Millennial Cycles: Relevance and Mechanisms

Matt Hitchman AOS Department Colloquium October 1 2012

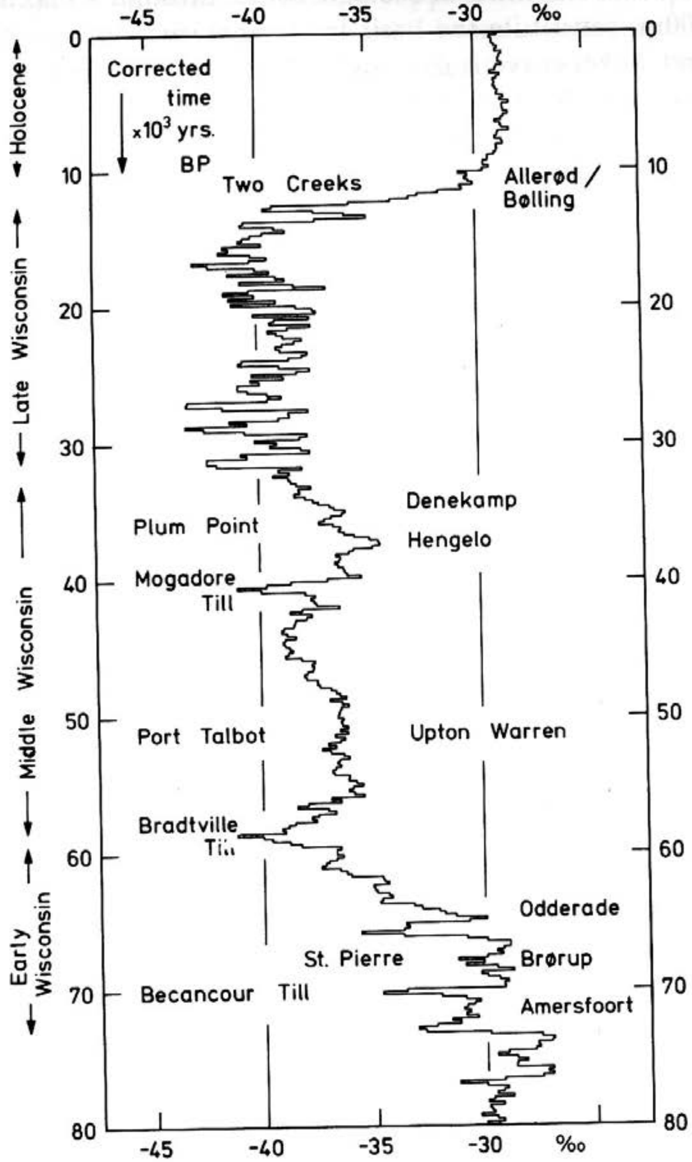
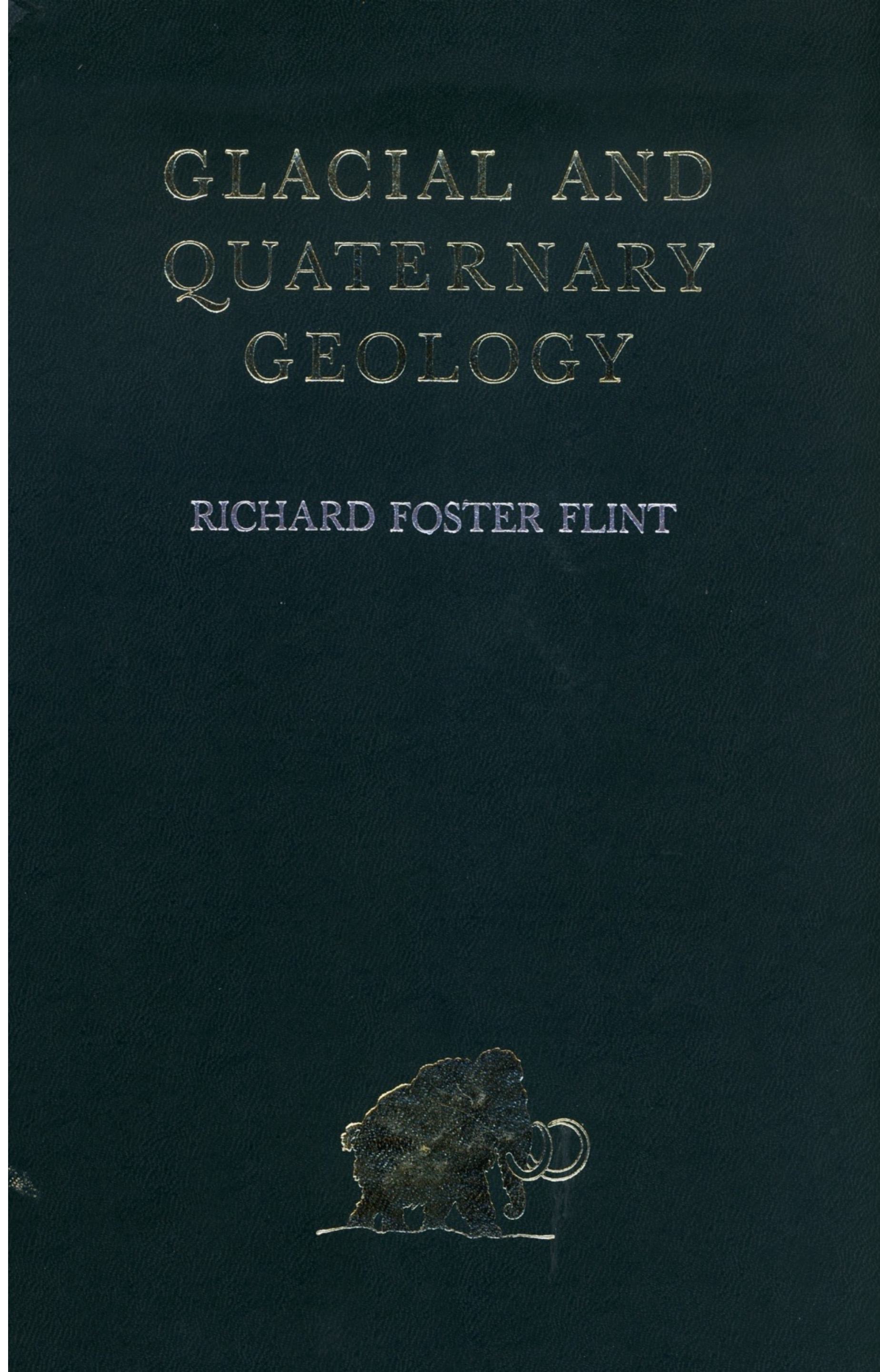


Figure 16-12 Curve representing a large part of the Camp Century, Greenland, ice core, in which δ(0[18]) is plotted against time, calibrated as explained in text. The curve compares well with the curves shown in fig 16-11; hence its authors have suggested, by means of labels, possible correlations with stratigraphic units elsewhere. (Dansgaard et al. in Turekian, ed., 1971).

Steven Porter spring 1977



"A Hairy Comet"

"1500 year volcanic periodicity"

Reid Bryson

"Binary Companion"

"The Mayans Knew"

Yum Kax

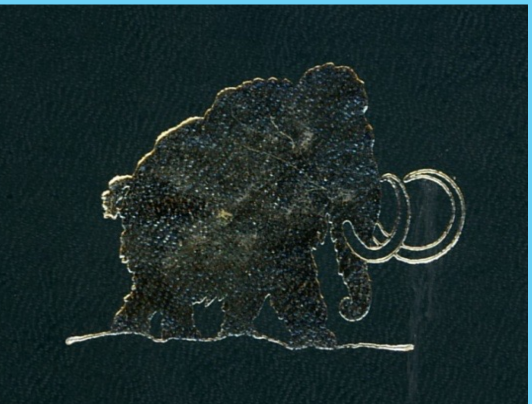
"Holocene 1500 year variations"

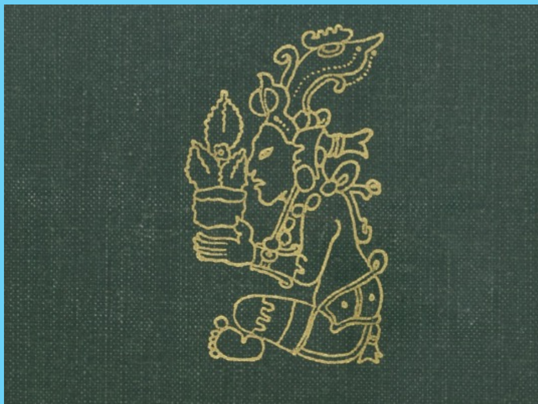
"Civilizations Wax and Wane at Millennial Scales"

What causes the millennial periodicity in the climate signal?

Is it internal or external to the climate system?

Do we understand the mechanisms of rapid cooling or warming (e.g., the end of Younger Dryas)?





Wally Broecker
The Great Ocean Conveyor

"A bipolar seesaw"

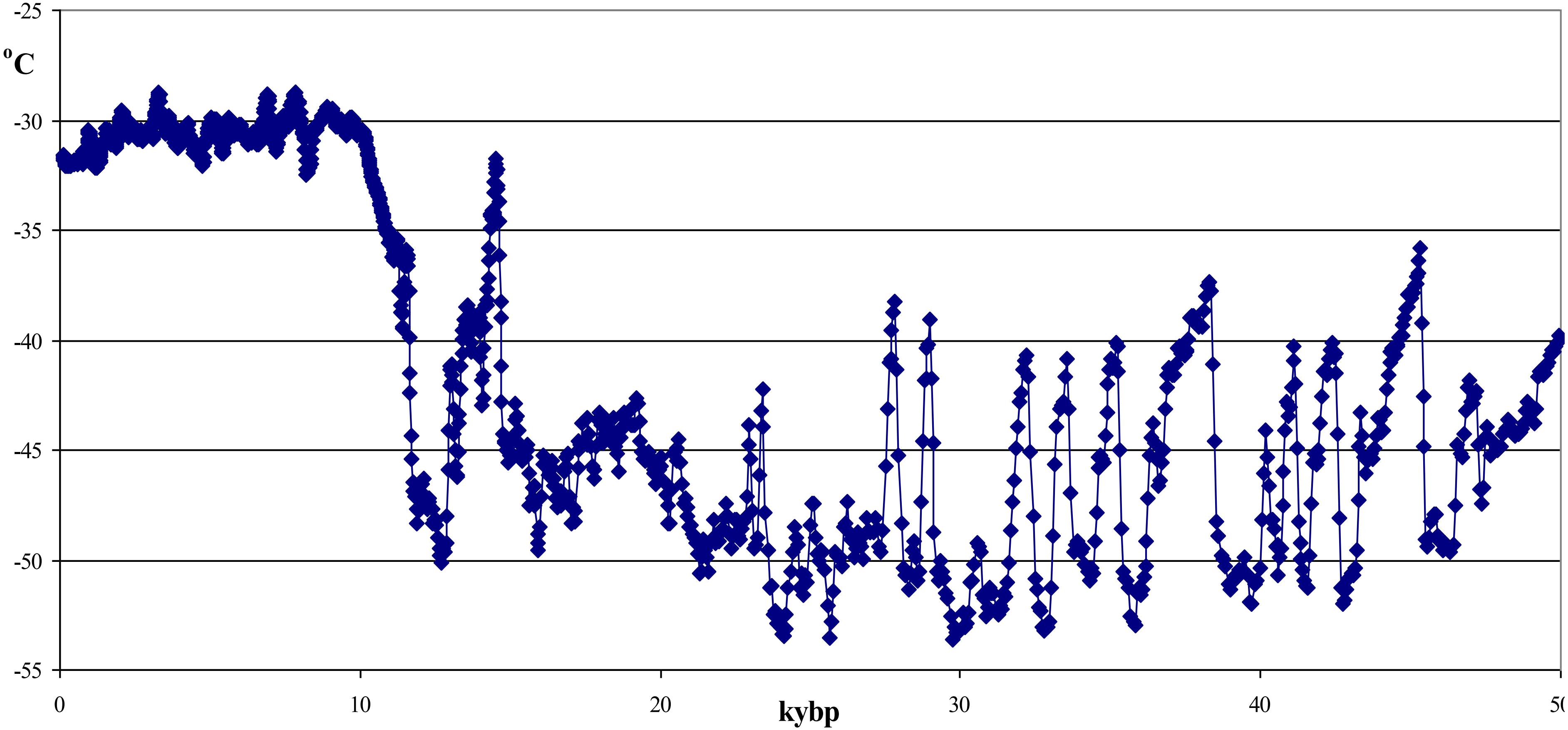


Figure 4.3. Variations in Greenland surface temperature (°C) at GISP2 over the past 50,000 years. Note the common occurrence of Dansgaard-Oeschger events during the Wisconsin Ice Age, but not during the Holocene [Alley et al. 2000, 2004, www.ncdc.noaa.gov/paleo].

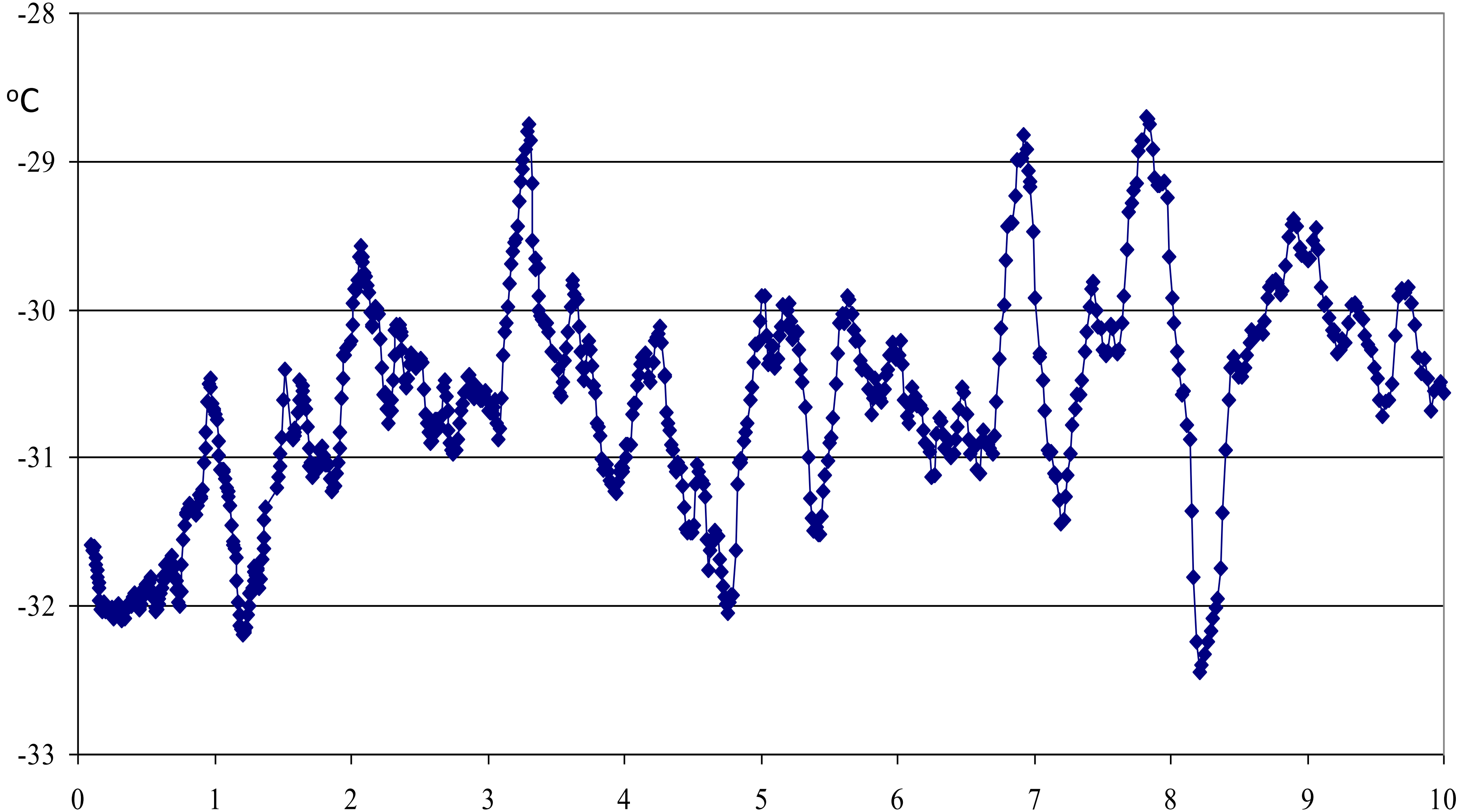


Figure 4.10. Variations in Greenland surface temperature (°C) at GISP2 over the past 10,000 years. Note the interesting variability at millennial time scales [Alley et al. 2000, 2004, www.ncdc.noaa.gov/paleo].

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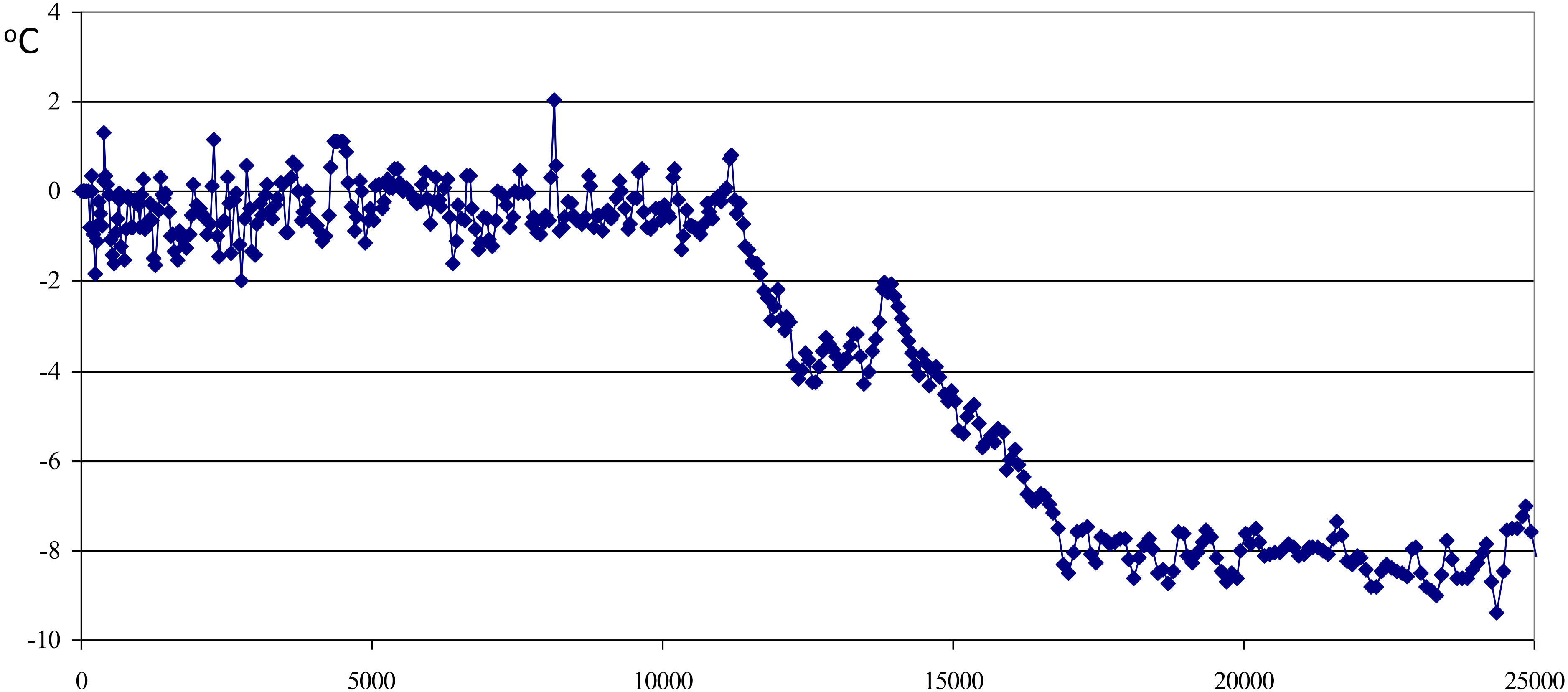

Figure 4.4b. Variation of global temperature over the past 25,000 years estimated from Vostok deuterium [Petit et al. 2001; data from www.ncdc.noaa.gov/paleo].

Figure 4.7. Bathymetry of the North Atlantic region [http://www.gebco.net/].

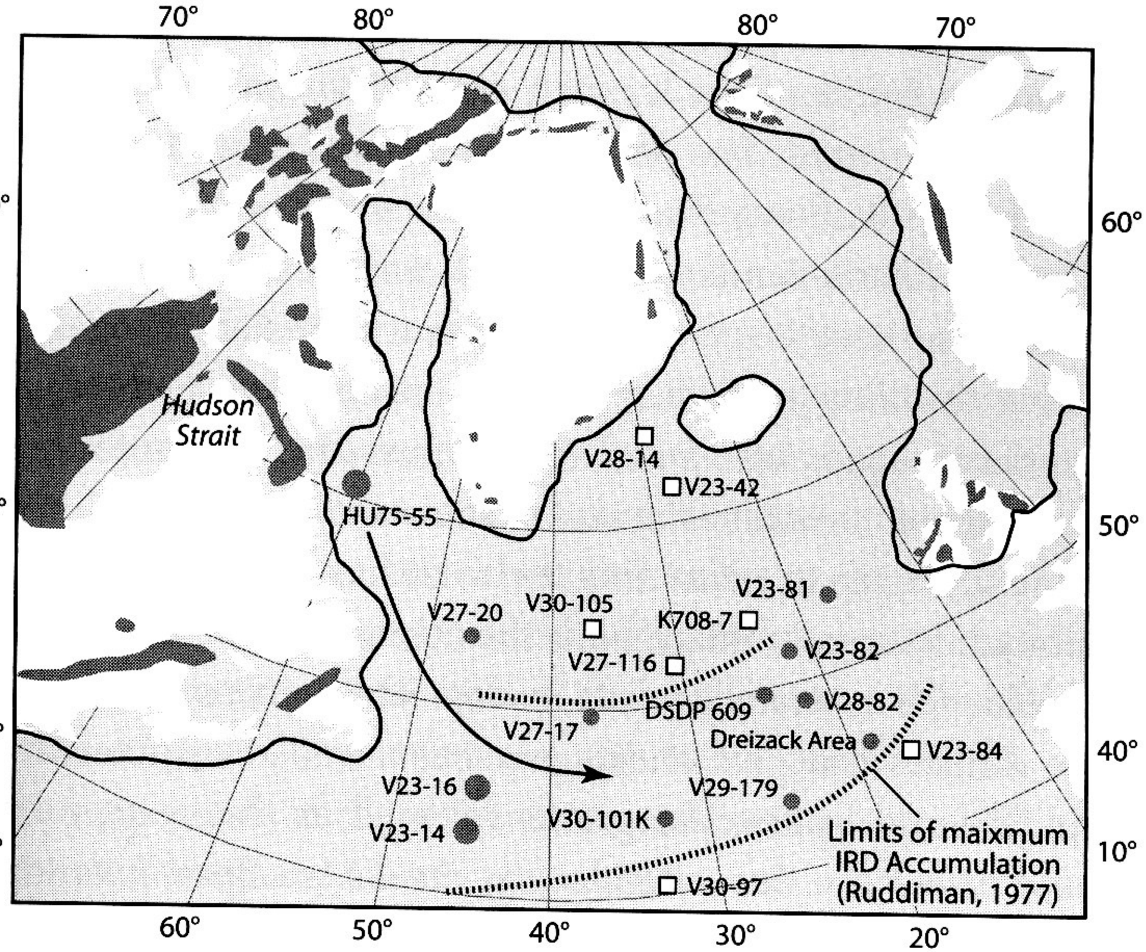

Figure 5-3. Map showing the location of cores in which detrital limestone-bearing Heinrich layers have been identified (solid circles) and of cores in which they are absent (open squares), as created by Sidney Hemming of Lamont-Doherty. The size of the circles is proportional to the thickness of the layers. The black patches on the land masses denote occurrences of sedimentary limestones that might serve as sources for the detrital calcite. The solid line shows the maximum size of the glacial ice sheets. The arrow shows the likely path taken by the Heinrich ice armadas.

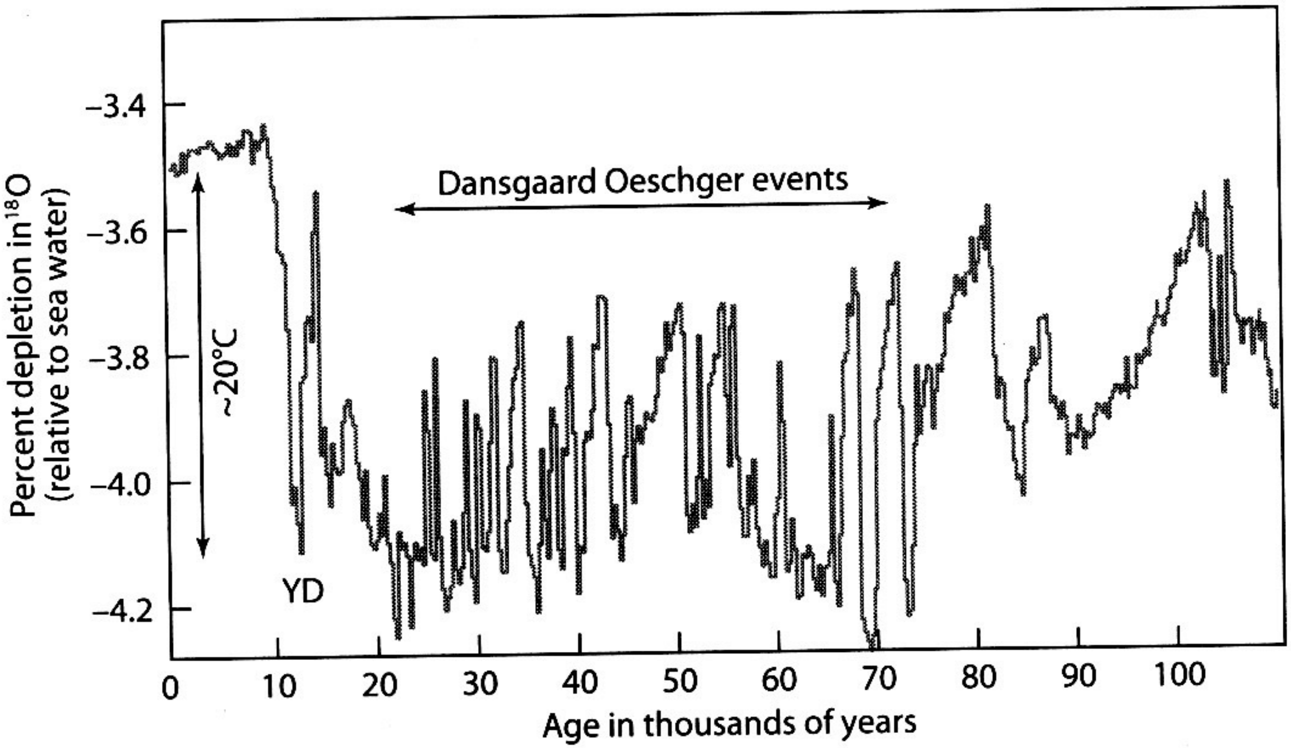

Figure 2-2. Unlike the stable isotope record in Antarctic ice, which is dominated by stately Milankovitch-paced cycles, that in Greenland ice is riddled with large and abrupt millennial-duration fluctuations known as Dansgaard-Oeschger events. The temperature scale on this diagram is based on a deconvolution of downhole thermal profile rather than on the ^{18}O measurements themselves, which suggest only half as large a temperature change as shown here. These measurements were made in the laboratory of Minze Stuiver at the University of Washington and in the laboratory of Willi Dansgaard in Copenhagen.

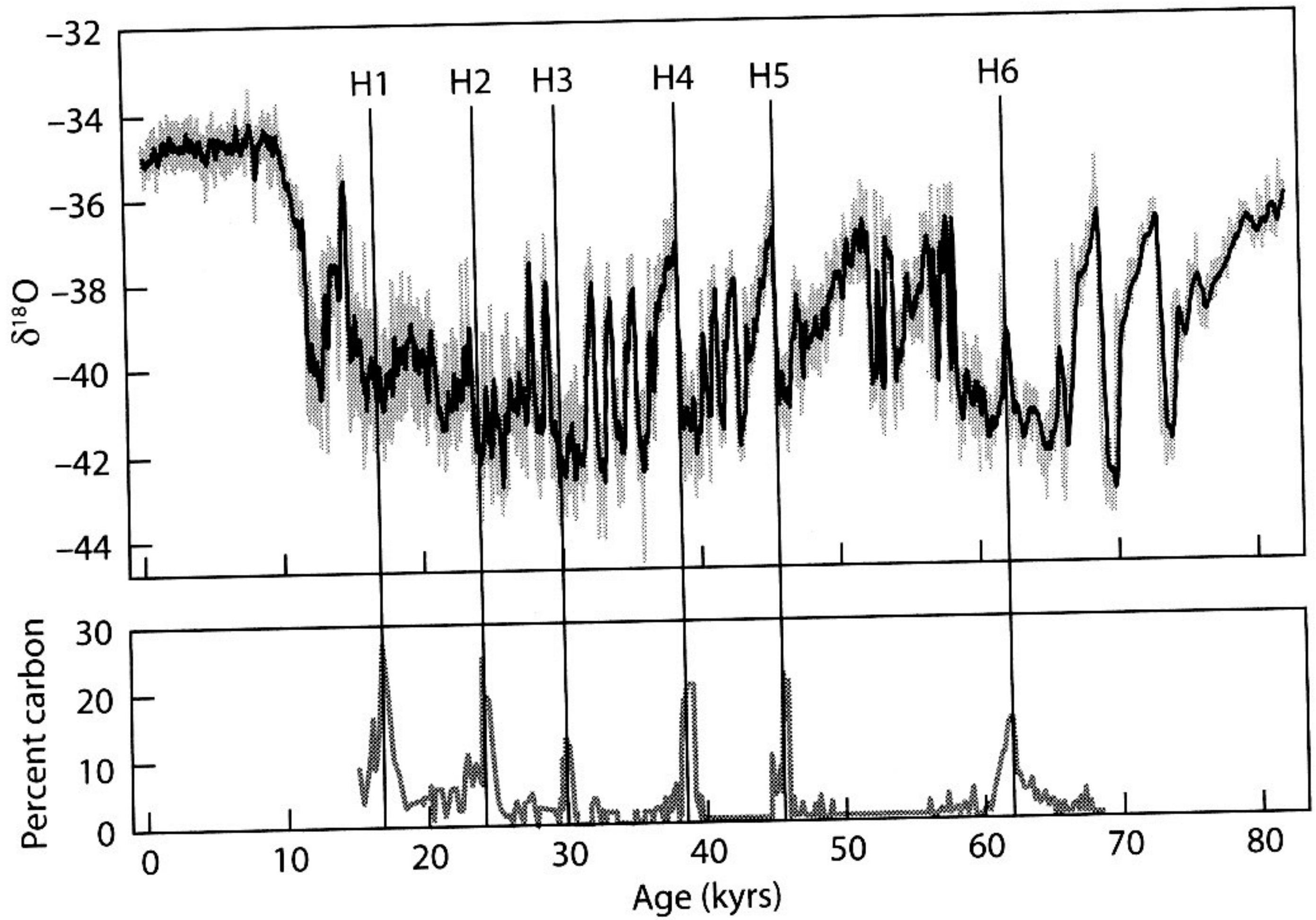

Figure 5-5. Gerard Bond's placement of the Heinrich ice armadas in the sequence of Dansgaard-Oeschger events as recorded in the GISP2 ice core. As can be seen, there appears to be a subcycle of weakening D-O events that culminates in a Heinrich outbreak.

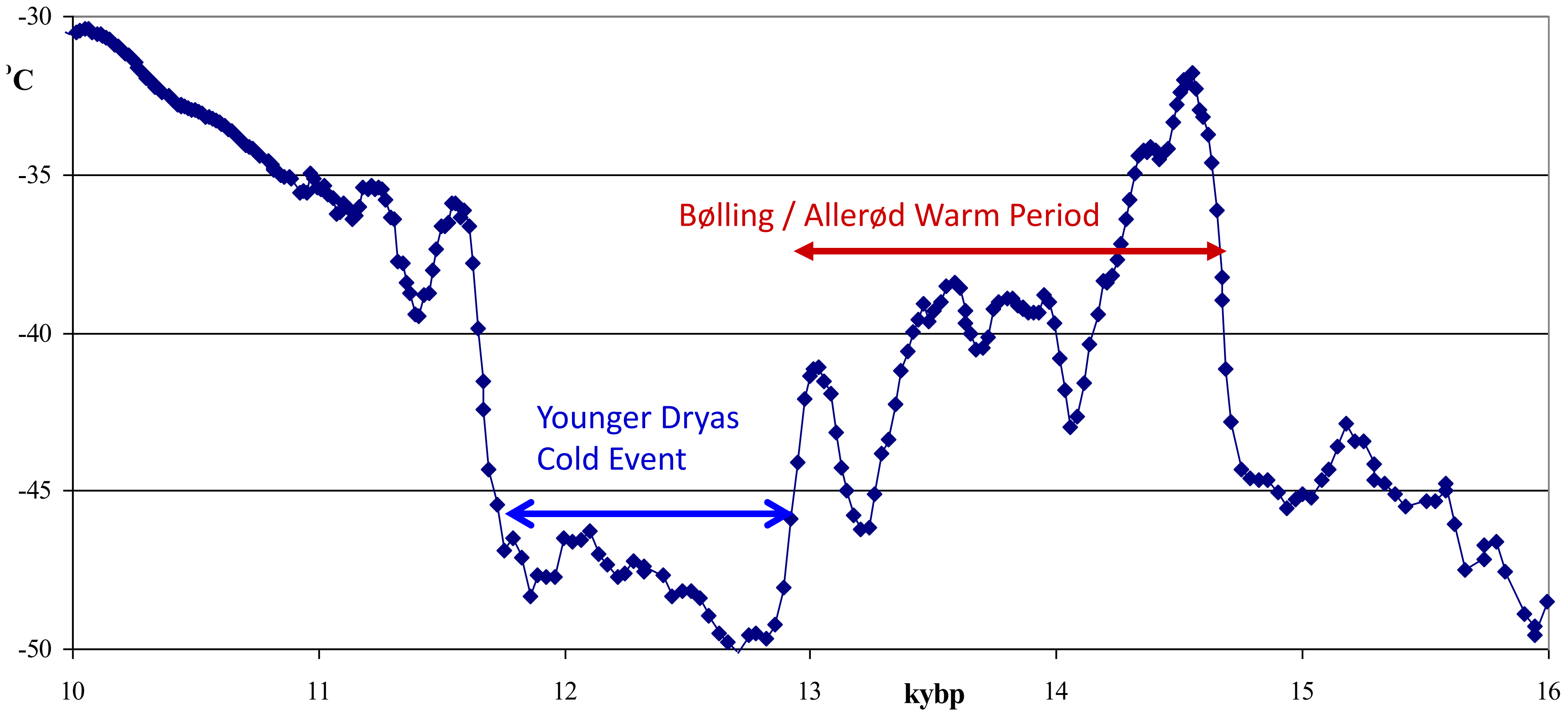

Figure 4.5. Variation in Greenland surface temperature during 16 – 10 kybp [Alley et al. 2000, 2004, www.ncdc.noaa.gov/paleo]. The Bølling / Allerød period (14.6 – 12.9 kybp) began with, and the Younger Dryas period (12.9 - 11.6 kybp) ended with rapid warming.

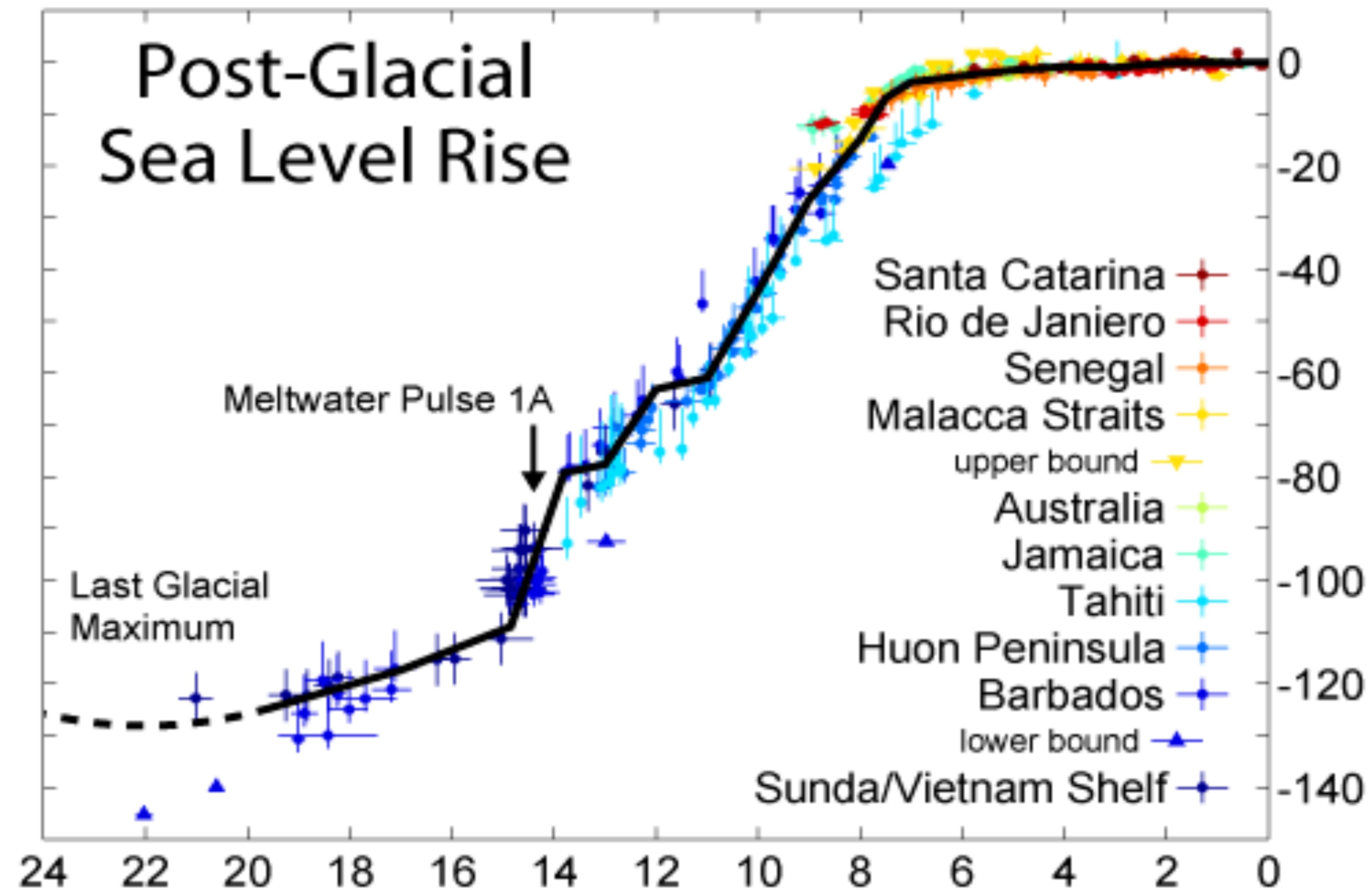

Figure 4.9a. Change in sea level (meters) from 22 kybp to the present. Note the meltwater pulse near 14.5 kybp that ushered in the Bølling / Allerød period [IPCC 2007].

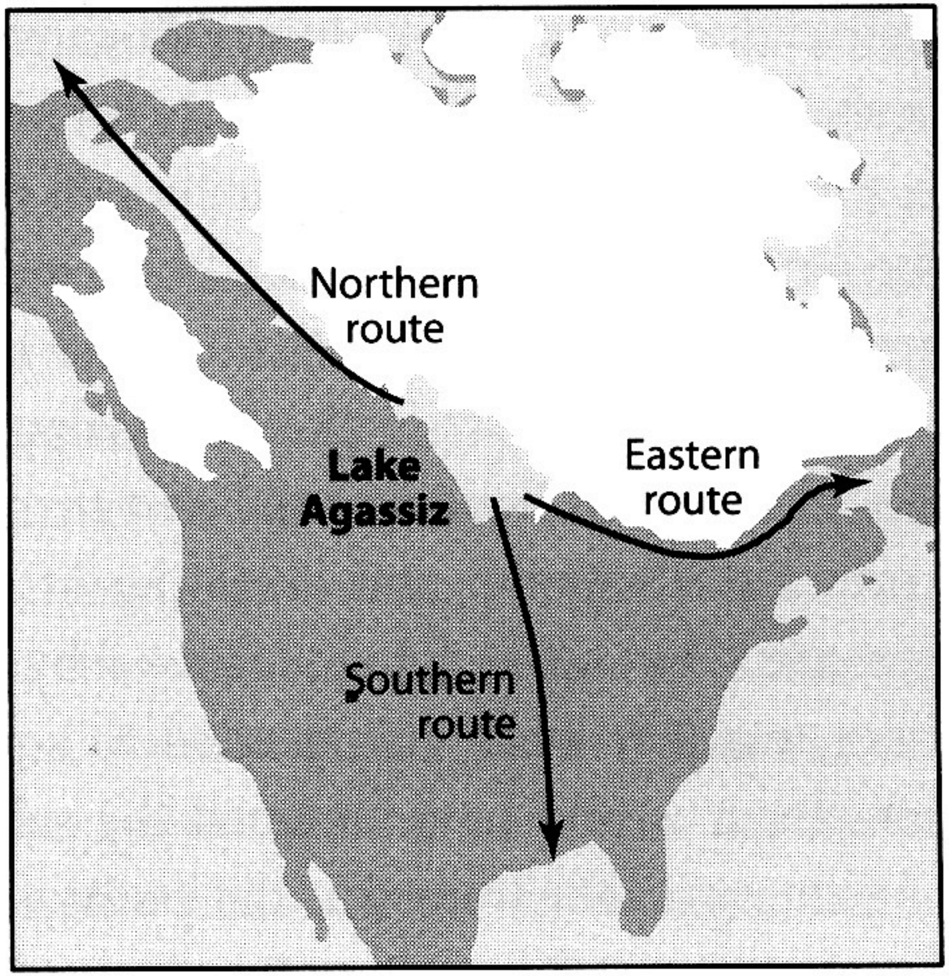

Figure 2-4. As the Laurentide ice sheet retreated at the close of the last glacial period, meltwater lakes formed around its margin. One of these, Lake Agassiz, underwent a major drop in level at about the time of the onset of the Younger Dryas cold snap. One hypothesis is that water released by this drop flooded to the east into the northern Atlantic, bringing the conveyor to a halt.

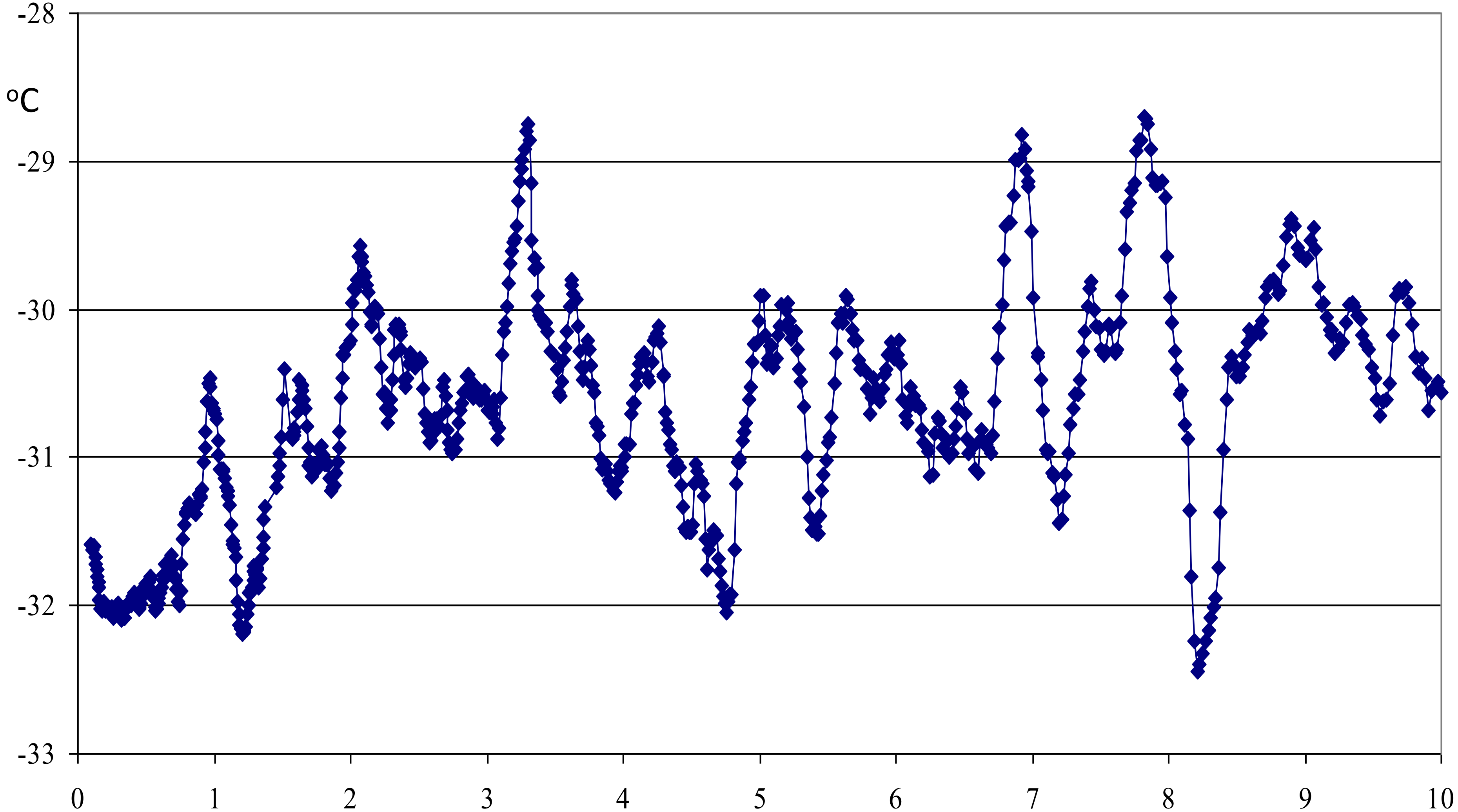

Figure 4.10. Variations in Greenland surface temperature (ºC) at GISP2 over the past 10,000 years. Note the interesting variability at millennial time scales [Alley et al. 2000, 2004, www.ncdc.noaa.gov/paleo].

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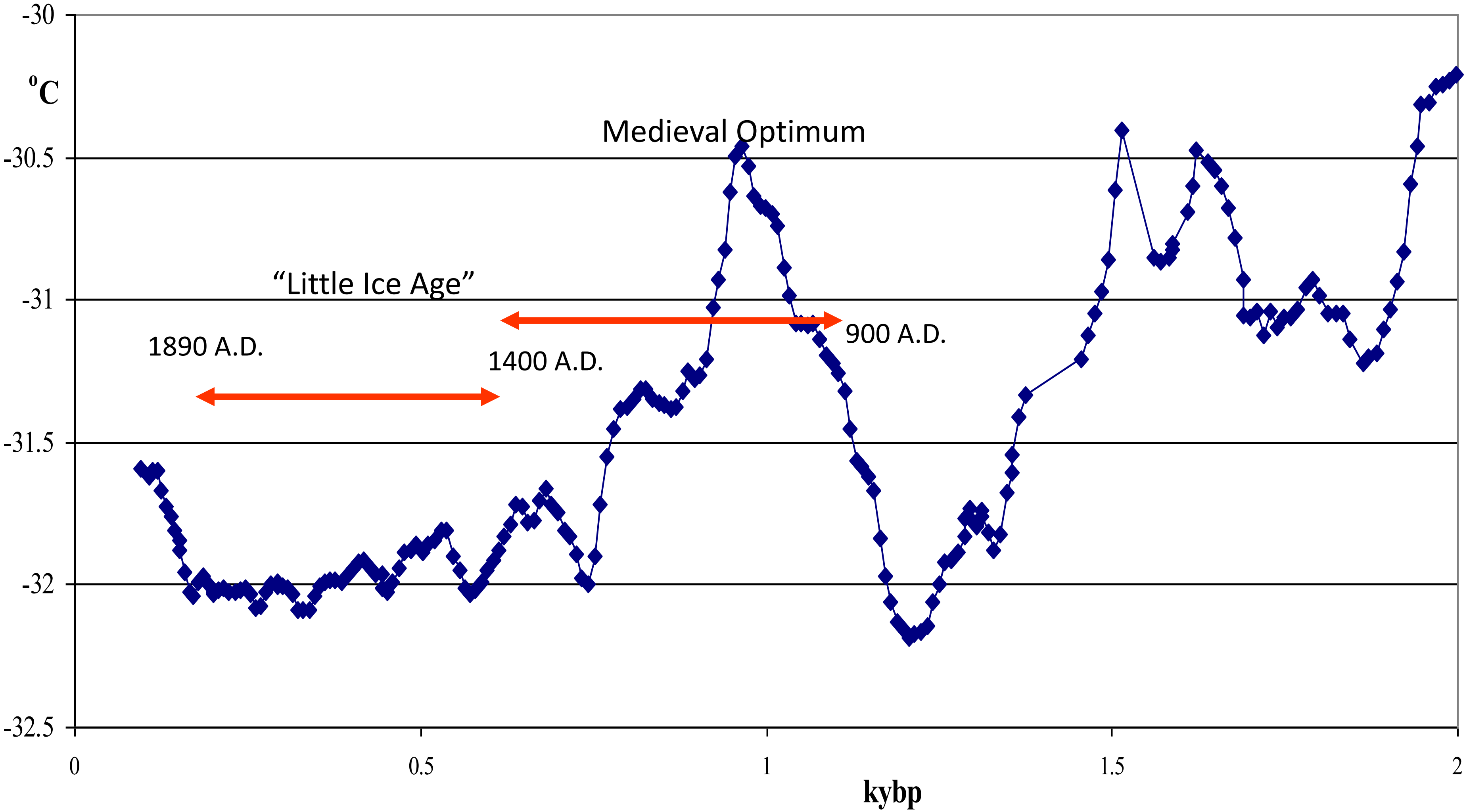

Figure 4.11. Variations in Greenland surface temperature (°C) at GISP2 over the past 2,000 years. Note the relatively warm period during 900 – 1400 A.D. (1100 – 600 ybp) and the cool period during 1400 – 1890 A.D. (600 – 120 ybp) [Alley et al. 2000, 2004, www.ncdc.noaa.gov/paleo].

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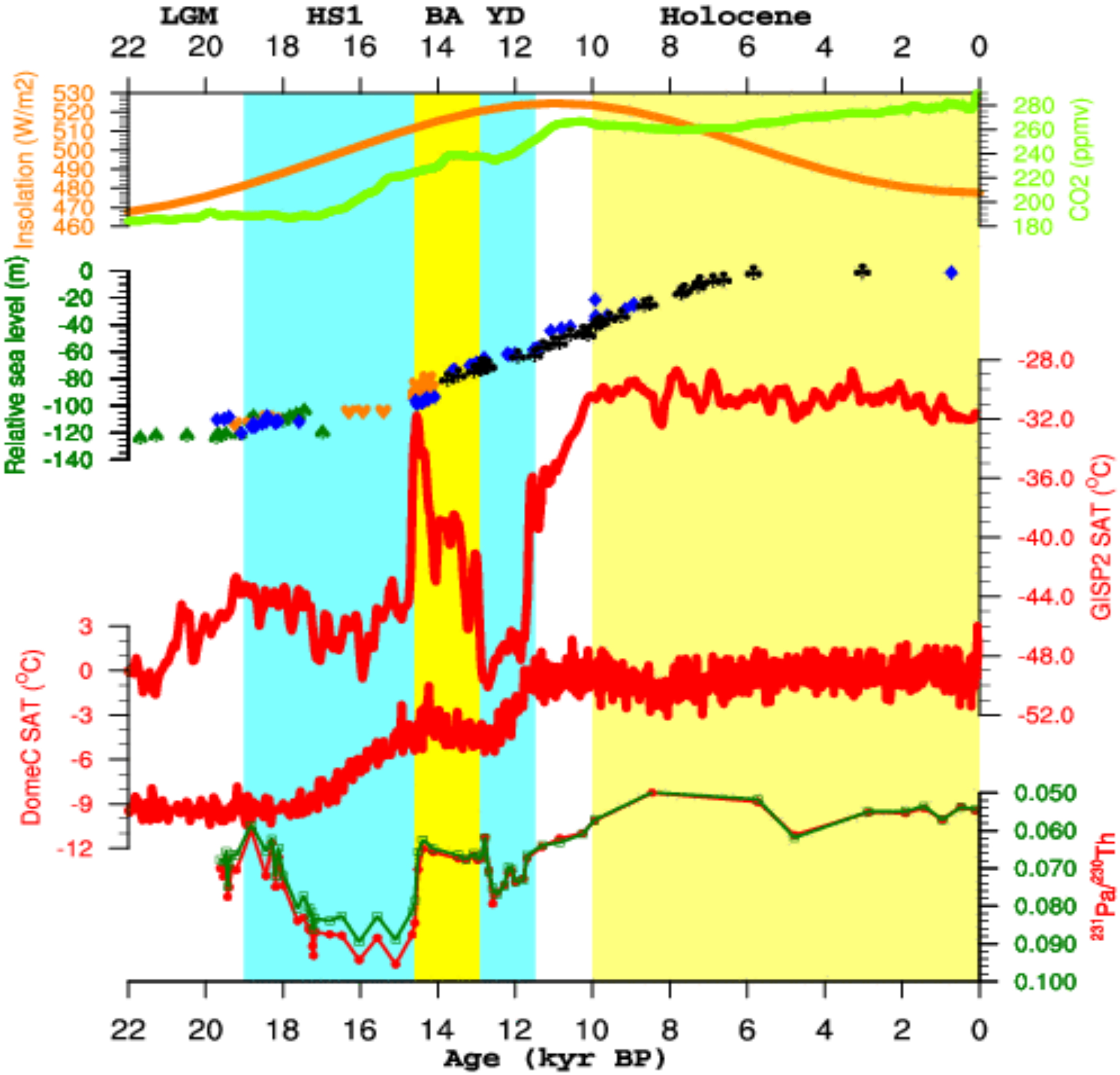
What might cause variations at millennial time scales?

Hypothesis #1

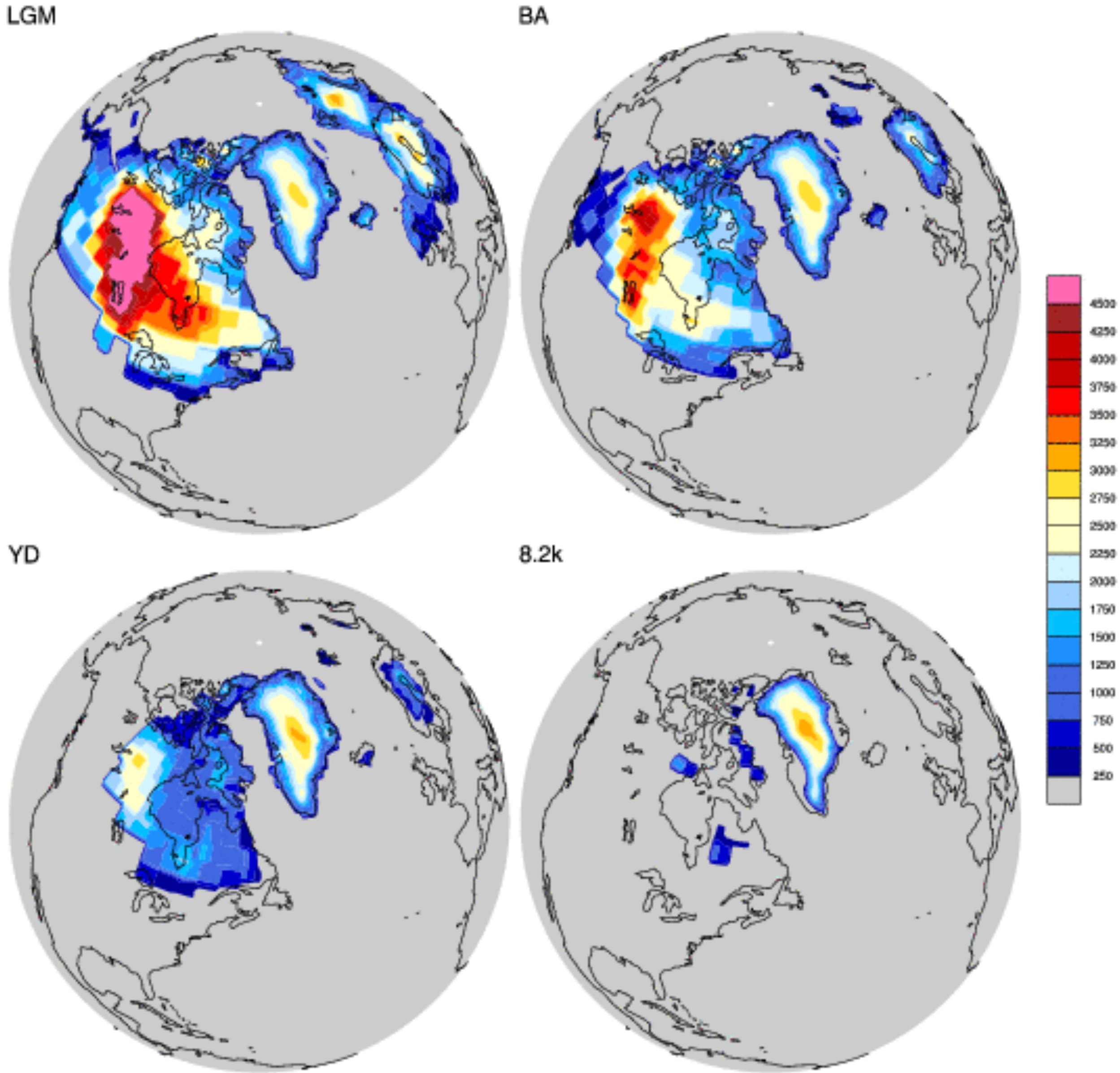
Millennial Cycles are a Natural Periodicity of the Ocean-Atmosphere-Cryosphere System

- Bipolar Seesaw
- Hosing Experiments in a GCM
- How does this oscillator work?

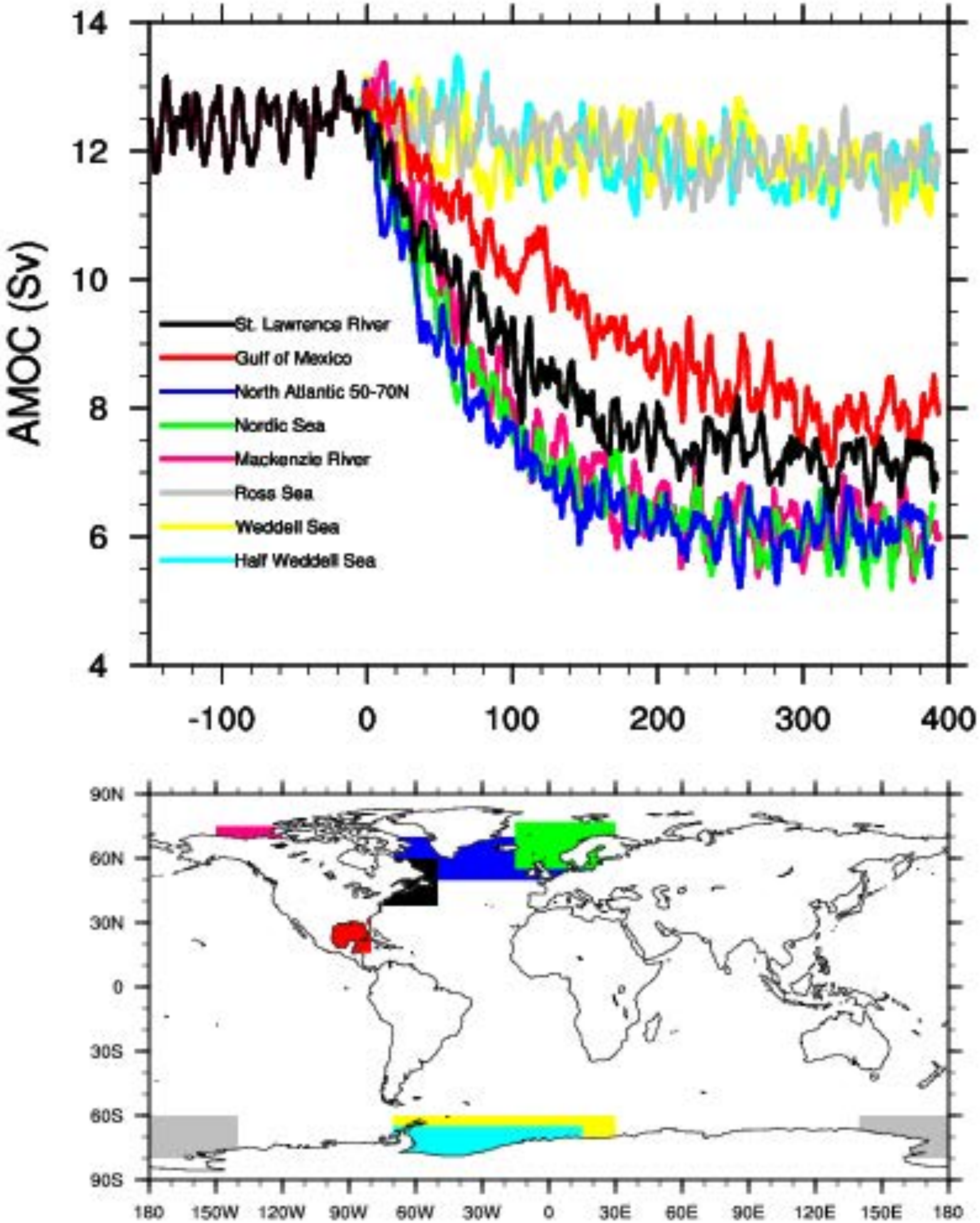


Feng He
Ph.D. 2011
UW Madison

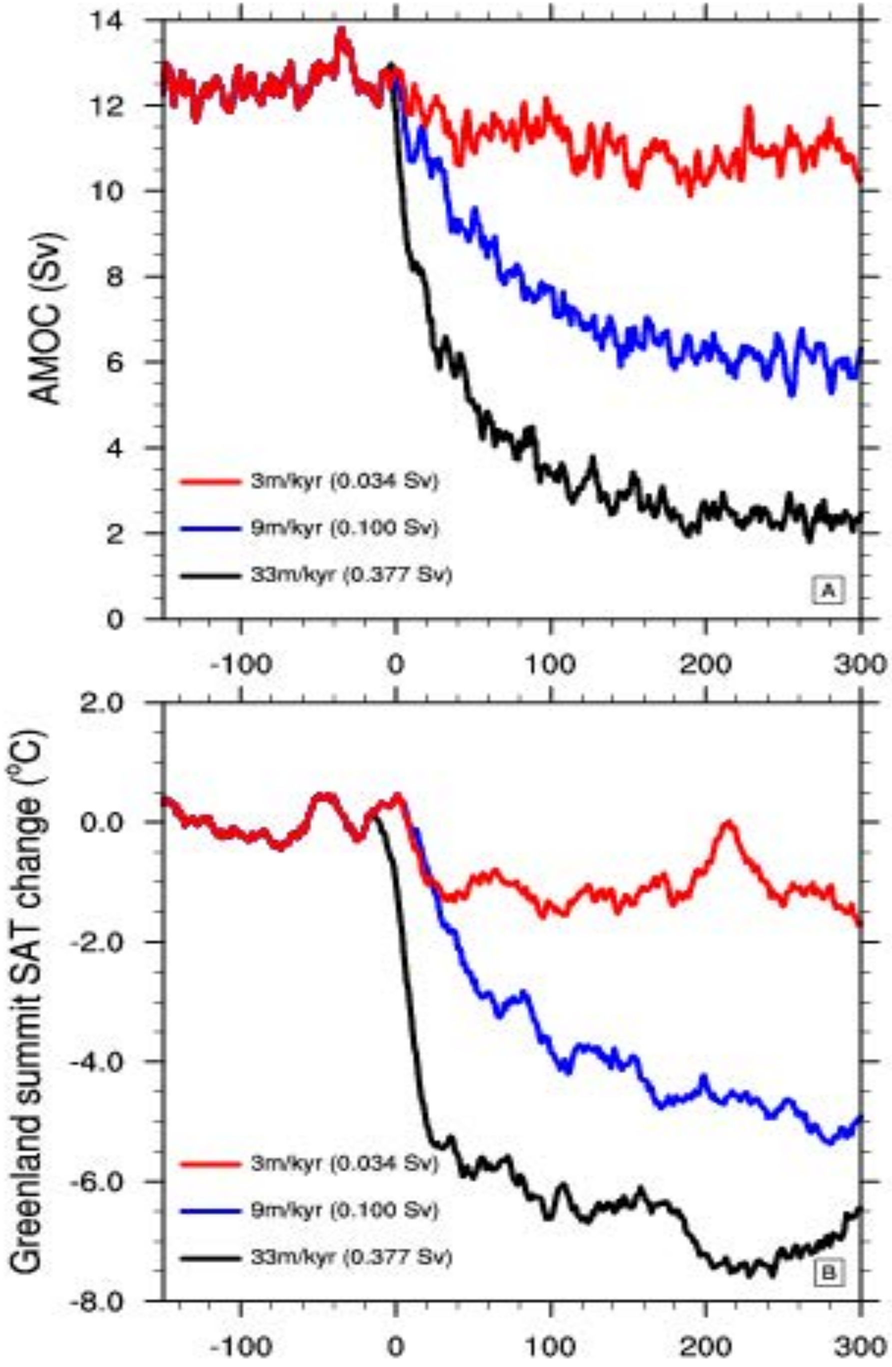
Climate evolution during the last deglaciation. (**A**) June 21st insolation at 60°N (orange) and atmospheric CO_2 concentration (green, ppmv). (**B**) Relative sea level data are from Barbados (blue), Bonaparte Gulf (blue), Sunda Shelf (orange) and Tahiti (black). (**C**) Greenland surface air temperature (SAT) based on Greenland Ice Sheet Project 2 (GISP2) $\delta^{18}O$ reconstruction with borehole temperature calibration. (**D**) Antarctic SAT based on Dome C $\delta^{18}O$ reconstruction. (**E**) Pa/Th ratio at Bermuda as a proxy for AMOC export.



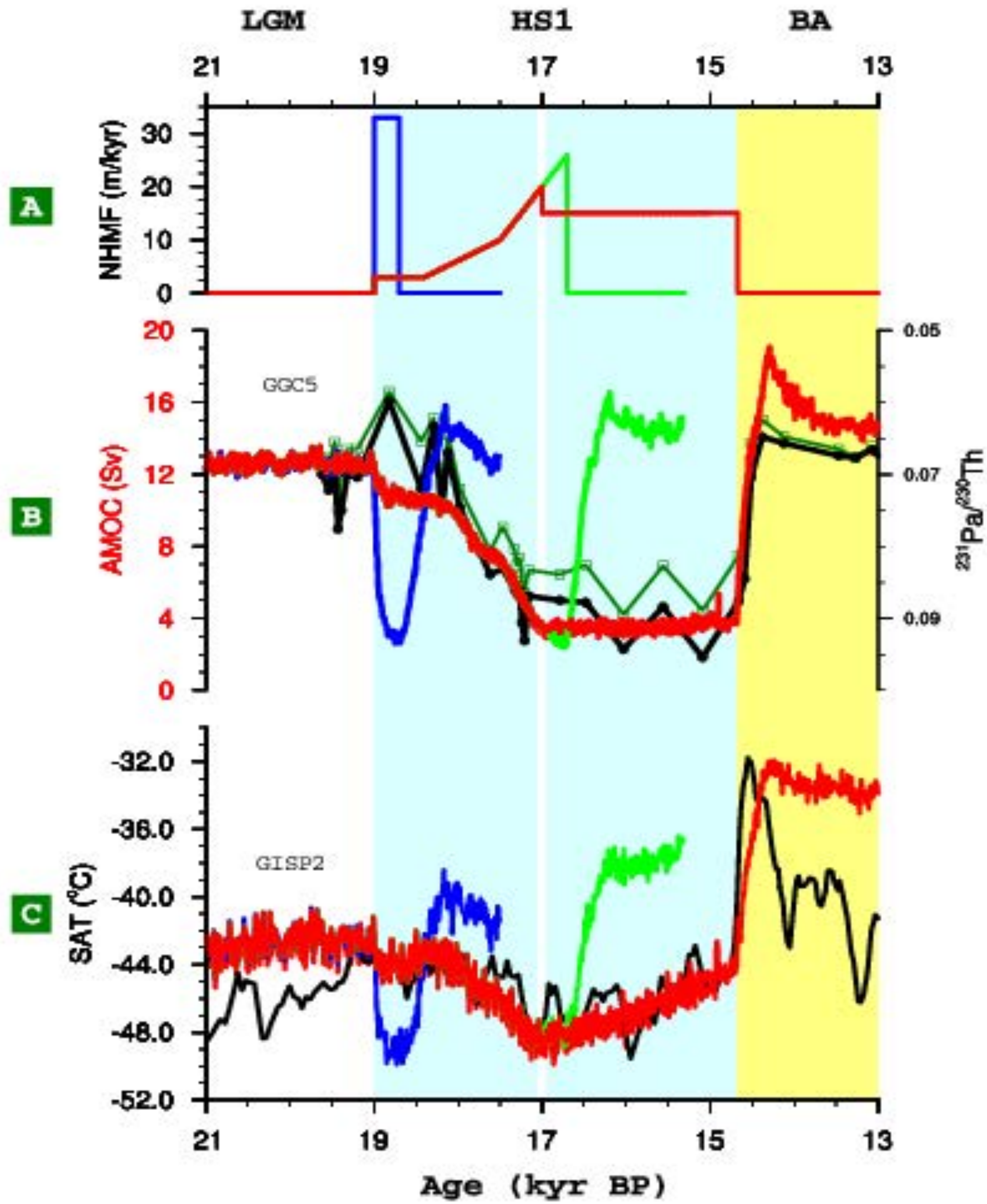
The height (in m) of the Northern Hemisphere Ice Sheet based on Ice5G reconstruction [Peltier, 2004] during the LGM (upper left), BA (upper right), YD (lower left) and 8.2 ka (lower right).



The sensitivity of the (top) AMOC to the (bottom) locations of the 0.1 Sv meltwater forcing. The locations of meltwater forcing includes the Beaufort Sea/Mackenzie River (pink), the Nordic Sea (green), 50 to 70° N of the North Atlantic (blue), the St. Lawrence River/western North Atlantic (black), the Gulf of Mexico (red), Ross Sea (gray), the Weddell Sea (yellow) and half of the Weddell Sea (light blue).



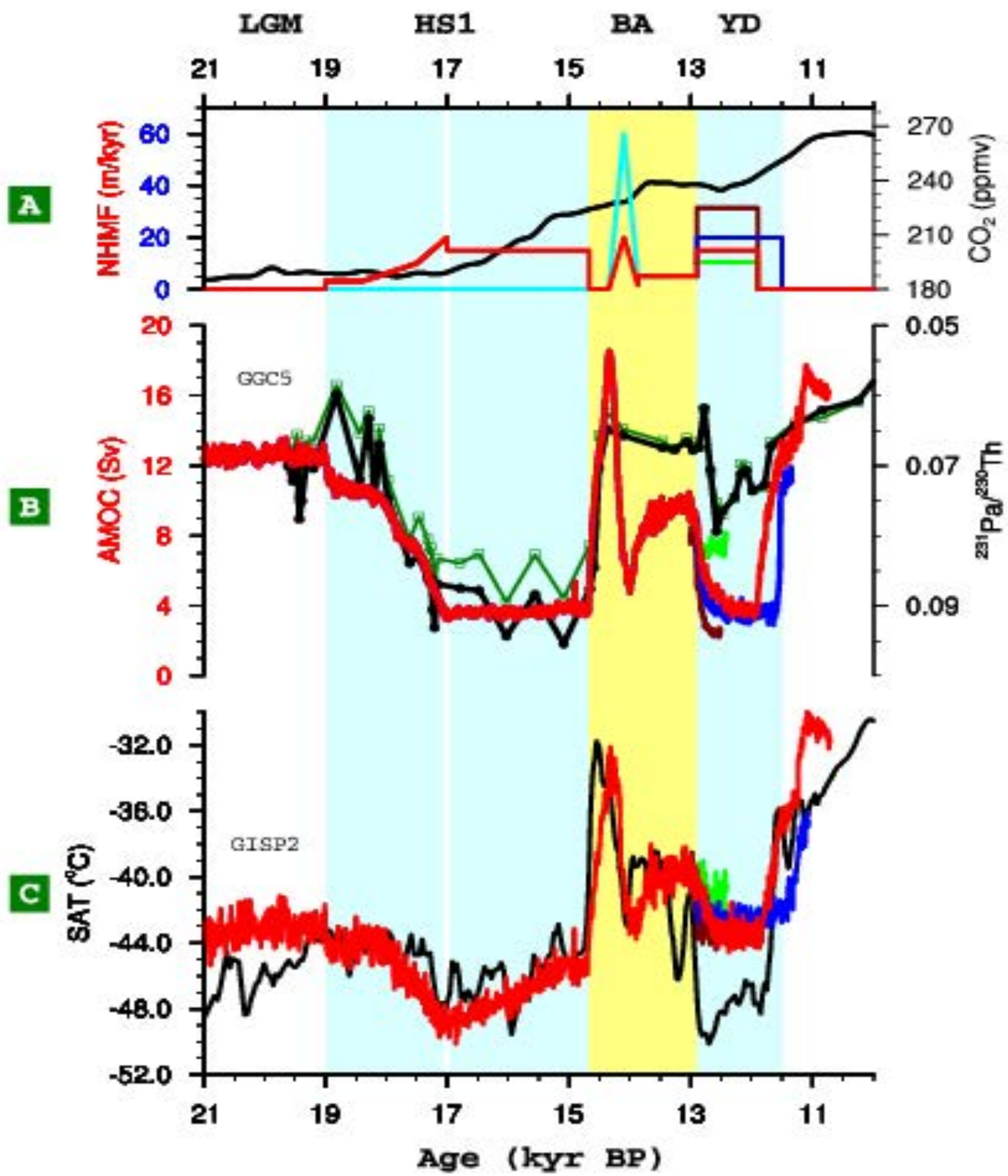
The sensitivity of the AMOC and Greenland SAT to
3 m/kyr, 9 m/kyr and 33 m/kyr meltwater forcing
in 50 to 70^{o} N of the North Atlantic.
1 m/kyr is approximately 0.0114 Sv.



Bolling Allerod Warm Period

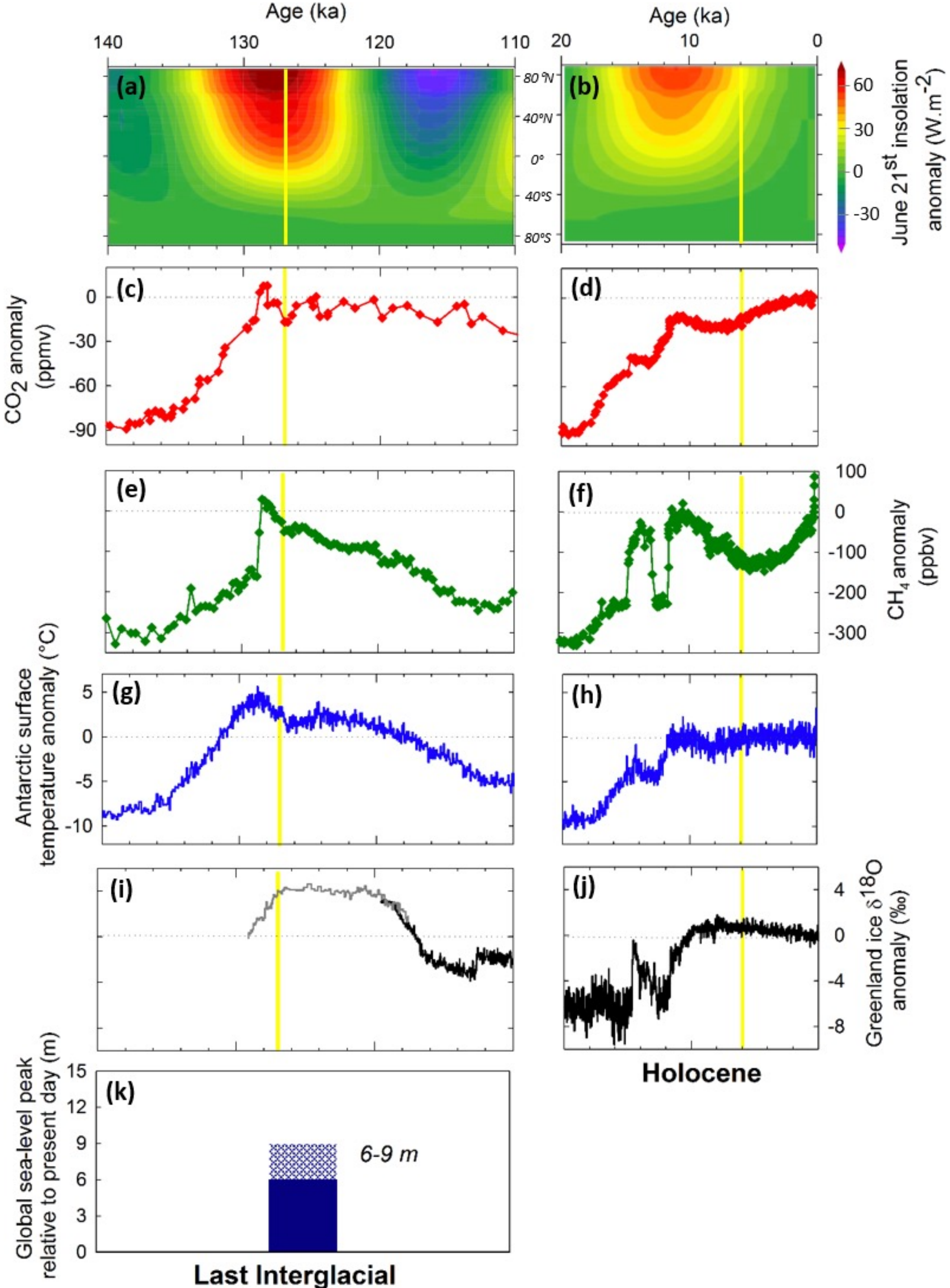
Overshoot of the
(B) AMOC and
(C) Greenland SAT
to the switch-off of
(A) NHMF in
TraCE-21K (red) and two
sensitivity experiments.

Reconstructions of the AMOC (black and dark green) [McManus et al., 2004] and Greenland SAT (black) [Cuffey and Clow, 1997] are plotted for comparison.



Younger Dryas cold period

Sensitivity of
(B) AMOC and
(C) Greenland SAT to
(A) NHMW during YD.
Atmospheric CO_2 concentration (black) is also plotted in (A).



Otto-Bleisner et al. 2017

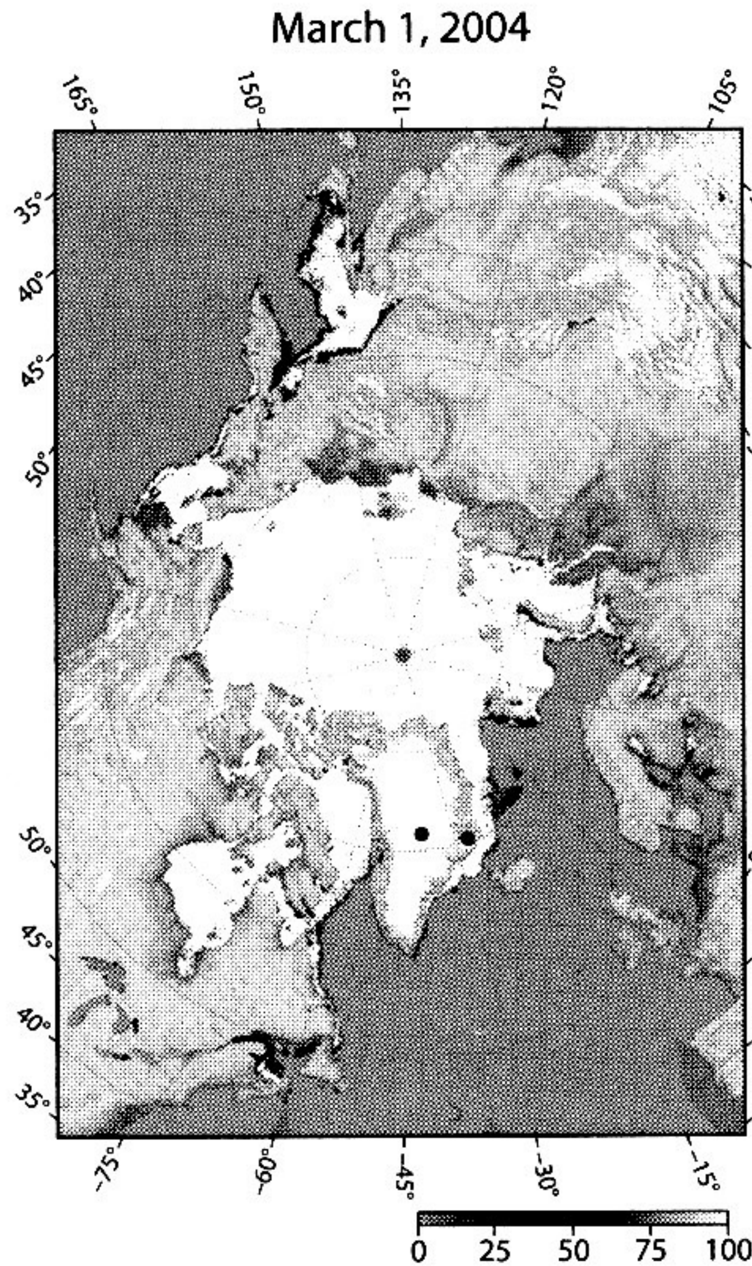
Figure 1. Forcing and climatic records across the Last Interglacial (LIG, left) and the Holocene (right). Records are displayed in panels
(a) to (j) as anomalies relative to their average value of the last 1000 years.
(a) and (b): 21 June insolation across latitudes;
(c) and (d): atmospheric CO2 concentration
(e) and (f): atmospheric CH4 concentration;
(g) and (h): Antarctic surface air temperature reconstruction: Greenland ice 18O: from the NEEM ice core (NEEM Community Members, 2013) in dark grey and from the NGRIP ice core (NorthGRIP Community Members, 2004) in black. Note that NEEM ice 18O is shifted by C2 ‰.
(k) LIG maximum global mean sea level (GMSL) relative to the present day; uncertainties in the amplitude are indicated by the shading (see Dutton et al., 2015a, for a review).
www.geosci-model-dev.net/10/3979/2017/ Geosci. Model Dev., 10, 3979–4003, 2017

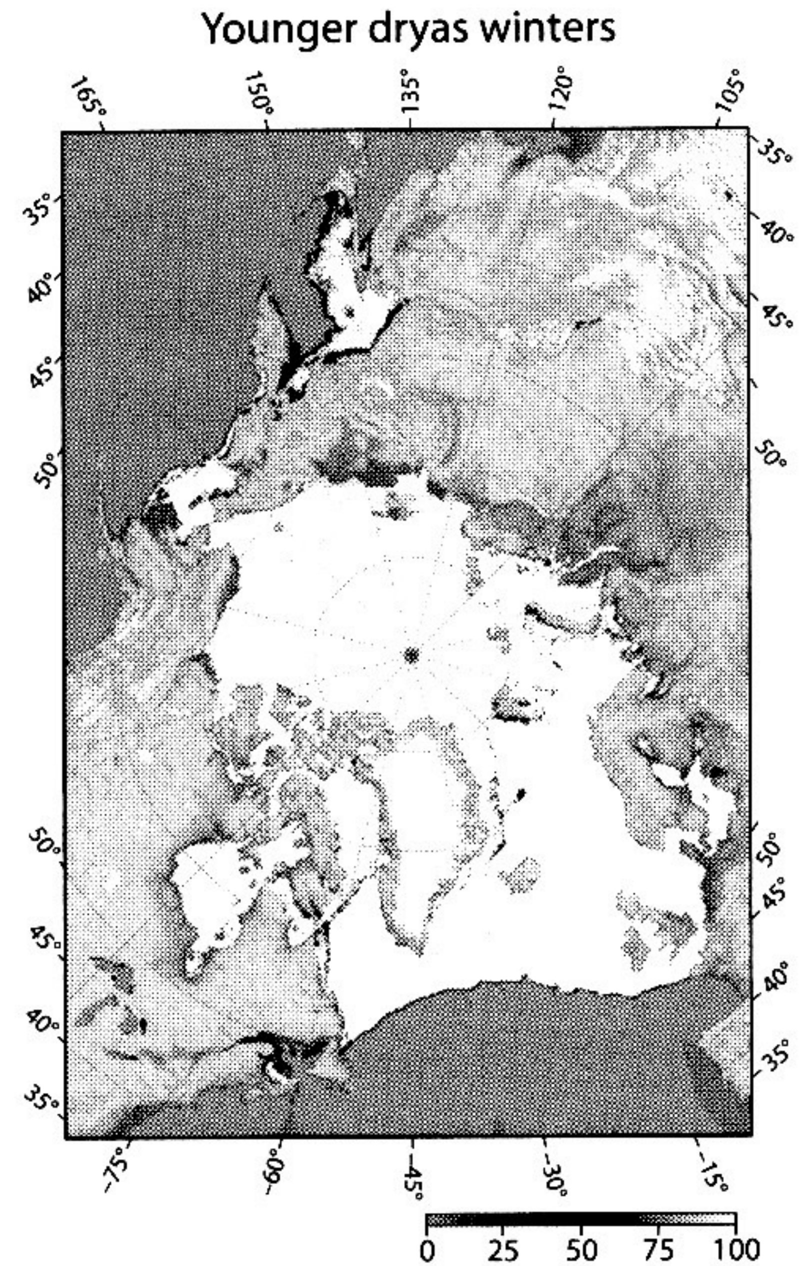
What causes the millennial-scale climate oscillations?

Export / import of water into the Atlantic Basin

What controls the heat gain (loss) to the atmosphere (ocean)

Sea ice cover


March 1, 2004
165°
150°
135°
120°
105°
35°
40°
45°
50°
-75°
-60°
-45°
-30°
-15°
0
25
50
75
100


Younger dryas winters
165°
150°
135°
120°
105°
35°
40°
45°
50°
-75°
-60°
-45°
-30°
-15°
0
25
50
75
100

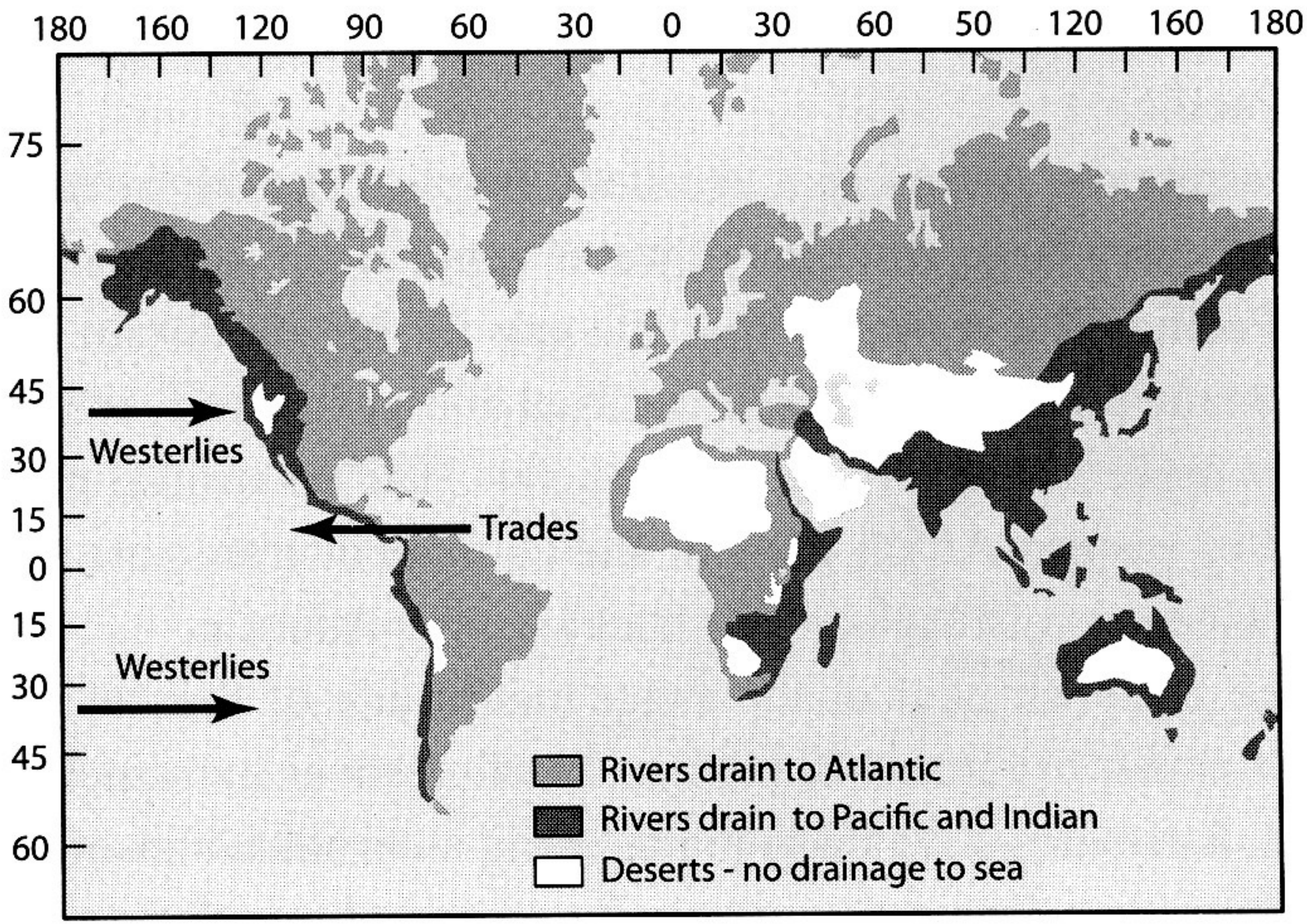


Figure 3-2. Map of the global drainage basins. The boundary between the gray and black regions corresponds to the divide separating drainage to the Atlantic from that to the Indian and Pacific Oceans. The white areas are deserts from which no river outflow occurs. Also shown are the directions of the major wind systems.

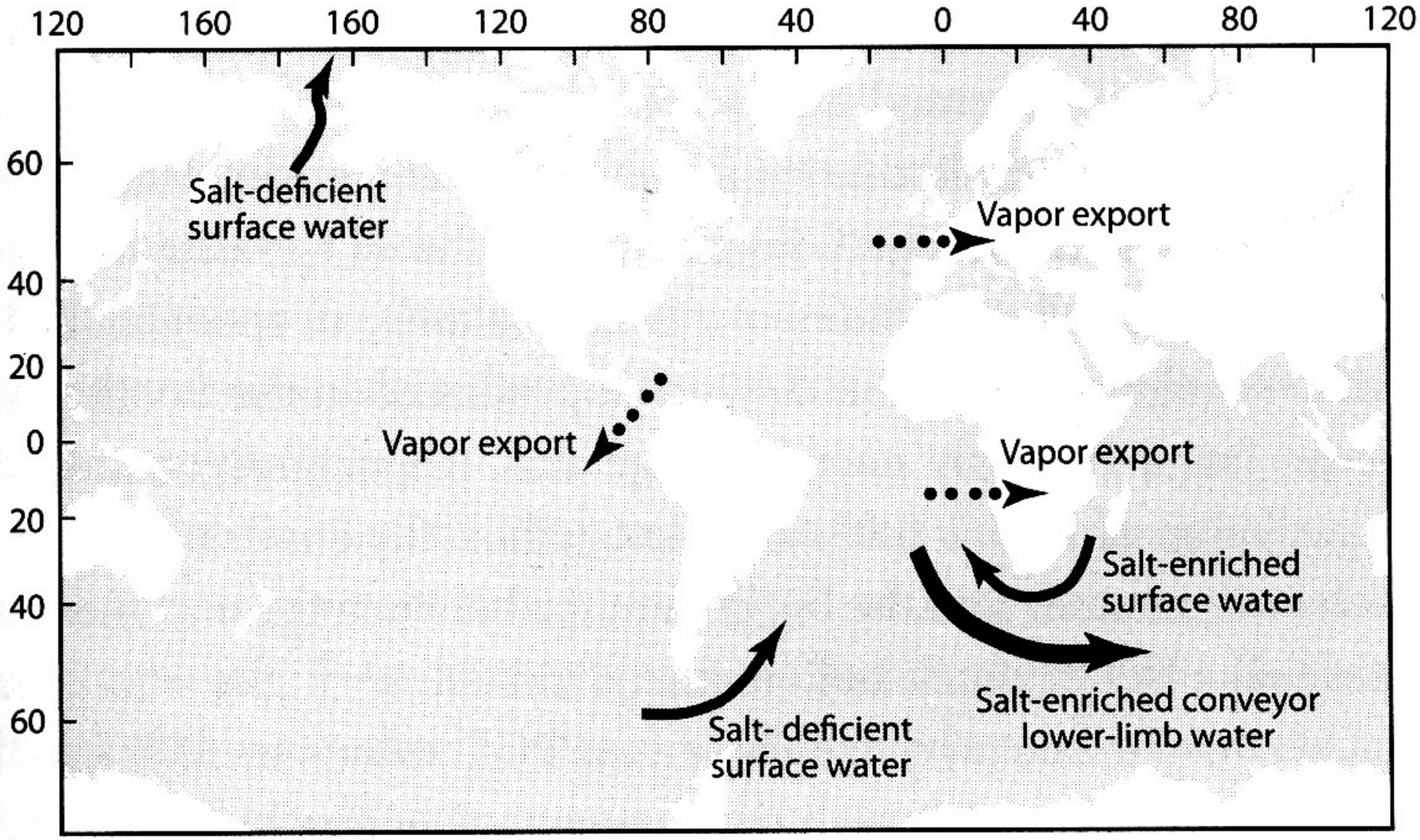


Figure 3-3. Map depicting the transports involved in the salt budget of the Atlantic Ocean.

A Saltier Mechanism for a "Bi-polar Seesaw"

North Atlantic Warm State (Salty)

- Hard to form extensive sea ice →
- Large heat flux to the atmosphere
- Easy to form NABW by heat loss
- Strong AMOC

Glacial melt water
Or Vapor Import
Into N. Atlantic basin
(more rain because
It's warmer) →
fresher

North Atlantic Cold State (Fresh)

- Easy to form extensive sea ice→
- Shuts off heat flux to the atmosphere
- With no heat loss its hard to form NABW
- Weak AMOC

On 1000 year
time scale,
Evaporation
from
Atlantic Basin →
saltier
(Broecker,
2010 The Great
Conveyor)

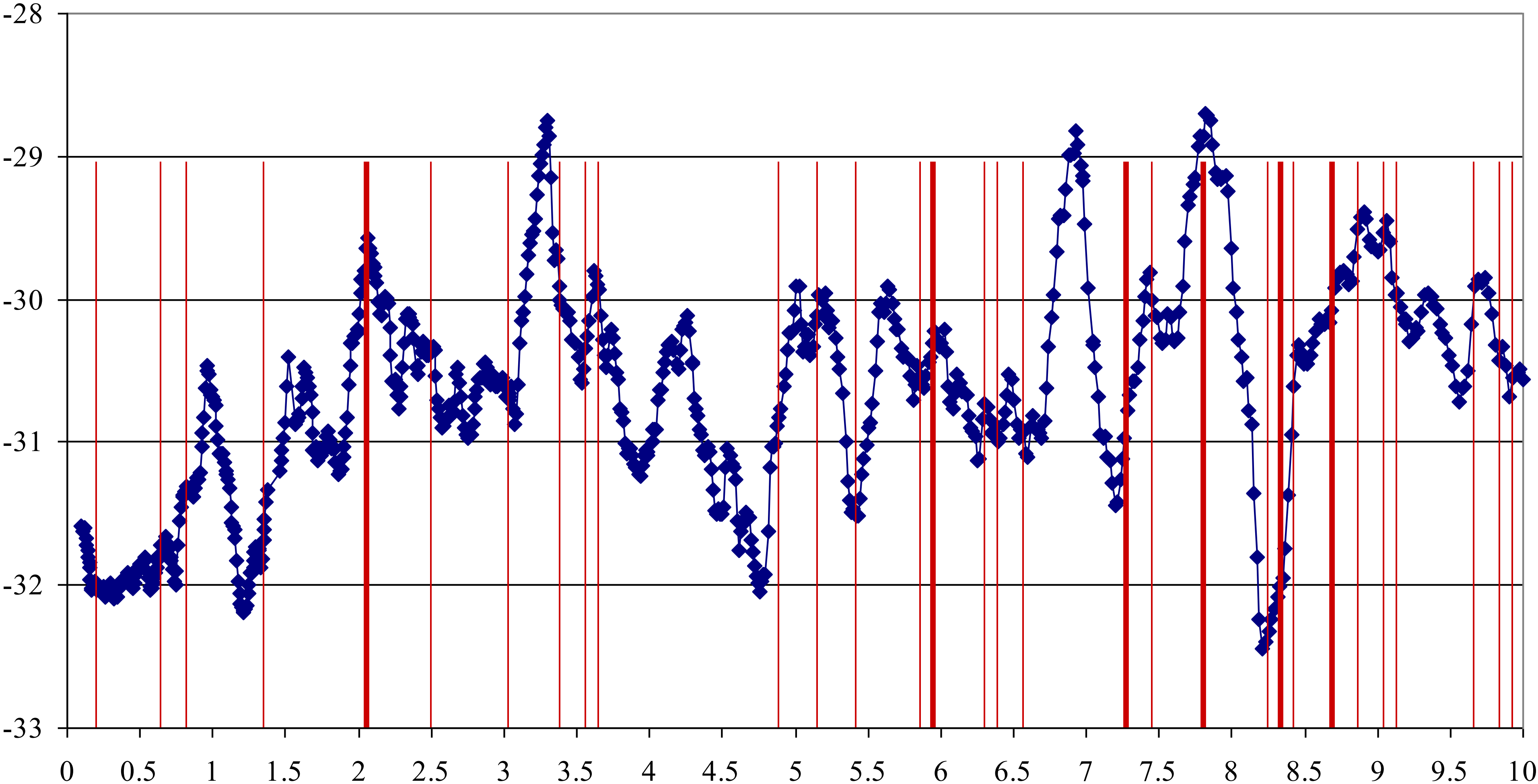
1) Presence or absence of sea ice is the key to maintaining the warm or cold state.
2) Atmospheric vapor export (or import?) from Atlantic Basin can cause cycling on a 1000-1500 year time scale.

Hypothesis #2

Millennial cycles are related to volcanism

- Volcanism responds to shifts in mass from the oceans to ice sheets on the continents

- Timing of major eruptions coincides with colder times


-28
-29
-30
-31
-32
-33
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10

Of the 29 largest volcanic eruptions in the last 8000 years, as seen in H_2SO_4 concentration at GISP2

19 occurred during temperature decline
5 occurred during temperature minima
2 occurred during temperature increase
3 occurred during temperature maxima

Hypothesis #3

Millennial cycles are due to solar manipulation of cosmic rays

- Oort cloud
- Hairy comet
- Binary companion "Nemesis"
- Natural solar variation

^{10}Be and ^{14}C are produced by cosmic rays, which are modulated by the strength of the solar wind.

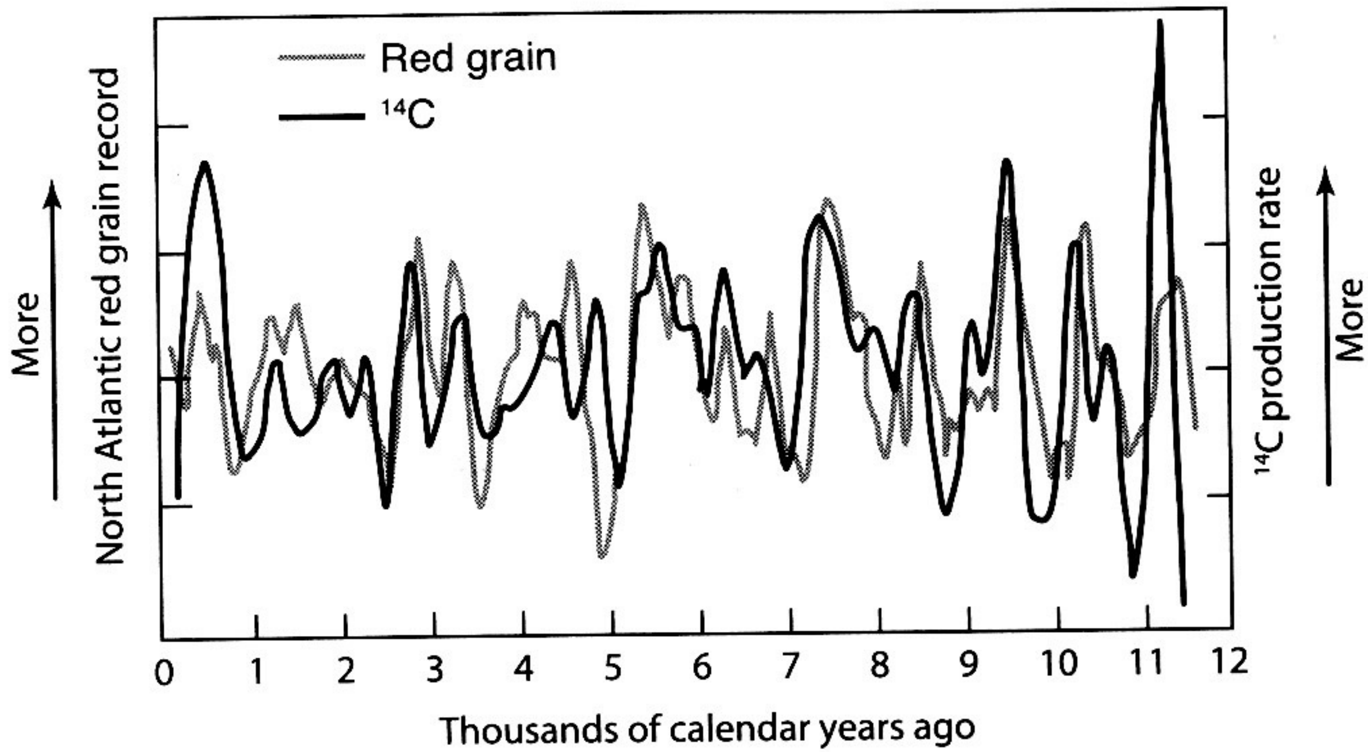
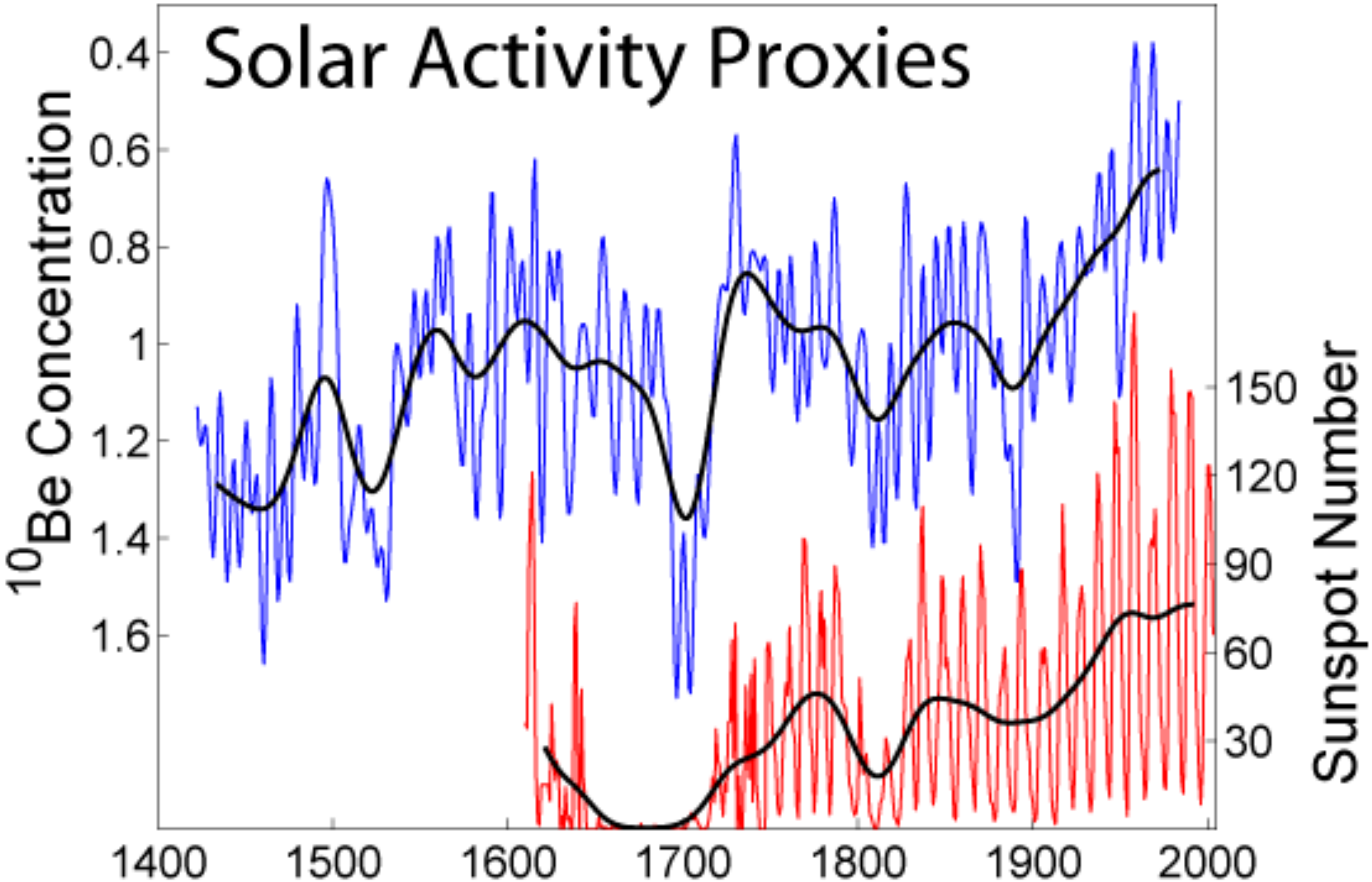


Figure 9-3. Gerard Bond compared his red-grain record with that of the production rate of radiocarbon atoms in the atmosphere. In order to focus on variations that occurred on a millennial timescale, he removed the long-term trend from the record. As can be seen, the match between the variations in cosmic ray production and that in the percentage of red-stained grains is reasonably good. This match led him to conclude that the red-grain cycles were paced by the sun.



https://commons.wikimedia.org/w/index.php?curid=2433283

Persistent Solar Influence on North Atlantic Climate During the Holocene

Gerard Bond,[1*] Bernd Kromer,[2] Juerg Beer,[3] Raimund Muscheler,[3] Michael N. Evans,[4] William Showers,[5] Sharon Hoffmann,[1] Rusty Lotti-Bond,[1] Irka Hajdas,[6] Georges Bonani[6]

Surface winds and surface ocean hydrography in the subpolar North Atlantic appear to have been influenced by variations in solar output through the entire Holocene. The evidence comes from a close correlation between inferred changes in production rates of the cosmogenic nuclides carbon-14 and beryllium-10 and centennial to millennial time scale changes in proxies of drift ice measured in deep-sea sediment cores. A solar forcing mechanism therefore may underlie at least the Holocene segment of the North Atlantic's "1500-year" cycle. The surface hydrographic changes may have affected production of North Atlantic Deep Water, potentially providing an additional mechanism for amplifying the solar signals and transmitting them globally.

Hypothesis #4

Millennial cycles are due to solar – planetary interaction

- Solar flares, sunspots, and planetary alignment
- ~ 400-year periodicity
- Mayan knowledge of Jupiter – Venus – Earth system

What did they know and when did they know it?

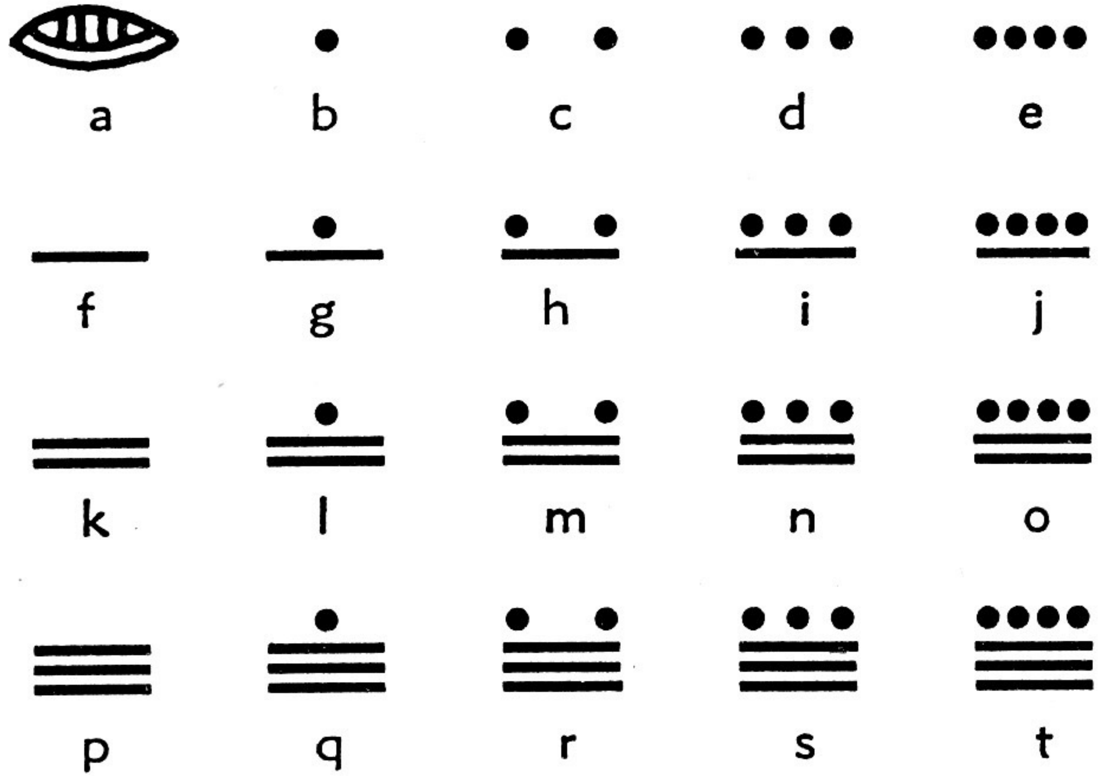
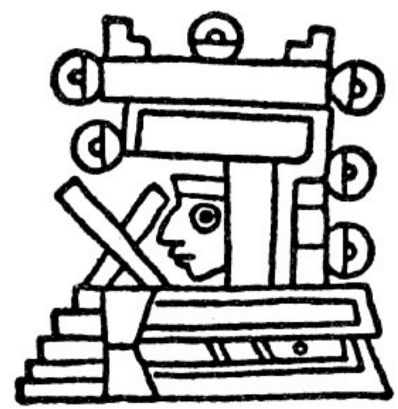
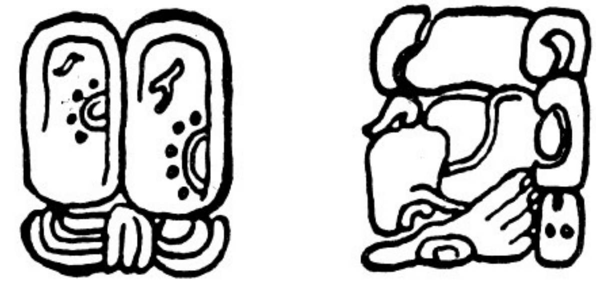


FIG. 23.—Glyphs for the numbers 0 and I to XIX inclusive, in bar-and-dot notation, the Maya "Roman Notation": (*a*) zero; (*b*) I; (*c*) II; (*d*) III; (*e*) IV; (*f*) V; (*g*) VI; (*h*) VII; (*i*) VIII; (*j*) IX; (*k*) X; (*l*) XI; (*m*) XII; (*n*) XIII; (*o*) XIV; (*p*) XV; (*q*) XVI; (*r*) XVII; (*s*) XVIII; (*t*) XIX.

"Let's Count Like A Mayan"



20 *kins*	= 1	*uinal* or 20 days
18 *uinals*	= 1	*tun* or 360 days
20 *tuns*	= 1	*katun* or 7,200 days
20 *katuns*	= 1	*baktun** or 144,000 days
20 *baktuns*	= 1	*pictun* or 2,880,000 days
20 *pictuns*	= 1	*calabtun* or 57,600,000 days
20 *calabtuns*	= 1	*kinchiltun* or 1,152,000,000 days
20 *kinchiltuns*	= 1	*alautun* or 23,040,000,000 days



Glyphs for 1 baktun

* The period of the fifth order, the *baktun*, was originally called the "cycle" by modern investigators. The ancient name for this period, however, was probably *baktun* as given above.

Calendar

365 days = 19 mo

18 x 20-day months

1 x 5-day month

Counting Days

365.242 days = 1 yr

1 tun = 1 yr – 5.242 dy

1 katun = 20 yr – 104.84 dy

1 baktun = 395 yr – 270.59 dy

13 baktun = 5126 yr – 230.5 dy

1 kin	1 dy
20 kin = 1 uinal	20 dy
18 uinal = 1 tun	360 dy = 1 yr - 5.242 dy
20 tun = 1 katun	20 yr - 104.84 dy
20 katun = 1 baktun	395 yr - 270.59 dy
13 baktun	5126 yr - 230.5 dy

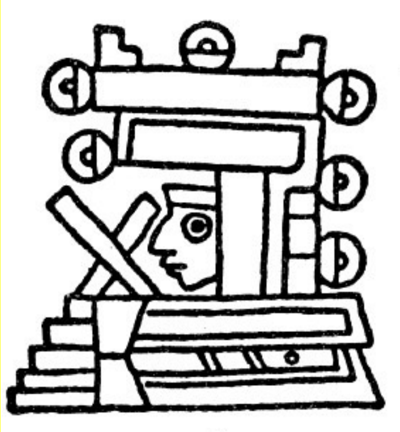
Mayan Date	Gregorian Date		
0.0.0.0.0	3114 BC	Aug 11 (223)	start of calendar
8.0.0.0.0	41 AD	Sept 7 (250)	
8.14.0.0.0	317	Sept 1 (244)	oldest glyph found
9.0.0.0.0	435	Dec 11 (345)	
10.0.0.0.0	830	Mar 15 (74.4)	
11.0.0.0.0	1224	June 17 (168)	
12.0.0.0.0	1618	Sept 20 (263)	
13.0.0.0.0	2012	Dec 23 (357)	
14.0.0.0.0	2407	Mar 27 (86)	

1 baktun

395 years

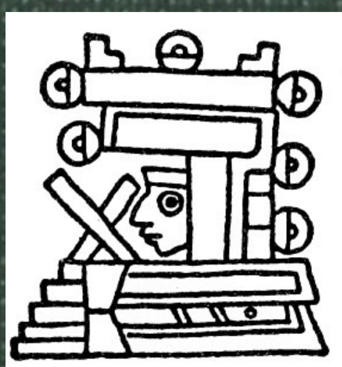
1 cycle of the Venus – Jupiter – Earth system

No hints regarding a ~1000-1500 year periodicity



Millennial Cycles:

Is it the sun?



Or a natural time scale in the hydrologic cycle?