Estimation of time varying strain rate in southern California: Detangling postseismic deformation from GPS measurements

Eric A Hetland
Department of Earth & Environmental Sciences
University of Michigan

Proposal Category A

Related SCEC Priorities: P2.a, P1.e, and P1.a

Summary of proposed project:

The project's goal was to determine time-varying horizontal strain rates and vertical deformation gradients, complete with their uncertainties, from GPS/GNSS displacement series in southern California. We proposed to use our recently developed code PyGeoNS (Python-based GEOdetic Network Smoother; Hines & Hetland, 2018), which is built upon a Gaussian process regression (GPR). GPR is a non-parametric, Bayesian method, resulting in a posterior estimate of time-varying strain-rates using a prior which describes the level with which transient deformation is expected to covary spatiotemporally.

The project's ultimate goal was to quantify transient strain-rates, complete with an estimate of their uncertainties, throughout southern California. Figure 1 shows the preliminary strain rates for southern California. Note that these strain rates were determined using a preliminary version of PyGeoNS, and not the final version as published in Hines & Hetland (2018). The strain-rates are based on the southern California from the SCEC crustal motion velocities (Shen et al., 2011). Our strain map is nearly identical to that of Shen et al. (2015), which was derived from the same data set. However, the formal uncertainties for the two strain maps are notably different. In Shen et al. (2015), the maximum uncertainties are found where the data density is highest, and the authors do urge caution in interpreting the uncertainties. In contrast, the strain map for PyGeoNS appropriately has the highest uncertainty in Nevada, where the station coverage is most sparse. Indeed, the only features which PyGeoNS identifies as being robust are those which are in areas with sufficiently dense coverage.

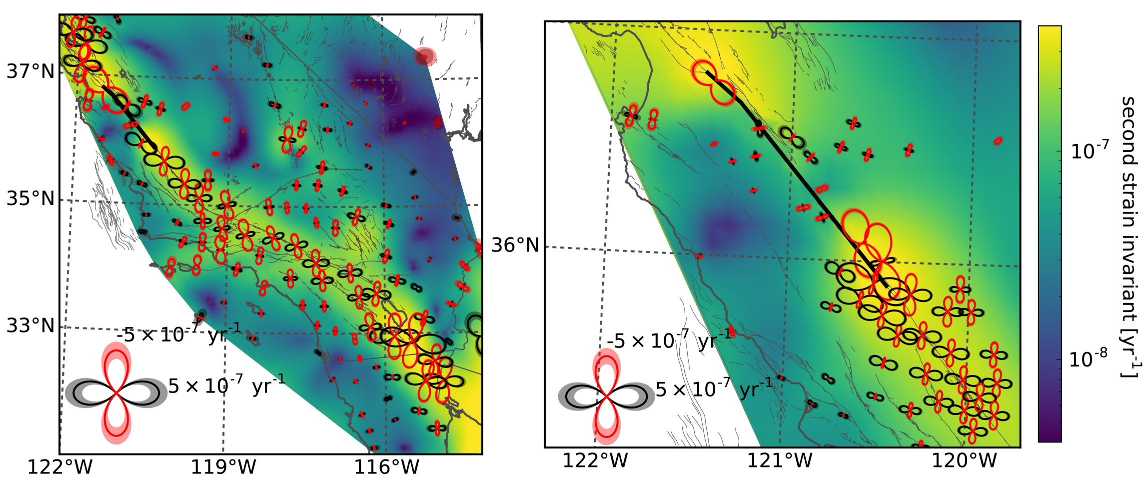

Figure 1: Horizontal strain rate tensors at select GPS locations, depicted by the normal component of strain along each azimuth, where black and red indicate extension and contraction, respectively, and shading indicates the 95% confidence. Strain rates are allowed to be discontinuous across the creeping segment of the San Andreas Fault (black line).

Figure 2 shows preliminary time-dependent strain-rate estimates made over the postseismic period of the 2010 El Mayor-Cucapha earthquake. Postseismic strain rates up to the Salton Sea exhibit NW-SE oriented extension. Further north, we see the pure shear consistent with steady interseismic deformation with E-W extension and N-S contraction. After

∼6 months, strain rates in the Imperial Valley return to a nearly pure shear regime, where the extensional axis is still roughly oriented NW-SE. The strain rates are large (up to 1.2 μstrain/yr) north of the border, and drop substantially north towards the Salton Sea region.

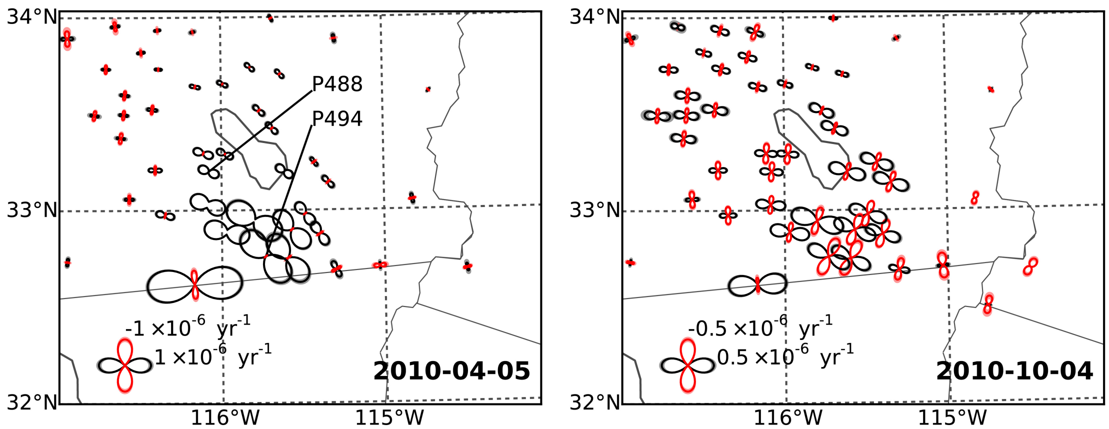

Figure 2: Estimated strain rates immediately following the EMC earthquake (left) and six months after the earthquake (right). Strain rates are derived from the UNAVCO GPS displacement time series. The earthquake epicenter was located in Baja California and produces extension in the quadrant containing the Imperial Valley. Postseismic strain can be observed out to epicentral distances of about 150 km. At greater distances, any postseismic changes in strain rates are indistinguishable from the steady, interseismic strain-rate.

It was our ultimate intention that the estimated time-dependent strain-rate data products would be of use to other researchers, for instance to constrain mechanical models of strain accumulation or postseismic deformation (P1.a & P1.b). To that end, we proposed to disseminate the derived data products widely. The PyGeoNS code is available for barrier-free access from the github.com code sharing repository.

Reasons for inability to complete project during proposed time-frame:

The original project was to be completed by a senior graduate student, T. Hines, the developer of PyGeoNS, during the last year of his PhD studies. The proposed project was to cover one term of graduate support for T. Hines. Notification of the award was significantly delayed, and as of late Spring 2017 we still were unsure whether the award would be granted. Due to the uncertainty in funds, T. Hines made plans to defend Summer 2017, and accepted a job with a start date of September 2017. When we were notified that the project was awarded, as T. Hines was no longer available to complete the project, I made plans to move a junior graduate student onto the project. That student was still committed to another project through the Summer, but spent Fall 2017 learning the methods in order to work on this project. We were anticipating that he would complete the project Winter 2018. Unfortunately, the student was dealing with significant personal difficulties and in January 2018 withdrew from the graduate program.

In Spring of 2018 I requested a no-cost extension of the project, describing a plan whereby I would move another junior graduate student onto the project, with anticipation of completing the work Fall 2018 or Winter 2019. That student has been making significant strides in learning PyGeoNS, and was on track to work on southern California starting late 2018. Right as it was becoming clear that competing the project Winter 2019 was a tractable goal for the student, the University of Michigan's office of sponsored research informed me that the grant had expired the previous month. I had been focused only on the proposed plan to complete the work by Winter 2019, and had obviously not realized that the extension was only approved through September 2018 — an extended time-frame I would not have been able to meet (the mismatch between the extension justification and extended expiration date was not noticed during administrative review of the extension request). It is frankly quite disappointing as I am motivated to complete the project, as is T. Hines, who has expressed his desire to assist the new student with the work.

References

Hines, T.T., and E.A. Hetland (2018). Revealing transient strain in geodetic data with Gaussian process regression. *J. Geophys. Int.*, 212, 2116–2130,, doi:10.1093/gji/ggx525.

Shen, Z.-K., R. King, D. Agnew, M. Wang, T.A. Herring, D. Dong, and P. Fang (2011). A unified analysis of crustal motion in Southern California, 1970–2004: The SCEC Crustal Motion Map. *J. Geophys. Res.*, 116, B11402, doi:10.1029/2011JB008549.