Natural Climate Change: A Geological Perspective

A presentation to the

Seminar on Sustainable Development

NBA 573, BEE 673

Sage Hall B-11

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by

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Earth and Atmospheric Sciences

Truth is so large a target that nobody can wholly miss hitting it, but at the same time, nobody can hit all of it…

Aristotle

Perspective

- Geologic history (4.56 billion years) is to all of recorded human history (6 thousand years) as 1 day is to the last 0.1 seconds of that day: We must use geological evidence to gain perspective.

4.56 Ga	Solar System	24 hrs
3.8	Amitsog Gneiss	20 hrs
0.57	Skeletal Creatures	3 hrs
0.066	Dinosaurs Extinct	21 min
0.003	Humanoids	1 minute
0.000006	Recorded History	0.1 sec

Outline

- Climate Changes:
  - 4.56 GA to 35 Ma (broadest overview)
  - 35 to 0 Ma (descent into and present cold period)
  - 120,000 to 10,800 years (last glacial cycle)
  - 10,800 to 0 years (present interglacial)
- Political Questions

The earth is made clement by 35C greenhouse warming:

Black Body Temperature of Earth:

$$R = \sigma T^4$$

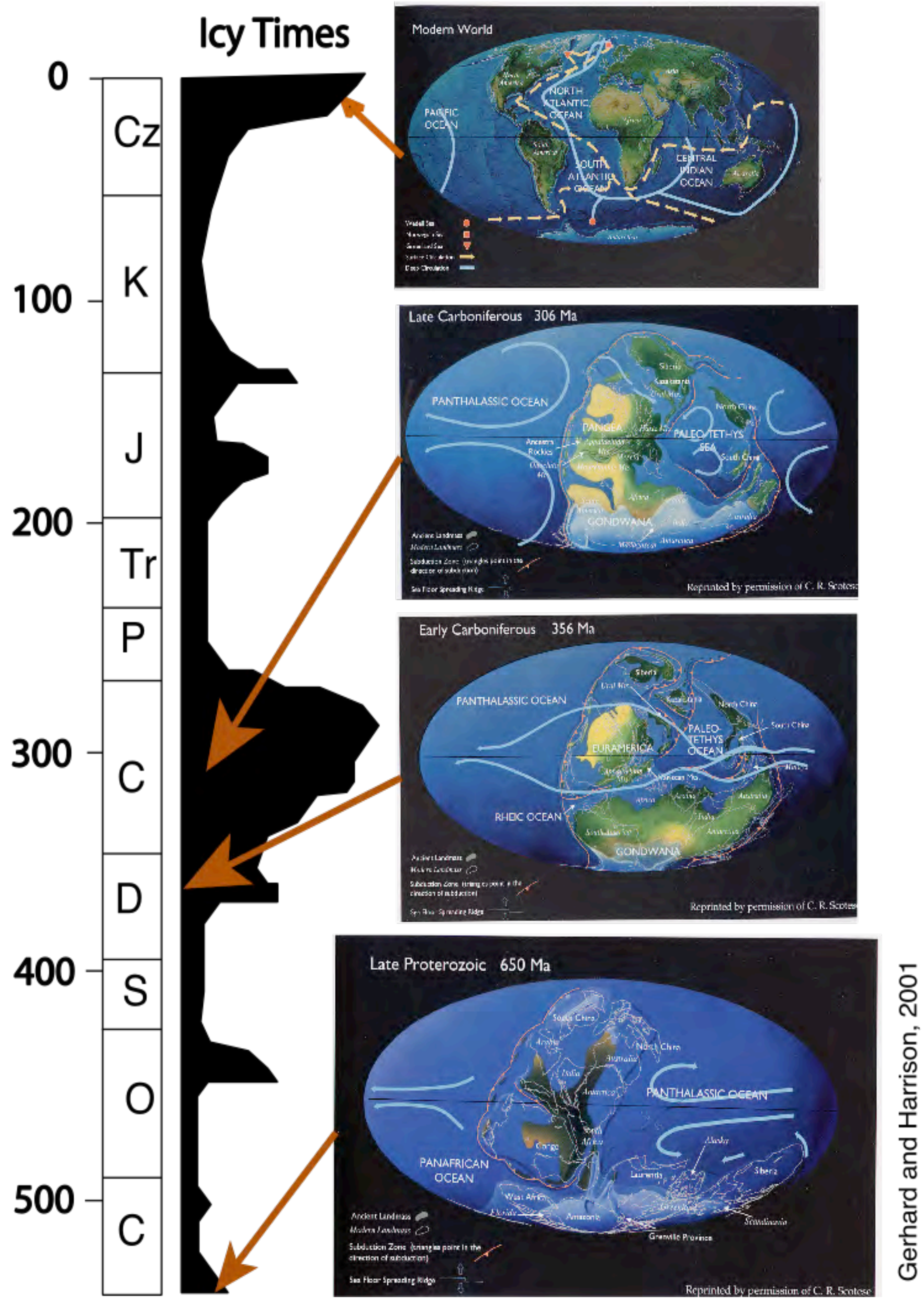
Plank's constant

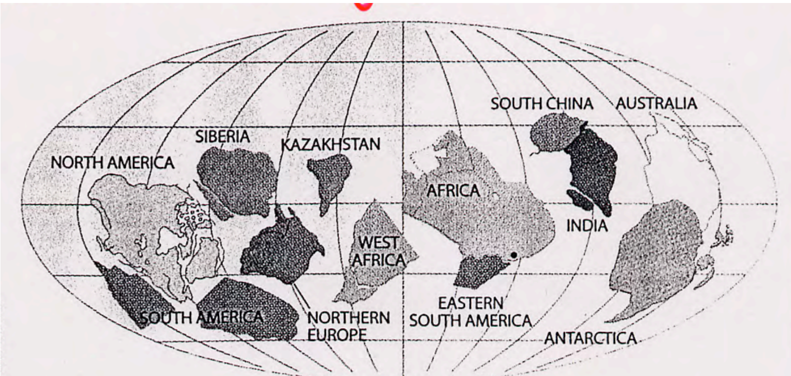
energy absorbed by earth from sun = energy radiated back to space from earth

$$(1 - A) R_{sun} \pi r_{earth}^2 = R_{earth} 4 \pi r_{earth}^2$$

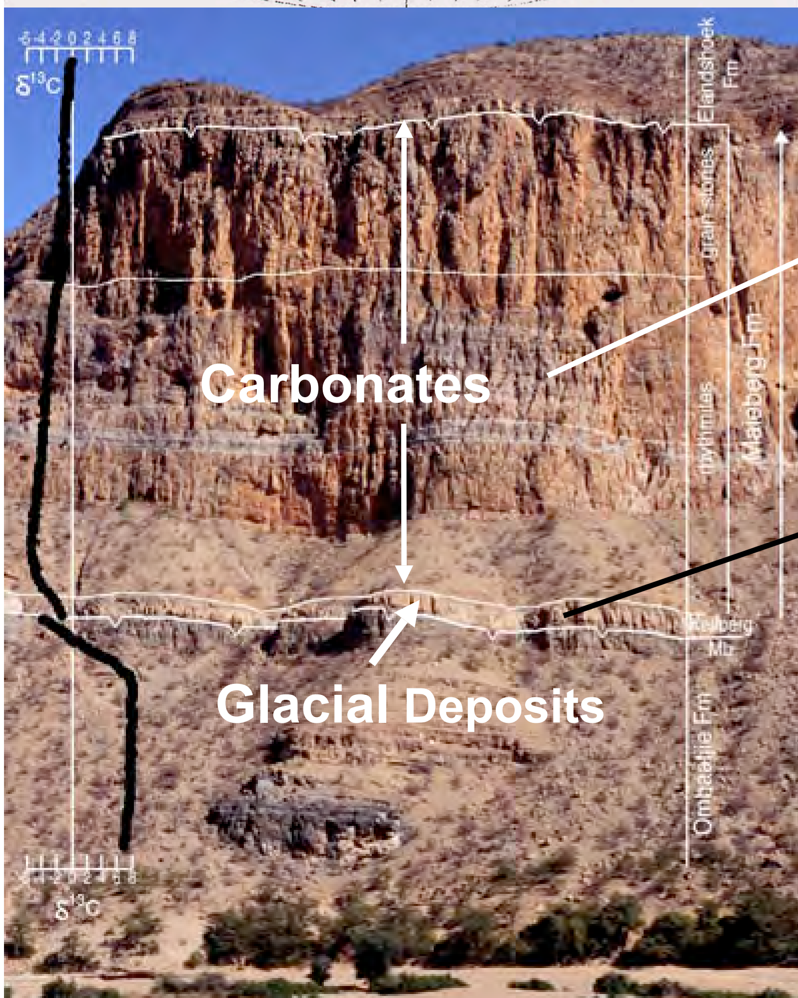
	Black Body T_{earth}	**Green House Warming for $T_{earth} = 15^{\circ}C$ or Implication**
=0.3 (today's albedo)	$-19.3^{\circ}C$	$35^{\circ}C$
=0	$4.3^{\circ}C$	cloud cover important
$_{sun}$ = 0.8 $R_{sun\ today}$, A=0.3	$-33^{\circ}C$	solar radiation important

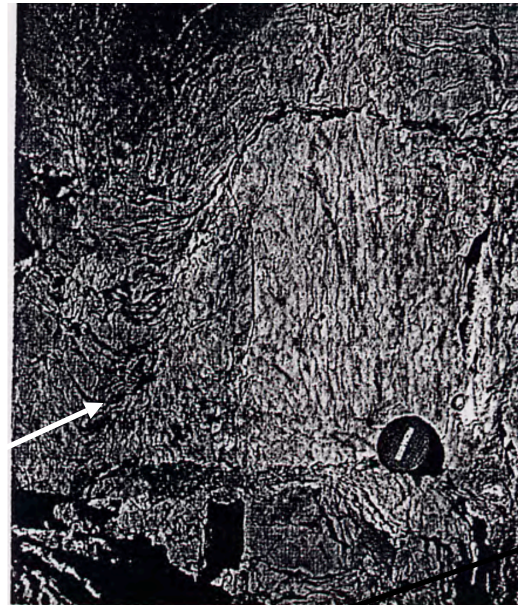
Glacial conditions seem to have occurred when ocean circulation was blocked by a N-S band of continents





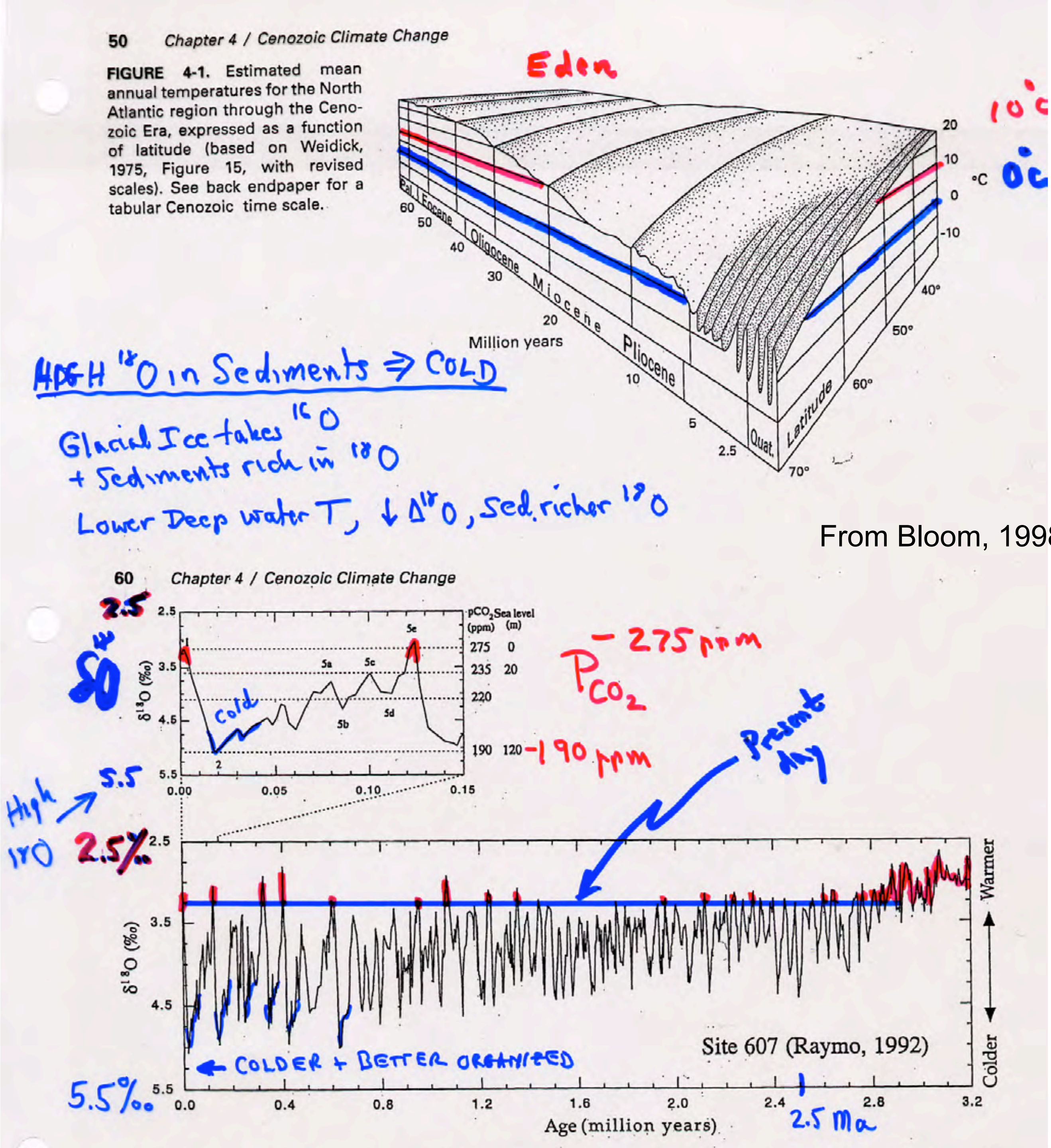
Hoffman & Schrag, Jan 2000. *Scientific American*





"Rock Layer that represents the abrupt end
Of a 700-million-year old snowball [earth] event.
Pure carbonate layers stacked above the glacial
deposits precipitated in the warm shallow seas
of the hothouse aftermath [of a completely
frozen earth]." 4-5 cycles of –50C to +50C amy
have bread super-adaptable biota and triggered
the explosive evolution that followed.

- Global temperature declined from Eocene (50 million years ago) to Pleistocene time (2.5 Ma).
- Ice has covered North Americand Europe 15 to 20 times over the last 2 Ma.
- Much of what we know comes from the oxygen isotopic ratio in ice cores and sediments



From Bloom, 1998

Deep-sea Oxygen isotope record for the Last 1.2 Million years

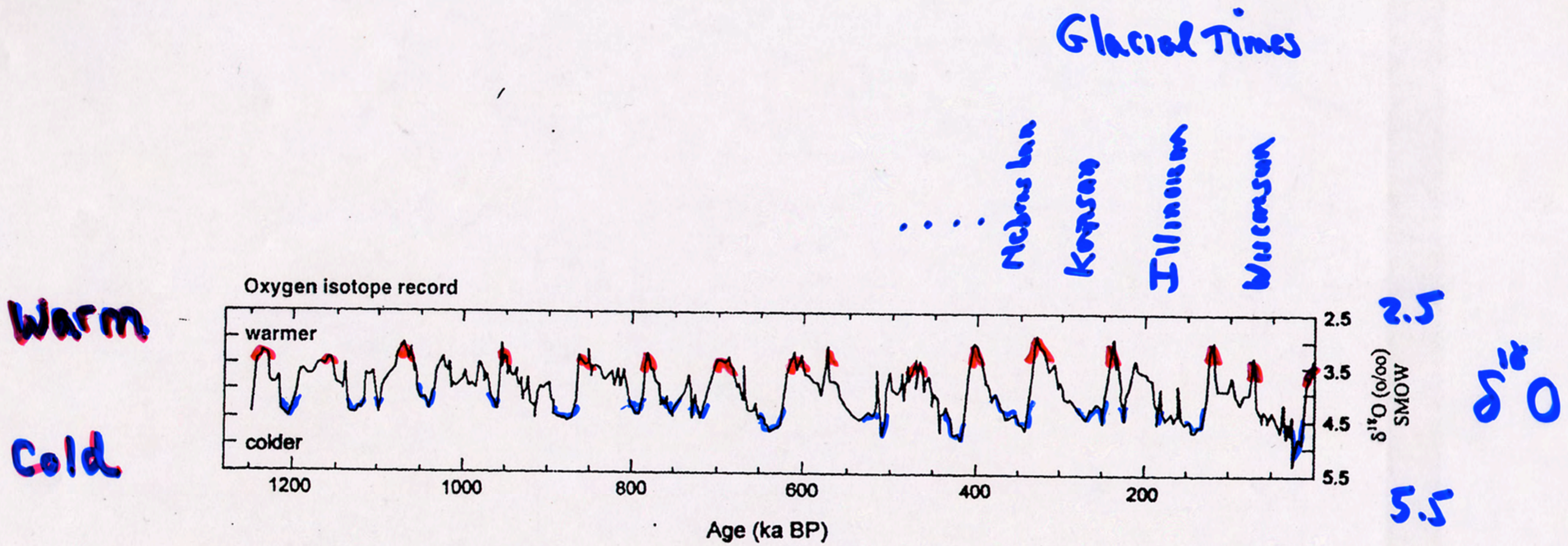


Figure 2-1. A deep-sea oxygen isotope record for the last 1.2 million years shows the cyclic pattern of glaciations and interglacials. From Raymo et al., *1997.*

Oceans are isotopically heavy (^{18}O- enriched) when Cold

- Except for 3 ice ages at 800-600, 320-250, and 35-0 Ma, earth has been hotter than present and thermally more stable
- 15 to 20 fairly regular glacial cycles have occurred in last 1.8 million years
- Present temperature highest ~1% of temperatures over last 2 million years
- Glacial cycles becoming more robust and larger amplitude

Last Glacial Cycle (Wisconsin)

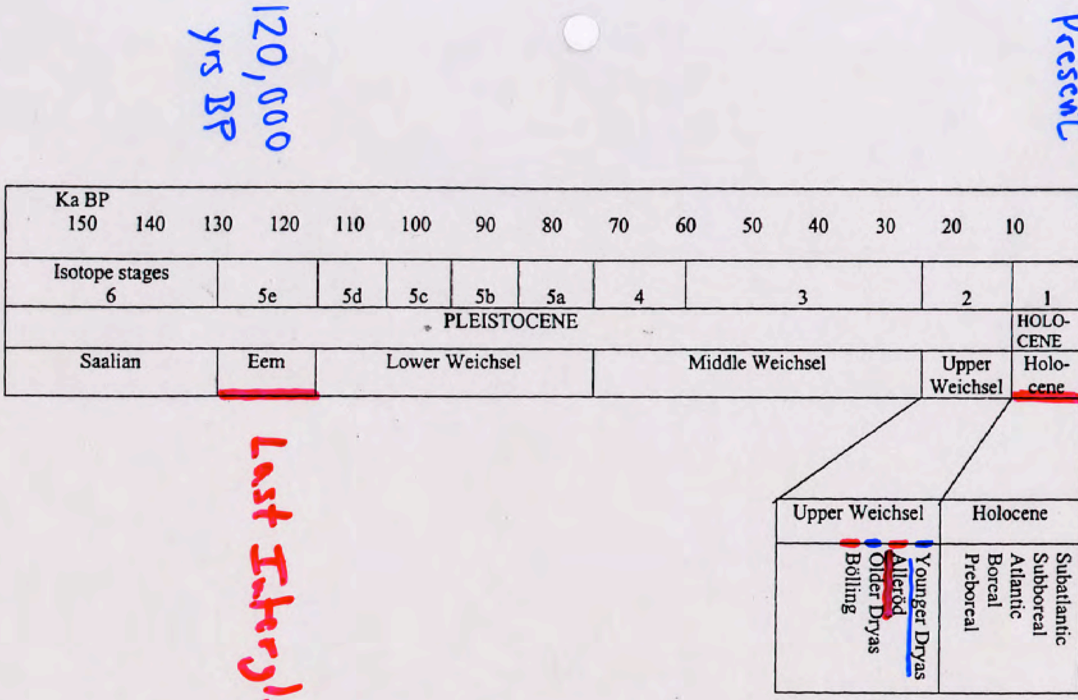
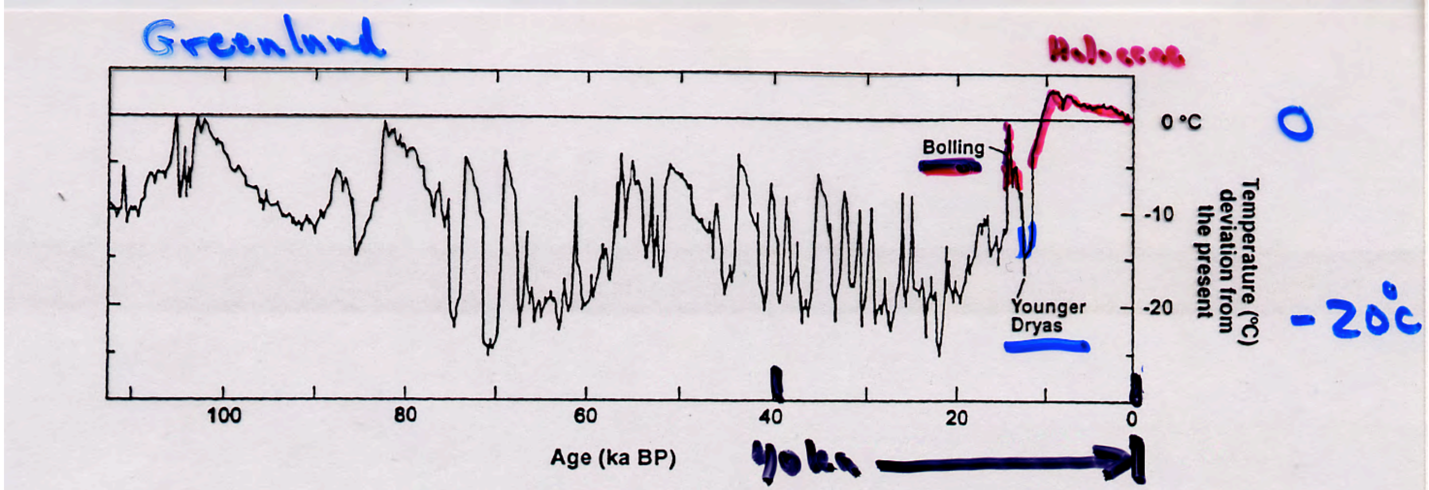
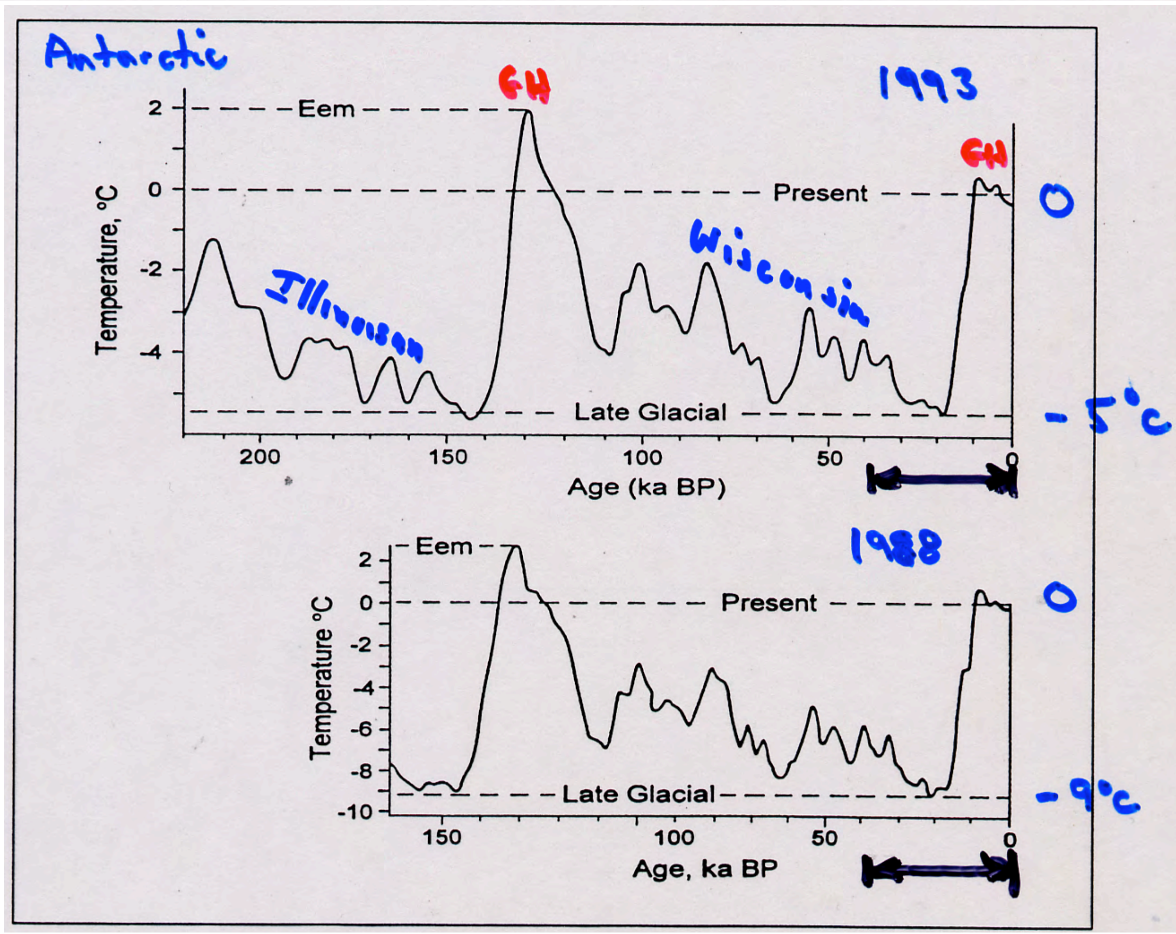


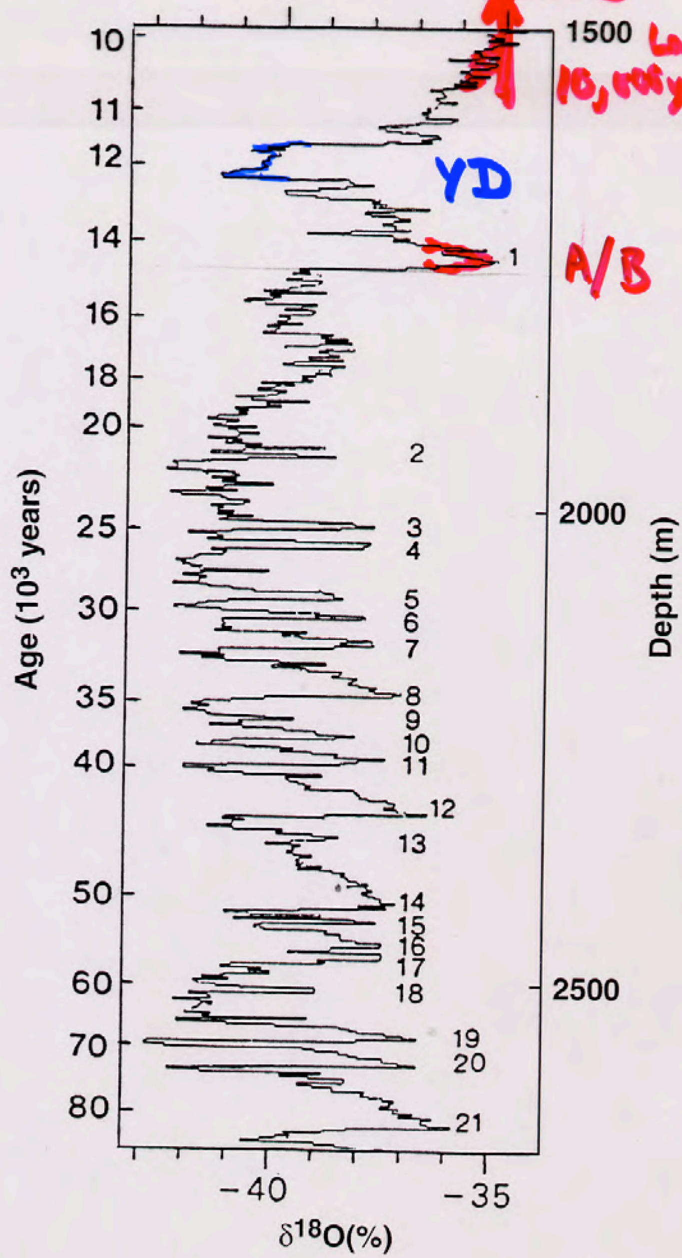
Figure 1-1. *Late Pleistocene and the Holocene stratigraphy, after Valen* et al., *1996. The upper panel indicates approximate age in ka BP. The second panel indicates the marine stratigraphy, i.e. the isotope stages. Uneven numbers denote relatively warm periods, even number relatively cold periods. The last warm period is called Holocene and the last glaciation is called Weichsel in northern Europe, Würm in southern Europe and Wisconsin in North America. A first recognised warm phase during the deglaciation was named Bölling and a second Alleröd. Two cold phases are named Older Dryas and Younger Dryas. The beginning of Bölling is dated to 14,3 ka BP, Older Dryas is a short cold event at 14 ka BP, Alleröd a warm period ending 12,4 ka BP and Younger Dryas ended and the Holocene begun 10,8 ka BP (Stuiver* et al., *1995).*


Greenland
Holocene
0 °C
Bolling
-10
-20
Younger Dryas
Temperature (°C) deviation from the present
0
-20°C
100
80
60
40
20
0
Age (ka BP)
40ka


Antarctic
GH
1993
2
Eem
0
Present
GH
0
-2
-4
Illinoisan
Wisconsin
Temperature, °C
Late Glacial
-5°C
200
150
100
50
0
Age (ka BP)
1988
Eem
2
0
Present
0
-2
-4
-6
-8
-10
Temperature °C
Late Glacial
-9°C
150
100
50
0
Age, ka BP

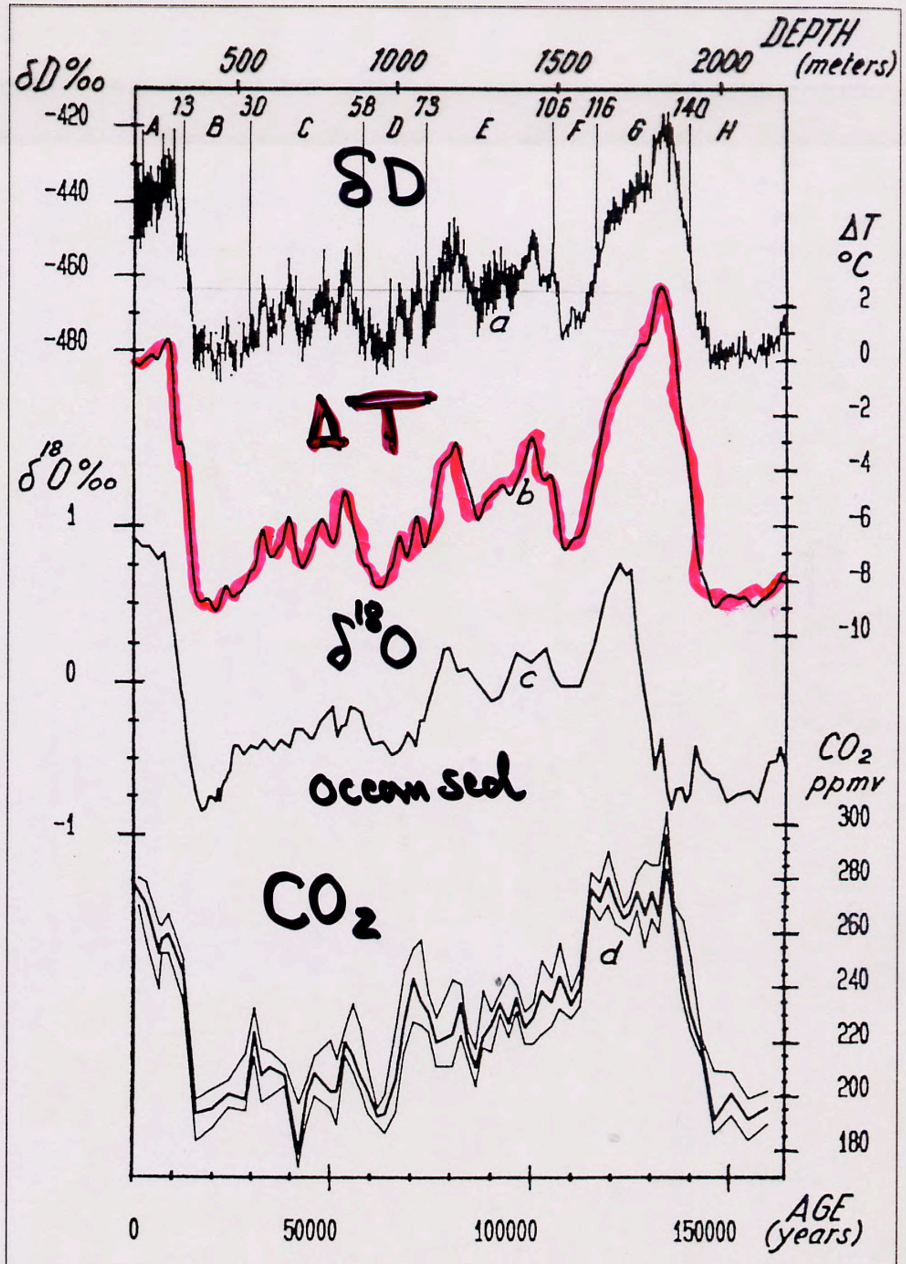
Greenland δ18O Ice Core

FIGURE 18-6. $\delta^{18}O$ record from the GRIP ice core, Summit, Greenland, between depths of 1500 to 2675 m, covering a time span from 10,000 to 87,000 years ago. Linear depth scale; time scale established by counting annual layers back to 14,500 years; beyond that by ice flow modeling. In the upper 1500 m of the ice core that covers 10,000 years of Holocene time $\delta^{18}O$ values are nearly constant at −35 ± 1‰. Warm peaks of Dansgaard-Oescher cycles 1 to 21 are numbered for reference. The late glacial cold interval known as the Younger Dryas followed warm peak no. 1 (modified from Dansgaard et al., 1993, Figure 1).



Ice isotopically light (^{18}O depleted) when cold

Vostoc, Antarctica



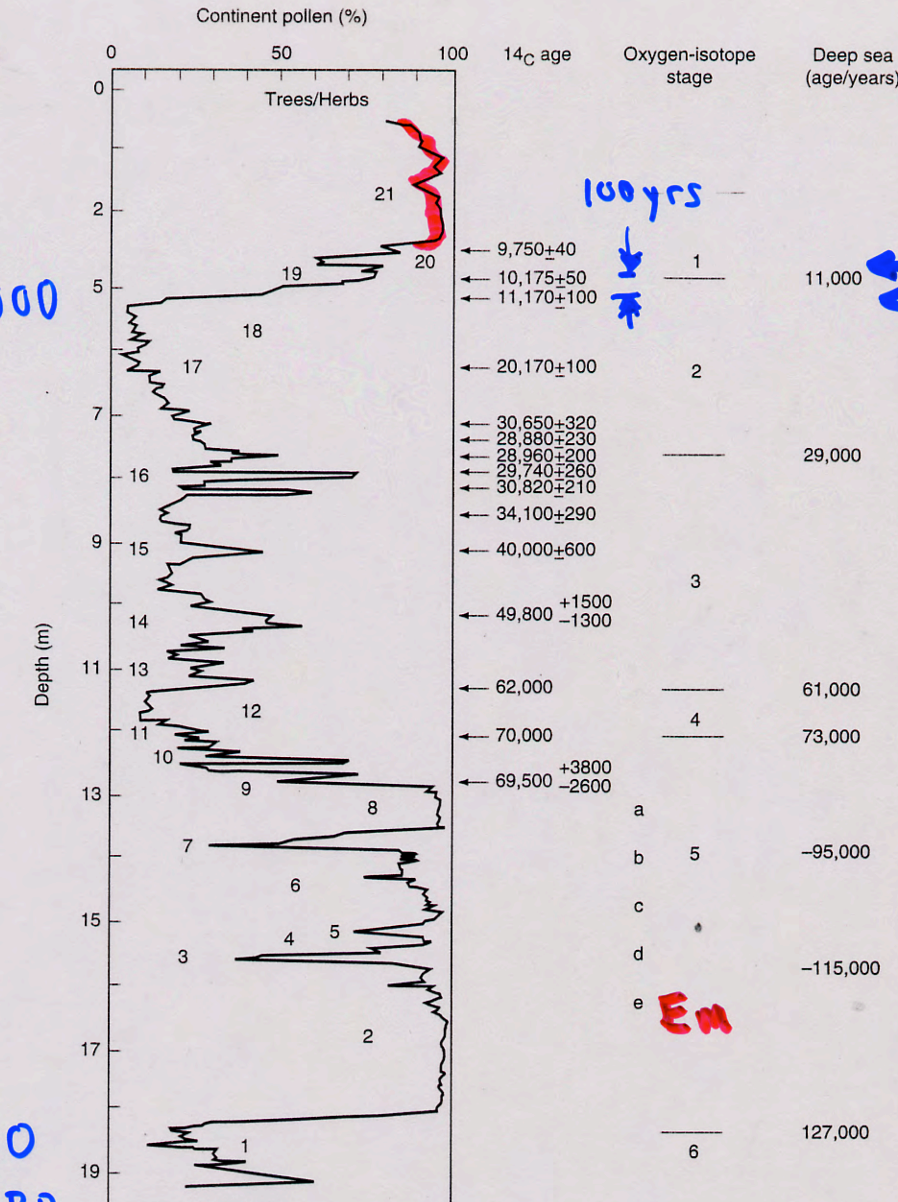
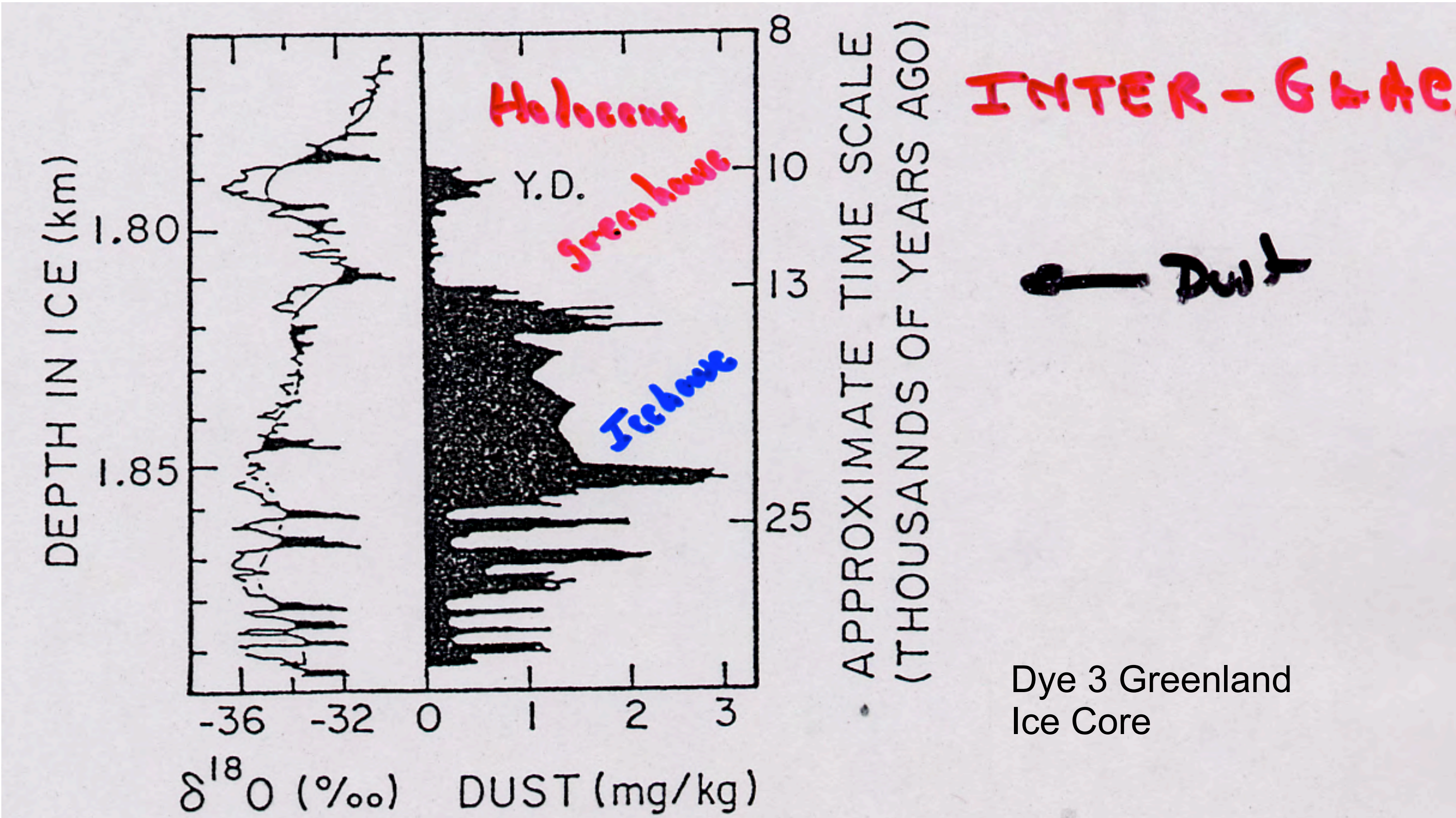


FIGURE 18-5. Diagram of total tree and shrub pollen versus herb pollen from Grande Pile, France. Depth scale (m). Radiocarbon dates at various levels are shown, with suggested correlations with the deep-sea oxygen-isotope record (simplified from Woillard and Mook, 1981, Figure 1).

Dust Correlates with $\delta^{18}O$



Oxygen isotope and dust record for the period
about 8,000 to about 40, 000 years ago

"Greenland ice sheet Project 2"

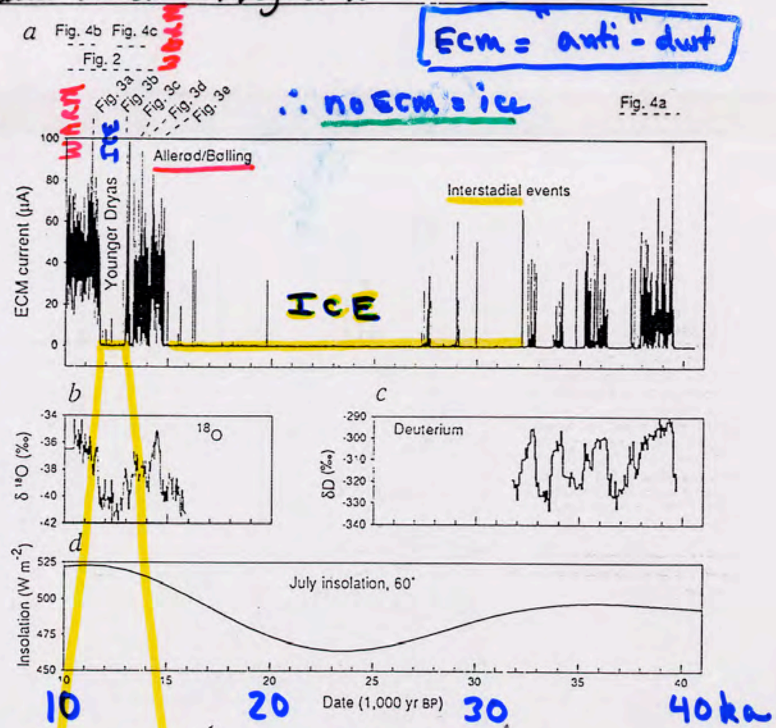


FIG. 1 *a*, GISP2 electrical conductivity measurement (ECM) record for the period of 10–40.5 kyr BP. Low current levels indicate that alkaline dust has neutralized the acidity of the ice. The record is resampled to a rate of one sample per year. The ages of the other expanded-scale figures (Figs 2–4) are indicated. The years indicated are calendar years. We adopt the carbon-14 datum of AD 1950 as present time. *b*, Isotopic ratio $^{18}O/^{16}O$ for the ages 10.5 to 16 kyr BP. *c*, Isotopic ratio D/H for the ages 32 to 40.5 kyr BP. The isotope samples are from contiguous 1-m sections of the core. Because of flow-induced thinning of annual layers, the 1-m sections correspond to one sample every 15 to 37 years in the $^{18}O/^{16}O$ record and one sample every 65 to 80 years in the deuterium/hydrogen record. The correlation between the ECM and the isotope records demonstrates that the ECM record is responding to climatic events. *d*, Mean July insolation for latitude 60° north[23].

acidic and alkaline conditions, the effect of small amounts of additional dust on the magnitude (but not the frequency) of the ECM signal may be disproportionately large. In the GISP2 core, however, detailed chemical analysis shows that the order-of-magnitude decreases in ECM that we consider here are associated with order-of-magnitude increases in calcium. The source for the calcium is believed to be airborne calcium carbonate dust. The ECM record has the highest time resolution (>15 samples per year) of available measurements, and together with the sensitivity to dust, this makes ECM suitable for investigating the rate of rapid atmospheric circulation changes.

The ECM record discussed here covers the time period 10 to 42 thousand years before present (kyr BP), and allows climate variability to be investigated on timescales of seasons to

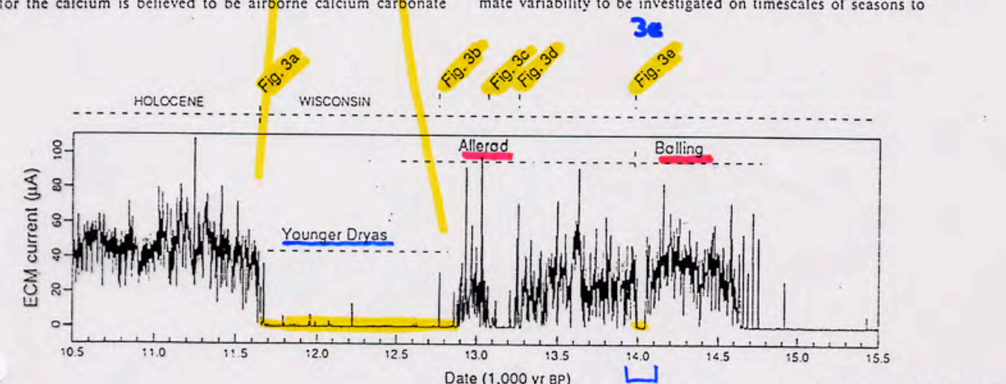
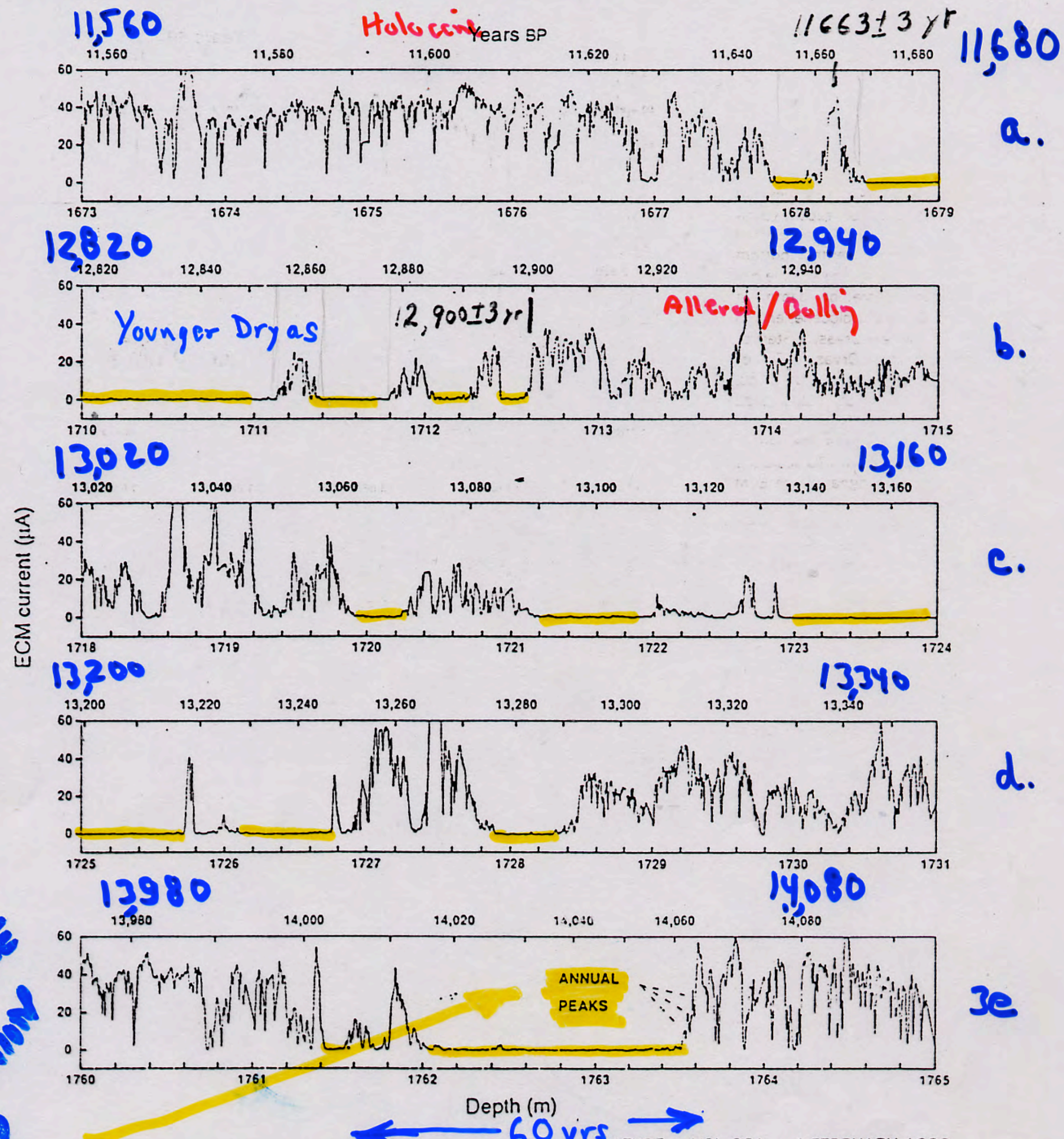


FIG. 2 Yearly averages of ECM in the GISP2 core at Summit, Greenland for the period of 10.5 to 15.5 kyr BP. The ages of expanded figures (Fig. 3*a–e*) are indicated.

Fig 3e 14,060 – 14,000
60 yrs

Taylor, et al., "flickering switch"

FIG. 3 *a–e*, Expanded ECM records of recent climate transitions plotted against depth (bottom axis) with one sample per millimetre of depth. *a*, Start of Holocene, end of Younger Dryas. *b*, Start of Younger Dryas. *c*, End of inter-Allerød cold period. *d*, Start of inter-Allerød cold period. *e*, Transition. The top axes are age, in years BP. At this scale the annual signal in the ECM can occasionally be resolved as small local peaks that occur once per year. During the transition at 14,060 BP (*e*), three annual peaks can be resolved. The annual layer thickness is ~6 cm per year during warmer, less dusty conditions and 3 cm per year during colder dusty conditions. Occasionally the number of ECM annual peaks and annual layers in a given segment differ slightly because particulate and visual stratigraphy records were also considered when annual layers were identified.



INCREDIBLE RESOLUTION ?

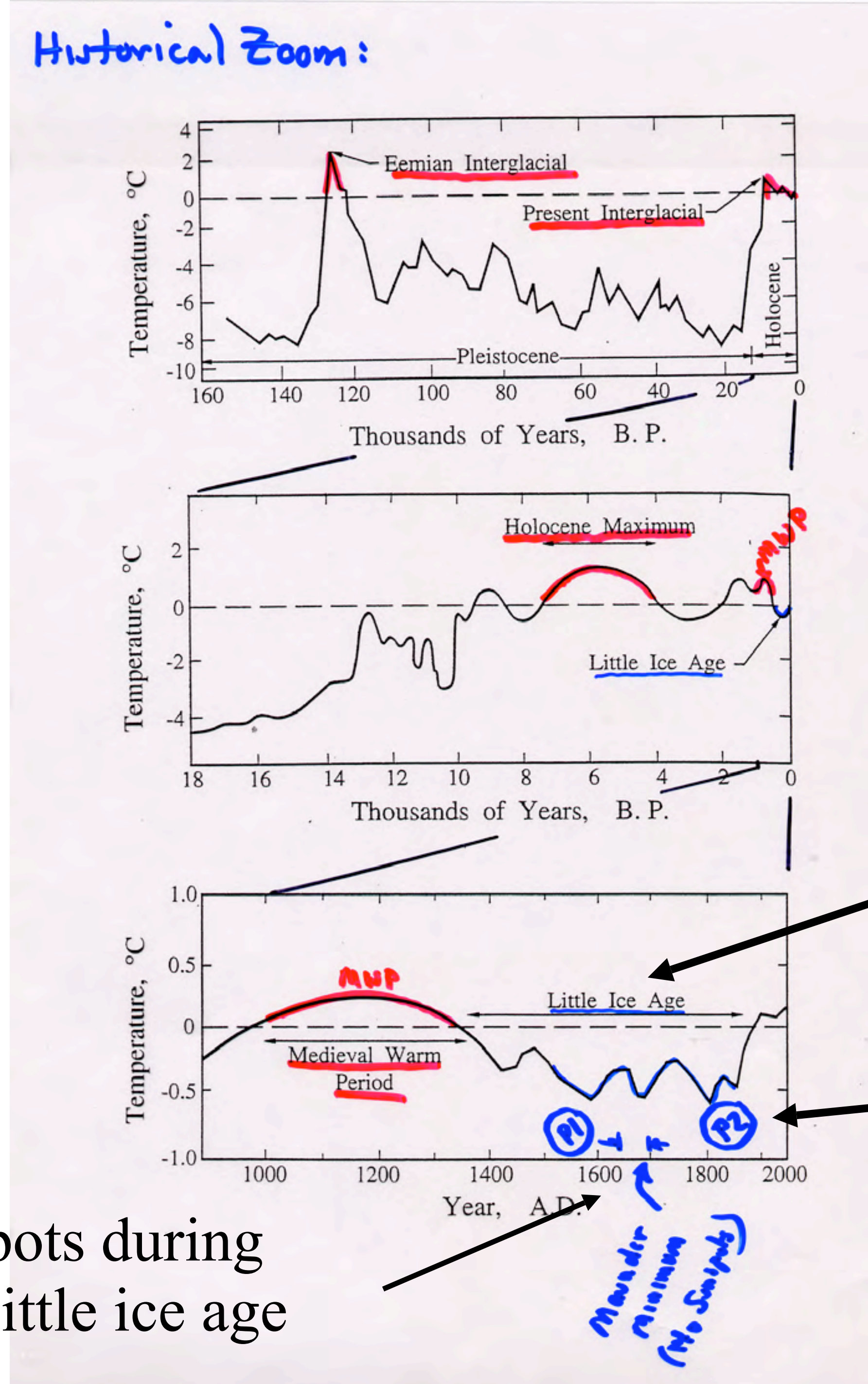
Taylor et al., "flickering switch"

- Lots of correlations with climate change:
  - Sea level
  - Temperature indicators (pollen)
  - δD, $\delta^{18}O$, $\delta^{13}C$, CH_4, CO_2, dust

- Natural climate change can be very rapid (e.g., years, flickering switch)

Historical Climate Change

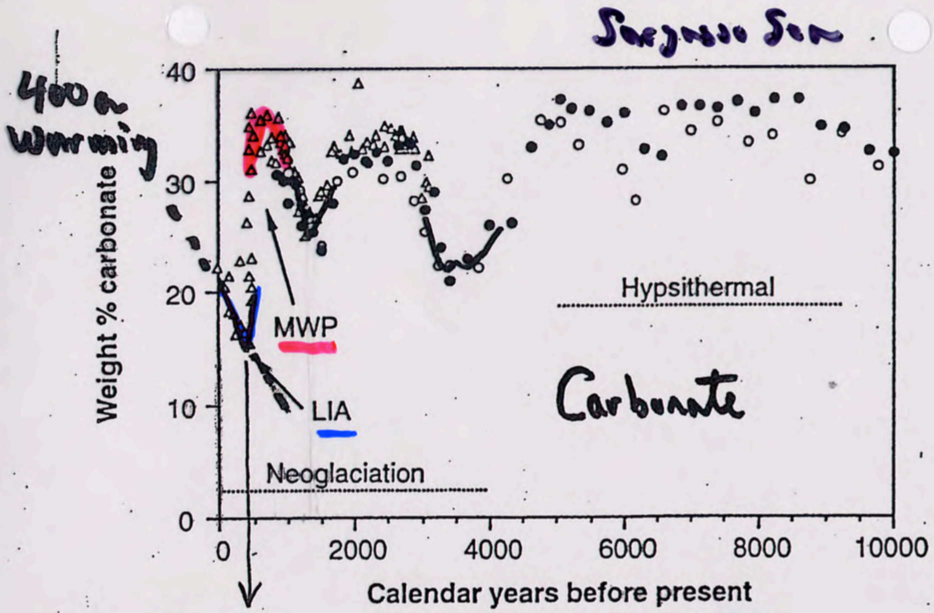
- Holocene Maximum (7000-4000 BP)
- Medieval Warm Period (1000-1400 AD)
- Little Ice Age (1400-1860 AD)
- Current Warm Period (1860-present)

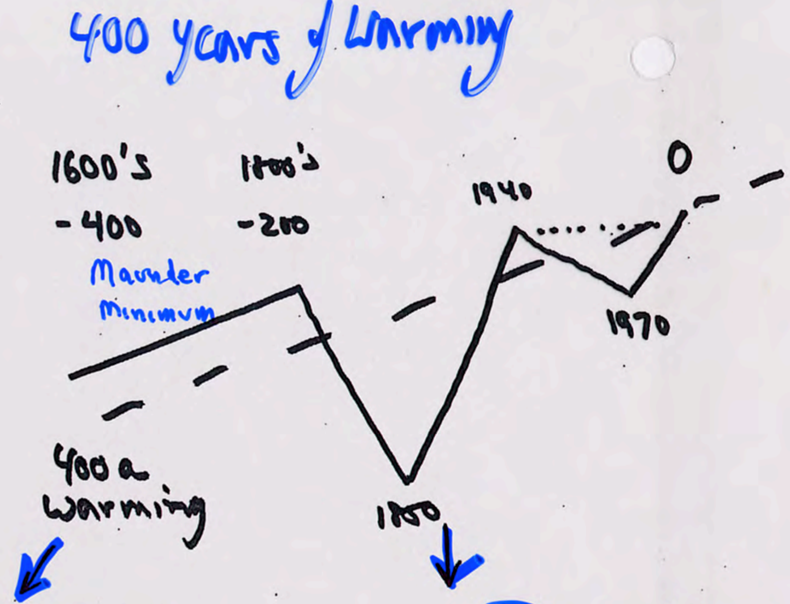


Little ice age

See pictures on next slide

No sunspots during parts of little ice age





1565 (P1)

'Hunters in the Snow.' In 1565, when Pieter Brueghel the Elder painted this picture, the Earth's climate was see-sawing in the Little Ice Age. Contemporary rates of formation of radioberyllium and radiocarbon indicate a shortlived increase in cosmic rays at the time, during a general trend in the sixteenth century towards warmer conditions.

Kunsthistorische Museum, Vienna/ The Bridgeman Art Library

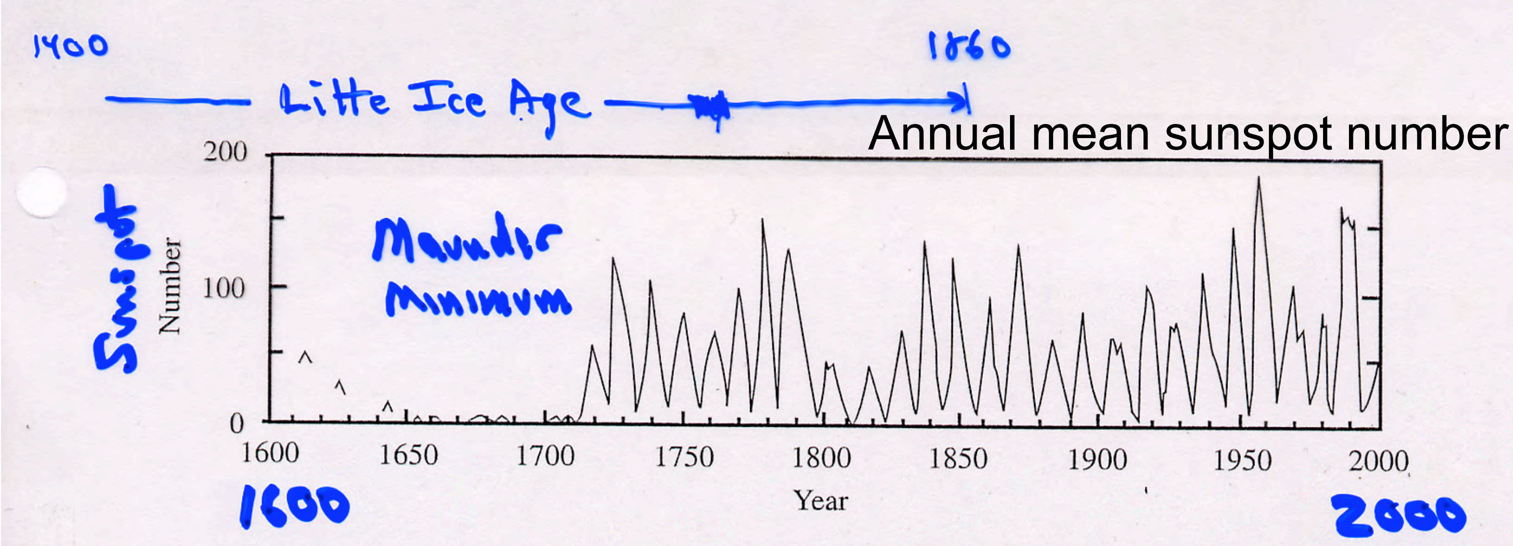
1895 (P2) Thames

Before the global warming. In the 1890s the world was, on average, about 0.5 degree cooler than the 1990s. The Sun was in a lazy mood, as shown by the low sunspot counts (OPPOSITE).

Royal Meteorological Society, Bracknell

LIA = little ice age

MWP = Medieval warm period



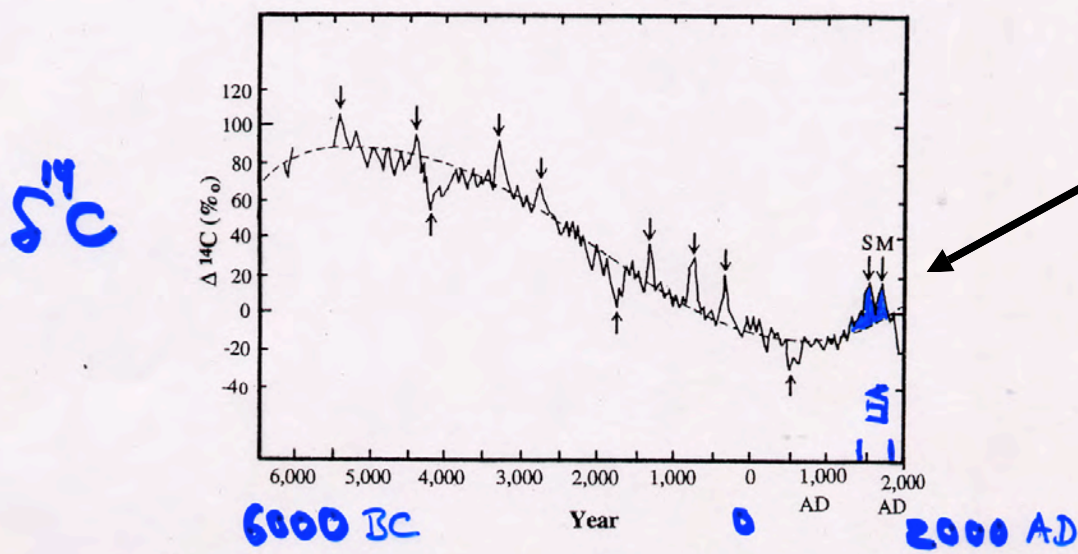
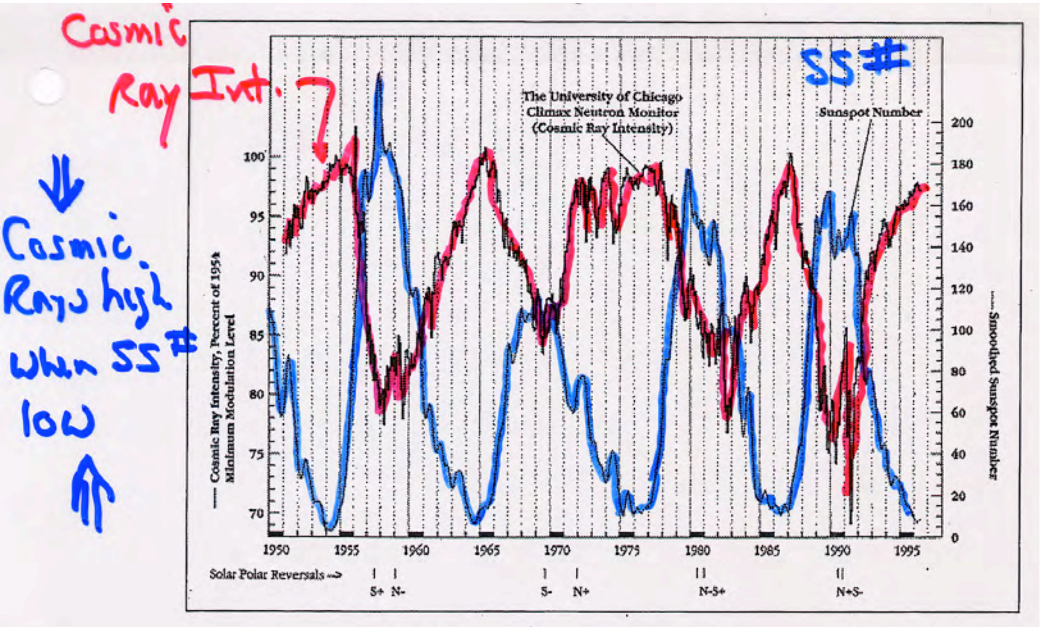


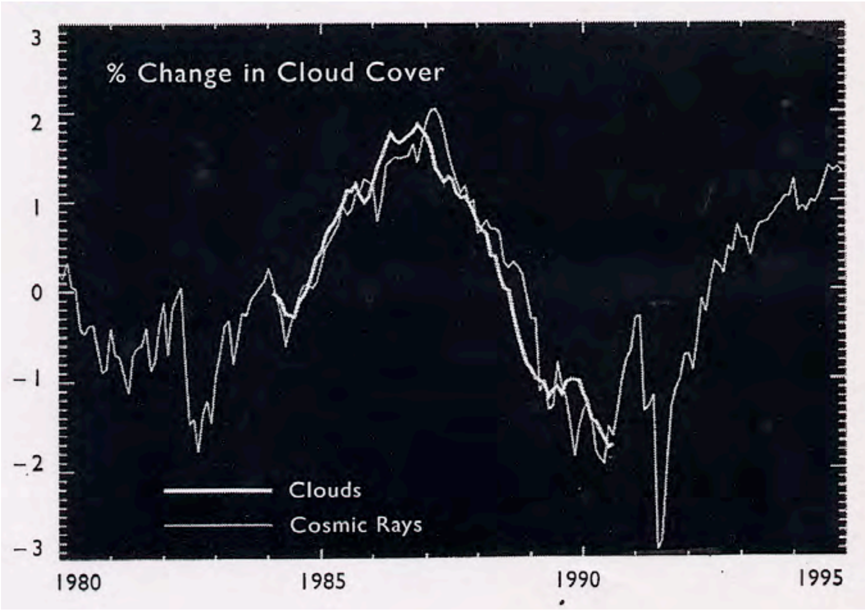
Figure IV.6 Carbon-14 content of the Earth's atmosphere over the past 7000 years. The ^{14}C content of wood samples dated by tree-ring counts has been corrected for decay and for isotope fractionation to find the actual atmospheric isotope composition. Variations of the atmospheric isotopic composition from that in a reference standard are given in parts per thousand (permil; ‰). M and S denote the Maunder and Spörer sunspot minima, respectively.

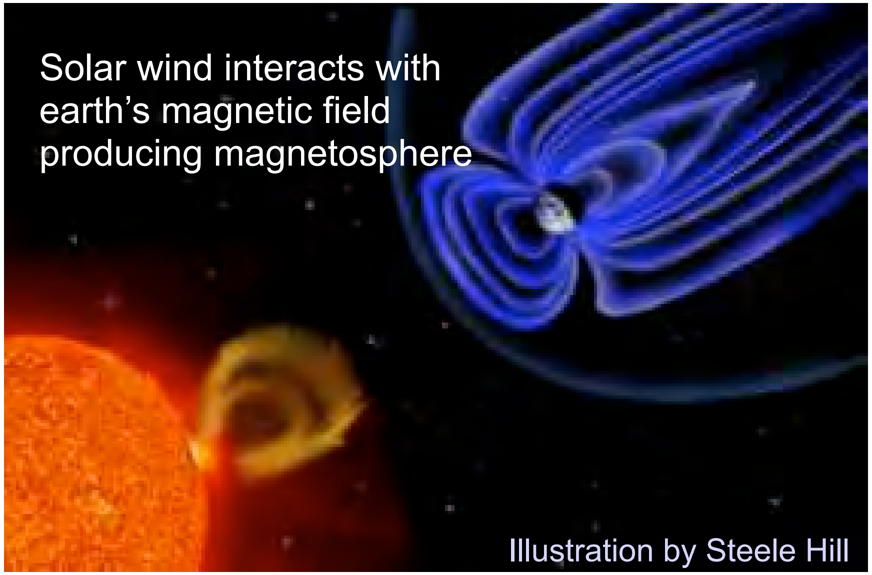
Cosmogenic isotopes more abundant when no sunspots (lower solar wind and weaker magnetosphere shield)

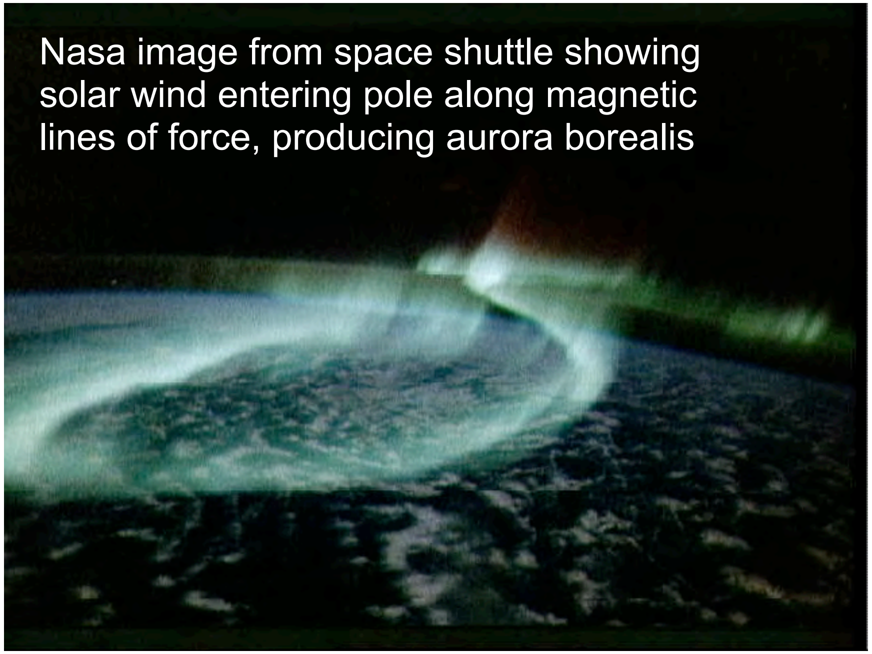
Cosmic Ray Intensity correlates with Sunspot activity



Clouds correlate with cosmic ray intensity (climate connection?)




Solar wind interacts with
earth's magnetic field
producing magnetosphere
Illustration by Steele Hill

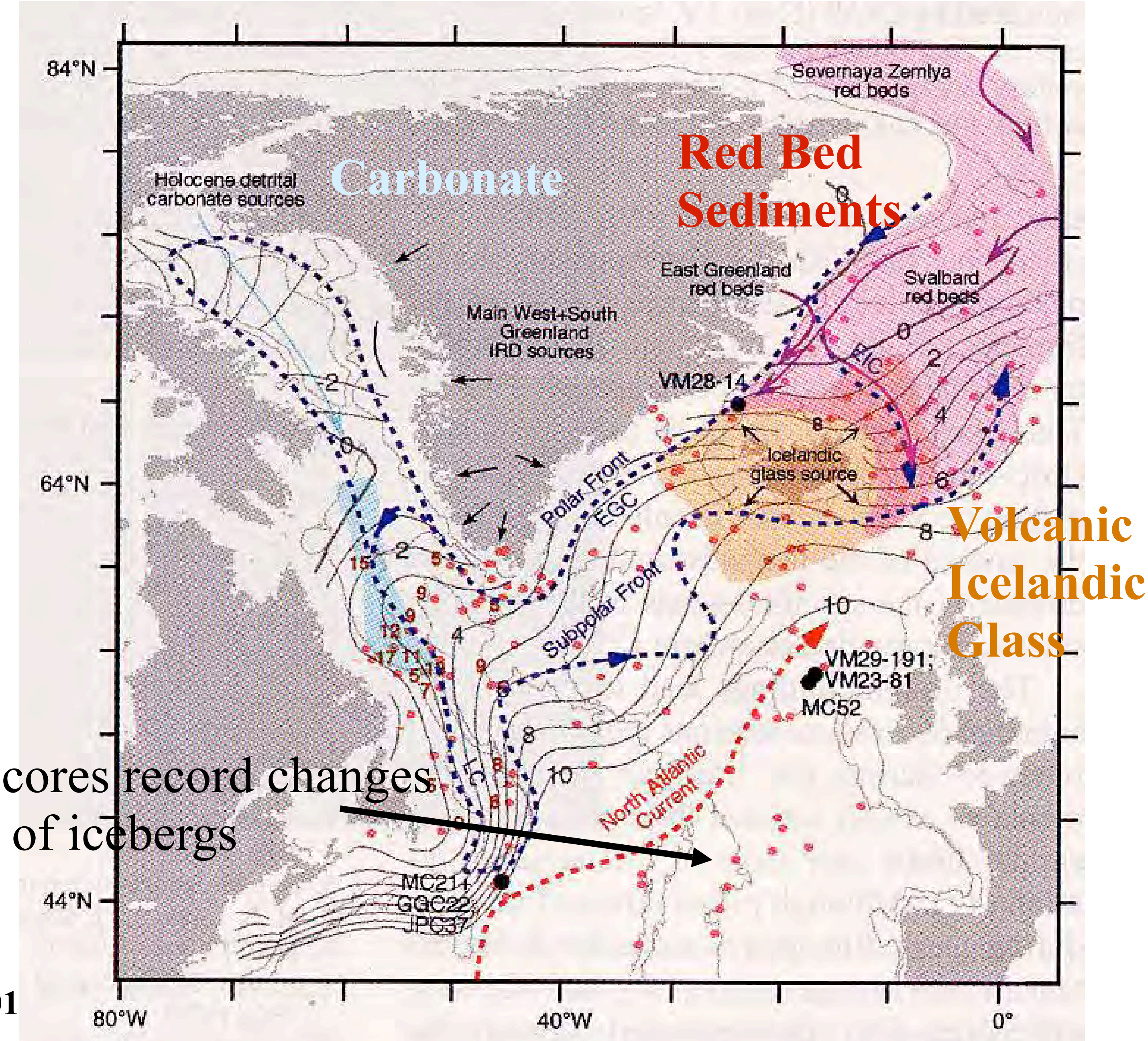

Nasa image from space shuttle showing
solar wind entering pole along magnetic
lines of force, producing aurora borealis


Greenland

- Holocene (current interglacial) changes in climate were:
  - historically significant
  - geologically recorded in areas of high sedimentation (Sargasso Sea)
  - associated with changes in solar activity

A test of the solar cause of Holocene Climate Change:

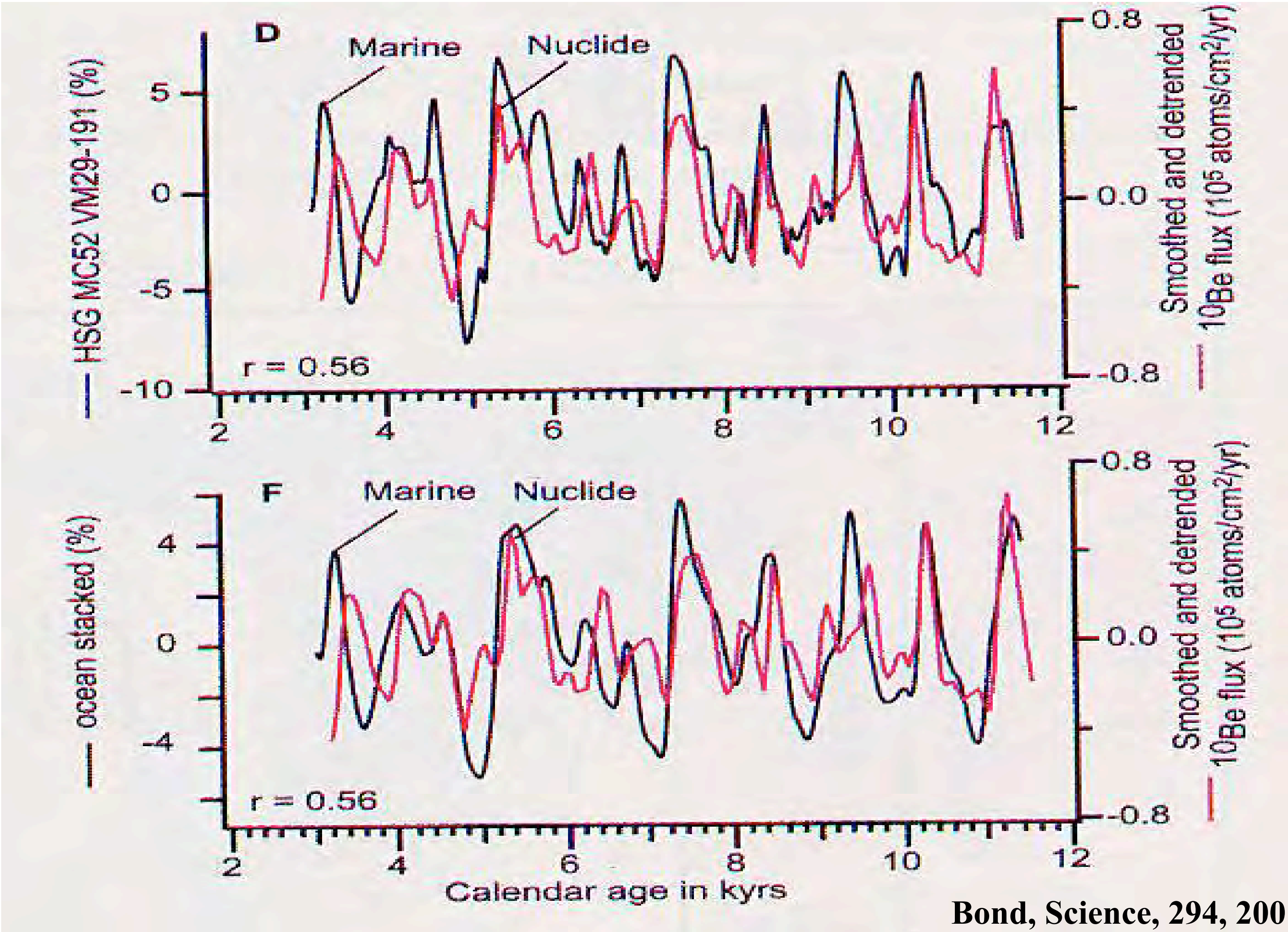
Sources of ice-rafted material in Canada and Iceland:



Ocean sediment cores record changes in southern limit of icebergs

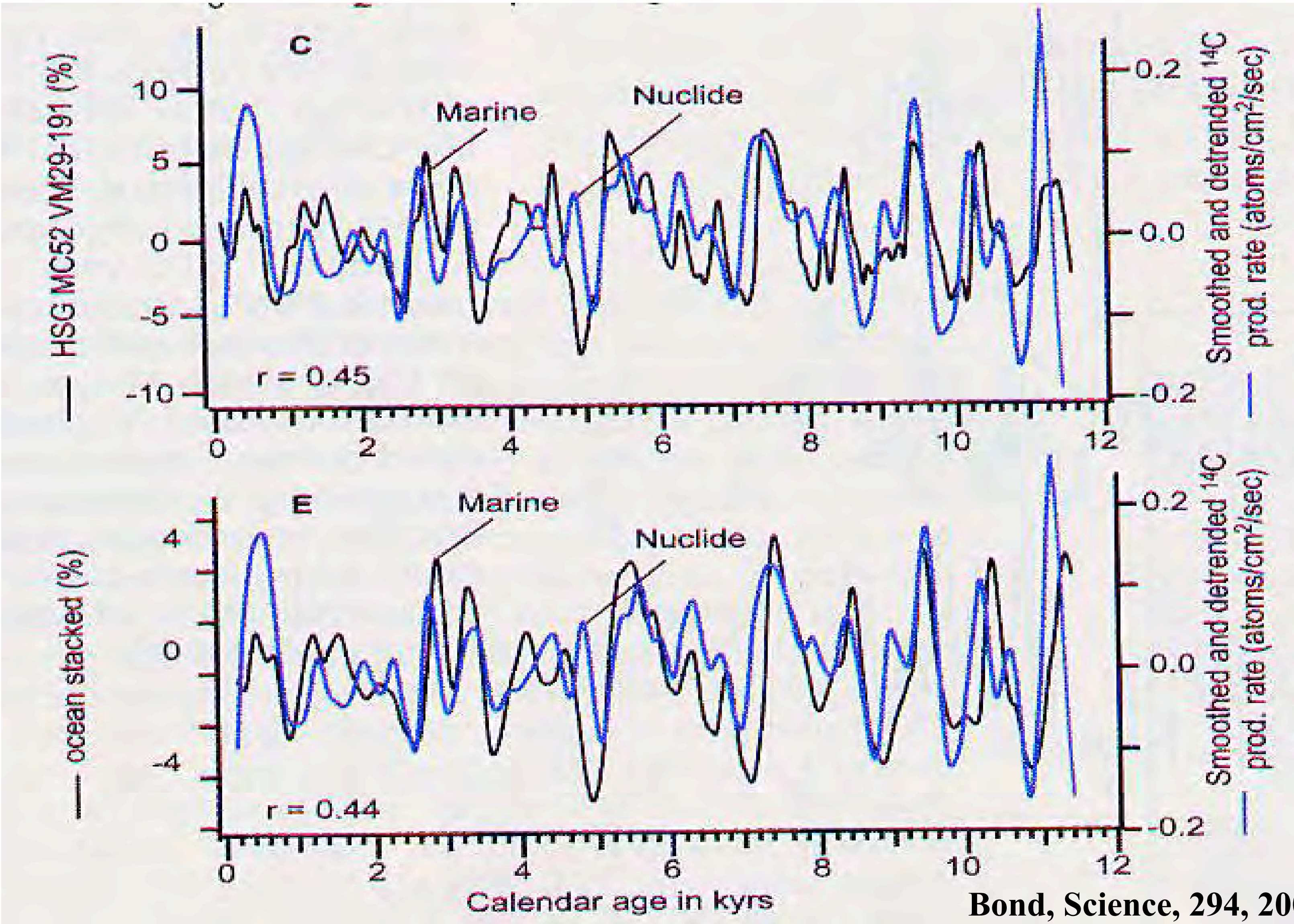
Bond, Science, 294, 2001

Comparison marine and cosmogenic ^{10}Be timeseries from ice cores indicates solar control



Bond, Science, 294, 2001

Comparison marine and ^{14}C timeseries from tree rings indicates solar control of iceberg limit



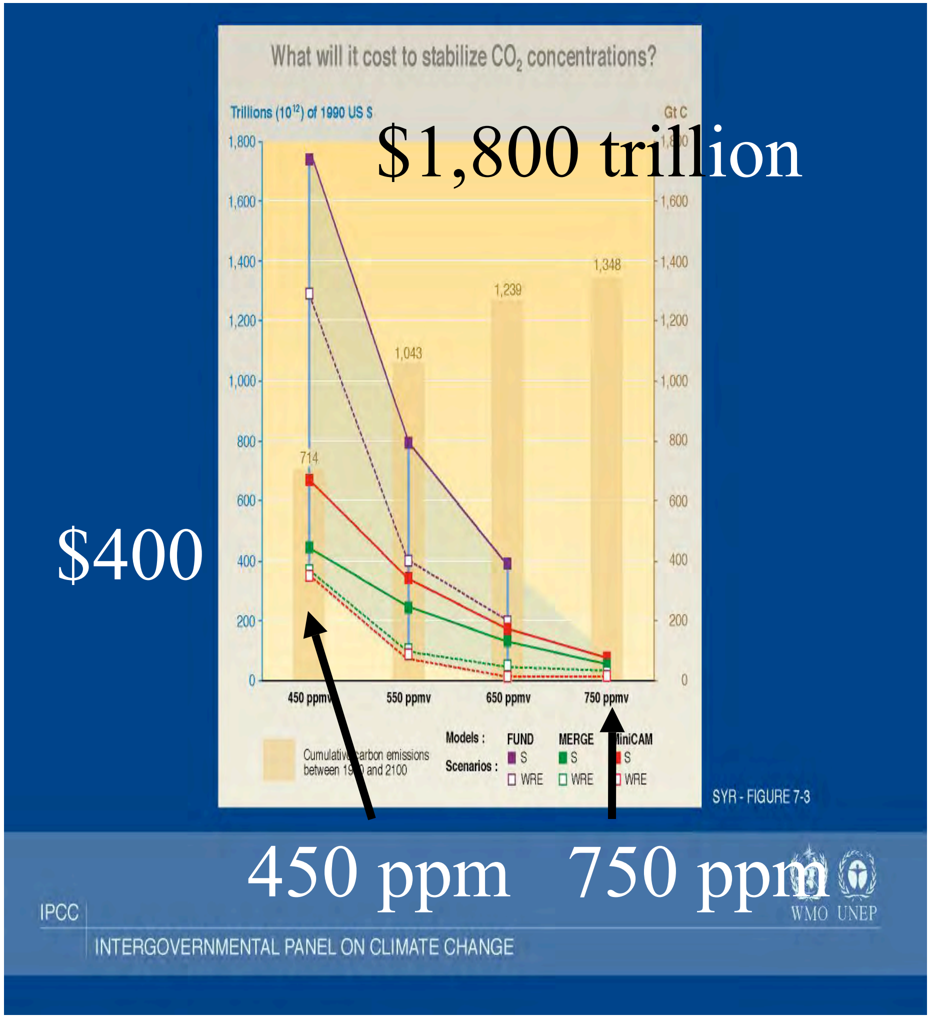
Bond, Science, 294, 2001

Political Questions: 1. Is climate change real?

- **Of course!**
  - Snowball earth
  - Permial Glaciation
  - Eocene “Indonesian” England→ “current” England
  - 15 to 20 ice ages (northern hemisphere glaciations)
  - Holocene optimum
  - Medieval Warm Period
  - Little Ice Age
  - Present Warm Period

3. Should we buy insurance (Kyoto)?

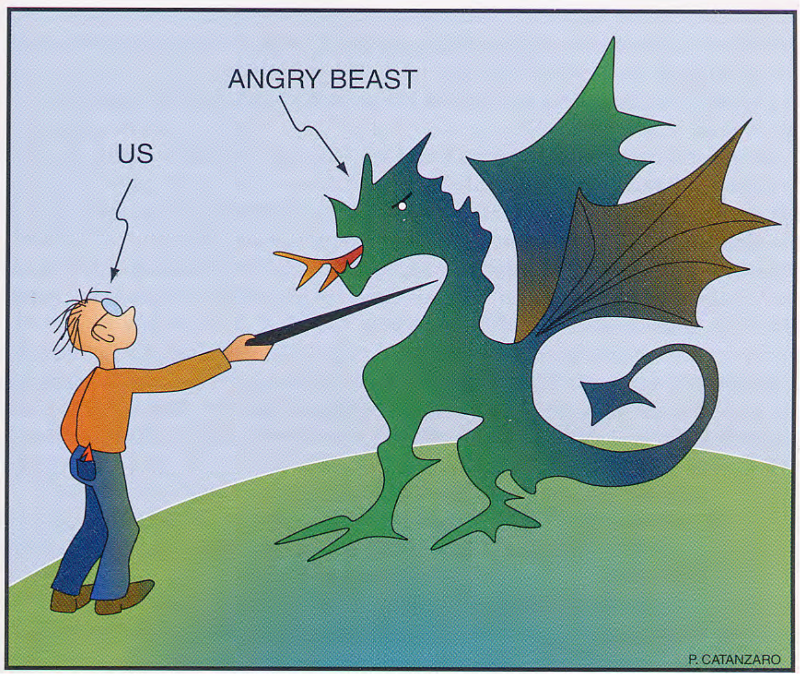
- Insurance against what?
  - Ice age?
  - Global Warming?
  - Warming that will trigger cooling and instability?
  - Solar changes?
  - Avoiding a scheduled ice age?
- CO_2 control Expensive!
- Legal collateral damage?
  - Objectivity of science
  - Flexibility to take other approaches (committed careers)
- Opportunity cost
  - Lots of other problems



Intergovernmental Panel on Climate Change http://www.ipcc

2. Is human activity a factor?

- Perhaps, but we don't understand how
- Broecker says prodding an angry beast is unwise
- But there are other creatures prodding the beast



Broecker, 2001

Implications for Sustainability?

- Last ~100 yrs unusually climatically stable
- Should not assume this is typical
- Switch is likely to flicker again

My Recommendation

- Make commitments carefully
  - economic rules will be difficult to change, have unanticipated consequences, and affect many careers
  - character of human impact unclear
    - avoiding ice age would be very good, but
    - warming could push us into cooling
    - if sun controls, human actions irrelevant
  - natural changes likely to occur regardless or human actions
- Wait for scientific clarification
  - it will come quickly
- Avoid politization of science
  - majority of scientists always wrong (required for progress)
  - humans tend to over-emphasize own importance
  - objective science best hope

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