Geodetic Tracking and Characterization of Precipitation-Triggered Slow Moving Landslide Displacements in the Eastern San Francisco Bay Hills, California, USA

Julien Cohen-Waeber, Roland Bürgmann, Nicholas Sitar, Alessandro Ferretti, Chiara Giannico, Marco Bianchi

Introduction

Contemporary geodetic technologies, such as continuous Global Positioning Systems (GPS) and Interferometric Synthetic Aperture Radar (InSAR), allow for remote detection and characterization of ground surface displacements with sub-centimeter precision and accuracy. These technologies are complementary with one another in that GPS allows real time tracking of a finite point while InSAR time series analyses allow widespread surface deformation tracking, though still far from real time.

This project combines GPS and InSAR for the temporal and spatial characterization of landslide deformation. Both methods have shown accelerated surface deformation as an effect of precipitation, though not in relation to recent seismic activity. These observations also suggest intra-slide deformation patterns not previously measurable. Ultimately, both InSAR and GPS studies not only confirm strong correlation and sensitivity to periods of precipitation, but similar kinematic behavior and downslope sliding velocities of around 30 mm/year.

InSAR Time Series Analyses

A review of three independent InSAR time series analyses of landslides in the Berkeley Hills, from separate satellite acquisitions and over different time intervals from 1992–2011 shows remarkable consistency (Hilley et al., 2004, Quigley et al., 2010, Giannico et al., 2011). In each case, surface deformation showed a clear correlation to precipitation, with similar mean downslope velocities (approx. 30 mm/year) and periods of acceleration during each wet season. These studies also suggest observable internal deformation when each slide is divided into groups of coherently moving masses and different sections mobilize separately (Quigley et al., 2010, Cohen-Waeber et al., 2013).

In Figure 2.16.1 (Top), the study of TerraSAR-X data acquisitions from 2009–2011, (Giannico et al., 2011) utilizing the SqueeSARTM algorithm by Tele-Rilevamento Europa (Ferreti et al., 2011), confirms these displacement trends in different parts of the same landslide. In this case, a significantly higher spatial resolution revealed that these slides are in fact moving as bodies of smaller coherent masses. By differencing the average displacements of the top, middle and bottom of the landslides, a pattern of apparent extension then shortening with the progression of precipitation is visible, in what could be called an “accordion effect” (Cohen-Waeber et al., 2013). Figure 2.16.1 (Bottom) illustrates early seasonal acceleration and deceleration of the lower landslide portions in contrast to the upper landslide portions.

Continuous GPS Tracking

To fully capture temporal landslide surface displacements, seven continuous GPS stations were installed on Lawrence Berkeley Laboratory (LBL) and Berkeley hills landslides, with data collection rates of 1 Hz for average daily solutions and 20 Hz in case of seismic activity. Each station is anchored on deep seated, reinforced concrete foundations and its measurements differenced from a near-by stable monument to limit non-landslide displacements as tectonic activity, clay activity or atmospheric error.

Through three mild wet seasons (since January 2012), well-defined precipitation-triggered slope movement has been
recorded from daily solutions, as shown through the displacement time series of stations LRA1 and LRA2 (Figure 2.16.2, Top, Middle). While an apparent antenna oscillation can be attributed to seasonal disturbance from surficial clay activity, the stations exhibit overall downslope displacements with similar average velocities as shown through the InSAR analyses. Furthermore, differencing these two stations located on the same landslide captures a sense of internal deformation and suggests the same “accordion effect” (Figure 2.16.2, Bottom).

**Preliminary Conclusions**

InSAR and GPS have demonstrated here their capability to record and characterize landslide motions that otherwise would not have been observed with such level of detail. While both methods of observation have not yet been compared on one landslide over the same period, they are complementary. Overall, our observations from several studies have yielded similar precipitation triggered down-slope velocities, and comparable internal mechanisms, exhibiting progressive accordion-like downslope failure typical to slow moving flow slides. Ultimately, tracking over longer periods will provide important insight on the triggering mechanisms and internal landslide behaviors described, including yet to be recorded seismically induced landslide motions.

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**References**


