Integrating Airborne LiDAR and Historical Aerial Photographs to Assess Landslide Kinematics And Evolution

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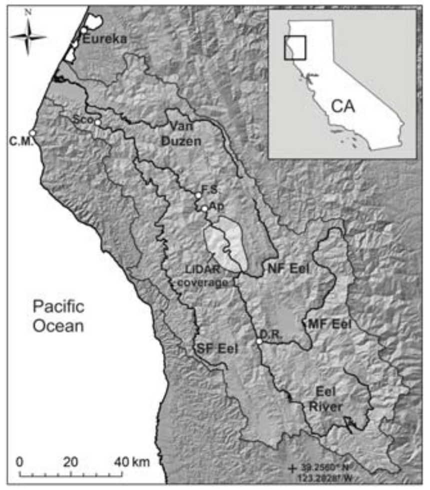
Summary

Large, slow-moving landslides (earthflows) can continuously move and evolve for centuries. They can exhibit complex spatiotemporal patterns of movement, although few studies have sufficient duration or spatial resolution to quantitatively assess the long-term activity, morphologic change, and behavior of large earthflows.

- We combine airborne LiDAR and 6 decades of aerial photos to document the evolution, kinematics, and morphology of the Boulder Creek earthflow.
- Photographic analysis reveals the rate and extent of earthflow activity peaked in the 1960's and has decreased since 1981.
- Major axial gullies have avulsed, while lateral gullies undercut adjacent hillslopes.
- There is significant redistribution of mass within the flow - areas of high compression exhibit complex thrusting and faulting features, while extensional areas show significant deflation.

Eel River, Northern California

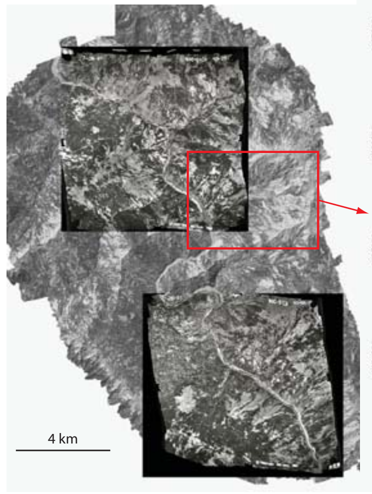
- Weak Franciscan melange rock, high seasonal rainfall (~1.3 m/yr) and tectonic uplift make the Eel River catchment prone to extensive landsliding
- The Boulder Creek Earthflow is a large, slow moving landslide adjacent to the Eel River. The 5 km long slide moves approximately 2 m/yr, although the rate of movement is highly variable both through time and across the earthflow (Roering et al. 2009).



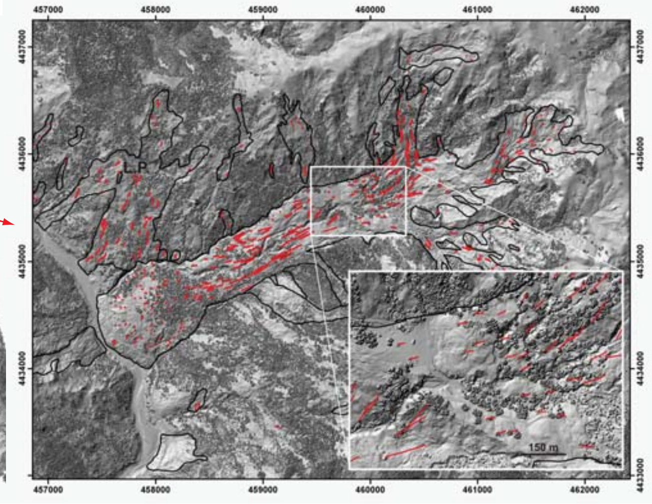
The Boulder Creek Earthflow is adjacent to the main stem Eel River, and within 230 km^2 of high resolution LiDAR coverage

Combining Airborne LiDAR and Photographs

- We orthorectified 6 sets of aerial photographs dating back to 1944 (1944, 1966, 1968, 1981, 1991, 1998)
- Incorporated 1 m resolution LiDAR (acquired 2006) as the reference image and elevation model
- Very accurate rectification (median error ~2 m), even in absence of camera calibration reports
- Combination of manual displacement mapping, automated correlation, and stereo-pair DEM extraction



Rectified aerial photographs overlying unfiltered LiDAR

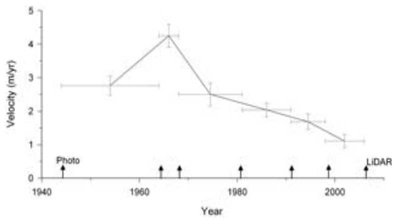


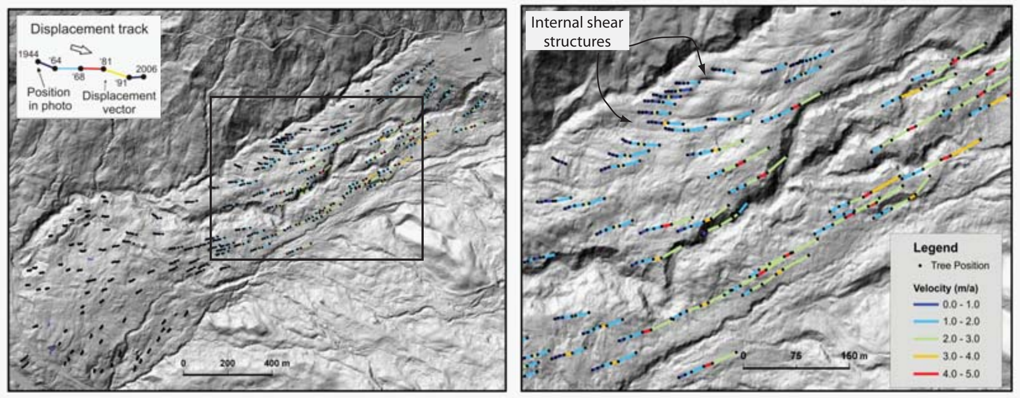
Boulder Creek earthflow mapped by tracking displacement of trees growing on earthflow surface from 1944 to 2006 (red lines)

Temporal Behavior

- By tracking the displacement of trees growing on the earthflow surface, we documented decadal-scale changes in earthflow velocity.
- Velocities peaked in the 1960's, and have declined steadily since 1981, potentially due to climatic changes associated with the Pacific Decadal Oscillation.
- The mid-century was cooler and wetter than past 30 years.

Decadal-scale velocity of Boulder Creek Earthflow transport zone

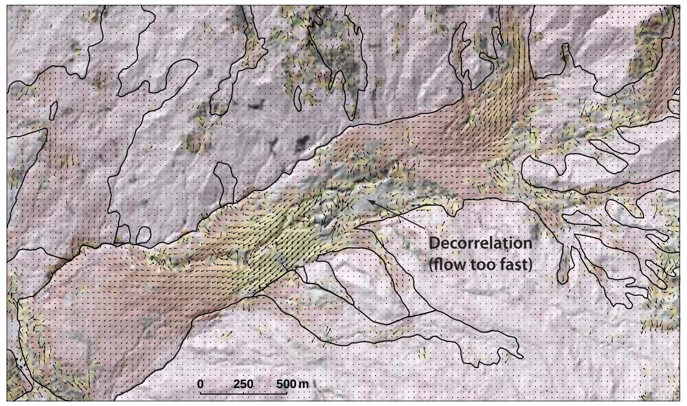




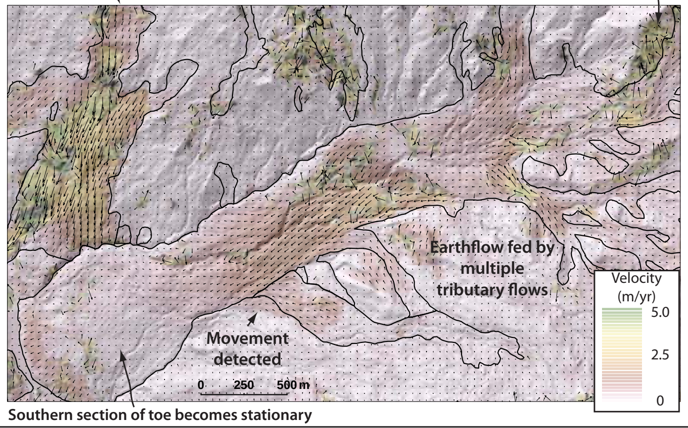
The fastest and most sustained movement occurs in the southern margin of the earthflow transport zone, with up to 175 m displacement over the 62 year study interval. This translation is accommodated by thickening and stacking of material above the earthflow toe, and deflation of the upper transport zone (see differential DEM to right). Lateral strain within the earthflow mass is primarily accommodated by fault-like shear zones

2-D Automated Change Detection - COSI-Corr Analysis

Boulder Creek 1964-1981



Boulder Creek 1991-1998



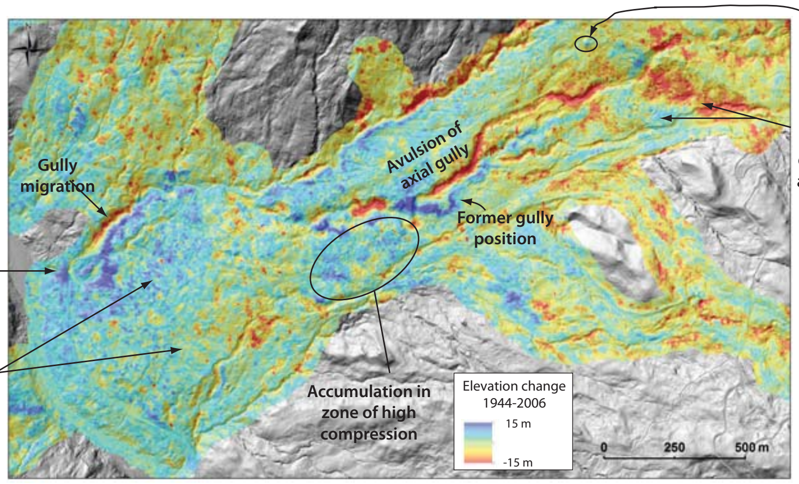
- To augment information from photos (beyond manual mapping), we used COSI-Corr to detect change between sequential images
- COSI-Corr software (Ayoub et al. (2009)) automatically detects change between sequential orthorectified aerial photos

- Identified broad zones of movement
- Direction and magnitude conformed to the manual displacement mapping and InSAR results (Roering et al 2009)
- Detected additional movement in locations with sparse vegetation where manual tracking was not possible

- Comparison between these two correlations reveals a general decline in activity across the Boulder Creek Earthflow in the 1990's
- Both the extent and rate of movement has decreased
- Note the activation of the landslide north of the toe, and the stabilization of the southern part of the toe

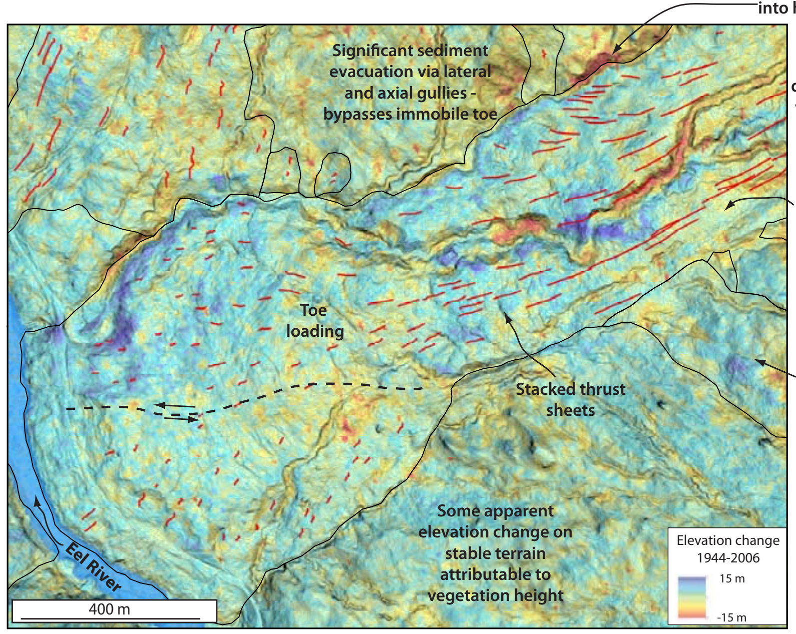
Active earthflow outlines in black from Mackey and Roering (in press)

3-D Change Detection with Photo Stereo-Pairs



To document vertical change, we extracted a DEM from a stereo-pair of 1944 photos (2 m resolution). Differencing the 1944 DEM from the LiDAR revealed significant changes in elevation in different parts of the earthflow. This included gully migration, source zone deflation, stacking and thrusting in zones of high compression, and even re-alignment of a railway bridge.

Earthflow Morphology and Evolution



Differential elevation (1944-2006) with 0.5 m surface contours from 2006 LiDAR

Multiple optical image techniques, coupled with high-resolution digital topography, allow a long-term perspective on the complex evolution of an active landslide.

References

Ayoub, F., S. Leprince, and J.P. Avouac, "Co-registration and correlation of aerial photographs for ground deformation measurements," *ISPRS Journal of Photogrammetry and Remote Sensing*, Volume 64, Issue 6, Pages 551-560, November 2009

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Acknowledgements

This work funded by NSF grant - EAR-0447190 to Roering. Many thanks to Sebastien Leprince, Francois Ayoub, and Joel Scheingross for assistance with image correlation and processing. Thanks to Stewart Ranch and Lone Pine Ranch for land access. LiDAR acquired by NCALM in 2006.