2006 SCEC Annual Report

Analysis and Modeling of Continuous GPS Data: Constraining Time Dependent Fault System Activity

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Summary

During the last year we worked to develop the tools to analyze the near continuous stream of GPS data in a way that allows to image fault related deformation in the elastic upper crust. To this end we developed three significant pieces of software to 1) analytically calculate displacements, stresses, and strains due to slip on a triangular dislocation element in elastic half-space, 2) interactively visualize and query GPS time series, and 3) estimate co-seismic slip distributions and changes in Coulomb failure stress on faults specified in the Community Fault Model using geodetic data. The first of these codes is described in an accepted manuscript ("Algorithms for the Calculation of Exact Displacements, Strains, and Stresses for Triangular Dislocation Elements in a Uniform Elastic Half Space", accepted at Computers and Geosciences) and MATLAB implementations of these algorithms will be available on Meade's web site (summit.fas.harvard.edu) as soon as the work is in press. During the summer of 2006 this work involved two undergraduate interns, William Cheng from Harvard and Mark Dyson from Carlton College. The latter of the two attended the SCEC annual meeting, presented a poster detailing some of the work described below and wrote a senior thesis based on this work.

Triangular Dislocation Elements

While we had intended to use the rectilinear approximation to the Community Fault Model (CFM-R) we realized that if accurate descriptions of stress transfer were to be calculated we should take advantage of the more accurate triangular meshes developed by the CFM effort. A secondary motivation for this approach was the large number of artificial discontinuities in fault surfaces introduced in the process of developing a rectangular mesh. These singularities are the source of strain singularities in elastic dislocation calculations and thus artificial "edges" may affect the near fault stress field. To this end we developed a new analytic algorithm for the calculation of the displacements, strains, and stresses associated with slip on a triangular dislocation element in a homogeneous elastic half space. While this problem has been addressed previously we decided to tackle in anew due to concerns regarding the accuracy of previous work. This new work is accurate to within one order of machine precision (for values near unity) and will be made available as open source code as both on Meade's web site (summit.fas.harvard.edu) and as an appendix to the manuscript "Algorithms for the Calculation of Exact Displacements, Strains, and Stresses for Triangular Dislocation Elements in a Uniform Elastic Half Space" which is currently in press at Computers and Geosciences. Additionally we developed an interactive tool to solve for fault slip distributions. This tool was developed to specifically allow for slip estimations on fault geometries specified by the SCEC developed CFM (Figure 1). This tool is currently being used by Mark Dyson at Carlton College to study the potential role of Coulomb failure stress interactions between the 1992 Landers and 1999 Hector Mine earthquakes. This work will constitute his senior thesis and be completed by the end of the spring 2007 term.

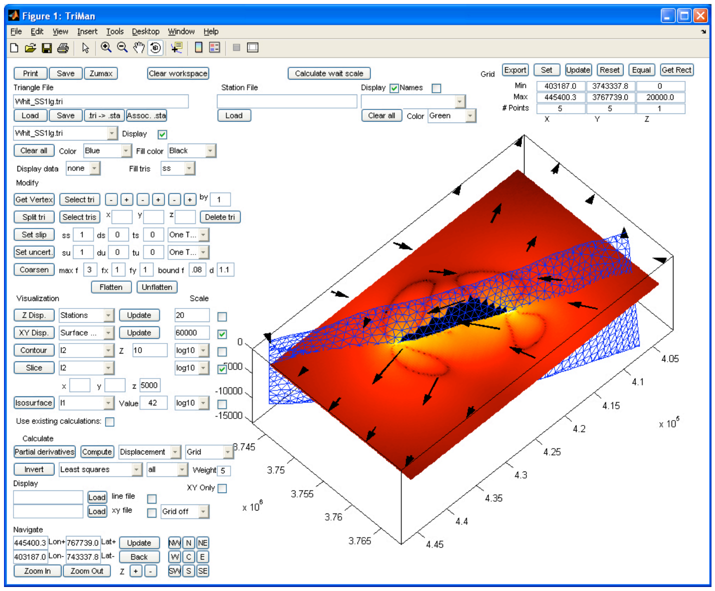

Figure 1. Screenshot with synthetic slip distribution, stresses, and surface displacements.

Interactive analysis of GPS time series

Geodetic signals of tectonic and or seismic interest may overprinted by other forcings such as those from anthropogenic groundwater withdrawal (*Bawden, et al.*, (2001). In order to determine which GPS stations might show these effects at the largest magnitude we developed an interactive viewer that allows for the dynamic querying of GPS time series and velocity fields (Figure 2). The basic idea is to show the spatial distribution of average velocities and allow for a user to click on one of the stations to view the time series associated with this station. In addition to viewing the time series best-fit linear and harmonic trends can be fit to the time series in order assess whether or not there are obvious fault related signals that need to be accounted for. To facilitate the determination of what GPS stations might be affected by fault motions the interface to these data allows for fault traces from both the CGS and CFM to be visualized along side geodetic and topographic data.

Adaptive filtering

The GPS signals that we are most interested in are those associated with post-, inter-, co-, and possibly pre-seismic slip on faults as well as slow slip events (e.g., *Linde, et al.*, 1996; *Dragert, et al.*, 2001). In order to accurately model these data and account for the noisy nature of these signals we used state-space filtering techniques. While similar techniques have been applied to GPS time series in the past (e.g., *McGuire and Segall*, 2003 our efforts to develop an automated method for modeling time series over a highly vastly different time scales led us to develop a new iterative method to adaptively determine how rapidly filter estimates. In detail, we designed a filter that does not oscillate over inter-seismic time scales but can also adjust rapidly enough to accurately model a rapid co-seismic "jump" (Figure 3), then adjust continually to the intermediate speed slip during the postseismic part of the seismic cycle. The iterative algrothithm compares the filtered prediction with the best possible fit to the data (in a least squares sense) and adapts the temporal smoothing parameter till the goodness of fit is within a prescribed bound.

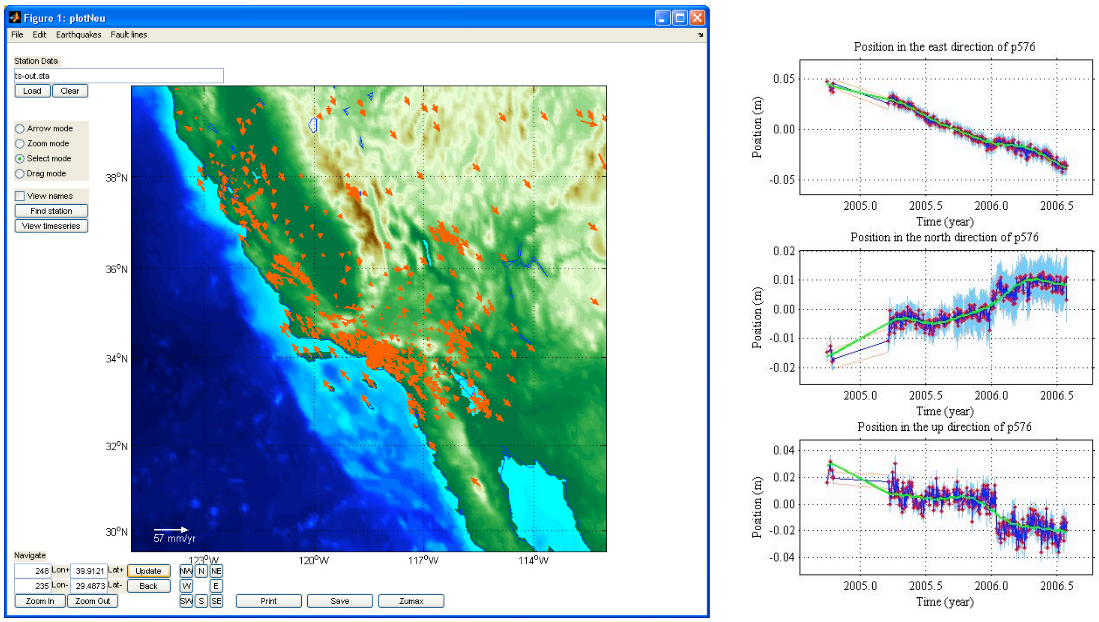

Figure 2. Interactive velocity/time series viewer and harmonic time series analysis. SCEC CMM3.0 velocities (orange arrows) are shown along with GTOPO30 topography. Using this interface a station or stations can be clicked on and their time series (red dots) viewed along with a harmonic analysis (green lines).

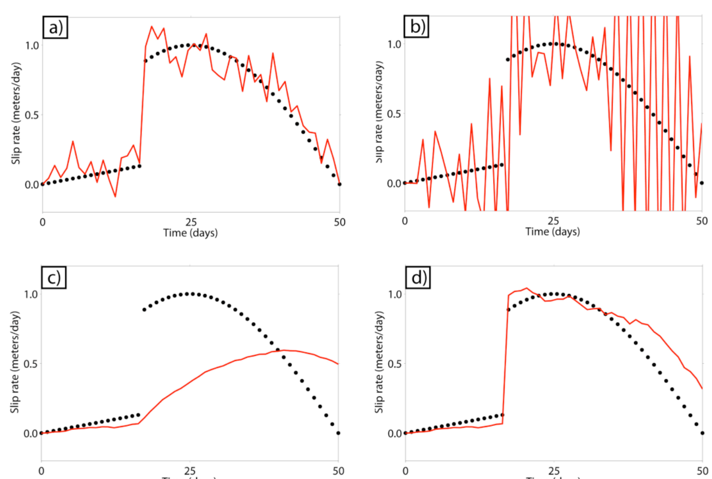

Figure 3. True fault slip time series (black dots) and filtered slip rate estimates (red lines). a) “Zero-memory” filter b) Weakly damped α-β filter where the estimator

oscillates around the true solution c) Strongly damped Kalman filter where the estimator cannot adapt quickly enough to model the transition from inter-seismic to co-seismic slip d) Adaptive filter described in the text. Note the smooth inter-seismic time series estimate, compare with c), and the rapid jump at the time of co-seismic deformation and the relatively smooth post-seismic decay.

References

Bawden, G. W., et al. (2001), Tectonic contraction across Los Angeles after removal of groundwater pumping effects, *Nature*, *412*, 812-815.

Dragert, H., et al. (2001), A silent slip event on the deeper Cascadia subduction interface, *Science*, *292*, 1525-1528.

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McGuire, J. J., and P. Segall (2003), Imaging of aseismic fault slip transients recorded by dense geodetic networks, *Geophys. J. Int.*, *155*, 778-788.