Contemporary Vertical Motions Across the Sierra Nevada/Great Basin Transition: GPS Measurements and Models

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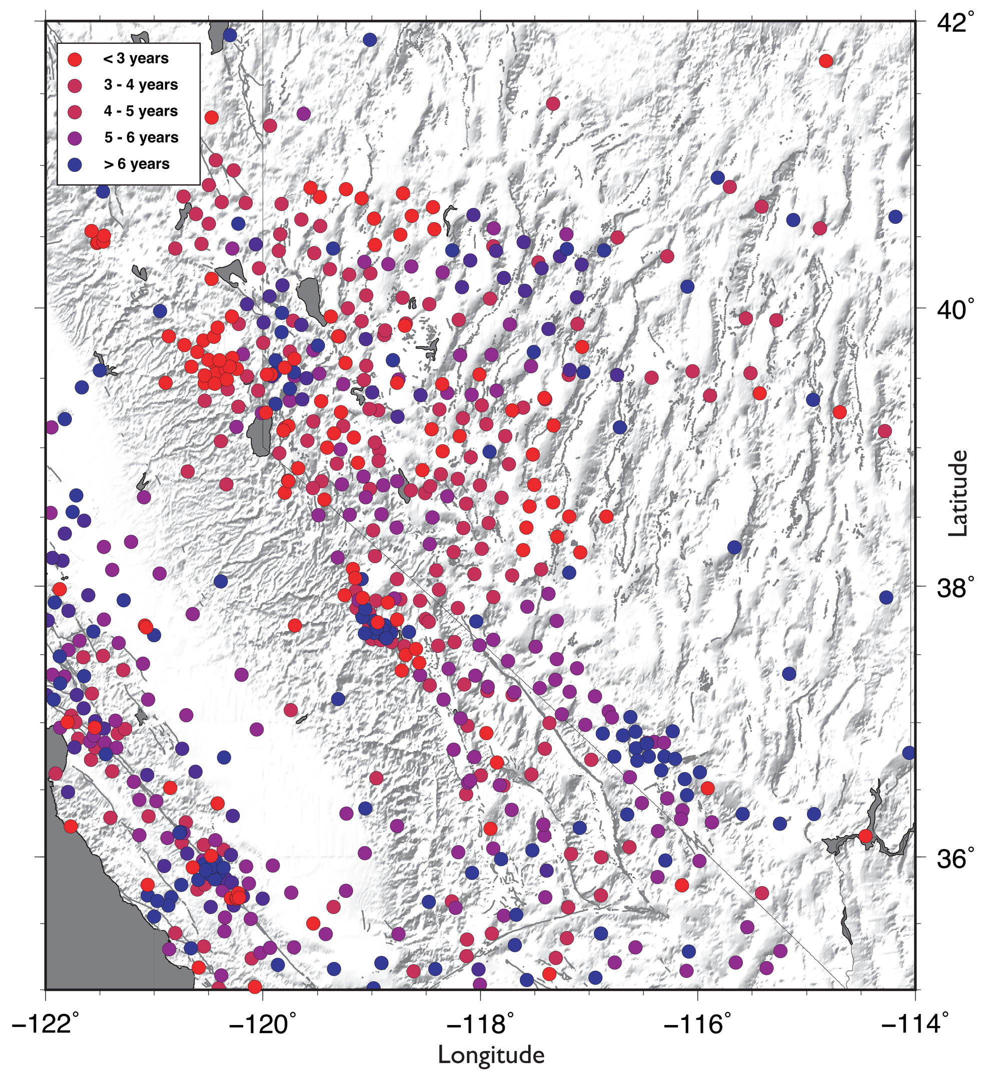
Abstract

Contemporary vertical motions of the Sierra Nevada are one key to understanding longer term geologic processes that drive uplift, and are expected to at a rate on the order of 1 mm/yr. It has been demonstrated that vertical rates this small can be measured with GPS when station quality is high and the time series are long. (e.g. Bennett et al. 2009) We present vertical component GPS velocities for stations on the Sierra Nevada microplate (SNGV), Walker Lane and Basin and Range Province based on a recent complete reprocessing of all available GPS data with the latest version of the GIPSY/OASIS software and analysis models. Many stations of the EarthScope Plate Boundary Observatory nucleus (e.g. BARGEN and BARD) have recorded data for over 11 years, and have vertical rate uncertainties that are likely below 0.3 mm/yr. The Mobile Array of GPS for Nevada Transtension (MAGNET) complements these networks and has a greater geographic density of stations, but generally have time series that are shorter (6 years maximum). The variance of vertical velocities is a strong function of the length of the GPS time series, with large scatter for shorter time series. This suggests that we require at least 5 years of data on continuous GPS sites in order to reliably infer rates of vertical motion of the crust when the rates are of this magnitude.

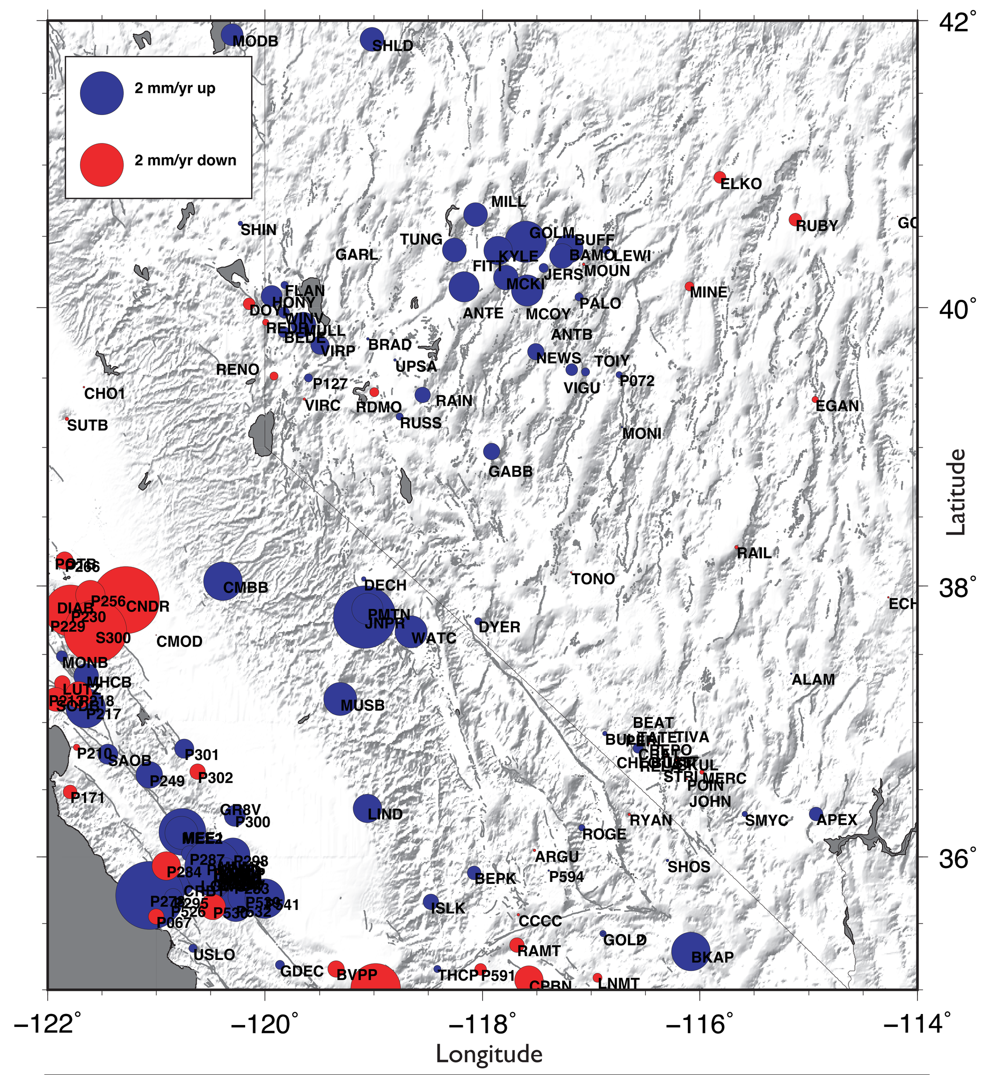
For stations with long enough time series, motions reflect at least two separate processes. The first is westward tilting of the SNGV microplate, with upward motion along its east side and downward motion in the central Great Valley of California. While the upward component is detected on several long-running stations on the west slope of the Sierra Nevada Mountains, the downward motions of stations in the Great Valley are effected in many locations by non-tectonic processes. The second process is postseismic relaxation from historic earthquakes in central Nevada and southern California. Adjusting the vertical GPS motions for postseismic effects using models of viscoelastic relaxation allows us to estimate long term vertical motions. We estimate the contemporary long term tilting rate of the SNGV from GPS velocities corrected for the effects of interseismic locking on block-bounding faults and viscoelastic postseismic relaxation.

Available GPS Sites
Present Length of GPS Time Series



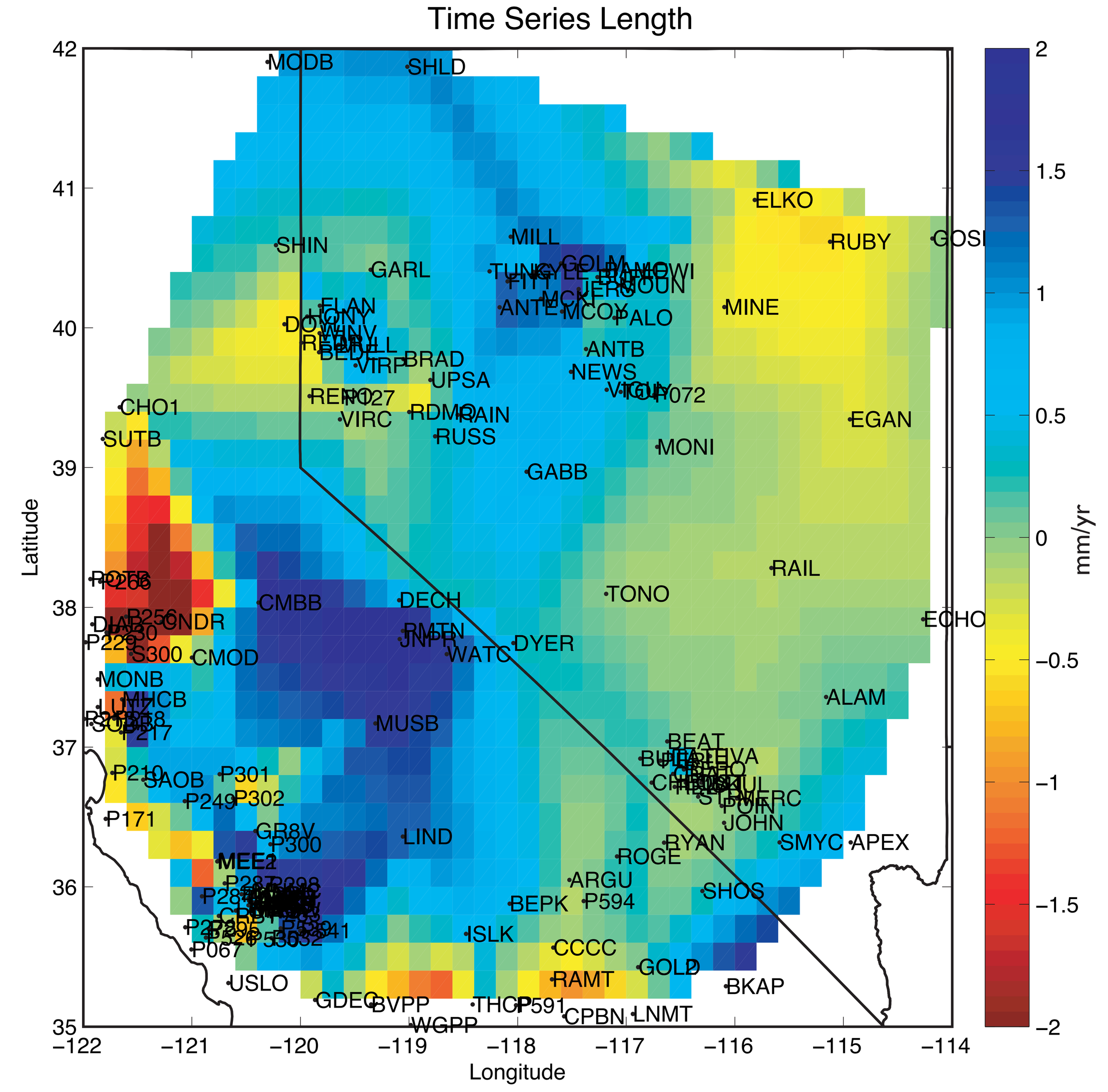
Above) Station distribution showing MAGNET and continuous GPS sites in California and Nevada. Ultimately, the vertical GPS velocity field with have at least this geographic density when at least 5 years of data are collected at each sites. Color represents the length of the time series that are presently available. Blue > 5 years, Red < 2 years.

Vertical Rate from GPS at Sites
with >5 years of data, and annual oscillations < 4mm



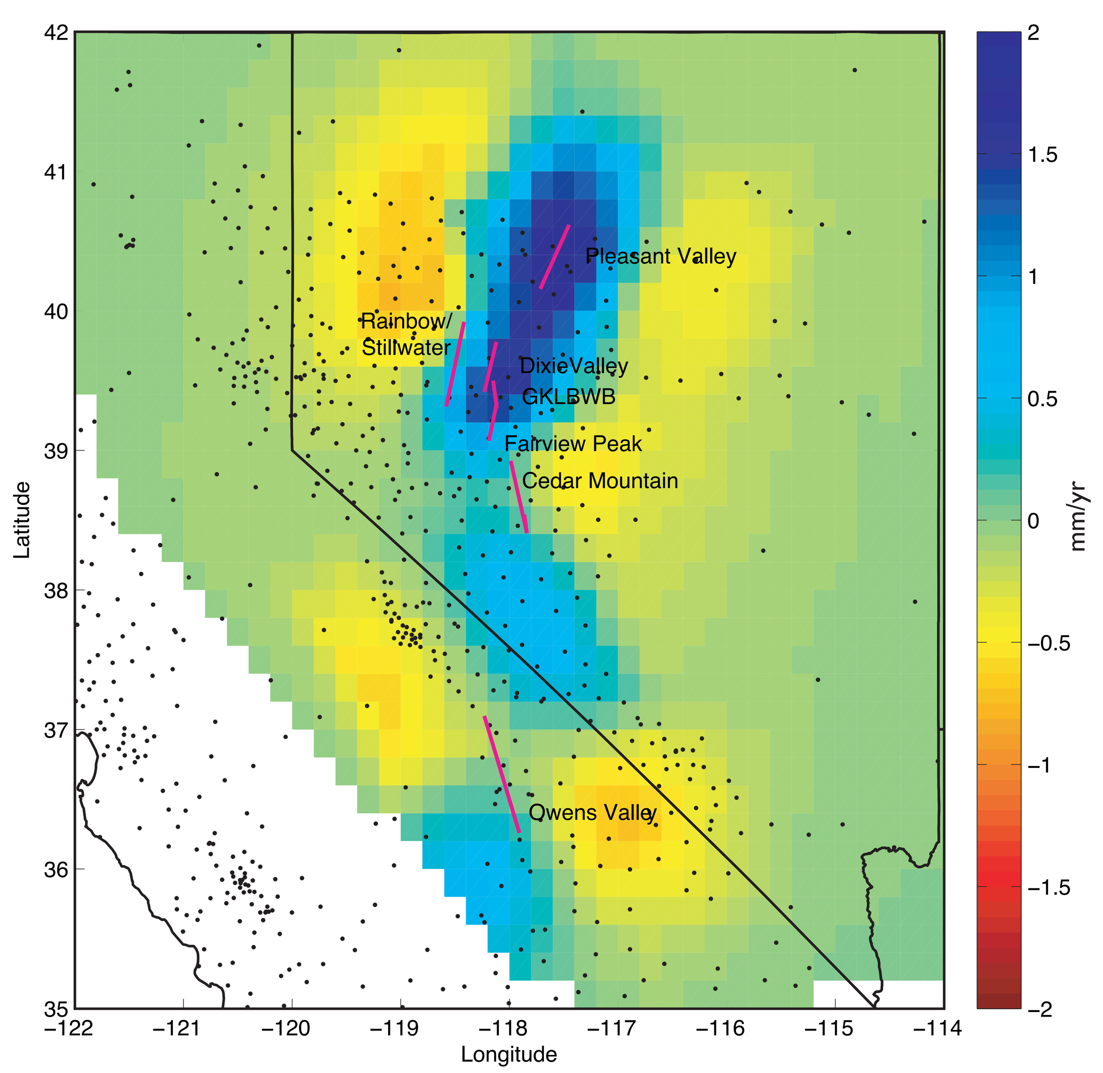
Above) Vertical GPS velocity for stations with >5 years of data (see above left) and with annual oscillations less than 4 mm in amplitude. We remove stations with strong annual oscillations because these bias the rates and because these sites tend to be located in places that are not stable bedrock. Labels are site names. The vertical component of these rates are in ITRF2005, and thus are in an Earth center of mass reference frame. Also areas strongly affected by non-tectonic processes are removed (e.g. Coso and Long Valley).

Minimum 5 Years
Time Series Length



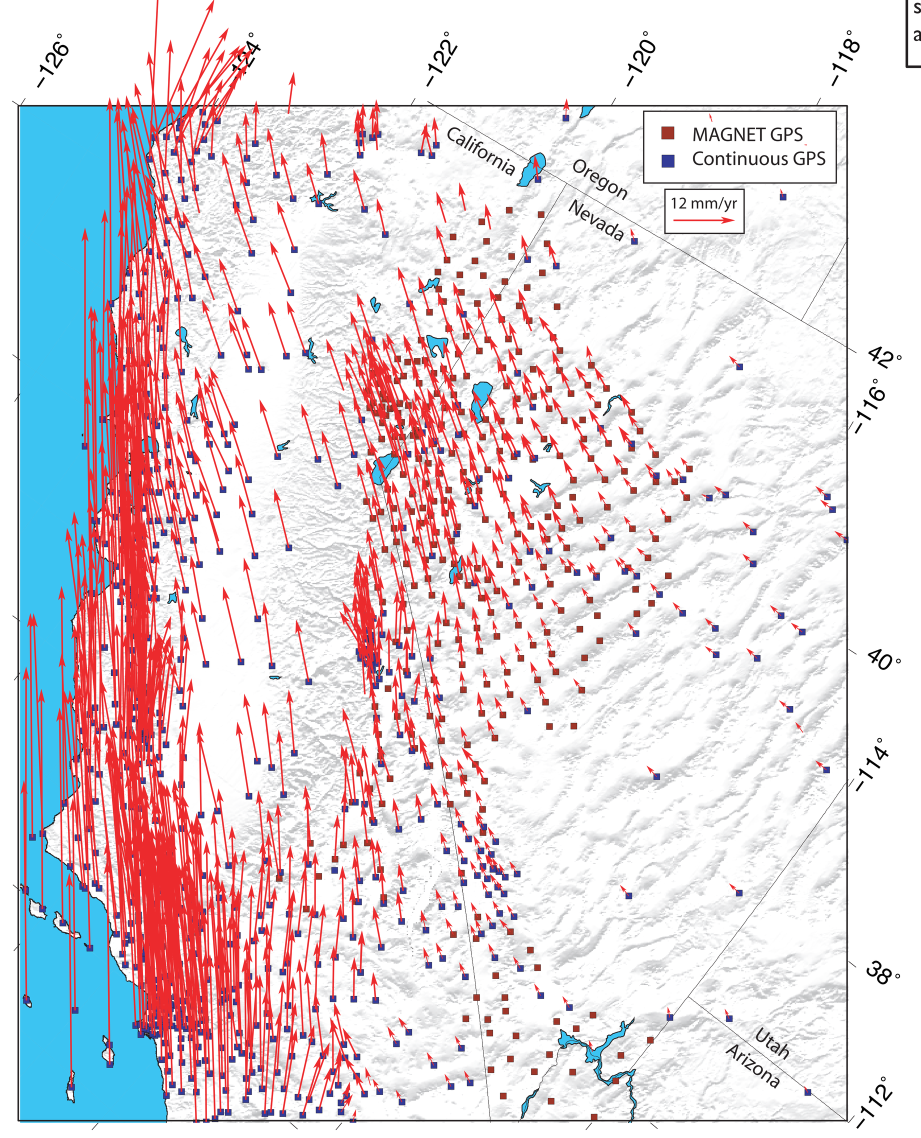
Above) Vertical velocity interpolated from GPS rates obtained from time series with at least 5 years of data. Rates in the Basin and Range of eastern and southern Nevada are extremely similare, with RMS <0.3 mm/yr. Sites around the Central Nevada Seismic Belt move upward ~2 mm/yr, sites in Walker Lane show more complex patterns, but are generally more simliar to eastern Nevada. Sierra Nevada stations with sufficient data are few, and limited to the western slope, but move generally upward by 1-2 mm/yr. Vertical rates in the Central Valley of California are more complex, probably owing to lack of sites on extremely stable bedrock.

Model of Postseismic Relaxation

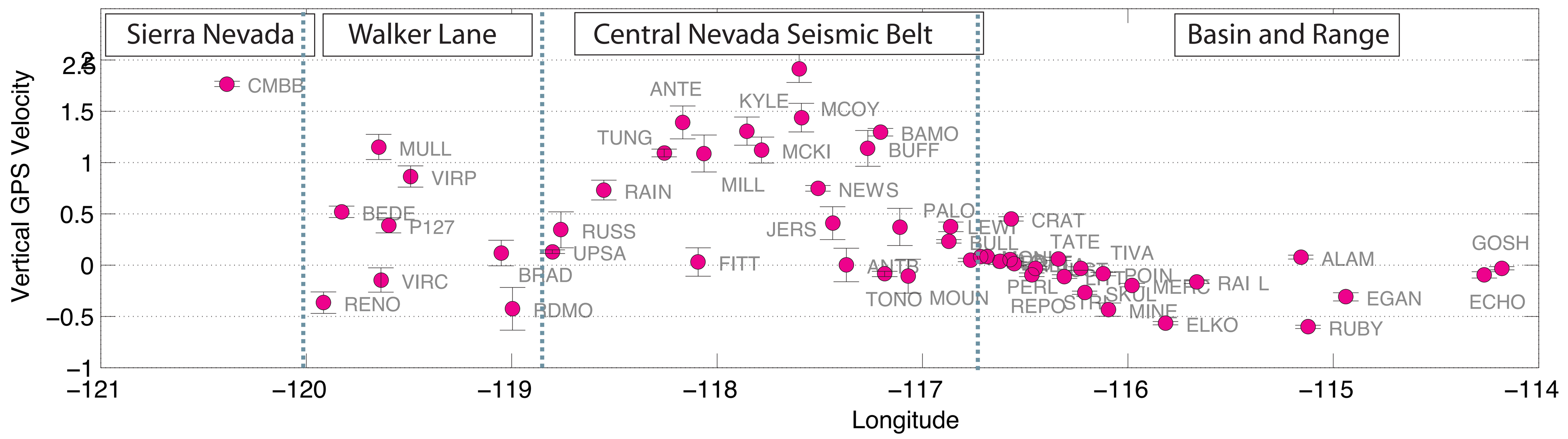


Above) Vertical velocity predicted from a model of viscoelastic postseismic relaxation from earthquakes in of the central Nevada Seismic Belt. Model derived by Hammond et al., (2009) using VISCO1D code of Pollitz, (1997). Magneta bars show location and length of rupture for each earthquake in the model. Uplift of 2 mm/yr in central Nevada bears strong resemblance to observed vertical GPS velocity (above left).

Horizontal GPS Velocities in California and Nevada

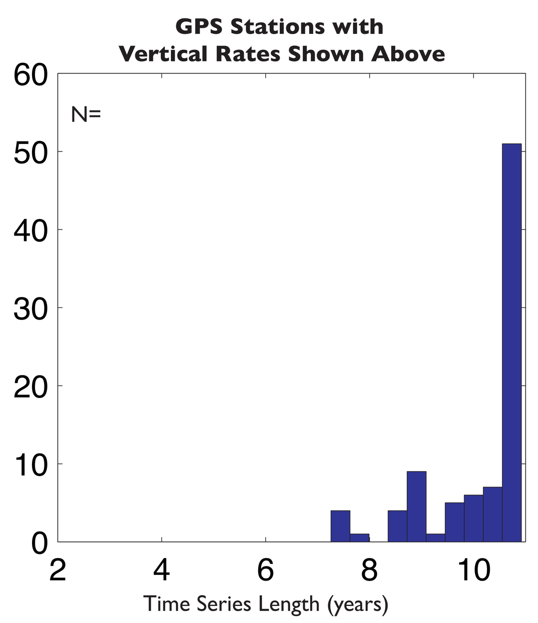


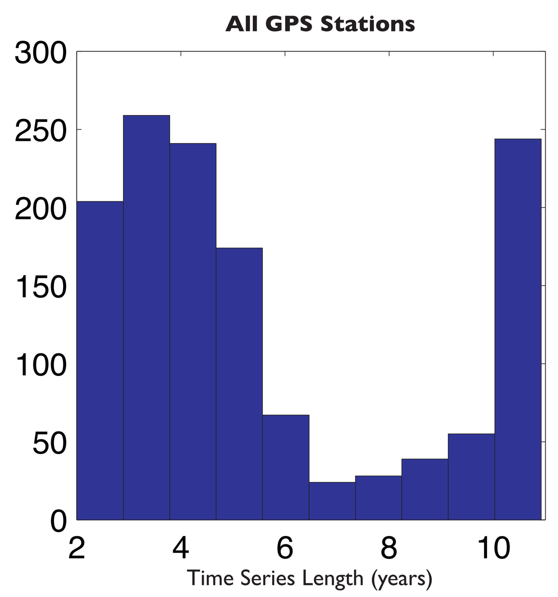
Above) Horizontal GPS velocities for stations in California and Nevada from MAGNET and other continuous GPS stations. Rates are with respect to stable North America. Sierra Nevada/Great Valley microplate moves northwest and has a decidedly counterclockwise rotation, which contributes to variations in the pattern and style of deformation in the Walker Lane. Red stations are MAGNET, blue are continuous sites.

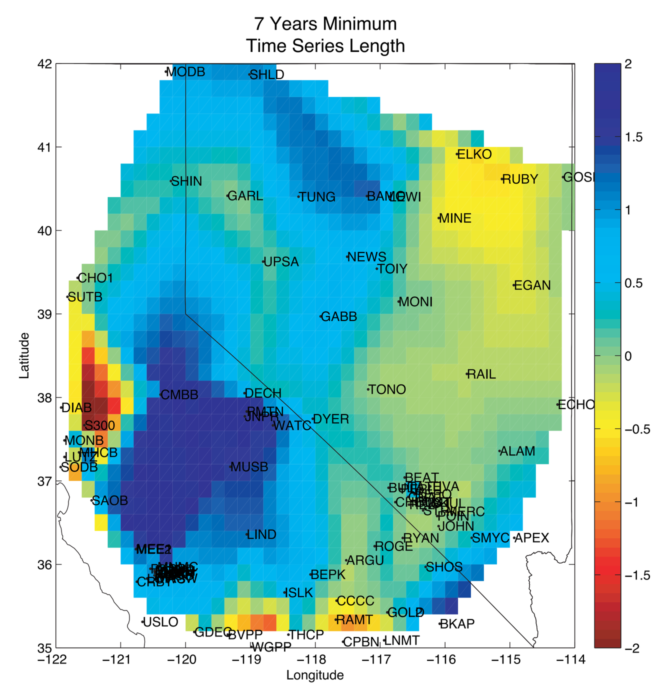


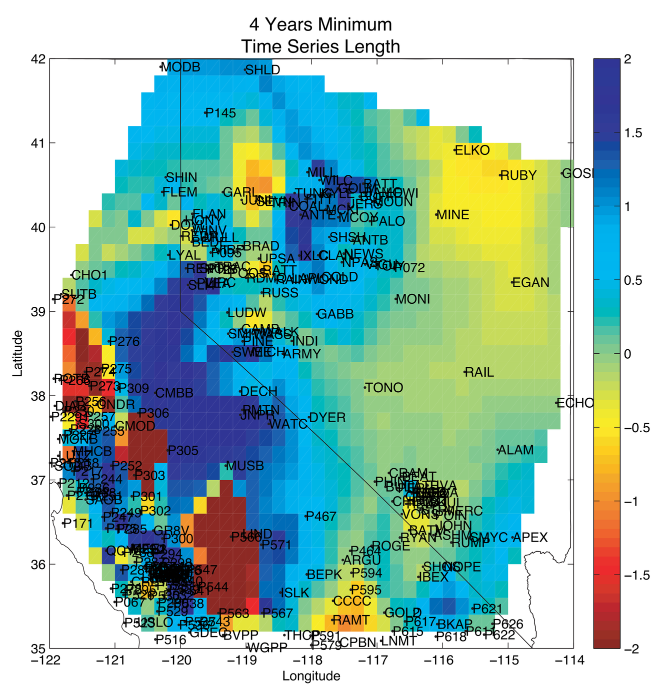
Above) Profile of GPS velocity in Earth center of mass reference frame across a profile that extendes from the California Central Valley, across the Sierra Nevada, Walker Lane, central Nevada Seismic Belt and into the eastern Nevada Basin and Range. Rates in eastern Nevada are very similar, with RMS<0.3 mm/yr. Central Nevada Seismic Belt uplift of ~2 mm/yr is evident. The signal is more complex inside the Walker Lane, where crustal strain rates are an order of magnitude larger than in the Basin and Range. Sierra Nevada uplift is on the order of 1-2 mm/yr as shown by site CMBB, at the far left.

Right) Histograms of time series length for stations used in this analysis (left) versus all PBO, BARGEN and MAGNET stations that are, or will be, available in the near future (right). This illustrates how many more reliable vertical rates will become available to study long term uplift and collapse of the Sierra Nevada/Great Basin system.









Below Left) Same as above, except using 7 year minimum time series length. Below right) same except using 4 years minimum time series length. Trade-off between improved geographic resolution of vertical rate, and inclusion of higher variance (owing to noise) rates is evident.

Conclusions

- Many GPS stations in the Sierra Nevada/Great Basin transition have enough data (> 5 years time series) to provide reliable rates of vertical motion of the solid Earth from GPS.
- The number of such stations will increase dramatically in the next few years as the EarthScope Plate Boundary Observatory and MAGNET GPS stations continue to collect data.
- Early results show that GPS stations on the Sierra Nevada western slope tend to move upwards in an Earth center of mass (CM) reference frame, and stations in the Central Valley of California move downward. Rates in the eastern NV Basin and Range are extremely similar (RMS ~0.2 mm/yr). Rates in the Walker Lane, where strain rates are highrer, are more variable.
- Results suggest a westward structural tilting rate that is bounded by 2 mm/yr east block uplift, 2 mm/yr west block subsidence, separated by ~100 km. This gives ~2 degrees/My upper bound for contemporary structural tilting of the block.
- Postseismic viscoelastic relaxation from 19th and 20th century earthquakes is most likely the cause for the pronounced ongoing ~2 mm/yr uplift in central Nevada.
- Postseismic relaxation from these earthquakes is likely not the cause of the vertical motions seen on the west slope of the Sierra Nevada.

References

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Acknowledgements

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