Time-dependent deformation of California from inversion of GPS time series

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- Correcting PBO and CMM4 GPS time series for transients; quakes, afterslip and volcanoes
- Estimates of secular GPS velocities (for CGM)
- Estimates of source parameters
- Time-dependent deformation – strain rate histories and Coulomb stress histories

Extracting velocities from GPS time series

- Model all transients as physical process using small number of free parameters
- Earthquakes as planar sources,
- Afterslip with log decay constant or generic slip history (~20% of moment),
- Volcanic regions with Mogi sources and generic time history,
- Resulting linear term is secular velocity.

GPS time series model (TDEFNODE):

$$X(t) = X_o + V(t-t_o) + S(t) + Q_i(M_k)H(t-t_i) + Q_j(M_k)A_j(t,t_j)$$
$$+ M_v(t) + R(t) + O(t) + E(t)$$

t_i – time of event
X_o, t_o – reference position and time
V – linear velocity
S – seasonal (annual and/or semi)
Q – Earthquake co-seismic displacements for mechanism M
M_v – volcanic source
R – mantle relaxation
H – Heaviside
A – Afterslip time history (sampled history or Shen log function)
O – offsets, equipment change or other non-tectonic
E - errors

Products: linear site velocities, source parameters, seasonal amplitudes

Details:

Source parameters for 20 earthquakes and afterslip for 10 of them (some quakes are outside the 'study' area). Start with simple planar sources (Okada) and assume a log time dependence for afterslip (Shen et al; $D(t) = A \log10(1 + (t-to)/Tc)$. The model has 236 free parameters for the transients and about 270k observations (3 component positions of time series). The parameters are estimated by weighted least-squares (simulated annealing and grid search).

Velocity uncertainties are estimated using the misfit variance and random walk (1.0 mm/sqrt(yr)). The method imposes spatial correlations on the transient corrections to the time series (i.e., the amplitude at all sites for a given event is derived from 9 or 10 parameters rather than each time series having an independent amplitude). This may do a poorer job on the PBO velocities (in general) but I think it will help with the CMM4 and PNW velocities at survey-mode sites with only a few observations and shorter cGPS time series. I plan to apply it to the longer survey-mode time series that YK Shen is now developing. This approach also addresses the CGM goal of estimating earthquake source parameters.

Data

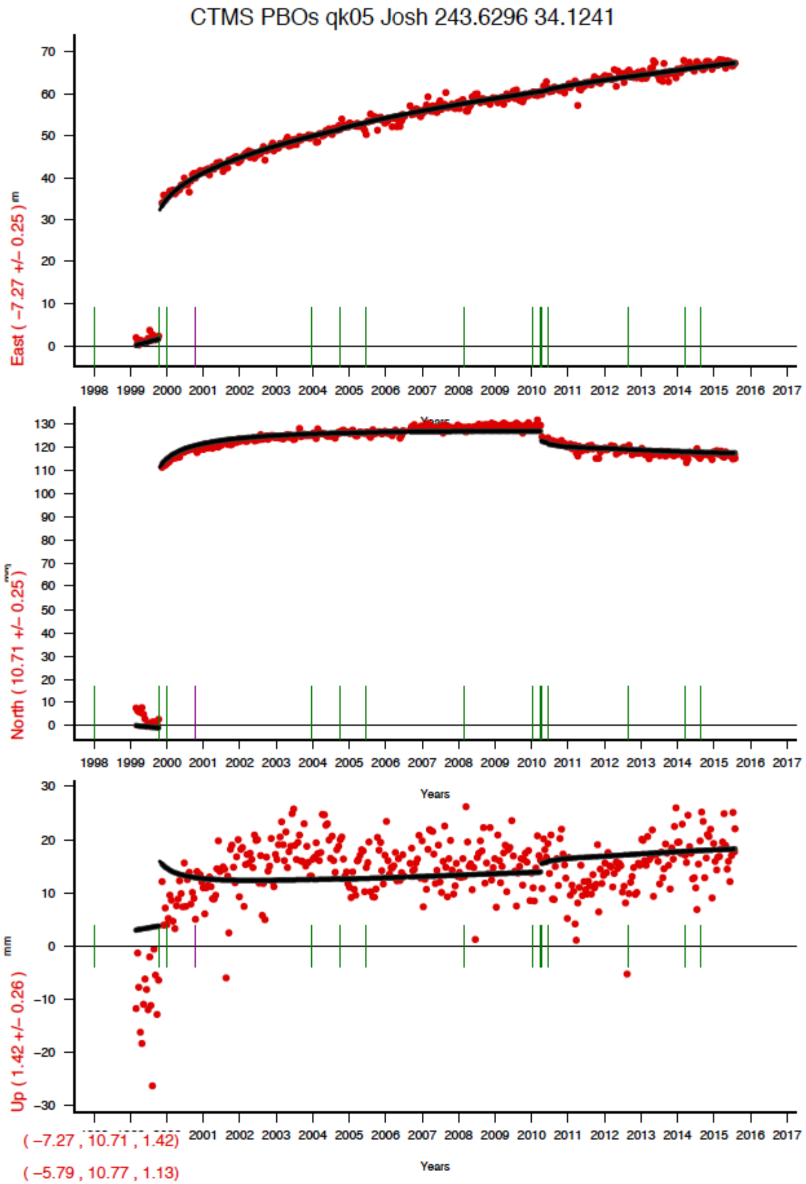
- PBO time series 1996-2015
- CMM4 time series 1991-2004
- PNW time series 1991-2015

- Fix offsets, solve for seasonal terms, remove outliers

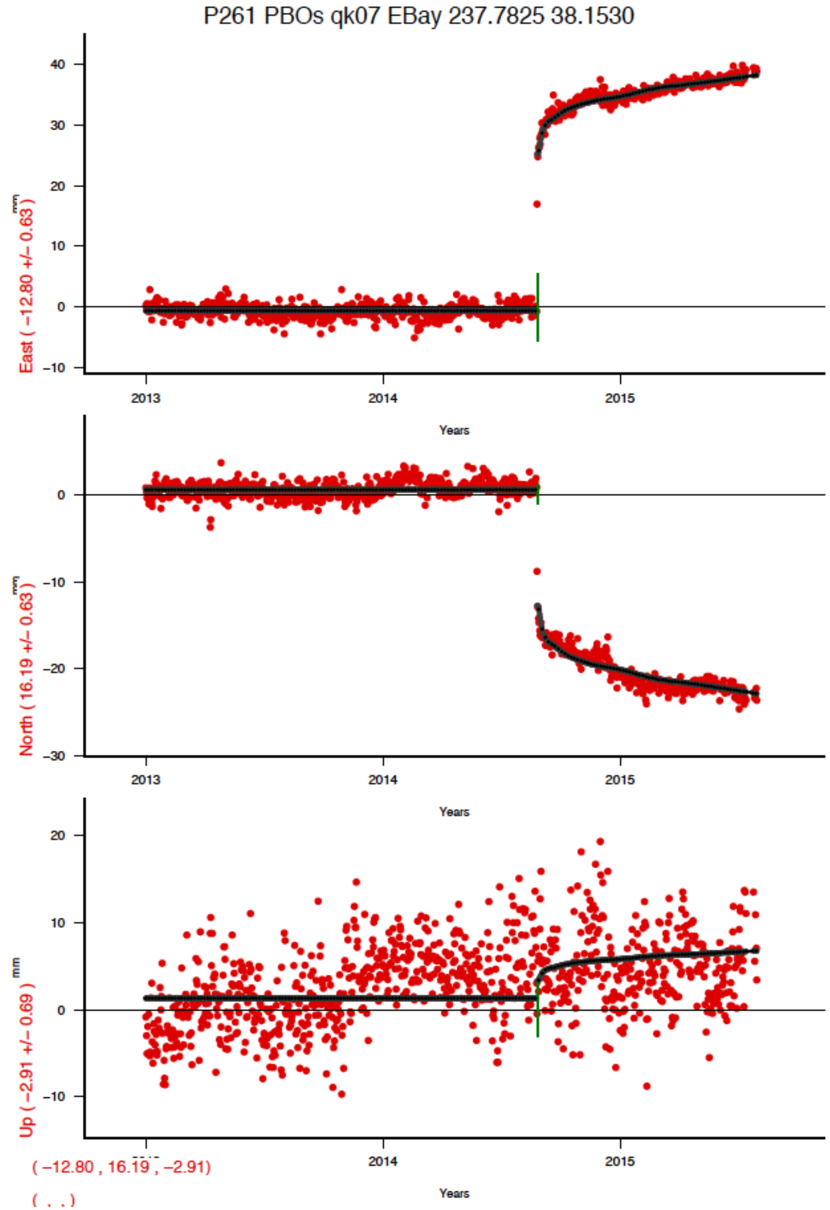
Strain rates and Coulomb stress

- Given a set of best-fit parameters, 3D strain rates can be calculated at any time and any point in the model domain
- From the strain rates, Coulomb stress changes can also be calculated for a given target fault orientation and depth
- These can both be compared to seismicity

In the plots below the time series have been de-trended by their predicted secular velocities. Red dots are observed positions and black are predicted.

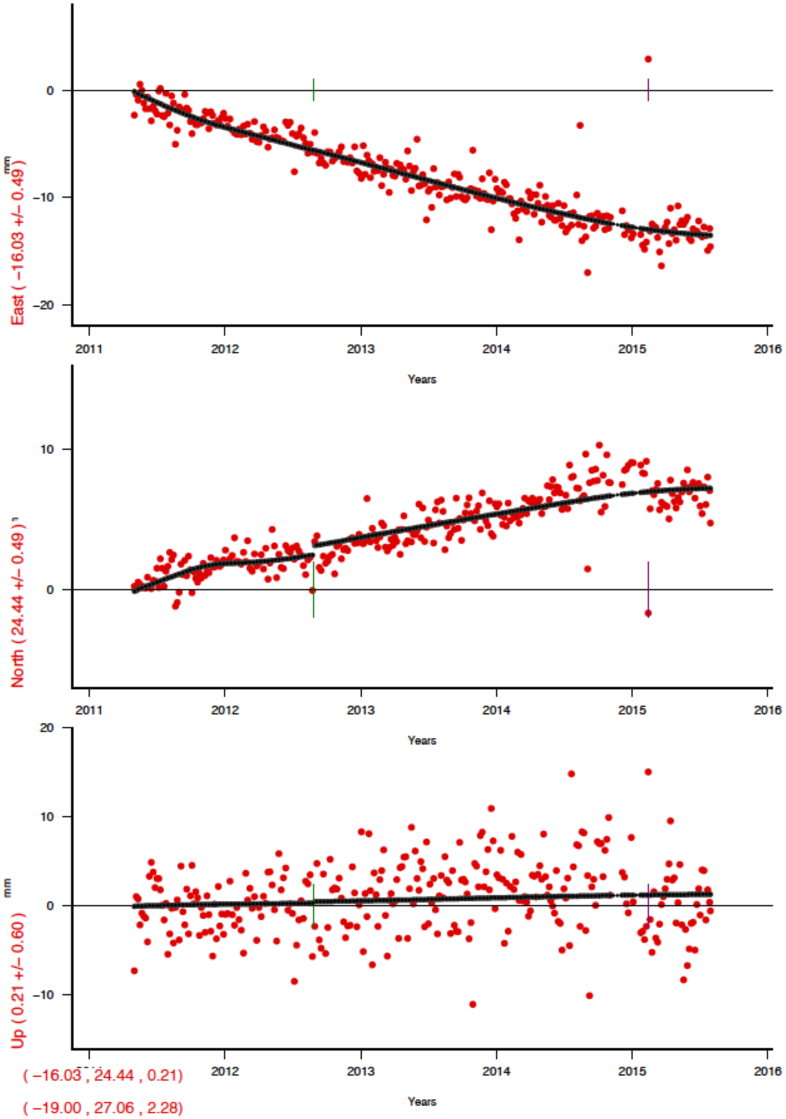


Hector Mine and El Mayor Cucapah

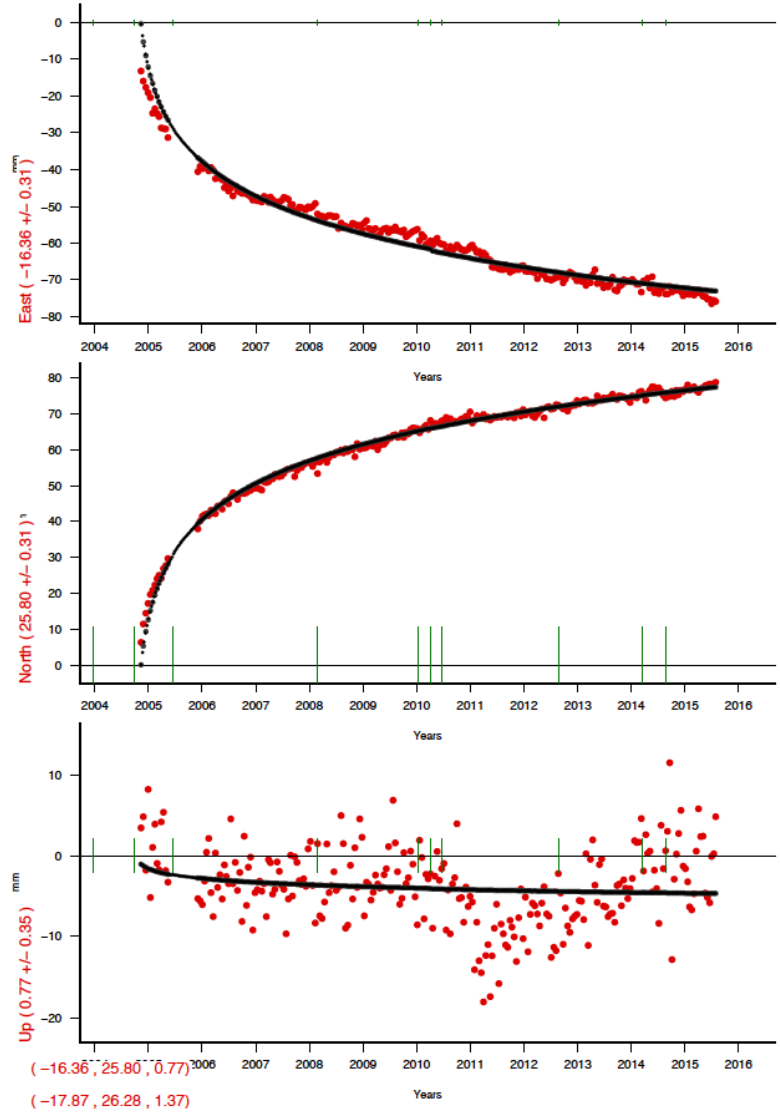


Napa quake

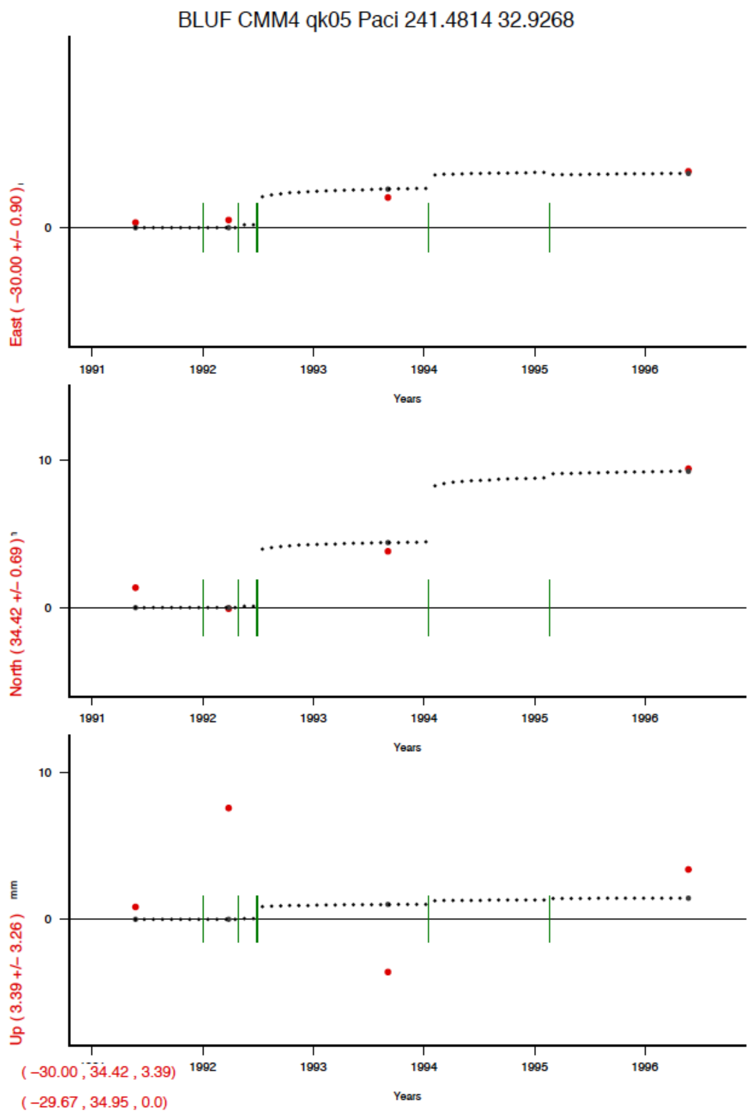
PTAX PBOs qk06 Anza 244.5437 32.3775

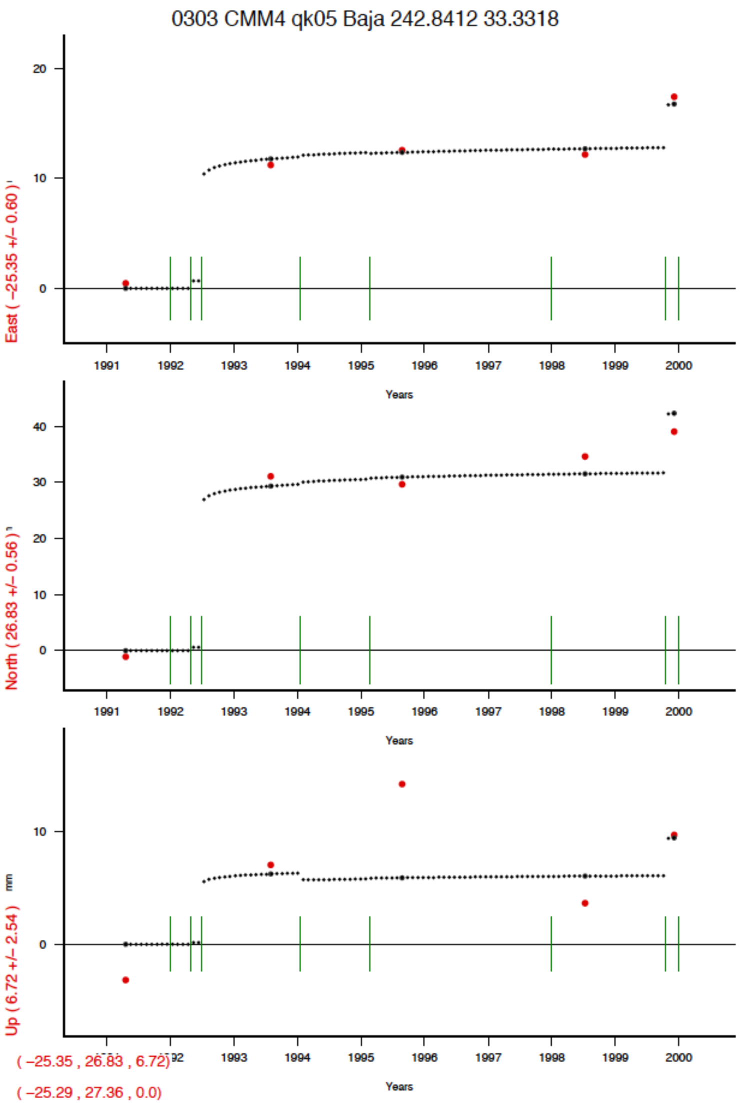


P281 PBOs qk05 Luis 239.6105 35.8411

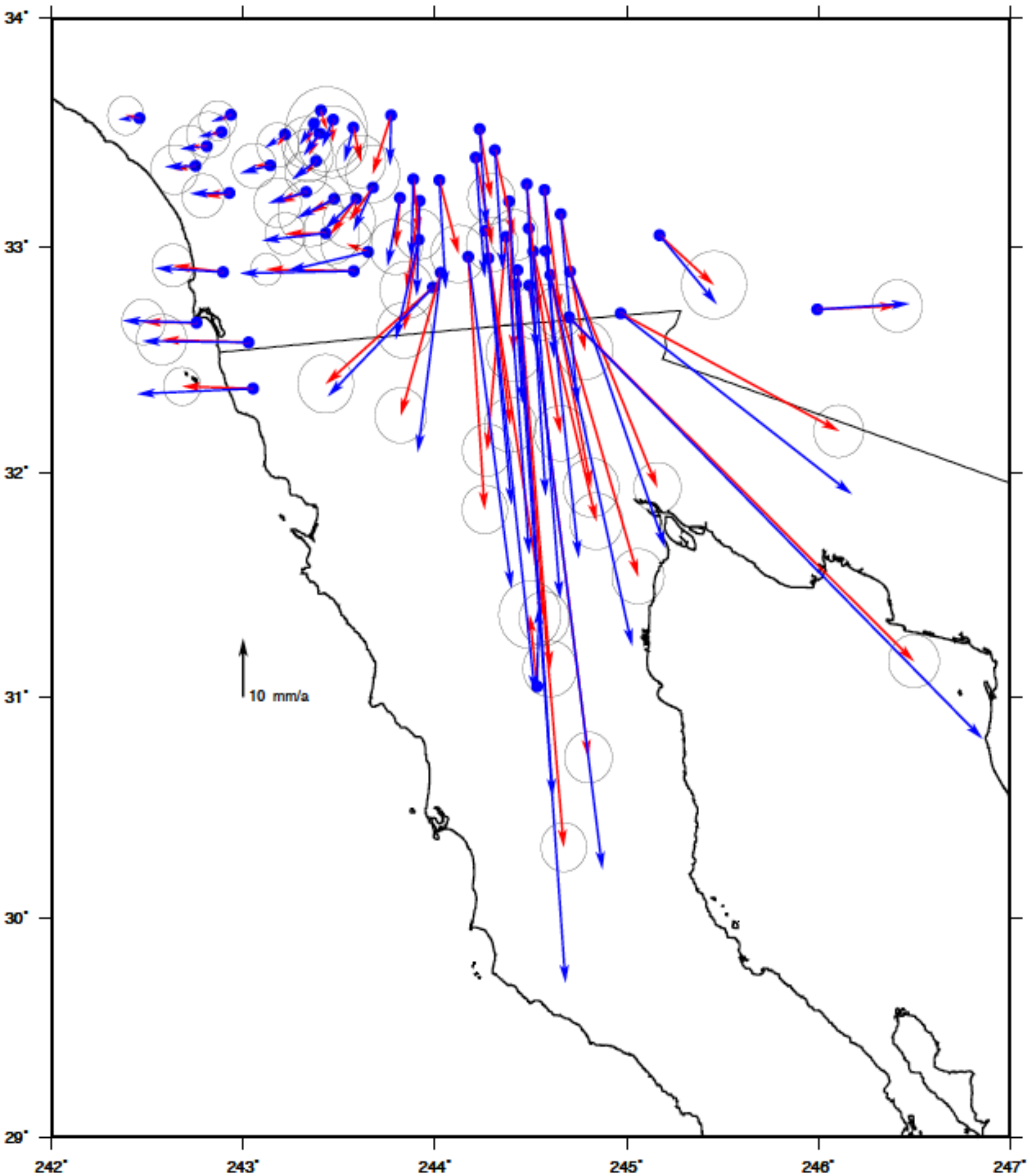


Examples of survey-mode time series



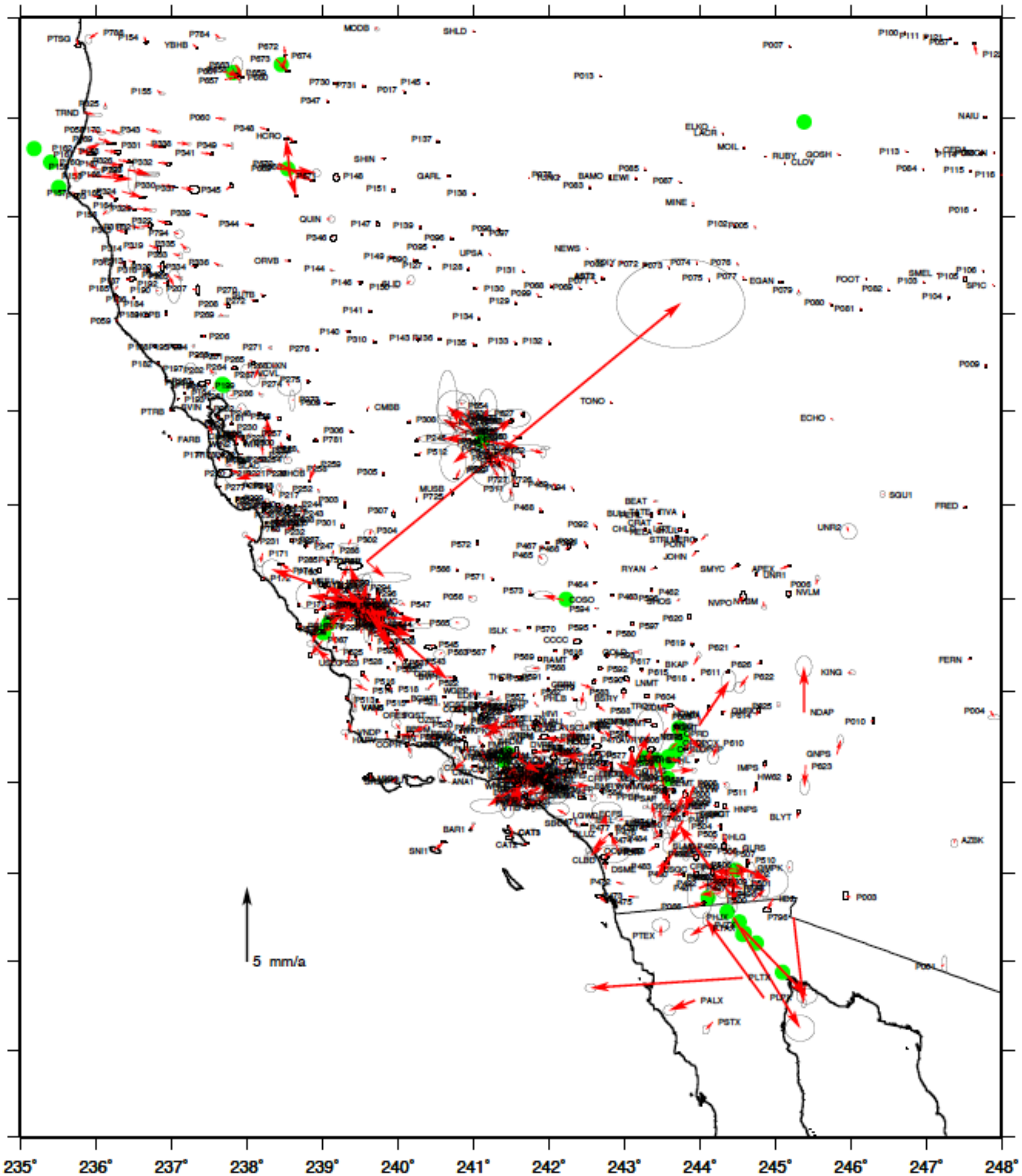


EMC_2010.258



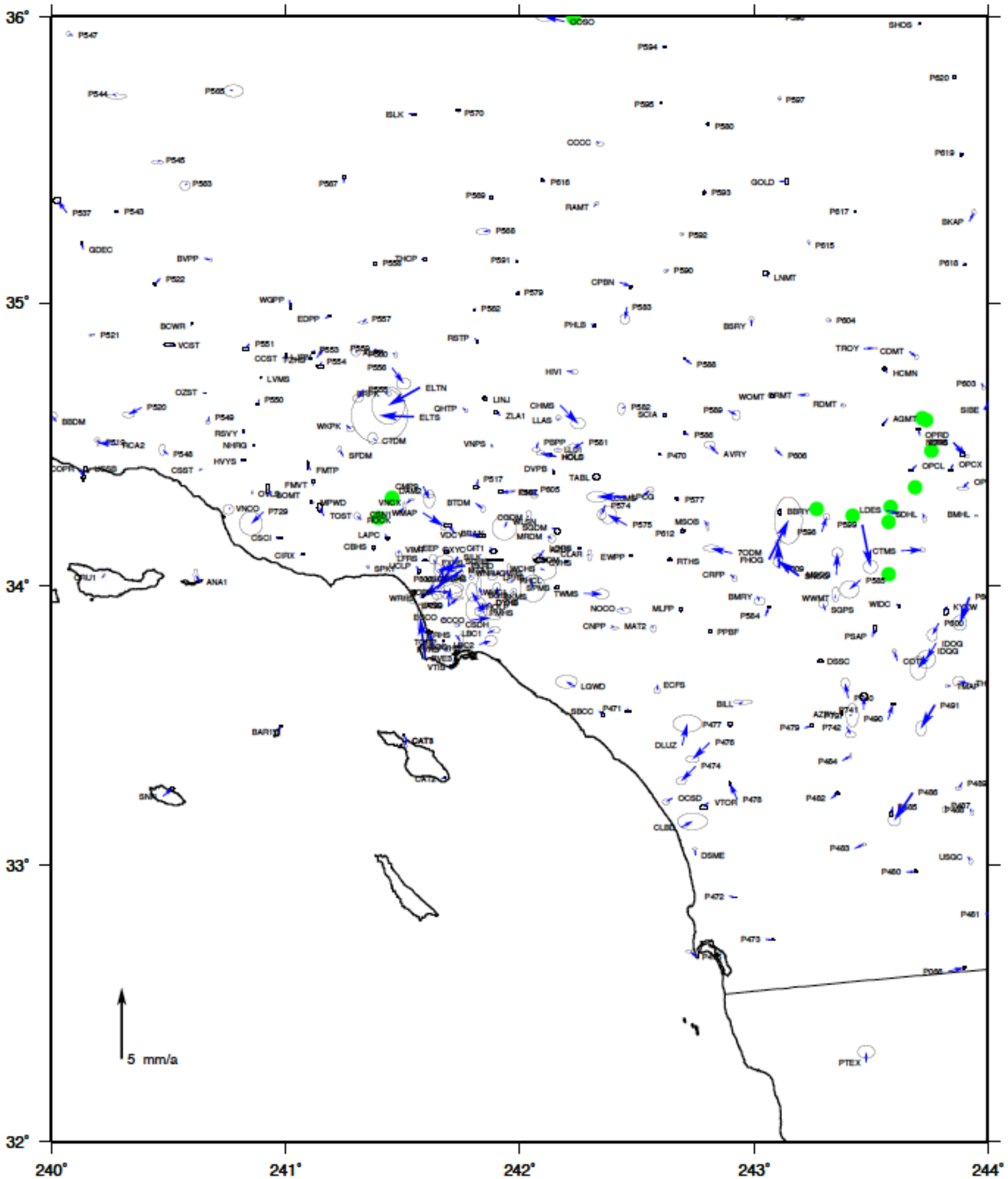
In some cases co-seismic displacements are used.

Red = observed, blue = predicted

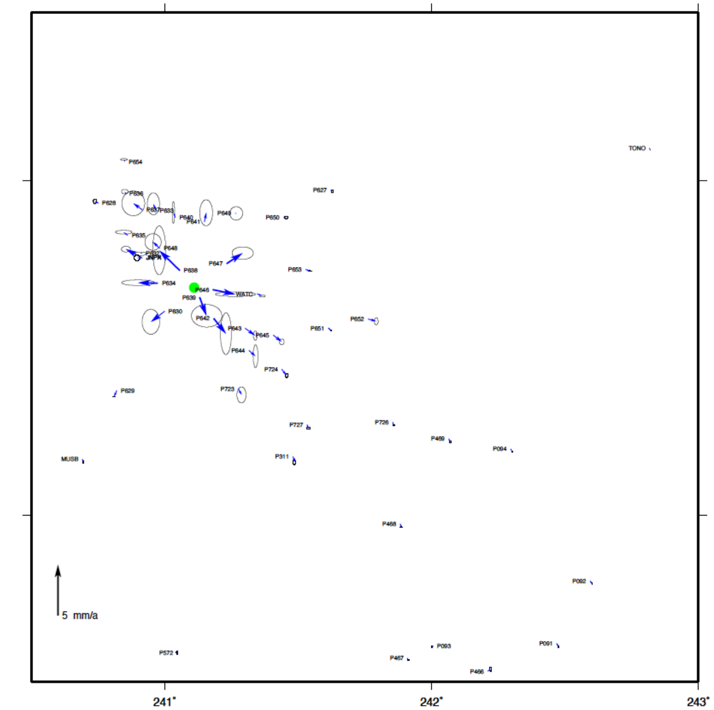


Compare to PBO velocities

(Green dots are transient sources)



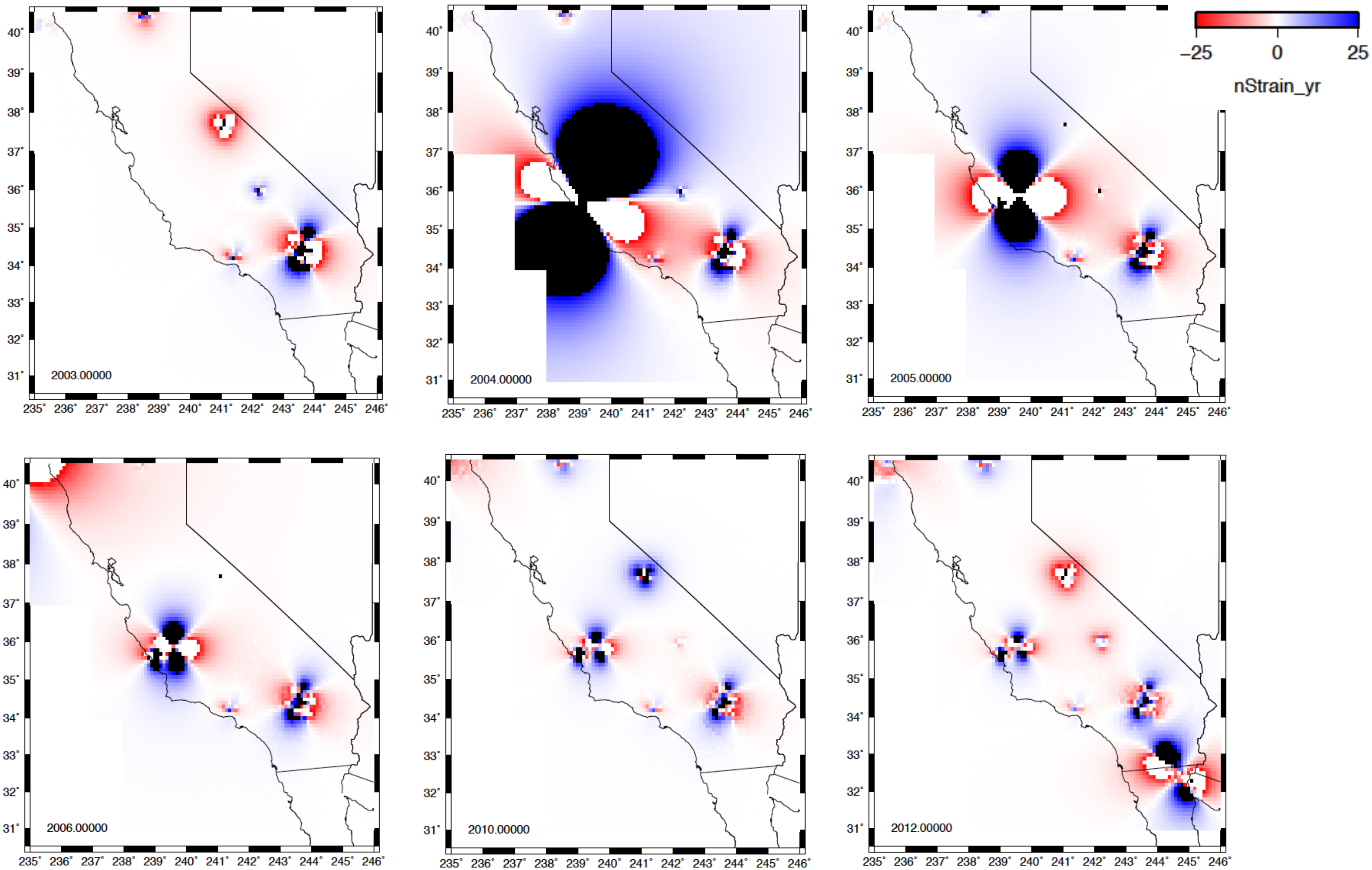
Southern California



Long Valley

Difference between PBO velocities and from this work

Snapshots of Transient Areal Strain Rates



Quicktime movie at: http://web.pdx.edu/~mccaf/CA/strain.mov

Next steps:

- Generate secular motion model and strain rates using secular velocities and block model
- Compare velocities to other methods (CGM effort)
- Effect on geodetic fault slip rates
- Compare strain rates and Coulomb stress to seismicity
- Etc.

Community Block Model