

# 1 Abstract

The ground surface underlying the Laurentian Great Lakes is currently undergoing vertical adjustment after being depressed by the weight of an ice sheet formed in the most recent glacial period. The rate of glacial isostatic adjustment (GIA) varies by location, and exerts a significant control on the flow of water in the Laurentian Great Lakes as the inclination of the ground surface changes. In order to predict the future movement in this area, the rate of GIA must be inferred from measurements of the water level in the geological record. These measurements are made by measuring the elevation of a subsurface sedimentary contact relating to past lake levels, which are then age dated with optically stimulated luminescence (OSL) to provide an age value of sediments. Elevation and age data are then compiled to create site paleohydrographs per lake basin.

The focus of this paper is to analyze this data by measuring the relative difference in water levels between study sites, comparing differences in relative water levels to create a plot of relative elevation over time. Once this is done, the rate of change per unit time is obtained from a linear regression, representing an estimate of the value of GIA between each pair of sites. (This is done for all possible combinations of the four sites used, Grand Traverse Bay (GTB), Au Train Bay (ATB), Batchawana Bay (BATB), and Tahquamenon Bay (TAHB).

The results of this process were a strong agreement of 95% confidence intervals on GIA rates obtained from forward and reverse regressions for the combination of ATB-BATB (23.5 to 31 cm/century) and BATB-TAHB (11 to 17 cm/century). Agreement was also seen for GTB-TAHB (anywhere from -3 to 8.5 cm/century), ATB-GTB (9 to 13 cm/century), ATB-TAHB (19.5 to 29 cm/century), and BATB-TAHB (11 to 17 cm/century).

(LGL)

, the Wisconsinan.

an influence

the LGL

What about water level gauges? (Add please)

Also please add context, require long term data to best record long term process.

for any study site

Add text to explain what "this" is referring to.

repeat

95%? or something different?

not the same?

This part needs clarification. Please describe better.

Have to add description that includes "unequally spaced data" - in your title. You propose a method to calculate GIA between study sites using measured and interpolated data between linearly data points.

interpreted from sediments that formed at similar time periods

difference in

the surrounding Lake Superior, namely

## 2 Introduction

The Earth's crust rests on top of the mantle, its elevation rising and falling with the amount of mass weighing on it. During glacial periods, a significant portion of the water on earth is transferred in form from water in the oceans to glacial ice, weighing down the continental crust. This causes the crust to ride lower in elevation, a change which is quickly reversed when the weight is removed as the ice sheets melt. This vertical motion of the crust while returning to its previous position is known as glacial isostatic adjustment (GIA).

This process of isostatic rebound has implications for the routes that the flow of water on the Earth's surface takes; the "tilting" of the surface caused by uneven rates of GIA in different locations may open or close locations along basins, causing some rivers and lake outlets to close, while potentially opening others. Additionally, the change in "tilt" has potential to change shorelines of existing basins, which has implications for property assessment and long term engineering projections for structures such as locks and dams.

? which one's?  
Needs explanation

Need to mention highest rates in areas where glacial ice was thickest & longest lasting.

Low so?  
Long-term relative movement of the ground surface due to GIA is much longer than property assessments.

Yes, that are built to last over several decades ~~even~~ (i.e. 20-50 years)  
Impact - location & maintenance of infrastructure.

Need to add something about the LGL's <sup>Laurentide</sup> ice sheet oscillated across LGL's many times helping to sculpt the lake basins through (erosion & deposition) ...

Use references:

Karrow & Galkin (1985) Geological Association of Canada Special Paper 351  
Larson & Schaetzl (2001) Journal of Great Lakes Research, 27 518-546.

And mention - GIA has been identified as one of the top 3 factors contributing to water level change but long term rates of GIA are difficult to estimate without long term data.

International Upper Great Lakes Study (International Joint Commission) (2009 & 2012)  
Reference.



Need to show figures  $\leftarrow$  individual gauge data in map  
 And describe these  $\rightarrow$  merged gauge & model data  $\rightarrow$  pattern & rates?  $\leftarrow$  Genes for LGLT  
 And then pattern & rates for Lake Superior.

## 2.1 Previous Work

Mainville & Craymer (2005) used water gauge data collected around the Great Lakes over the past 150 years to create monthly means of water level. Differences in these values between sites would then be plotted against time to get a rate of elevation change between sites over time (ie GIA). However, combinations of sites were shown to produce inconsistent results, so a second method using a least squares adjustment process was used, iteratively removing some monthly mean outliers which fell some arbitrary residual distance or farther from the linear regression line until none remained "too far away" from the final regression. A third, and ultimately best method was developed by Mainville & Craymer (2005) by using the original method of directly comparing monthly water level means, but applying adjustments for the epoch, site, and month of each monthly water mean when subtracting between sites. Their findings showed better agreement with the ICE-3G global model of GIA than ICE-4G (Mainville & Craymer, 2005).

This calculated value is interpreted to represent GIA, a long-term process or adjustment of the crustal mantle from the weight of the Laurentide Ice Sheet.

Poor grammar - please reward.

- To calculate GIA

Johnston et al. (2012) attempted to refine previous estimates made using water gauge data by using data over a much longer timescale. In this method, water levels were inferred from the elevation of beach deposits from the late Holocene sediment record around Lake Superior, the ages for each data point measured by dating samples from these beach deposits (known as strandplain sequences) with Optically Stimulated Luminescence (OSL) age dating. This data differed from that used by Mainville & Craymer in that data collected did not have elevations sampled at the same points in time for calculation of relative rates. As a result, the elevation vs time data was modelled with a linear regression for each site, the difference in slopes representing the GIA rate between sites (Johnston et al, 2012). In a later 2014 paper, Johnston et al. attempted to refine the method by adjusting the model of each site upward or downwards with common lake level lows and highs observed in the other sites (Johnston et al, 2014).

used relict shorelines on beach ridge strandplains to estimate rates of GIA

5000 years in Lake Superior,

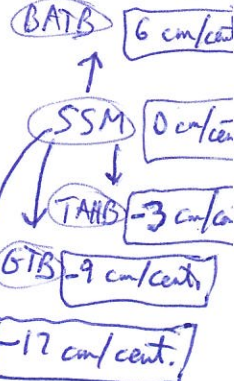
inferred from using of these beach deposits. Now, need to state the number that Johnston et al. (2012) report.

In order to project the future impact of this process on the Great Lakes Basin, an estimate of the historical rate of GIA is needed. This estimate is obtained by comparing the elevation of the water mark at two different locations around a basin, and observing how this difference changes over time. The elevation of the water can be inferred by a variety of indicators in the sediment record, in this case, beach deposits known as strandplain sequences are used, their ages determined by optically stimulated luminescence (OSL) dating. This raw data is presented in Figure 1.

GIA - long term

LGL

GIA relative to outlet at Sault Ste. Marie (SSM)



But you are focusing on Lake Superior.

All rates of GIA were similar to Mainville & Craymer (2005) except between (SSM-outlet) & (ATB)

Johnston et al (2012) = -17 cm/cent  
 Mainville & Craymer (2005) = -12 cm/cent

Did you get close to these?

Explain in Discussion section but it's present here.

Need to improve explanation

Please improve grammar here

Modelled linear rate in 4 time periods or phases:

- Sault
- Algoma (most sites)
- Sub-Sault
- Nipissing

Calc. Difference between linear rates between sites. Explain.

No, Johnston et al (2014) summarized more than two decades of research creating paleohydrographs & preliminary compared ~~basin wide~~ paleohydrographs from Lakes Michigan, Baedke & Thompson (2000) Journal of Great Lakes Research 26(4): 416-426, and Superior (Johnston et al. 2012).