El Mayor Postseismic

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Introduction

Data Processing

We use continuous GPS position time series provided by University Navstar Consortium (UNAVCO) for Plate Boundary Observatory (PBO) stations within a 400 km radius about the El Mayor-Cucapah epicenter. Our analysis is on the coseismic and postseismic deformation resulting from the EMC earthquake, which we collectively describe as $u(t)$. We consider GPS position time series, $u_{\text{obs}}(t)$, to be the superposition of $u(t)$, secular tectonic deformation, annual and semi-annual fluctuations, and coseismic offsets from sigificant earthquakes over the time span of this study. The June 14, 2010 Mw5.8 Ocotillo earthquake and the August 26, 2012 Brawley swarm, which consisted of a Mw5.5 and Mw5.3 event, are the only earthquakes after the EMC earthquake that produced noticeable offsets recorded by GPS. Although the Ocotillo earthquake had its own series of aftershocks (Haukson), neither earthquake produced transient deformation that is detectable with GPS. We thus model $u_{\text{obs}}(t)$ as

$$\begin{aligned} u_{\text{obs}}(t) =& u(t) + c_0 + c_1 t + \\ & c_2 \sin(2\pi t) + c_3 \cos(2\pi t) + c_4 \sin(4\pi t) + c_5 \cos(4\pi t) + \\ & c_6 H(t - t_{\text{oc}}) + c_7 H(t - t_{\text{bs}}) + \epsilon. \end{aligned} \tag{1}$$

Where t_{oc} and t_{bs} are the times of the Ocotillo earthquake and Brawley swarm respectively, $H(t)$ is the Heaviside function, c_0 through c_7 are unknown coefficients, and ϵ is noise with zero mean and variance that is assumed known.

Stations which recorded signals that clearly cannot be described by the aforementioned processes are not included in our analysis. This includes stations in the Los Angeles basin, which record deformation that is largely anthropogenic. In order to ensure an accurate estimation of the secular deformation, we only use stations that were installed at least six months prior to El Mayor-Cucapah earthquake. While several stations were installed after the EMC earthquake to improve the spatial resolution of postseismic deformation [Spliner et al. (2015)], our inverse method uses postseismic displacements rather than velocities (e.g. Pollitz), which requires the knowledge of the stations preseismic position. Despite our inability to utilize potentially rich data, we prefer to use postseismic displacements rather than potentially dubious estimates of postseismic velocities.

The October 16, 1999 Hector Mine earthquake, which occurred within our study region about 270 km north of the EMC epicenter, has produce transient postseismic deformation which we do not wish to model either mechanically or through empirical line fitting. We thus restrict our analysis to deformation observed six years after the Hector Mine earthquake, past which point postseismic deformation for nearfield sites occurs at an approximately steady rate [Savage and Svarc (2009)]. When considering stations further away from the Hector Mine epicenter, postseismic transience persists for only about two years [Spliner et al. (2015)].

We do not assume a parametric form for $u(t)$, (e.g. [Rollins et al. (2015)]), but rather we model $u(t)$ as integrated Brownian motion, so that

$$\dot{u}(t) = \sigma^2 \int_0^t w(s)ds. \tag{2}$$

where $w(t)$ is white noise and the variance of $\dot{u}(t)$ increases linearly with time by a factor of σ^2. We use a Kalman filtering approach to estimate $u(t)$ and the unknown parameters in eq. 1 which we describe now.

In the context of Kalman filtering, our time varying state vector is

$$\mathbf{X}(t) = [u(t), \dot{u}(t), c_0, ..., c_7] \tag{3}$$

and eq. 1 is the observation function which maps the state vector to the GPS observations. We initiate the Kalman filter by assuming a prior estimate of $\mathbf{X}(t)$ at time t_0 which has a sufficiently large covariance to effectively make our prior uninformed. For each time epoch, t_i, Bayesian linear regression is used to incorperate GPS derived estimates of displacement with our prior estimate of the state, $\mathbf{X}_{i|i-1}$, to form a postserior estimate of the state, $\mathbf{X}_{i|i}$, which has covariance $\mathbf{\Sigma}_{i|i}$.

We then use the posterior estimate of the state at time t_i to form a prior estimate of the state at time t_{i+1} through the transition function

$$\mathbf{X}_{i+1|i} = \mathbf{F}_{i+1}\mathbf{X}_{i|i} + \delta_{i+1} \tag{4}$$

where

$$\mathbf{F}_{i+1} = \begin{bmatrix} 1 & (t_{i+1} - t_i) & \mathbf{0} \\ 0 & 1 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{I} \end{bmatrix} \tag{5}$$

and δ_{i+1} is the process noise, which has zero mean and covariance described by

$$\mathbf{Q}_{i+1} = \sigma^2 \begin{bmatrix} \frac{(t_{i+1}-t_i)^3}{3} & \frac{(t_{i+1}-t_i)^2}{2} & \mathbf{0} \\ \frac{(t_{i+1}-t_i)^2}{2} & (t_{i+1} - t_i) & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} \end{bmatrix}. \tag{6}$$

The covariance of the new prior state, $\mathbf{X}_{i+1|i}$, is then described by

$$\mathbf{\Sigma}_{i+1|i} = \mathbf{F}_{i+1}\mathbf{\Sigma}_{i|i}\mathbf{F}_{i+1}^T + \mathbf{Q}_{i+1}. \tag{7}$$

This process is repeated for each of the N time epochs at which point we use Rauch-Tung-Striebel smoothing to find $X_{i|N}$, which is an estimate of the state at time t_i that incorporates all N GPS observation. Our final estimates of $u(t)$ are used in subsequent analysis, while the remaining components of of the state vector are considered nuisance parameters. In the interests of computational tractability, we downsample our smoothed time series from daily solutions down to weekly solutions.

We illustrate the effect of filtering in figure (). We assume a constant σ^2 for each station, which is chosen to be just large enough for the earliest transient deformation at the most nearfield site, P496?, to be faithfully described by the filtered solution.

Cite Freed 2007 for far reaching postseismic after Landers/Hector Mine.

Observations

Prior Studies

Postseismic Modeling

We use a fault geometry from [Wei et al. (2011)], which was determined using teleseismic, GPS, and InSAR data.

After the El Mayor-Cucapah earthquake, additional GPS stations were installed In Baja California to record postseismic deformation with better spatial coverage. Two of the stations PTAX and PHJX were installed near the epicenter in the Cucapah Mountains. We do not include these two stations in our analysis because the geometry of the faults that ruptured during the earthquake is more complicated than our assumed fault geometry [Oskin et al. (2012)] and the near field stations would be most sensitive to error in our geometry. We also leave of these near field stations in order to avoid any near field processes which we do not consider in this paper [Gonzalez-Ortega et al. (2014)].

Numerous stations exhibit extraneous signals which can be at [Aagard et al. (2013)]

Rheological constraints

Results

Acknowledgements

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