4 Time-dependent Model of Creep on the Hayward Fault from Joint Inversion of 18 Years of InSAR and Surface Creep Data

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4.1 Introduction

Spatial and temporal variations of aseismic fault creep represent important factors in realistic estimation of seismic hazard due to their influence on the size and recurrence interval of large earthquakes along partially coupled faults. To solve for a time-dependent model of creep on the Hayward fault, we invert 18 years of surface deformation data (1992 - 2010), obtained by interferometric processing of 52 and 50 synthetic aperture radar (SAR) images acquired by the ERS1/2 and ENVISAT satellites, respectively, and surface creep data obtained at more than 25 alinement and creepmeter stations. To jointly invert the residual InSAR displacement time series and the surface creep data and to obtain a time-dependent model of creep on the Hayward fault, we use an iterative re-weighted L2-norm minimization approach combined with a linear Kalman filter. The time-dependent model constrains a zone of high slip deficit (low creep rate) that may represent the locked rupture asperity of past and future M≈7 earthquakes.

4.2 Approach

In this research, we include 18 years of InSAR data collected by the ERS-1, ERS-2 and Envisat satellites. A total of 831 interferograms are processed from 102 images collected between 1992 and 2011. These are processed into a time series of surface range change and used as input in the time-variable modeling. The time history of the creep on Hayward fault is obtained by time-dependent joint inversion of the InSAR time series and surface creep data. To this aim, we employ a method consisting two main operators: (i) a L1-norm minimization operator and (ii) a recursive filter, Kalman Filter (KF), to generate time series of the creep. These two operators are combined in an iterative manner (Shirzaei and Walter, 2010). The InSAR data are complemented by observation of surface creep obtained from alinement array measurements (Lienkaemper, et al., 1991; Lienkaemper and Galehouse, 1997) and creepmeter data (Bilham and Whitehead, 1997) along the Hayward fault.

4.3 Observations and Results

Figure 2.8a shows a map of the LOS velocities of the obtained InSAR time series. Major components of the resolved signal include displacement due to plate motions and elastic strain accumulation across the San Andreas fault system, and non-tectonic land subsidence and re-bound. Here, we focus on the discontinuity along the Hayward fault that is an indicator for shallow fault creep and comprises shorter wavelength features compared to the long term interseismic deformation components (e.g., [Schmidt, et al., 2005]). The time-dependent creep rate model of the Hayward fault for 1992-2010 is shown in Figure 2.8b. The darker colors indicate more right-lateral creep. In Figure 2.8b, the location of the creepmeters and alinement arrays and their associated observations of actual surface creep are shown for comparison with the creep model. There is very good agreement between the model and surface creep observations. Our results show that the upper 3-4 km of the Hayward fault from 45 to 70 km distance, creeps faster than the northern section (km 0 - 30). In the north, the faster creep occurs at a depth of 5 - 10 km. A large locked patch that creeps at < 1 mm/yr is constrained at 25 - 45 km, in agreement with earlier works (Simpson, et al., 2001; Malservisi, et al., 2003; Funning, et al., 2005; Schmidt, et al., 2005) but not with the model result of Evans, et al. (2012).

4.4 Conclusion

We present a spatiotemporal model of creep on the Hayward fault. To this end we explored an 18-year-long time series of InSAR deformation and surface creep data. Our time-dependent creep model reveals a persistent accumulation of slip deficit (more than 90% of the geologic slip rate) along a buried ~25-km-long and ~7-km-wide section of the fault. These results suggest that the creep rate is faster at shallow depths along the southern Hayward fault compared to the northern fault section, which has higher rates at depth. This variation may reflect changes in the regional stress field and/or material heterogeneities along the Hayward fault. Given the fact that most of the Hayward fault accumulates a slip deficit of 30%-90% of its long-term slip budget, we estimate a seismic moment accumulation of $M_w \sim 6.3-6.8$, respectively, due to rupturing only the large central locked zone or rupture propagation to the entire 70 km of the Hayward fault including the area of low deficit, since the last big event in 1868.

4.5 References


Evans, E. L., J. P. Loveless, and B. J. Meade (2012), Geodetic constraints on San Francisco Bay Area fault slip rates and
Figure 2.8: a) The LOS velocity from 1992-2010 InSAR time series. Red and blue colors indicate movement toward and away from the satellite, respectively. The satellite incidence angle and heading angles are 23° and 188°. b) Average right-lateral creep rate along the Hayward fault. In addition to microseismicity shown by black dots, the magenta circles show the location of repeating events. Average 1992-2010 rates from surface measurements are shown by symbols on top with same color scale. (See color figure on cover.)


Funning, G., R. Bürgmann, A. Ferretti, F. Novali, and D. A. Schmidt (2005), Kinematics, asperities and seismic potential of the Hayward fault, California from ERS and RADARSAT PS-InSAR, *EOS, Transactions American Geophysical Union*, 86, 52.


