Intraplate strain and stress in the North American plate interior: Calibrating GIA effects on seismogenic faults with plate-wide GPS measurements

Final report

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Contents

Abstract

This report summarizes activities accomplished by principal investigators Eric Calais and Charles DeMets for USGS awards 07HQGR0049 and 07HQGR0059. The primary goal of the awards was to seek evidence for any pattern of short-term deformation in the central and eastern United States (hereafter abbreviated CEUS) using measurements from continuously operating Global Positioning System (GPS) receivers in North America. Sources of such deformation include crustal isostatic rebound due to melting of the continental ice sheet at the end of the previous ice age (circa 12,000 years ago), and possibly interseismic elastic strain accumulation from deeply seated faults in the New Madrid region of the central U.S. or possibly elsewhere, and postseismic viscoelastic rebound from the 1811-1812 earthquake sequence in the same region. Processing of relevant GPS data from hundreds of continuous GPS stations in the study region was done with GAMIT software at Purdue University and GIPSY software at the University of Wisconsin. Velocity fields from both are described briefly below and were the basis for one publication and several abstracts listed at the end of the report.

1 Background

The goal of this two-year collaborative project was to extract information about earthquake hazards from the GPS velocity field in the CEUS and adjacent areas of Canada using all available continuous GPS data. Funds for the work were divided between PIs Eric Calais at Purdue University and Charles DeMets at UW-Madison, with primary funding for the grant at Purdue. Results related to a previous NEHRP grant award to the same PIs (03HQGR0001 and 03HQGR0002) were published in 2006 (Calais *et al.* 2006) and included analysis of continuous GPS station data from the eastern and central U.S. through mid-2005. A key goal of the present project was to extend those GPS coordinate time series to the present, incorporate hundreds of new GPS stations that became operational after 2005, and assess whether the new velocity field contained any new information about short-term deformation in the CEUS.

2 GPS Data and Processing

2.1 GIPSY-OASIS Processing at the University of Wisconsin

Significant upgrades to the GPS processing engine at the Department of Geoscience, UW-Madison, were made during the two-year period of the grant to cope with both the increasing volume of daily GPS data, including data from hundreds of Plate Boundary Observatory continuous stations that became operational after 2005 and necessary upgrades to GIPSY-OASIS and related software from JPL. Improvements to the processing and post-processing procedures during this period included the following: (1) purchase and installation of a Linux computer with eight processing nodes, (2) upgrade of GPS software to parallelize the processing stream, (3) installation and testing of GIPSY Release 4 software, (4) installation and testing of AMBIZAP software from Geoff Blewitt, (5) upgrade of all network results from ITRF2000 to ITRF2005. These tasks required two months of dedicated effort in 2006 and 2007, constituting most of the work done by PI DeMets on this grant.

By the end of the grant period (late 2007), the automated GPS processing system at UW-Madison was generating daily results for ∼2000 stations, roughly 700 from areas of North America relevant to this project. Figure 2.1 shows the velocities of these stations as of early 2008 from GIPSY data processing at UW-Madison. Stations located in the central and eastern United States rotate counterclockwise about a pole located south of this map, representing the motion of the North American plate interior in the International Terrestrial Reference Frame 2005 (ITRF2005). More than 500 of the stations shown in Figure 2.1 are located in nominally undeforming areas of North America, including regions affected by isostatic rebound due to melting ∼12,000 years ago of the continental ice sheet that covered the northern tier states and nearly all of Canada.

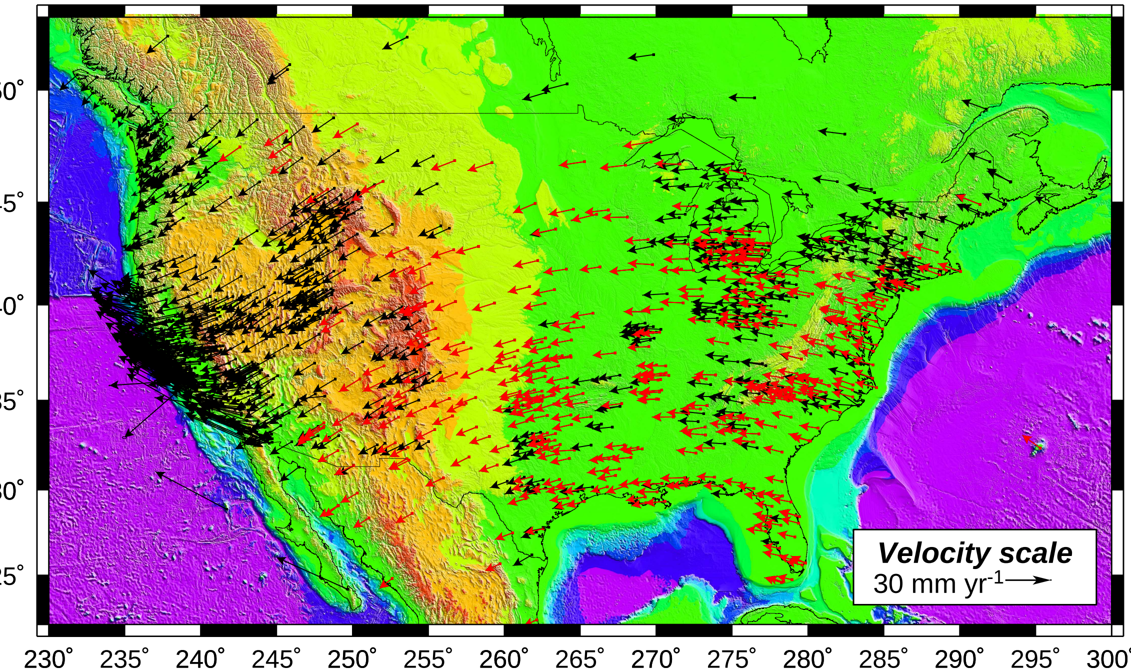

Figure 2.1: Velocities of North America plate continuous GPS sites running for three years or longer at the end of 2007 (red arrows) estimated from GIPSY processing at UW-Madison for this study. Black arrows show stations in operation for less than 3 years in late 2007 or stations not located on undeforming areas of the plate interior.

2.2 GAMIT-GLOBK processing at Purdue

PI Calais and students spent a significant amount of time in 2006 overhauling their GAMIT-GLOBK processing to (1) incorporate absolute phase center models into their processing scheme, (2) upgrade their results to a new version of the International Terrestrial Reference Frame (2005), and (3) adapt their code to a Linux cluster for faster and more flexible processing. By the end of the grant, daily data were being processed at Purdue for close to 800 continuous GPS stations operating in nominally undeforming areas of the U.S. and Canada, a three-fold increase since the project began in 2002 (Fig. 2.2). About 500 CGPS stations in the study area had position time series longer than 3 years, twice the number of stations that satisfied this criteria in our first publication (*Calais et al.* 2006). Because of the significant improvement in precision after time series exceed 3 years in length, the GPS velocity field has improved significantly. A new comparison and combination of GAMIT and GIPSY results was undertaken prior to the Fall 2007 AGU meeting, where Calais presented the work (*Calais et al.* 2007).

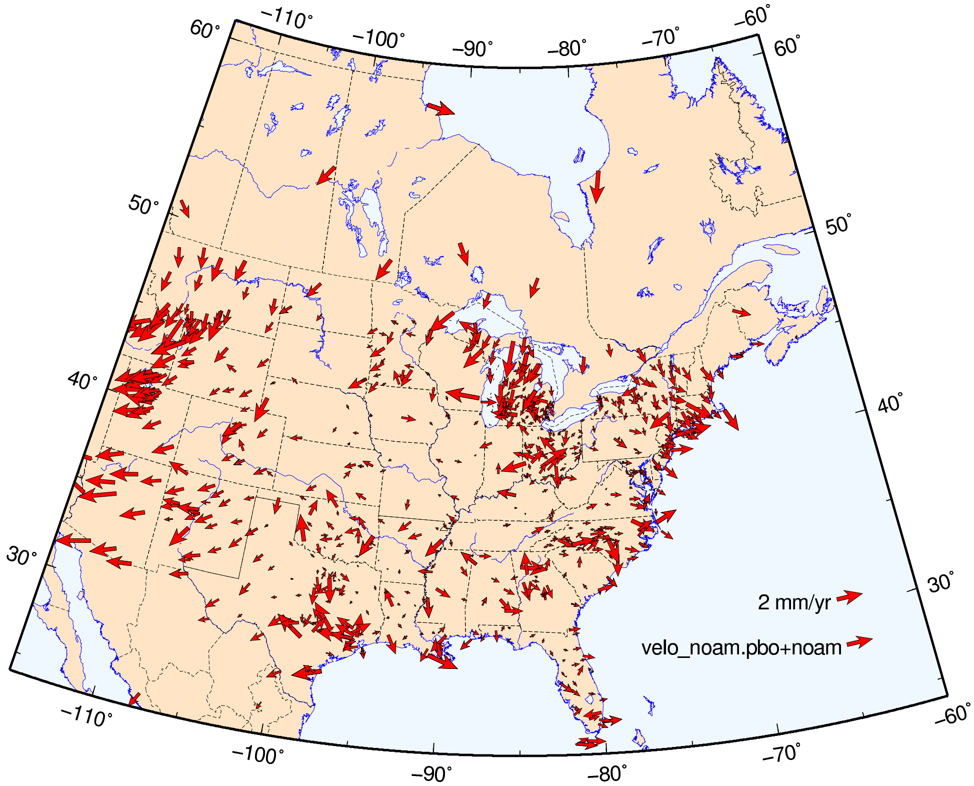

Figure 2.2: Residual North America plate continuous GPS velocity field from GAMIT analysis for stations running one year or longer at the end of 2009. The velocity of the North America plate relative to ITRF2005 predicted at each station location is subtracted from the station velocity relative to ITRF2005, leaving the residual station motion in a North America-fixed reference frame. Station velocities relative to ITRF2005 are predicted from the angular velocity that best fits the GAMIT-derived velocities of GPS stations from the plate interior.

3 Results: GIPSY and GAMIT GPS velocity fields

3.1 GIPSY-OASIS GPS velocity field

Of the many continuous GPS stations located in the CEUS (Fig. 2.1), 415 had been operating longer than three years as of early 2008 and had well determined coordinate time series. The angular velocity that best fits the 415 CEUS station velocities determined from GIPSY processing fits those velocities well, with weighted root-mean-square residuals of 0.63 mm yr^{-1} and 0.68 mm yr^{-1} for the north and east velocity components, respectively. A geographic view of the residual station velocities (Fig. 3.1) and summary of the north- and east-component misfits (Fig. 3.2) show no obvious pattern that might, for example, indicate that measurable elastic strain accumulates in areas near the rupture zone of the 1811-1812 M=8 earthquakes in the New Madrid region of the central United States.

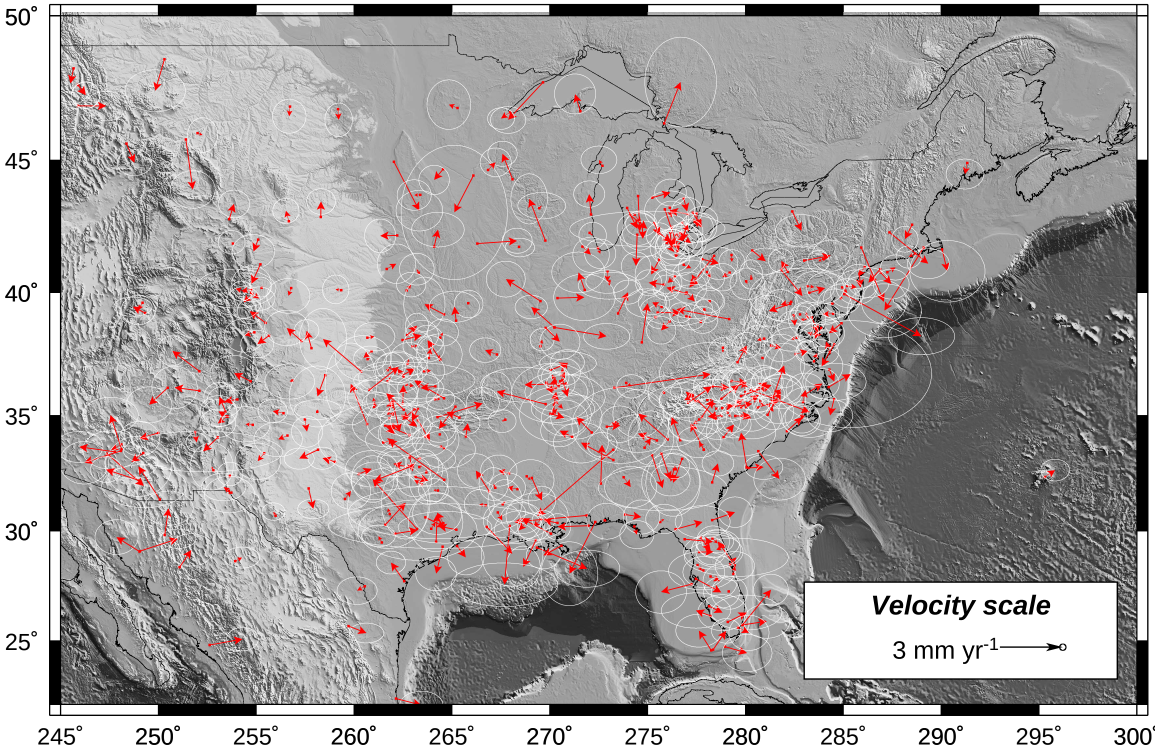

Figure 3.1: Residual North America plate continuous GPS velocity field from GIPSY analysis. The velocity of the North America plate relative to ITRF2005 predicted at each station location is subtracted from the station velocity relative to ITRF2005, leaving the residual station motion in a North America-fixed reference frame. Station velocities relative to ITRF2005 are predicted from the angular velocity that best fits the velocities of 415 GPS stations from the plate interior. GIPSY analysis results.

3.2 GAMIT-GLOBK GPS velocity field: Application to New Madrid seismic zone

For the GAMIT GPS velocity field (Fig. 2.2), stations in eastern and central Canada and the northern tier states of the United States move slowly southwards, consistent with the motion predicted by models of isostatic post-glacial rebound. Readers are referred to *Calais et al.* (2006) for further information about these results. *Calais and Stein* (2009) use the residual velocity field shown in Fig. 3.3 to estimate an approximate upper limit of only 0.2 mm yr^{-1} for the residual motions of stations relative to the plate interior. Relative to the regional residual velocities report in previous studies, including our own (*Calais et al.* 2006), the newly estimated residual station velocities in the New Madrid region are smaller and may imply less seismic hazard than results from previous studies. Encouragingly, the stations with the largest residual velocities are those with the poorest quality time series, as determined by the number of outliers, and the amplitudes of their long-period and seasonal noise. Simulations to generate synthetic GPS time series that include realistic noise and unmodeled hydrologic and atmospheric loading effects show that even the largest station velocity residual motions can be explained as nontectonic artifacts (supplementary material, *Calais and Stein* 2009).

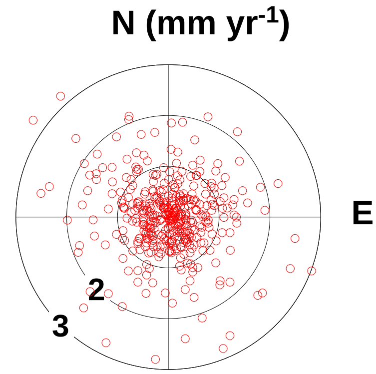

Figure 3.2: Misfits of best-fitting angular velocity for North America plate to GIPSY-derived velocities for the 415 GPS stations used to estimate the best-fitting angular velocity. Each red circle indicates the misfit for a single GPS site measured in units of millimeters per year to the north and east. Concentric circles indicate misfit magnitudes for 1, 2, and 3 mm yr^{-1}.

4 Summary

Funding from the USGS NEHRP grants to Purdue University and the University of Wisconsin was used to undertake significant upgrades to the GPS data processing engines at both institutions and enabled continued improvements in both the accuracy and precisions of the North American region GPS velocity fields generated from both GIPSY and GAMIT. The improved accuracy and consistency of the GPS station velocities from undeforming areas of the plate permitted stronger new bounds to be estimated for any regional elastic or viscoelastic deformation related to the 1811-1812 New Madrid region earthquakes. Results from this work were presented via three meeting abstracts, and peer-reviewed papers in 2006 and 2009, as listed below.

5 Publications

Two papers and three abstracts were published during or after this grant and resulted directly from support provided under this or the previous related grant, as follows:

1. Calais, E., J. Y. Han, C. DeMets, and J. M. Nocquet, Deformation of the North American plate interior from a decade of continuous GPS measurements, *J. Geophys. Res.*, **111, B06402,** doi: 10.1029/2005JB004253, 2006.
2. Calais, E. J.Y. Han, C. DeMets, and J.M. Nocquet, Geodetic strain in plate interiors, invited presentation at the UNAVCO annual meeting, March, 2006. Boulder.
3. Calais, E., C. DeMets, and J. Y. Han, Deformation of the North American plate interior from GPS, Fall AGU abstract G21B-0494, San Francisco, 2007.
4. Calais, E. and C. DeMets, Geodetic strain rates in the New Madrid seismic zone, 2000-20008: Converging toward zero, Fall AGU abstract G34A-07, San Francisco, 2008.
5. Calais, E. and S. Stein, Time-Variable deformation in the New Madrid seismic zone, *Science*, **323**, 1442, 2009.

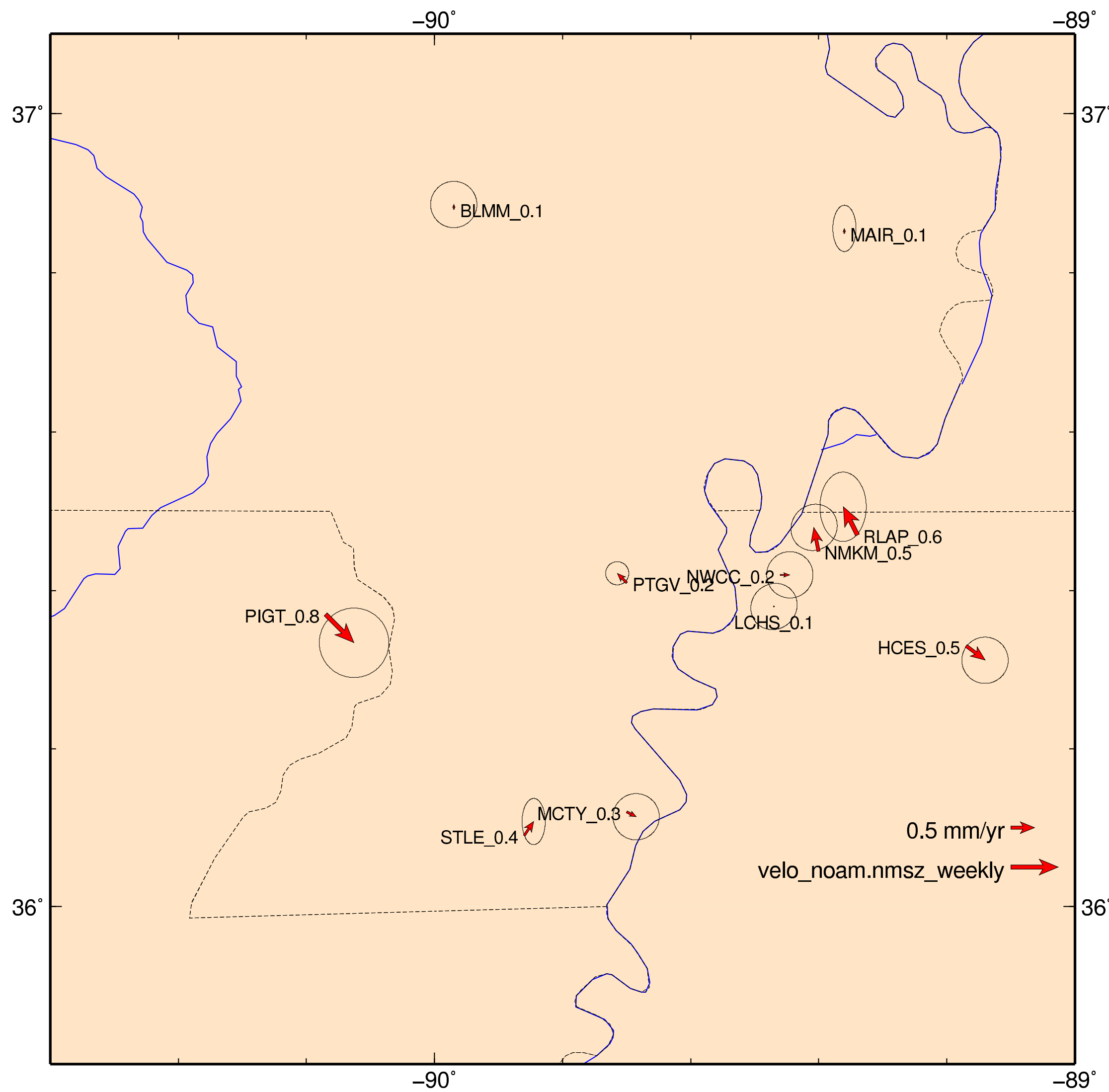

Figure 3.3: Focus on New Madrid region, central United States - Residual motions of North America plate continuous GPS sites after removing the motion predicted at each site by the angular velocity that best fits those station velocities. GAMIT analysis results