Abrupt Climate Change linked to Sea-level Rise from Freshwater Outbursts affecting the THC

- ❑ Links between early Holocene ice-sheet decay, sea-level rise and abrupt climate change
  - Torbjorn E. Tornqvist, Marc P. Hijma, 2012.

- ❑ Reduced North Atlantic Deep Water Coeval with the Glacial Lake Agassiz Freshwater Ouburst
  - Helga (Kikki) Flesche Kleiven, et al., 2008.

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G610 Holocene

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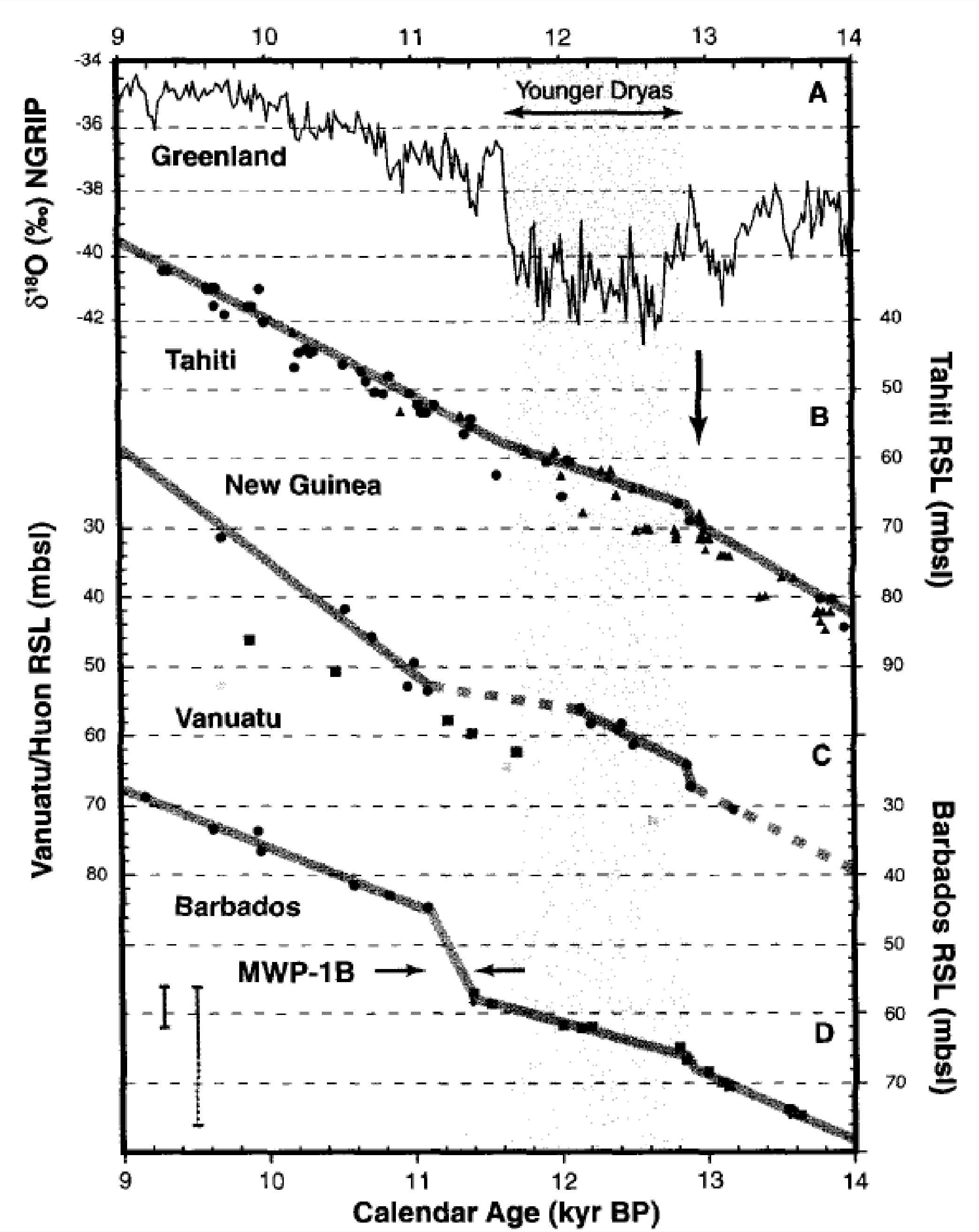
Overview

- Holocene sea level rise
- Tornqvist and Hijima
  - Lake Agassiz
    - Formation
    - Outburst events
    - Timing
    - Duration , magnitude, and geologic evidence
      - Erin Presents
  - Sea-level jumps and abrupt climate change (8.2kyr B.P. cooling)
  - Sea-level fingerprinting
  - Conclusions
- Kleiven
  - MOC and THC
  - Eirik Drift MD03-2665 climate proxy records
  - Implications:
    - Deep-water changes
    - Surface ocean response
  - Wider climatic implications and Conclusions

Holocene Sea-level Rise

- Methods
  - Coral (up to 9kyr BP)
    - Good indicators of sea-level rise
    - Limited vertical resolution (>5m)
    - Bard et al., 2010
  - Coastal peat and landforms (0-8 kyr BP)
    - Most recent (~10 m) rise
    - Data decreases dramatically ~6-8kyr B.P.
    - (Engelhart et al., 2011) and (Shennan and Horton, 2002)
- Glacial Isostatic Adjustment Required
  - Response of solid Earth to mass redistributions
  - Must be removed from RSL rise

Early Holocene Sea-level rise

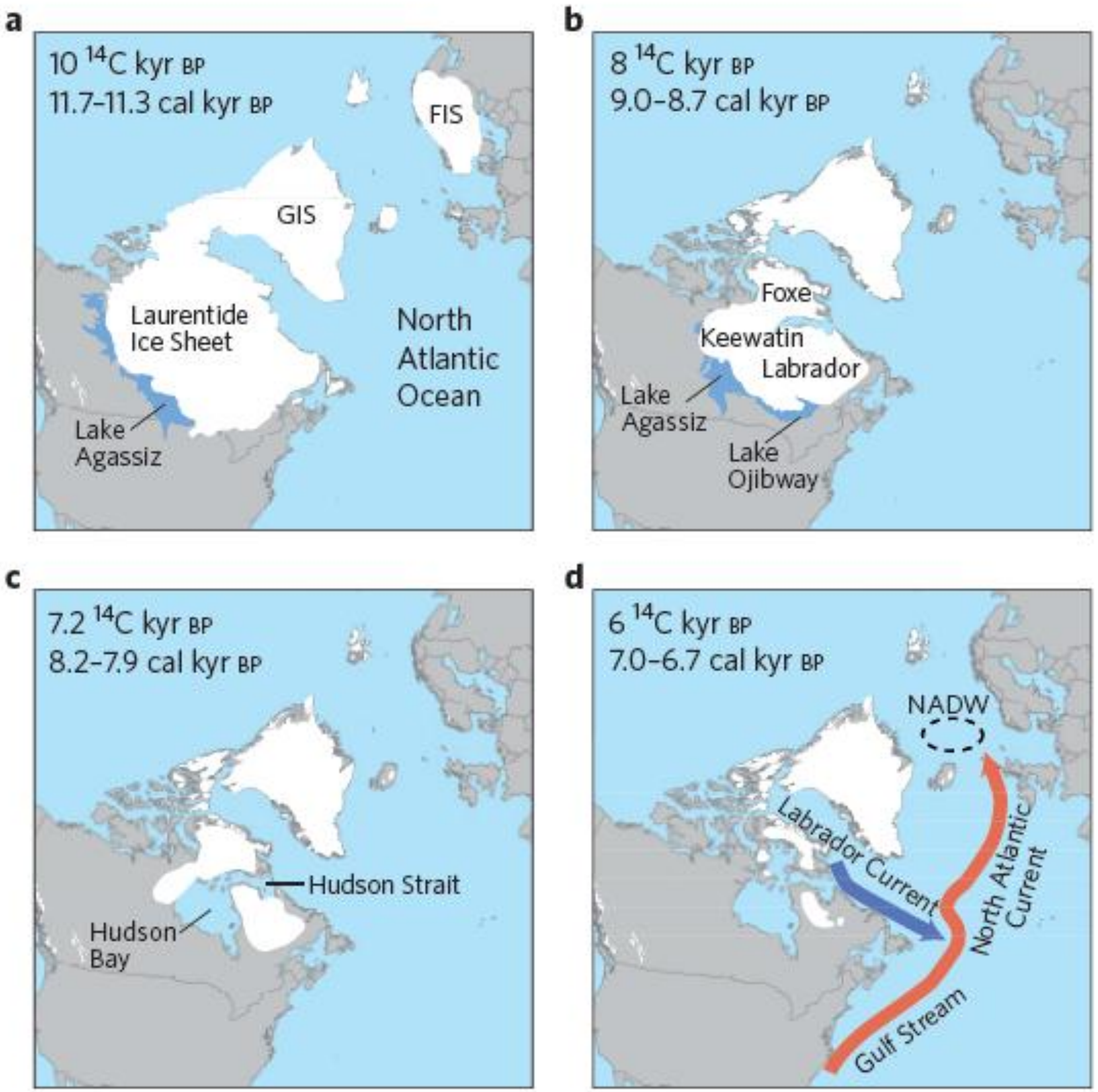


(Bard et al., 2010)

- 12kyr B.P. to 7kyr B.P.
- ½ of global sea-level rise occurs (50-60m)
- >1cm yr^{-1}
- Constant sea level rise punctuated by several rapid rise events
    - Meltwater pulse 1A, 1B
    - 14ka, 11.3ka

Links between early Holocene ice-sheet decay, sea-level rise and abrupt climate change

Tornqvist and Hijma, 2012

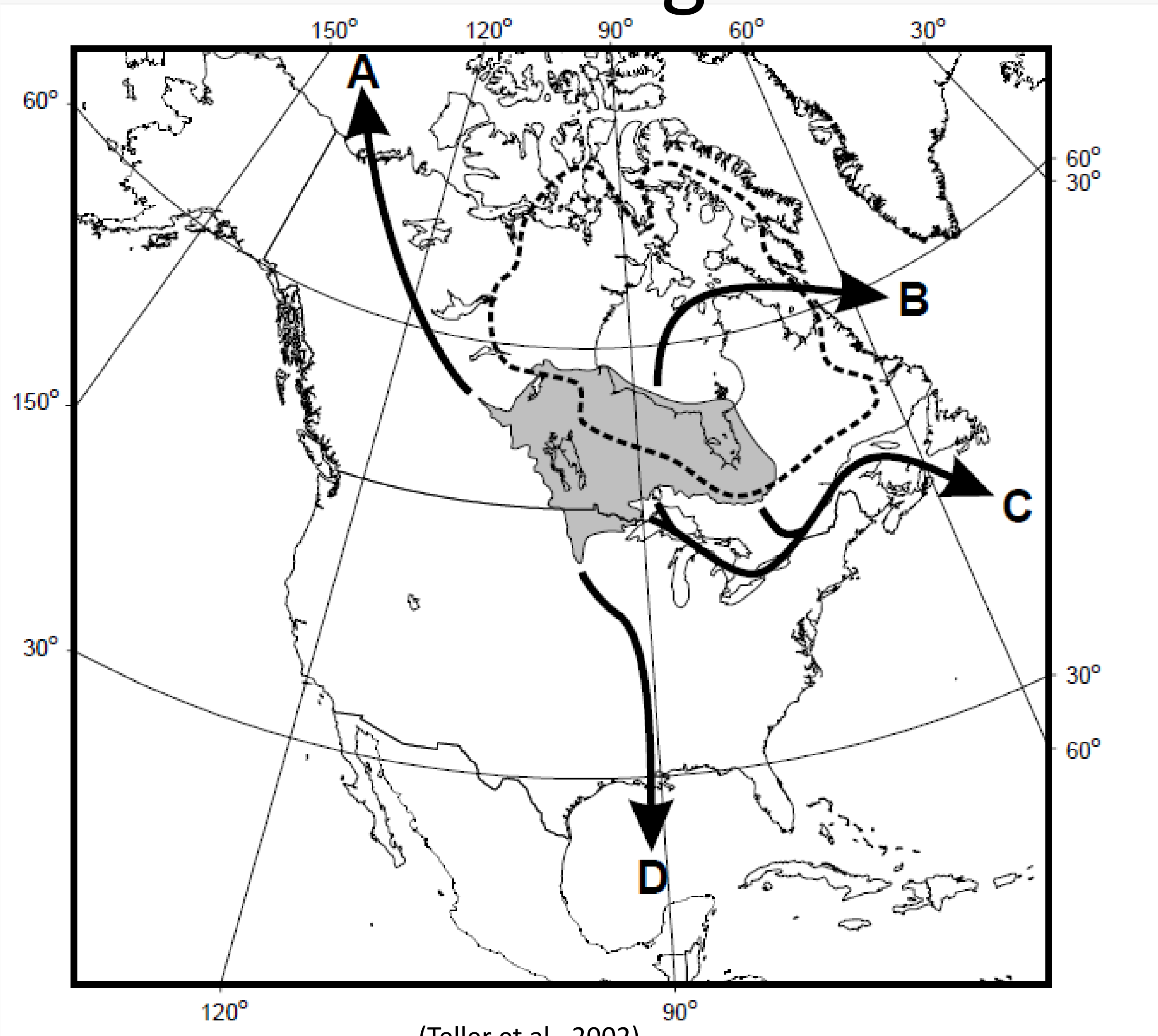


(Tornqvist and Hijma, 2012)

Lake Agassiz

- Gradual decrease of the Laurentide Ice Sheet during the Early Holocene
- LIS retreat well constrained spatially compared to the AIS
- Ice thickness data poses problems for lake volume studies
- 4ka occurrence
- 5 main stages characterized by drainage basin

Lake Agassiz outlet direction changed over time



(Teller et al., 2002)

Stages

- Lockhart (11.7 to 11ka)
- Moorhead (11 to 10.1ka)
- Emerson (10.1 to 9.4ka)
- Nipigon (9.4 to 8.2)
- Ojibway (8.2 to 7.7ka)

Multiple Outburst floods

Table 1
Freshwater fluxes from proglacial lakes in the early Holocene.

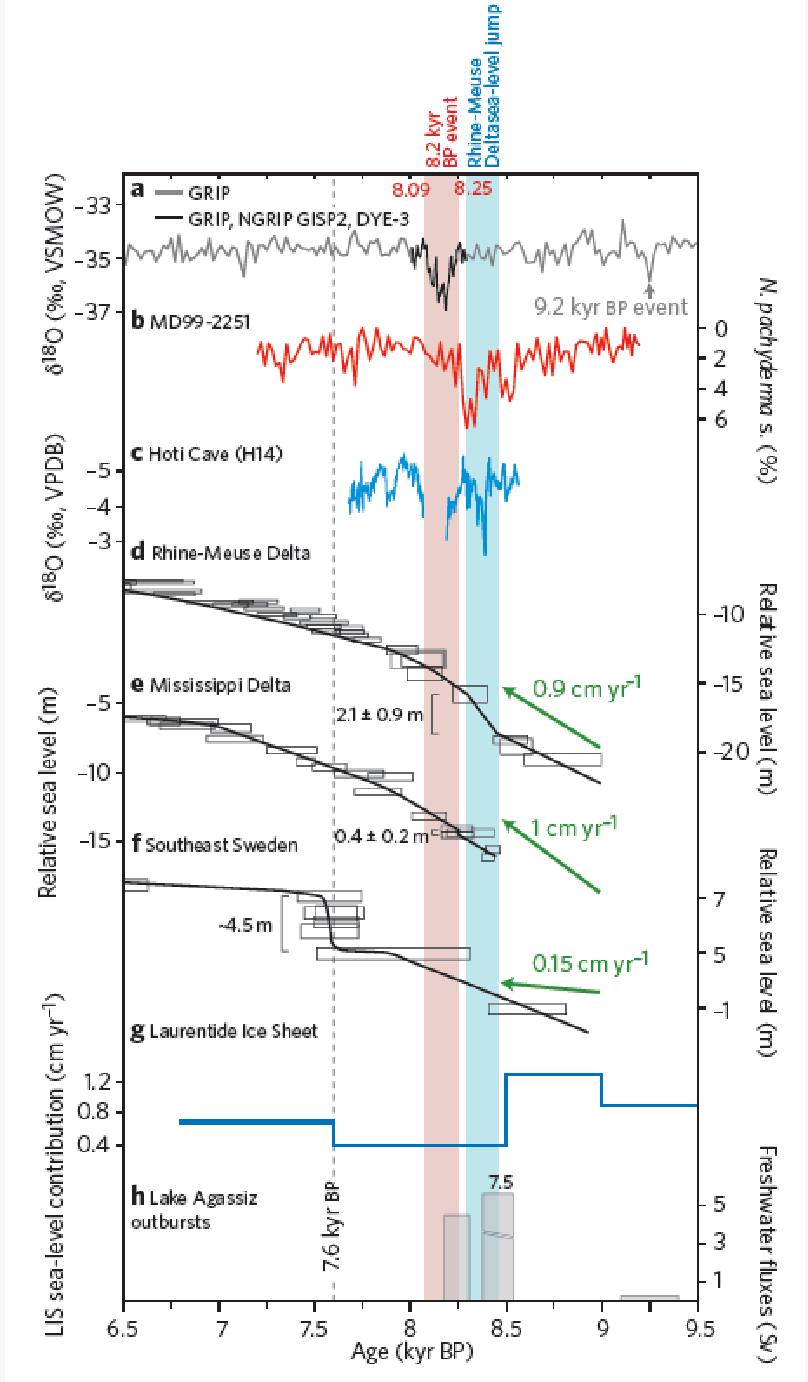
Lake	Date of discharge, cal. BP[a]	Volume of discharge, km^3	Sea level equivalent, m	Reference
Agassiz-Ojibway	11,700	9300	0.026	Teller et al., 2002
	11,200	5900	0.016	
	10,600	7000	0.019	
	10,400	3700	0.010	
	10,300	2100	0.006	
	10,000	1600	0.004	
	9500	2300	0.006	
	9200	1600	0.004	
	8400	113,100	0.314	
	8400	49,000	0.136	
Baltic ice lake	11,600	9300	0.026	Nesje et al., 2004; Björck, 1995
Ancylus lake	9800	n/a	n/a	Nesje et al., 2004; Björck, 1995
Nedre Glamsjø lake	10,300	120	<0.001	Longva and Thoresen, 1991; Nes
Fraser River basin	11,000	n/a	n/a	Blais-Stevens et al., 2003

[a] Note: the discharge date assumes instantaneous discharge: actual discharge times may have been longer.

(Smith et al., 2011)

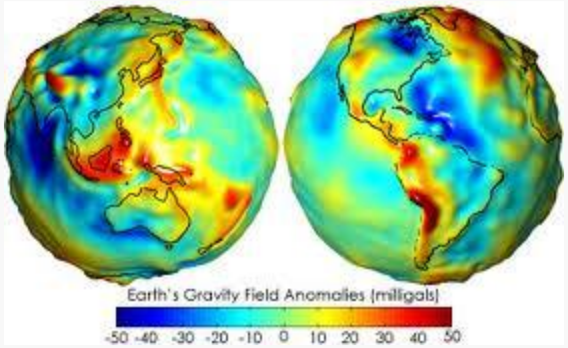
Sea-level rise

- Comparison between Early Holocene high-resolution paleoclimate and relative sea-level records
    - Steady sea-level increases
    - Punctuated by abrupt sea-level rise during the first proposed outburst event
- 8.2kyr cooling event
    - Northern Hemisphere cooling
    - mean annual temperature drop of 3.3 ± 1.1 °C in Greenland
- Two stage outburst event based on the offset in atmospheric cooling from sea-level rise and ocean current changes



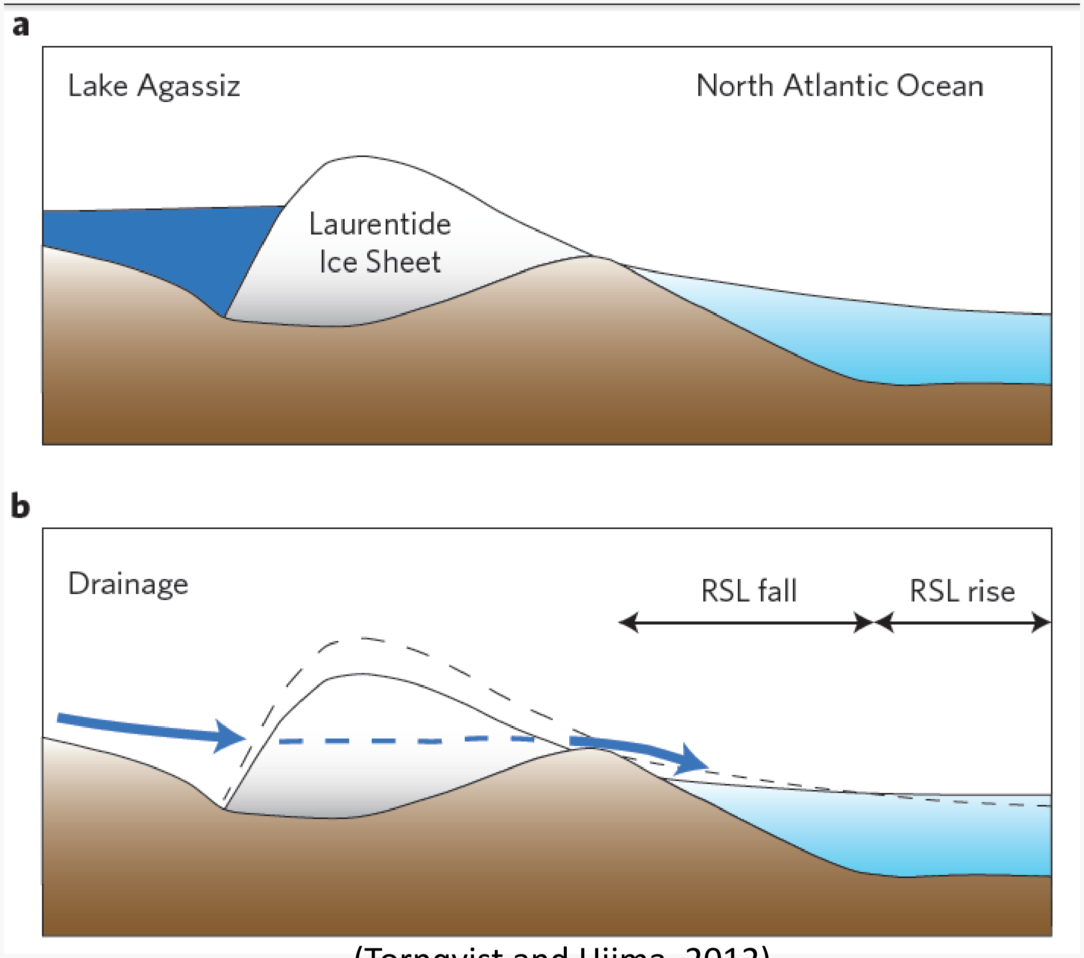
(Tornqvist and Hijma, 2012)

Model Study: Sea-level Fingerprinting



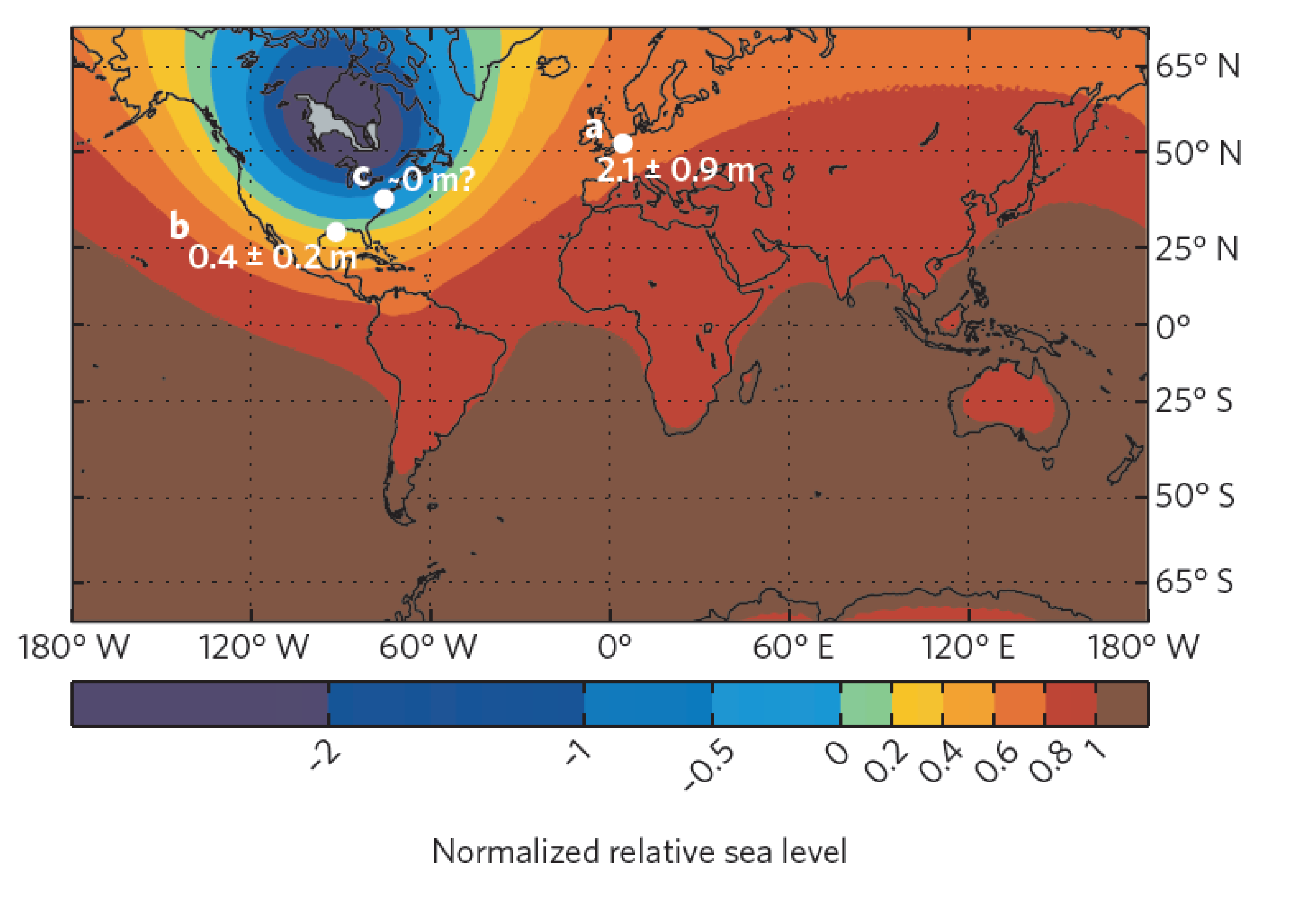
- Attribute past episodes of sea-level rise to spatially constrained meltwater sources
  - Based on gravitational distortions of the geoid
    - Geoid: representation of the Earth's surface based on gravitational measurements and deviations from a baseline value.
  - Problems: Tides affect past sea-level indicators
    - Tides have changed through time
    - Opening Hudson Bay reduced tidal range (Atlantic)

Gravitational Effects of Ice Mass



(Tornqvist and Hijma, 2012)

Modeled Sea-level Fingerprint

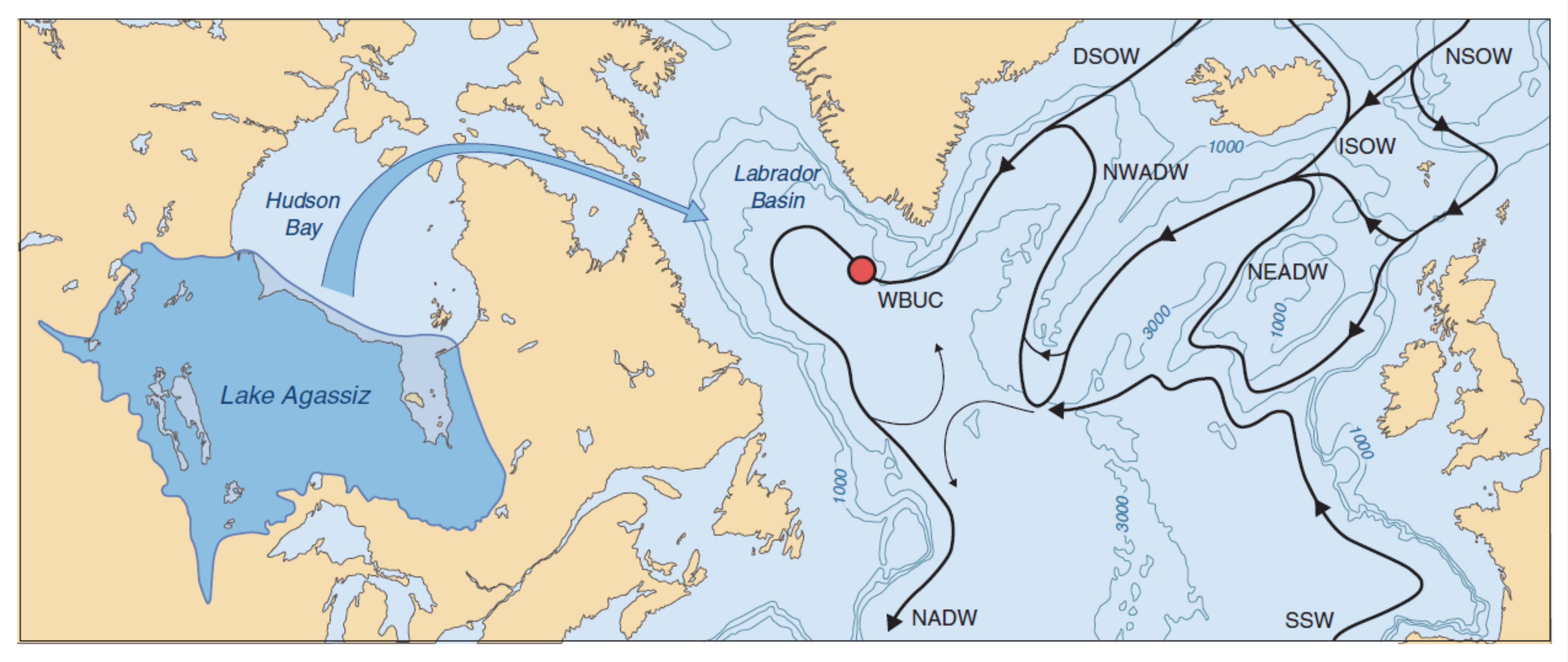


(Tornqvist and Hijma, 2012)

Conclusions (Tornqvist and Hijma)

- Progress has been made with respect to recognition of decimeter to meter scale sea-level jumps during the Holocene.
- Some of which have been linked to abrupt climate change
- Sea-level fingerprinting will increase the accuracy of determining meltwater sources and better correlate abrupt climate change events
- Future research needed
  - Partitioning ice volumes and melt rates between the LIS and AIS
  - Constrain freshwater volumes as potential triggers to assess future probabilities of climate change
  - Refine GIA models by comparing them to empirical data

Reduced North Atlantic Deep Water Coeval with the Glacial Lake Agassiz Freshwater Outburst
Flesche Kleiven. et al. 2008

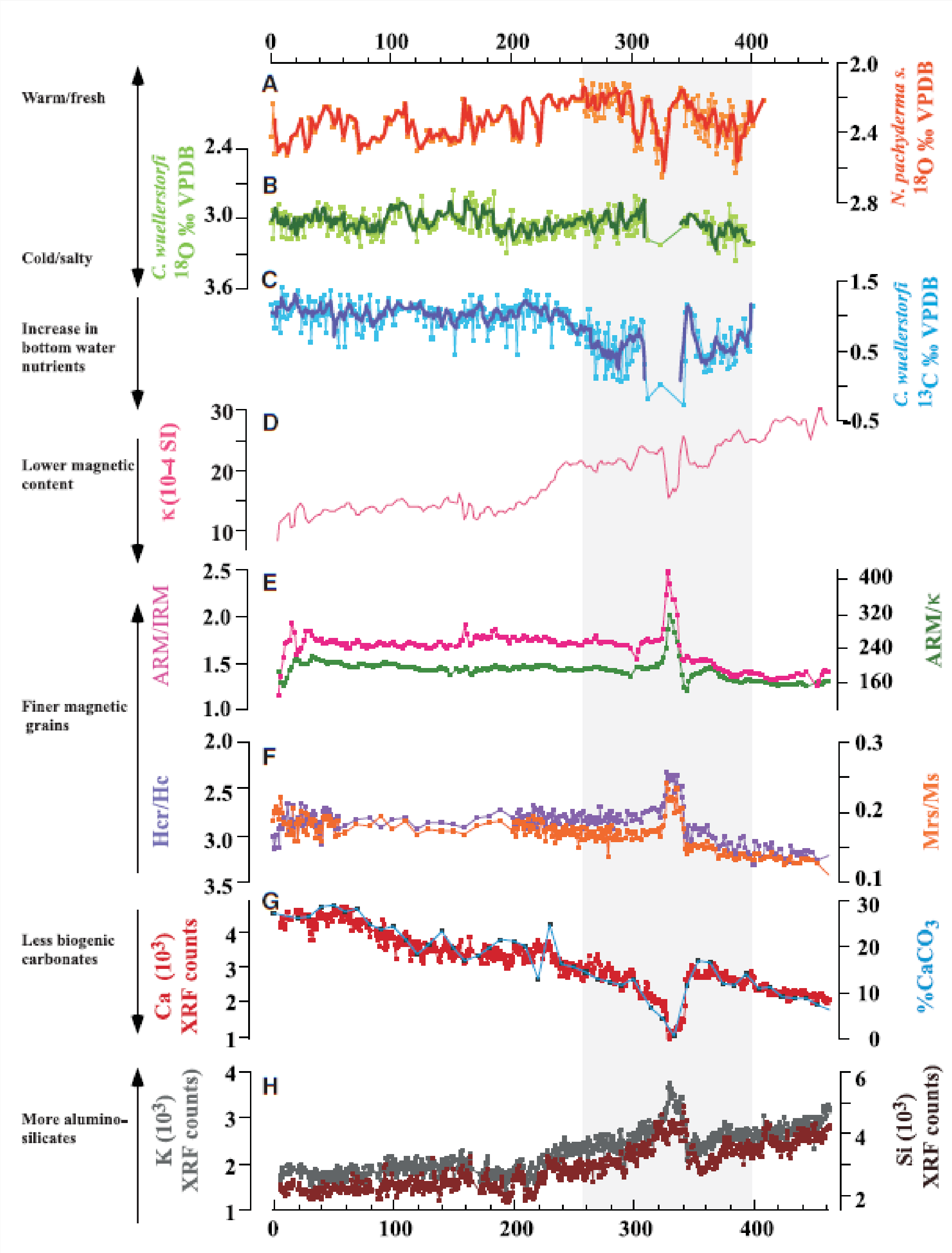


(Kleiven et al, 2008)

Eirik Drift MD03-2665
3440m depth

Aims and Objectives

- Provide a record that can be used to test the mechanisms (physics) of the 8.2ka event
- Understand the changes in the ocean circulation over this time period
- Confirm the scale and duration that computer simulated models have predicted climate change can occur



(Kleiven et al, 2008)

Eirik Drift MD03-2665 Sediment Core Proxy Record

- Sediment, geochemical, and magnetic proxy data
- Large deviation at 3.45m core depth
- Epibenthic carbon isotope drop indicate a shift in bottom water nutrients (Imply current change)
    - Shift to southern source waters
        - LNADW (high del ^{13}C)
        - Southern source deep water (low del ^{13}C)
- Decrease in Magnetic (magnetite) particles both concentration and grain size
    - Main transport paths for magnetite:
        - Bottom currents
        - Iceberg discharges
- XRF shows drop in Ca and K, Si increase (60%)
    - Marine shift to Terrestrial

Magnetic Particle Analysis

- 2G-Enterprises Model 755 cryogenic magnetometer
- u-channels: u shaped sample collection of center of core section
- Measured at 2cm intervals
  - ARM/IRM Anhysteretic Remnant Magnetization/Isothermal RM
  - ARM/k (k = volumetric magnetic susceptibility)
  - Hcr/Hc
  - Mrs/Ms
- Measures magnetic variations as small as 1e-8 A/m
  - good permanent magnet can be on the order of 10^6 A/m
- Purpose:
  - Intensity and orientation of Earth's magnetic field at deposition
  - Concentration, grain size, mineralogy
    - used here to imply source

http://paleomag.uqar.ca/spip.php?article47

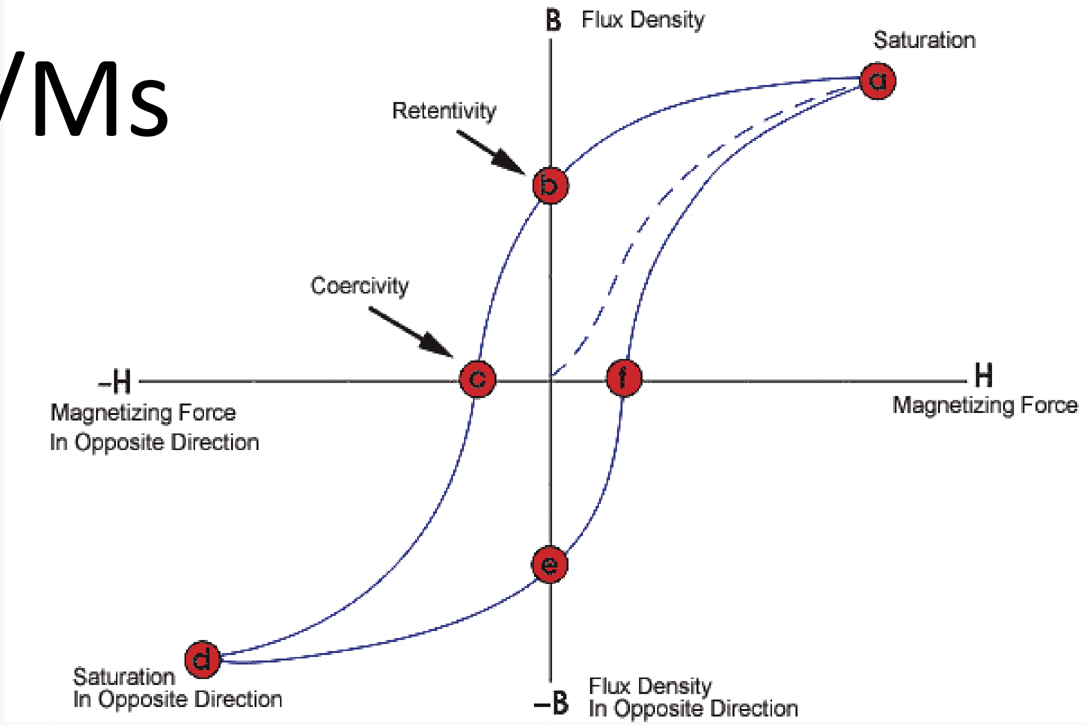
RM type interpretation

- ARM: indicates fine grained magnetic material (20-100nm magnetite)
- IRM: affects all particles that can hold a magnetic remanence
  - ratio is a proxy for fine grained material to total concentration

- Results compromised by:
  - Compaction, slumping, turbidity currents, bioturbation, dewatering

Hcr/Hc vs. Mrs/Ms

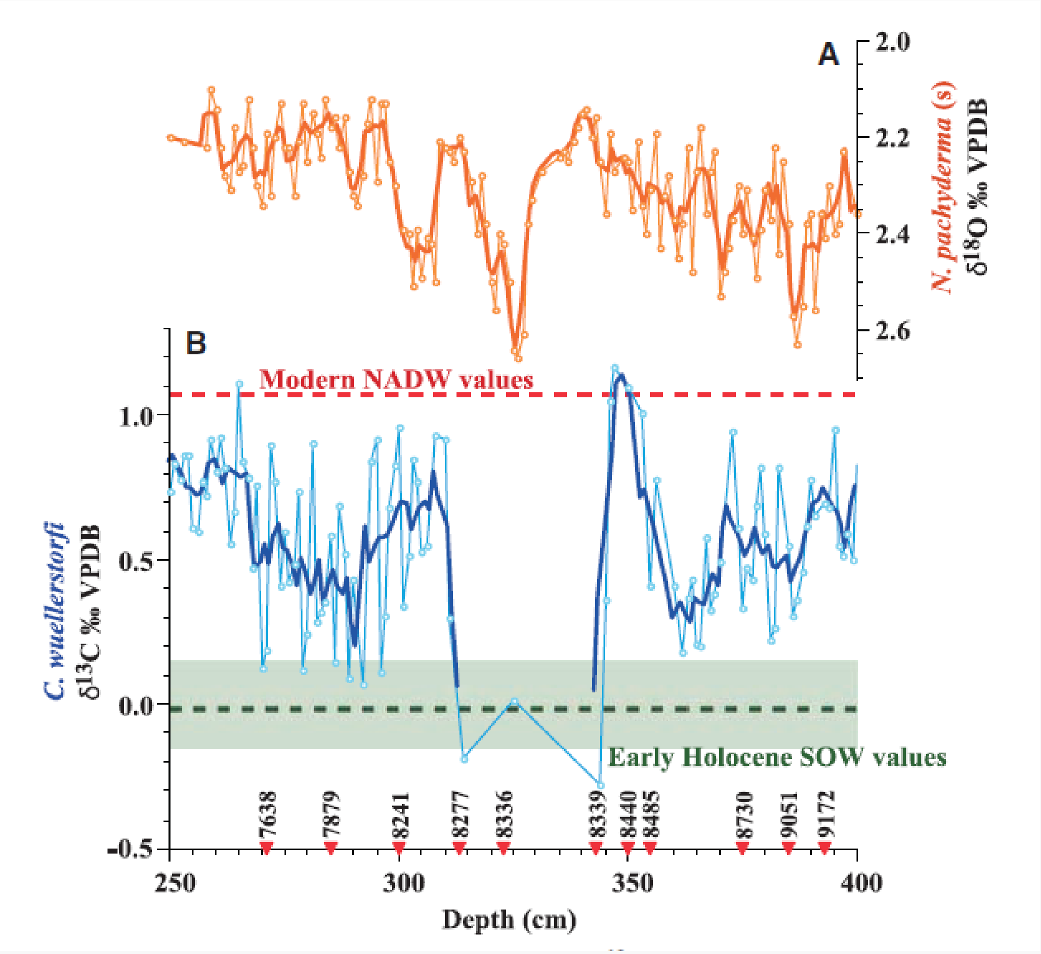
- M_{rs}: Saturation remanence
- M_s: Saturation magnetization
- H_{cr}: Remanent coercive force
- H_c: ordinary coercive force



http://www.ndt-ed.org/EducationResources/CommunityCollege/MagParticle/Physics/HysteresisLoop.htm

- Used to distinguish domain state
  - Implies grain size
    - only one mineral compared
    - must have mineral composition

Surface Ocean Response

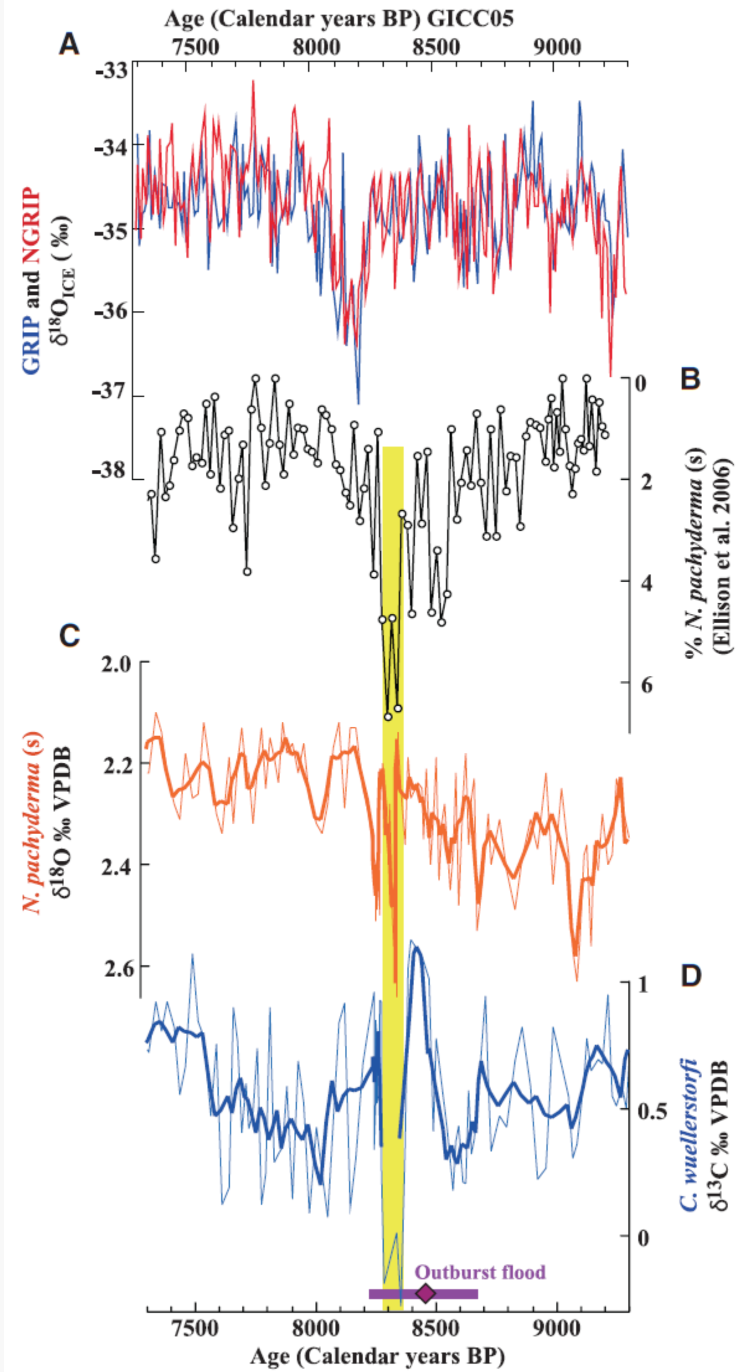


(Kleiven et al, 2008)

- MOC weakened in model experiments
- Near surface cooling of ~1.5 °C
- Delayed response in planktonic del ^{18}O to outburst events indicates two possibilities
  - Freshwater dampens the effects
  - or delay in cooling was a reality

Absent Lower North Atlantic Deep Water

- Relationship of Greenland ice cores and NADW core are within dating uncertainties
- Proposed that this core site saw a shorter change in ocean currents than is seen in other currents cores and reflected in the Greenland ice core



(Kleiven et al, 2008)

Conclusions (Flesche Kleiven)

- Ocean cores reflect a change in geochemistry consistent with the records of the 8.2ky B.P. cooling event
- Reduced influence of low-nutrient LNADW between 8.38 to 8.27ky B.P. suggests a reduction in the MOC
  - Lasted ~100yrs at core site
- Surface oceans cooled ~1.5°C based on planktonic foraminiferal ^{18}O
- Ocean overturning circulation can change rapid enough to affect abrupt climate change events

Questions?

Movie Time

http://www.skepticalscience.com/Jerry-Mitrovica-Current-Sea-Level-Rise-is-Anomalous-Weve-Seen-Nothing-like-it-for-the-last-10000-Years.html#.UHdPCsklICE.gmail

Marine Reservoir Correction

- Radiocarbon ages appear to be several hundred years older than terrestrial samples
  - due to large carbon reservoir of ocean
  - corrections needed
    - varies depending on location
- Difference between region and average global marine reservoir correction (ΔR)
- CALIB or OxCal calibration Software