Progress Report - Year 1
"Testing intraplate deformation in the North American plate interior"
NEHRP Award 03HQGR0001

Eric Calais
Purdue University - Department of Earth and Atmospheric Sciences
West Lafayette, IN 47907
Phone: 765-496-2915 Fax: 765-496-1210 Email: ecalais@purdue.edu
Keywords: Neotectonics, GPS-continuous

October 7, 2003

1 Background

This is a two-year collaborative project between C. DeMets (Univ. Wisconsin, Madison), J.M. Nocquet (Oxford, UK), and E. Calais (Purdue). The main objective is to determine whether there is measurable strain currently accumulating on potentially seismogenic intraplate structures in the stable part of the north American plate (central-eastern US and part of Canada). To do so, we use existing continuous GPS stations from the CORS network (operated by the NGS) and from the IGS network. We apply rigorous techniques for combining geodetic solution from independant analysis centers and derive a consistent velocity field covering the stable interior of the North American plate, with realistic uncertainty estimates. We use the resulting velocity field to define a stable North American frame to map residual velocities, from which we analyze the pattern and magnitude of strain within the North American plate interior.

2 Investigations and Results: Year 1

During the first year of the project, we completed the processing of 7.5 years of continuous data for up to 255 stations using the GAMIT software.

For processing time considerations, we divided the network into 10 regional subnetworks of about 25 sites. All subnetworks share 6 common IGS sites (AOML, USNO, ALGO, NLIB, MDO1, AMC2) well determined in the ITRF that will serve to tie the subnetorks together and with the ITRF. GAMIT uses double-differenced GPS phase measurements to estimate daily solutions, i.e. a least squares adjustment vector and its corresponding variance-covariance matrix for station positions and orbital elements. We solve for station coordinates, satellite state vectors, 7 tropospheric delay parameters per site and day, horizontal tropospheric gradients, and phase ambiguities using IGS final orbits and earth orientation parameters. We apply elevation dependant antenna phase center models following the tables recommended by the IGS, solid Earth and polar tide corrections following the IERS standards (IERS, 1996), and ocean loading corrections using the CSR4.0 ocean tide model (Eanes, 1999) with the 8 principal diurnal and semidiurnal tidal constituents.

We met with collaborators DeMets and Nocquet in June 2003 at Purdue to compare the GAMIT and GIPSY (generated by DeMets) solutions. We resolved a number of inconsistencies between the GAMIT and GIPSY solutions, mostly due to incorrect antenna heights. We ran preliminary geodetic combinations of the loosely constrained GAMIT and GIPSY solutions, together with the IGS and the full ITRF-2000 solutions, in order to quantitatively compare the individual solutions and to rigorously estimate velocity uncertainties and covariances. The combination procedure is explained in detail in *Altamimi Z., P. Sillard and C. Boucher, J. Geophys. Res., 107, 2214, doi:10.1029/2001JB000561, 2002* and *Nocquet, J.-M. and Calais, E., Geophys. J. Int., 154, 72-88, 2003.*

The combination methodology handles reference frame constraints simultaneously for all individual solutions in a rigorous way (e.g. Brockmann, 1997; Davies and Blewitt, 2000; Altamimi et al., 2002). Because we only use 14-parameters transformations and minimally constrained solutions in the combination, relative positions and velocities of individual solution are not affected by the reference frame definition. We apply a weighting scheme that rescales the variance-covariance matrices of each individual solution and provides realistic formal errors.

The combination of four loosely contrained solutions (GAMIT, GIPSY, IGS, and ITRF2000) shows weighted RMS of individual solutions in the combination of 0.3 to 5.7 mm in position and 0.2 to 0.7 mm/yr in velocities (Table 1). The χ^2 is very close to 1 for each of the 4 individual solutions in the combination, meaning that the 14-parameter transformation model used in the combination procedure is consistent with the uncertainties of the individual solutions and with their residuals in the combination (given the scaling factors below).

A posteriori variance factors (= scaling factors) are estimated during the combination so that the χ^2 approaches unity. Table 2 shows that standard deviations in the GAMIT and IGS solutions were underestimated by a factor of 2.5, in the GIPSY solution by a factor of 2.1. This is consistent with the fact that the GIPSY uncertainty estimates already accounted for colored noise in the GPS position time series. It is important to note that the variance of all solutions is increased in the combination process.

The final combination contains 249 sites. We performed a preliminary analysis of the fit of the GPS data with a rigid plate model. To do so, we computed an angular velocity for North America / ITRF2000 using sites located located between -110/-65 longitude and 25/50 latitude (central and eastern US). Results (Table 1) shows angular velocity values all very close with a reduced χ^2 usually close to 1, but increasing as we reduce the threshold on the velocity standard deviation. This could either mean that the uncertainties for the best determined sites are underestimated or that the rigid plate model does not fit the best determined sites.

Figure 1 shows residual velocities for case 1 of Table 3. Very few sites have residual velocities larger that their uncertainty. Also, there does not appear to be a spatial pattern in the residual velocity distribution.

Figure 2 compares residuals for case 5 of Table 3 (in red) with residuals derived from the GIPSY individual solution only (in blue). Again, there is no clear correlation or pattern emerging. The distribution of the residuals (bottom right plot) indicates that the combination has resulted in a general decrease of the residual velocities: 75% of the sites have residual velocities less than 1 mm/yr in the combination, compared to 45% in the GIPSY only solution. We obtained a similar result by comparing the GAMIT solution with the combination.

We started to analyze the vertical motion rates and found that they follow the expected pattern of glacial isostatic adjustment over North America. We also find possible evidence for subsidence in some areas of the southern and central US.

3 Detailed Summary: Year 1

Specific tasks accomplished during Year 1 include:

1. Completed GAMIT data processing for up to 255 sites for the 1996-2003 time period.

2. Met at Purdue in May 2005 with collaborators DeMets (Univ. Wisconsin) and Nocquet (Oxford).
3. Performed first geodetic combination of the GAMIT, GIPSY, IGS, and full ITRF2000 solution.
4. Started analysis of the combined solution in terms of internal deformation of the North American Plate interior.
5. Started analysis of vertical displacement rates.

During the second year of the project, we will:

1. Continue processing CORS and IGS continuous GPS data with GAMIT.
2. Update and finalize the geodetic combination.
3. Produce a final velocity field for the North American Plate interior with realistic uncertainties and covariances.
4. Analize velocities in terms of internal deformation of the North American Plate interior.
5. Compare residual velocities with monument and equipment type.
6. Meet with collaborators DeMets and Nocquet to discuss final results.
7. Prepare a publication of the results and conclusion of this study.

4 Non-technical summary

Present-day deformation of the interior of stable tectonic plates is usually assumed to be begligeable, yet large eathquakes sometimes occur within plate interiors. Here, we use data from existing geodetic sites equipped with continuously recording Global Positioning System receivers in order to measure present-day deformation in the central and eastern US. We use a data processing strategy based on redundancy and rigorous statistical tests. Preliminary results show that the present-day deformation is lower that the detectability threshold currently achievable with the amount of GPS data available, *i.e.,* less than about 1 mm/yr.

5 Publications

Song, Y., E. Calais, C. DeMets, and J.M. Nocquet, Testing intraplate deformation in the North American plate interior from a combined geodetic solution, AGU Fall meeting, 2003.

6 Data availability

All GPS data used in this analysis are available from public ftp archive, in particular at SOPAC for the IGS stations (lox.ucsd.edu) and at the NGS for the CORS stations (www.ngs.noaa.gov). Results from processing of the raw data at Purdue and UW Madison will be made available once the complete velocity solutions are generated, combined, and edited. The final velocity solution(s) will be distributed as a SINEX file through E. Calais (ecalais@purdue.edu).

Solution	wrms (position)	wrms (velocity)
GIPSY	5.7 mm	0.7 mm/yr
AMIT	1.8 mm	0.5 mm/yr
ITRF2000	0.7 mm	0.4 mm/yr
IGS	0.3 mm	0.2 mm/yr

Table 1: Weighted RMS of individual solutions in the combination.

Solution	Variance factor
GIPSY	4.6
GAMIT	6.2
ITRF2000	2.9
IGS	6.0

Table 2: A posteriori variance factor for each individual solution used in the combination.

case	site selection	sites	reduced χ^2	χ^2	latitude	longitude	angular velocity
1	All sites	201	0.7842	312.883	-6.186 +- 1.10	-84.071 +- 0.32	0.1875 +- 0.0026
2	std dev on horizontal velocities less than 3 mm/yr	112	1.3653	301.739	-6.216 +- 1.11	-84.082 +- 0.32	0.1874 +- 0.0026
3	std dev on horizontal velocities less than 2 mm/yr	95	1.5621	292.111	-6.241 +- 1.12	-84.061 +- 0.33	0.1873 +- 0.0026
4	std dev on horizontal velocities less than 1.5 mm/yr	76	1.8719	278.910	-6.158 +- 1.14	-84.062 +- 0.34	0.1875 +- 0.0027
5	std dev on horizontal velocities less than 1 mm/yr	58	2.3145	261.538	-6.050 +- 1.17	-83.979 +- 0.36	0.1880 +- 0.0028
6	the same as the ones used in C. DeMets estimation	149	0.7443	219.577	-5.171 +- 0.90	-83.910 +- 0.29	0.1915 +- 0.0020
7	the same as the ones used in C. DeMets estimation and stdev < 2 mm/yr	91	1.1406	204.172	-5.195 +- 0.91	-83.876 +- 0.30	0.1913 +- 0.0020

Table 3: Estimation of angular velocities for the North American plate.

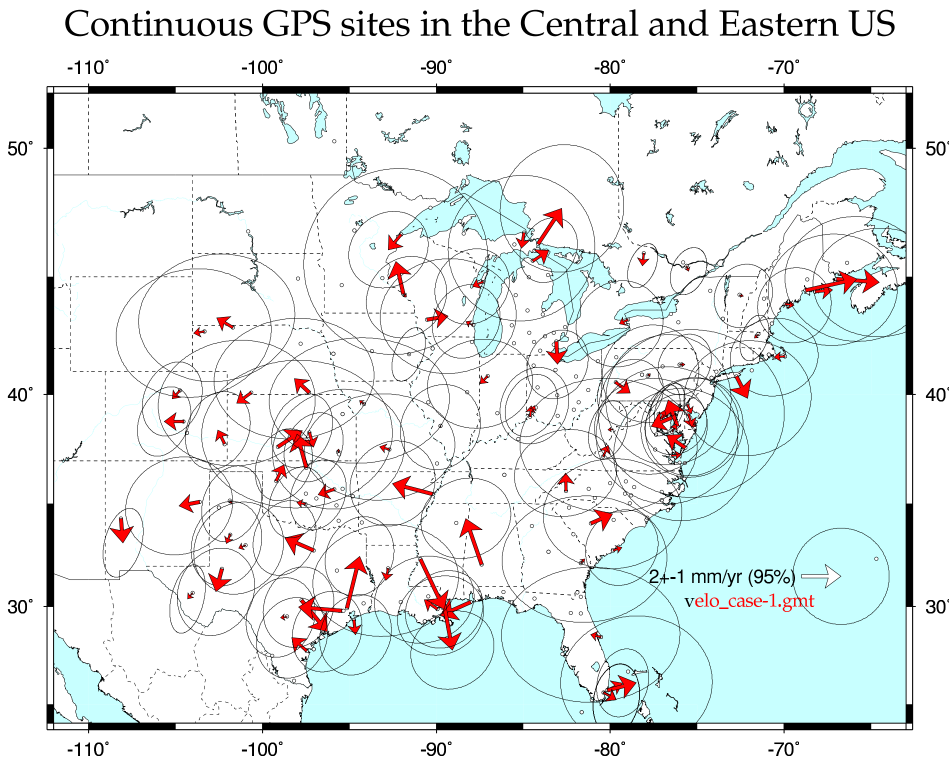

Figure 1: Residual velocities with respect to a best-fitting North American plate frame (case 1 of Table 3). Uncertainty ellipses are 2-D, 95% confidence. Only sites with uncertainty < 2 mm/yr and velocity < 3 mm/yr are shown.

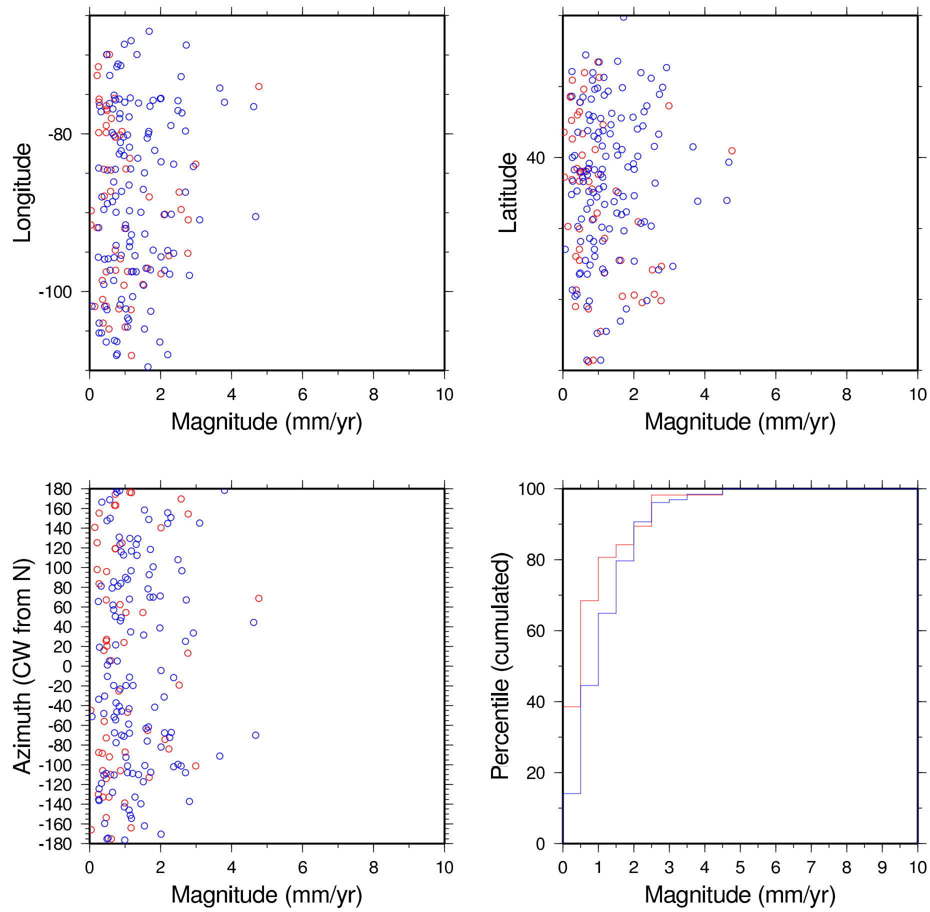

Figure 2: Magnitude of residual velocities with respect to a best-fitting North American plate frame as a function of site longitude, site latitude, and velocity azimuth. Bottom right panel shows the distribution of the magnitude of the residual velocities. Red: combined solution, Blue: GIPSY solution.