Idea326

Proposal for International Polar Year: Observation of Glacial Isostatic Adjustment in the Arctic with GPS

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We recommend that a set of continuously operating Global Positioning System (CGPS) sites be installed at Arctic sites in order to improve our new ability to measure coherent motions due to glacial isostatic adjustment (GIA) following the last glaciation. These sites could be colocated with other environmental monitoring stations. The data will improve our ability to study the history of the large ice sheets, mantle rheology, and the tectonic effects of deglaciation.

During the Pleistocene a number of cycles of glaciation occurred that accumulated ice several kilometers thick extending from polar regions to adjacent continents (Figure 1). These glaciations followed a pattern of slow buildup followed by very rapid melting this resulted in a time-dependant change of the earth's shape known as glacial isostatic adjustment (GIA) that is still ongoing. Quantifying the motion associated with GIA has proved challenging because until a few years ago only indirect observations from geomorphic features (e.g. raised beach ridges), relative sea level changes (e.g. measured by tide gauges), and changes in the earth's gravity field, could be made. The advent of space geodesy, which can measure crustal velocities less than a few mm/yr, offers the ability to directly measure GIA. In particular a number of continuous GPS sites have recently been established in and around areas affected by GIA and offer an opportunity to quantify and understand this deformation. Numerical models of GIA predict vertical and horizontal motions of several mm/yr, well within the resolution of CGPS data. Although the general pattern of upward versus downward and toward versus away from the areas of maximum load are robust, the predicted magnitude and details of these effects can vary significantly between models, because they depend on both the ice loading history and mantle viscosity structure, neither of which are well known [e.g. *Rutter*, 1995; *Peltier*, 1998; *Milne et al.,* 1999]

During the Last Glacial Maximum (LGM), ice sheets in the Northern Hemisphere extended from the Arctic southward to Siberia, Fennoscandia, Greenland, and Canada. GIA motion has been best constrained in Fennoscandia where the ice-sheet extent was limited to a single well constrained area and extensive tide-gauge, over 64 and 26 CGPS sites are present within 600 km of the area of maximum loading. Constraining the amount of GIA motion is important as it may give insight into its possible role as a cause or trigger of seismicity in eastern North America [e.g., *Stein et al.*, 1979, 1989; *Hasegawa and Basham*, 1989; *Adams*, 1989].

Although GIA in North America spans a much larger area, roughly all of Canada, its detection has proved challenging due to the dearth of measurements near the area of maximum loading, Hudson Bay. Until two years ago only one space-geodetic site and one tide-gauge station (Churchill) were located within 1000 km of the center of Hudson Bay. This situation has improved because 10 new CGPS sites have recently been established within 1500 km of Hudson Bay (Figure 2). The lack of sites is even worse across northern Eurasia, where considerable controversy exists with regards to ice extent and thickness [*Grosswald and Hughes*, 2002]. Only three CGPS sites are located across this area two in northeastern Russia (BILI and TIXI) and one in Ny-Alsund (NYAL).

We are currently analyzing 115 CGPS sites in Eastern North America with the specific aim of identifying the GIA signal. Unfortunately, most existing sites were installed under U.S. auspicies and are south of the Great Lakes. We first quantify the rigidity of the North American plate as a whole, focusing on the horizontal residual velocities, and estimate the strain distribution within the plate. Next, because the predicted GIA vertical signals are much larger than the horizontal ones (Figure 3), we use them to detect the "hinge line" where motion changes from uplift to the north to subsidence in the south. This line is roughly at the Great Lakes.

These initial results show that GPS can observe present-day motions due to GIA, and hence provide a new powerful constraint on GIA models. These models can now be improved, yielding better estimates of ice load history and mantle viscosity. For these purposes, sites nearest the ice maximum, where signals are largest, are crucial. In contrast, sites in the lower 48 U.S. states are less helpful because GIA is not the primary cause of crustal motion, so the data record other processes.

Our primary limitation is posed by the lack of CGPS sites in the Arctic, We thus proposed that as part of the International Polar year, ten continuous CGPS sites be established in at U.S. and Canadian sites. These would cost about $20,000 each, and could be collocated with other facilities to reduce installation and data transmission costs. In addition, provided foreign collaborators are interested, other sites in Eurasia and elsewhere could be installed.

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Figure 1. Ice load contours at Last Glacial Maximum (18,000 yr bp) (Grosswald and Hughes, 2002).

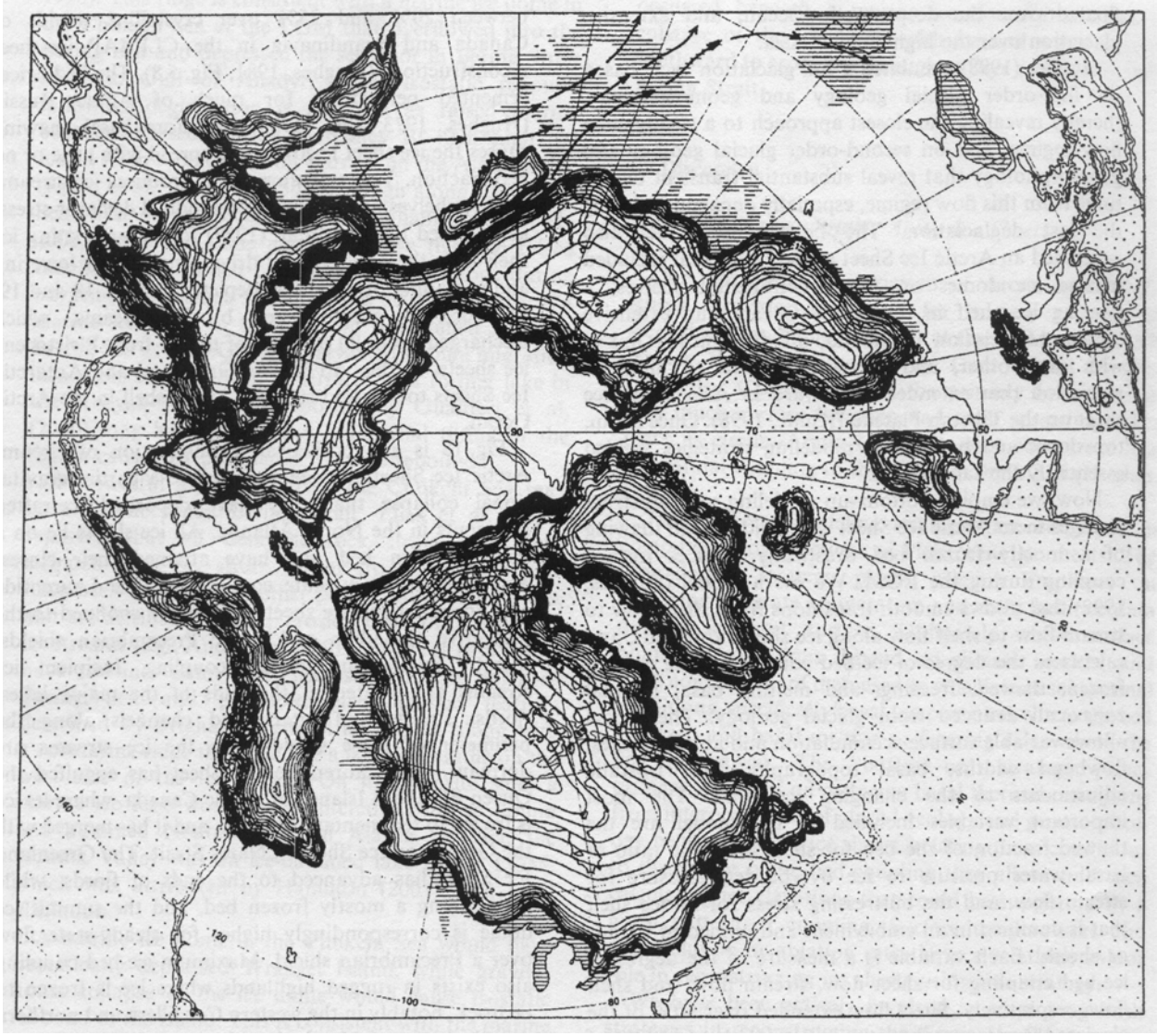

Figure 2: GPS sites available for GIA studies and approximate ice sheet boundaries.

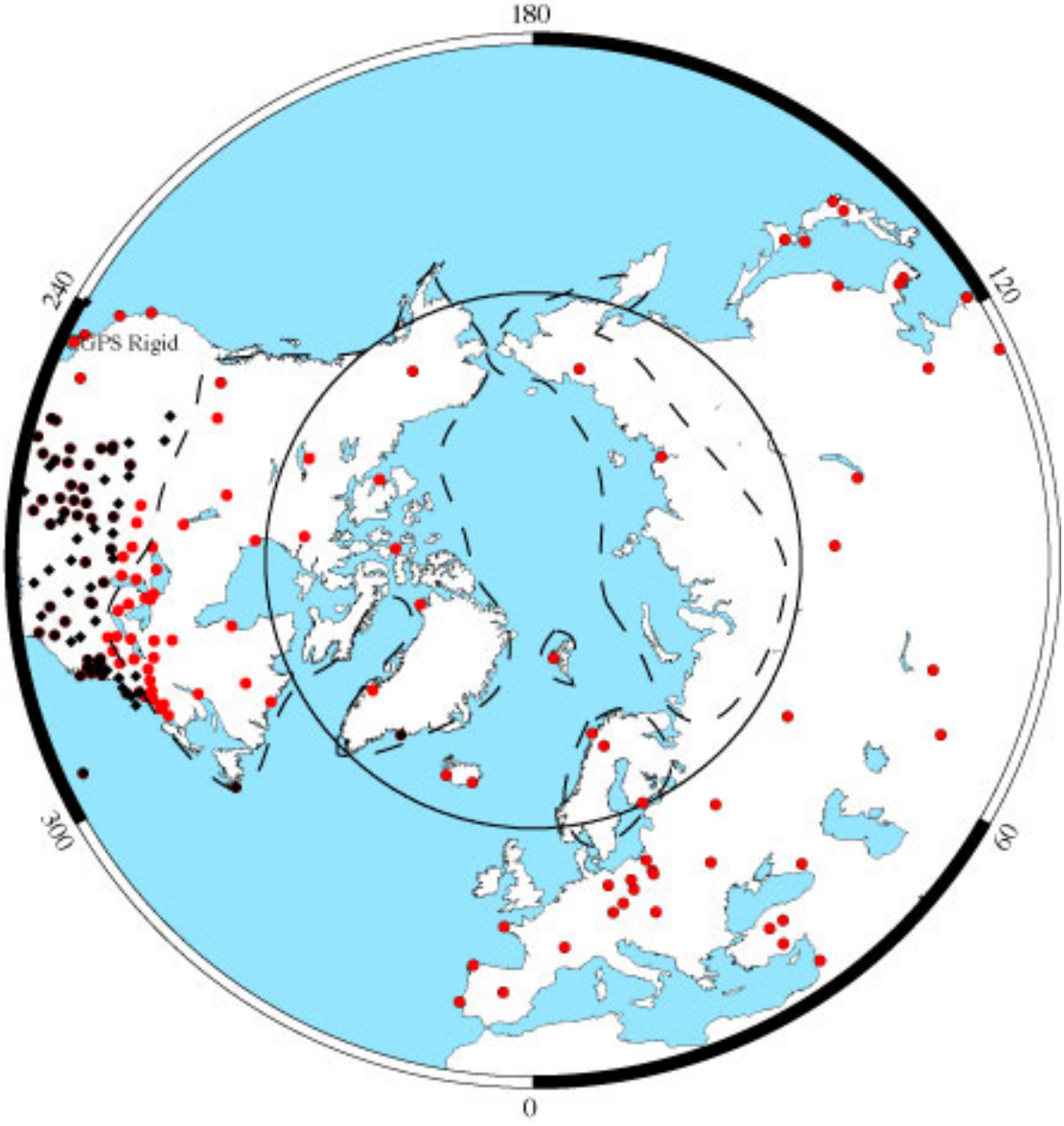
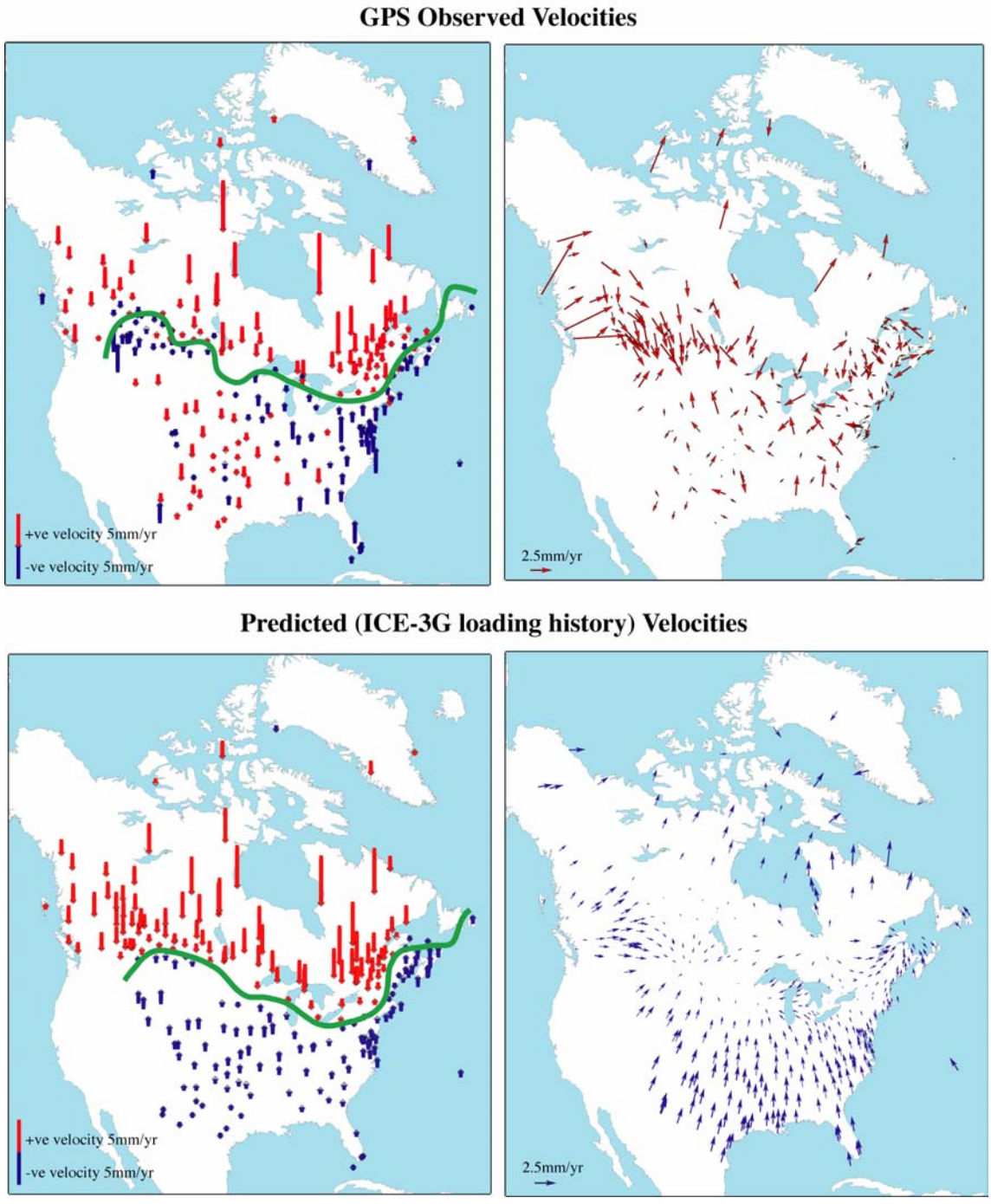
Figure 3. Top: Observed vertical (left) and horizontal (right) velocities at GPS sites. Bottom: Motions predicted by GIA model. The data show the predicted trends, but model parameters (mantle viscosity and ice load history) need to be refined for detailed fits. Additional data from Arctic sites would significantly improve constraints on the models.