Using InSAR + GPS to Monitor Crustal Deformation in the Walker Lane

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Introduction

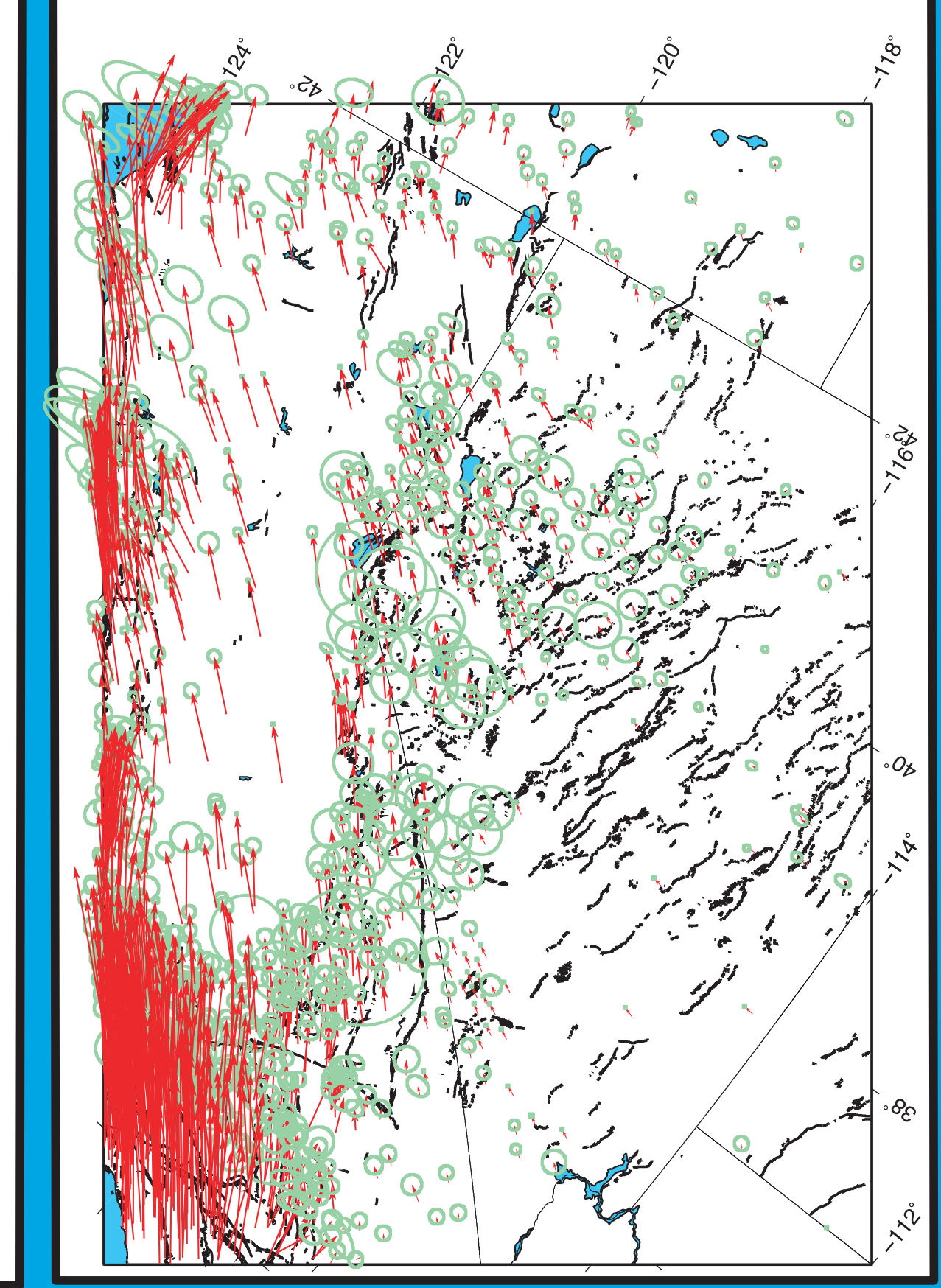
Great progress has been made in the past 5 years on building crustal deformation strain maps of the Walker Lane and western Great Basin using GPS observations. The number of GPS velocities available from the EarthScope Plate Boundary Observatory and from the Mobile Array of GPS for Nevada Transtension (MAGNET) is still increasing. However, spatial resolution realistically possible with GPS observations is much lower than what InSAR can provide.

This presentation outlines a proposed stategy for integrating InSAR observations with the velocity field obtained for GPS networks. Radar line-of-site velocity maps will be incorporated into the strain mapping using additional constraint equations that project the model velocity field into the radar line of site. Reduction in the number of additional data will be achieved by limiting the phase rate observations to a set of interferometric point scatterers that lie in areas of expected bedrock stability selected via a geologic mask.

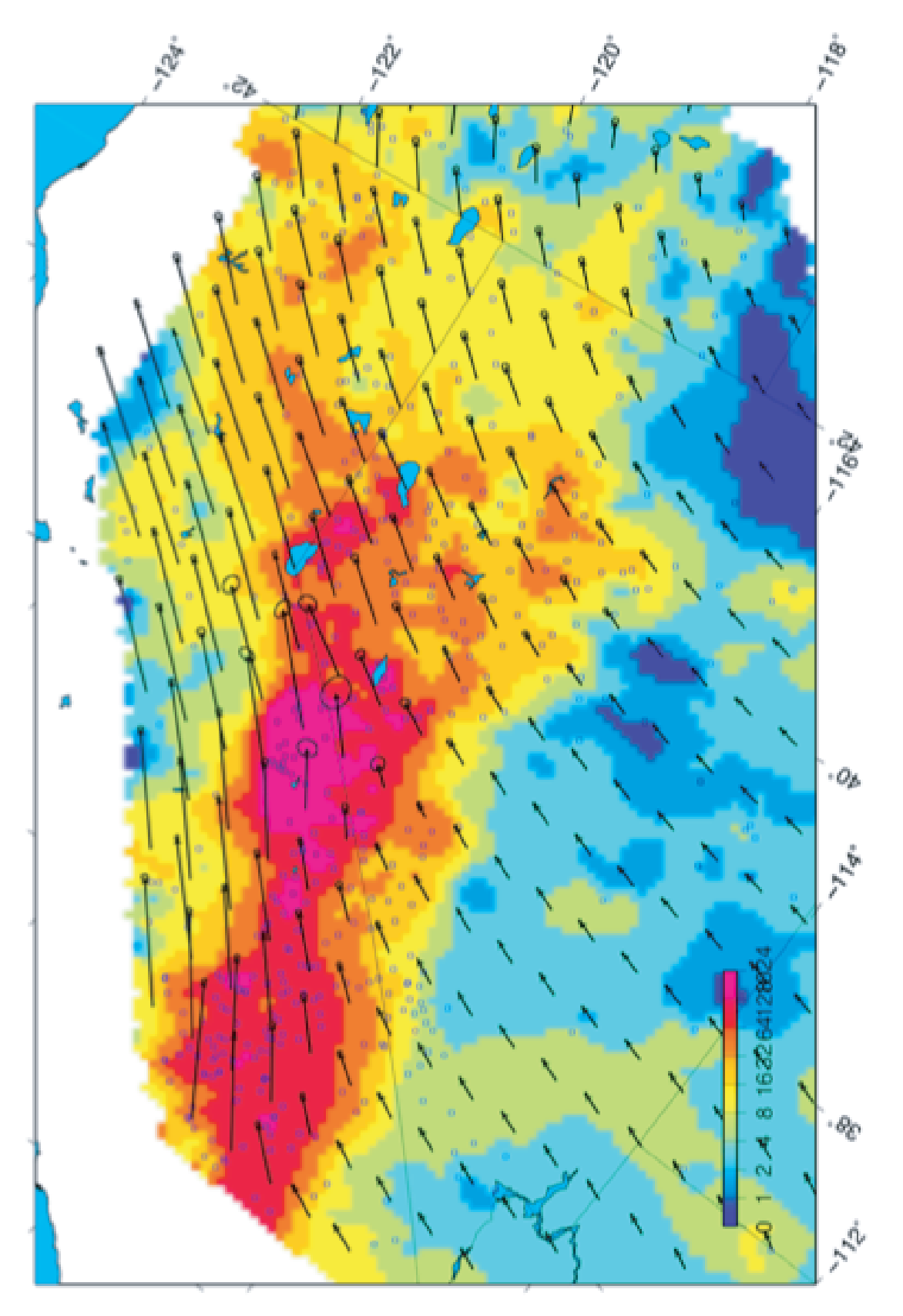
Atmospheric effects represent one of the most important sources of noise in this procedure. This noise can be mitigated by stacking or by applying calibrations to the interferograms. We have experimented with the GTTM model of Li et al., (2006), but are actively exploring other techniques for mitigating atmospheric effects.

GPS

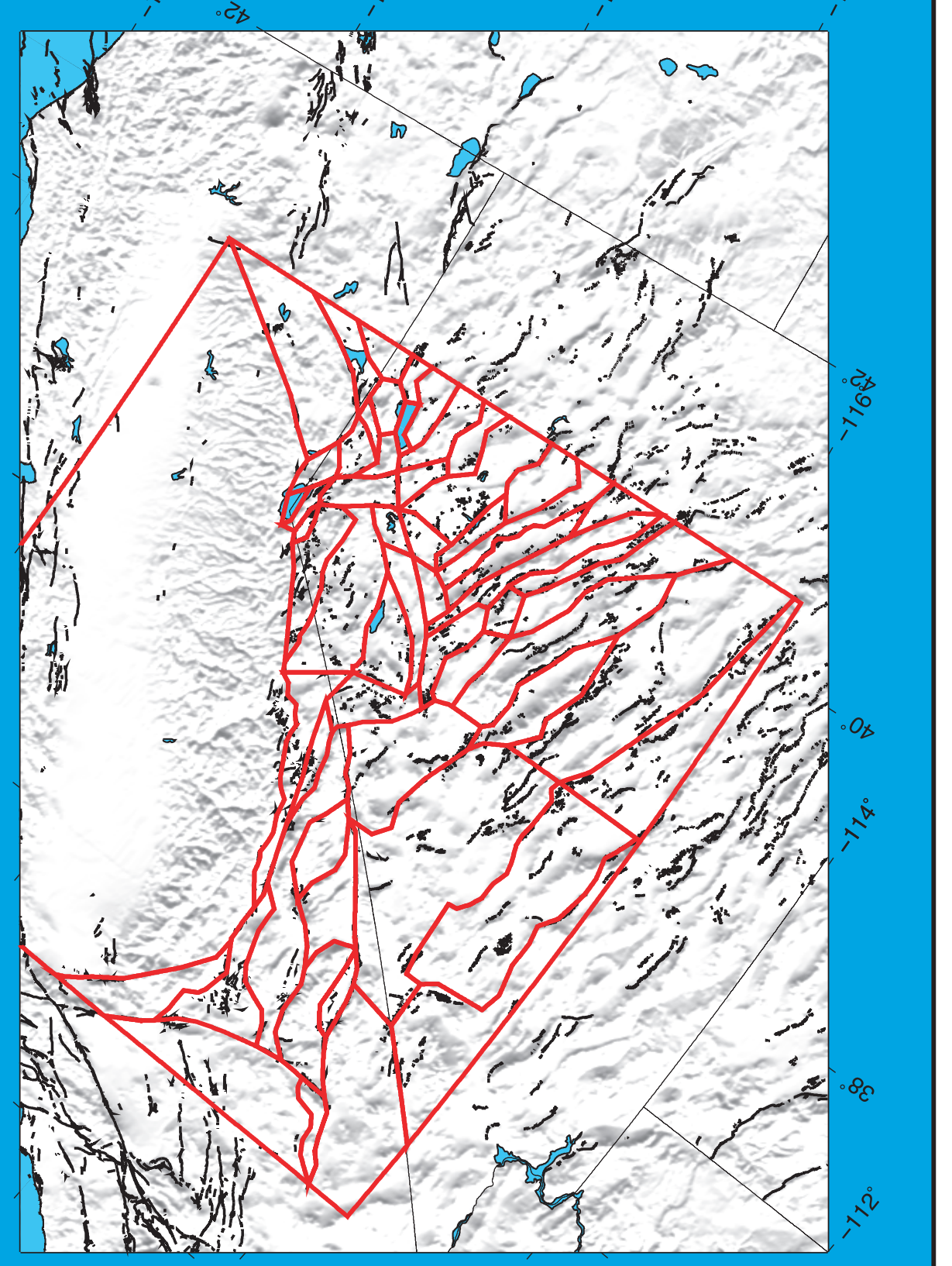
Velocities in a North America Frame



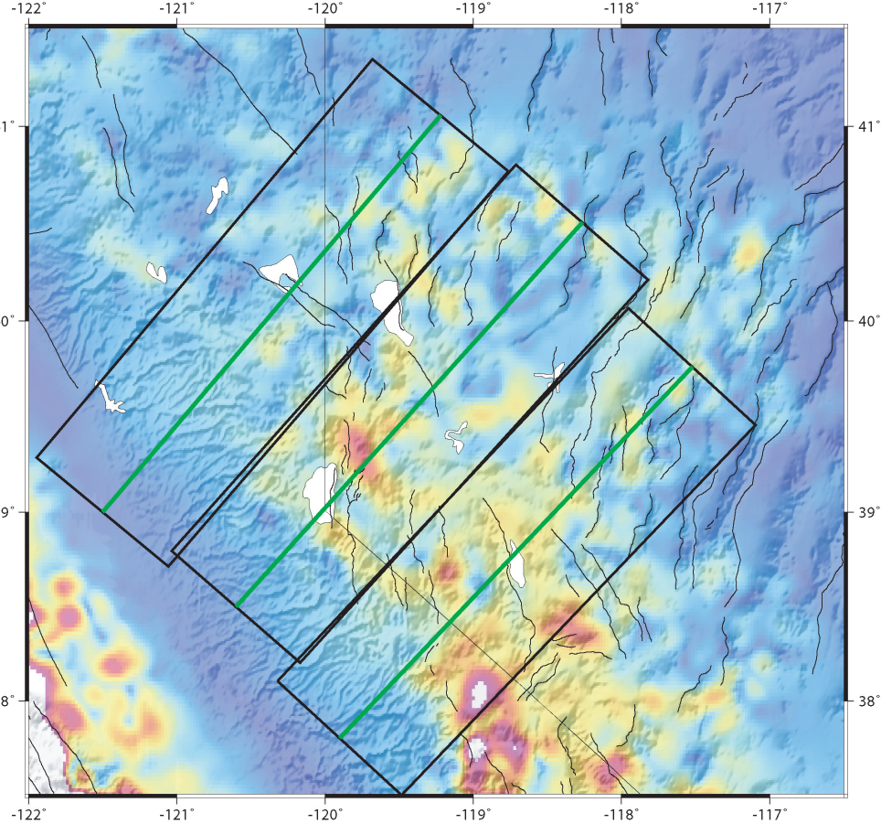
Strain Rate Maps

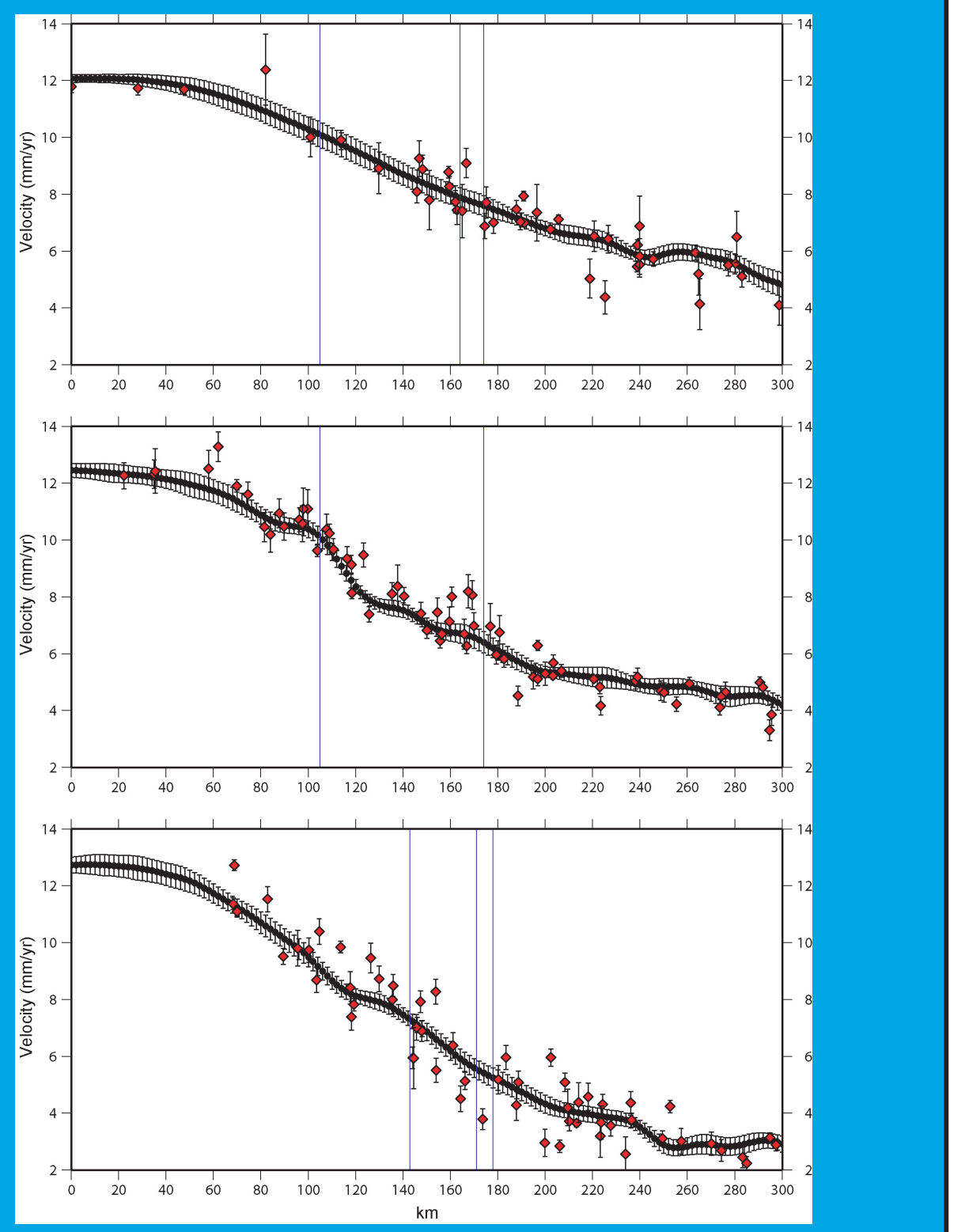


Block Models



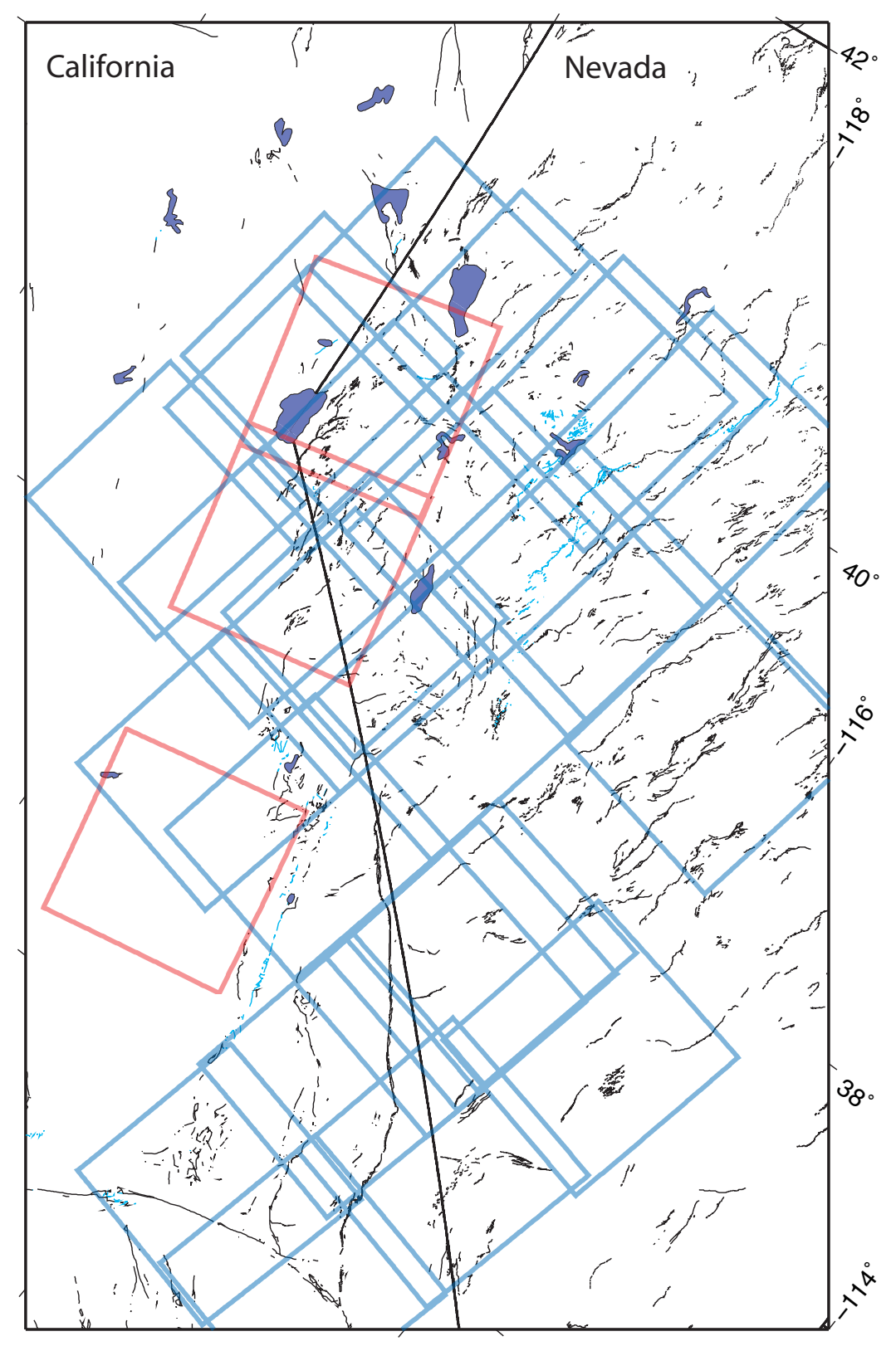
Example of a regional strain map (below) and profiles of GPS data and strain map model predictions (right) show how GPS data are revealing structure in the velocity field that are a challenge to model with spline-based continuums. Interpolation of the velocities with additional constraint between the GPS sites has the potential to enchance our resolution of crustal deformation, and possibly provide fundamentally new constraints on vertical tectonics.



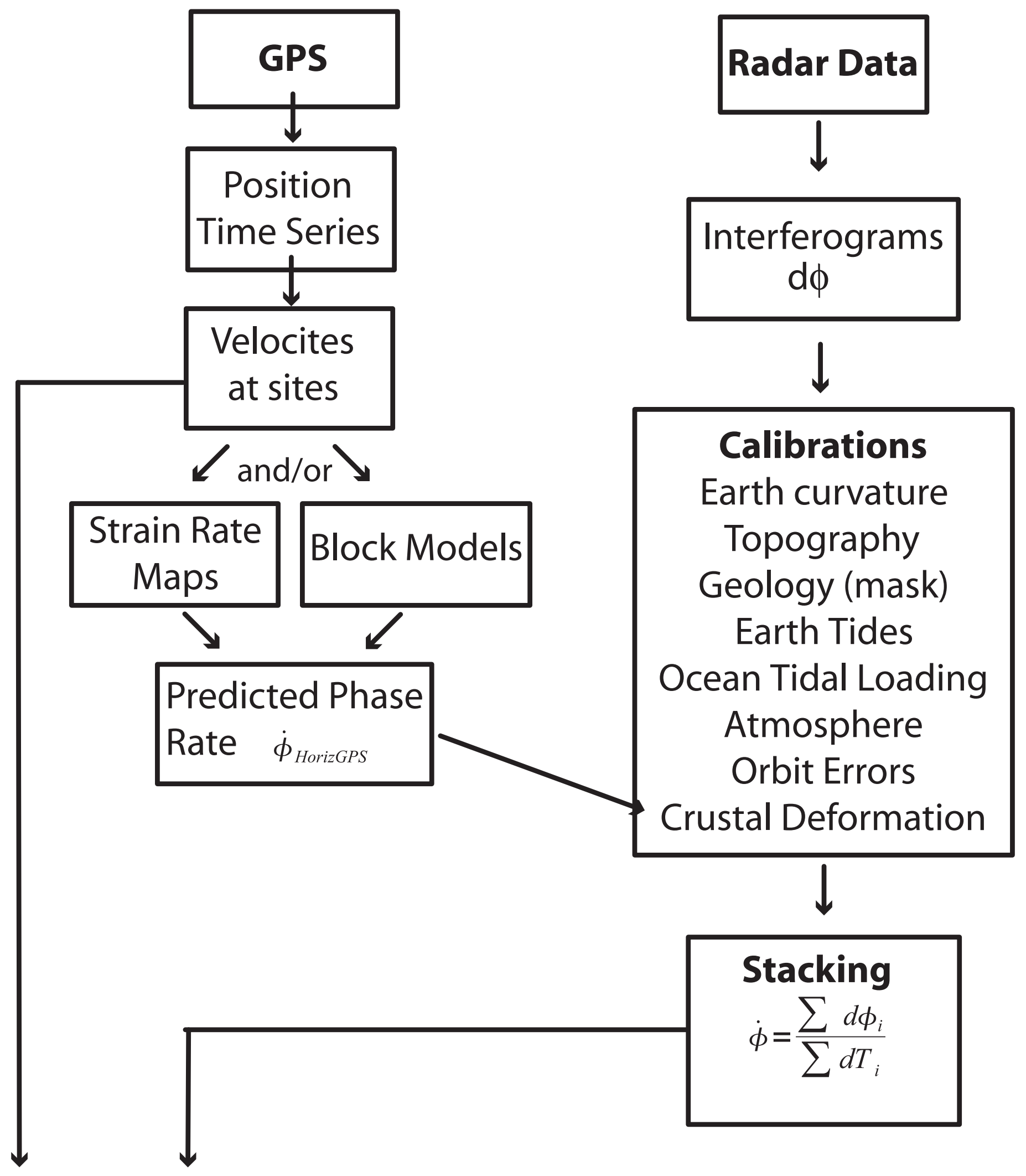


InSAR Data Processing to Strain Rate Mapping

InSAR: Available Scenes



Algorithm - Step 1



GPS → Position Time Series → Velocites at sites → and/or → Strain Rate Maps / Block Models → Predicted Phase Rate $\dot{\phi}_{HorizGPS}$

Radar Data → Interferograms $d\phi$ → **Calibrations**: Earth curvature, Topography, Geology (mask), Earth Tides, Ocean Tidal Loading, Atmosphere, Orbit Errors, Crustal Deformation → **Stacking** $\dot{\phi}=\frac{\sum d\phi_i}{\sum dT_i}$

Algorithm - Step 2

The usual strain mapping equations express the problem as a linear inverse:

$$\frac{\partial v_{1N}}{\partial m_1}dm_1+\frac{\partial v_{1N}}{\partial m_2}dm_2+\ldots+\frac{\partial v_{1N}}{\partial m_M}dm_M=v_{1N}$$
$$\frac{\partial v_{1E}}{\partial m_1}dm_1+\frac{\partial v_{1E}}{\partial m_1}dm_2+\ldots+\frac{\partial v_{1E}}{\partial m_M}dm_M=v_{1E}$$
$$\vdots$$

here v_N, v_E are the GPS rates in the north and east directions, respectively, and m_i are the M model parameters.

We can add constraints along InSAR line of site by projecting the model equations with the dot product along line of site vector ***l***. Since the line of site vector is 3 dimensional, but velocities used in strain mapping are only horizontal, we will be explaining all of the residual phase in terms of horizontal tectonics.

$$\frac{\partial \mathbf{v_1}\cdot\mathbf{l}}{\partial m_1}dm_1+\frac{\partial \mathbf{v_1}\cdot\mathbf{l}}{\partial m_2}dm_2+\ldots+\frac{\partial \mathbf{v_1}\cdot\mathbf{l}}{\partial m_M}dm_M=\mathbf{v_1}\cdot\mathbf{l}=\dot{\phi}$$
$$\vdots$$

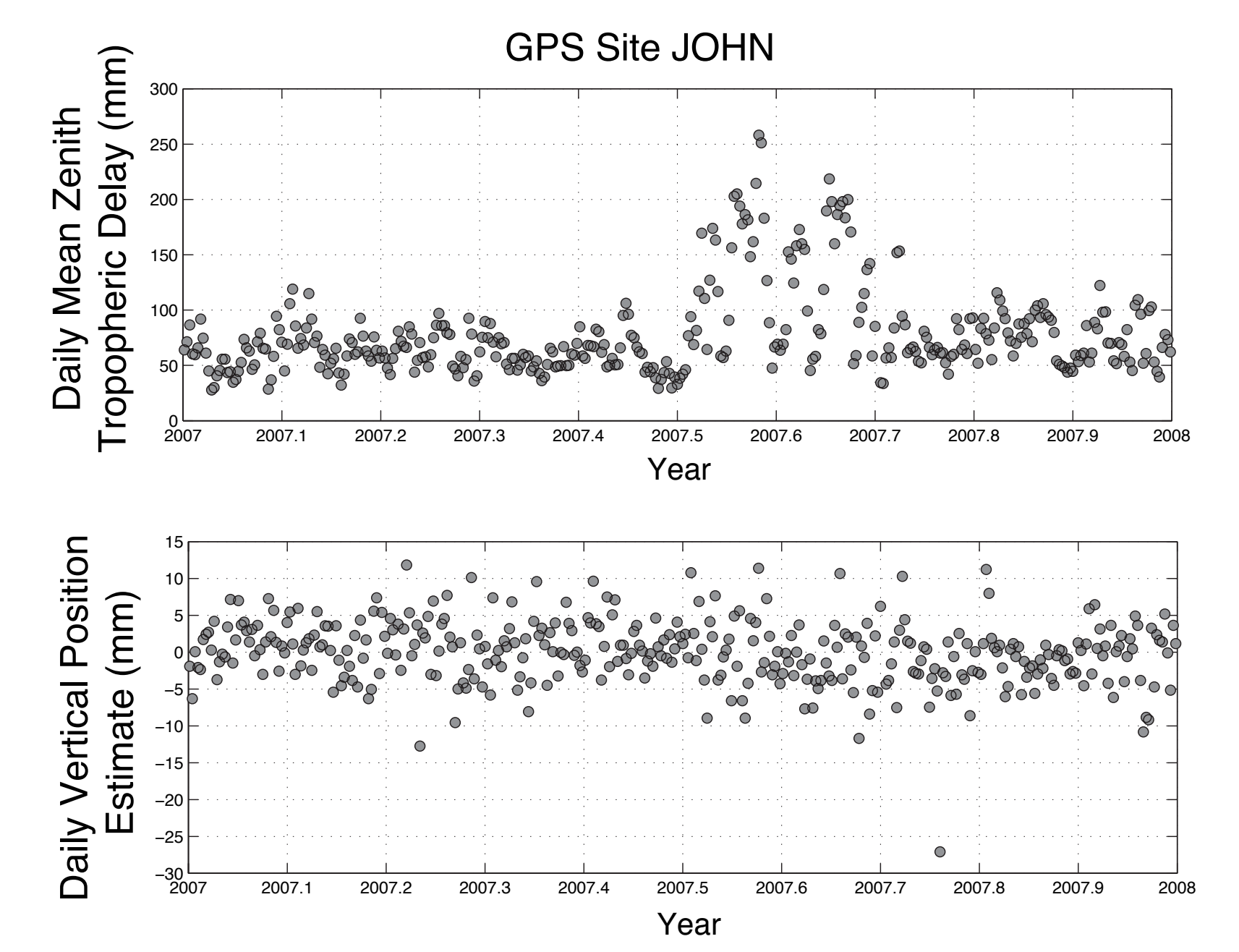
where

$$\frac{\partial \mathbf{v_1}\cdot\mathbf{l}}{\partial m_1}=\frac{\partial v_{1N}}{\partial m_1}l_N+\frac{\partial v_{1E}}{\partial m_1}l_E$$

which is a linear combination of the partial derivatives from the original strain rate map inversion matrix.

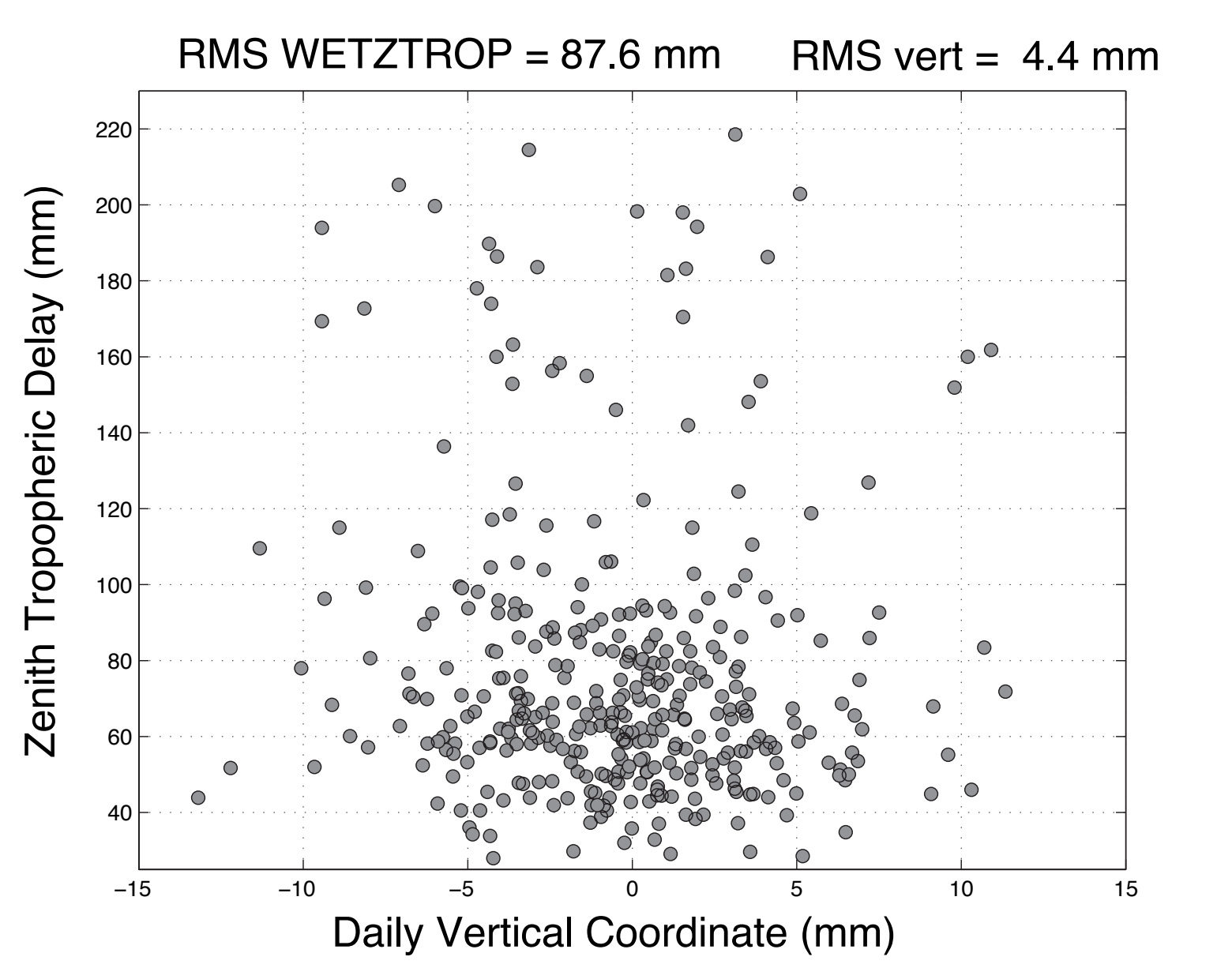
This assumes that vertical tectonics do not contribute substantially to the phase rate field. However, this can be addressed by using block models instead of strain maps to solve for crustal block motions. This has not yet been tried, but can be incorporated once our block modeling codes are generalized to 3d (a work in progress).

GPS Atmosphere Estimates

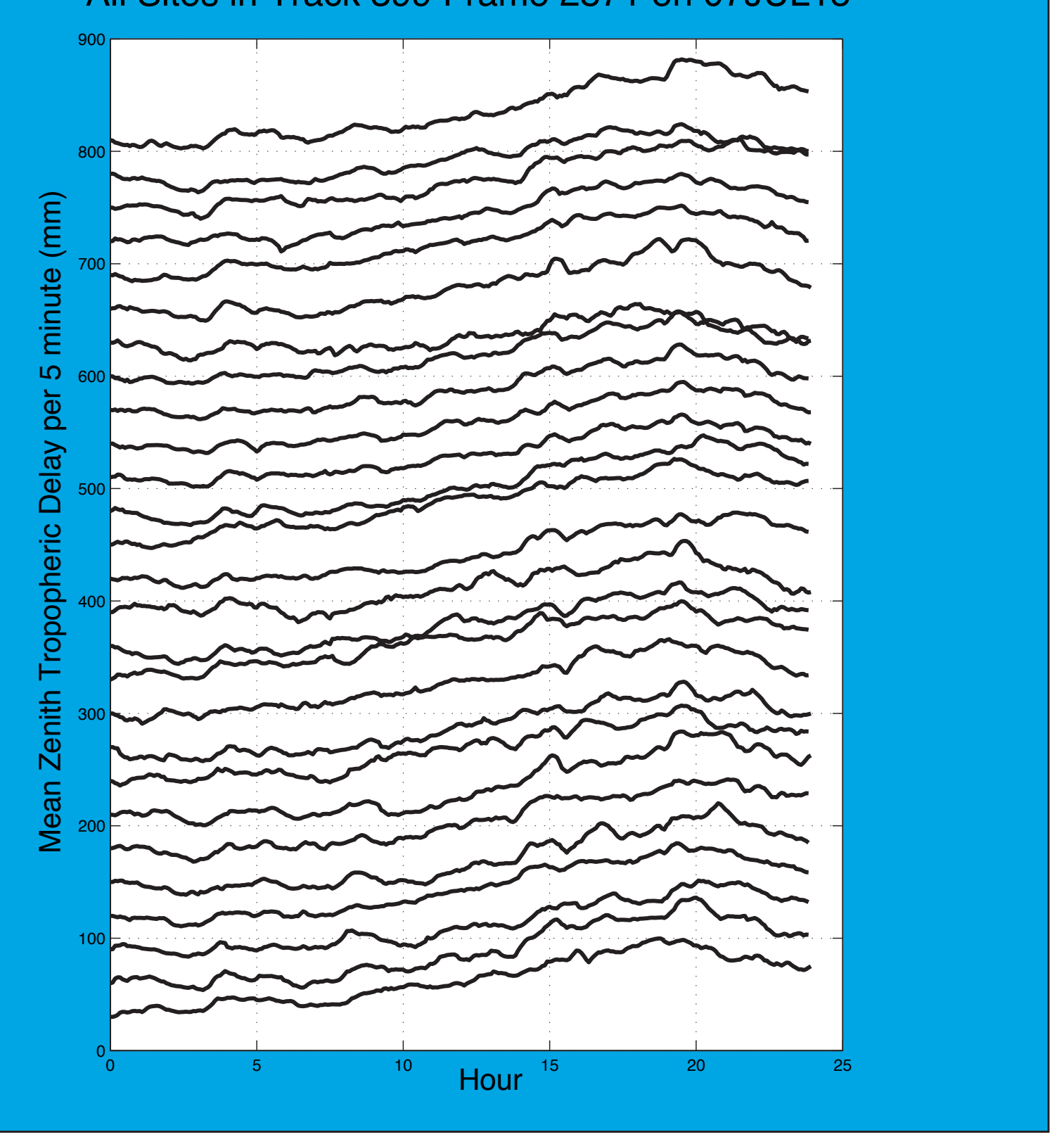


Estimates of GPS satellite to receiver signal delay owing to tropospheric effects are obtained from GIPSY/OASIS II every 5 minutes assuming a random walk model. The magnitude of these effects are 50-250 mm (left and below left), and they can vary by up to 100 mm on any given day (below). Thus these signals are large compared to the expected vertical motions from tectonics.

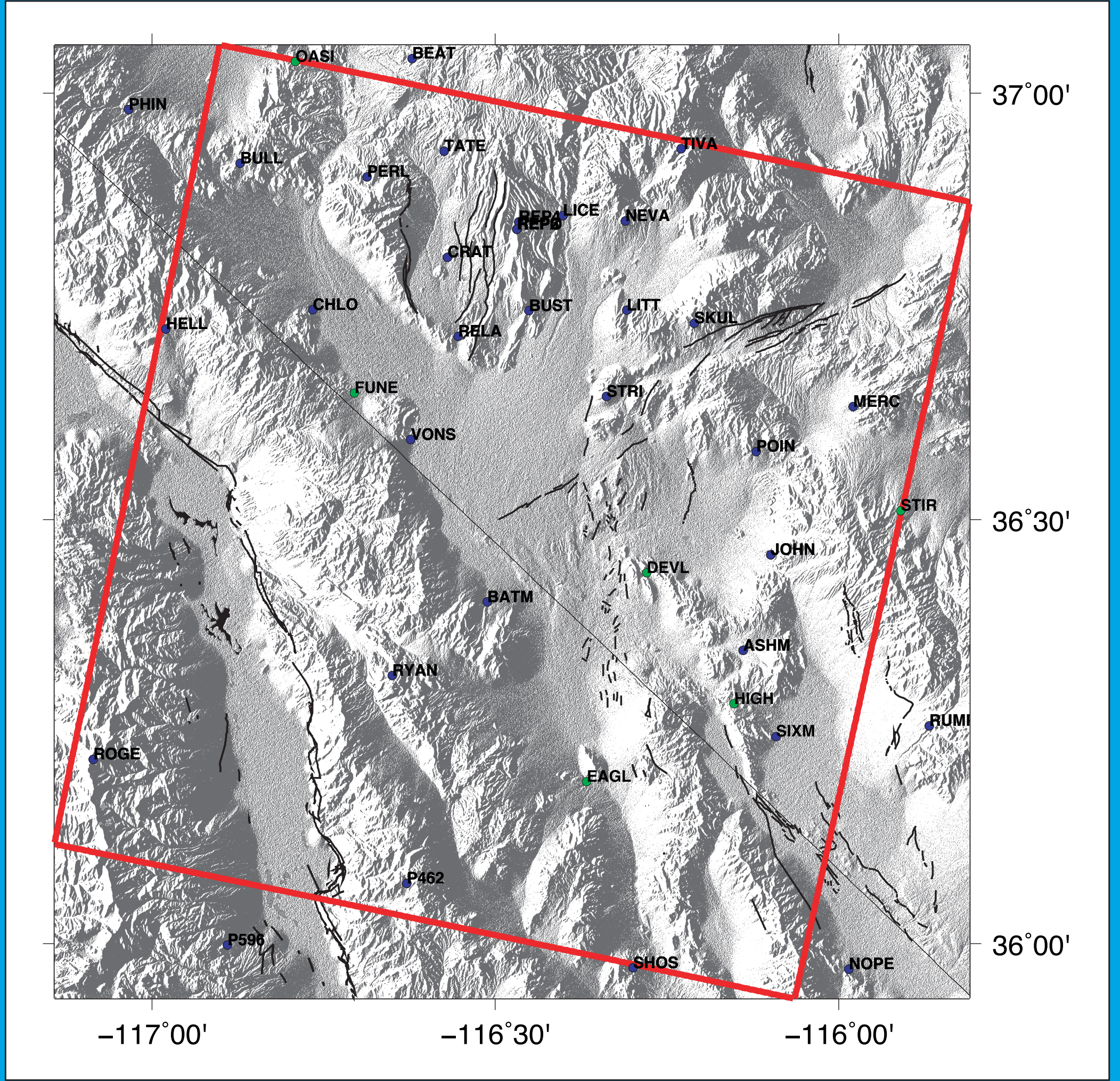
However, when large changes in the tropospheric estimates occur, they do not seem to be propagated into the vertical position, suggesting that (in this example) GIPSY is doing a good job compensating for these effects.



All Sites in Track 399 Frame 2871 on 07JUL15

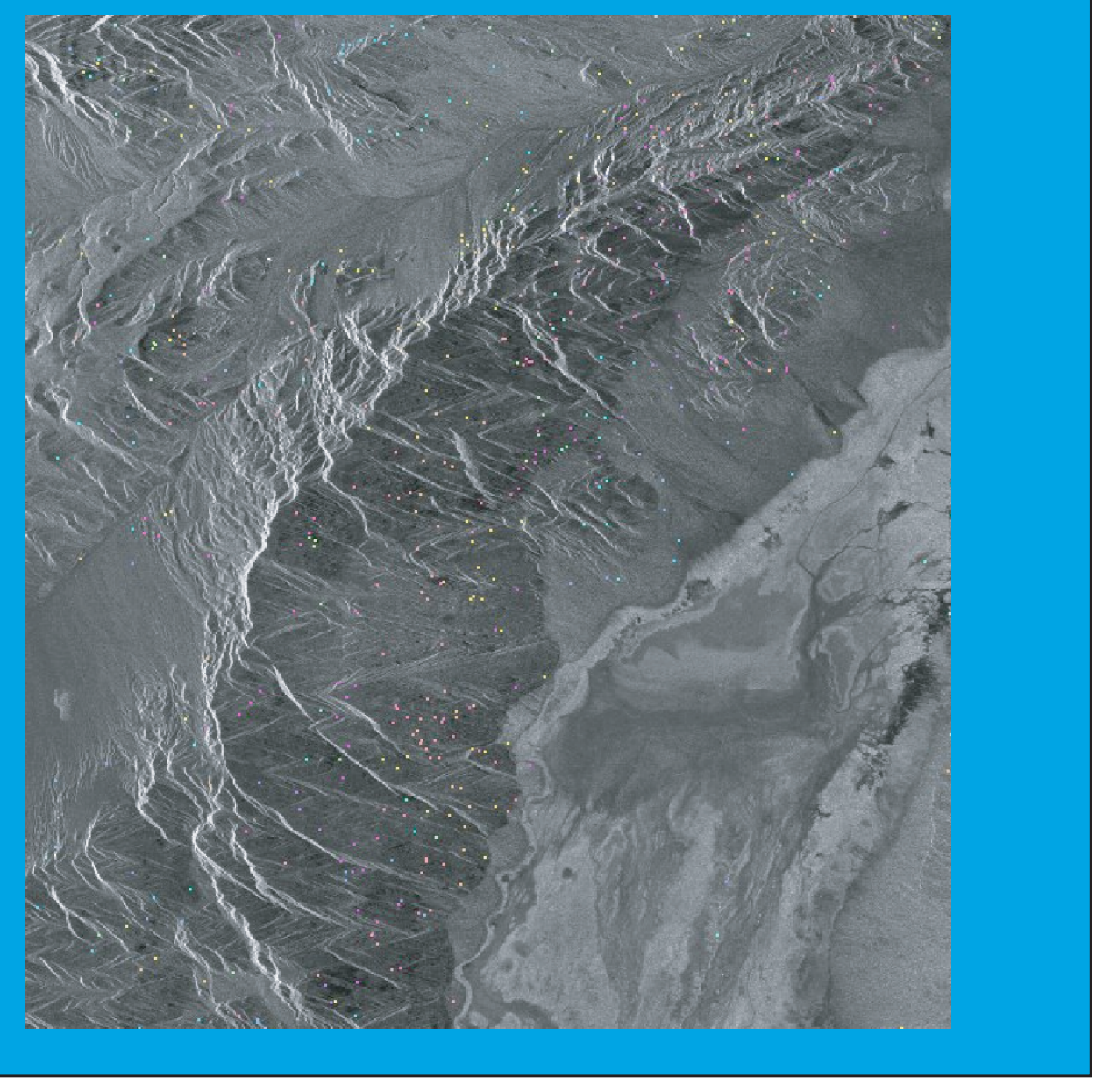


A Beginning - Yucca Mountain...



Left) As a test case for our procedure we will use ERS and Envisat Scenes from track 399, frame 2871 (shown in red) and 2889. For these frames there are over 140 scenes available in the WinSAR and GeoEarthScope archives to stack out non-tectonic signals. GPS reveal that there is approximately 1 mm/yr of deformation across the Yucca Mountain network of 16 sites. Inside this area are 16 stable GPS sites that have been in operation continuously since late 1999, plus more recently installed stations in the BARGEN and PBO networks.

Below) Preliminary identification of point scattering pixels has been made using Gamma IPTA. These points have both the spectral characteristics of a point scatterer and are stable across 16 ERS1 scenes.



Acknoweldgements
This work is supported by the NASA EarthScope geodetic imaging program. We use the GAMMA software for processing of radar data.

References
Li, Z., E. J. Fielding, P. Cross, and J.-P. Muller (2006), Interferometric synthetic aperture radar atmospheric correction: GPS topography-dependent turbulence model, Journal of Geophysical Research, 111, B02404, doi:10.1029/2005JB003711.