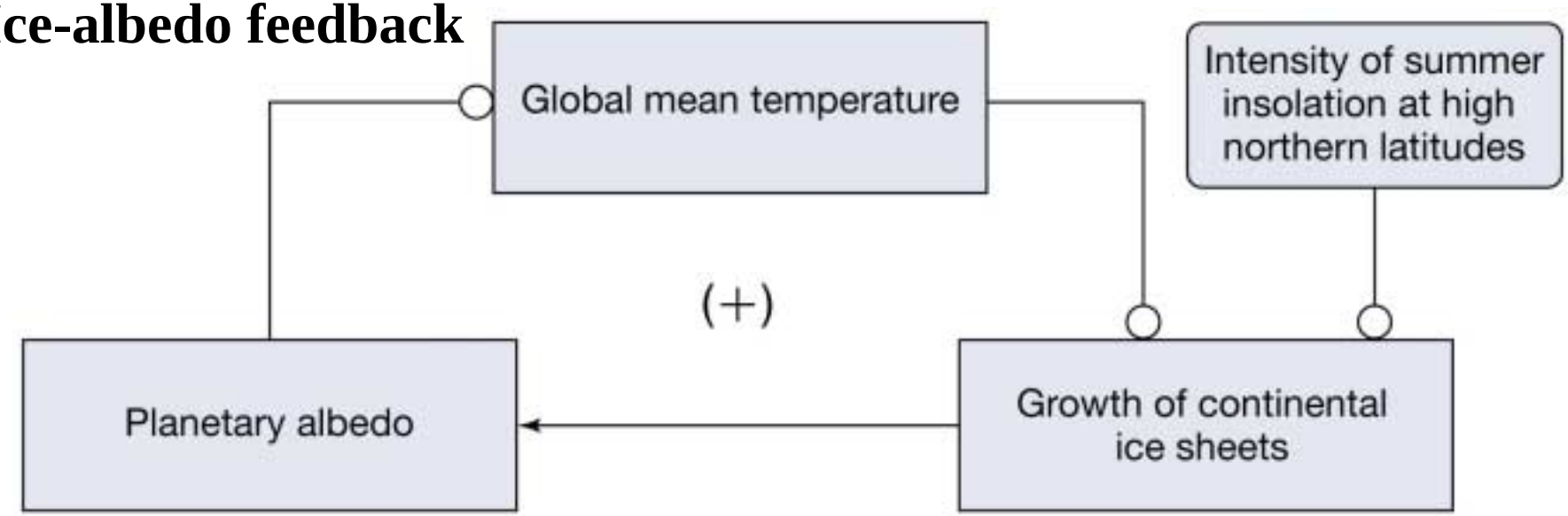
Obliquity (or Tilt)
41,000 years

Precession
26,000 years



Orbital Theory: Trigger and Feedback Mechanism

Ice-albedo feedback



Trigger with feedback causes ice-sheets...

to grow and keep growing

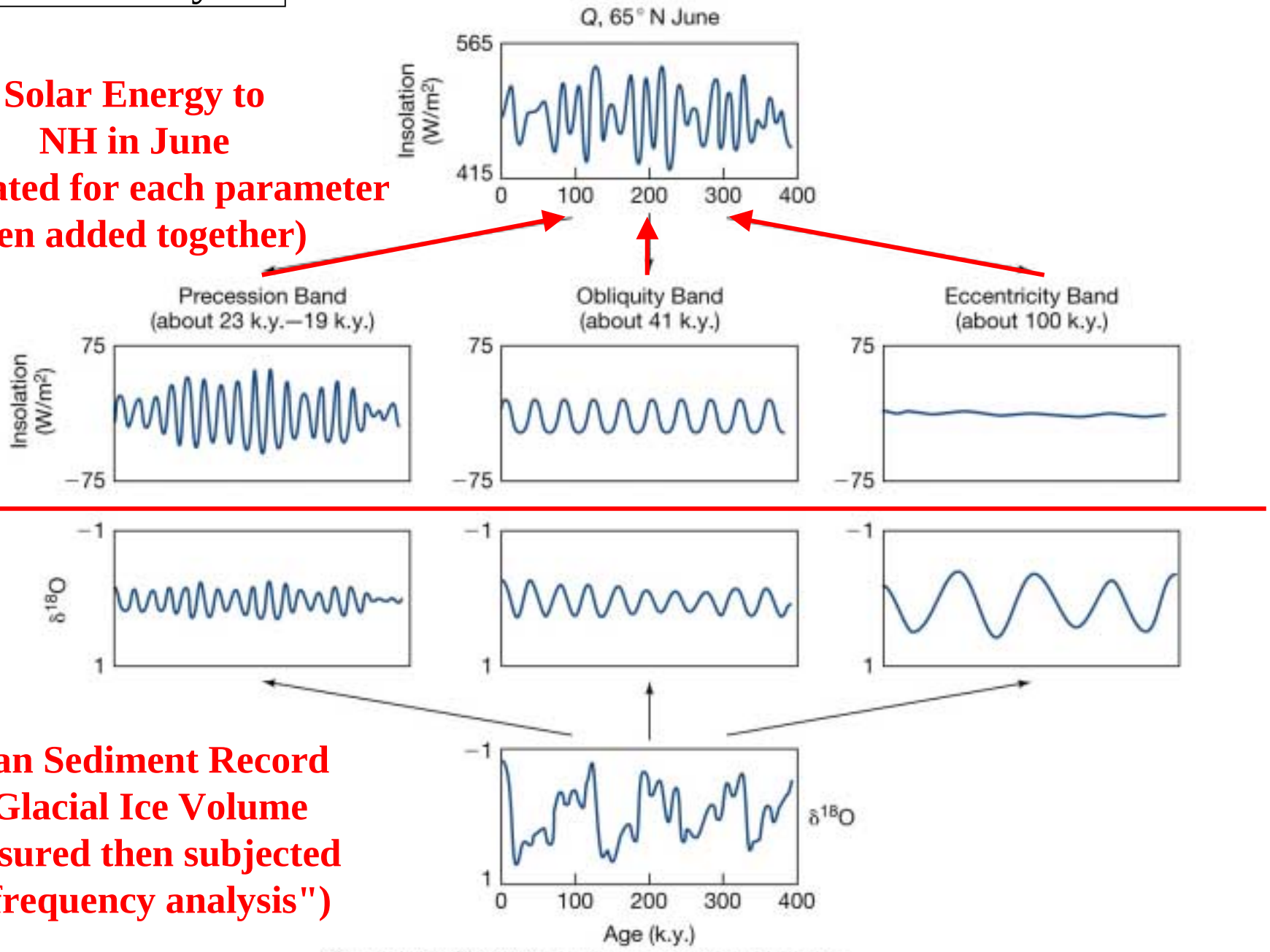
or

to melt and keep melting

- Other feedbacks are needed to explain the magnitude of the changes.
- Greenhouse gases (e.g. CO_2 and CH_4) seem to be involved. See text.

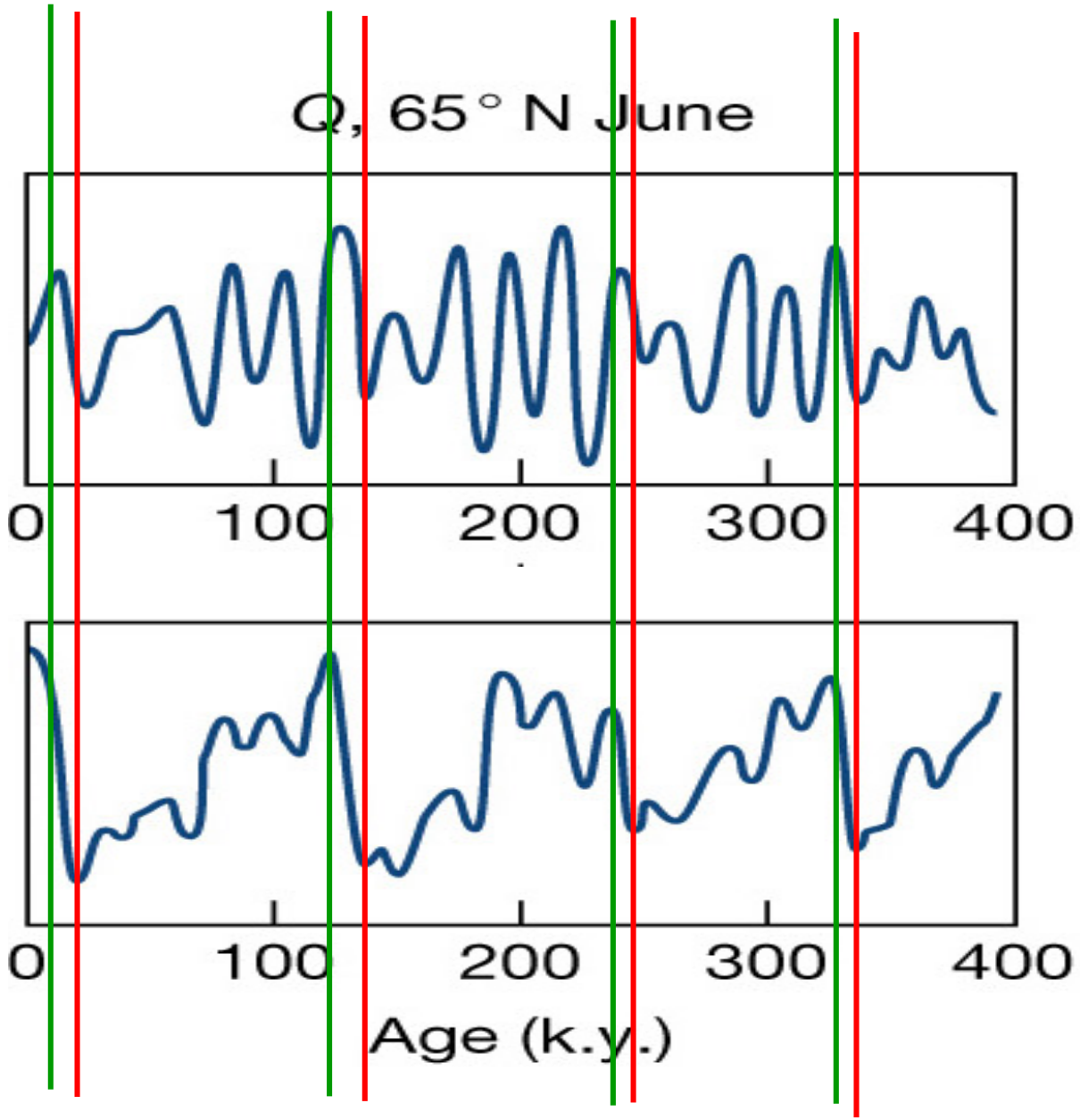
Orbital Theory

Solar Energy to NH in June (calculated for each parameter then added together)



Ocean Sediment Record of Glacial Ice Volume (measured then subjected to "frequency analysis")

Test of Orbital Theory: Is the timing right for major melt events?



Solar Input
NH, June,
High Lat

Response
Glacial
Ice-Volume

end
melt

begin
melt

Tues Nov 18

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Wed Nov 19

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Recent climate changes - Text

History of the Holocene
(KKC 12:232-236 - not required)

- wild swings coming out of latest glaciation
  (Younger-Dryas)

- warm period 5000-6000 yr b.p.
- cool period ~3000 yr b.p.
- Medievel warm ~1000 yr b.p.
- Little Ice Age ~300 yr b.p. (1400-1850 A.D.)

Recent climate changes - our focus

- Natural variability
- Volcanoes and Climate (KKC 12:236-240)
- Sun and Climate (KKC 12:240-242)

Motive: context for assessing the question of future climate change

- Natural variability is "noise" in the temperature record

- Volcanoes provide a test of the theory that changes in energy balance cause changes in GAAST

- Solar changes are frequently invoked and emphasized by the "skeptics" as an alternative explanation for the observed, recent warming.

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.
Examples???

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 Chap 1)
- natural variability

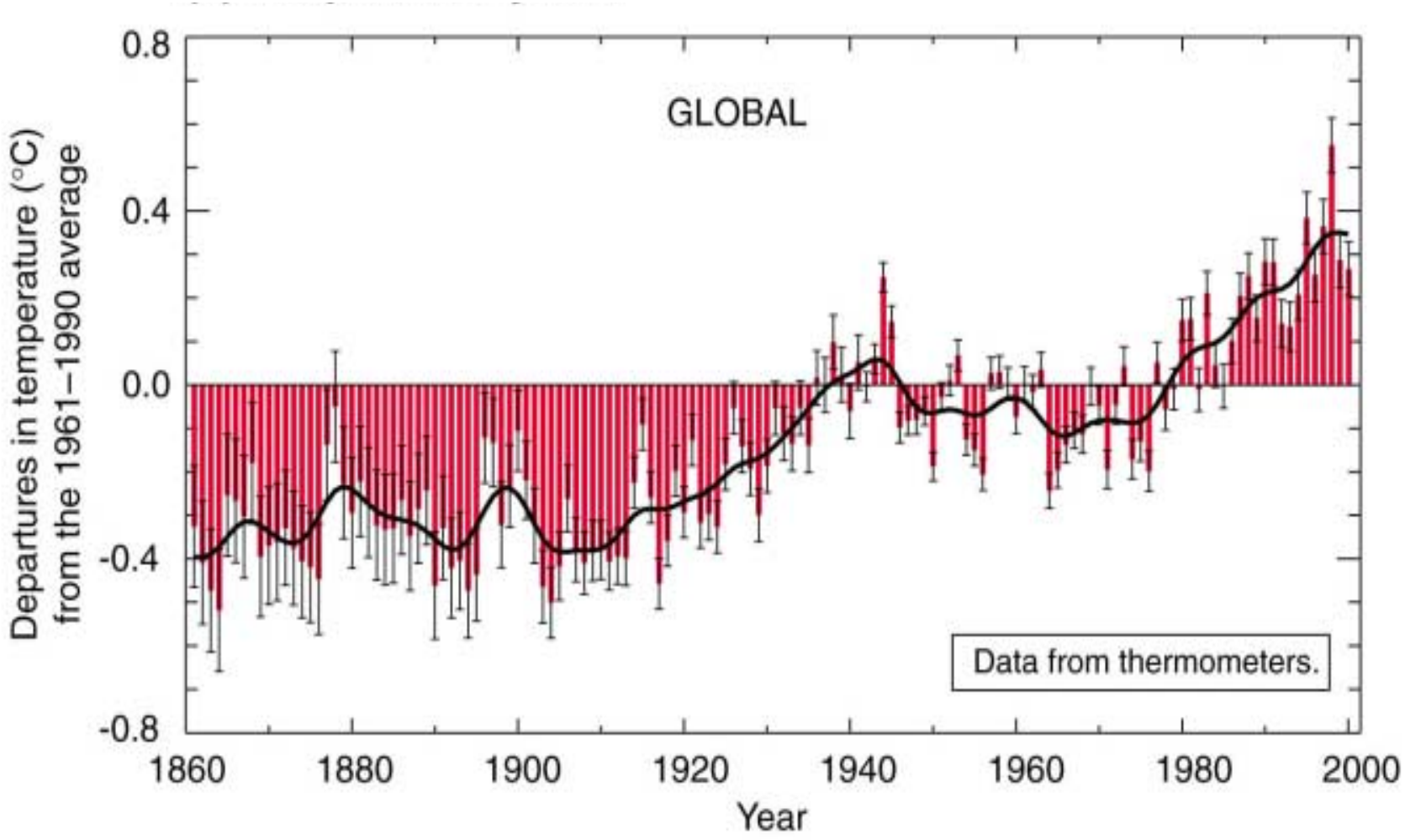
In essence, we need to be able to answer this question:

How large are natural changes in GAAST?

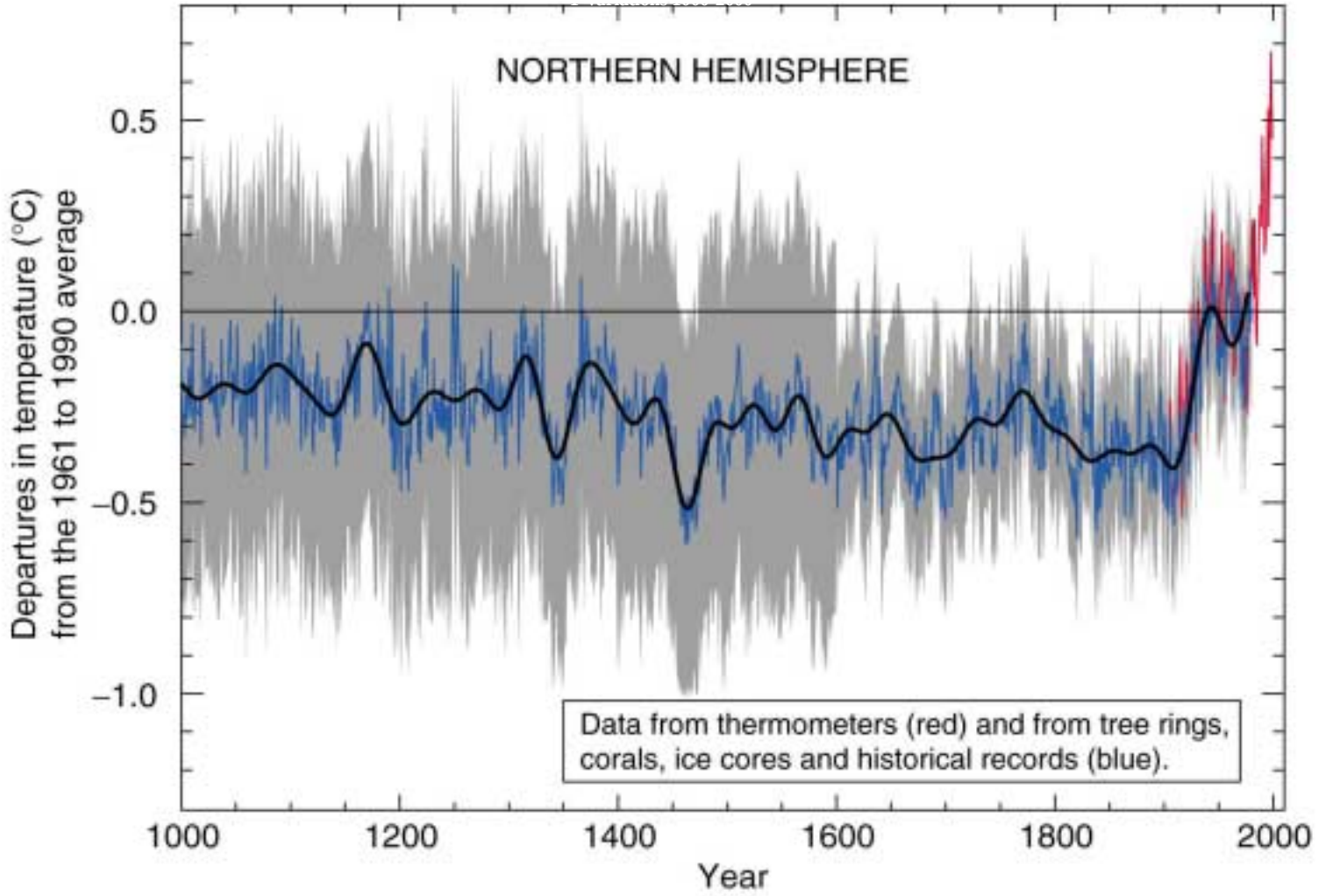
Given that information, we can assess the likelihood that the industrial-era changes in GAAST represent natural variation and not a human-induced effect.

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

Variations of the Earth's surface temperature for the past 140 years

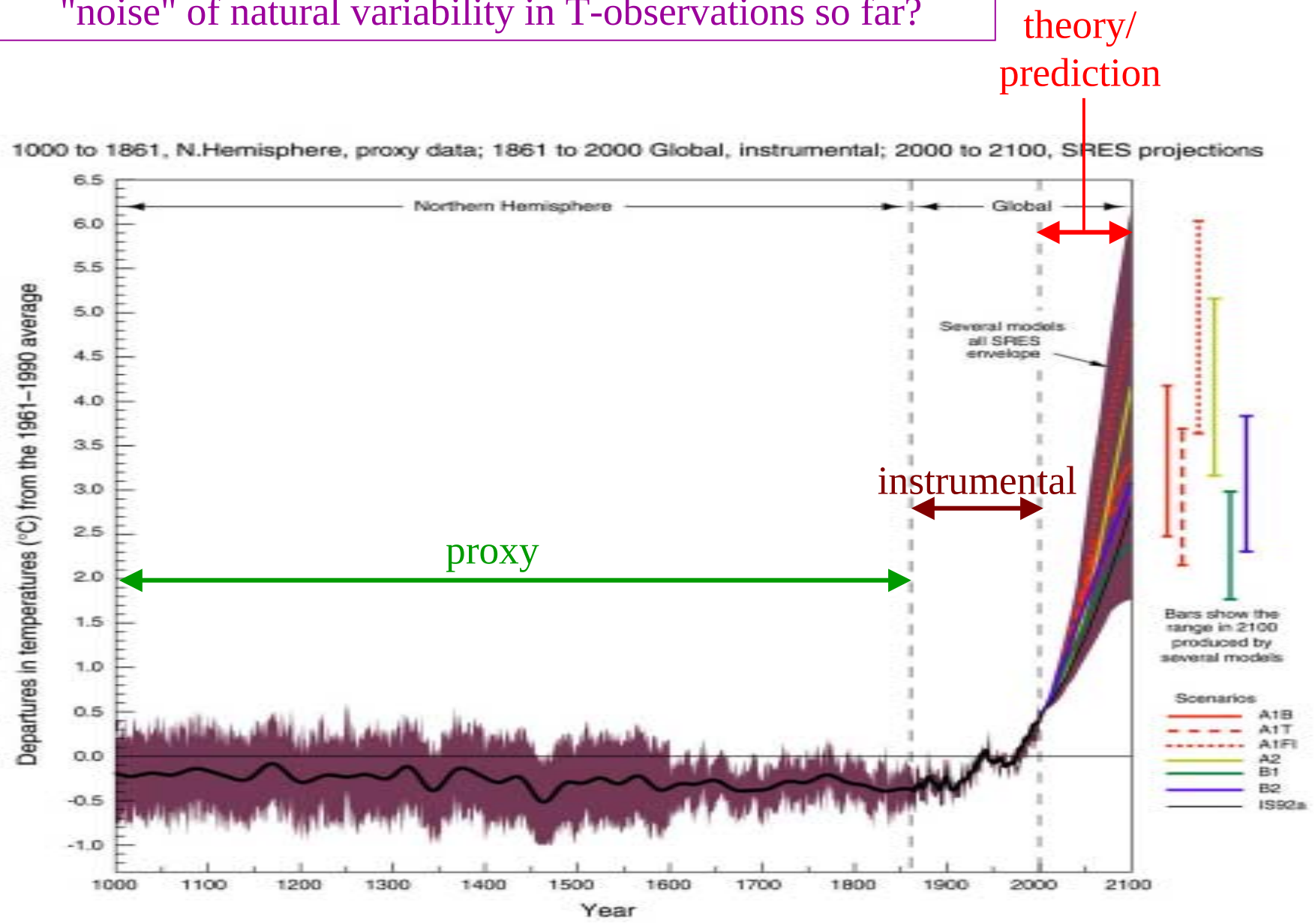


Variations of the Earth's surface temperature for the past 1,000 years



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

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



Natural climate variability due to Volcanoes and the Sun

Two types of natural variability of climate:
- unforced change (internal variability)
- change that is forced by natural causes

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

Physical basis of the forcing:

volcanoes: very well-understood (stratospheric particles reflect sunlight)
sun: highly speculative (cosmic rays and clouds)

Basis for historical research - proxy records

volcanoes: ash and sulfate in snow and ice-cores (many 1000's of years)
sun: sunspot observations (centuries to a few thousand years)

Forcing Mechanisms

Forcing mechanism (physical basis of the forcing):

- well understood for volcanoes
    i. particles in the stratosphere reflect sunlight, increasing Earth's albedo
    ii. for Pinatubo (1991) the 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 to be implausible.)

Mechanism of Volcanic Perturbation

- particles in stratosphere increase Earth's albedo
- negative climate forcing (cooling)
- well-understood

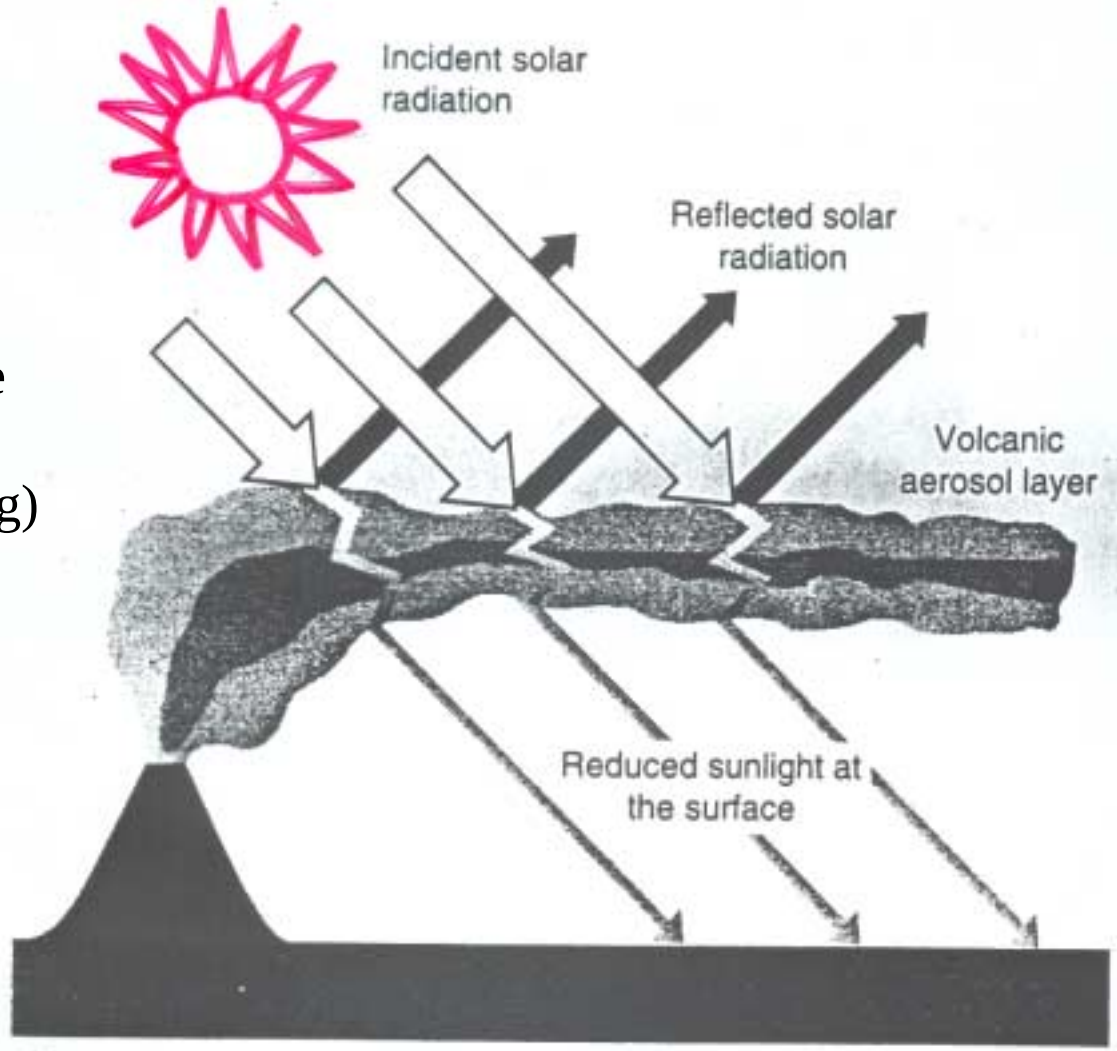


Figure 11.17 The effect of volcanic eruptions on the radiation balance and climate. The layer of particles generated in the stratosphere by a large eruption is seen to reflect sunlight, increase the Earth's albedo, and reduce the heating of the surface.

Duration and Evidence of Volcanic Perturbation

- duration is 2-3 years (particle lifetime in stratosphere)

- evidence of global cooling?

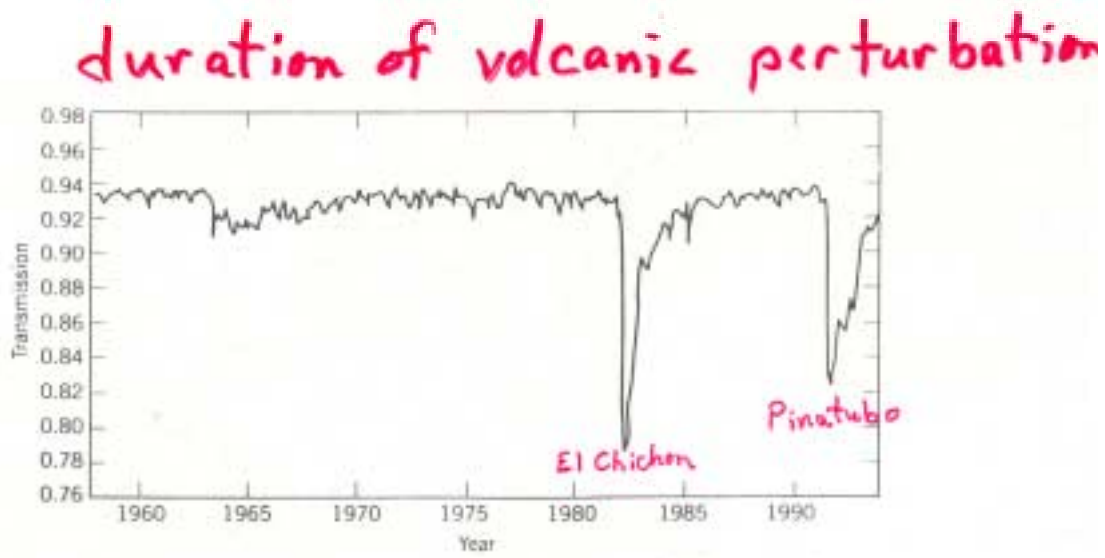


Figure 4.3 A measure of the transmission of sunlight through the atmosphere determined at the Mauna Loa Observatory, Hawaii, over the past 35 years.

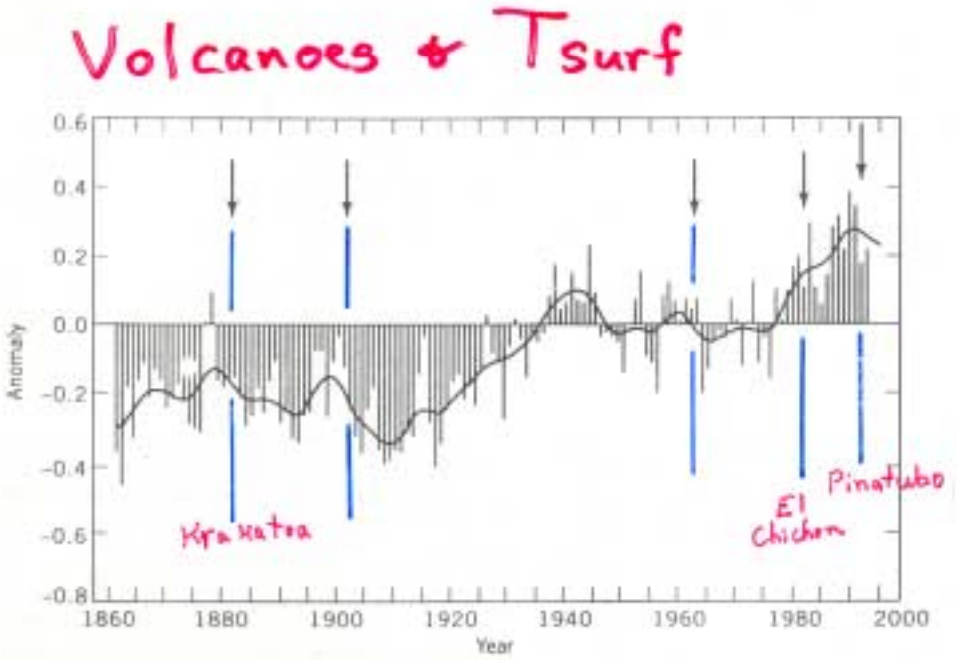
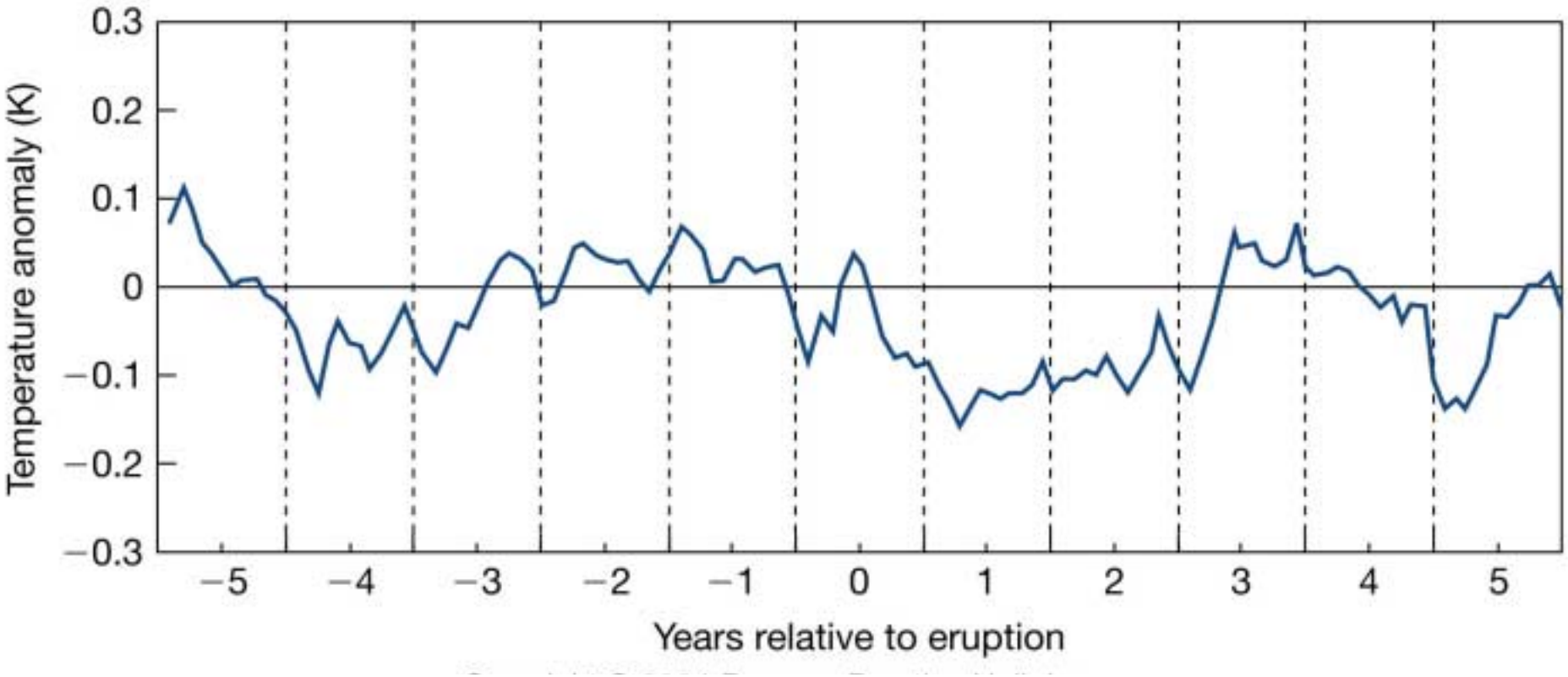


Figure 4.4 The global-average surface temperature record from Figure 1.5 with the years of major volcanic eruptions indicated by arrows.

More Sophisticated Evidence, Fig 12-6



Compositing method:

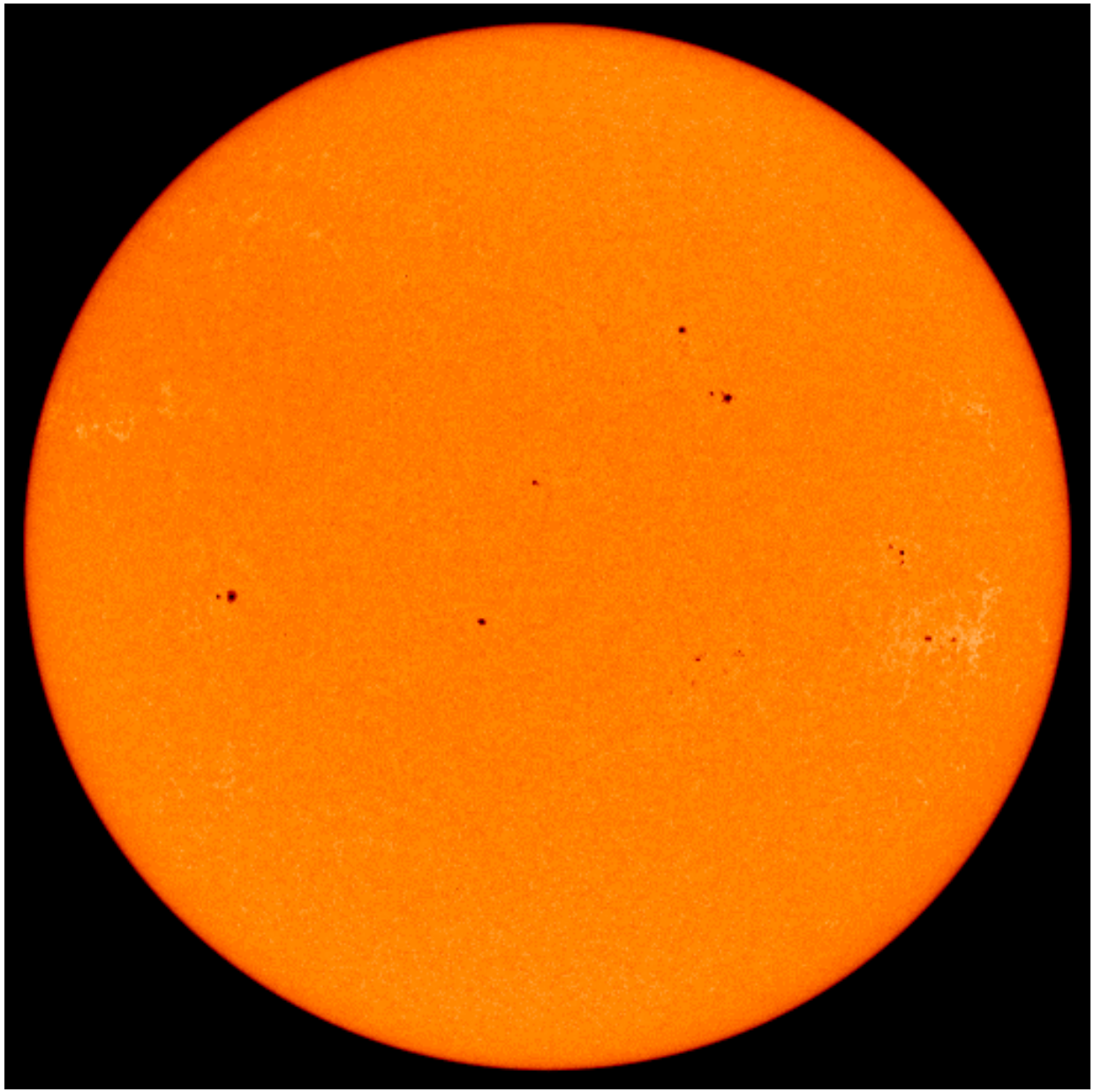
- calculate the average time-series for six major volcanic events
- zero on this timeline is the moment of the eruption
- zero on temperature scale is the average over the 5 years preceding the eruption

Question for in-class activity:

Is this convincing evidence that volcanoes affect GAAST?
Why or why not? (think "signal" and "noise")

www.spaceweather.com

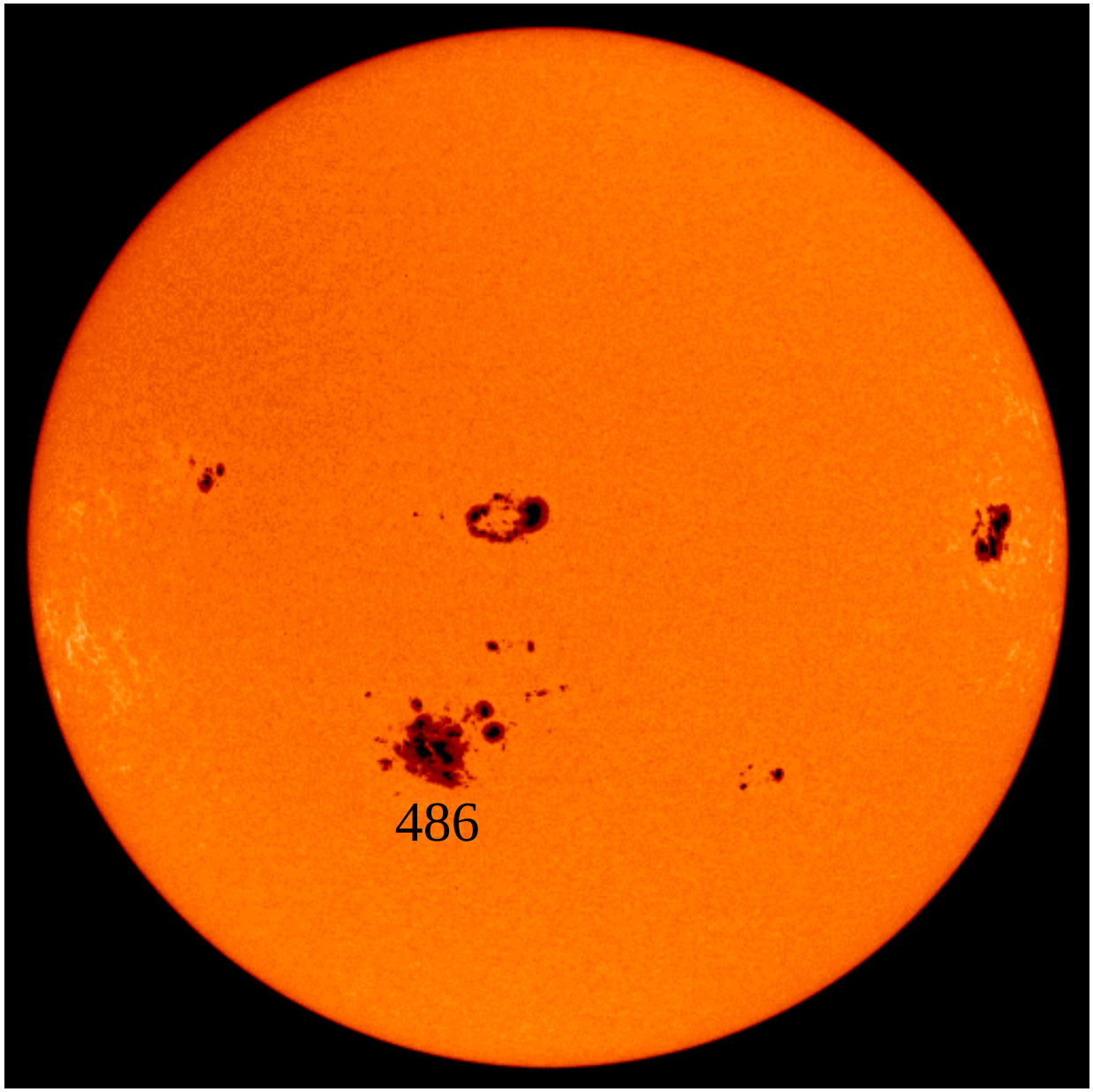
Sun Spots Feb 12, 2003



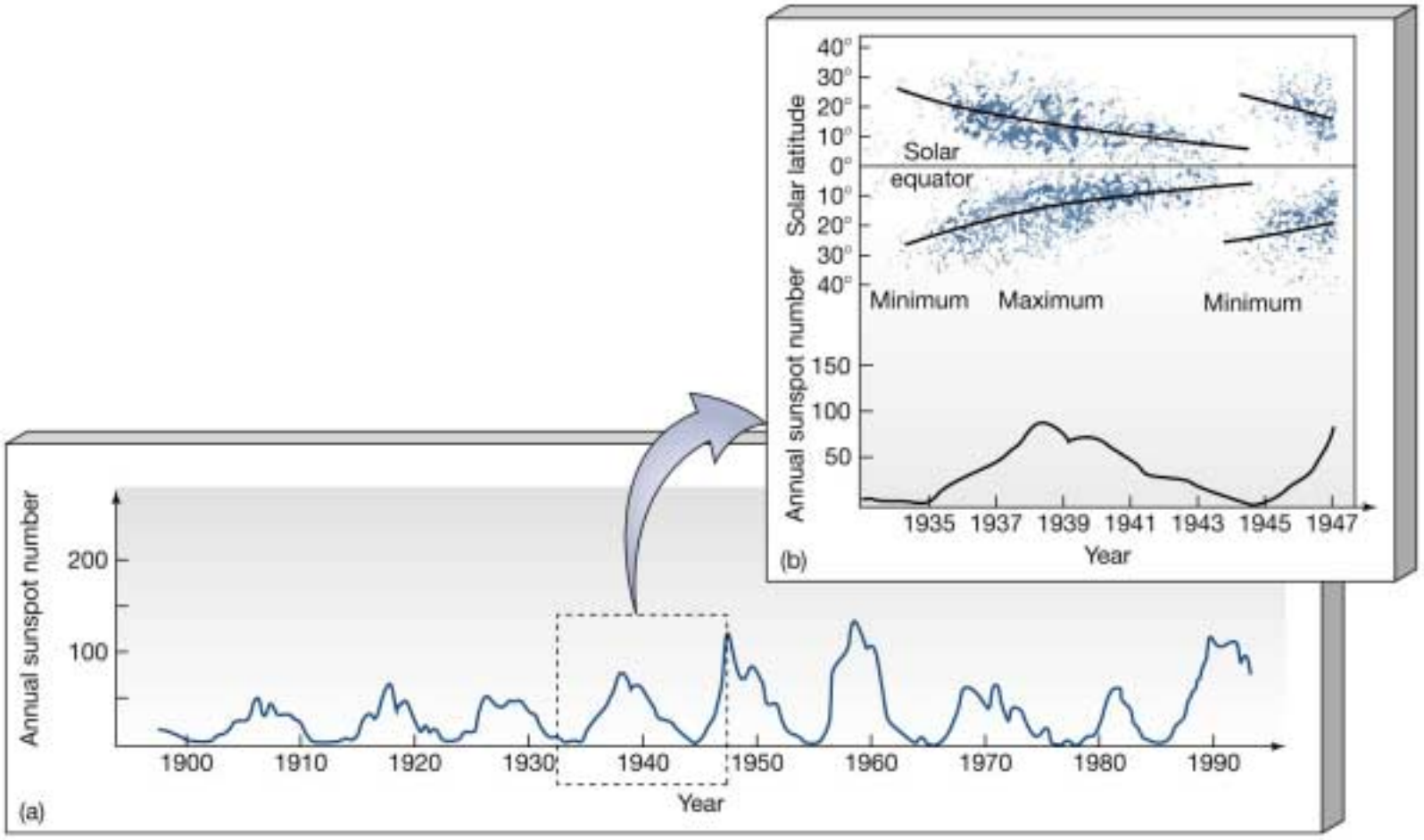
www.spaceweather.com

Sun Spots Oct 28, 2003

28Oct, 2003, 1110 UT:
"one of the most power solar flares in years... erupted from sunspot 486."

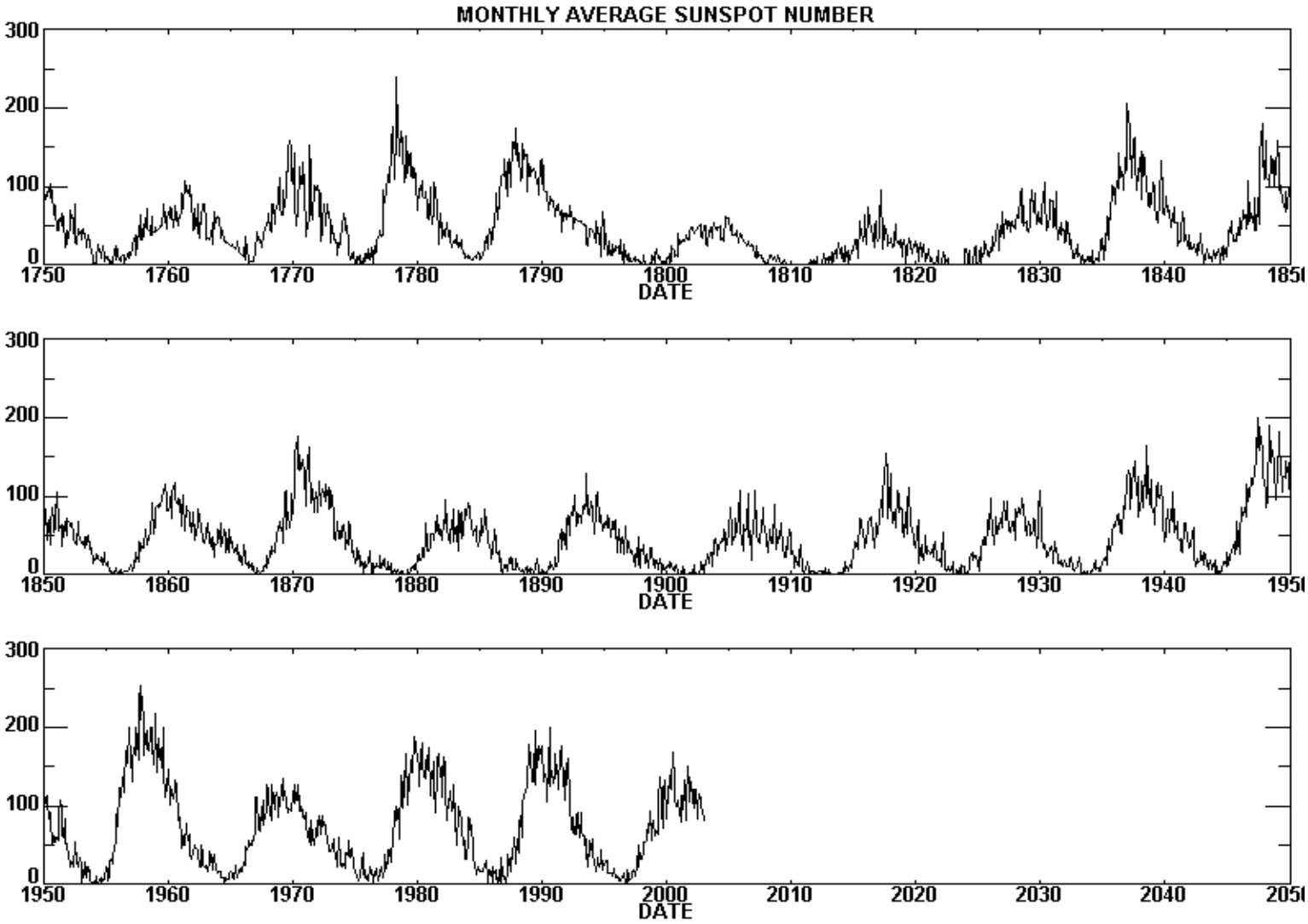


11-year solar cycle and sunspots: Fig 12-7



Sunspot record from 1750 showing "11-year" cycle and long-term fluctuations

Note: Amplitude of cycle changes over time
Length of cycle also changes (harder to see)



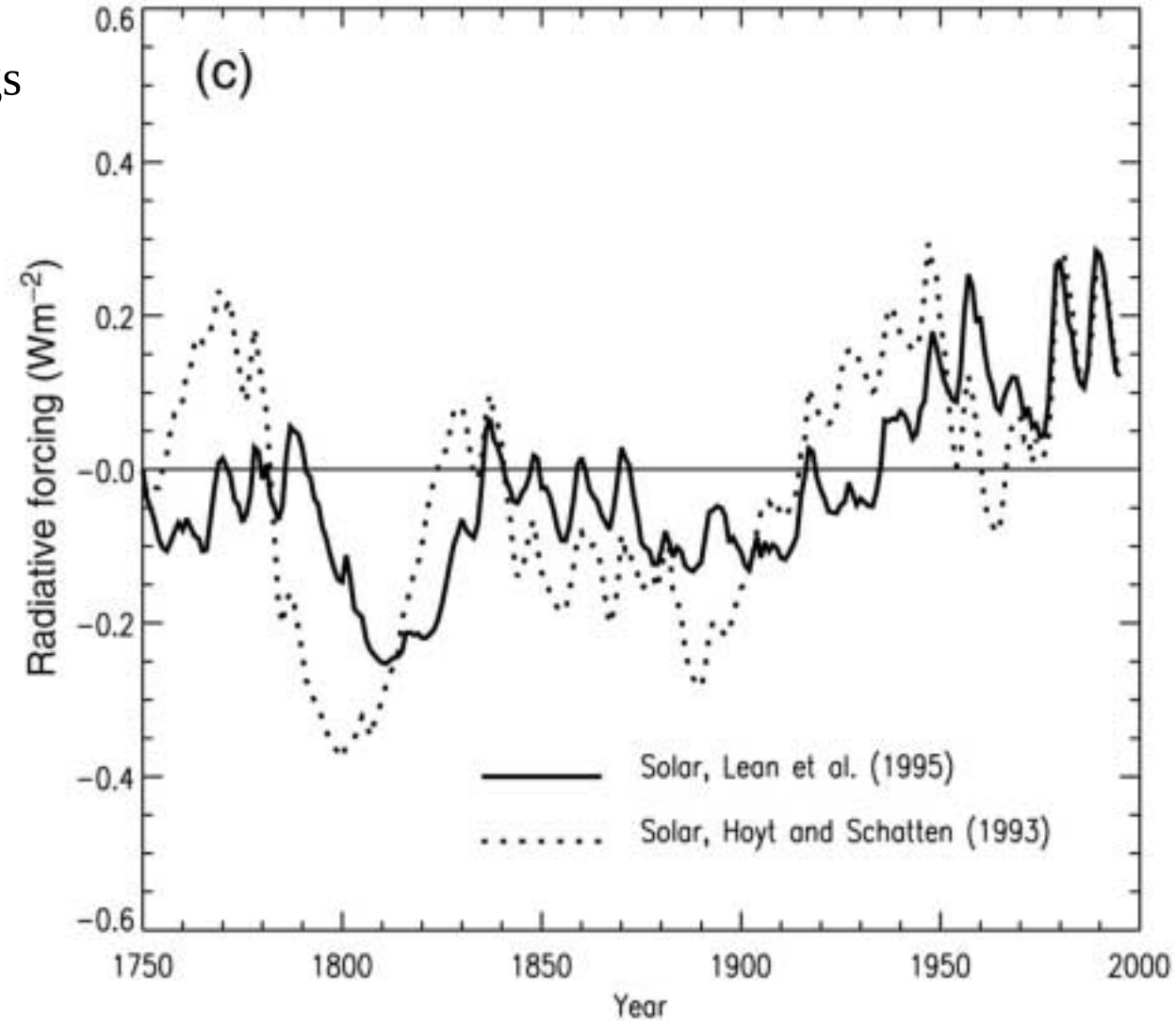
http://www.spaceweather.com

http://science.msfc.nasa.gov/ssl/pad/solar/images/zurich.gif

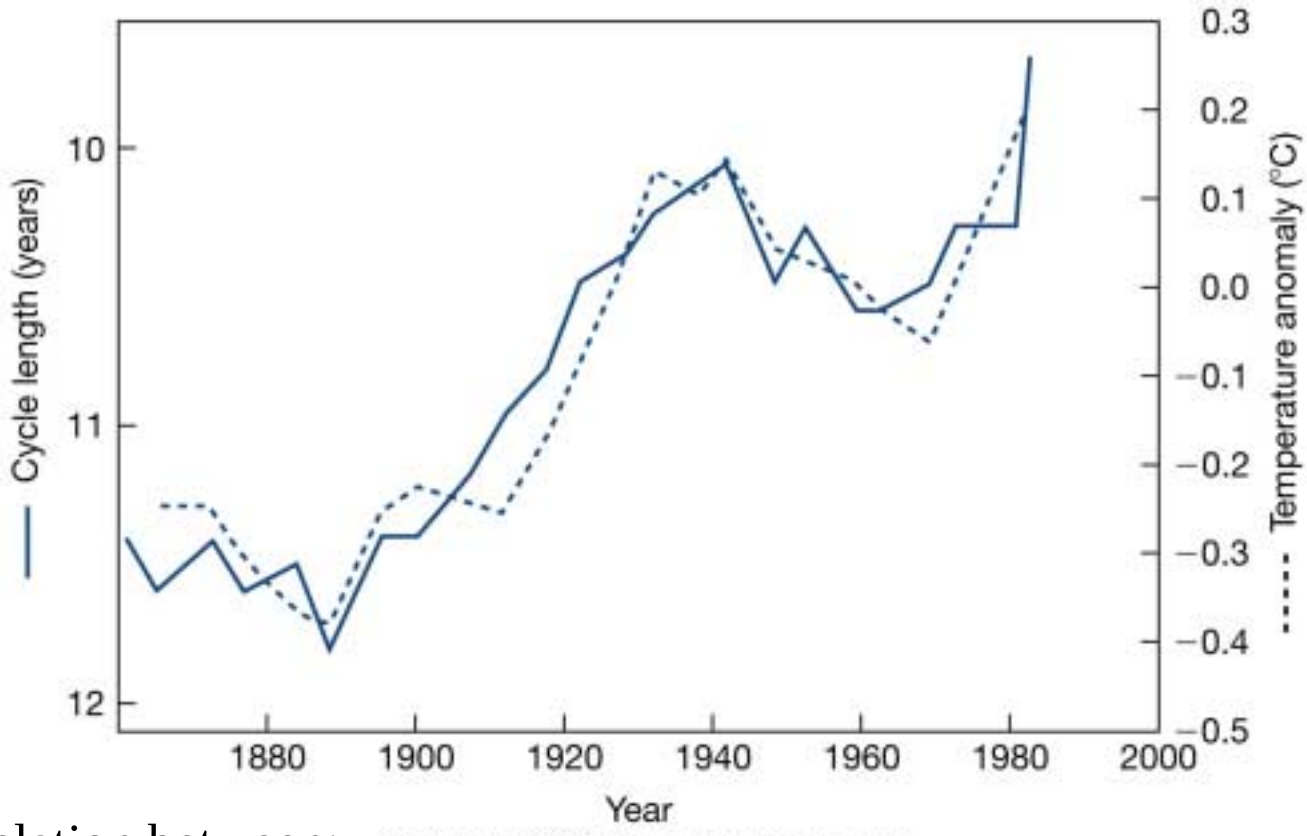
Estimated climate forcing by solar irradiance variations 1750-2000

Can these natural forcings explain the observed surface temperature changes?
How would you decide?

Are the forcings correlated with the temperature changes?
Are they large enough to account for the temperature changes?
If the climate responded to these small changes, why would it not have responded to the much larger forcing from anthropogenic GHGs?



Sun - Climate Correlation: Fig 12-8



Note: excellent correlation between:

Length of Solar Cycle

and Earth Surface Temperature

Question:

Is this persuasive evidence that solar variations are responsible for the temperature variations?

Why or why not?

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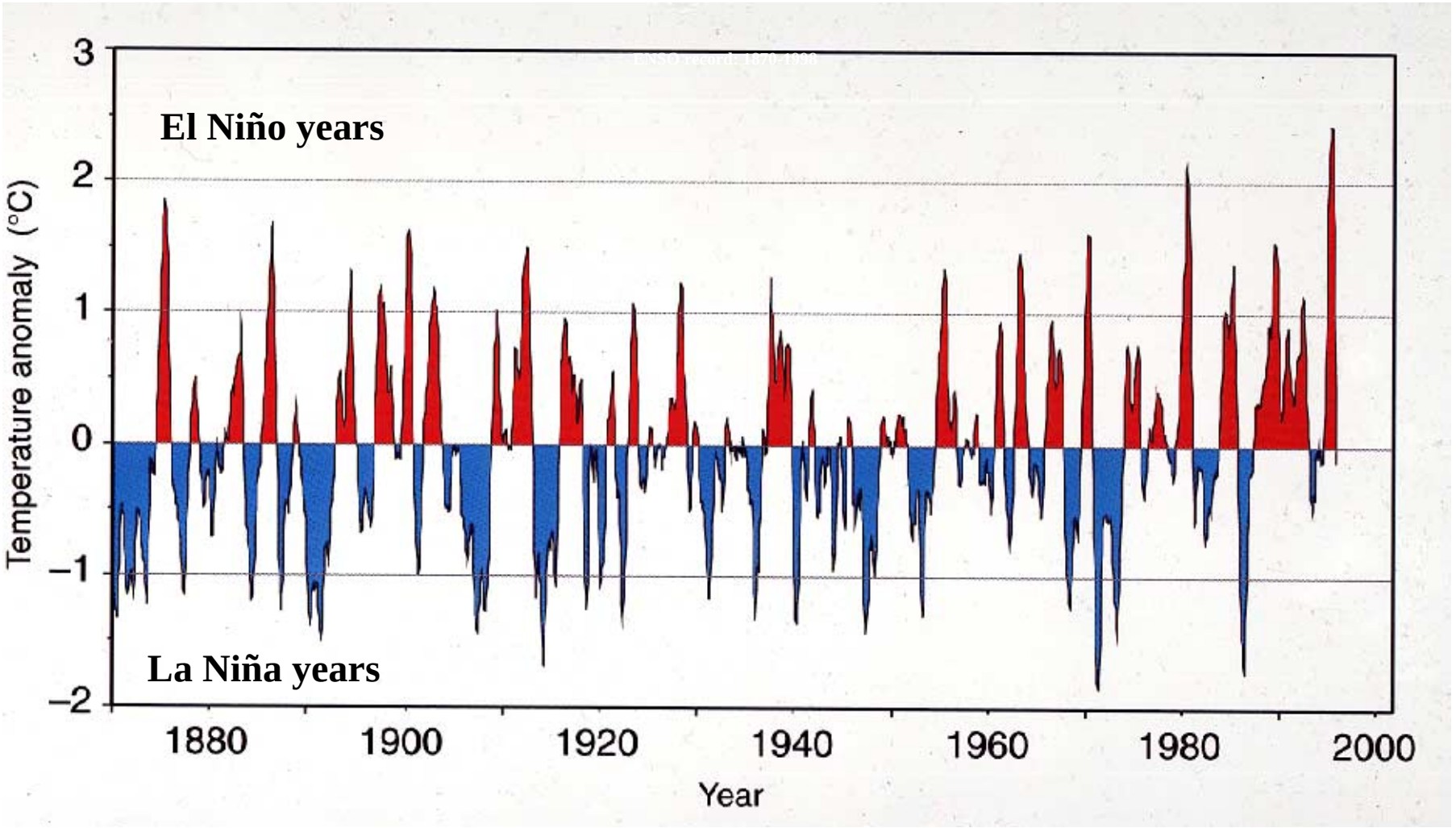
ENSO Record*… Trend?



*As shown by changes in sea-surface temperature (relative to the 1961-1990 average) for the eastern tropical Pacific off Peru