Annual Report, 1998: Geodetic Constraints on Interseismic, Coseismic, and Postseismic Deformation in Southern California; T. Herring, R. King, S. McClusky, R. Reilinger

In collaboration with geodesists at JPL, Scripps, UCLA, and USGS, we have used VLBI, and GPS measurements to infer the recent inter-seismic, co-seismic, and post-seismic motion of sites in southern California. During the past year we have focused our investigation on improving the accuracy and density of pre- and post-Landers velocities estimated from GPS surveys and on the combination of these data to produce version 2.0 of the SCEC velocity field. We discuss here three aspects of our analysis: use of multiday orbital arcs to improve the analysis of pre-Landers data; improved post-Landers results for the southernmost sections of the San Andreas system; and approaches to realizing a consistent reference frame for these studies.

Efforts to estimate possible Landers-induced changes in crustal velocities have been limited primarily by the density and accuracy of the pre-Landers measurements in the affected area. There are four potential sources of data that may be used for these studies: VLBI measurements performed by NASA and NGS at 7 sites between 1984 and 1991; GPS surveys of 15 sites between 1986 and 1992; continuous GPS observations at 3 sites between 1990 and 1992, and EDM measurements performed by the USGS at ~100 sites between 1970 and 1990. Each of these data sets has limitations—in time span (continuous GPS), spatial density (VLBI), accuracy (survey-mode GPS), or the need for an external frame (EDM)—so that an optimal estimate of the pre-Landers velocity field will likely require the use of all four. During the current year we examined approaches to the analysis that might improve the accuracy of the survey-mode GPS, using as an example the 1991 Salton Trough - Riverside County (STRC) survey since it was potentially the most important for improving the velocity field. For GPS measurements prior to 1992, the accuracy of the analysis is usually limited by the small number of tracking stations with high quality receivers, leading to a poorly constrained orbit and corruption of the regional data by combination with the poor quality global data. To obtain a more accurate orbit, we used 4-day orbital arcs, allowing for unmodeled perturbations through time- and satellite-dependent stochastic variations of orbital parameters. To isolate the effects of noisy receivers at many of the global tracking stations, we separated the processing of the global and regional data, combining them in the end via quasi-observations (station positions and orbital parameters) (Dong et al, 1998). We also spent some time manually editing the data from some of the poorly behaving receivers at the global tracking stations. Figure 1 shows a comparison for an 80-km baseline of a conventional analysis, in which we combined the regional and global data and used single-day orbital arcs, and the new analysis. The scatter of daily estimates is reduced from 8 mm to 6 mm for the north component and from 10 to 4 mm for the east component. The uncertainty of the mean position from the five daily estimates, after scaling by the square-root of chi-square per degree of freedom, is reduced from 3.5 mm to 2.7 mm for the north component and 4.5 mm to 1.7 mm for the east component. We cannot yet say whether these improvements in positional uncertainties would be achieved for all pre-Landers surveys and whether they would translated into sufficient improvements in velocities to warrant the effort required for the analysis.

The inclusion in our post-Landers solution of data from the 1997 survey of the southernmost San Andreas system has resulted in a significant improvement in the velocity field for key segments of the fault system. In Figure 2 we show the residuals after subtracting the velocities predicted by the elastic dislocation model of Bennett et al.(1996). This model divides the region into blocks that are translating with differential velocities and calculates the elastic deformation caused by slip beneath a given locking depth on screw dislocations marking the block boundaries. The effects of fault-normal displacements are not included in this model. The new slip rates, while more tightly constrained, are consistent at the 95% confidence level with those reported by Bennett et al (1996). A surprising and important result is the relatively high slip rate (5_2 mm/yr) on the Vallecitos - San Miguel fault system in Mexico, which may transfer strain to the Rose Canyon fault in southern California. If confirmed by future measurements, this relatively high slip rate would imply correspondingly high seismic risk in the Tiajana - San Diego region. The residual velocities in Figure 2 are, in general, small in the vicinity of strike-slip block boundaries, but more significant in the regions of fault step overs, e.g., at the southern end of the Salton Sea. An important question is whether these residuals are the result of neglecting elastic strain accumulation associated with the boundary-normal component of motion, or for some other mechanism of transfer of motion between faults. The high quality of geodetic data available for this complicated region and new data expected this year will provide valuable input for investigating the variety of processes discussed in Hager's progress report and our proposal for 1999.

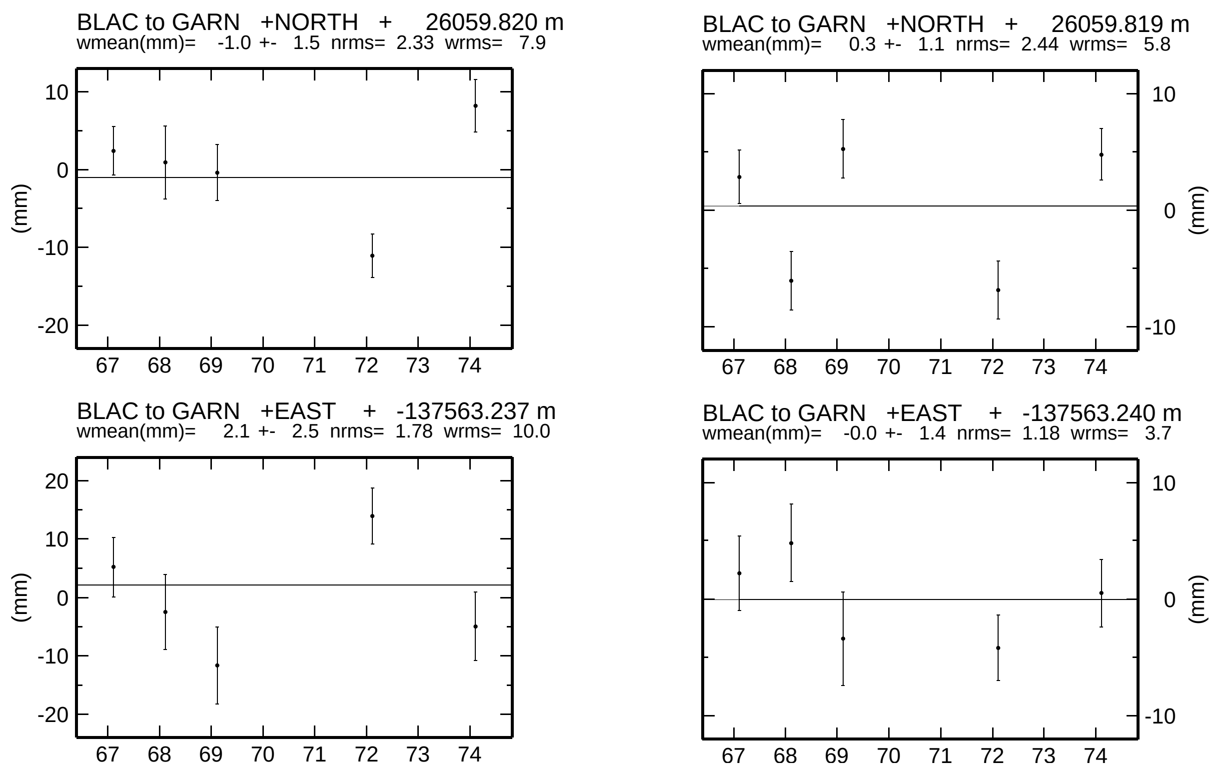

Figure 1. Daily estimates of horizontal components for a 80-km a baseline surveyed in February,. 1991. The left panel shows results from our original analysis using single-day orbital arcs and combining the global and regional phase observations; the right panel shows results using 4-day arcs with variable stochastic perturbations and with separate processing of the global (mixed receiver types) and regional (common receiver type) phase observations.

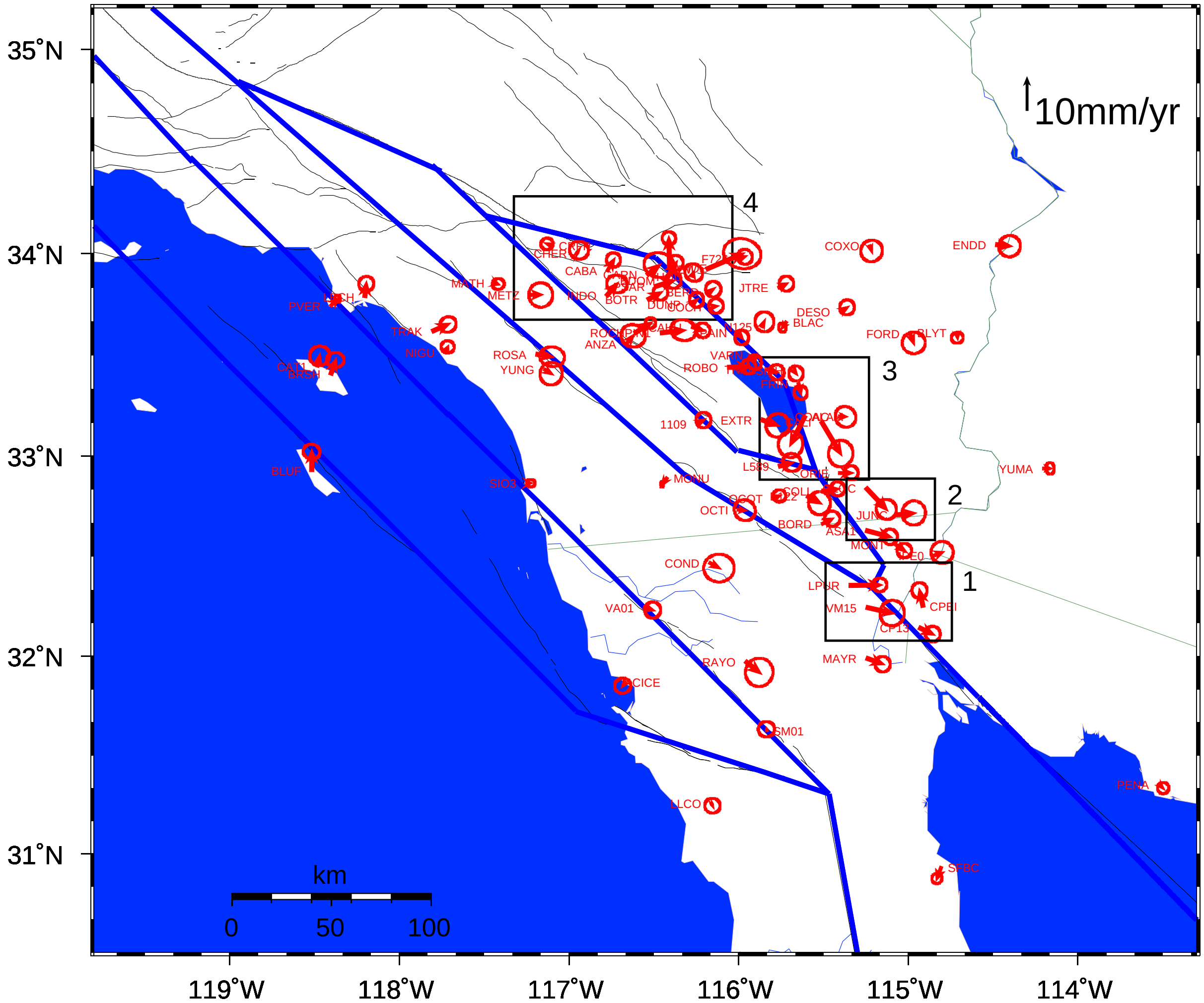

Figure 2. Residual velocities after removing the predictions of a block model for southern California and northern Mexico, shown with 95% confidence ellipses. The fault segments and blocks of the model are shown by solid lines. Boxes show areas of anomalous deformation: 1 and 3 correspond to active step-overs characterized by large rates of fault-normal extension; area 2 suggests additional right lateral faulting east of the Imperial fault; area 4 shows apparent westward escape in a zone of compression.

To perform a tectonically meaningful comparison of pre- and post-Landers velocities we need to be able to define the reference frame for the analysis consistently for the full span of our data (1984–1998). Conceptually, the simplest way to define the frame is by assigning zero velocities (with some uncertainty) to an ensemble of GPS and VLBI stations that have observed for the entire period, are widely enough distributed to provide robust geometry, and are located on stable North America. Unfortunately, only four sites have been used throughout this period—Algonquin (Ontario), Yellowknife (NW Territories), Westford (Massachusetts), and Richmond (Florida)—some of which have motions at the level of several mm/yr from postglacial rebound or local instabilities, and none of which has had a consistent monument or instrumentation. A reasonable extension of this approach is to expand the set of stations to a larger number within North America, account approximately for non-tectonic motions, and rely on averaging to reduce the effect on the California analysis. The most robust approach, from a geodetic point of view, is to use a global ensemble of stations and introduce the effect of plate motion through a geological model (NUVEL-1A) or an analysis of a long series of global observations (ITRF96). In developing the current version (2.0) of the SCEC velocity field, in collaboration with our colleagues at UCLA, we investigated the effect of several variations of all of these approaches. In each case we applied frame constraints by minimizing the departure of the horizontal velocities of a selected set of stations from their apriori values while estimating translational and rotational rates. (Velocities are relatively insensitive to the constraints placed on station positions, so defining the frame in position is not important.) The most significant differences we found for stations in California were region-wide shifts in east velocity with respect to the assumed North American frame. When we used both GPS and VLBI data in the solution, we obtained consistent California velocities (within 1 mm/yr) when we assumed either ITRF96 velocities (and NUVEL-1A plate motions) for 16 global stations or zero velocity for 7 stations in southwest North America: Platteville (CO), Ft Davis (TX), Los Alamos (NM), Pietown (NM), Vernal (NV, Kitt Peak (AZ), and Flagstaff (AZ). Assuming zero for six mostly northern North American stations— Algonquin, Yellowknife, Westford, and Richmond plus Fairbanks (AK) and Penticton (BC)—shifts California velocities 4 mm/yr westward. If we include only GPS data in the solution, the frame is more sensitive to station selection, with east-west shifts up to 8 mm/yr. Maintenance of a consistent frame for tectonic interpretation is particularly difficult because the significant changes in both the VLBI and GPS networks coincided approximately with the date of Landers. Note, however, with our approach to defining the reference frame, various realizations of the frame will differ only by translational and rotational rate without internal distortion of the solution (see Dong et al. (1998), Appendix C)**.** Thus changes in strain rate can be distinguished from changes in the reference frame.

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