

Abrupt climate change and freshwater forcing: is the problem solved?

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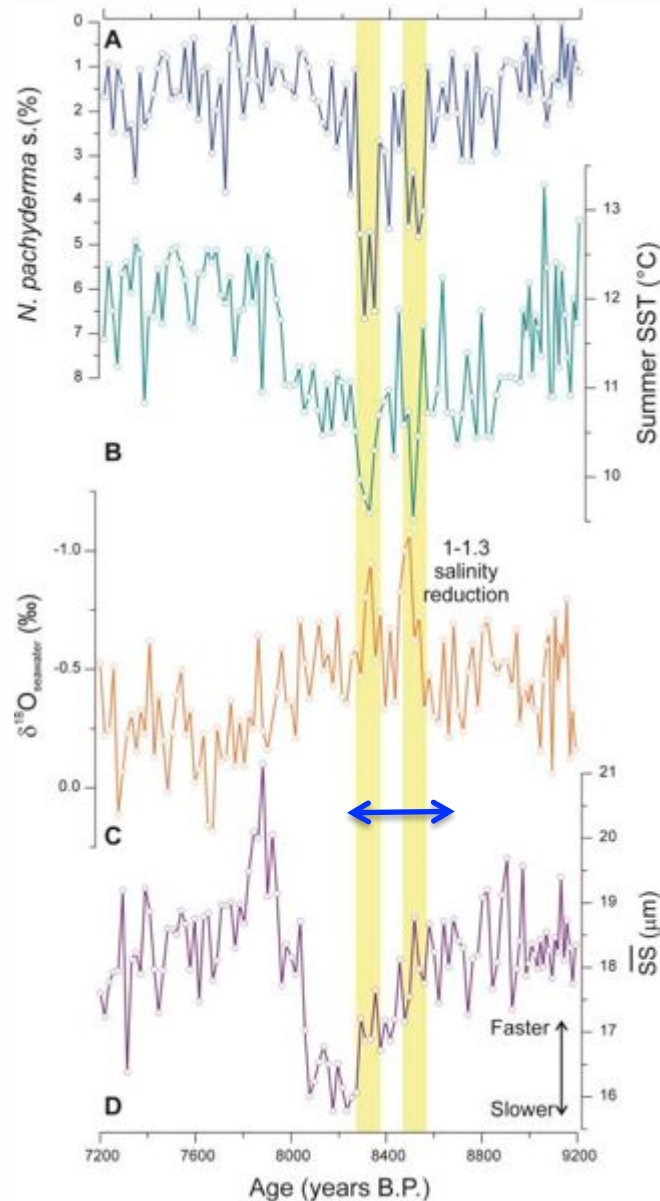
Many abrupt changes in paleoclimate records have been identified...

- **Dansgaard-Oeschger (DO) events**
- **Heinrich events**
- **Younger Dryas**
- **“8.2ky” event**

But these do not seem to be the same, and there are plenty of problems:

- **Magnitude of changes**
- **Chronology**
- **Causation -- “freshwater forcing”**
- **Teleconnections**

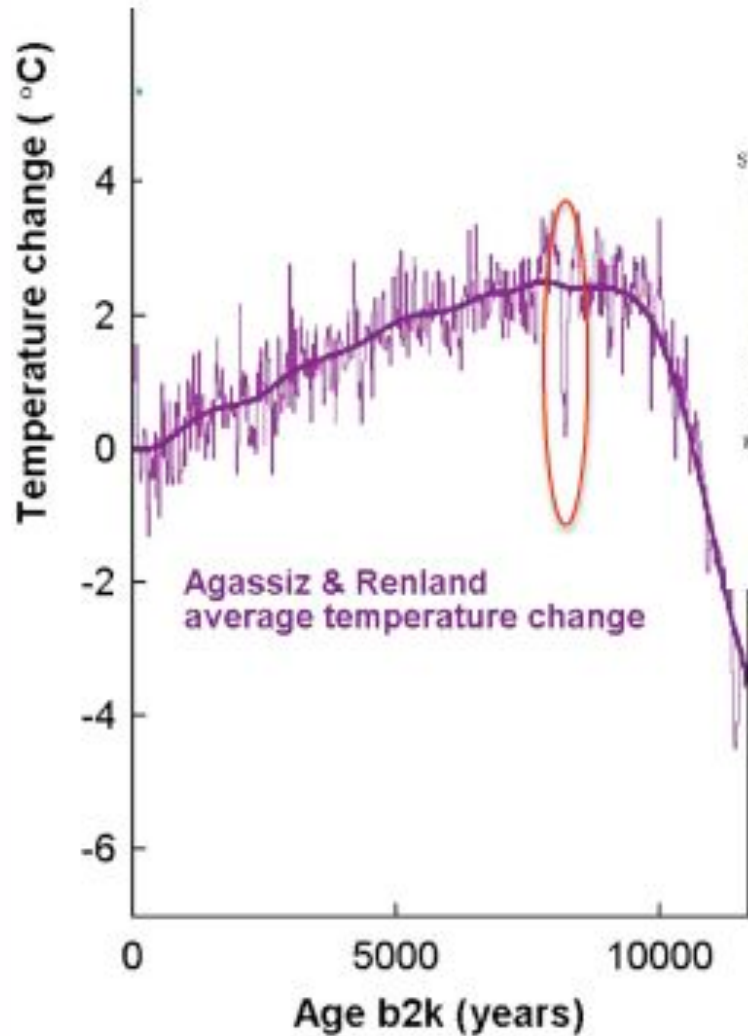
Sub-polar N. Atlantic sediment record



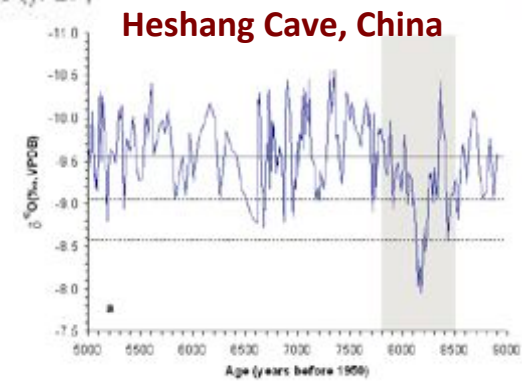
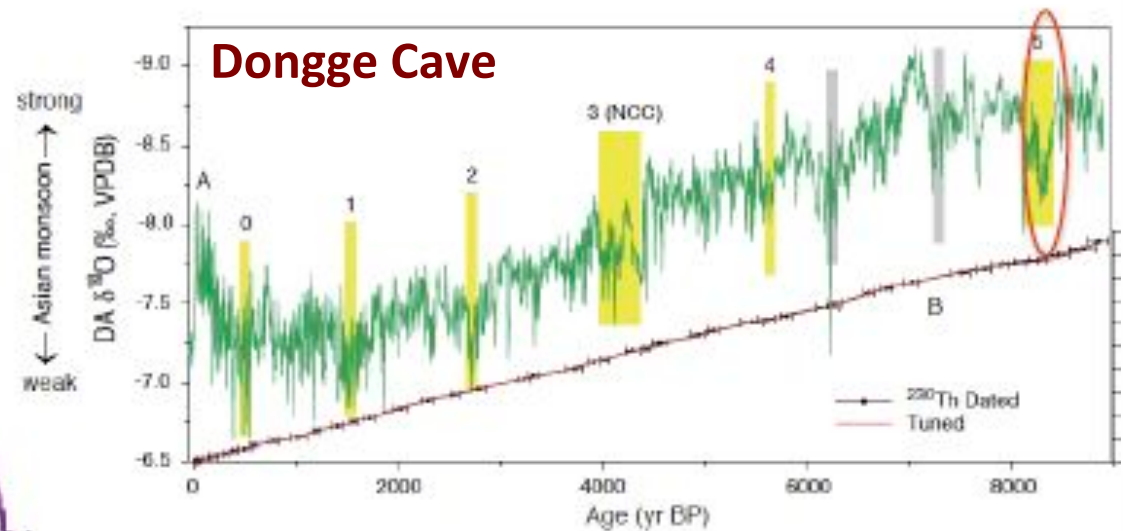
The “8.2ka event”

Laurentide proglacial
lake drainage

Source: Ellison et al., 2006



Sources: Vinther et al., 2009

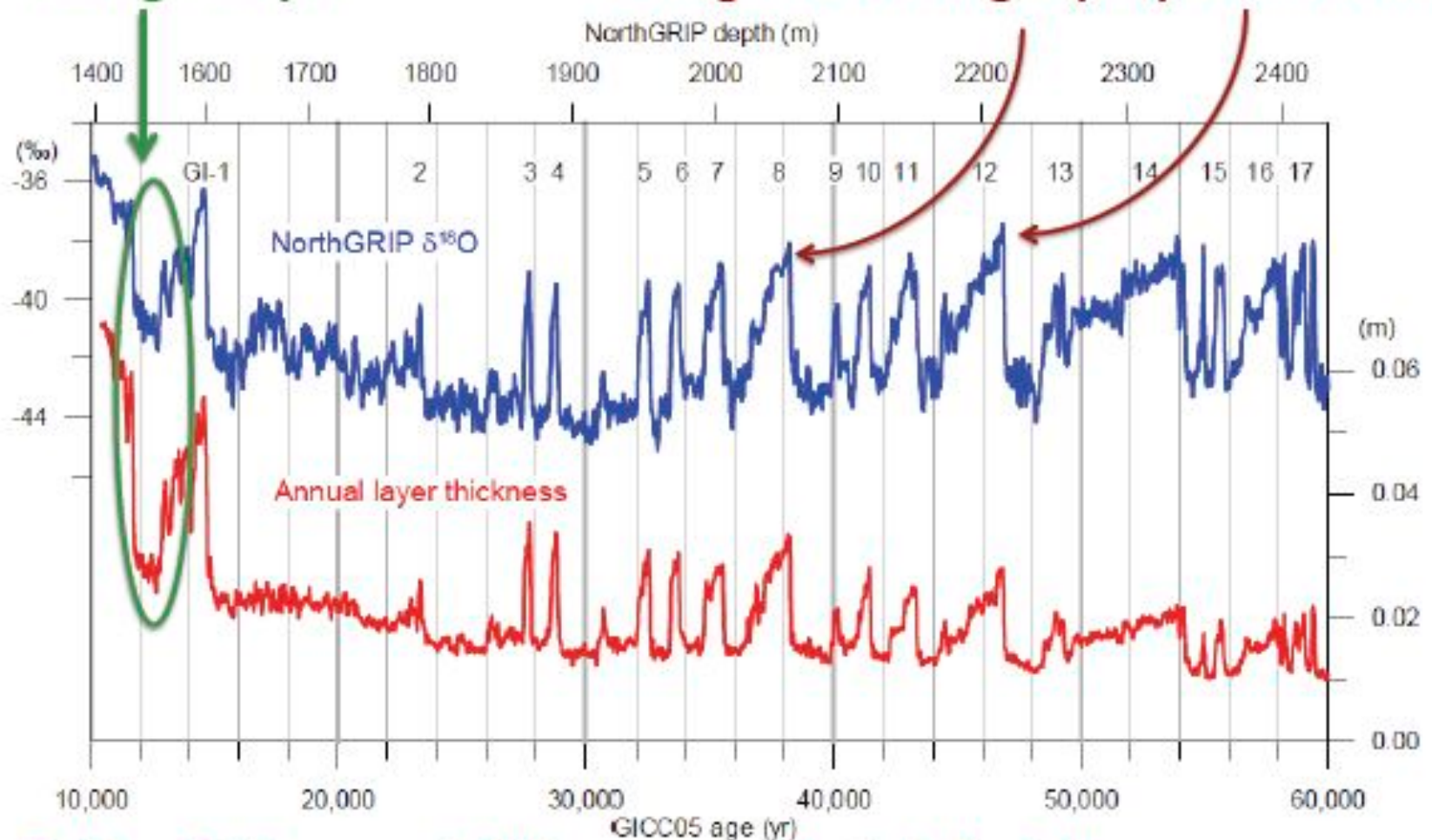


Liu et al. 2013

Wang et al., 2005

Younger Dryas

Dansgaard-Oeschger (DO) oscillations



Problem # 1: these are not all the same, even if isotopically similar...

Source: Svensson et al., 2008

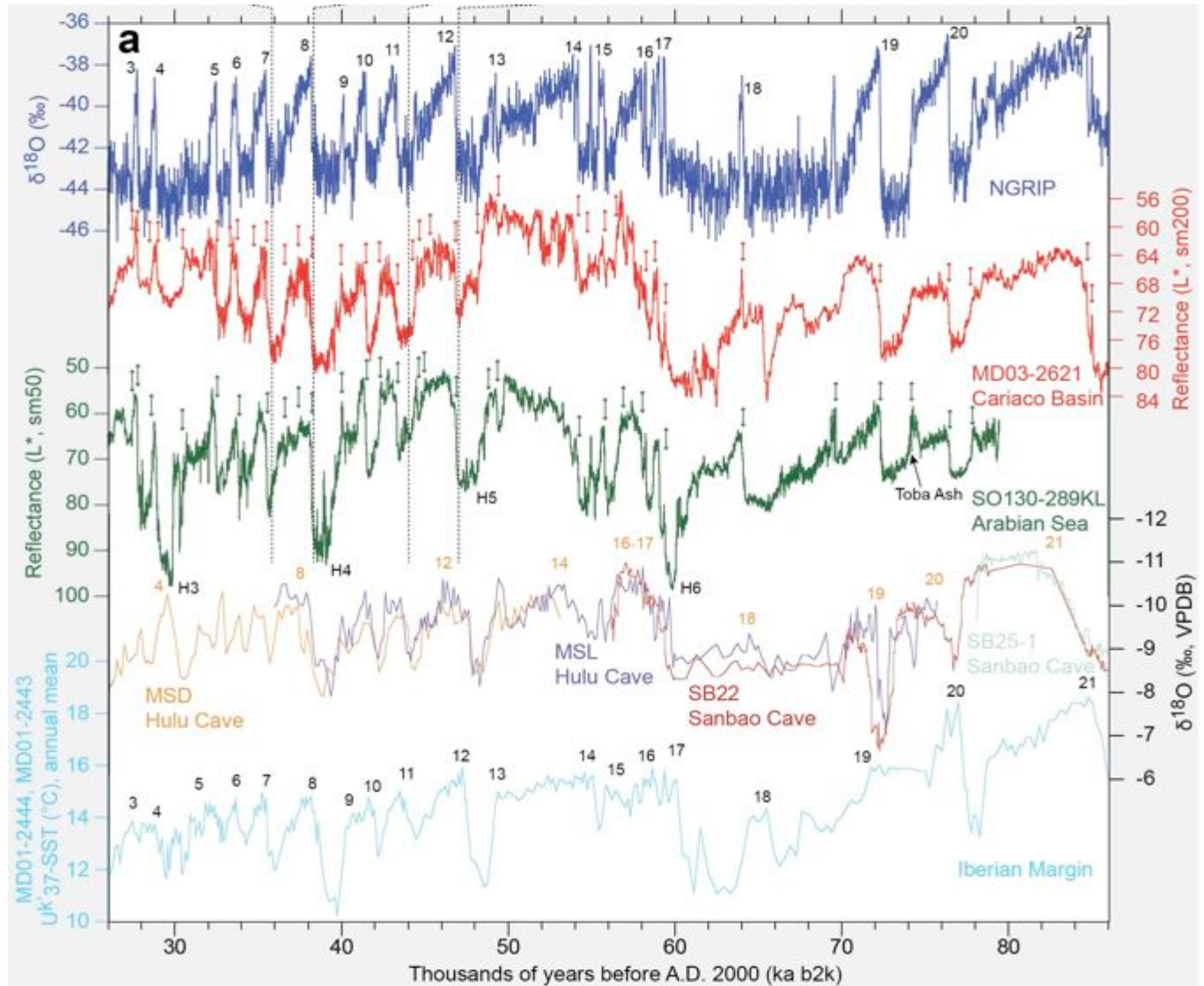
NGRIP

CARIACO

ARABIAN SEA

HULU CAVE

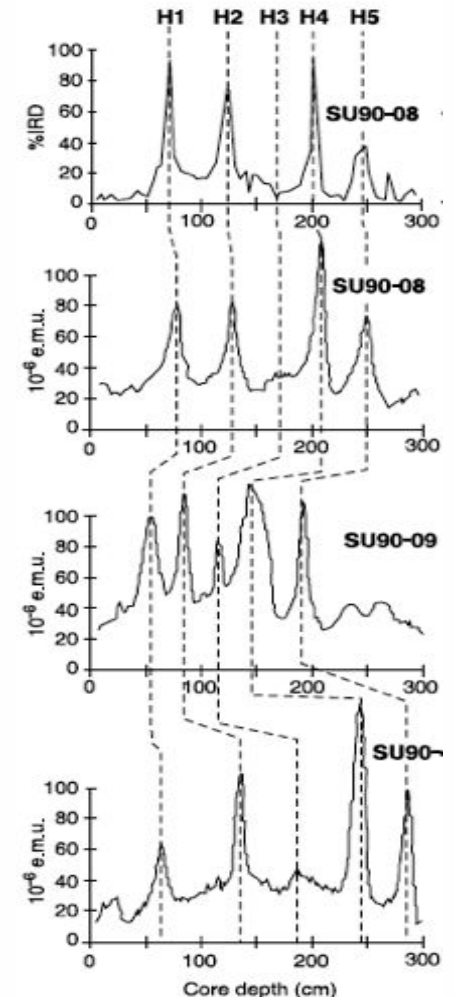
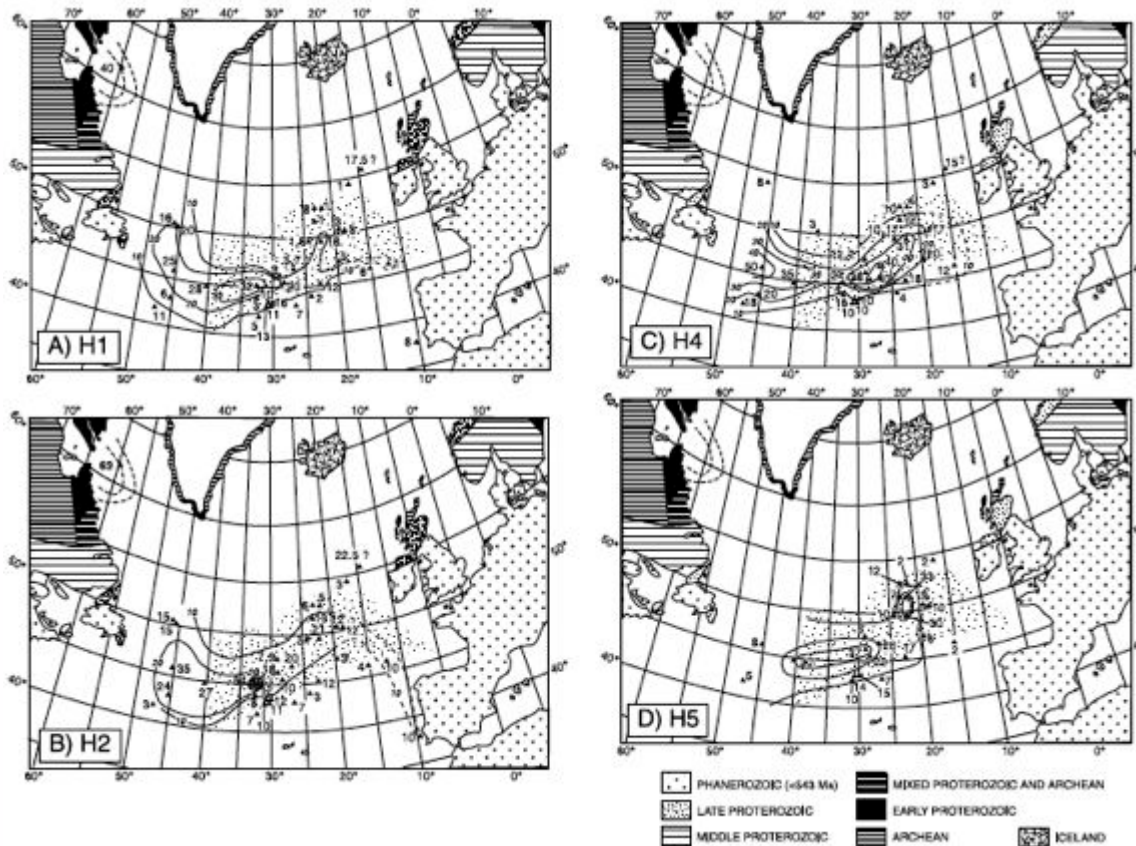
IBERIAN MARGIN



Heinrich Events: ice-rafted debris (IRD) in North Atlantic cores

Isopachs (cm)

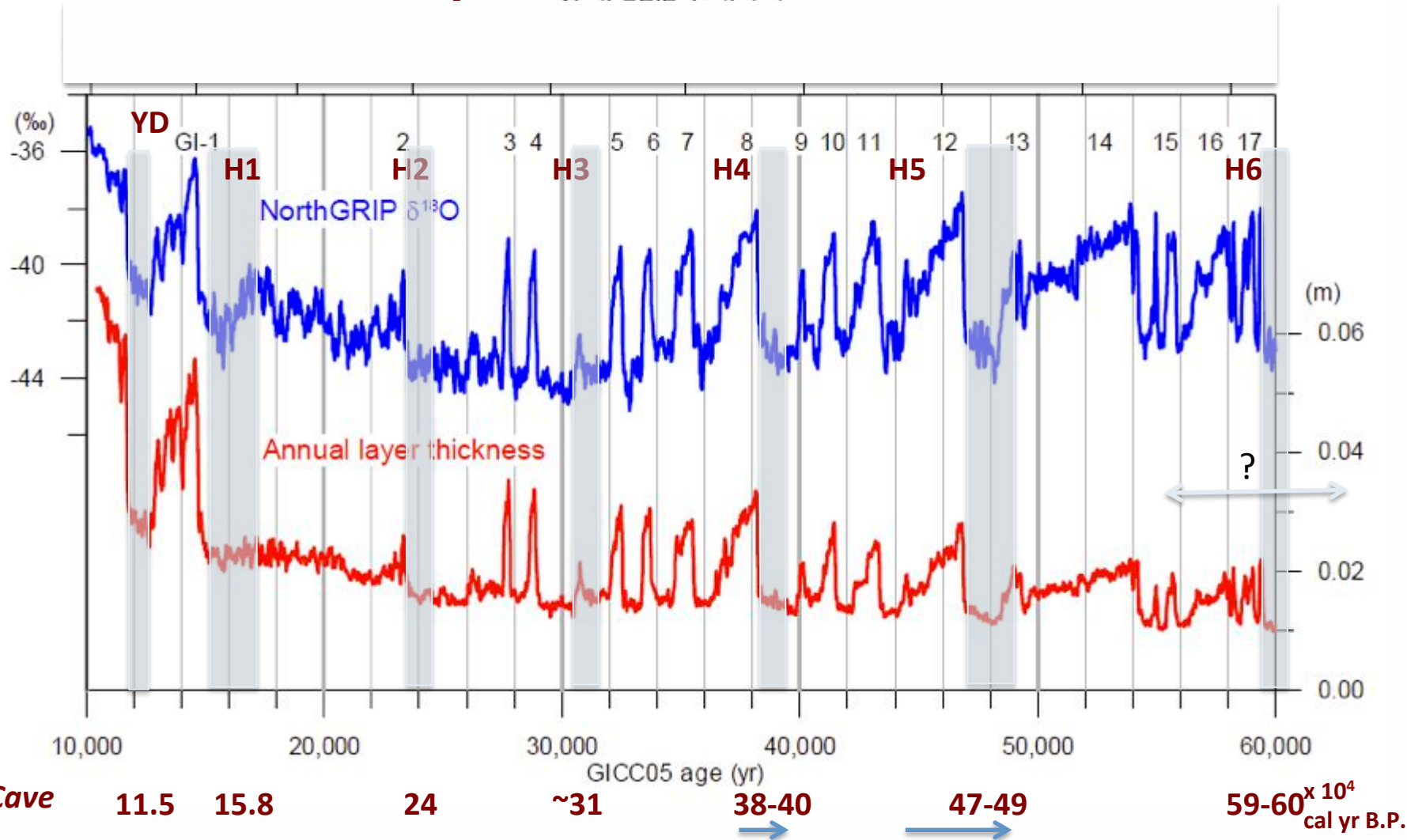
magnetic susceptibility



Source: Hemming, 2004

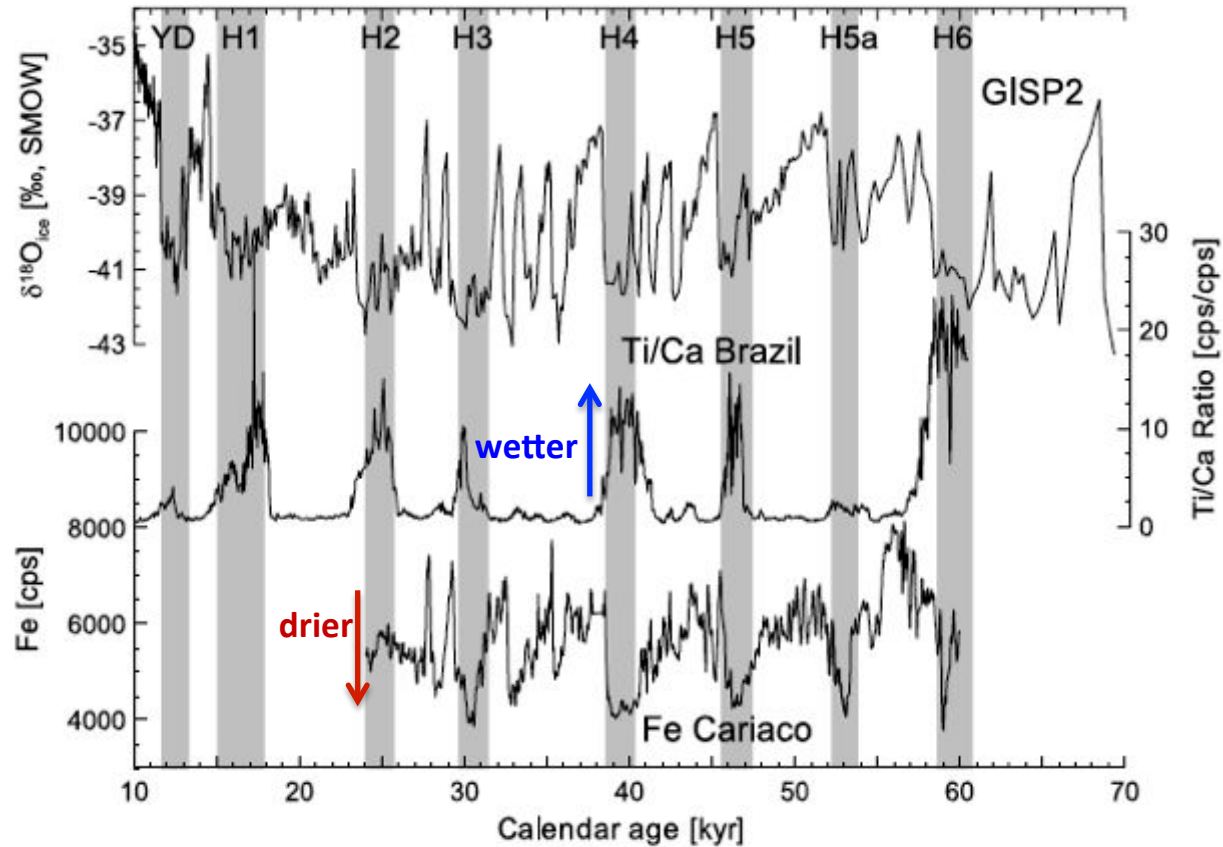
Problem # 3: How do Heinrich events map onto DO events?

Heinrich Events: only H0-H2 are well-constrained in time



ITCZ moved South:

* * * * *



Source: Jaeschke et al. 2007

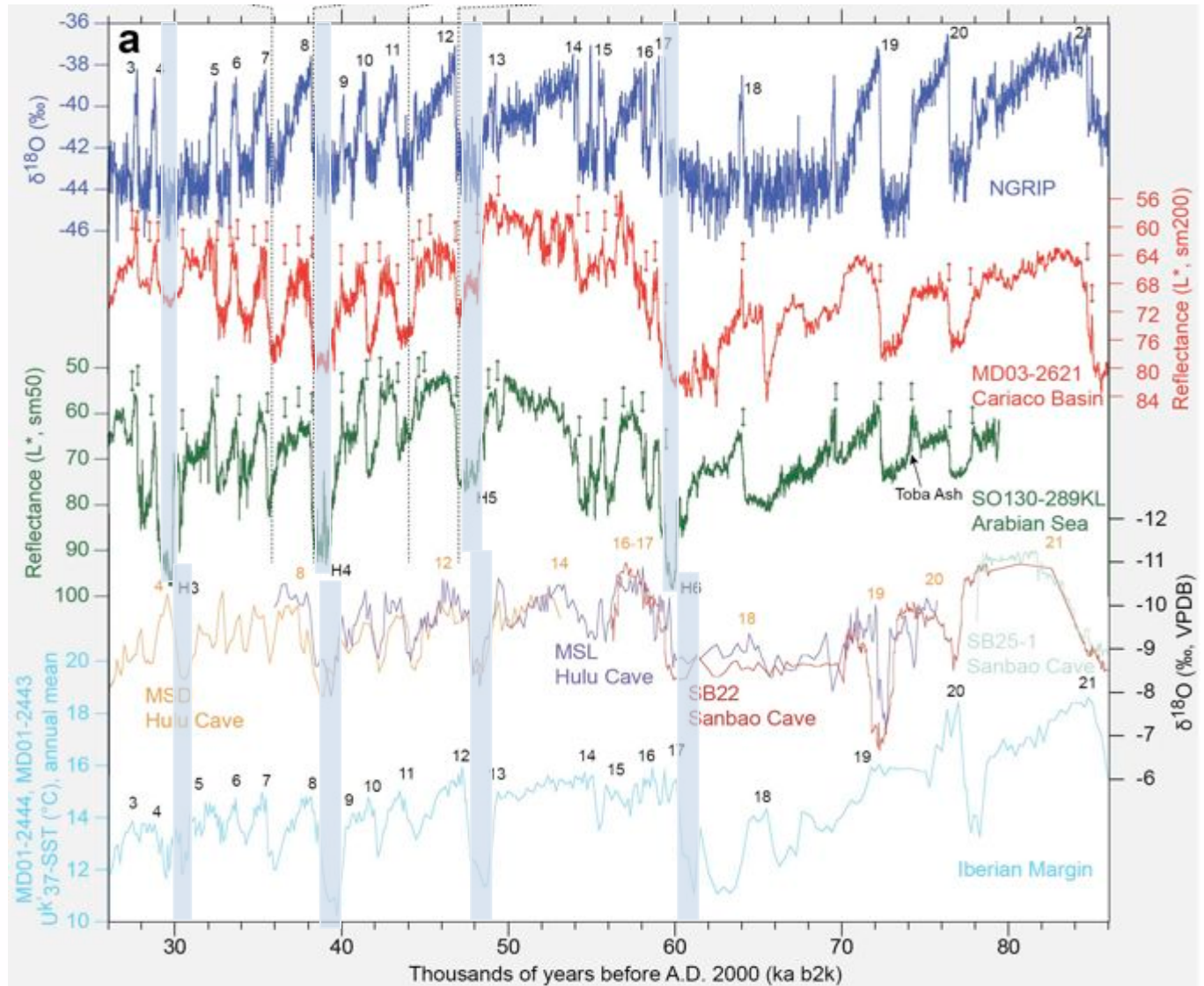
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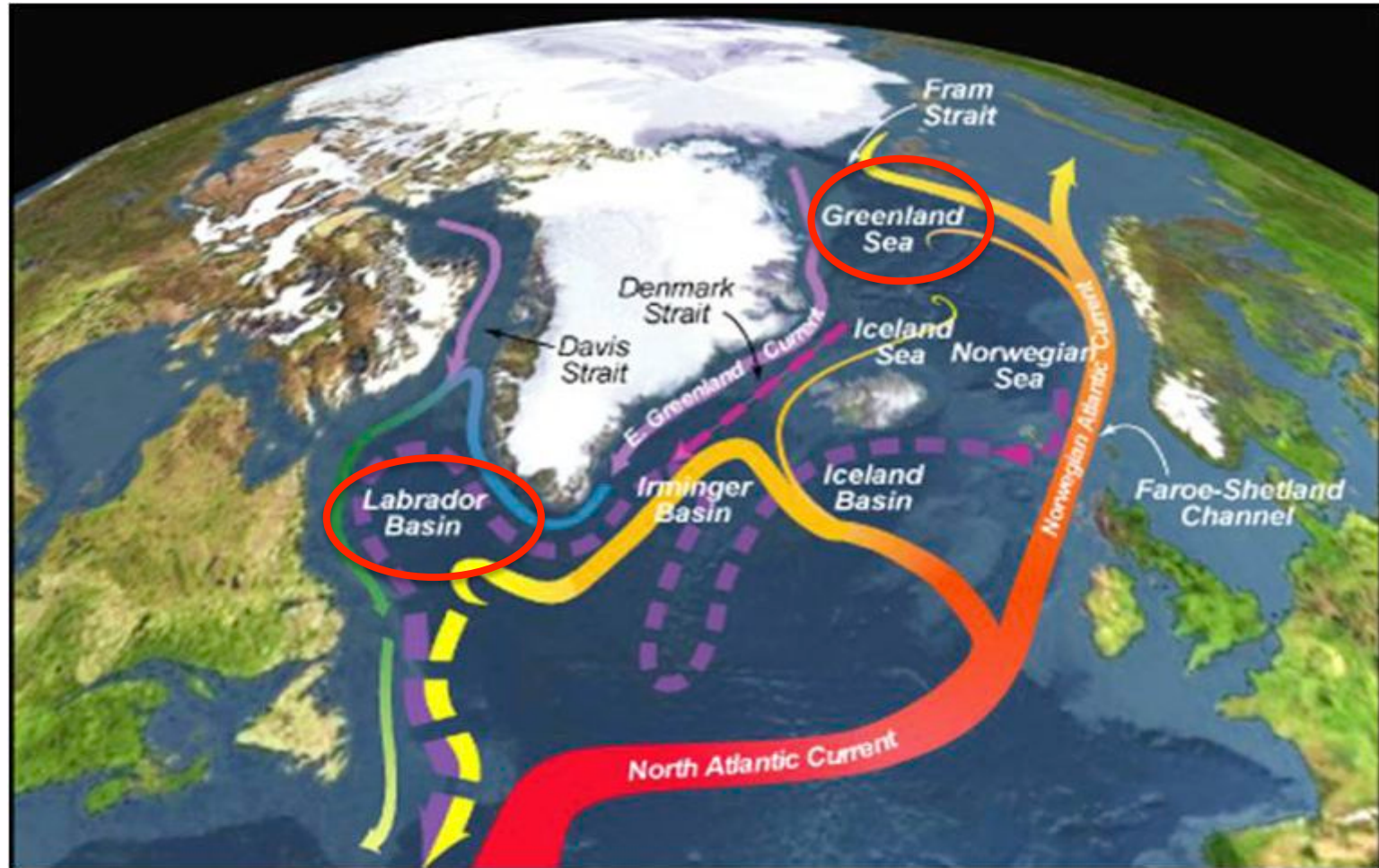
HULU CAVE

IBERIAN MARGIN



It is generally agreed that these abrupt changes are related to a reduction (or shutdown) of the Atlantic Meridional Overturning Circulation (AMOC) due to freshwater forcing (which reduces deepwater formation, which in turn limits warm water returning to the North Atlantic region)....but what is the source of the freshwater?

Is it the same for 8.2ky, the YD, Heinrich events etc...?

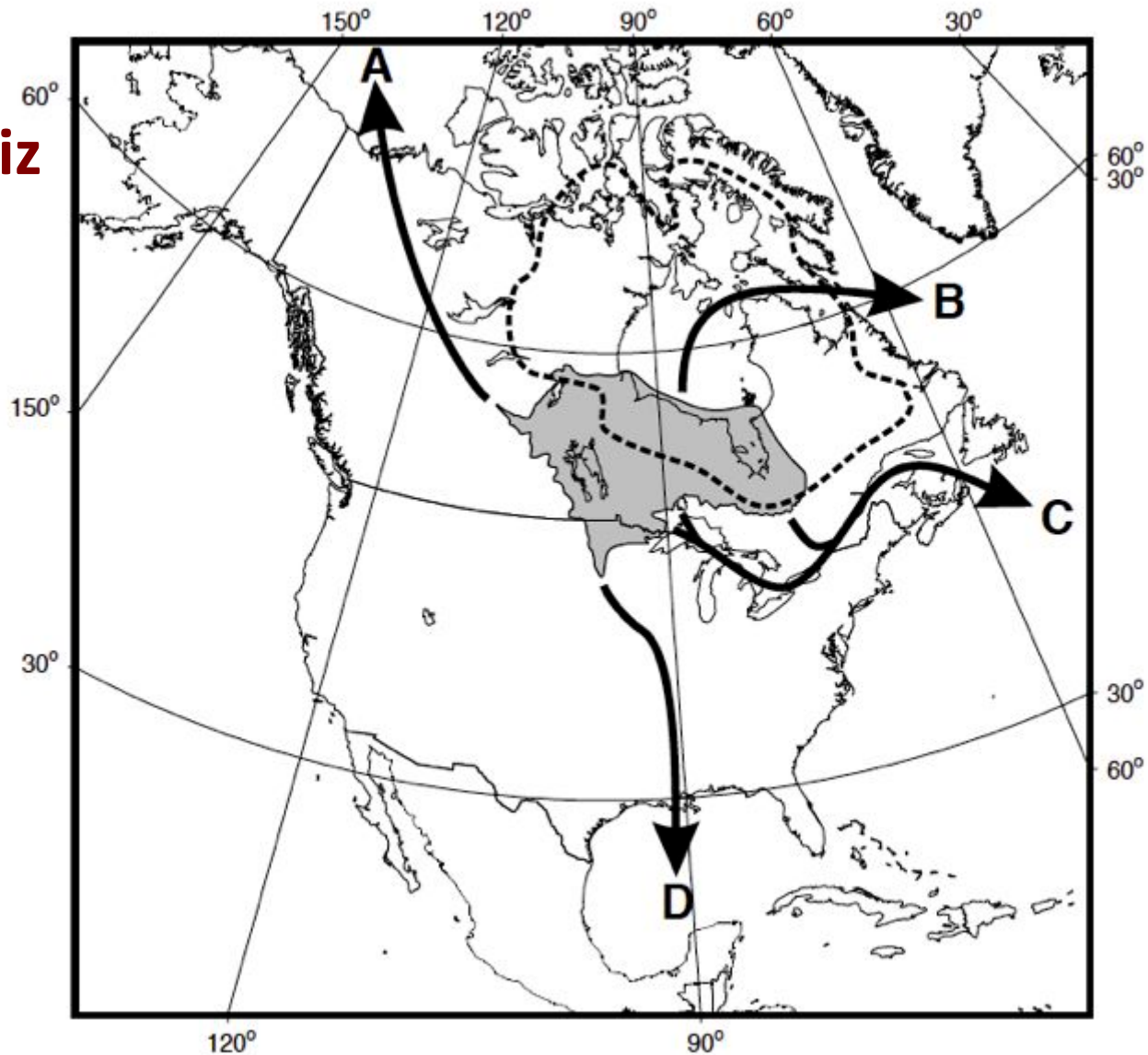


An increase in the stability of the water column by the addition of freshwater to the North Atlantic could reduce the Atlantic Meridional Overturning Circulation (AMOC)...

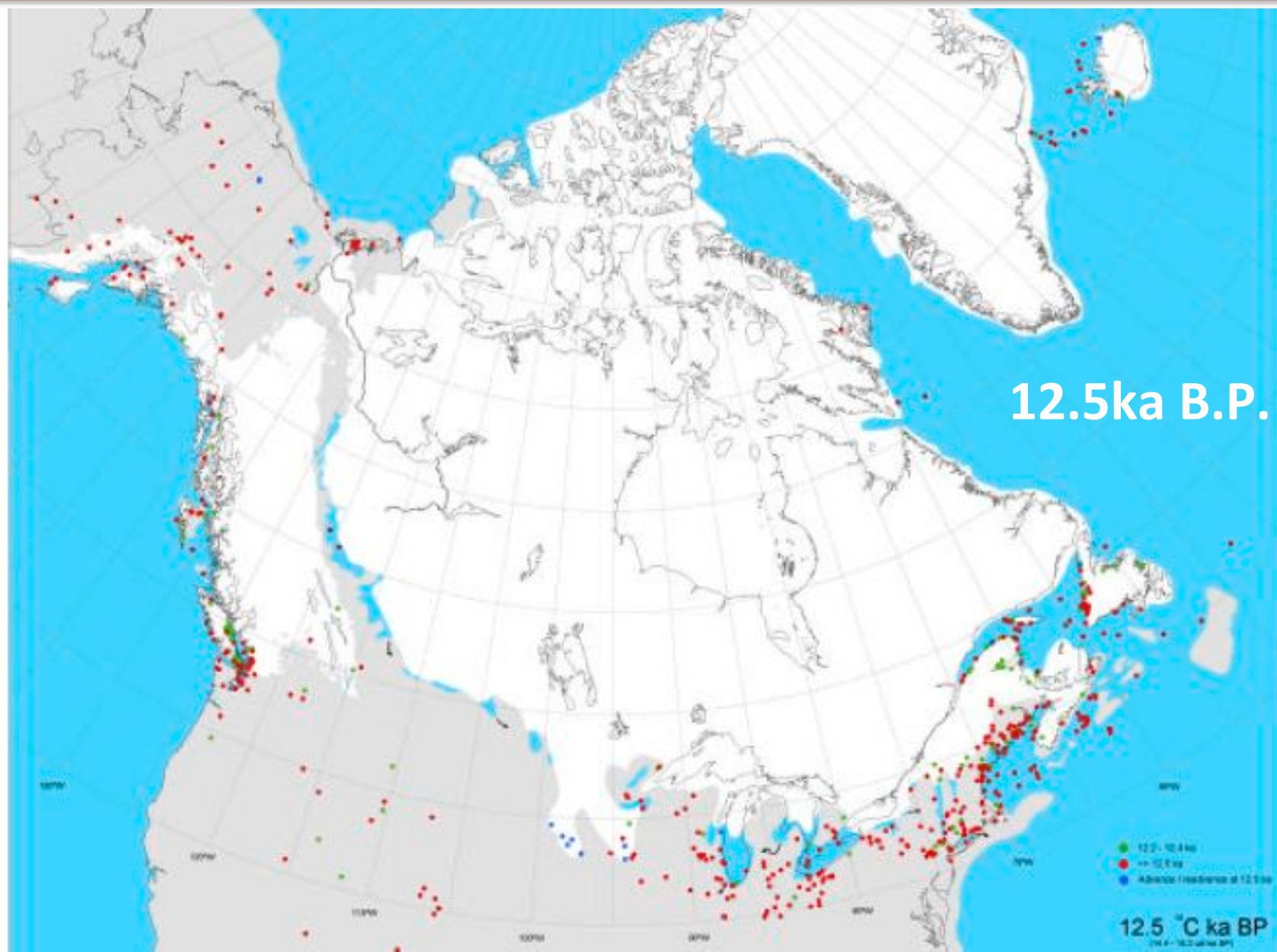
But....

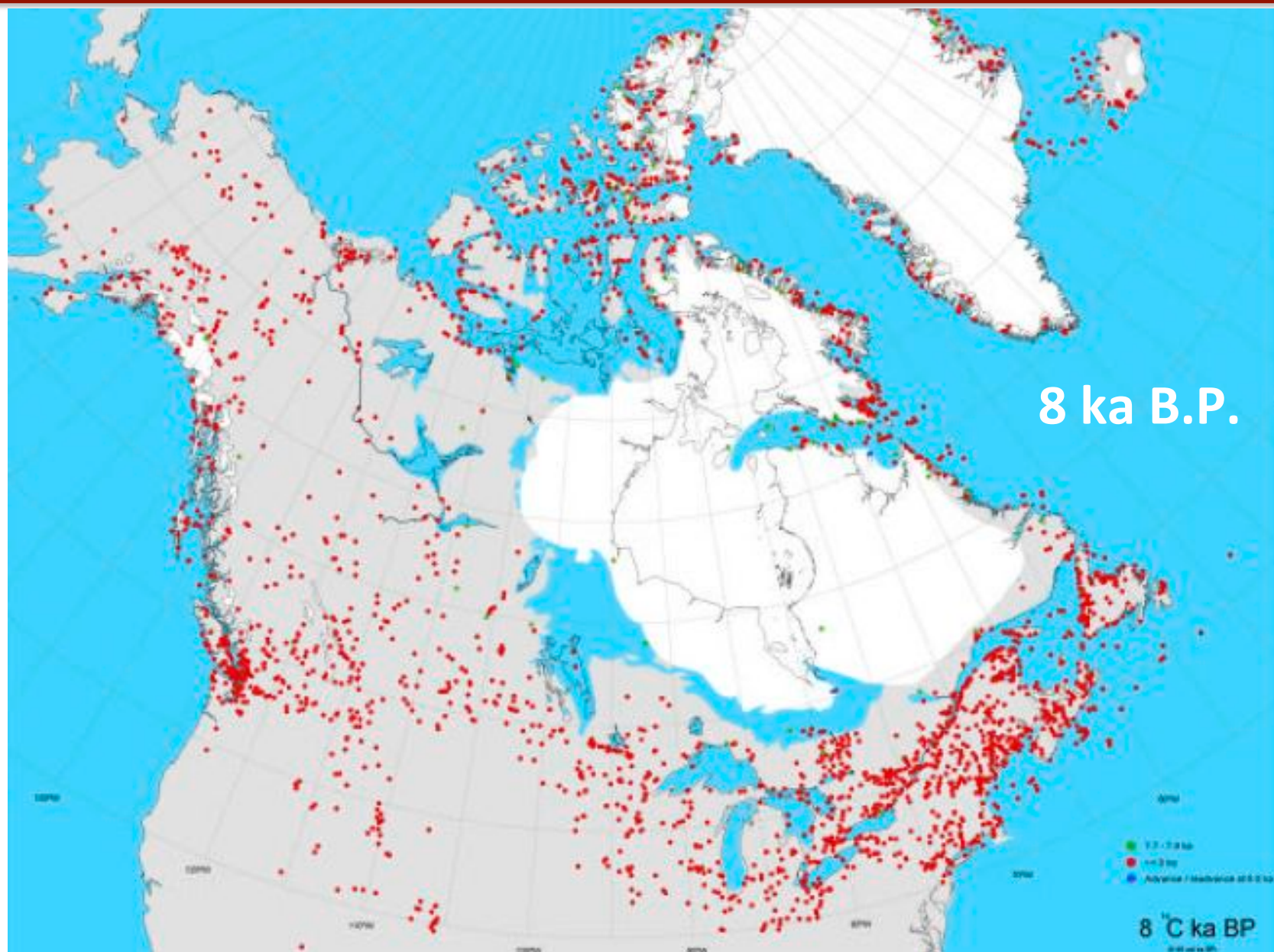
Where did the freshwater come from?

Lakes Agassiz & Ojibway freshwater routing



Source: Teller et al. 2002





Estimated Freshwater fluxes from Laurentide sources:

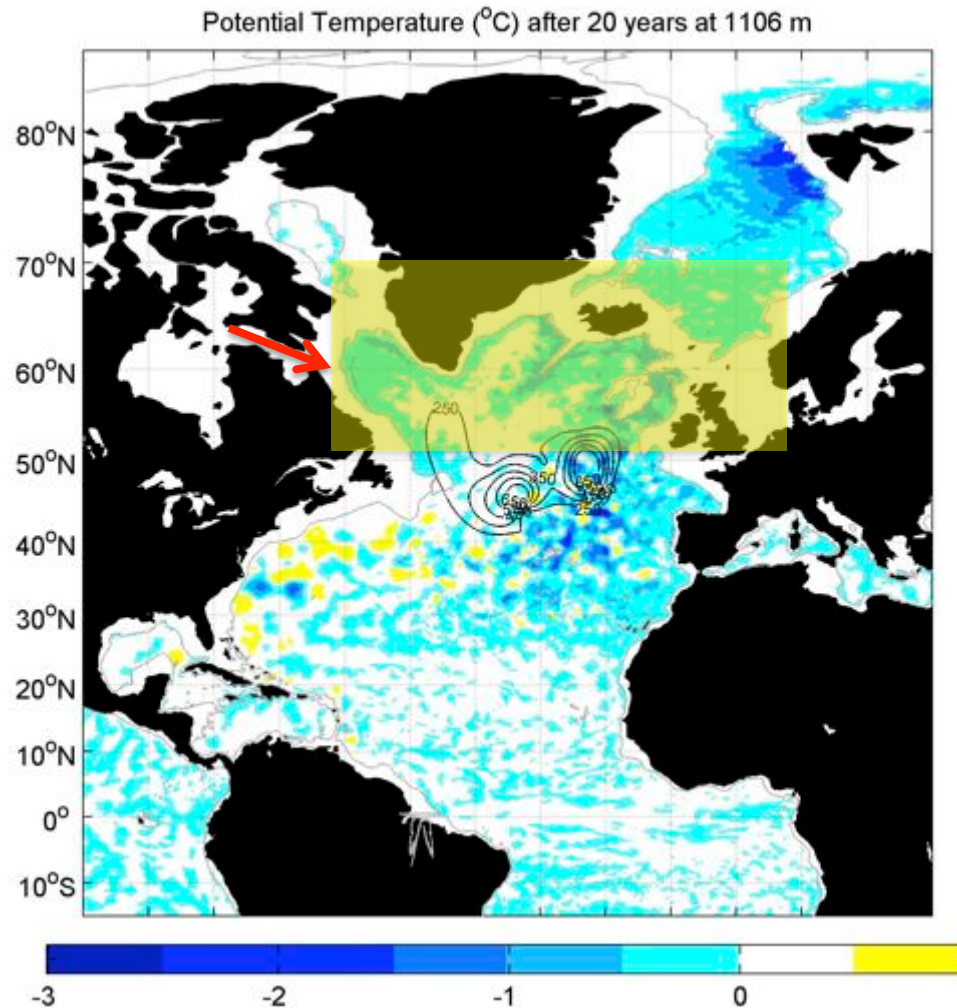
(1) the Younger Dryas:	9,500 km ³	0.3Sv*
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(2) the “8.2 ka event”:	163,000 km ³	5.2 Sv*
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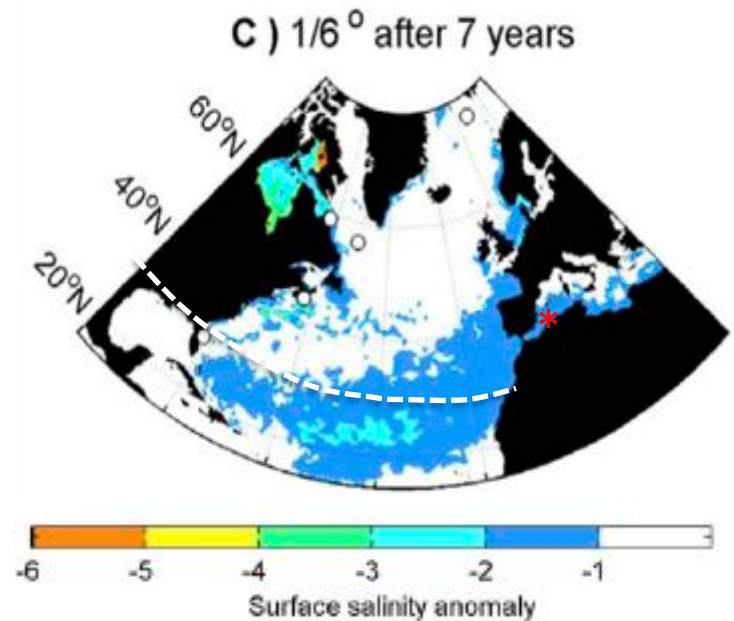
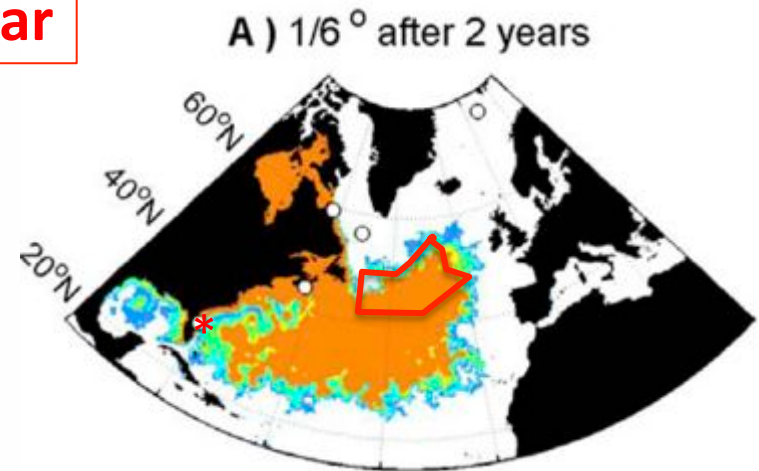
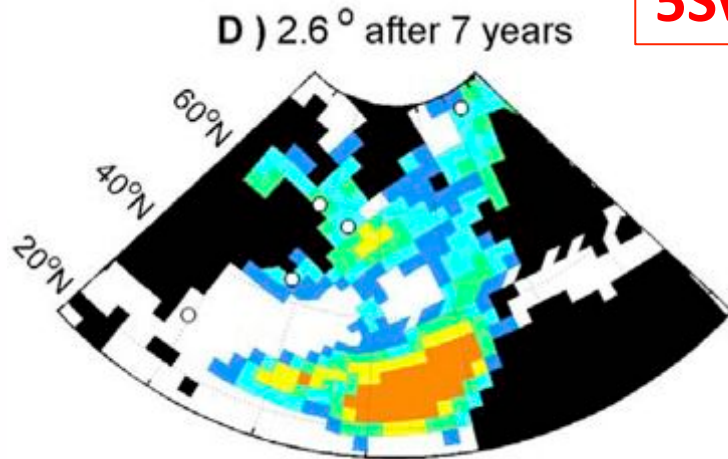
*...if released in 1 year.

Source: Teller et al. 2002

“Hosing experiments”



5Sv for 1 year

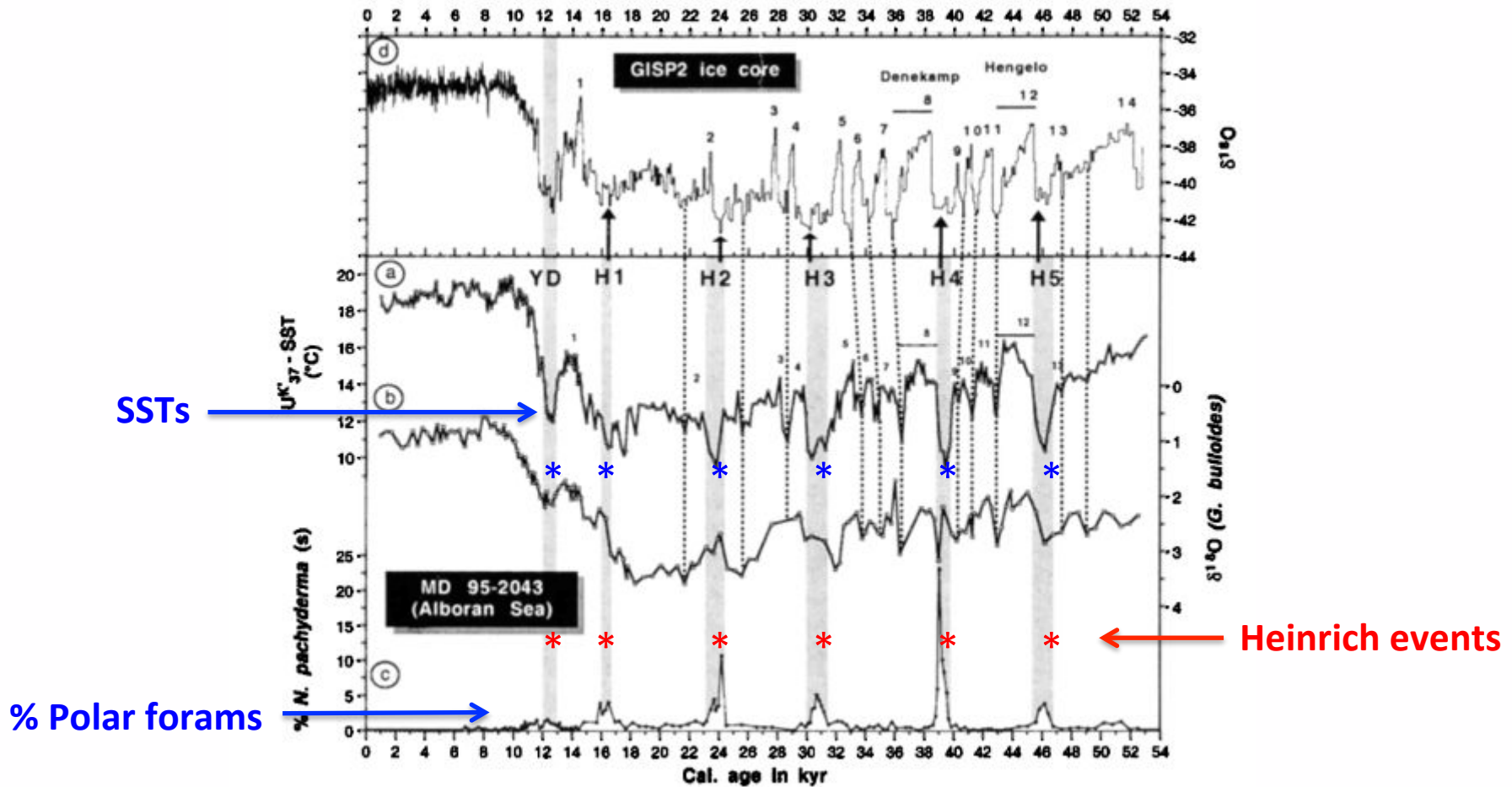


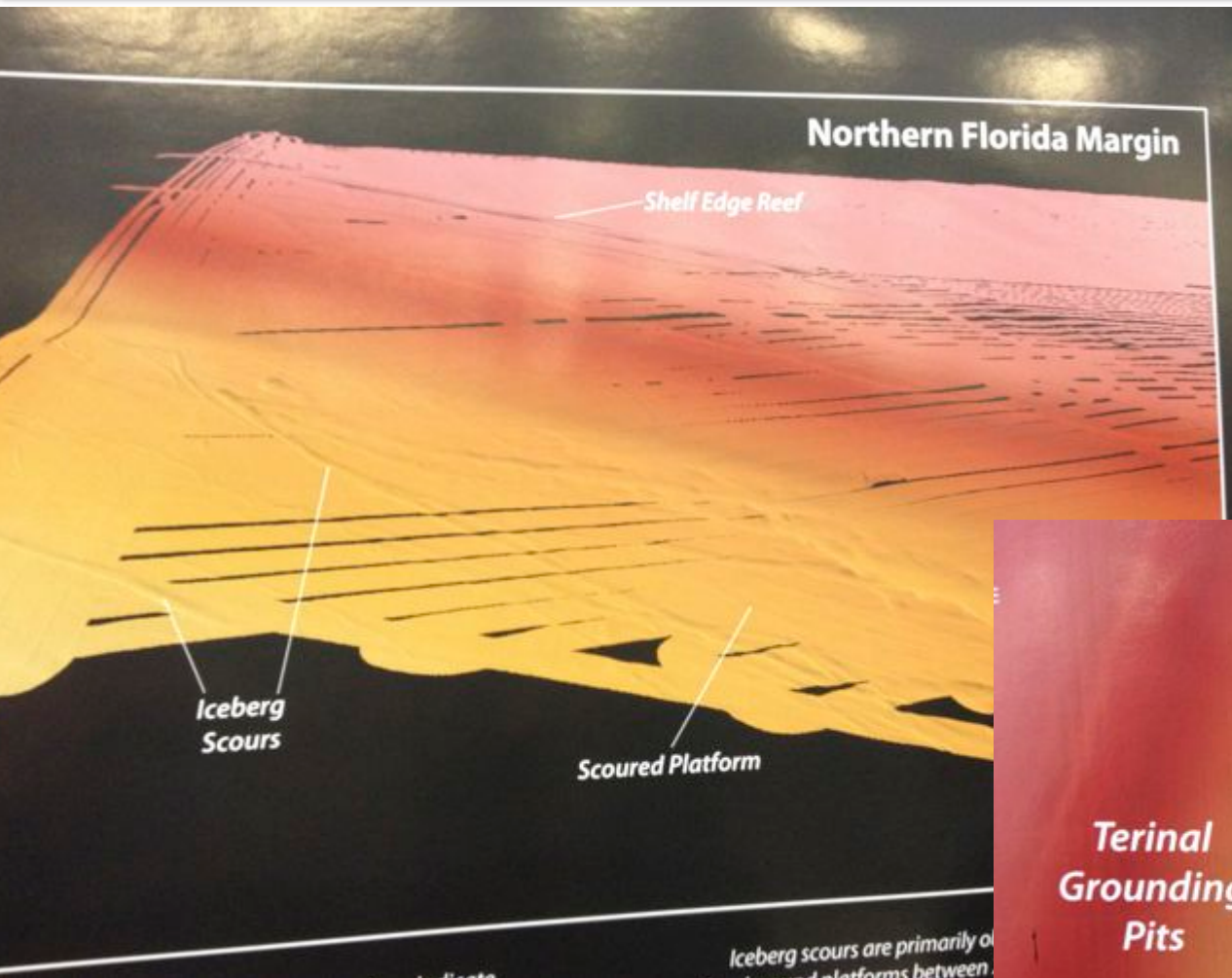
The ocean pathway of freshwater is highly dependent on a model's spatial resolution

Resolving coastal currents, frontal boundaries and shelf-breaks dictates how realistically a model will transport freshwater around the ocean and to the convective regions.

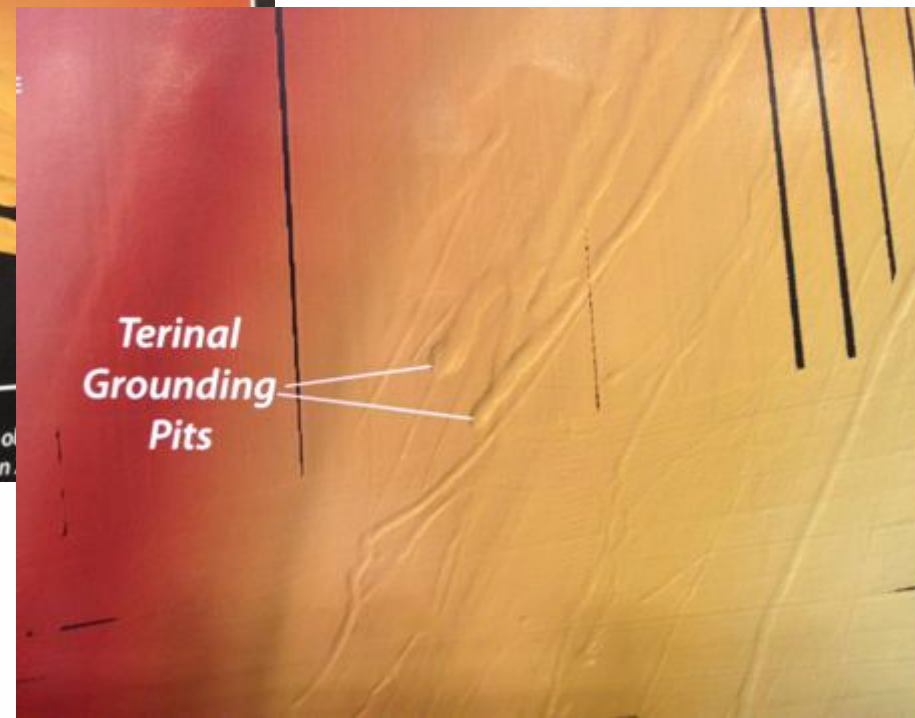
Source: Condron & Winsor, 2011

Sedimentary record: Alboran Sea, western Mediterranean

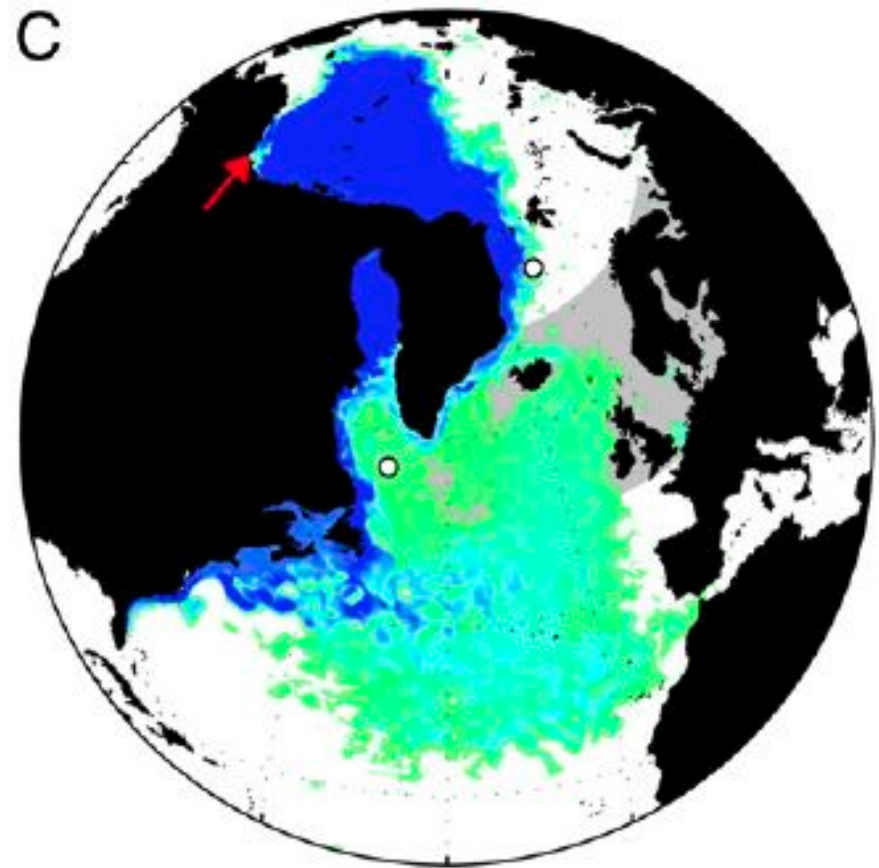
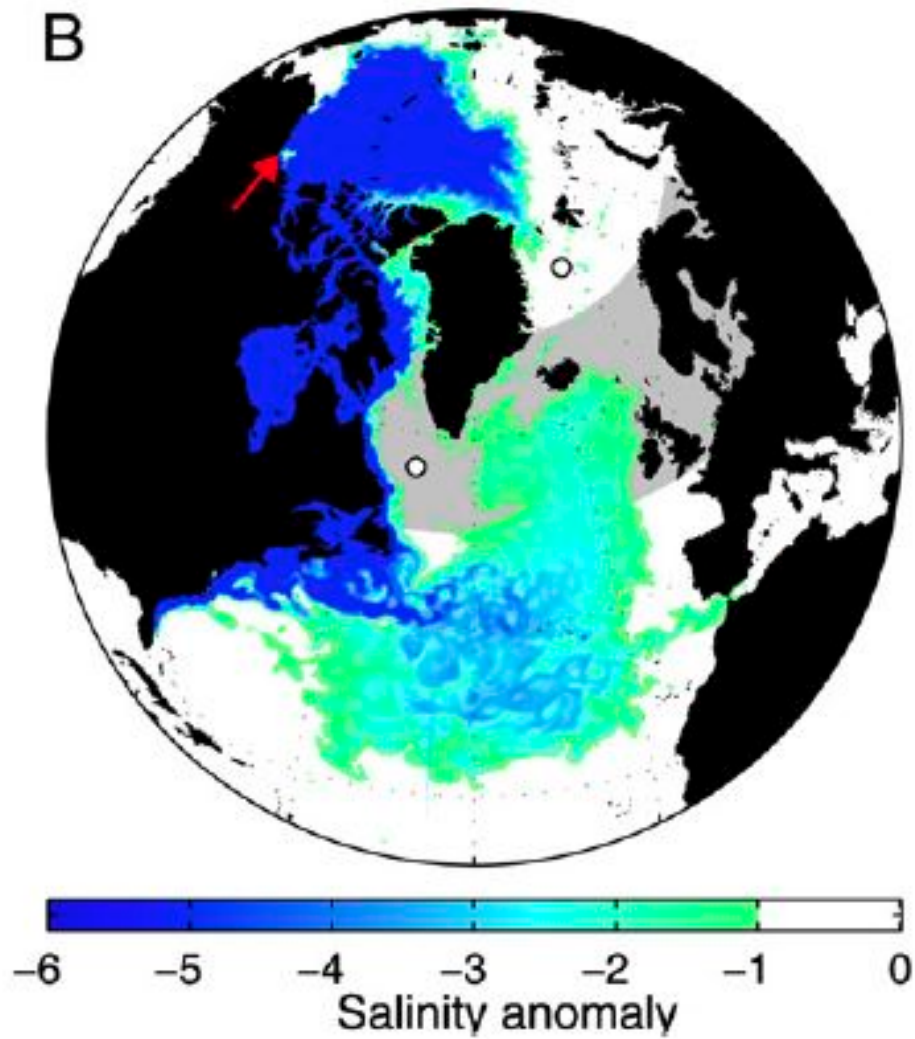




Iceberg scour marks
170-330m depth
Florida's Atlantic coast

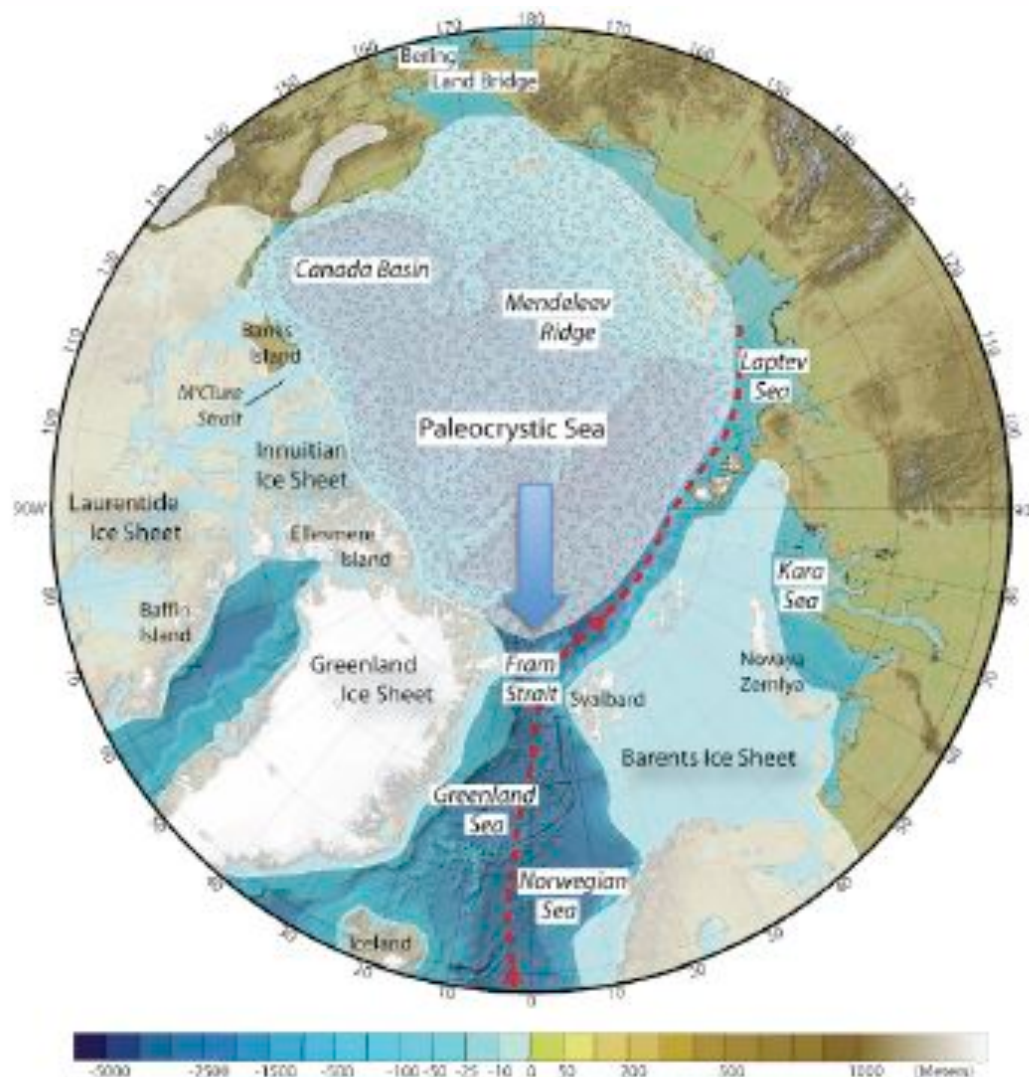


Source:
Jenna Hill (pers. comm)

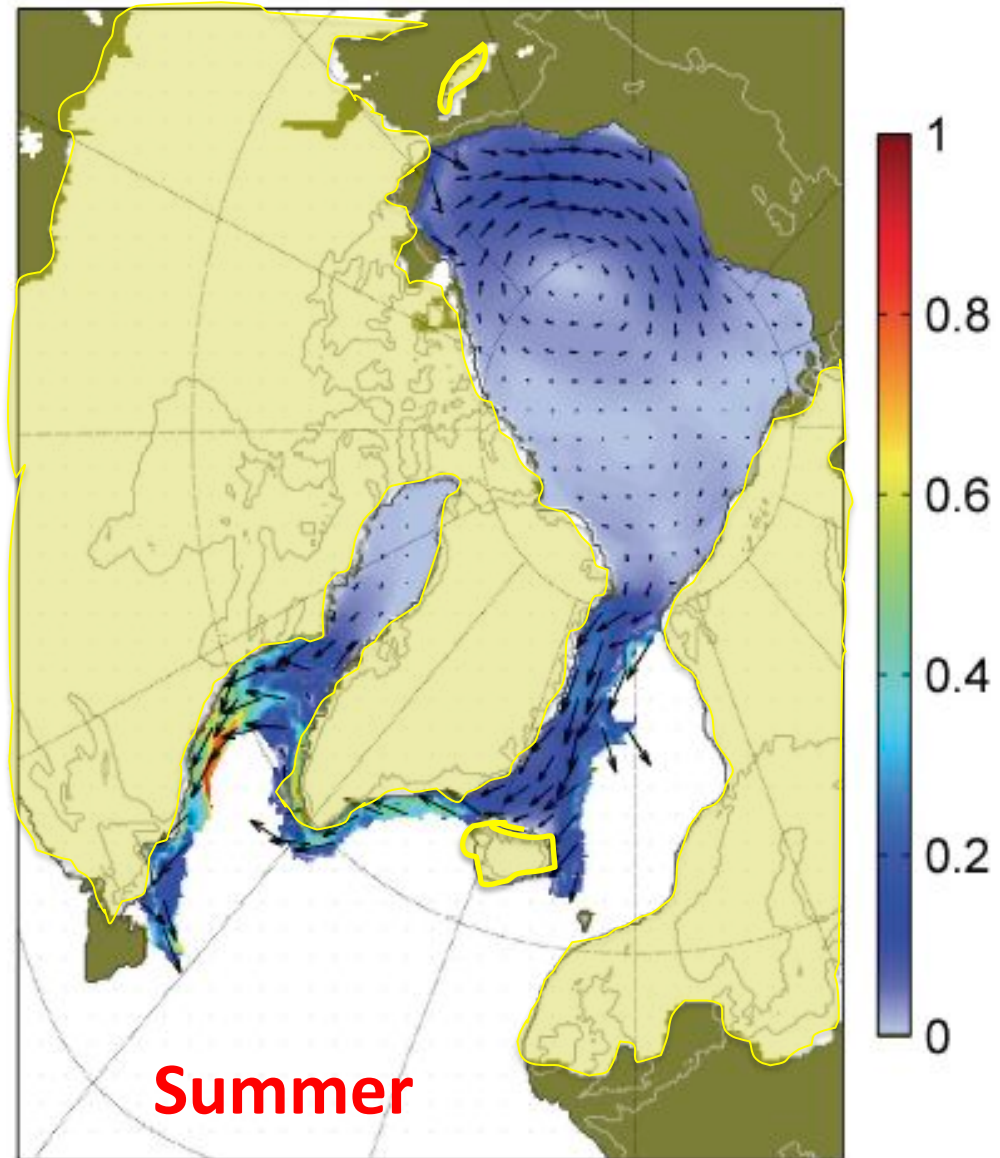
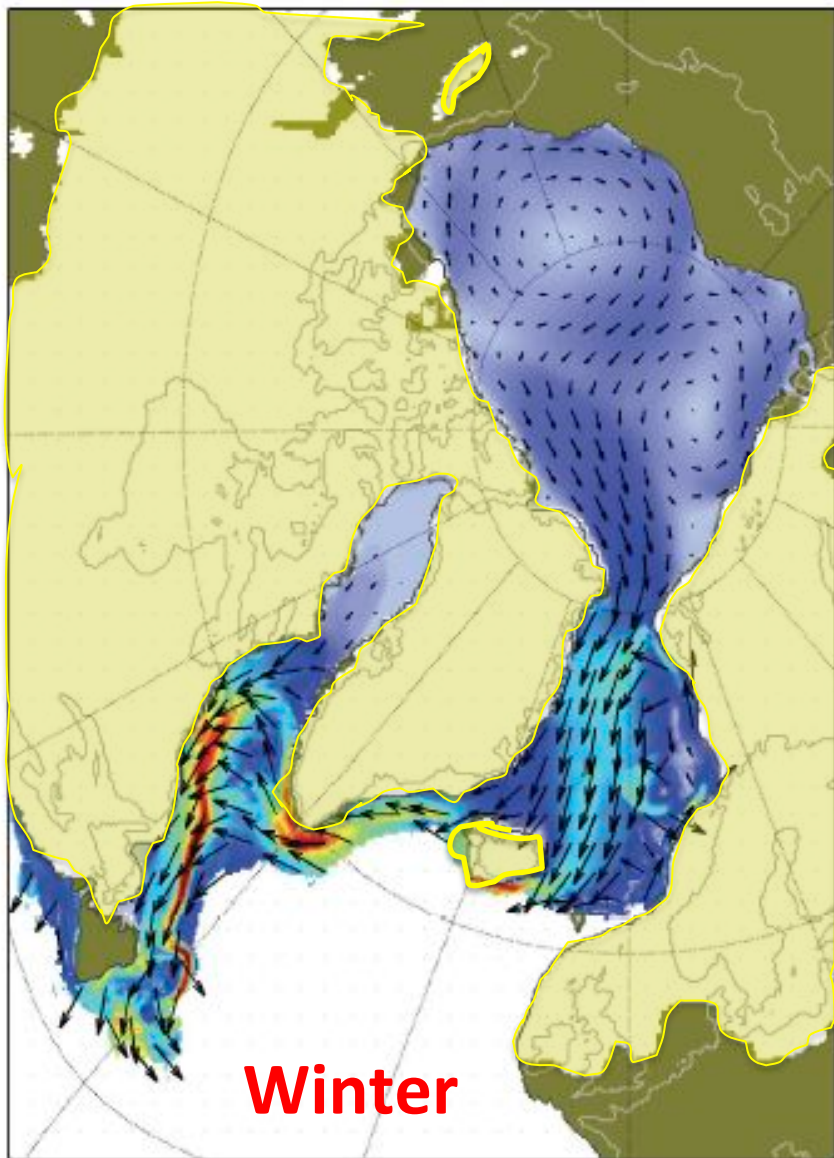


Source: *Condon & Winsor 2012*

**An alternative
model: very thick
Arctic Ocean sea
ice shut down the
Atlantic Meridional
Overturning
Circulation (AMOC)**



Source: Bradley & England, 2008



Source: Otto-Bliesner & Brady 2011

Estimated Freshwater fluxes from Laurentide sources:

(1) the Younger Dryas: 9,500 km³ 0.3Sv*

(2) the “8.2 ka event”: 163,000 km³ 5.2 Sv*

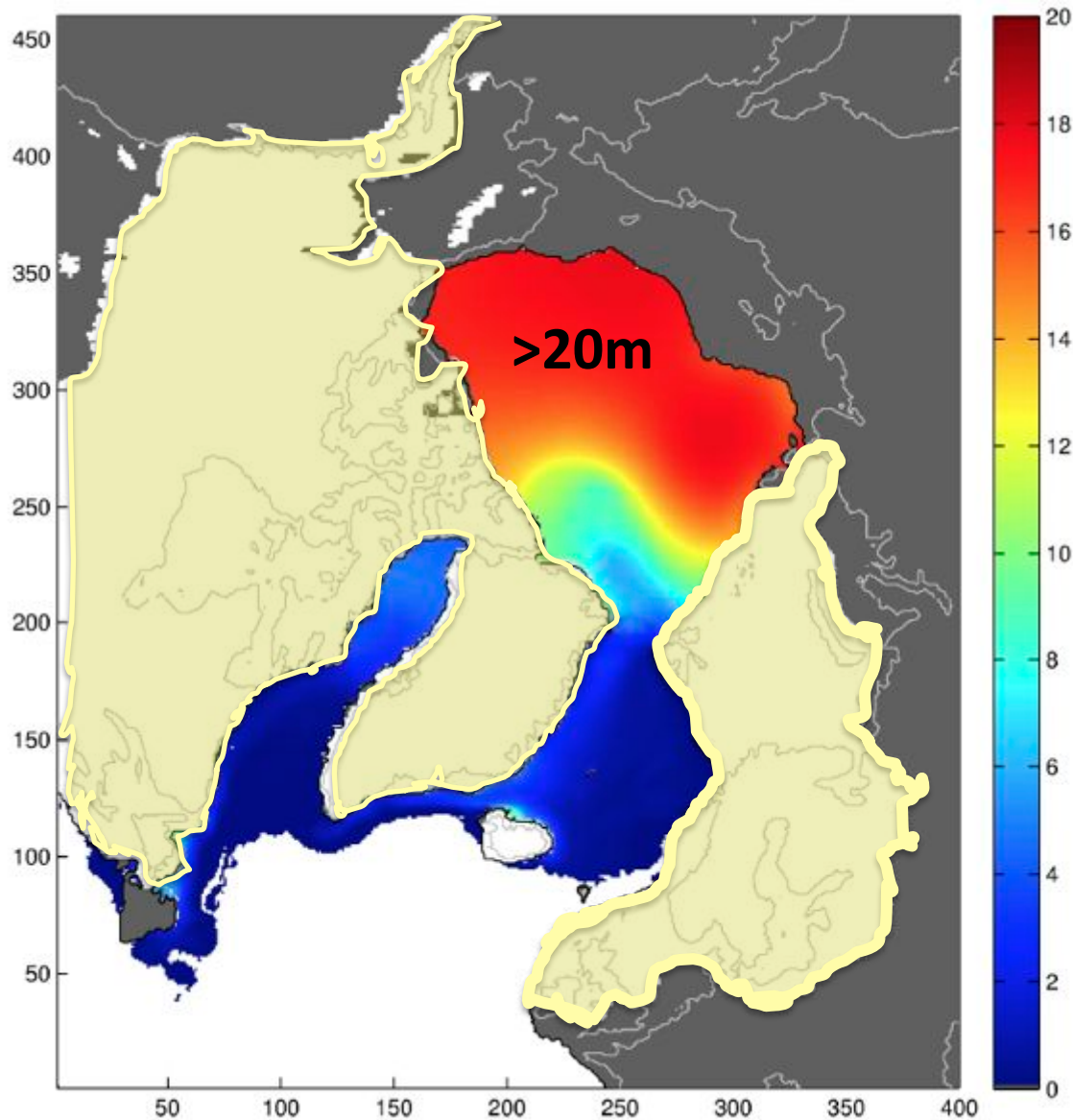
*...if released in 1 year

An Arctic Ocean source?

5cm snow (water equivalent) over Arctic Ocean (14M km²)
= 700 km³ in 1 year

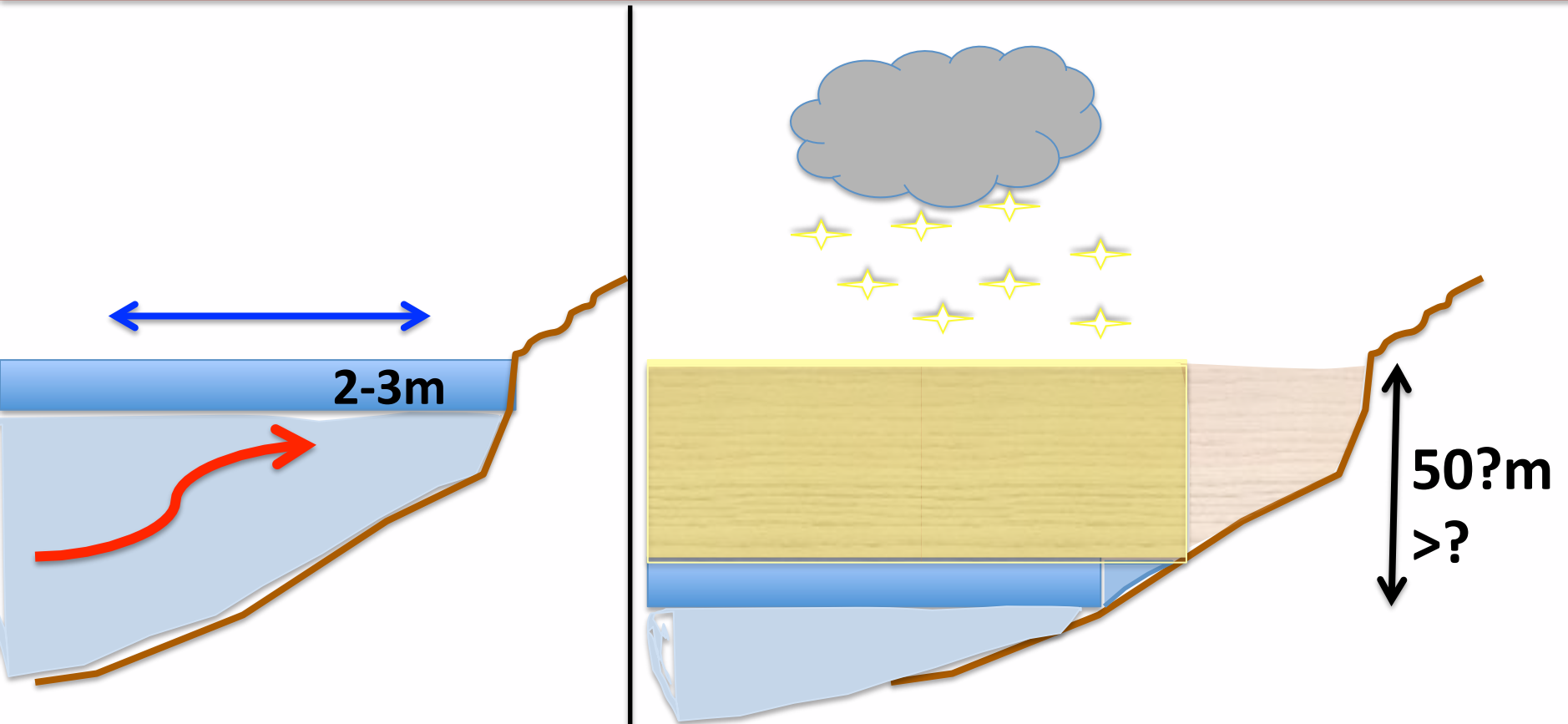
Thus, snowfall accumulating on the Arctic Ocean ice in ~14 years would be equivalent to “storing” YD floodwaters

...and equivalent to the 8.2ka floodwaters in 233 years...



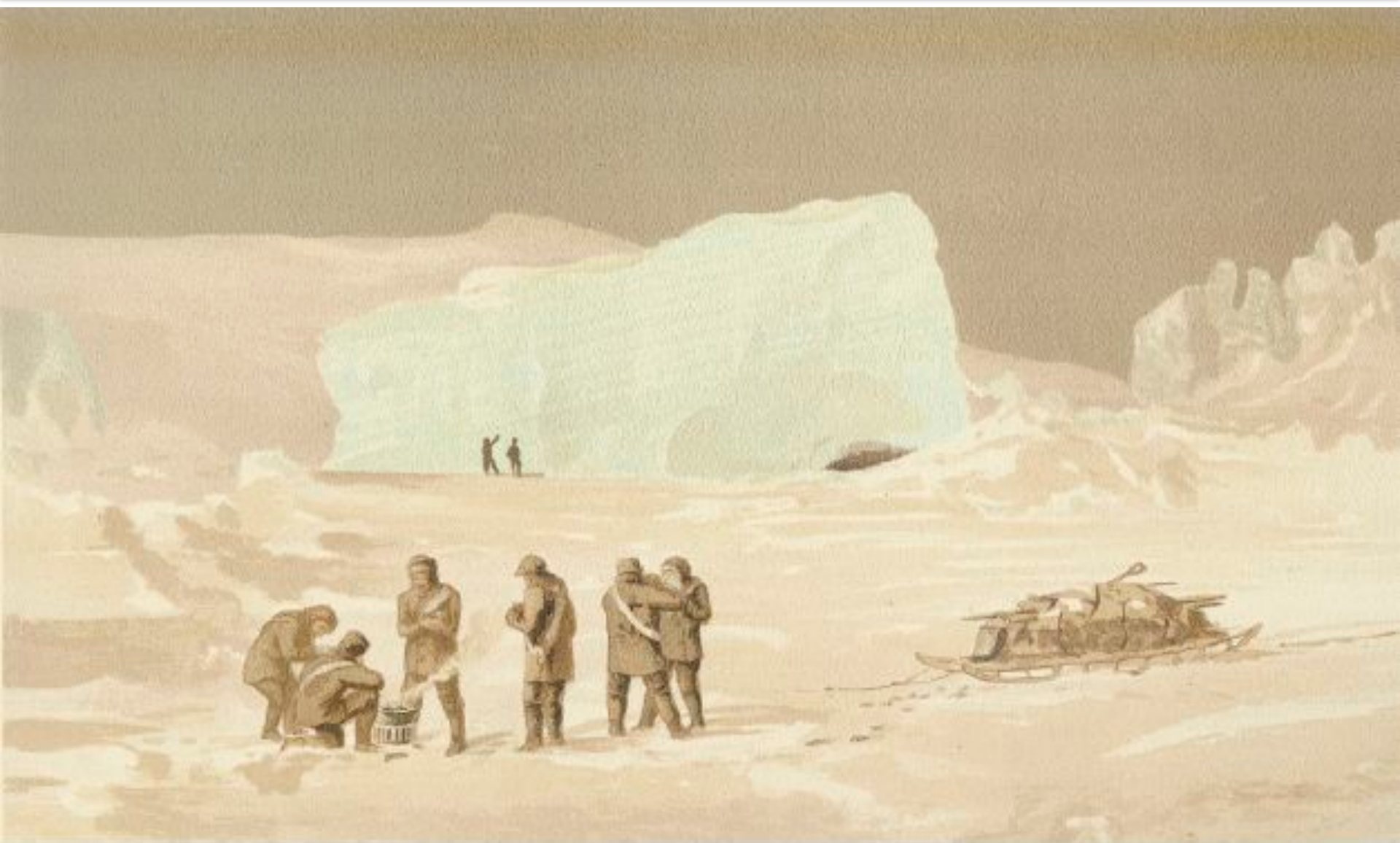
**Ice thickness
after 75 years**

**100 year LGM
spin-up
+ 75 years with
20% lower wind
speed & 10w m^{-2}
less LW↓**



“Paleocrystic Ice”





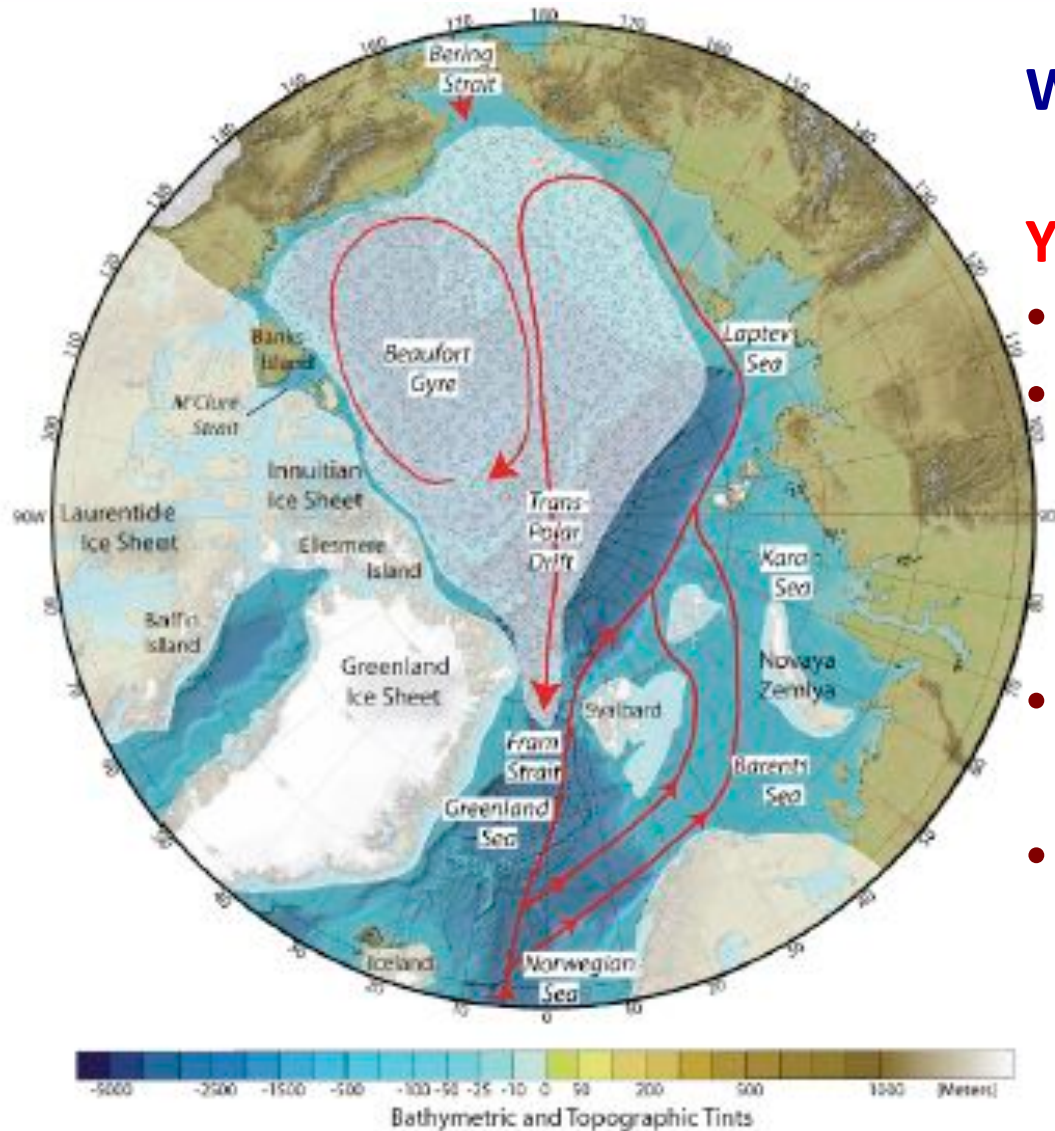
Source: Moss, 1878

Arctic Ocean sediment cores reveal periods of non-deposition, due to very thick ice cover which prevented any biological activity

Polyak et al. (2004) report, *“an interval of drastically declined sedimentation rates, possibly including a hiatus, between ca. 13 ka and at least 19 ka...this episode possibly started as early as 24–25 ka...The non-deposition... points to an exceptionally heavy ice cover during the Last Glacial Maximum (LGM)...as a cause of nondeposition.*

This interpretation is consistent with extremely low abundance or complete absence of biogenic remains during the low-sedimentation interval and immediately above it.”

- During the LGM and late Glacial, restricted circulation led to a reduction in heat flux to the Arctic Basin from the North Atlantic...
- Bering Strait was closed
- Sea-ice would have been stagnant, & accumulated snowfall as firn and superimposed ice on the surface
- Unlike today, when ice thickness is limited to 2-3m, “paleocrystic ice” would have been 10s of meters thick
- Release of this ice to the North Atlantic would place freshwater *directly* into the AMOC core regions of the Greenland and Labrador Seas



What triggered the changes?

Younger Dryas time:

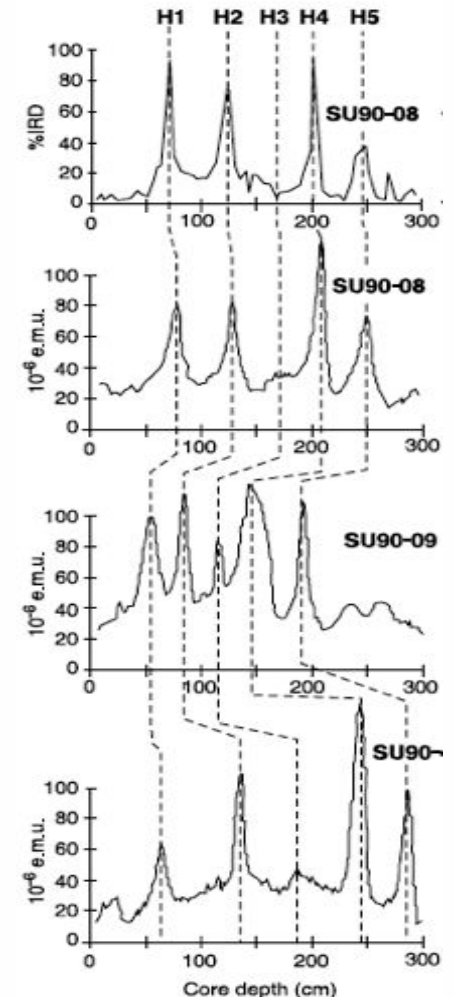
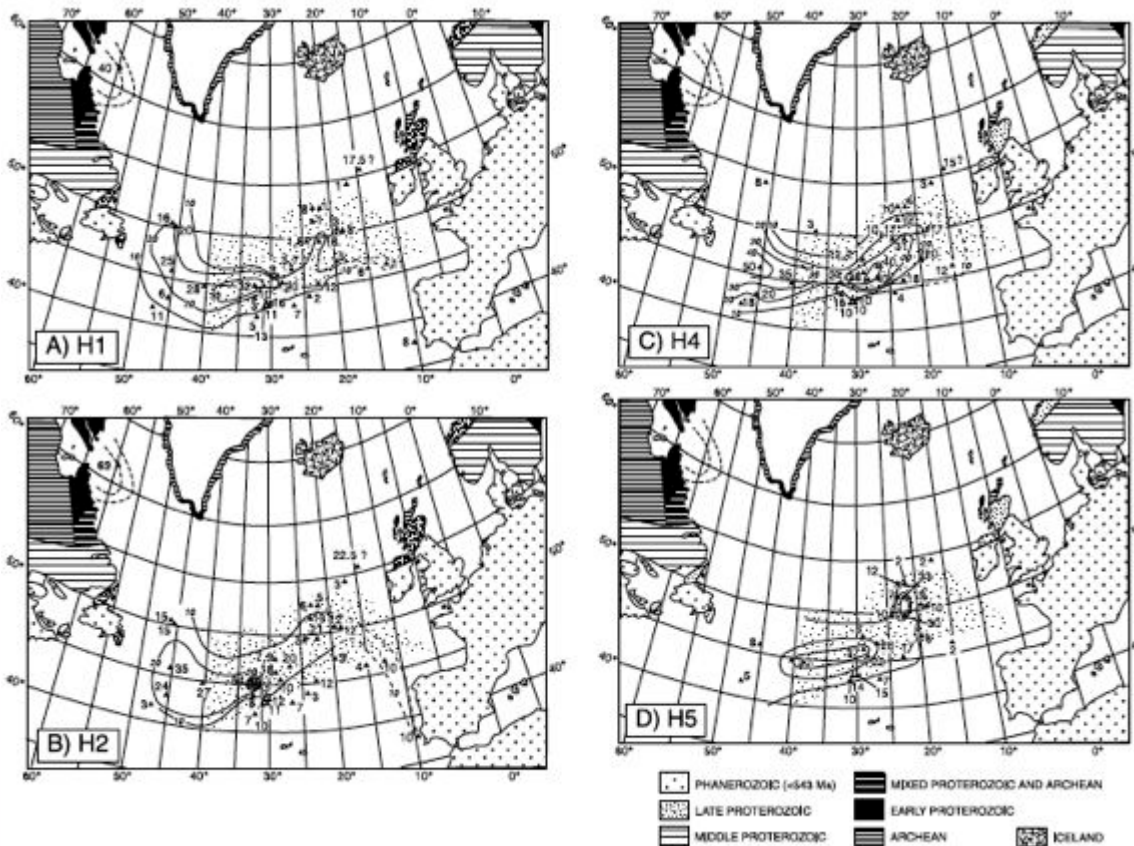
- Sea-level was rising
- Barents Sea Ice Sheet had broken up, allowing warm Atlantic water to enter the Arctic Basin
- Bering Strait opened [~ 13 ka]
- Freshwater entered the Laptev Sea from major rivers

Source: Bradley & England, 2008

Heinrich Events: ice-rafted debris (IRD) in North Atlantic cores

Isopachs (cm)

magnetic susceptibility

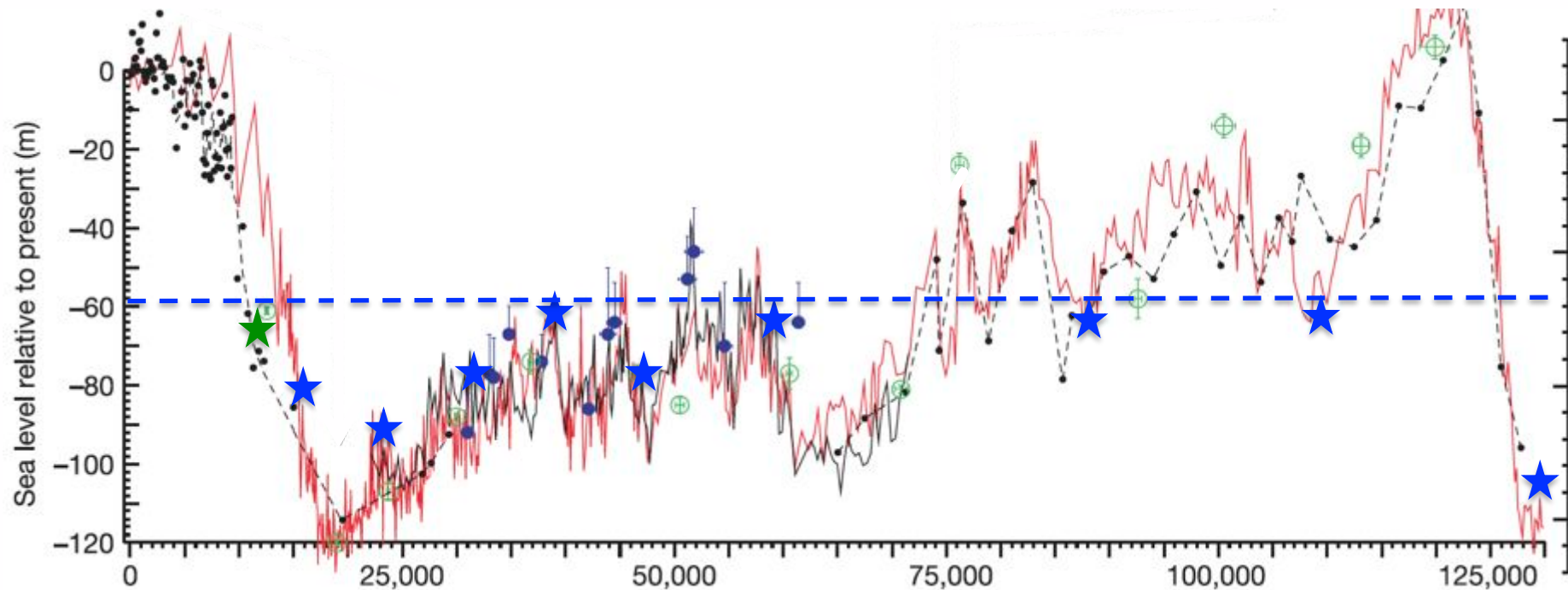


Source: Hemming, 2004

What about Heinrich events?



Sea-level reconstruction and the timing of Heinrich events



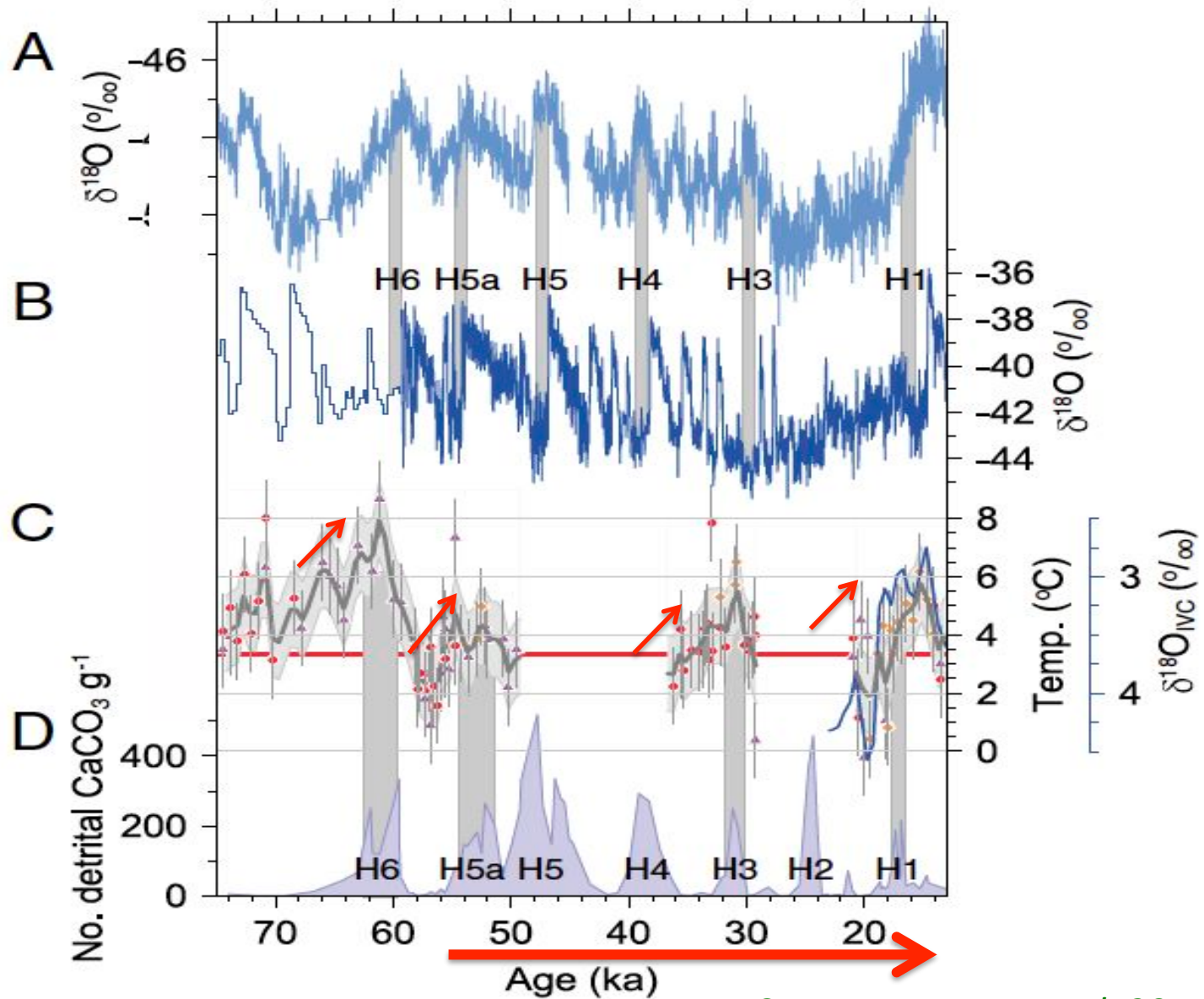
Sea-level Source: *Siddall et al. 2003*

EPICA-DML

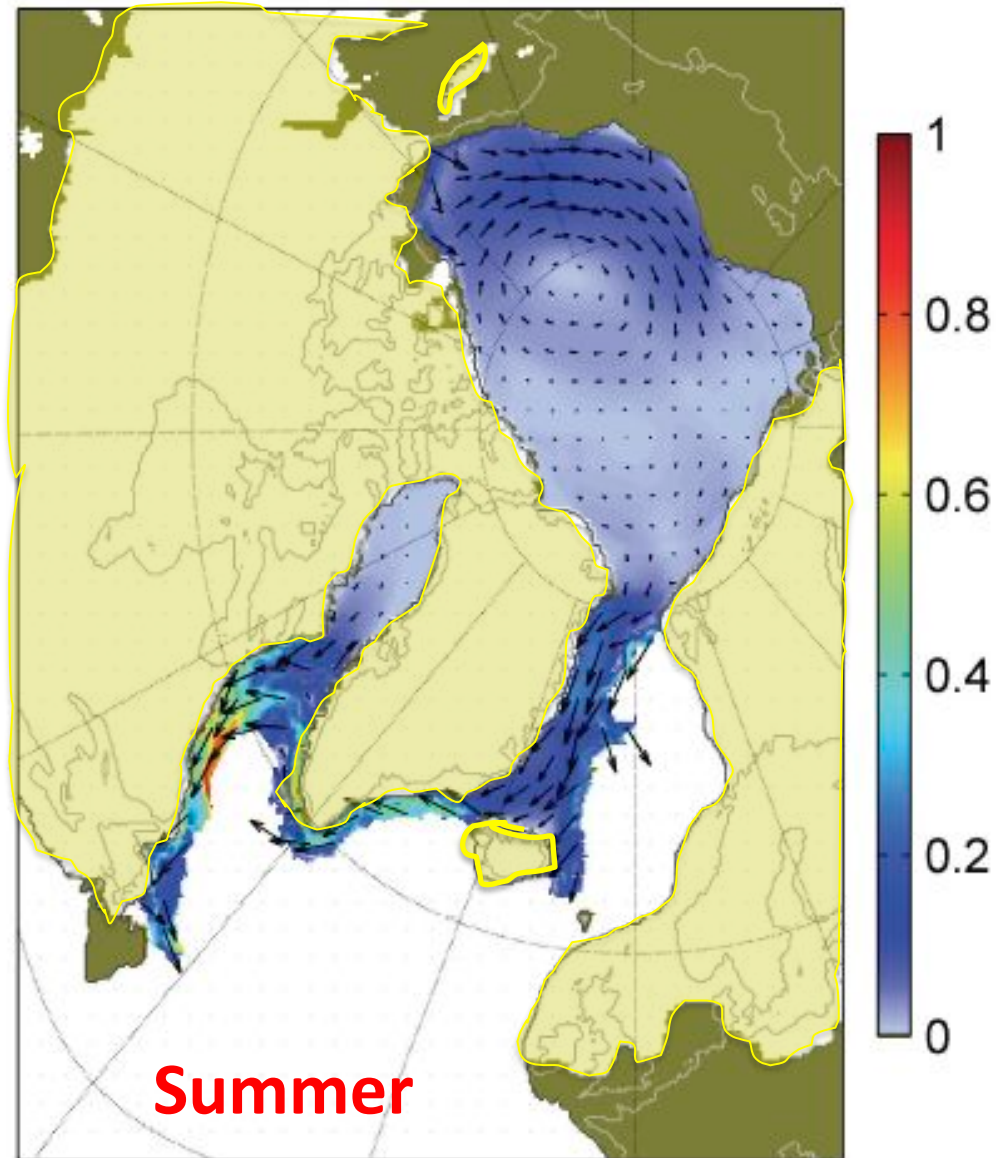
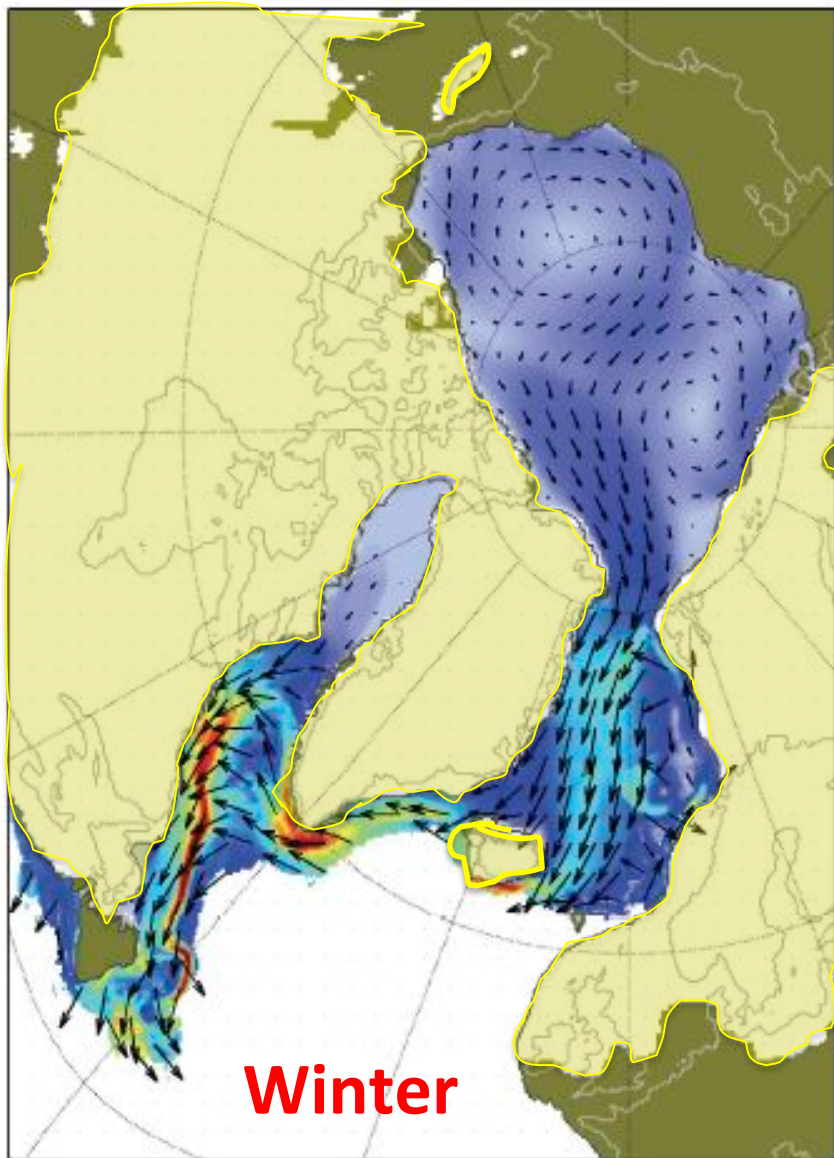
NGRIP

N. ATLANTIC
Benthic Mg/Ca

IRD



Source: Marcott et al. 2011



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**Abrupt climate change
and freshwater forcing: is the
problem solved?**

No!

