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Characterizing Non-tectonic and Interseismic Deformation in the Ventura Basin Region, CA

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Summary

Hager et al. [1999] and Donnellan et al. [1993a] demonstrated that ongoing contractional deformation recorded by geodetic measurements in the western Transverse ranges of southern California is related to tectonic strain accumulation along active reverse faults that bound the Ventura basin. This study addresses four major remaining neotectonic questions for the greater western Transverse ranges region:

- To what extent do non-tectonic processes contaminate GPS velocities in this region and what proportion of the non-tectonic motions are periodic (seasonal) and what proportion is non-periodic (e.g. aquifer drawdown and/or hydrocarbon extraction)?
- Can the heterogeneous interseismic deformation patterns in the western Transverse Ranges region can be reproduced with a Community Fault Model (CFM)-based mechanical model similar to that used by Marshall et al. [2009]?
- Are geodetically-derived fault slip rates compatible with longer term geologic slip rates in the region?
- What are the predicted slip rates on the numerous unconstrained faults in the region?

We have found that all continuous GPS sites in the western Transverse ranges region, regardless of the geology of the local substrate (bedrock versus sedimentary basin fill), exhibit periodic seasonal motions; however, these periodic motions do not greatly affect velocity estimates and can be statistically characterized and removed. While we have identified a few locations of potential non-periodic anthropogenic motion, our work shows that the large and ongoing anthropogenic deformation signals observed in the nearby Los Angeles basin [e.g. Argus et al., 2005] are not seen to the same degree in the western Transverse ranges. Thus, most of the region’s GPS sites should yield reliable tectonic velocities.

An interseismic model using the non-planar CFM surfaces and based on the technique of Marshall et al. [2009] has been created. The model is the first mechanical interseismic model of the region to use the geologically constrained CFM surfaces. The model produces surface velocities that largely agree with the GPS velocity field, and the best fitting locking depth (14 km) is similar to previous estimates [Hager et al., 1999]. This model predicts fault slip rates that generally agree with long term geologic estimates. Therefore, no slip rate discrepancies are apparent in the region. The model results also provide slip rate estimates for numerous otherwise unconstrained faults in the region.
1. Introduction

Ongoing transpression in the western Transverse ranges of southern California has resulted in a complex network of oblique-slip, strike-slip, and reverse faults that now accommodate localized shortening in the Ventura basin [e.g. Huftile and Yeats, 1995]. Previous studies of the Ventura basin region utilized geodetic data to determine contemporary deformation and fault slip rates [Donnellan et al., 1993a; Donnellan et al., 1993b; Hager et al., 1999]; however, these works did not attempt to determine the influence of non-tectonic deformation on geodetic velocities, nor did they utilize geologically-constrained three-dimensional fault surfaces [e.g. Cooke and Marshall, 2006; Marshall et al., 2008]. Using a combination of filtering techniques to remove non-tectonic signals, Marshall et al. [2008] determined a regional tectonic strain rate for the Ventura region and estimated long term (thousands of years) fault slip rates along the geometrically-complex fault surface representations provided in the SCEC Community Fault Model (CFM). A remaining question, and the focus of this study, is whether the heterogeneous interseismic deformation patterns in the Ventura region can be reproduced with a CFM-based model similar to that used by Marshall et al. [2009]. Additionally, with the addition of the Plate Boundary Observatory and increased InSAR coverage and availability, interseismic deformation can now be quantified with greater precision and spatial density than what was available to previous studies.

2. GPS Processing Results

Because GPS sites in southern California record the sum of tectonic, seasonal, and anthropogenic ground motions, we applied several analysis techniques to determine both the tectonic and non-tectonic rates of deformation. We began with the MEaSUREs combined filtered time series solutions which represent the combination of a GIPSY (JPL) and GAMIT (SOPAC) solution that has the common mode error from the entire network removed. While network-wide filtering had already been performed on the MEaSUREs time series, local non-tectonic signals may still be present. We used the software package QOCA [Dong et al., 2006] to removal of time series offsets due to coseismic events and equipment changes, and to estimate annual/semi-annual periodic motions. The resultant velocities are dominantly linear implying constant velocity and successful removal of seasonal and periodic deformation (Figure 1). To determine which of the remaining non-linear signals are spatially-coherent and thus likely to be non-tectonic in origin, we performed Principal Component Analysis (PCA) on the residual data. In the end, we have a regionally filtered data set with dominantly linear time series suggesting that the majority of temporally variable non-tectonic signals have been removed. The spatial pattern of the resultant velocities clearly shows a component of right lateral shear consistent with strain accumulation on the locked San Andreas fault, as well as contraction across the Ventura basin (Figure 2).

3. InSAR Processing Results

The presence of a linear time series in our filtered GPS data does not guarantee that all non-tectonic signals have been removed. For example, many GPS stations in the nearby Los Angeles basin are currently undergoing subsidence from long-term aquifer draw-down [e.g. Argus et al., 2005], which could produce a linear time series that may contaminate our tectonic velocity estimates. Because
anthropogenic deformation can be highly localized and the GPS station spacing in the Ventura region is typically on the order of 10 km or more, we cannot be confident that localized anthropogenic signals will be detectable in the GPS data alone. Therefore, we have processed InSAR interferograms following the approach of Argus et al. [2005] and Bawden et al. [2001]. To avoid decorrelation issues due to vegetated terrain, we used the software package StaMPS [Hooper et al., 2012] to identify persistent scatterers in the 24 available Envisat scenes (track 213, frames 2907 and 2925, 2003–2010). The full persistent scatterer data set contains more than two million points, but to facilitate comparison to GPS and mechanical modeling results, we have down-sampled the InSAR data to 1 km spacing (Figure 3).

The InSAR data show generally good agreement with the GPS velocities when the latter are projected into the Line Of Sight (LOS) of the Envisat satellite (Figure 3). The InSAR shows a possible anthropogenic signal that could ‘contaminate’ our estimates of tectonic deformation in the greater Oxnard area, at a site just west of MPWD, and also a small localized subsidence signal northwest of site VNCO, near the Ventura Avenue anticline where ongoing oil pumping is occurring. The far northeast section of the InSAR data does not agree well with the GPS LOS velocities, which may reflect interseismic strain accumulation on the San Andreas fault. Based on this interpretation of the InSAR data, GPS sites VNCO, P729, and TOST may have anthropogenic contamination in the resultant velocities. The remaining GPS sites should provide reliable tectonic velocities.

4. Three-Dimensional Mechanical Modeling of Interseismic Deformation

Existing deformation models of the Transverse Ranges region of southern California incorporate highly simplified fault structures and are not well suited to investigate deformation in regions of finite non-planar faults. Paleoseismologic investigations and kinematic folding studies have constrained long
term slip rates along some exposed and near surface faults in southern California [Azor et al., 2002; Çemen, 1989; Dolan et al., 2000; Hitchcock et al., 2001; Huftile and Yeats, 1995; Rockwell, 1988; Yeats, 1988], however these methods have not fully constrained the configuration and slip rates of faults in the region. Using the CFM, Marshall et al. [2008] predict complex secular slip distributions throughout the Ventura region that are generally in agreement with geologic estimates (Figure 4). In order to determine if a model driven by geodetic strain rates can reproduce both geologic slip rates and the details of interseismic geodetic deformation field, we have updated the Marshall et al. [2008] three-dimensional Boundary Element Method (BEM) mechanical model using a technique for simulating both geologic and interseismic timescales of deformation [i.e. Marshall et al., 2009]. The updated geologic timescale model predicts slip rates that are similar to those presented in Marshall et al. [2008] and generally in agreement with long-term geologic estimates. Therefore, short term geodetic strain rates appear to be compatible with geologic shortening rates and no significant geologic/geodetic slip rate discrepancies appear to exist. Furthermore, we see no anomalously high strain rates near the Ventura Avenue anticline.

Using the technique of Marshall et al. [2009] we have created the first three-dimensional CFM-based interseismic models of the region. The best-fitting locking depth was found to be 14 km, which is slightly shallower than the 18-20 km base of seismicity in the region [Lin et al., 2007], but similar to the locking depth found by Hager et al. [1999]. The model-predicted velocity field matches the general pattern of surface contraction in the Ventura basin, but systematic mismatches arise near the west and east boundaries of the region, suggesting that the strain rate tensor varies across the region.
Conclusions

We have found that all continuous GPS sites in the western Transverse ranges region, regardless of the geology of the local substrate (bedrock versus sedimentary basin fill), exhibit periodic seasonal motions; however, these periodic motions do not greatly affect velocity estimates and can be mathematically removed. While we have identified a few locations of potential non-periodic anthropogenic motion, our work shows that the large and ongoing anthropogenic deformation signals observed in the nearby Los Angeles basin are not seen to the same degree in the western Transverse ranges. Thus, most of the region’s GPS sites should yield reliable tectonic velocities.

An interseismic model using the non-planar CFM surfaces and based on the technique of Marshall et al. [2009] has been created. The model is the first mechanical interseismic model of the Ventura basin to use geologically constrained CFM surfaces. The model produces surface velocities that largely agree with the GPS velocity field, and the best fitting locking depth (14 km) is similar to previous estimates [Hager et al., 1999]. This model also predicts fault slip rates that generally agree with long term geologic estimates, suggesting, no geologic/geodetic slip rate discrepancies in the region. The model results also provide slip rate estimates for numerous otherwise unconstrained faults in the region.

6. Broader Impacts

This work has fostered collaborations between researchers at the Jet Propulsion Laboratory, the University of California Riverside, and Appalachian State University. At Appalachian State University, PI
Marshall has now begun training undergraduate students in GPS processing, dislocation modeling, and stress/strain theory. In 2011, an Appalachian State undergraduate student presented her work at the annual AGU meeting. Marshall is also currently training a Ph.D. student at the University of Massachusetts on GPS processing, and working with a Master’s student at the University of California Riverside on fault meshing. These efforts are aimed to produce future researchers that are better prepared for graduate school and the research community. Also, by training undergraduate students, interest and understanding of earthquake science is promoted.

7. SCEC3 Peer-Reviewed Publications


8. Conference Presentations Related to This Work


Marshall, S.T., Funning, G.J., Owen, S.E. 2011 Tectonic, Seasonal, and Anthropogenic Deformation Rates in the Western Transverse Ranges, California from the San Andreas to the Santa Barbara Channel, Eos, Transactions of the American Geophysical Union.


Marshall, S.T., Funning, G.J., Owen, S.E. 2011 Deformation Rates in the Western Transverse Ranges, California from the San Andreas to the Santa Barbara Channel measured with GPS and Persistent Scatterer InSAR. Southern California Earthquake Center Annual Meeting, Palm Springs, CA.


References


