Observing Glacial Rebound Using GPS

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Glacial Isostatic Adjustment (GIA)

GIA is the earth's response to the removal of the great ice sheets

Last glacial maximum 18,000 yrs ago

Since then, ice melted back

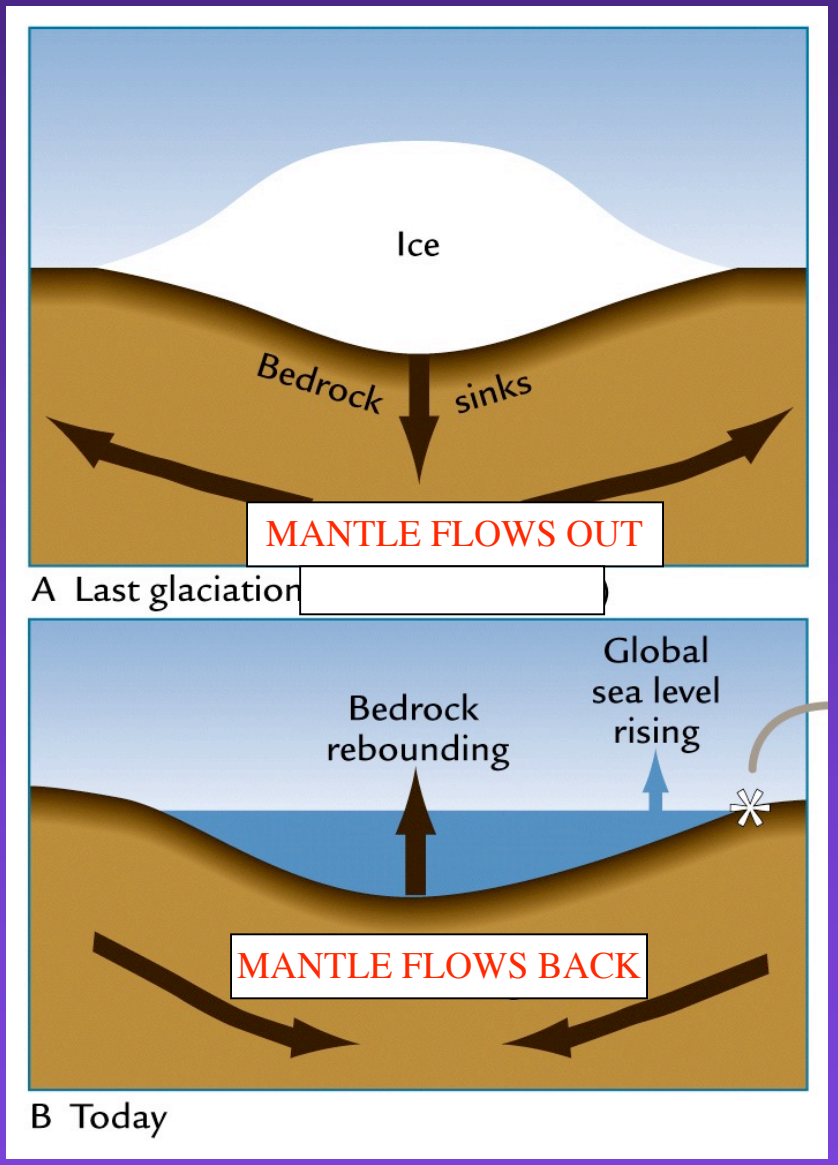
http://jesse.usra.edu/archive/jesse01-300-01/

Why Motion Today?

Small motions resulting from "post-glacial rebound" stem from the fact that the mantle below the earth's crust flows like a super-viscous fluid -- much, much stickier than road tar or maple syrup.

The mantle is still flowing to fill areas underneath the places where the heavy ice sheets pushed out the mantle 18,000 years ago.

GPS can detect motions as small as 1 mm or 1/25 of an inch per year.



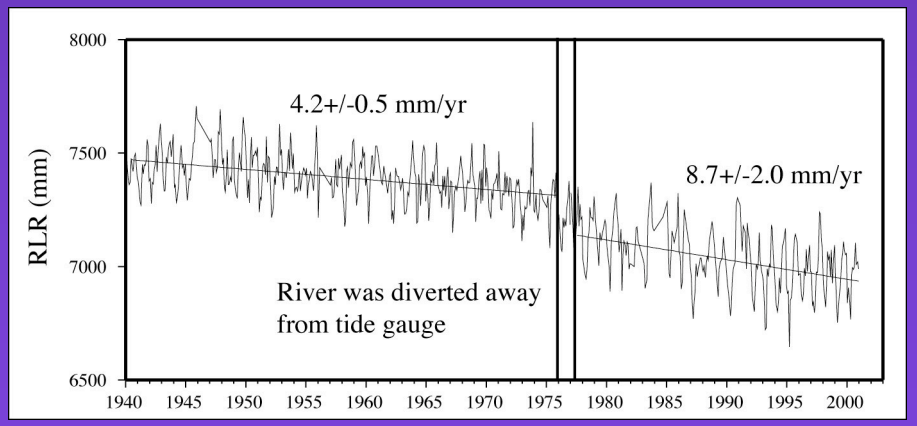
Other Constraints on GIA in North America

Raised Beaches

Successive beaches left as fossil shorelines, recording uplift history

Tide Gauges

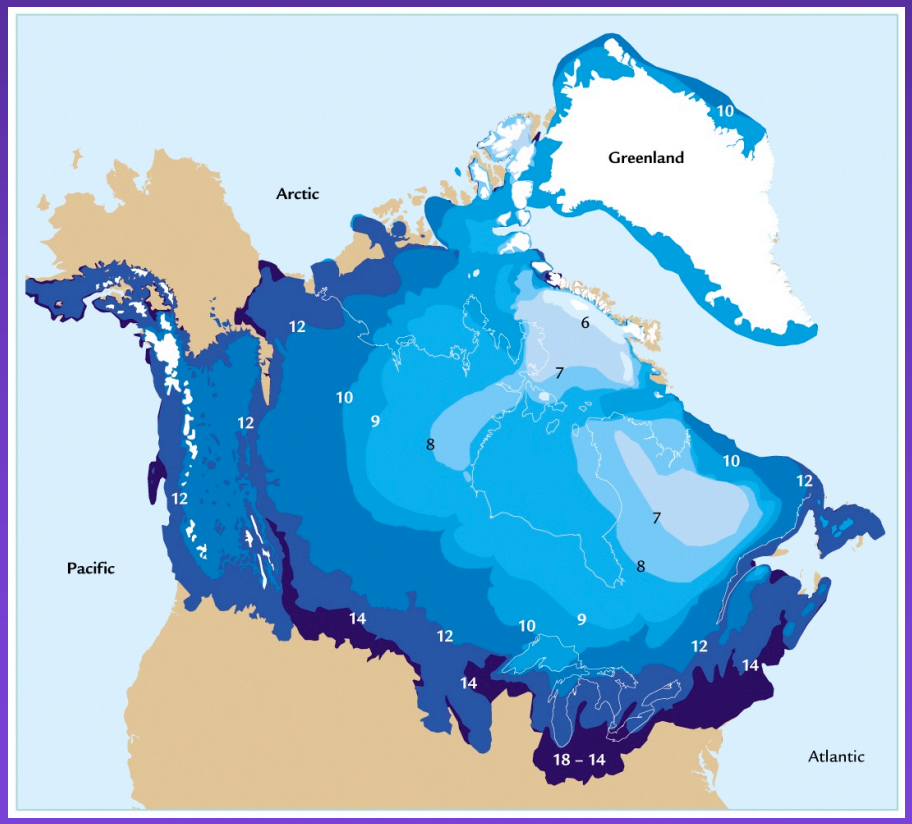
Tide gauge at Churchill shows land rising today



Within 1,500 km of Hudson Bay only 1 T. G.

Why study GIA ? - Climate

Studies give insight into ice ages & climate, the nature of the earth's interior, and perhaps earthquakes within North America



Extent of ice sheets can be measured

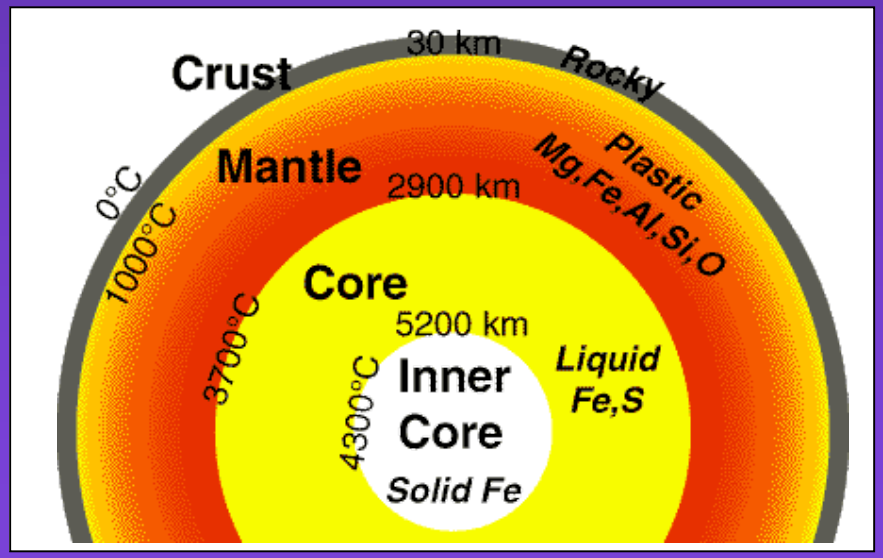
Thickness of ice sheets estimated from relative sea level curves and water volume budgets

Volume of ice 25-34 M km^3 equivalent to 50-70m sea level change

Ice thickness history poorly known

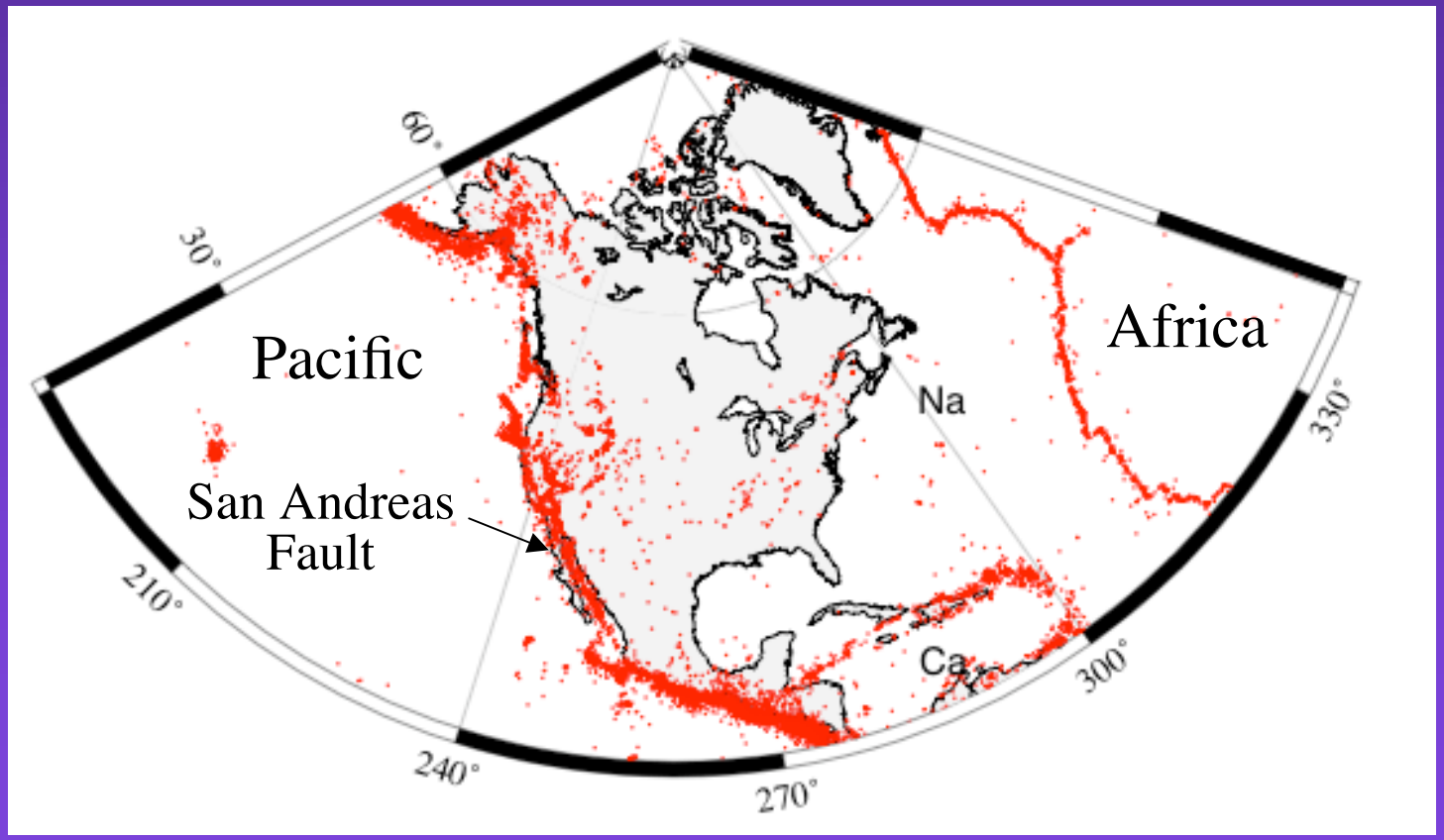
Why study GIA ? - Earth's interior

- Measuring GIA yields an estimate of the viscosity (gooeyness) of the earth's mantle, and how it varies with depth and from place to place
- Viscosity gives insight into the temperature and composition of the earth, and hence how our planet evolved



Why study GIA ? - Earthquakes

- GIA may be cause of some earthquakes within plate interiors
- Most earthquakes happen on boundaries between plates
- Unclear what causes the others
- GIA has long been suspected as one possible cause

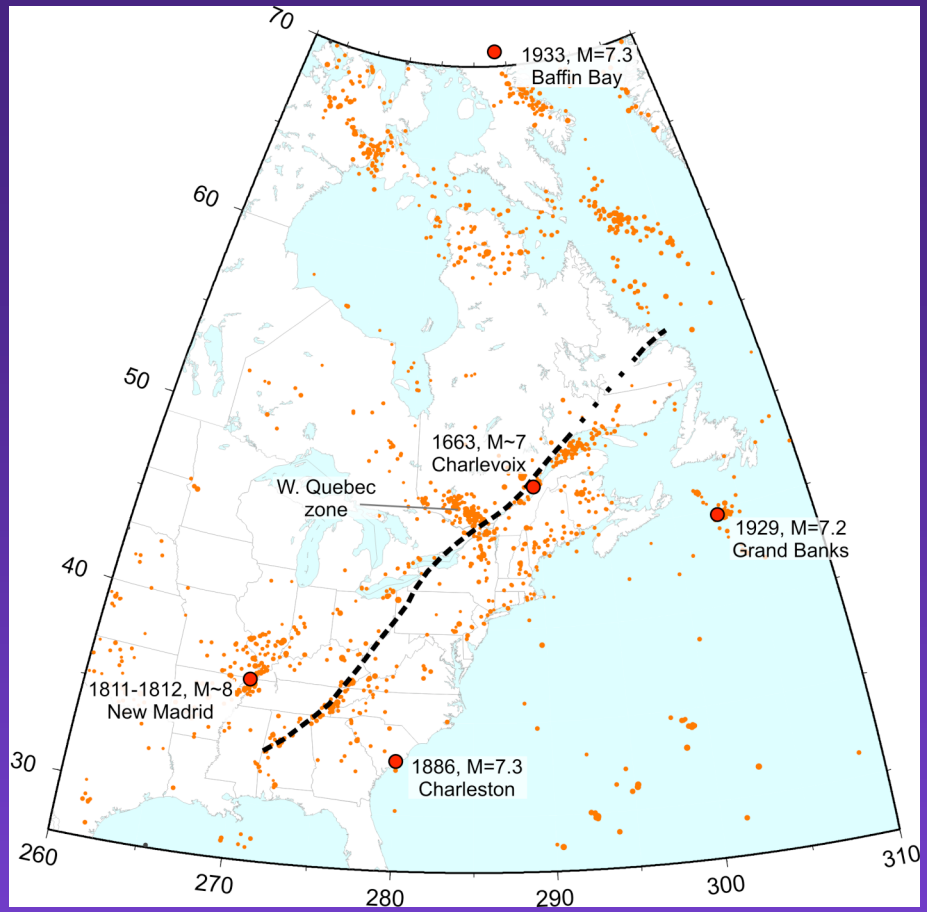


Why study GIA ? - Earthquakes

GIA may be cause of some earthquakes within plate interiors:

Stein et al [1979] - coasts of Atlantic Canada, NE US
Stein et al [1989] - other glaciated coasts (Greenland, Beaufort Sea, Norway)
James & Bent [1994]; Wu & Johnston [2000] - St. Lawrence Valley
Grollimund and Zoback [2001] – New Madrid

Hard to tell how significant an effect this might be until we know how large GIA motions are



Damage from 1929 Grand Banks, Newfoundland M 7.2 earthquake (tsunami caused 27 deaths)

Why Space Geodesy* - GPS ?

See what's happening NOW

Simple

Go to a point, measure position with space technology

Wait

Remeasure position

Calculate velocity (repeat earlier step as needed/funded)

Cheap and mobile

In many cases, a permanent GPS site does this daily

Compare results to independent geologic data

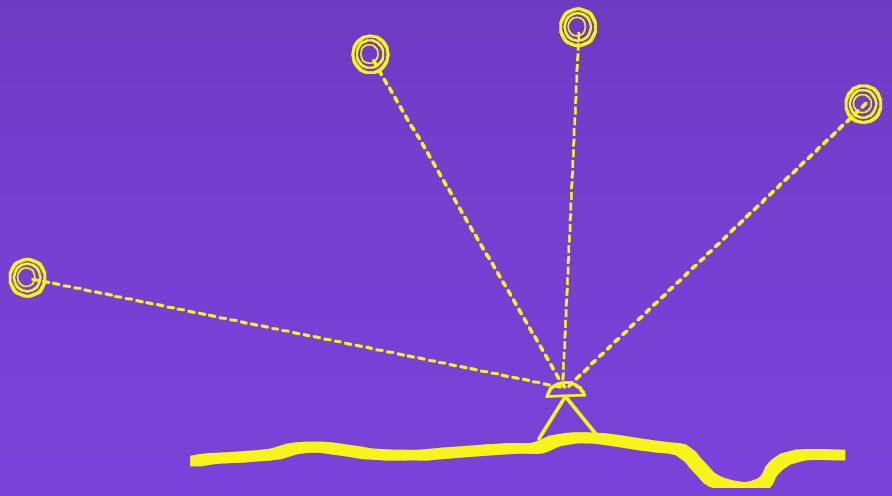
*** Geodesy - science of the earth's shape (surveying)**

Global Positioning System

24 Satellites
5-8 overhead most of the world

Measuring distances and triangulating

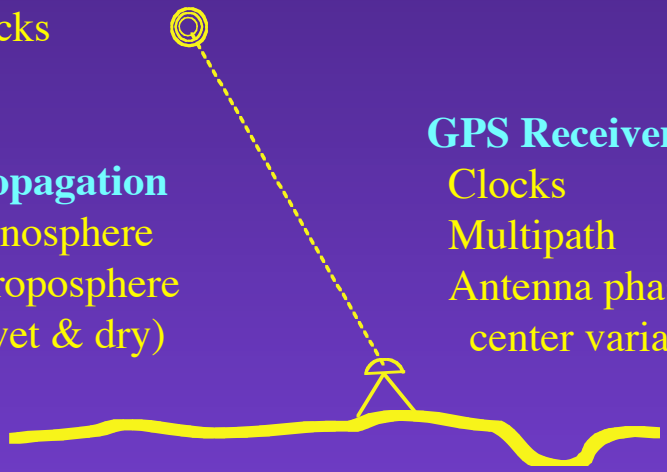
3 satellites unique position
4 satellite necessary to correct receiver clock errors



GPS Satellite
Orbits
Clocks

Propagation
Ionosphere
Troposphere
(wet & dry)

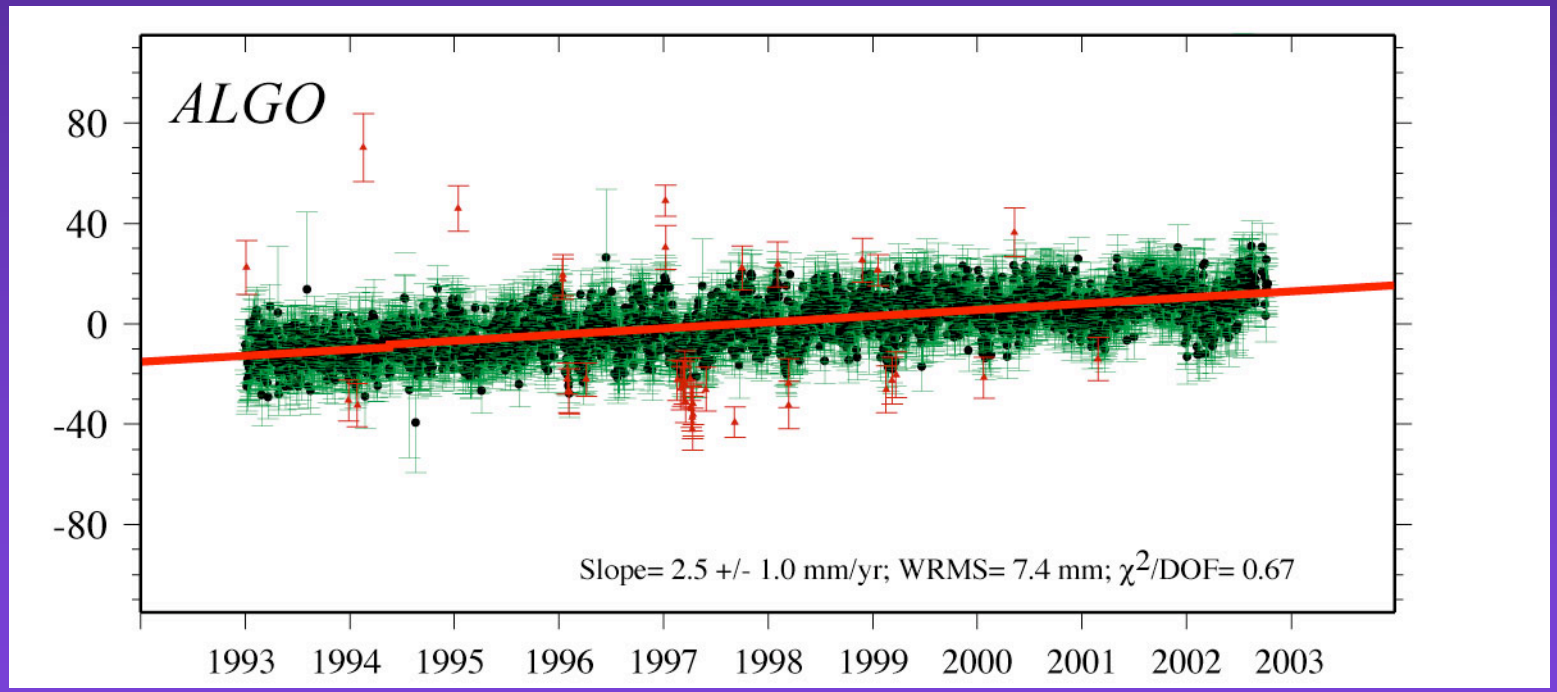
GPS Receiver
Clocks
Multipath
Antenna phase center variation



3-D Crustal Motion
Tectonic motion
Ocean tides
Solid earth tides
Subsidence
Glacial isostatic adjustment
Monument stability

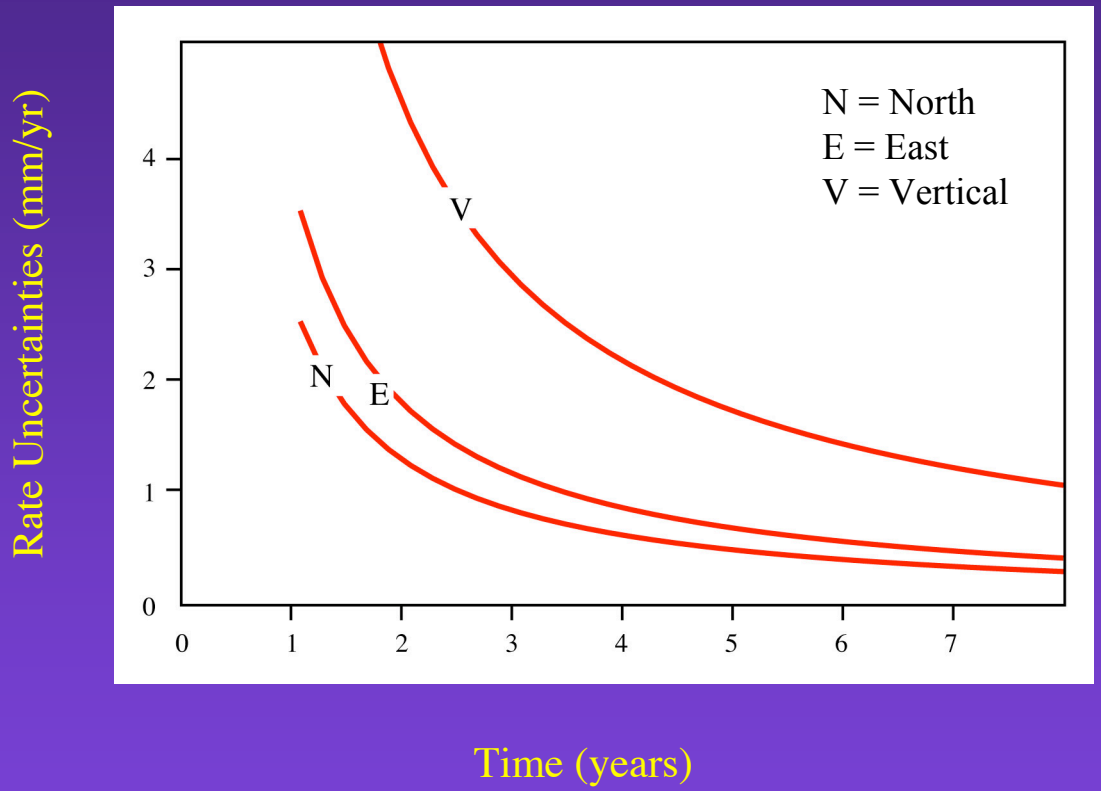
Accuracy of GPS velocities

Precision of GPS velocity estimates increases over time by fitting a weighted least squares line to daily positions



The velocity error for this time series is only 1 mm/yr

Uncertainties decrease with length of measurements

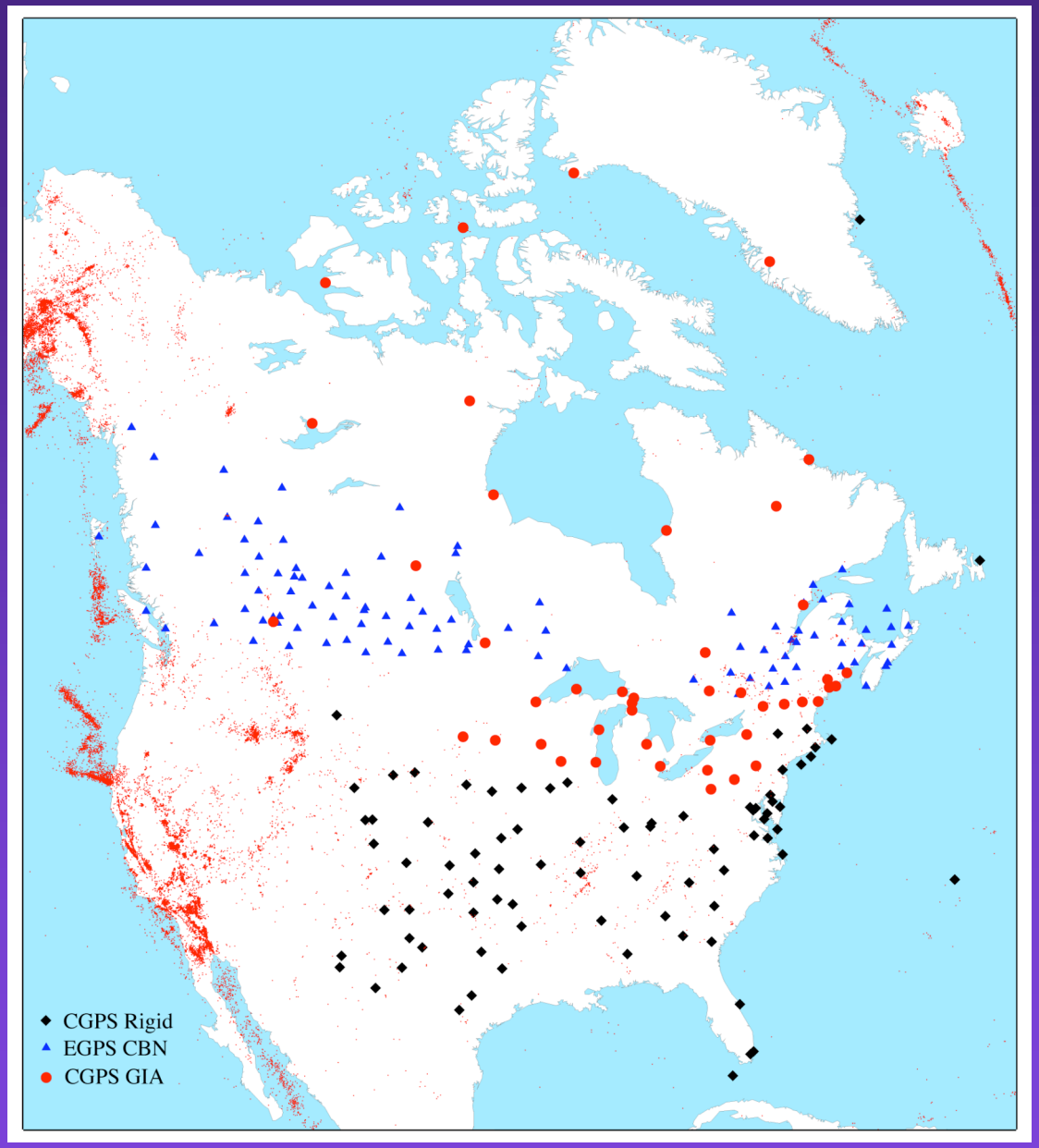


GPS Sites

Continuously operating sites in Canada (NRCan) and US (National Geodetic Survey and other agencies)

Critical constraints provided by episodically occupied sites in Canada (NRCan Canadian Base Network)

Network installed primarily for survey control purposes, but also provides unparalleled new tool for basic science

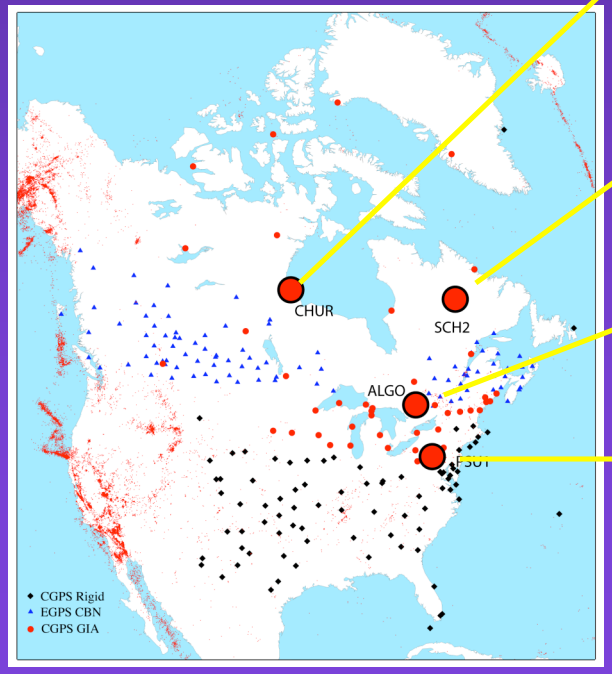


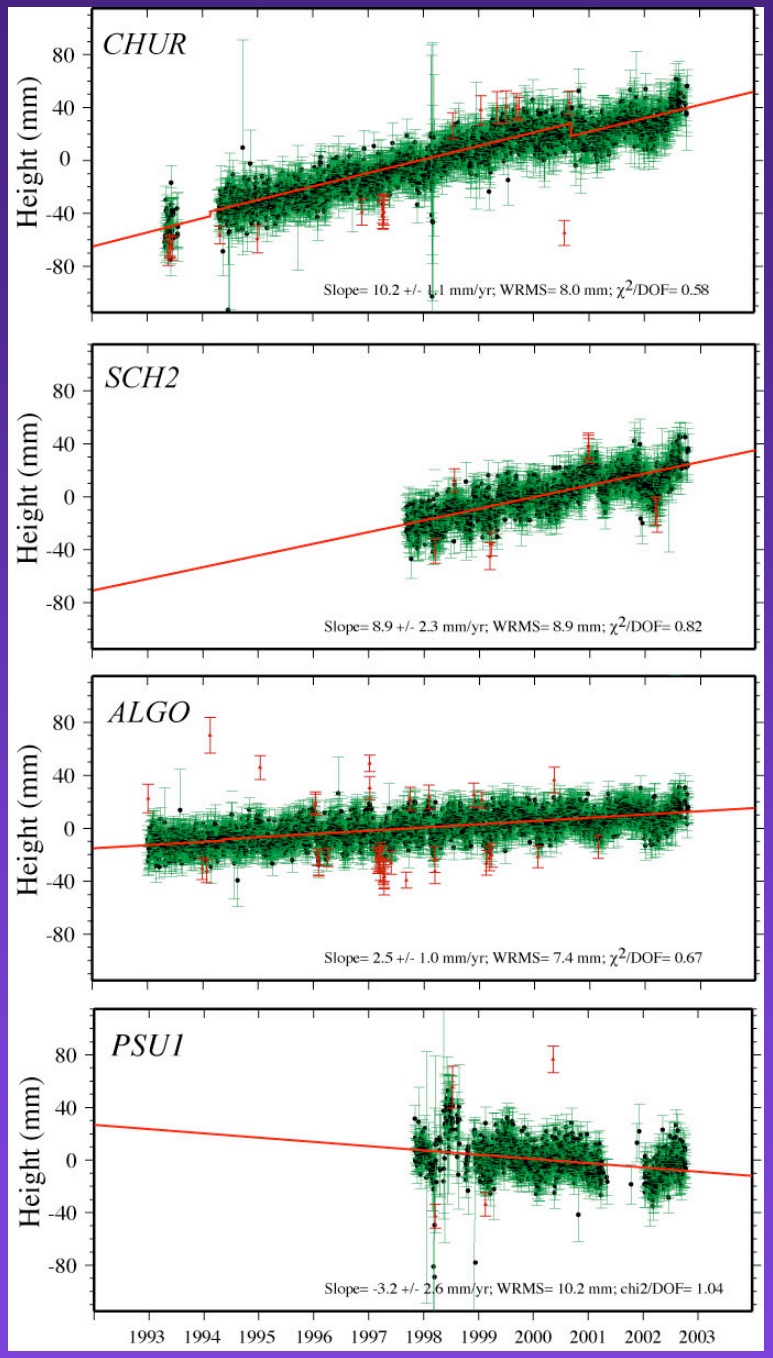
Detecting GIA using GPS

GPS vertical velocities

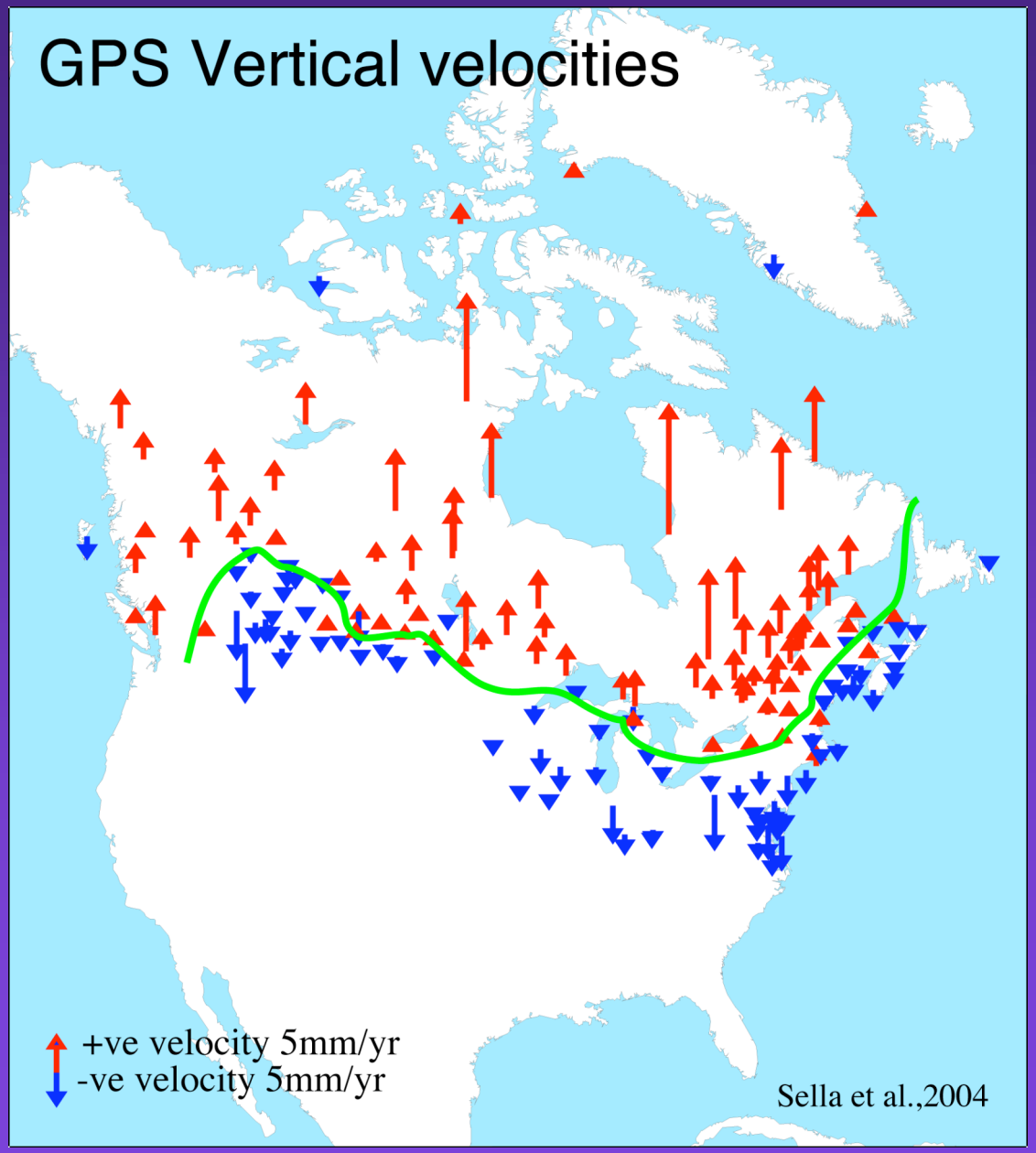
UPLIFT

SUBSIDENCE



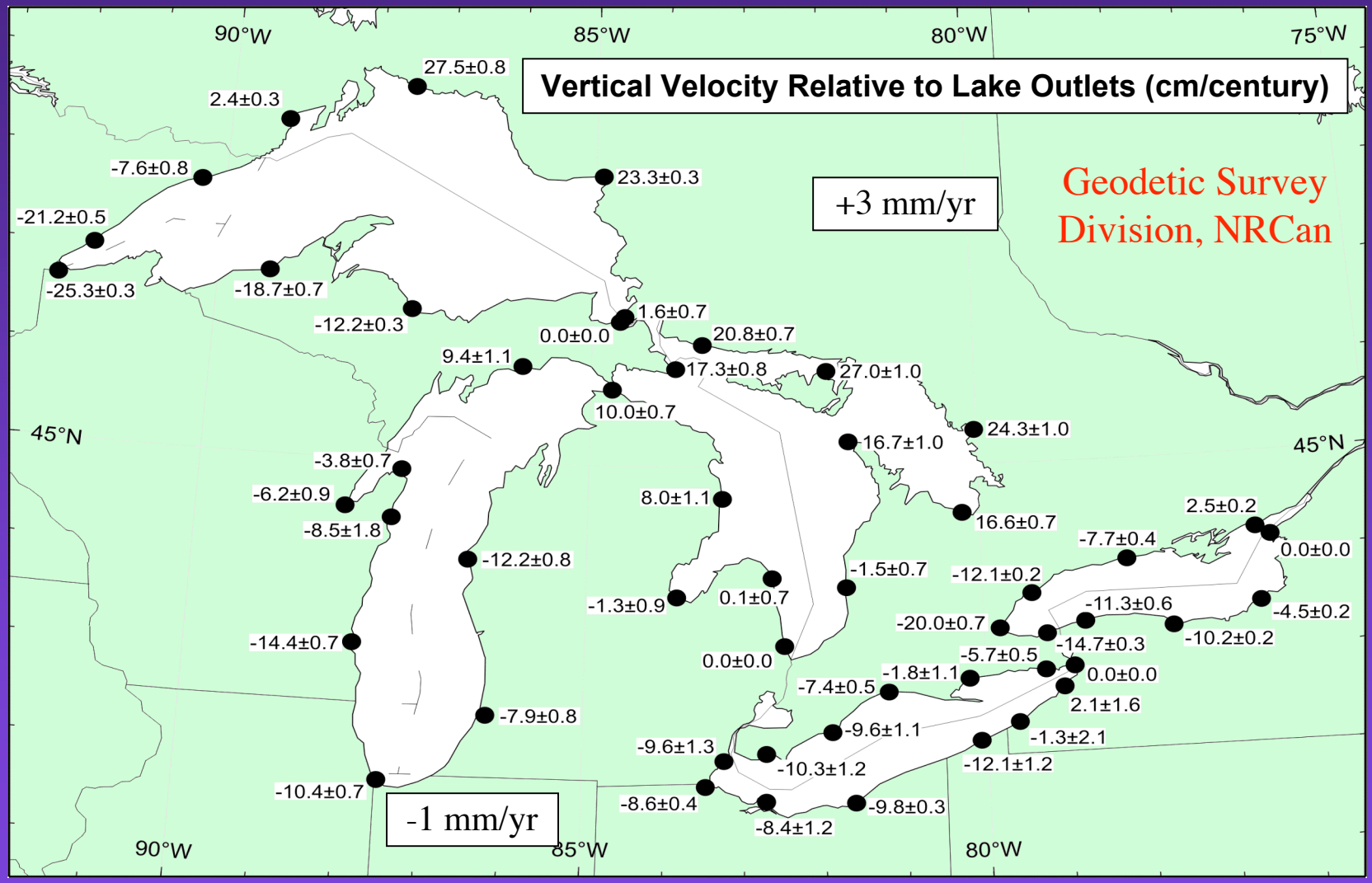


GPS Observed Vertical Velocities



Clear pattern of positive velocities in and around Hudson Bay that decreases going southwards to zero (hinge line), beyond which velocities are initially negative and then rise to near zero

Great Lakes Water Gauges Show Same Pattern

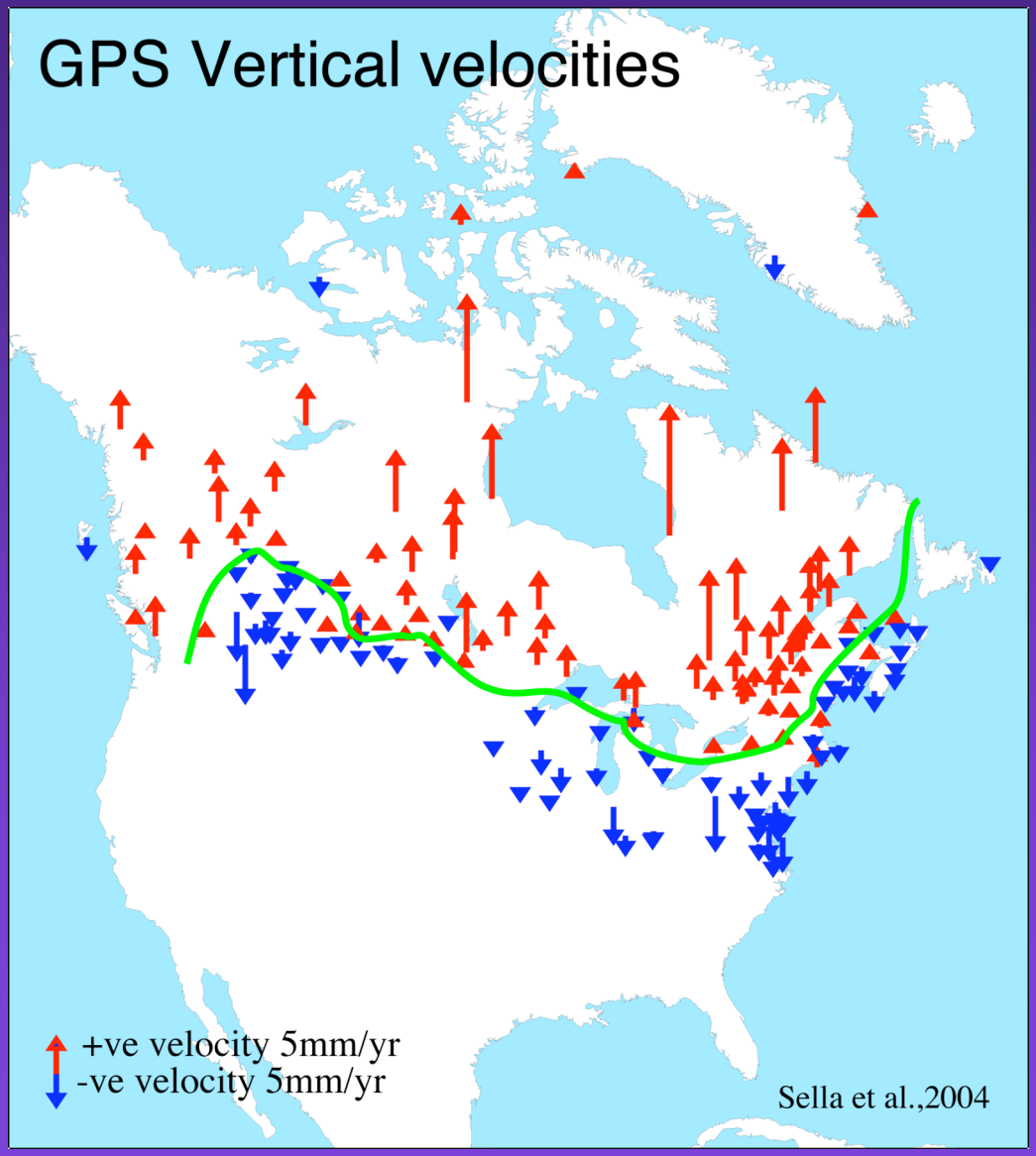


GIA Effects on Lakes

GIA affects water levels on the Great Lakes and Lake Winnipeg. As the northern shores rise, water levels are steadily decreasing. Conversely, as the southern shores sink, water levels are rising. This impacts industries and homeowners along the shores of the Great Lakes and also safe navigation and the international management of water levels.

Note: Average water level doesn't change

What's Next?



Add more sites, especially in northern Canada

Understand the horizontal motions (tricky, since smaller) that will give insight into the ice load history, earthquake-generating potential, and mantle viscosity

Improve mathematical models of all these