Award Number: 03HQGR0104

INVESTIGATION OF INTRAPLATE STRAIN IN NORTH AMERICA USING GPS

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Program Element: Research on earthquake physics and effects

Key Words: Neotectonics, Geodesy, GPS-Campaign, Regional modeling

Final Technical Report

Abstract

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Final technical report

Our proposal focused on using data from continuously operating GPS (CGPS) sites on the North American plate east of the Rocky Mountains to map the strain field and assess the relative roles of various possible platewide and regional sources of stress that may contribute to generating or triggering intraplate earthquakes.

Our pre-proposal GPS dataset (CGPS sites only) suffered from a major limitation in that the sites were located almost exclusively in the U.S. As a result, it had only limited ability to resolve the effects of glacial-isostatic adjustment (GIA) that has been proposed as a major cause or trigger of intraplate earthquakes both in Canada and in the U.S. as far south as New Madrid. Fortunately, and unexpectedly, during the past year we identified and obtained data from a large (over 100 site) episodically occupied GPS (EGPS) network used for regional reference frame purposes by the Geodetic Survey of Canada.

Initial analysis of the combined dataset yields a new detailed velocity field spanning eastern North America. This field shows the striking result that intraplate deformation is dominated by GIA. We observe:

a) Upward rebound motion (~10 mm/yr) near Hudson Bay, the site of maximum ice load at the last glacial maximum, which decreases to slower subsidence (1-2 mm/yr) south of the Great Lakes
b) Horizontal motion directed outward from the major former ice load at Hudson Bay and a secondary load east of the Rockies
c) A broad zone of slower uplift across the central US that does not appear to be caused by GIA because the associated horizontal velocities seem – with the current data - randomly oriented.

Although the general sense of the motions is consistent with published GIA models, its relative magnitude and distribution is not consistent with any specific models. As a result, we can now for the first time directly constrain the magnitude and geographic distribution of GIA-related strain so that alternative models can be tested both to improve knowledge of GIA and its possible seismogenic effects.

MAIN BODY:

Understanding the nature of intraplate earthquakes in eastern North America, exemplified by the New Madrid, Charleston, St. Lawrence Valley, continental margin, and other earthquakes, has long been the focus of many scientists and has major societal implications. Nonetheless, despite considerable effort by many investigators using diverse techniques, progress has been slow. Due to the fact that plate interiors behave almost rigidly, earthquake data are limited, making identification of patterns of strain release challenging. Hence although various possible stress sources have been proposed including platewide (ridge push), regional (glacial-isostatic adjustment, or GIA), and local (density anomalies), differentiating between them has not been possible.

This situation is changing since the advent of space geodesy, in particular GPS, that directly measures how motion across a region varies in space and time. GPS has been applied successfully in plate boundary zones, where deformations are large, so causal mechanisms can be easily tested. In contrast, using this approach in plate interiors that deform more slowly is much more challenging. Resolving this motion requires both maximizing the precision of measurements and sampling densely over the full geographic area to ensure recording the entire signal.

We and others have been using GPS data from eastern North America to investigate deviations from rigid plate behaviour for a number of years. Although we have been able to quantify the deviations from rigidity (Dixon et al., 1996; Newman et al., 1999; Sella et al., 2002, 2004), which are now seen to be on average less than 1 mm/yr, mapping the strain – which involves identifying a spatially coherent intraplate velocity field – had not been possible with the available data. However, owing to the increase in the number of GPS sites and their improved spatial distribution, we can now do so.

Three-dimensional intraplate velocity field

Figure 1 shows our new velocity field, which resolves both horizontal and vertical motions. Because a best-fitting rigid plate motion has been removed, these data indicate deviations from rigid plate behavior and hence intraplate deformation. The velocity field is clearly dominated by glacial-isostatic adjustment (GIA), and shows a number of clear patterns:

a) Upward rebound motion (~10 mm/yr) near Hudson Bay, the site of maximum ice load at the last glacial maximum, which decreases to slower subsidence (1-2 mm/yr) south of the Great Lakes until it can no longer be resolved from other motions

b) Horizontal motion directed outward from the major former ice load at Hudson Bay and a secondary load east of the Rockies

c) A broad zone of slow uplift (~1-2 mm/yr) across the central US that does not appear to be caused by GIA because the associated horizontal velocities seem – with the current data - randomly oriented.

d) Further west, coastal sites show the influence of the subducting Juan de Fuca Plate, a plate boundary effect.

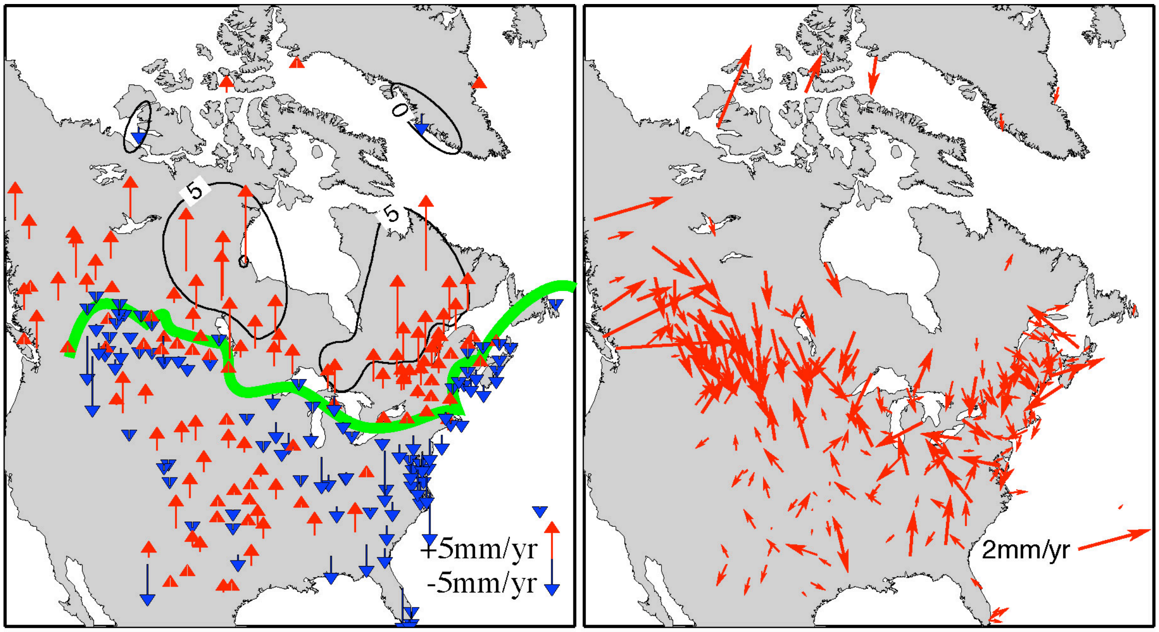

Figure 1. Observed intraplate GPS velocity field after removing the motion of rigid North America. A GIA signal is clearly present in the vertical, and visible in the horizontal as illustrated by arrows north of the Great Lakes all pointing outward from the ice loads located to the North.

The velocity field includes 160 continuously operating GPS (CGPS) sites, for which we analyzed all available data from 1993 to 2003 (Figure 2). In addition, the Geodetic Survey Division of Canada kindly provided data from 120 episodically occupied GPS (EGPS) sites that are part of the Canadian Base Network (CBN). These sites have been occupied for 2-5 days every two to three years from 1994 to 2002. These sites have dramatically improved the velocity field's resolution of GIA.

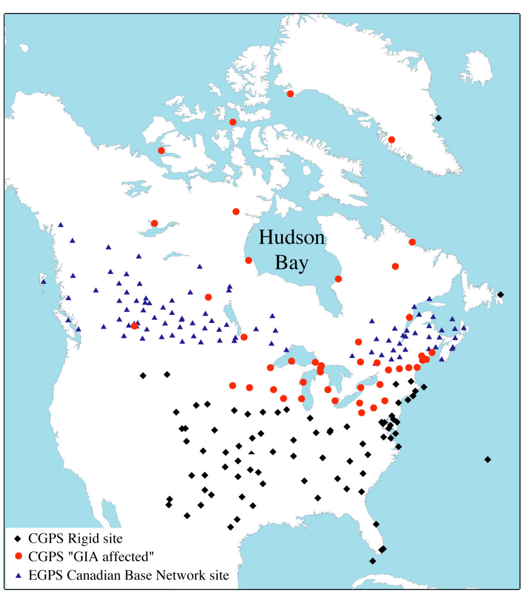

Figure 2. Distribution of GPS sites analyzed. Black diamonds are 83 CGPS sites used to define the motion of rigid North America. Red circles are 47 CGPS sites that may be subject to significant GIA motion. Blue diamonds are 100 EGPS sites that are part of the Canadian Base Network (CBN).

A number of patters appear in both the observed horizontal and vertical velocities (Figure 3): In the central US (green area), where we selected our rigid plate sites (Figure 1 diamonds), we observe very small residual velocities that appear random suggesting that they represent local site effects rather than a regional effect, moreover the vertical velocities are very small. These observations are consistent with the motion expected for a rigid plate. Around the St. Lawrence Seaway (yellow area) we find a clear pattern of small magnitude south to southeastward directed vectors with positive velocities. These are consistent with GIA effects from unloading of ice on the east side of Hudson Bay. Similarly in and to the northeast of Hudson Bay (blue area), large magnitude vertical and horizontal northeast oriented vectors are observed. These sites are much closer to the area of maximum ice loading and also show a pattern consistent with GIA. In southwestern Canada (purple area) a pattern of large vectors oriented to the south/southeast may reflect unloading from Cascadia's ice although a number of the sites have small negative vertical velocities. Further west the coastal sites show the influence of the subducting Juan de Fuca Plate.

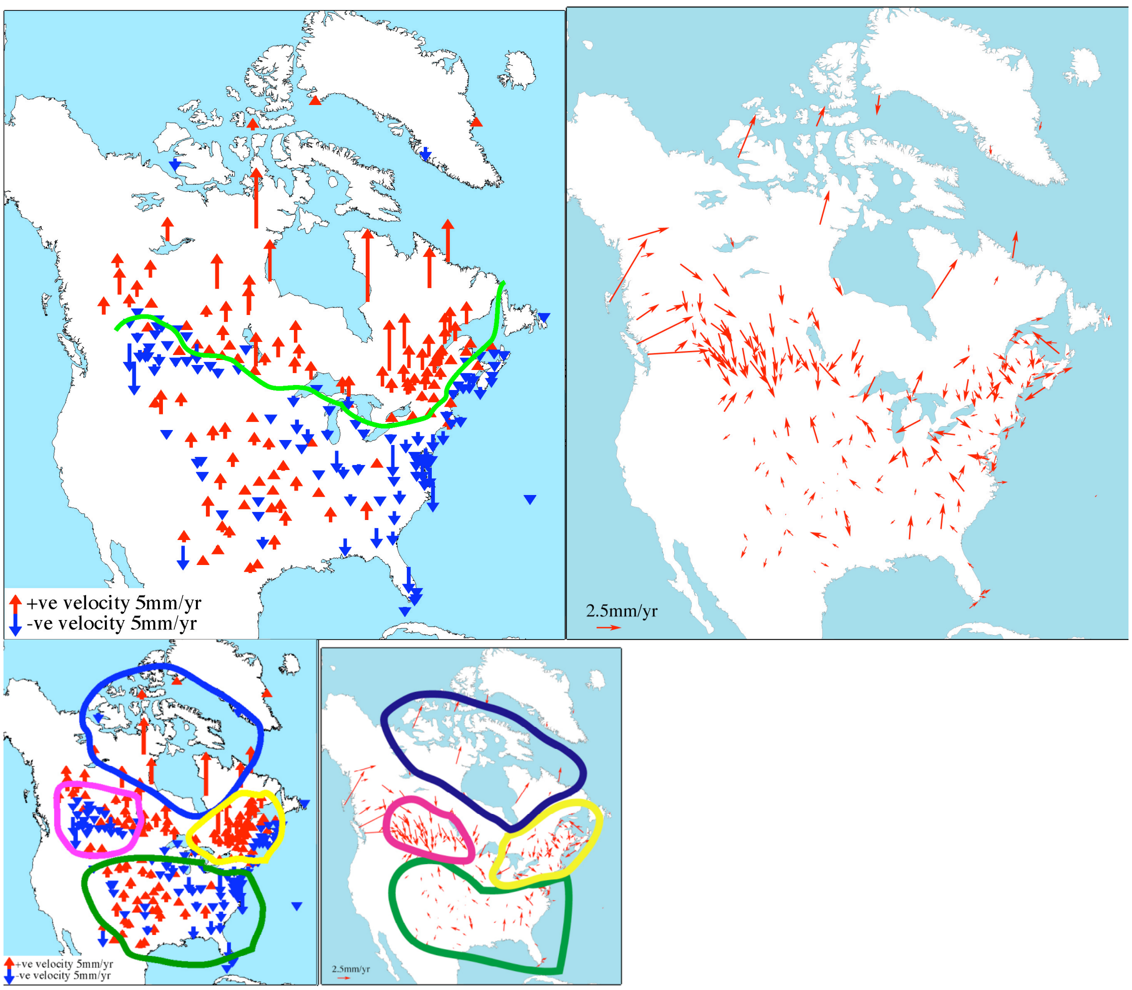

Figure 3. Top Left Vertical velocities observed by GPS with respect to IGS-2000. **Top Right** Residual horizontal velocities after removing North American plate motion defined using the 83 site solution (Figure 2 black diamonds). Smaller maps shows areas discussed in text above.

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***Stein, S., G. Sella,** V. der Lee, and C. Stein, Earthquakes and the thermo-mechanical structure of the earth. Earthscope Annual meeting, 2004.

Activities related to this proposal:

Sella became a member of the NSF-UNAVCO committee on defining Stable North America Reference Frame (SNARF). The purpose of this committee is to identify the optimal reference frame of stable north America for use by the Plate Boundary Observatory.

In Collaboration with S. Mazzotti and T. Dixon we convened a special session for the Spring AGU: S. Mazzotti, **G. Sella, S. Stein,** and T. Dixon, Seismicity and geodynamics of Eastern North America and other mid – plate environments. Special session Spring AGU. 2004.

Stein was invited to give a lecture at the USGS, Menlo Park entitled: Science, hazard, and policy questions for continental intraplate earthquakes in the New Madrid seismic zone.