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

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

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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

- 12 kyr B.P. to 7 kyr B.P.
- \( \frac{1}{2} \) of global sea-level rise occurs (50-60m)
- >1 cm yr\(^{-1}\)
- Constant sea level rise punctuated by several rapid rise events
  - Meltwater pulse 1A, 1B
  - 14 ka, 11.3 ka

(Bard et al., 2010)
Links between early Holocene ice-sheet decay, sea-level rise and abrupt climate change

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

(Tornqvist and Hijma, 2012)
Lake Agassiz outlet direction changed over time

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)

(Teller et al., 2002)
## Multiple Outburst floods

### Table 1

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

$^a$ 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 $3.3 \pm 1.1 \degree$ 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
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%)
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

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

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

- 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

(Kleiven et al, 2008)
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

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 ($\Delta R$)
- CALIB or OxCal calibration Software