MONITORING SLOW MOVING LANDSLIDES IN THE BERKELEY HILLS WITH TERRASAR-X DATA

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1. INTRODUCTION

Large, slow moving landslides in the Berkeley Hills cause costly damage and pose a potential threat to public safety due to the close proximity of the Hayward Fault. Now in the Berkeley Hills there are four large, slow moving, deep-seated landslides. All the landslides extend through residential areas and move on the order of cm/year, each covering an area of roughly 0.25-1.00 km^2. Over the years, the landslides have caused costly damage to homes, breakage of underground utility pipes, and confusion over property lines. Although deformation on these landslides is typically quite small and slow, the Hayward fault runs close to the head of each landslide. It is currently not well understood how the landslides respond to seismic activity on the Hayward fault, but significant deformation is conceivable under wet conditions and a moderate to large seismic event. Space-borne Synthetic Aperture Radar (SAR) interferometry is a powerful tool for measuring movements on ground by exploiting phase difference of SAR images taken at different time instances. In this paper we aim to monitor the Berkeley Hills landslides through different SAR data especially TerraSAR-X data and time series analysis.

2. PREVIOUS RESULTS WITH ERS DATA

A previous study by Hilley et al. [1] used InSAR data from European Remote Sensing satellites (ERS-1 and ERS-2) from 1992-2000 to image the landslides and estimate rates of motion (Figure 1). He used 46 scenes to construct a range-change time series for the Berkeley vicinity in the eastern San Francisco Bay area. Here, the active Hayward Fault (HF) bounds the western margin of the East Bay Hills (EBH), which rises to ~370m above sea level [2]. The Permanent Scatterer (PS) InSAR analysis was utilized. PS are typically radar-bright and phase stable structures such as building corners, telephone poles and rock sparse. For each pixel the PS analysis obtains a time series of relative range change. The slow-moving landslides of the Berkeley Hills are clearly indicated by the faster moving yellow and red pixels. Positive range change in the ERS data is consistent with southwest motion of the landslides, away from the west-looking satellite.

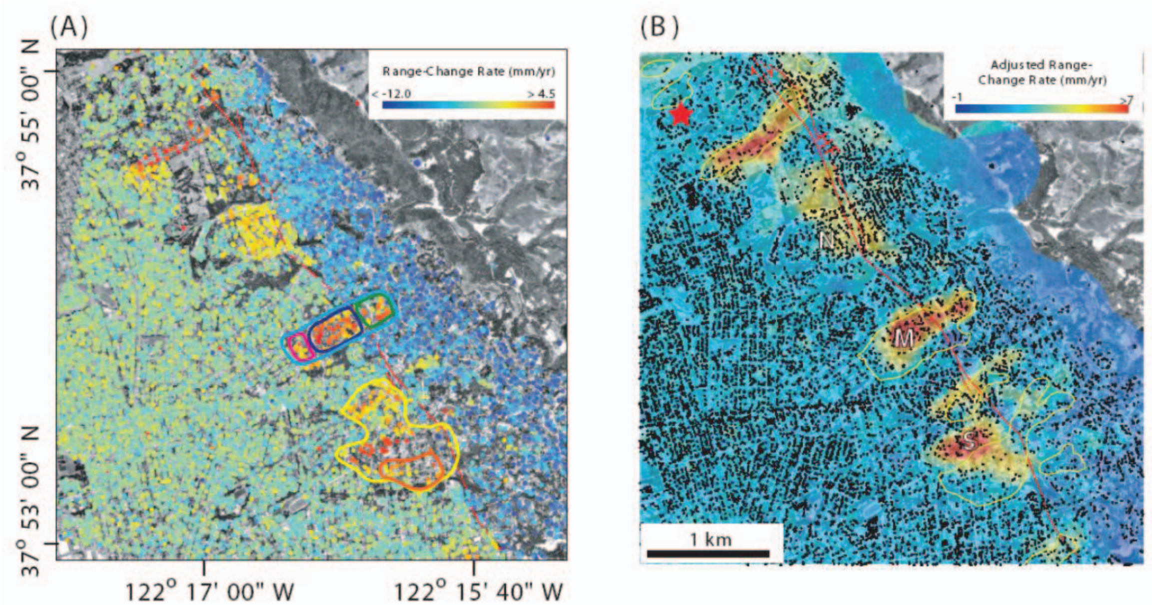

Figure 1. Each PS pixel in the study area is plotted and colored according to range change rates. (A) Tectonic surface creep along the Hayward Fault is clearly visible as a sudden step in range change rate of 1-2 mm/yr. The active trace of the fault from field mapping is indicated by a red line. Lines drawn around the two south most slides represent 6 groups of coherently moving PS that are used in the time series analysis. (B) Interpolated range-change rates with the range change offset across the Hayward fault removed. The red star shows the location of the M=4 earthquake that appears to have accelerated motion on the nearby landslide.

3. TERRASAR-X DATA SET AND TEST SITE

The TerraSAR-X satellite, launched on June 15, 2007, carries an X-band SAR operating at 9.65 GHz. One of the main goals of the TerraSAR-X mission is to produce high resolution imagery with near optical quality. The antenna on TerraSAR-X can be steered in both elevation and azimuth and can be used to generate Spotlight, Stripmap and ScanSAR images. Spotlight images have a resolution of about 1-meter, while Stripmap data have a ground resolution between 2 meters and 6 meters, and ScanSAR images have a resolution of approximately 16 meters. The satellite operates in an 11 day repeat orbit at an altitude of 514 km [3, 4]. Up to now, we have ordered and received 40 more TerraSAR-X Spotlight Single Look Complex (SLC) images and a few Stripmap SLC images delivered by DLR. The TerraSAR-X images were acquired over the San Francisco Bay Area particularly around the active landslides, coastal subsidence and shallow Hayward fault creep near the city of Berkeley. Berkeley is situated between latitude 37.45 and 38.00, longitude 237.30 and 238.00. The data acquisition interval is from November, 2008 to now. Four types of Spotlight images and one type of Stripmap images in time sequence were ordered and acquired: spot_012, spot_038, spot_049, spot_075 and strip_003, with different look angles and pass directions.

4. PRELIMENTARY RESULTS

We applied a two-pass differential interferometry approach using SRTM 1-arc-second DEM heights as reference to calculate the topographic phase. A time series of interferograms are used for the atmospheric correction. We used the 'cascaded' interferograms to do the stacking. Every image appears in two interferograms except the first and last image. Now we only got a few very preliminary results of Stripmap interferograms and stacking of Spotlight interferogram (Figure 2). And the positive range change in the landslides area is consistent with southwest motion of the landslides, away from the west-looking satellite. Also we analyzed the baseline and coherence. The coherence images show high coherence values in the urban area but low values in mountain area which cause problems with the landslides area's unwrapping. So we still have to work on the spotlight data processing problems in the near future [5].

Our initial analysis with ERS was hampered by our inability to determine the actual 3D motions of the sliding material. So we hope the four beams of TerraSAR-X data from different viewing geometry will significantly improve our ability to full characterize the kinematics and temporal patterns of the landslides. We are still in the early stages of this investigation and will acquire data as much as more with the rainy season coming. Results from TerraSAR data will be carefully compared and integrated with InSAR data from other spacecraft, including the ERS-1/2, Envisat, RADARSAT-1 and ALOS satellites will be integrated in a rigorous analysis and monitoring effort of active surface deformation in the region.

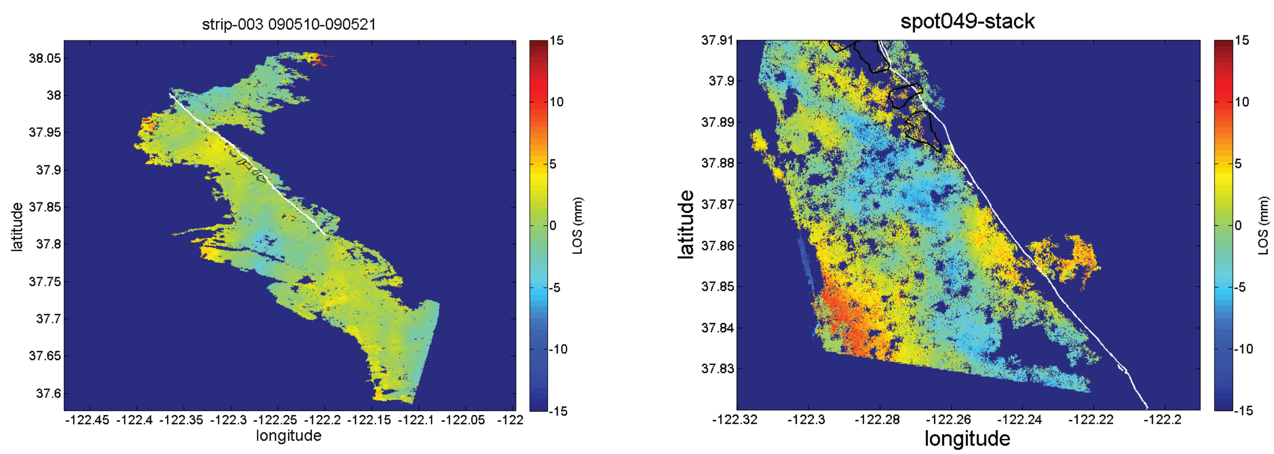

Figure 2. Stripmap interferogram and stacking of Spotlight interferogram

5. ACKNOWLEDGMENT

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6. REFERENCES

[1] Geroge E. Hilley, Roland Bürgmann, Alessandro Ferretti, Fabrizio Novali, and Fabio Rocca, "Dynamics of slow-moving landslides from permanent scatterer analysis," *Science*, 304, pp.1952-1955, June 2004.

[2] Roland Bürgmann, Eric J. Fielding, and J. Sukhatme, "Slip along the Hayward fault, California, estimated from space-based synthetic aperture radar interferometry," *Geology*, 26, pp. 559-562, 1998.

[3] TerraSAR-X Ground Segment Basic Product Specification Document, TX-GS-DD-3302.

[4] TerraSAR-X Ground Segment Level 1b Product Format Specification, TX-GS-DD-3307.

[5] Eineder, M., N. Adam, and R. Bamler, "Spaceborne Spotlight SAR Interferometry With TerraSAR-X," *IEEE Trans.on Geosci. Remote Sens*, 5, pp. 1524-1535, 2009.