Impact of High-Amplitude Climatic Change in the Great Lakes: Implications for Climate-Hydrology Sensitivity

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Research Question

Objective: Increase understanding of the Great Lakes' sensitivity to climate change.

Hypothesis: Major changes in lake levels that result in closed low stands are caused primarily by climatic processes.

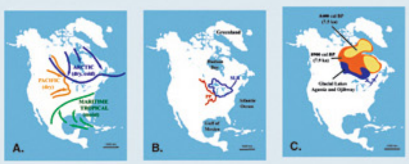
Approach

1. Corroborate and test Great Lakes closed lowstands. Seismic data and core studies will identify the target time interval, both from large and small lakes using paleomagnetic and AMS ^{14}C methods.
2. Evaluate paleoclimatic change for the interval spanning the closed lowstands using multi-proxy data from the Great Lakes and small lakes in the Great Lakes watershed. Both a transfer function approach and isotope studies will be used.
3. Evaluate sensitivity of lake levels to high-amplitude climate change using numerical paleohydrological modeling in association with the Great Lakes Environmental Research Laboratory at NOAA.

Background

Previous reconstructions of late-glacial and post-glacial lake phases in the Great Lakes have attributed major changes in lake levels to non-climatic processes (e.g. isostatic rebound or outlet elevation change). New data indicate that early-middle Holocene lake closure events that could only have been forced by abrupt periods of severe dry climate occur in the Great Lakes. These events markedly contrast with relatively small changes in lake levels recorded within the last two centuries. Knowledge of high-amplitude rapid hydrological change is important as some scenarios of future climate driven by global warming suggest that lake-level reductions below presently-known variability may be possible in the Great Lakes watershed.

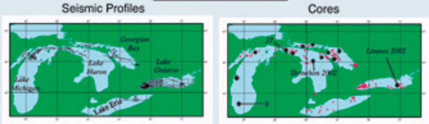
We hypothesize that the lakes were first driven below their outlets after 9000 cal BP (8 ka) by the effect of enhanced southward incursions of dry Arctic air during late deglaciation in Hudson Bay. Subsequently, atmospheric circulation shifted about 8200 cal BP, and eastward flows of warm-dry Pacific air intensified. The latter shift is reflected in the eastward expansion of prairie vegetation in the southern Great Lakes. This effect may have delayed recovery of lakes Michigan and Huron from closed status until about 7800 cal BP (7 ka). These closed-lake events provide a useful example of past high-amplitude climate-hydrology variation because the hydrology of the Great Lakes basin had already entered its present non-glacial state.



A. Present-day distribution of airstreams (5-month dominance) over North America (adapted from Bryson, 1966; Bryson and Hare, 1974).
B. Shows Great Lakes (inside blue line) and their drainage basin (blue line), outflowing St. Lawrence River (SLR), present Prairie Peninsula vegetation zone (PP).
C. Location of the Laurentide ice sheet about 8900 cal BP (7.9 ka - orange shading) and 8400 cal BP (7.5 ka - yellow shading) (outline from Barber, et al., 1999; A. F. Dyke, pers. comm., 2002). Note that drainage from proglacial lakes Agassiz and Ojibway (blue shading) after 8 ka bypassed the Great Lakes basin, discharging via Ottawa and St. Lawrence rivers to Atlantic Ocean (blue arrows show direction of flow).

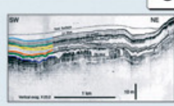
Data Sources

Seismic Profiles | Cores



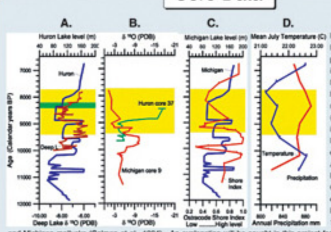
Locations of archived seismic profiles (sediment cores are located on profile tracks) collected since 1991 in all the Great Lakes except Lake Superior. Black dots indicate cores selected for detailed analysis in the target study interval of 9400-7700 cal BP for delineation of basin conditions, and comparison with master core 37.

Seismic Data



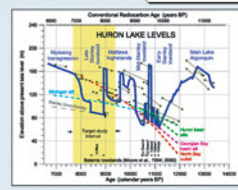
High-resolution seismic profile from northern Lake Huron shows lake-wide reflectors (color-named) which truncate underlying reflectors in shallow waters. The lake-wide reflectors are seismo-stratigraphic sequence boundaries, and are associated with coarser sediment deposited during times of lower lake level. The uppermost reflector (light blue) corresponds to the Lake Stanley lowstand shown in graph at right (from Moore, et al., 1994).

Core Data



History of variations of lake levels and selected parameters, with target study interval depicted in yellow. A) Note correlation of lowest Huron water levels and most negative $\delta^{18}O$ in Deep Lake (Hu et al., 1999). Green bar indicates similarity in timing of lowest Huron levels, final drainage of proglacial lakes Agassiz and Ojibway to Hudson Bay, and 8.2 cal ka Greenland cool event (Barber et al., 1999). B) $\delta^{18}O$ ratios in Huron ostracodes (Rea et al., 1994a; Dettman et al., 1995) and Michigan mollusks (Colman et al., 1994). An explanation will be sought in this project for the much larger shift (about 4-fold greater) to depleted $\delta^{18}O$ in Huron basin compared with Michigan basin at 8900 cal BP. C) Similarity in changes of lake levels and an ostracode shore index (with lag) (adapted from Forester et al., 1994) is indicated in the Michigan basin for the target study interval (yellow). D) Mean July temperature and mean annual precipitation derived by transfer functions from pollen content at Volo Bog (Bartlein et al., 1984) suggest increased evaporation and reduced water supply for southern Lake Michigan about 7800 cal B.P. Present values are 22.4°C and 933 mm.

Lake Level



Paleo-lake levels (thick blue line) in the Huron basin (adapted from Anderson and Lewis, 2002). Within the target time interval of this study (9400-7700 cal BP), the water level was below the lowest possible basin overflow route (dashed red line marked North Bay outlet) from ca. 8900-7800 cal BP. The lake was hydrologically closed, drawn down by a climatic shift to a drier regime with more evaporation and/ or less precipitation and runoff. In this plot of elevation vs age, radiocarbon-dated lake level indicators (olive-colored symbols and lines showing one-sigma uncertainty) and overflow outlets (colored dashed lines) have been reconstructed by removing the effects of differential glacial shown at their original altitudes. The symbols indicate the type of indicator: right-pointing triangles represent isolation basins from which the large lake has regressed; left-pointing triangles represent basins which the lake has transgressed and inundated; circles represent water level at a delta or beach; downward-pointing triangles represent in situ tree stumps requiring a lake level below their root elevations (see below). The lake level indicators are compiled and described in Lewis and Anderson (1989), Lewis et al. (1994) and Blasco et al. (1997). Seismic lowstands are low lake levels identified by seismo-stratigraphic sequence boundaries in seismic profiles as at left (Moore et al., 1994; 2000). Stanley unconformity is a sedimentary erosional discontinuity in northwestern Lake Huron indicating low lake levels (Hough, 1962; Lewis et al., 1994), believed to be correlative with the Flowerpot (F) beach now submerged 53 m beneath Georgian Bay (Blasco, 2001).

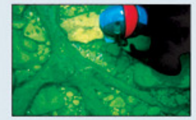
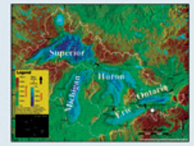
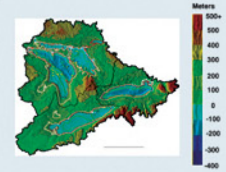


Photo showing a SCUBA diver and a submerged tree stump rooted in growth position. This is one of 7 such stumps, radiocarbon dated between 7320 and 9360 BP, found in water depths between 3 m and 43 m on the sill at the entrance to Georgian Bay. (From Blasco et al., 1997.)





A - (LEFT). Modern Great Lakes watershed.
B - (RIGHT) Closed lakes at 7.6 ka. Possible shorelines of the closed lowstands are shown in yellow, well offshore from the potential open lake shorelines at 7.6 ka (red) and present shorelines (white). Topography and bathymetry digitally reconstructed from (A) by removing effects of differential glacial rebound using GIS data processing, a capability available to this project (Gareau et al., 2000).

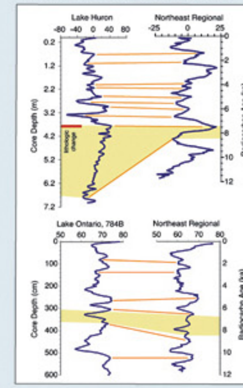
Dating Techniques

- AMS ^{14}C methods
- Correlation of paleomagnetic directional records to the radiocarbon-dated regional geomagnetic secular variation curves shown below.

Stratigraphic Framework

Application of Northeastern United States Secular Variation (King and Peck, 2001):

Our approach will be to study secular variation of new and existing cores, and to correlate these cores to the regional secular variation records to identify the interval of interest (8.4 - 6.8 ka) as shown below on two recently aquired cores. Yellow shading highlights area of interest. Detailed climate proxy studies and AMS 14C dating will then be done on samples obtained from the interval of interest.



Lake Huron (Manitoulin Basin): Shenehon 2002 Declination (°)

Declination record for Lake Huron, compared to the Northeastern United States declination secular variation record. The inclination correlation (not shown) confirms the declination correlation. This correlation is also confirmed by the position of a lithostratigraphic change dated at 7.6 ka by Rea, et al. (1994), and Dobson, et al., (1995), shown by the red line. This change is located at a depth of 3.71 meters.

Lake Ontario: Limnos 2002 Inclination (°)

Inclination record for Lake Ontario, compared to the Northeastern United States inclination secular variation record. The declination correlation (not shown) confirms the inclination correlation. This correlation is also confirmed by previous secular variation studies of Lake Ontario sediments by Pippert, 1994. The converging tie lines toward the 280-320 cm interval of core 784B indicate a reduction in sediment accumulation rate, possibly a result of lowered lake level.

Conclusions

Our approach to building the chronostratigrahic framework using geomagnetic secular variation studies appears to be sound. Preliminary results suggest that closed-basin status in the eastern Great Lakes region occurred within the 8.4 - 6.8 ka interval. Additional studies of the sensitivity of the Great Lakes water levels to climate change are needed because of the profound societal implications of possible significant lake level lowering that could result from predicted global warming scenarios.