SCEC Crustal Motion Map:
Collaborative Analysis

Report for 2005

Zhengkang Shen, Robert W. King, Thomas A. Herring, Duncan Carr Agnew

1. Introduction

The Southern California Earthquake Center has supported the development of a number of community models, one of which is the Crustal Motion Map, or CMM (formerly known as the Horizontal Deformation Velocity Map). Version 3.0 of this was released in August 2003; see *http://epicenter.usc.edu/cmm3*.

2. CMM Update Activities

Over the past year we have made good progress towards a new version of the CMM which will provide even more complete coverage, and address some of the remaining issues in Version 3. Our goal remains one that is, so far as we know, nearly unique in the crustal-motion community: to collect all relevant GPS data and process them in a consistent fashion, so as to produce the fullest possible set of station velocities for use in geophysical interpretation and seismic hazard estimation. This project combines data sets that otherwise would be difficult to evaluate, or would not be used at all.

Our activities this year have been modified somewhat by the funding, by the California Earthquake Authority (CEA) of a new Working Group on California Earthquake Probabilities (WGCEP). The WGCEP will be producing hazard estimates for all of California; to do this requires (among other things) estimates of fault-slip rates for the whole state. The WGCEP therefore plans to fund several groups to produce such estimates by inverting geodetic data; but to do this inversion requires a statewide set of station velocities. Our group agreed to produce this. The timetable of the WGCEP has meant that this needed to be started during 2005 (in advance of funding); this activity has consumed significant effort during the year.

2.1. Data Archiving

As before, our first tasks have been to get data into the archive at the SCEC Data Center, and to prepare metadata. The more carefully this is done, the easier the subsequent processing. As always, all data are publicly available. **Figure 1** shows the locations for which we archived data in 2005—though by no means all of the data were actually collected in that year. As the map shows, we archived data from around the Parkfield and San Simeon earthquakes, along the Eastern California Shear Zone, from Los Angeles and San Bernardino, from Baja California, and from the Coachella and Imperial Valleys, and from a Caltrans survey in Northern California. Some of these datasets (unlike many we had archived earlier) were already well-organized, so we developed a “shortcut” archiving method for these—which also minimized overlaps with other archives. In 2005 we processed 1131 files through our standard procedure and 3173 through the shortcut procedure, bringing the total number of files archived to 23244, covering a total of 2251 points. The left panel of **Figure 1** shows the locations of points with data archived in 2005.

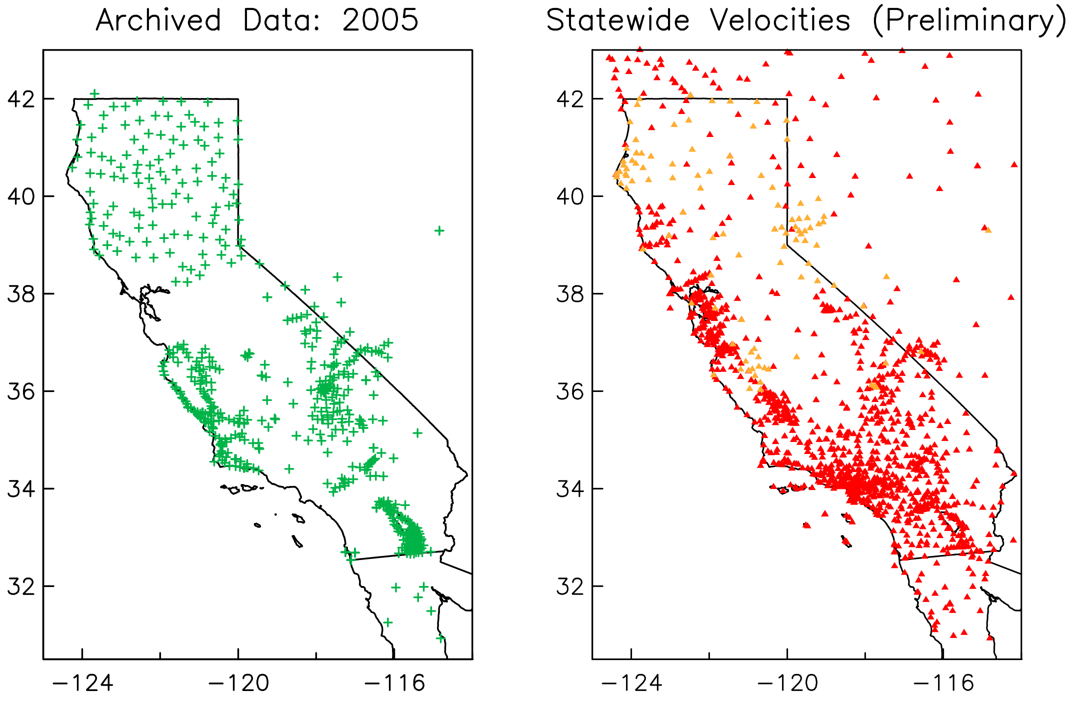

Figure 1

2.2. Data Processing

All of the data archived this year has now been processed through the initial production of daily solution files (SINEX) from the original phase data. Given the more powerful CPU available, we have moved this processing to MIT from SOPAC, with the metadata provided by UCSD. The UCLA group has reprocessed some of the earlier time periods to take account of corrections and changes. This part of the processing is now fairly straightforward and can be done nearly "hands-off"—though it does require reruns as new models are developed. For example, as the CMM proposal indicates, new phase-center models for the satellite antennas promise to improve the vertical component significantly.

Subsequent processing involved parallel efforts at UCLA and MIT (using QOCA and GLOBK) to produce site timeseries and velocities. As before, cross-checking between these provided consistency and greater freedom from errors. We produced, for use by the WGCEP and for initial checking, a preliminary version of the CMM4 velocity field, incorporating all the newly-processed daily solutions, except for:

- Postseismic data files within 3 weeks after the Landers and Hector Mine shocks.
- Coseismic sites with less than 3 epochs or 2 years span.
- All the non-coseismic sites with less than 3 epochs, or less than 4 years span

Producing velocity files from this allowed us to locate problems, many of which required iteration, in some cases back to the initial processing.

Figure 1 in the CMM proposal shows the impact of these efforts, in terms of adding new points to the next version of the CMM (and to a lesser extent decreasing the errors in other points). For southern California and northern Baja California, we have added about 240 points; this number is not exact because we are doing final quality control on the results.

To meet the needs of the WGCEP we have also produced a preliminary set of velocities for all of California (and the immediate environs). These were found by combining velocity fields from several sources: a much faster but less rigorous procedure than our standard processing. The velocities used came from

1. For southern California, our preliminary update to the CMM.
2. The BAVU velocities from the San Francisco Bay area.
3. Velocities for the region north of BAVU from an ongoing project of Mark Murray's.
4. Velocities for Cascadia and northern California from an on-going project of Rob McCaffrey's.

The right panel of **Figure 1** shows the coverage of this model (in red); the points in orange are ones we expect to add in the near future.

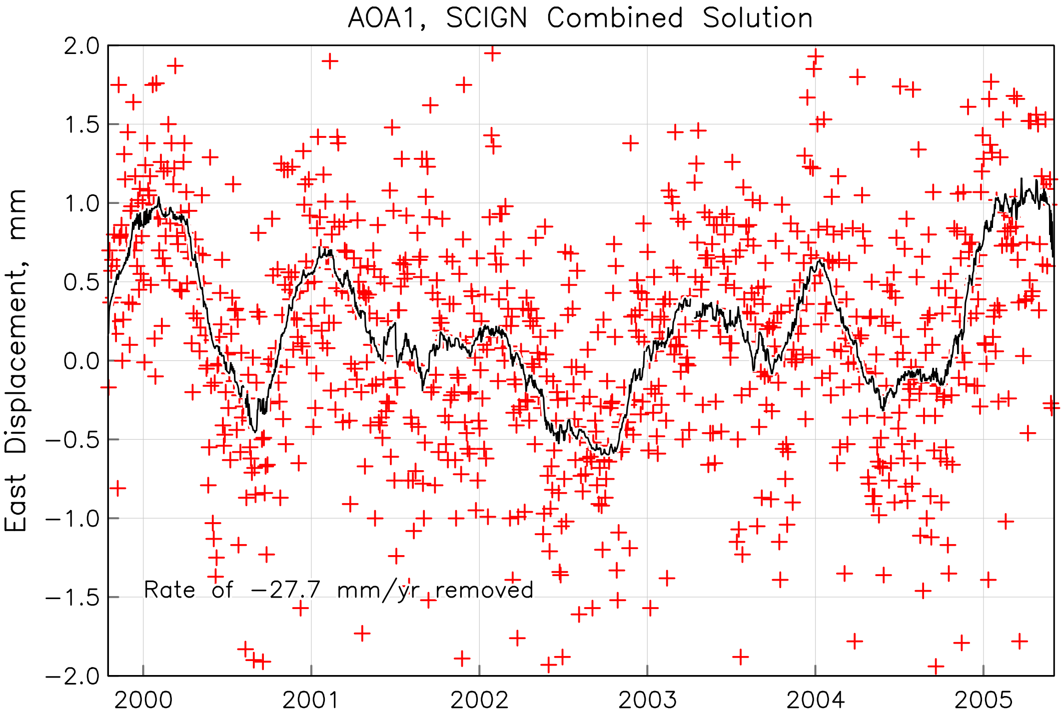

Figure 2

2.3. Error Estimation

Part of our work this year has involved improving estimates of errors in site positions and velocities estimated from GPS observations. These include uncorrelated ("white") and correlated ("red") noise, as seen in **Figure 2**, in which the red crosses are daily values (visually dominated by white noise) and the black line a smoothed version (which shows the correlated behavior). These noise levels depend on: the satellite and tracking network (weaker in earlier years); the instrumentation, signal environment, atmospheric conditions, and monument stability at each site; and deficiencies in our models for the motions of the satellites and of the sites (e.g. from loading). For continuous observations we can estimate the correlated noise e.g., Zhang *et al.* (1997); Mao *et al.* (1999); Williams *et al.* (2004)). We model the noise spectrum by a first-order Gauss-Markov (FOGM) process:

$$\phi_{xx}(t) = \sigma^2 e^{-|t|/\tau} \tag{1}$$

where $\phi_{xx}(\tau)$ is the first order Gauss-Markov autocorrelation function, σ^2 is the long-term variance, and τ is the correlation time.

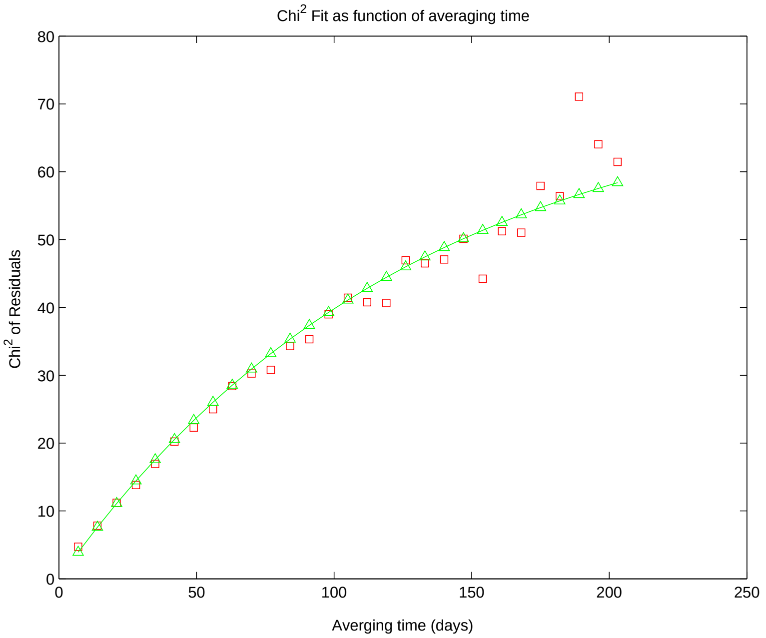

Figure 3

We estimate the parameters for this noise model from time series for individual stations by averaging the residuals over increasingly longer intervals and computing χ^2per-degree of freedom (χ^2/dof) for each interval. **Figure 3** shows this for the time series in **Figure 2**; as expected for non-white noise the χ^2/dof values increase with increasing averaging time for nearly all times series. (The light squares are the averages computed from the data; triangles and line represent the best fit exponential function). We then fit this to the FOGM model to estimate the correlation time and long-term variance, from which we can find uncertainties for the velocities given the length of the time series. Our analysis software (GLOBK or QOCA) models noise by a random walk (a special case of the FOGM model when the correlation time τ is infinite); we find the random walk level that would predict the same velocity uncertainty as the FOGM model at for the same span of time, and apply this model in our forward runs to estimate realistic uncertainties.

To determine whether or not the velocity uncertainties so estimated are realistic, we have compared the random scatter of velocities with their uncertainties in regions where the strain rates are very low (e.g. McClusky et al., 2000). In general the number of velocities which exceed the bounds of their error ellipses matches the expected number for the confidence level predicted by Gaussian statistics, to within about 20%. There are many factors that can distort the estimates for individual stations or groups of stations: non-stationarity of the noise process; spatially correlated errors, such as post-seismic relaxation; or a much poorer fit of χ^2/dof for long averaging times. Determining the long-term variance by averaging of the times series becomes more difficult as the number of samples decreases, and is impossible for sparsely sampled survey-mode data. We plan to use the errors estimated for continuous stations to infer reasonable values for survey-mode observations that share a similar time period and geographic region.

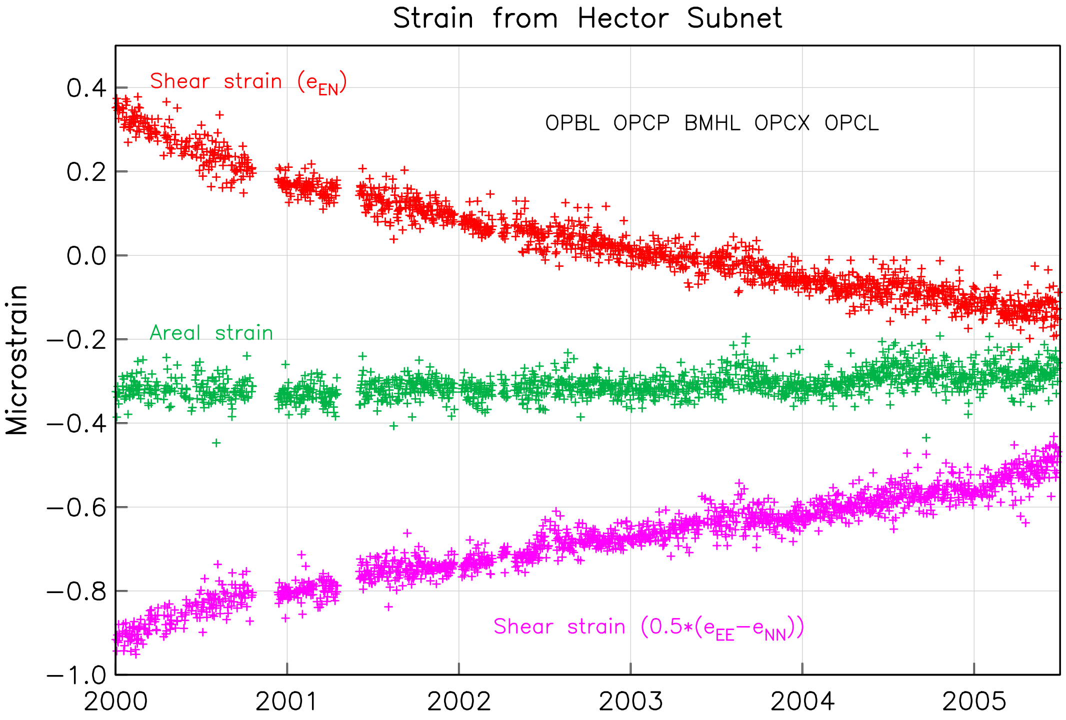

Figure 4

2.4. A SCIGN Transient

We discuss briefly some other work done by Agnew on behalf of SCEC, even though this was not strictly speaking a part of the CMM project. Rate changes in a number of GPS time series were first noticed by USGS personnel in June 2005, and led to some concern that there might be a deformation transient in progress across most of Southern California. To supplement the USGS work, we computed strain time series (found by combining a number of stations) for several areas of interest. **Figure 4** shows an example: the time series for the region of the Hector Mine earthquake, for which the strains are continuing to change postseismically, but in the very smooth way; there is no clear sign of unusual behavior in early 2005. The Salton Trough also showed no departures from steady strain change. In common with other investigators, this analysis did show a very large strain transient for the San Gabriel valley during the first part of 2005; its spatial pattern and temporal history suggest possible hydrologic influence. This transient remains under investigation, with a separate proposal to study it having been submitted to SCEC.

References

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