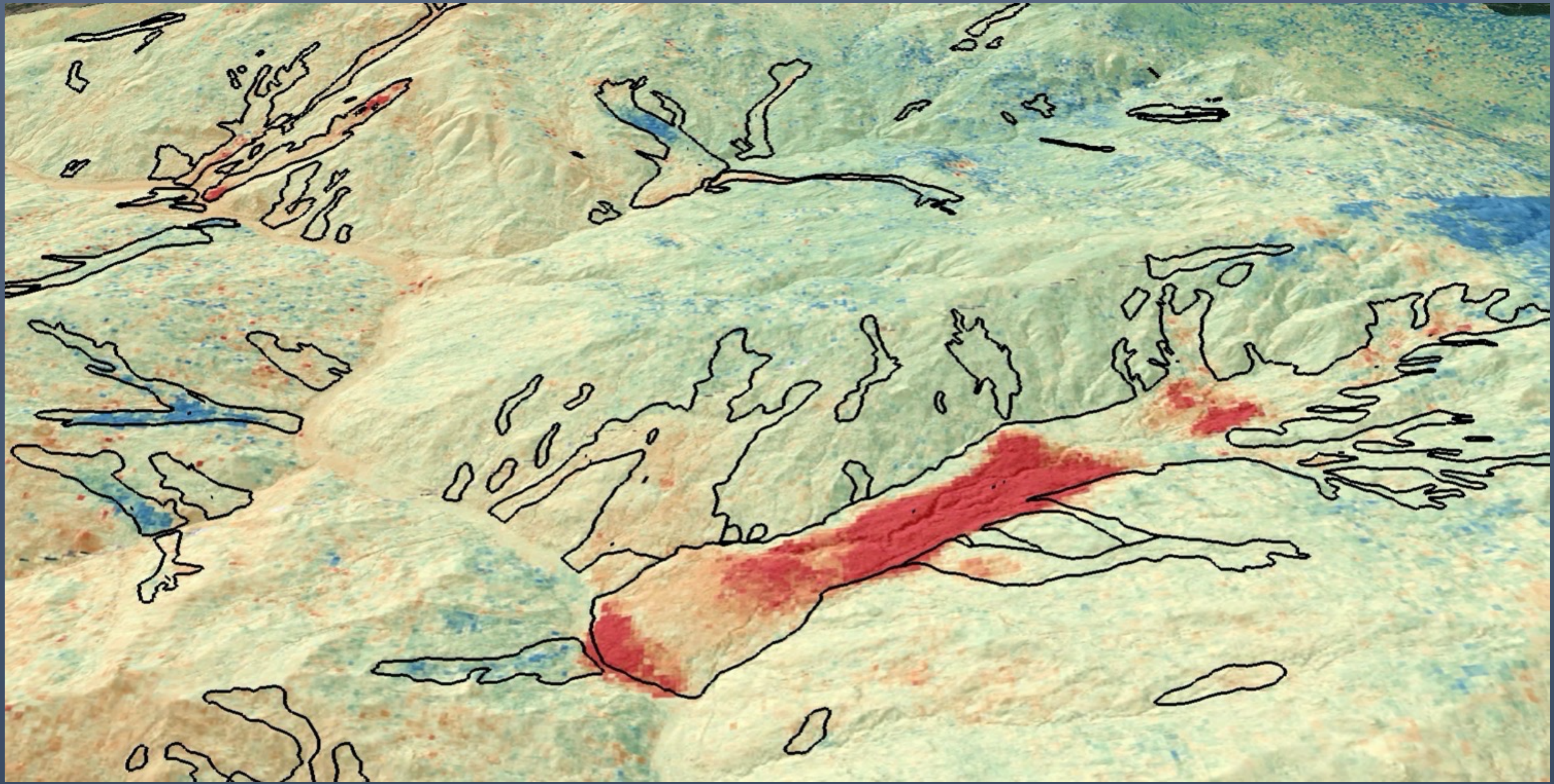
Rapid response of slow-moving landslides to extreme rainfall following historic drought in California



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National Aeronautics and Space Administration

Motivation

Introduction

- Slow-moving (~m/yr) landslides govern erosion and landscape evolution and pose a major hazard
- Move during seasonal wet periods when infiltrating precipitation increases the pore-water pressure within the landslide body.

Research Questions

How do slow-moving landslides respond to changes in rainfall?

  - Velocity changes in response to changes rainfall (i.e. pore pressure)
  - Slow down during periods of drought and speed up during wet periods

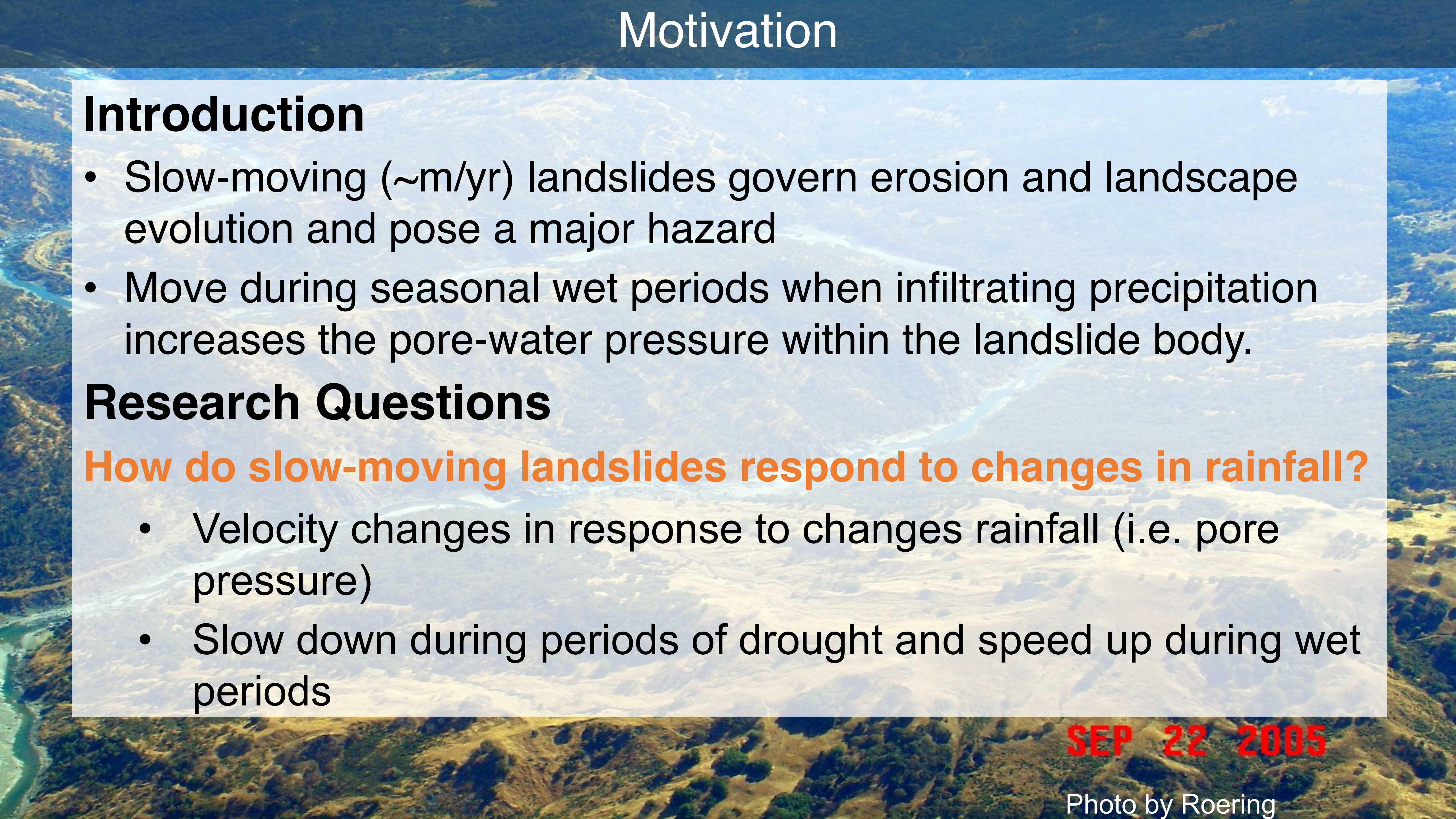
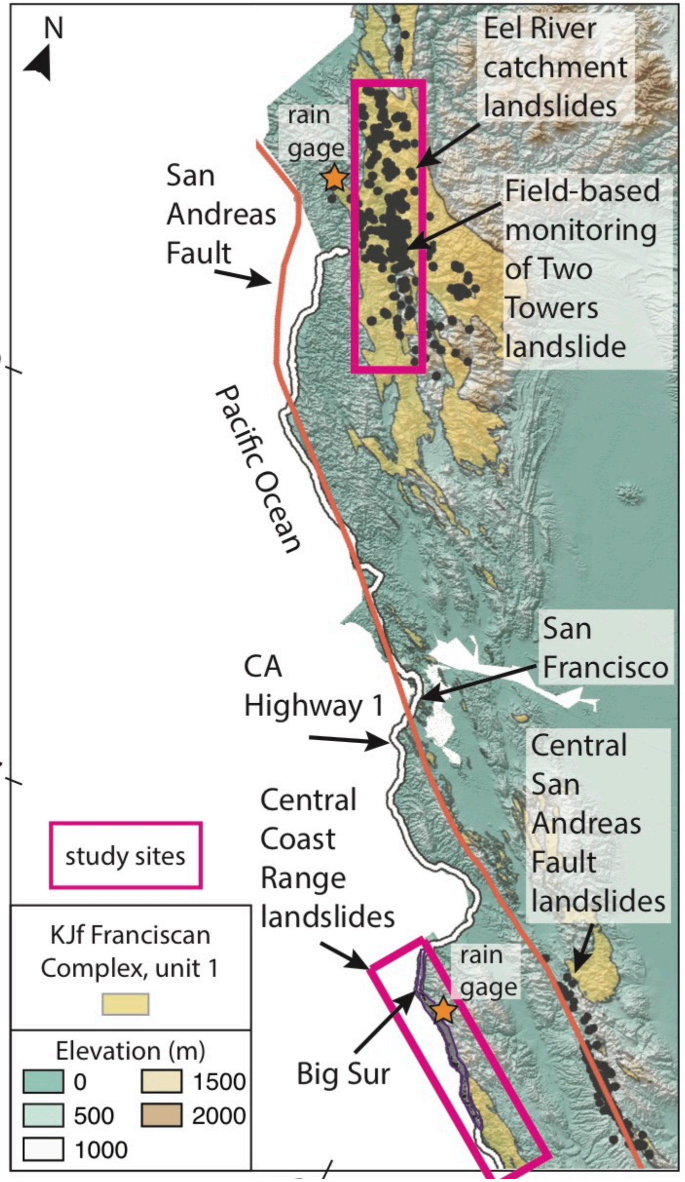


Photo by Roering

California Coast Ranges

Lithology and Tectonics



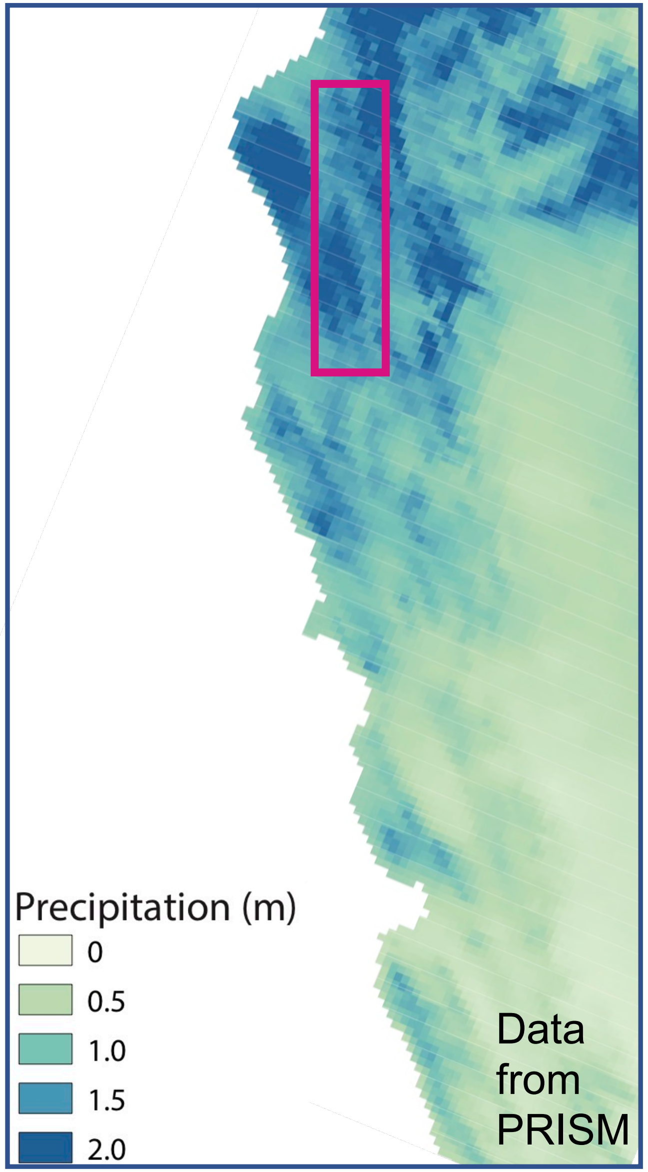
Tectonics

- Uplift rates ~ 1 mm/yr

Lithology

- Franciscan mélange
  - Clay-rich
  - Mechanically weak

Average Precipitation (1981 – 2010)



Eel River Catchment

- High erosion rates ~ 0.9 mm/yr
- Precip. ~ 1.7 m/year
- 80% between Oct & May

(Jennings, 1977; Lock et al., 2006;Wheatcroft and Summerfield, 2005)

Slow-moving landslides

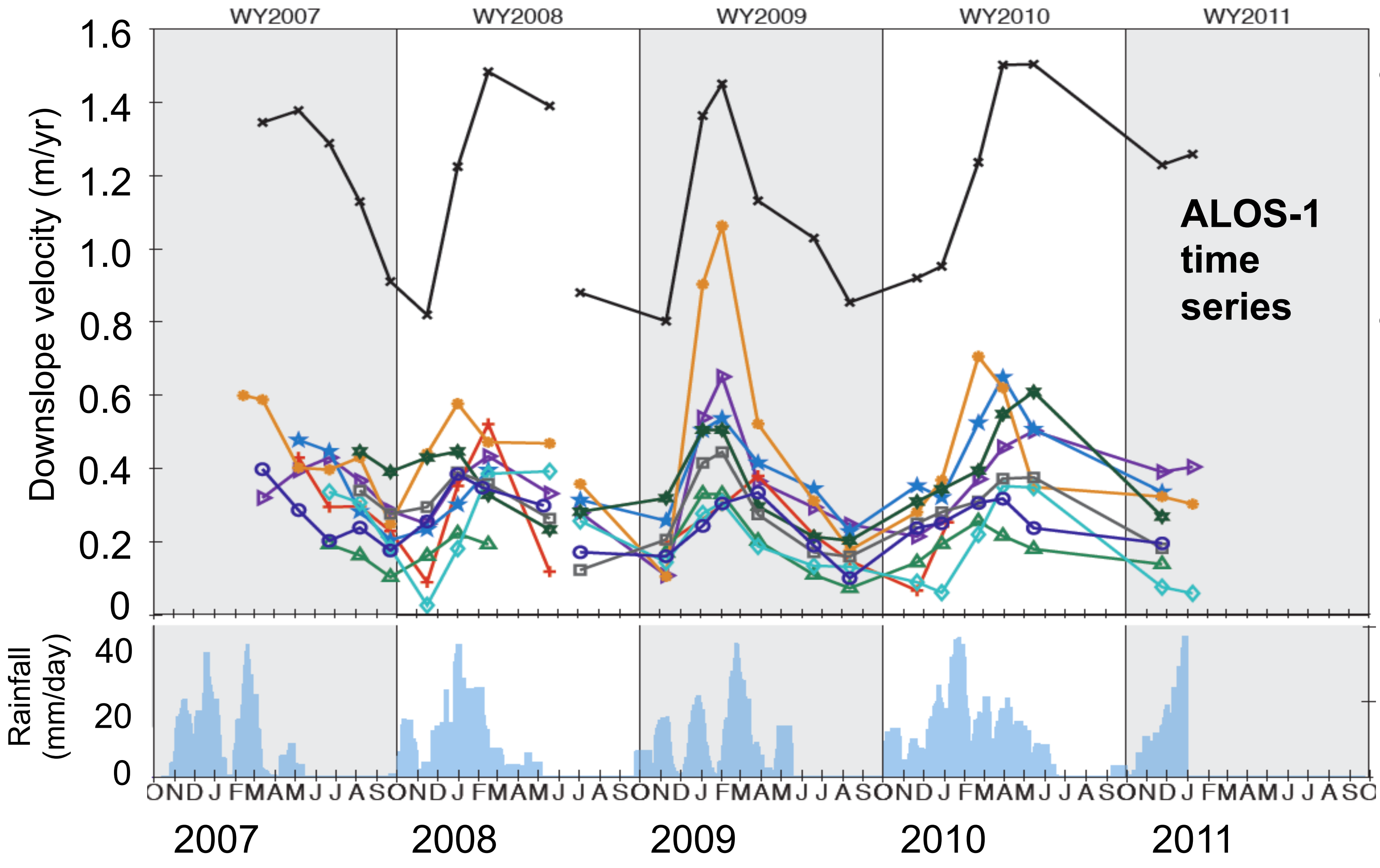
Eel River landslides

- Large (> 400 m long)
- Deep-seated (> 3 m)
- Slow moving (< 4 m/yr)
- Distinct kinematic zones
- Sliding along basal and lateral faults

Seasonal Kinematics: *2007-2011*

Handwerger et al., 2013

10 slow-moving landslides



- Seasonal velocity changes
- Driven by precipitation-induced changes in pore-water pressure

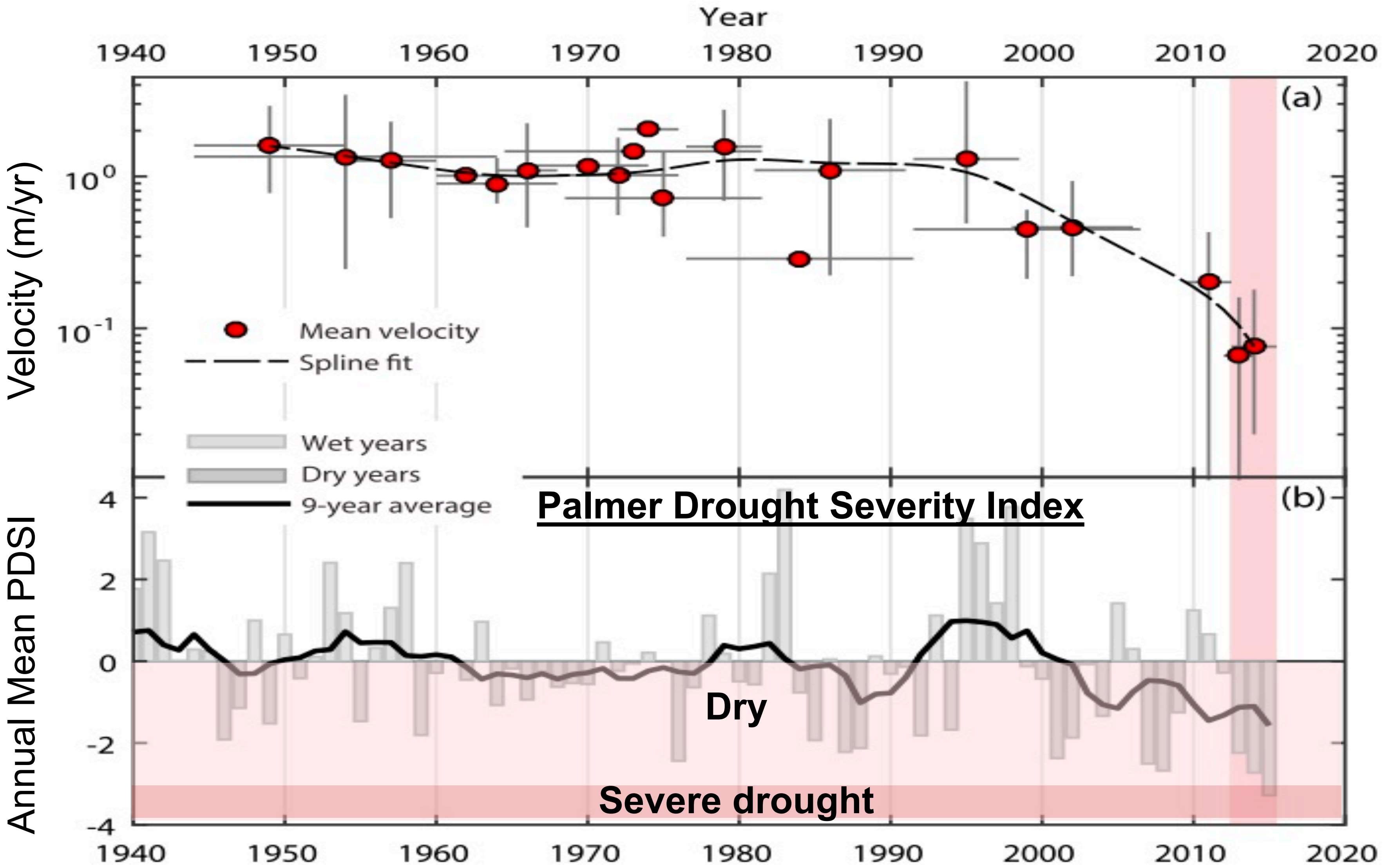
(Terzaghi, 1951; Iverson and Major, 1987)

Long-term kinematics: *1944-2015*

Bennett et al., 2016

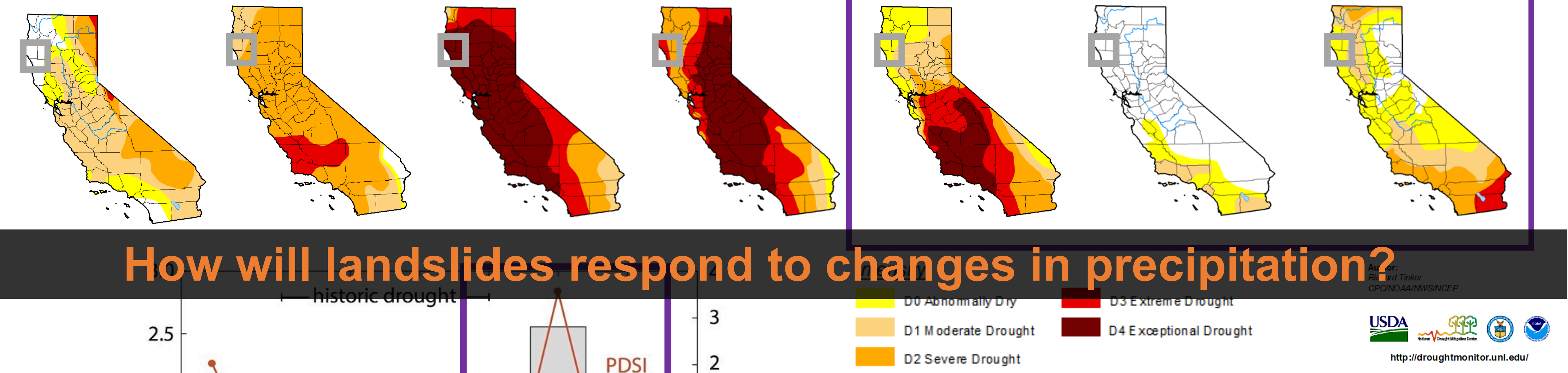
- Avg.velocity decreased due to long-term moisture deficit
- PDSI uses temperature and precipitation to estimate relative dryness.
- PDSI may serve as proxy for pore-water pressure

10 slow-moving landslides

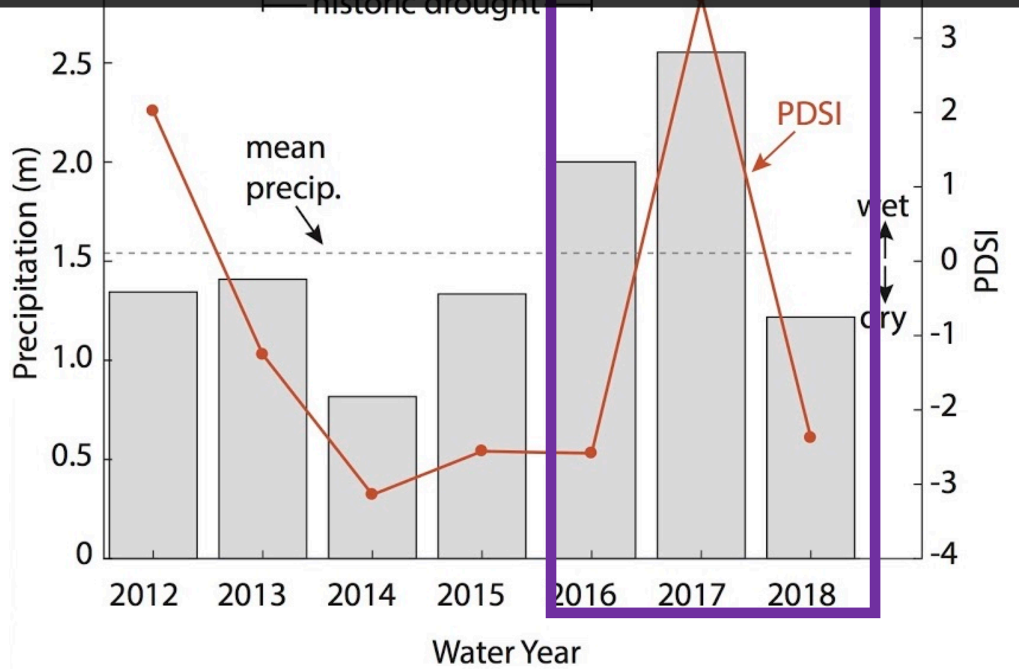


Northern California Coast Range

Drought Maps

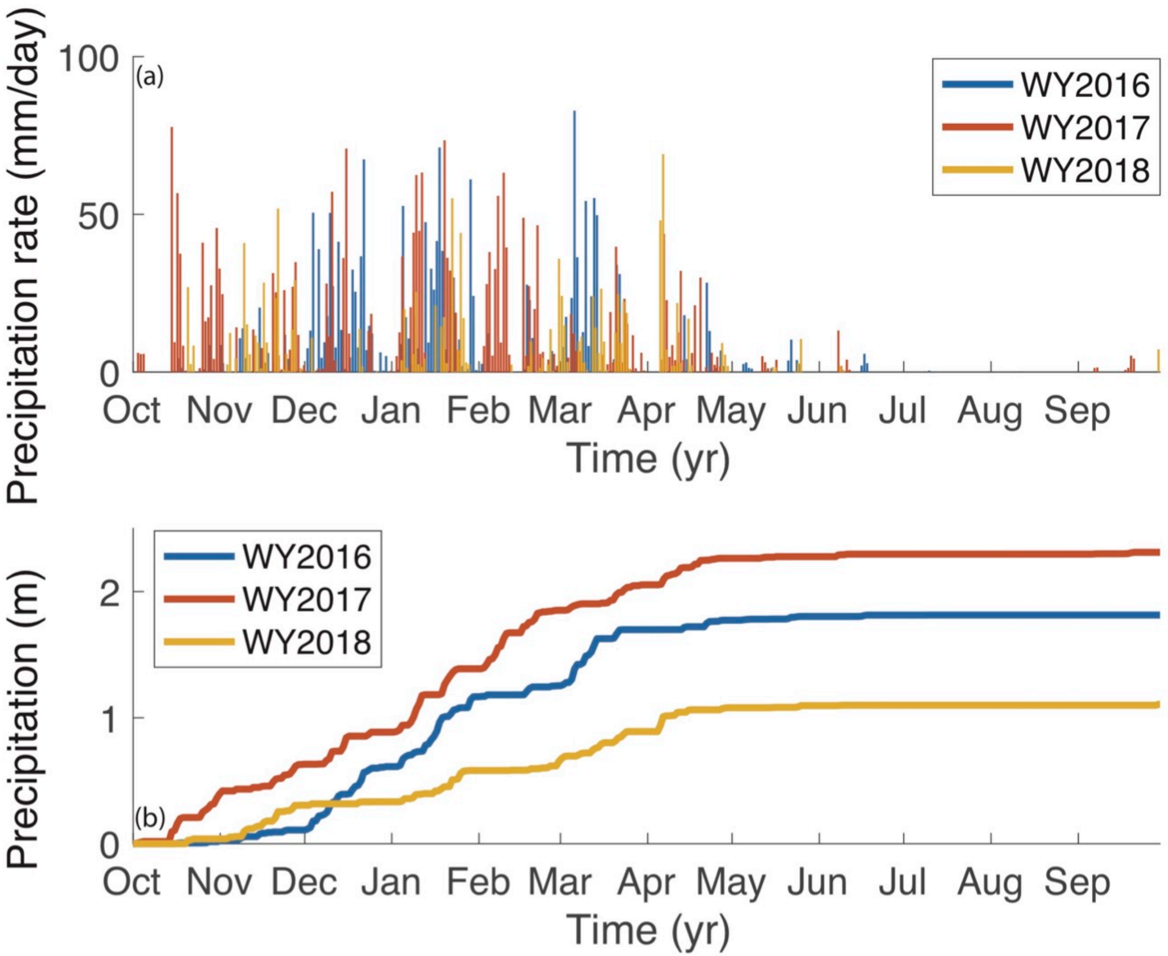


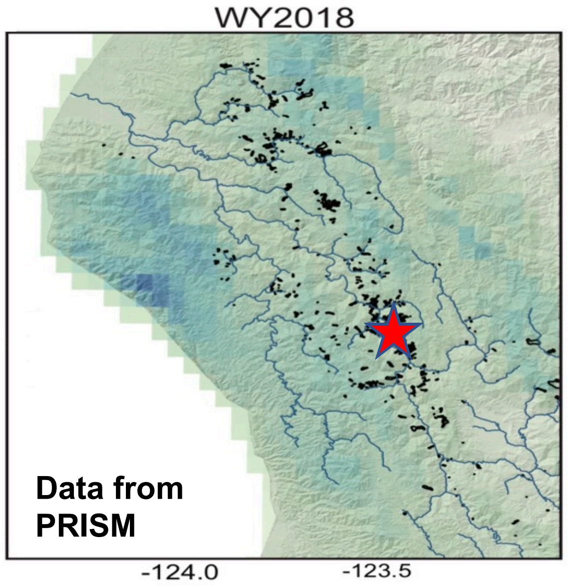
How will landslides respond to changes in precipitation?



- Historic drought 2012 - 2016
- Transition from historic drought to extreme rainfall
- Rapid shifts in precipitation

Water Year (Oct 1 – Sep 30) Precipitation Maps





Kekawaka Creek precipitation

- 1.8 m in 2016
- 2.3 m in 2017
- 1.1 m in 2018

Handwerger et al.
(in review)

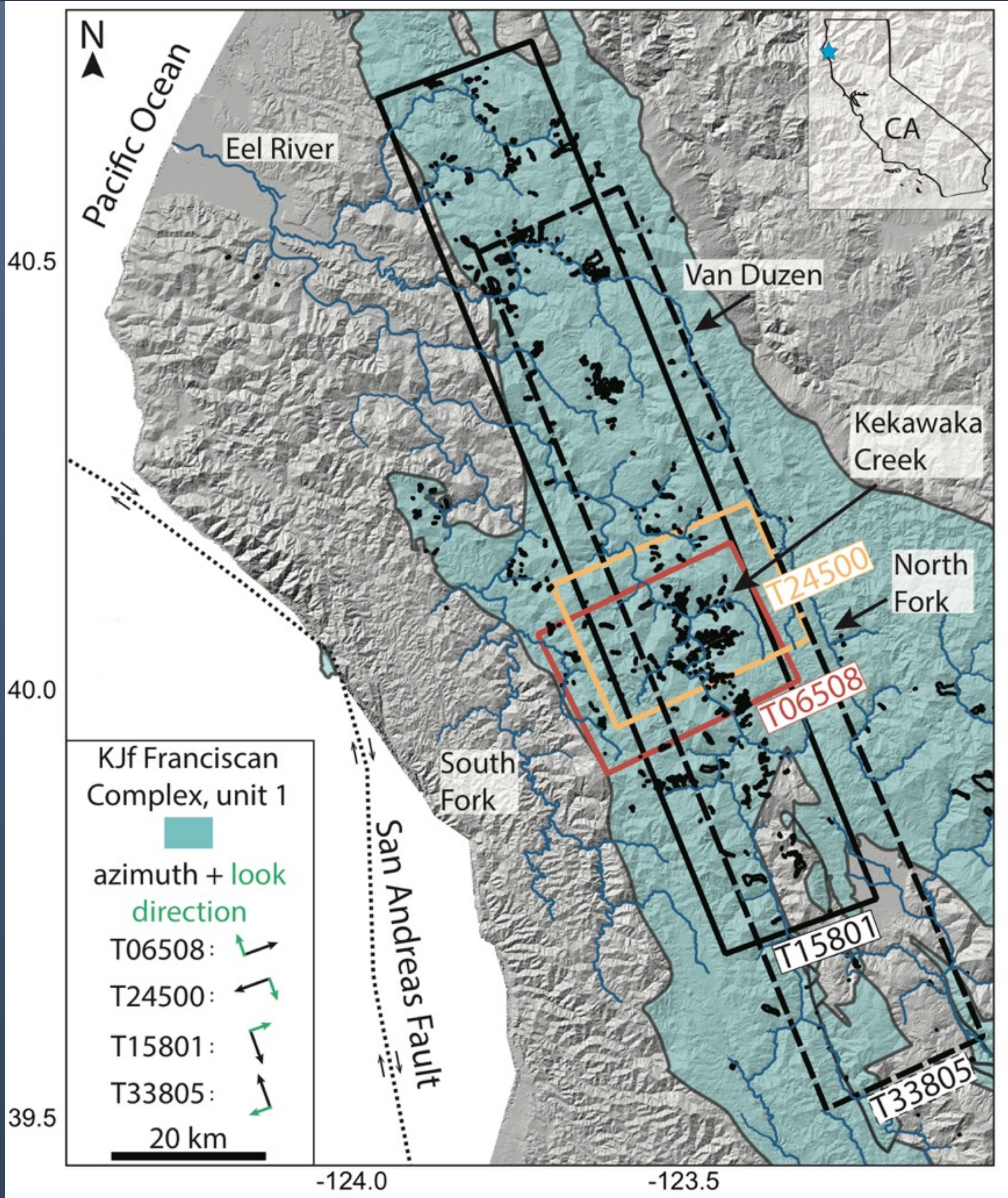
InSAR and Pixel Offset Tracking

NASA/JPL Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR)

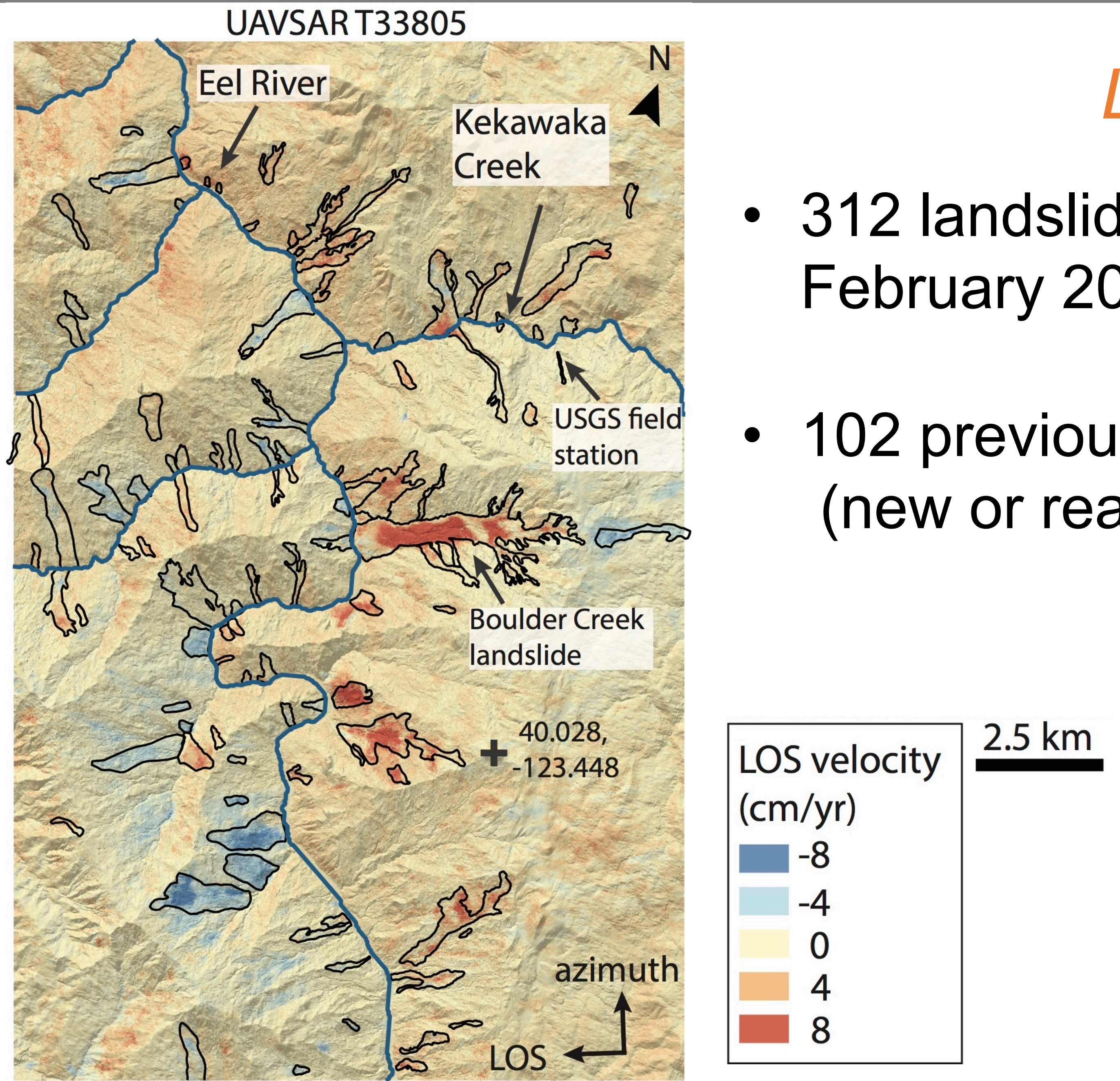
- 8 scenes between April 2016 and February 2018
- 4 different flight paths
- 112 InSAR pairs and 112 pixel offset pairs

SAR processing and time series inversion

- InSAR Scientific Computing Environment (ISCE) (Rosen et al., 2012)
- Generic InSAR Analysis Toolbox (GIAnT) (Agram et al., 2013)



Results

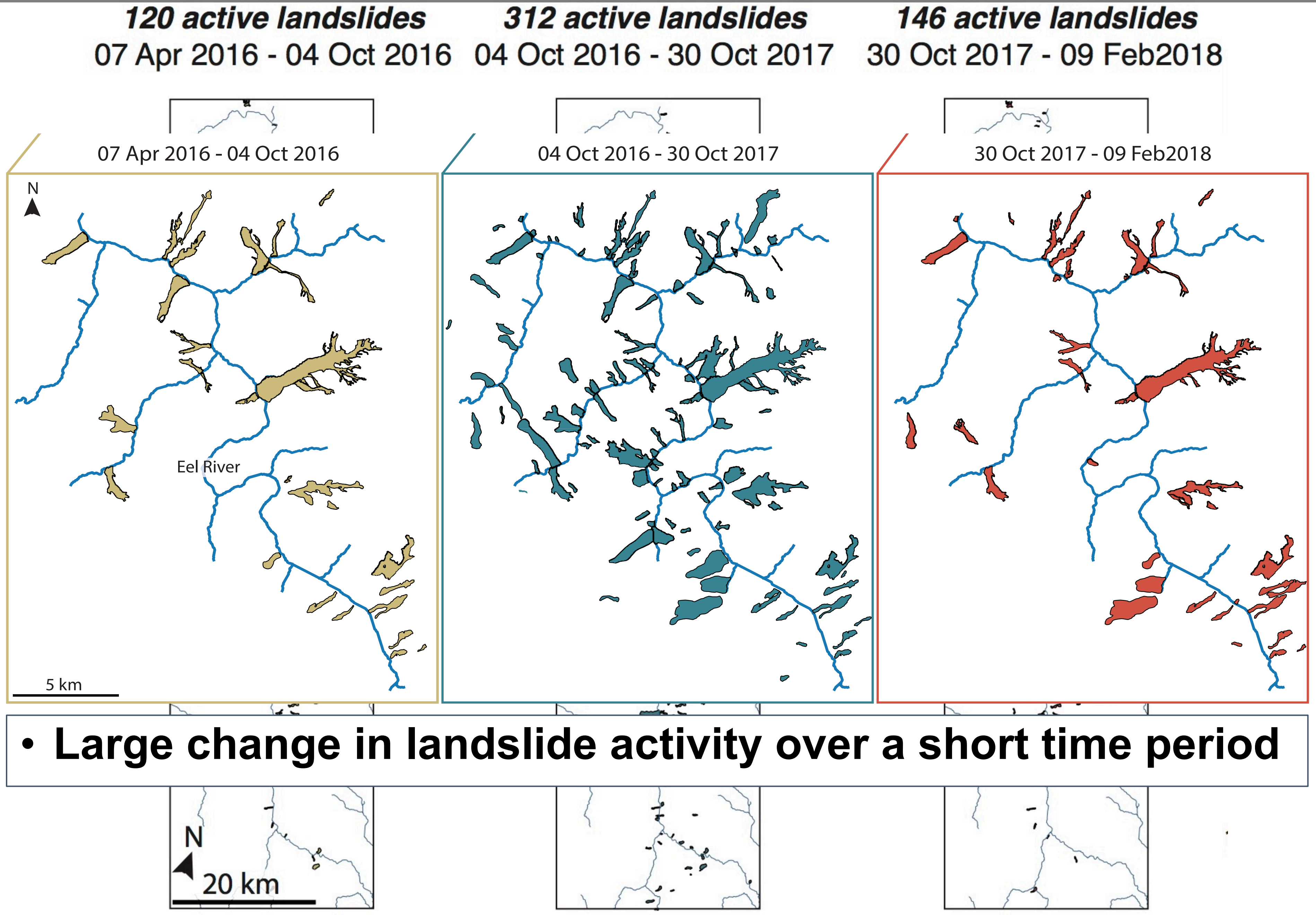


Landslide Inventory

- 312 landslides between April 2016 and February 2018
- 102 previously unmapped landslides (new or reactivated)

Additional landslide inventories
(Mackey and Roering, 2011; Handwerger et al., 2015; Bennett et al., 2016)

Results

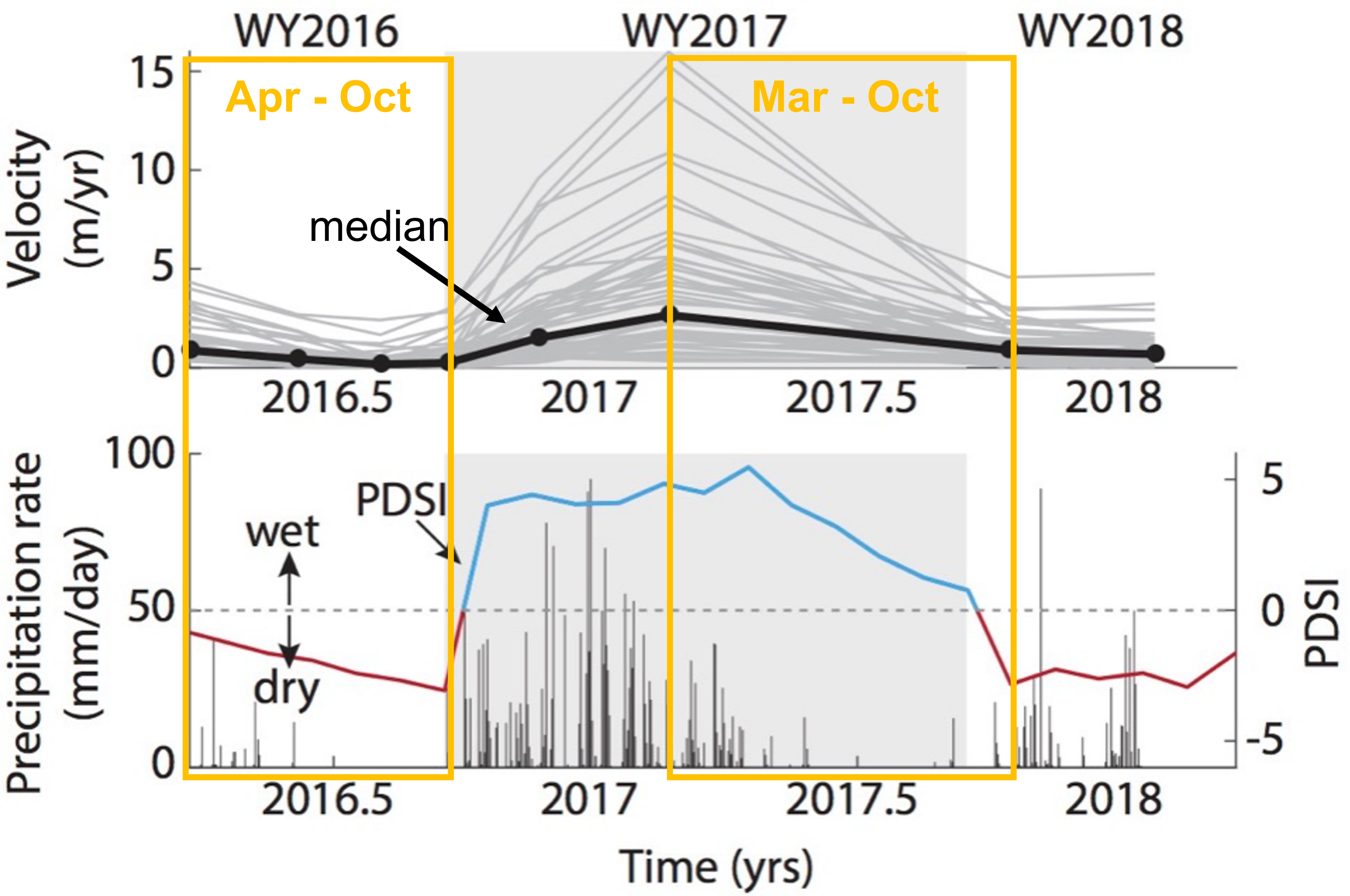


- **Large change in landslide activity over a short time period**

Results

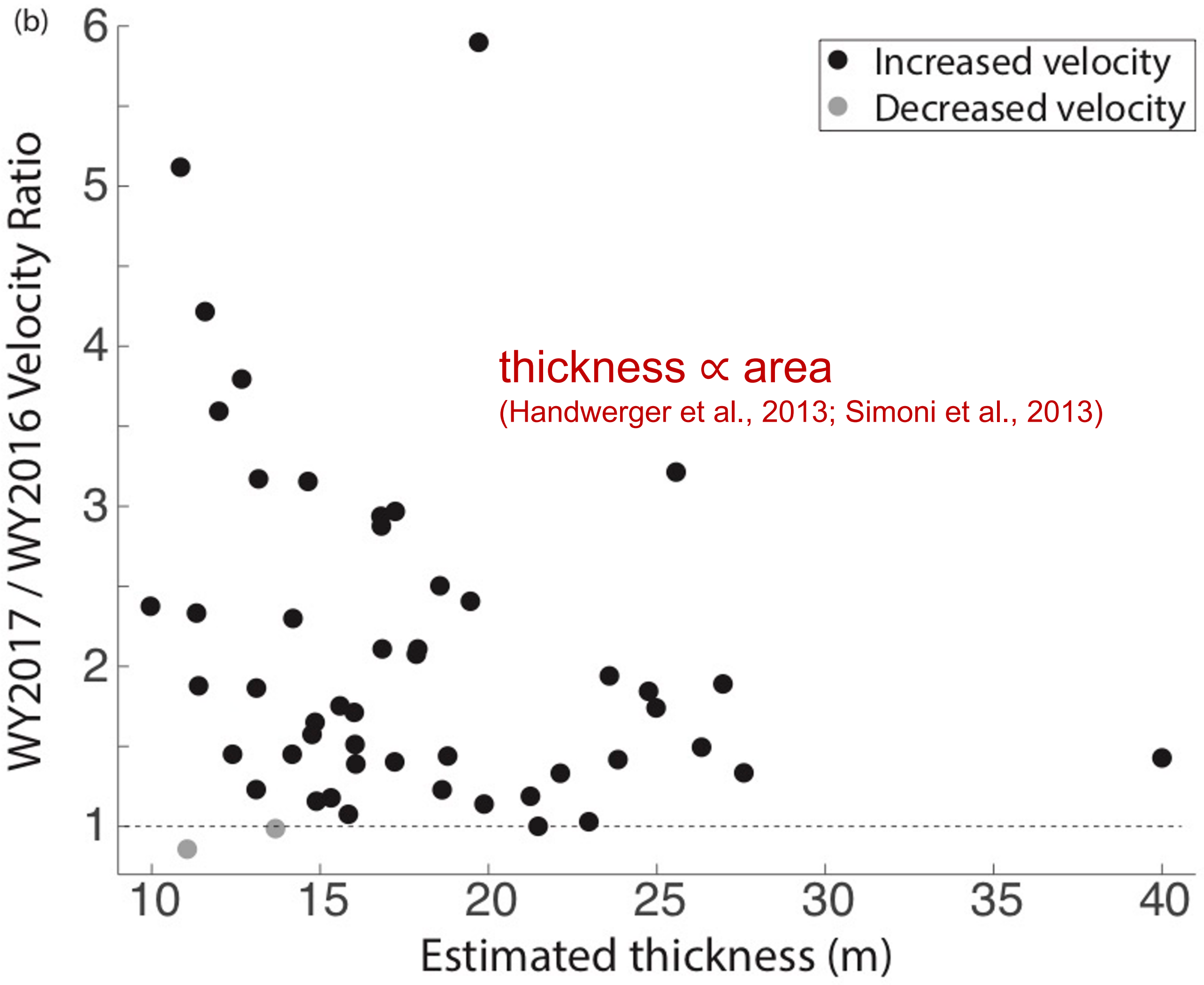
Pixel offset time series (51 landslides)

- Seasonal velocity changes driven by precipitation
- Increased velocity during the wet season of WY2017
- PDSI - transition from dry to wet conditions during WY2017



Results

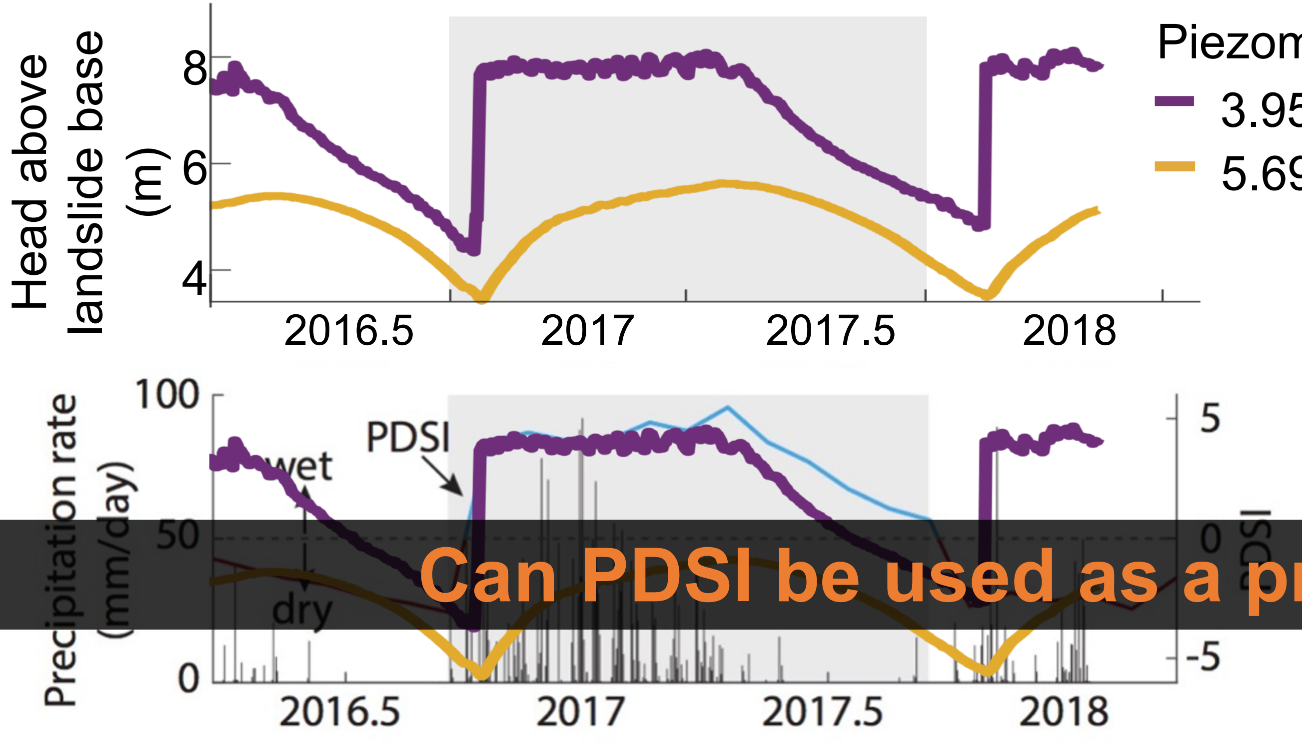
Pixel offset time series (51 landslides)



- 96 % of landslides had increased velocities due to extreme rainfall
- Up to ~6x increase in velocity during WY2017
- Stronger response for smaller and thinner landslides

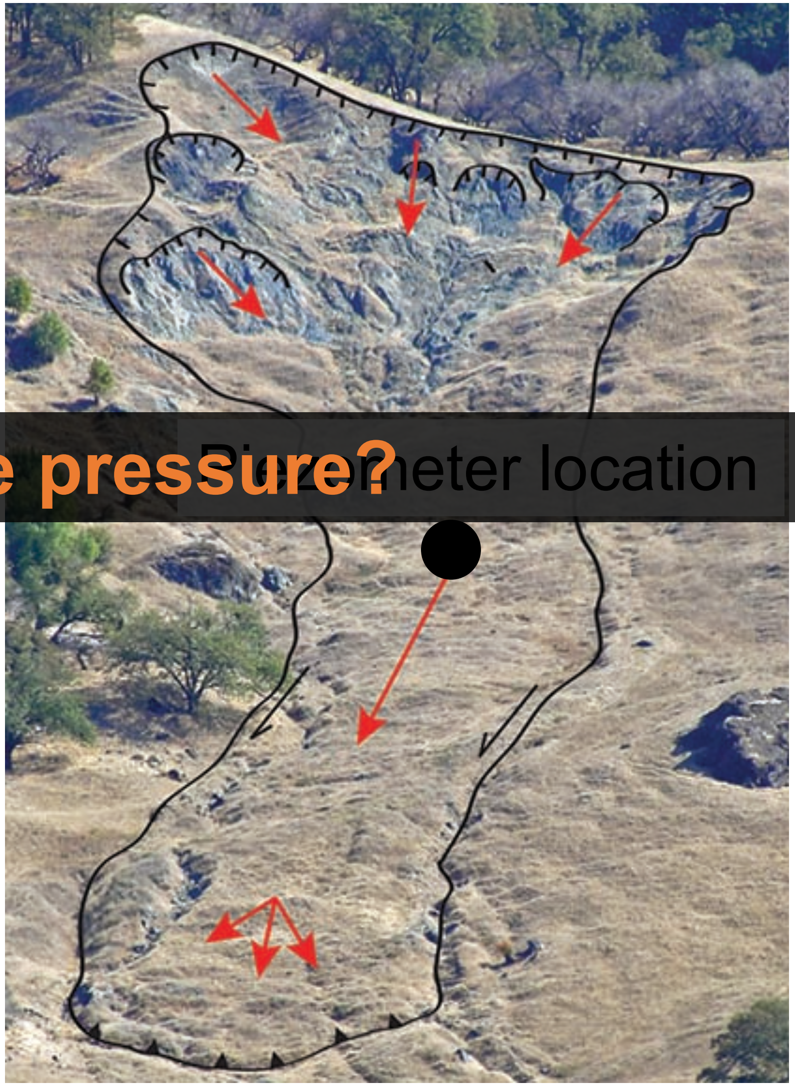
Handwerger et al. (in review)

Discussion



Can PDSI be used as a proxy for pore pressure?

Two Towers landslide



- Larger pore pressure changes for thinner landslides
- PDSI can describe pore pressure changes (in some cases)

Schulz et al. 2018

Summary

- Novel UAVSAR dataset to map and monitor landslides
- Widespread, but short-lived, triggering/reactivation of slow-moving landslides due to large increase in rainfall (i.e. pore-water pressure)
- Smaller and thinner landslides are more sensitive to changes in rainfall
  - stronger pore-water pressure changes
- PDSI may serve as a proxy for pore pressure and may be a useful tool to predict landslide motion

How will slow-moving landslides respond to future climate change?

- Precipitation extremes may lead to drastic changes in landslide behavior

Acknowledgements
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