Slow and fast motion of landslides along California Highway 1 from UAVSAR and Satellite SAR analysis

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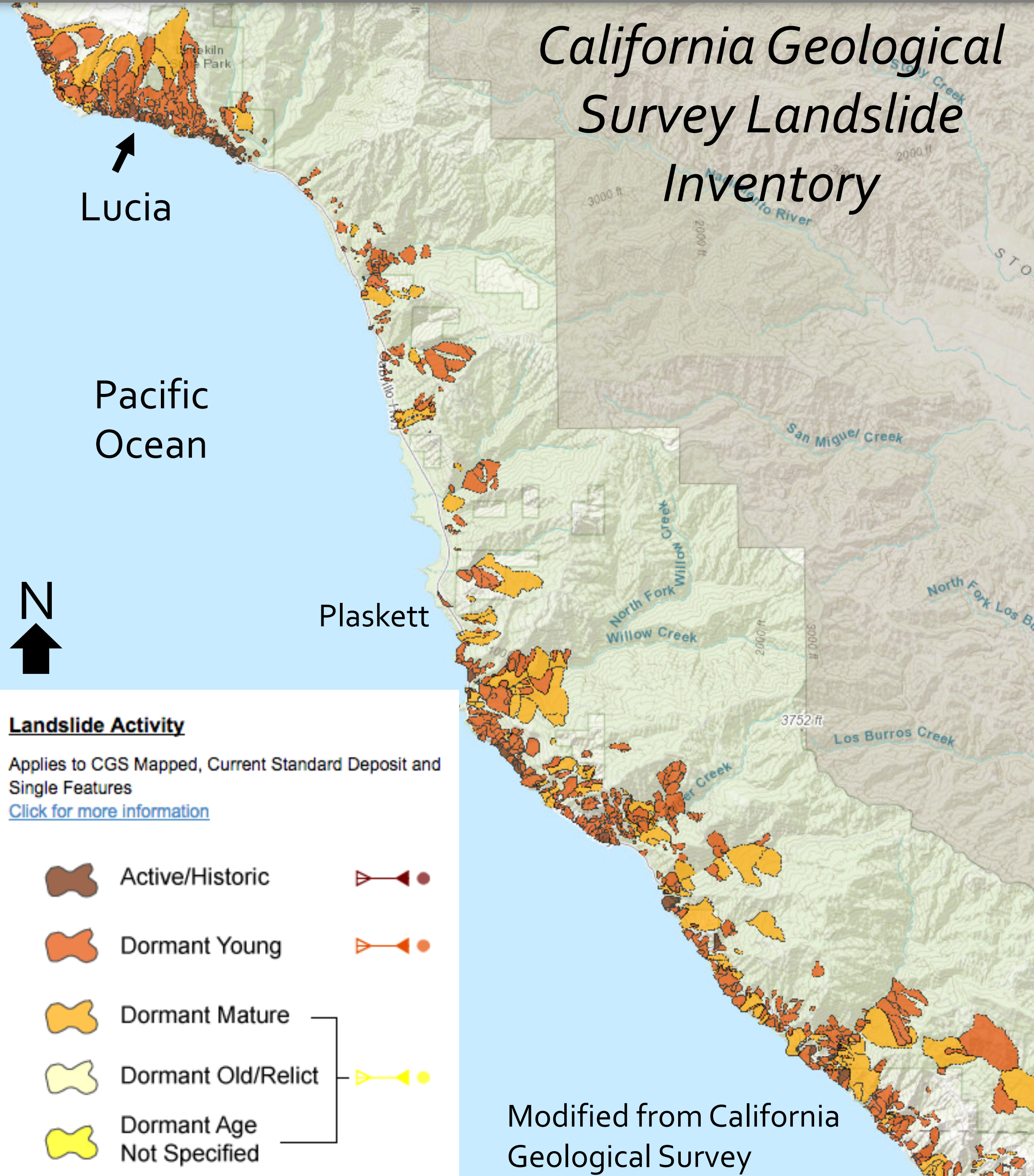
Outline

1. CA Highway 1 Landslides
2. Study Site
3. Methods
4. Results
5. Concluding Remarks

Landslides along CA 1

Landslides along CA 1

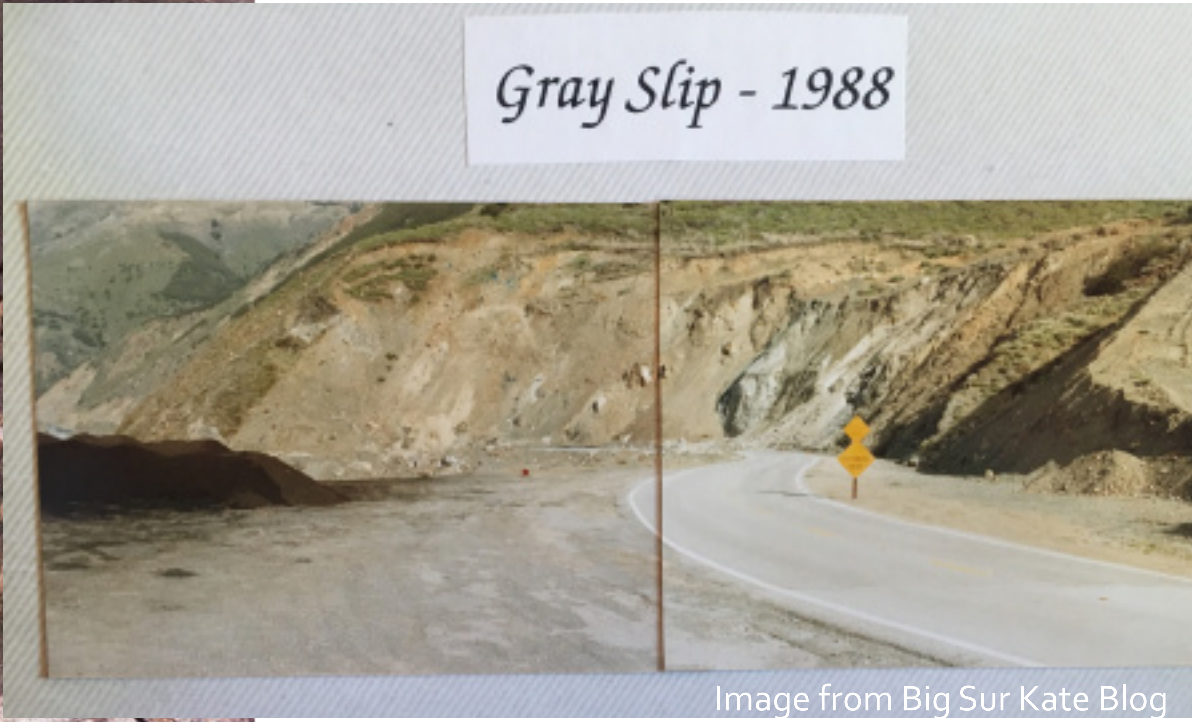


- CA Highway 1 was built in the 1920's
- The road has been buried by landslides more than 50 times!!
- Triggers and preconditioning factors:
  - Weak rocks
  - High rainfall
  - Active tectonics (uplift and earthquakes)
  - Wave erosion
  - Human influence

JPR Historical Consulting Services (2001)

Landslides along CA 1

Figure 6. Aerial view of the McWay slide of 1983. Photo by Lynn Harrison, Caltrans



Landslides along CA 1

April 5, 2006

AP Photo/Marcio Jose Sanchez)

March 17, 2011

https://sanfrancisco.cbslocal.com/
Caltrans

Photo By David Royal/ Monterey County Herald)

Landslides along CA 1

Winter of 2017

A coastline in motion, a road under siege

With two major landslides and one collapsed bridge, Highway 1 is still experiencing the effects of one of California's wettest winters on record.

Sources: OpenStreetMap, Mapzen, Caltrans

@latimesgraphics

Landslides along CA 1

Pfeiffer Canyon Bridge

Winter 2017

David Royal, Associated Press

Landslides along CA 1

Paul's Slide

Winter 2017

Feb 17, 2017

Image from Big Sur Kate

April 7, 2017


Image from Big Sur Kate

Landslides along CA 1

[Brian Mack](#)

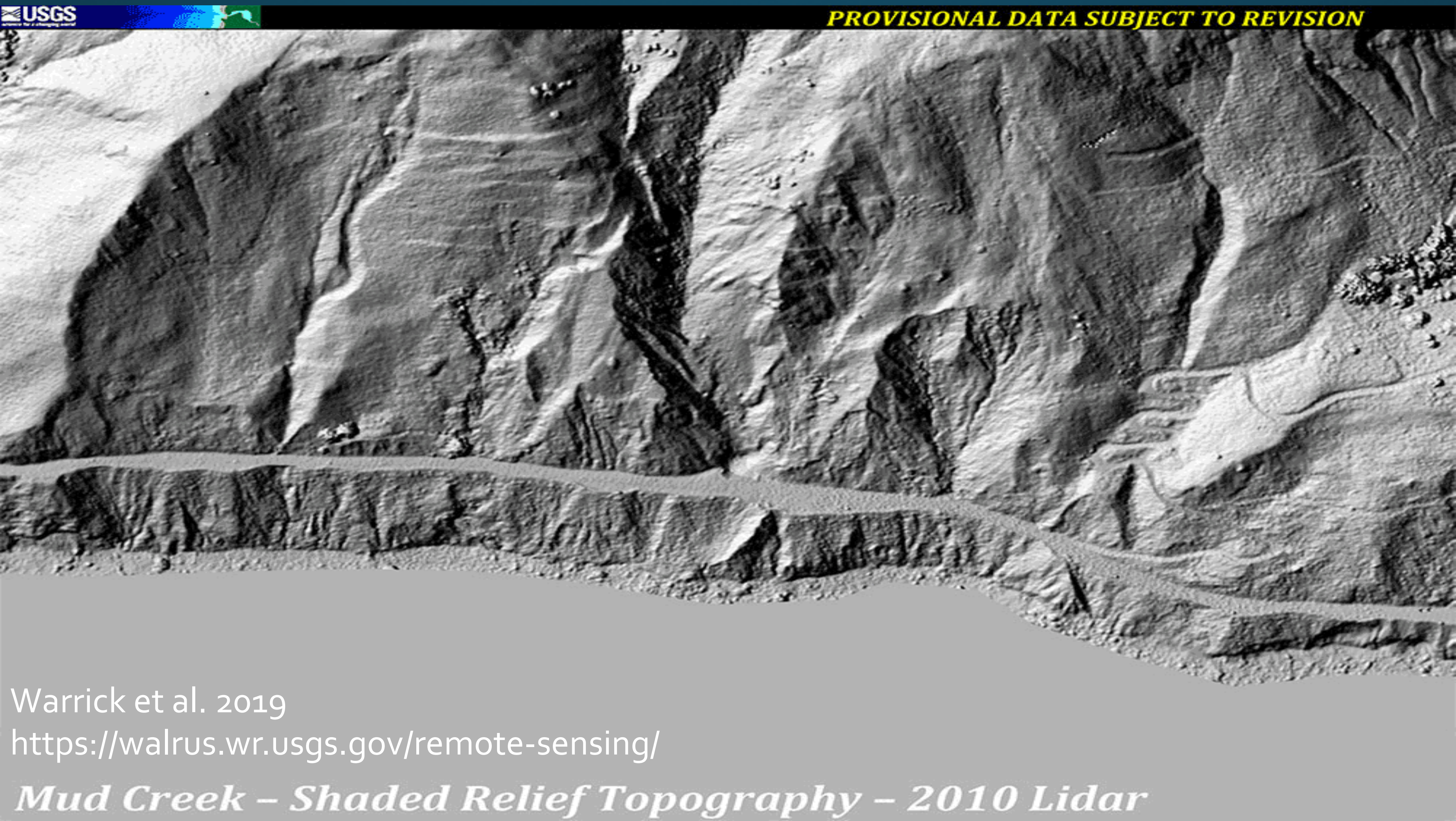
Published on May 22, 2017

https://www.youtube.com/watch?v=GCSimHiFNDA

Landslides along CA 1

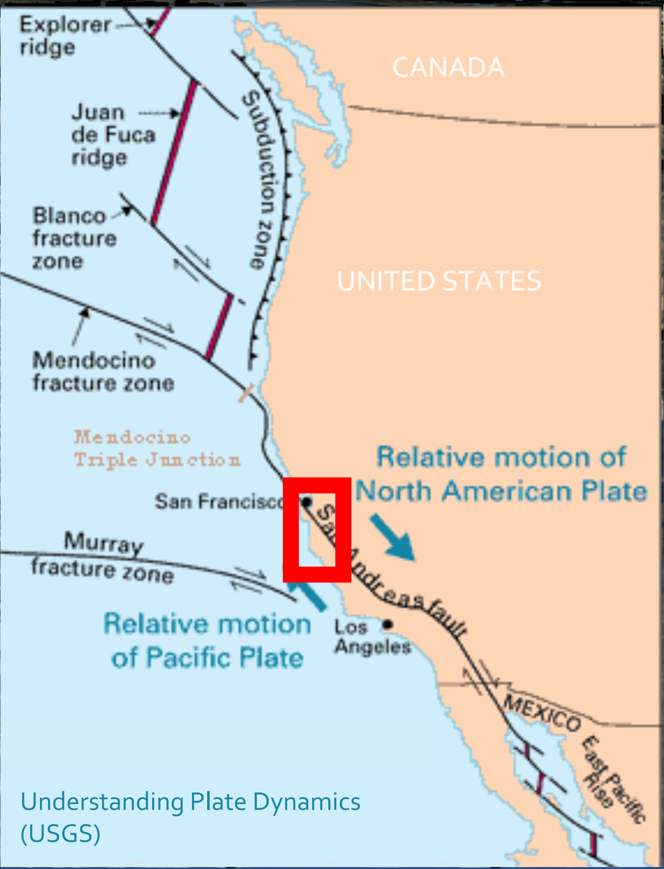
Mud Creek landslide

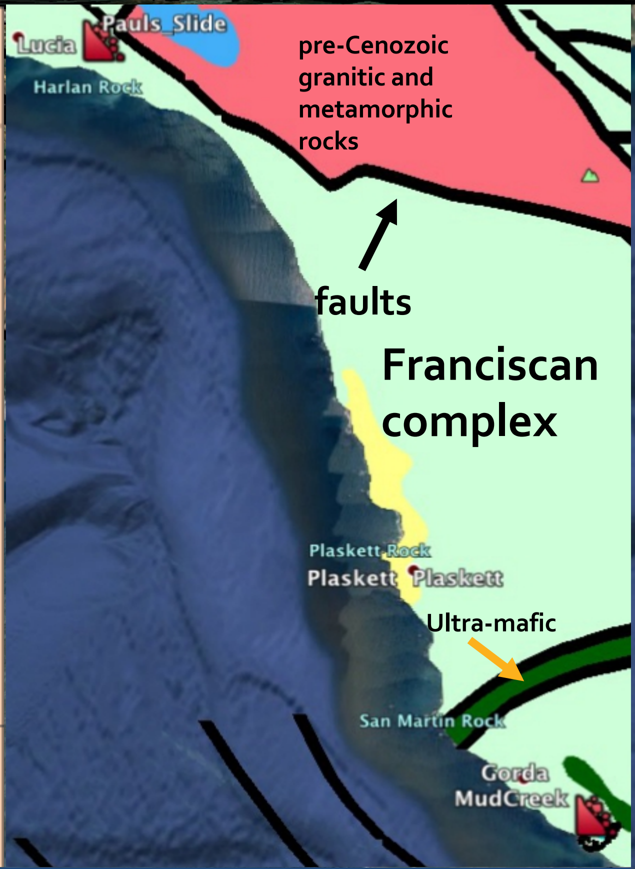
- May 20, 2017
- Volume = ~3 million m³ of material
- Highway reopened July 18, 2018 (~1 yr and 2 months)
- Repair cost ~$54 million



Warrick et al. 2019
https://walrus.wr.usgs.gov/remote-sensing/

Big Sur Coastline





Tectonics

- Santa Lucia Mountains
- Compressional deformation related to San Andreas and San Gregorio
- Uplift rates ~ 0.8 mm/yr

(Ducea et al., 2003; Johnson et al., 2018)

Lithology

- Franciscan mélange
  - Accretionary prism complex
  - Argillaceous matrix

(Kelsey 1978; Mackey and Roering, 2011)

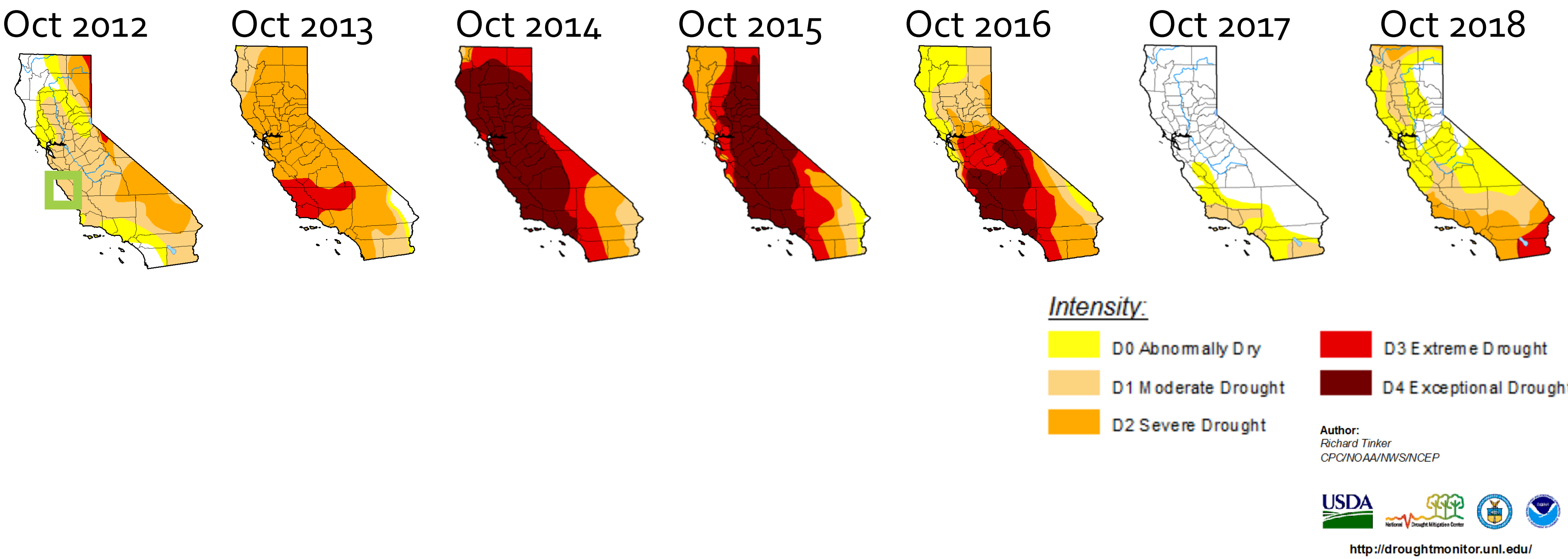
Big Sur Coast

- Precip. = 1 m/year
- 80% between Oct & May
- Coastal retreat rates ~0.3 m/yr

(Ducea et al., 2003; Hapke and Reid, 2007)

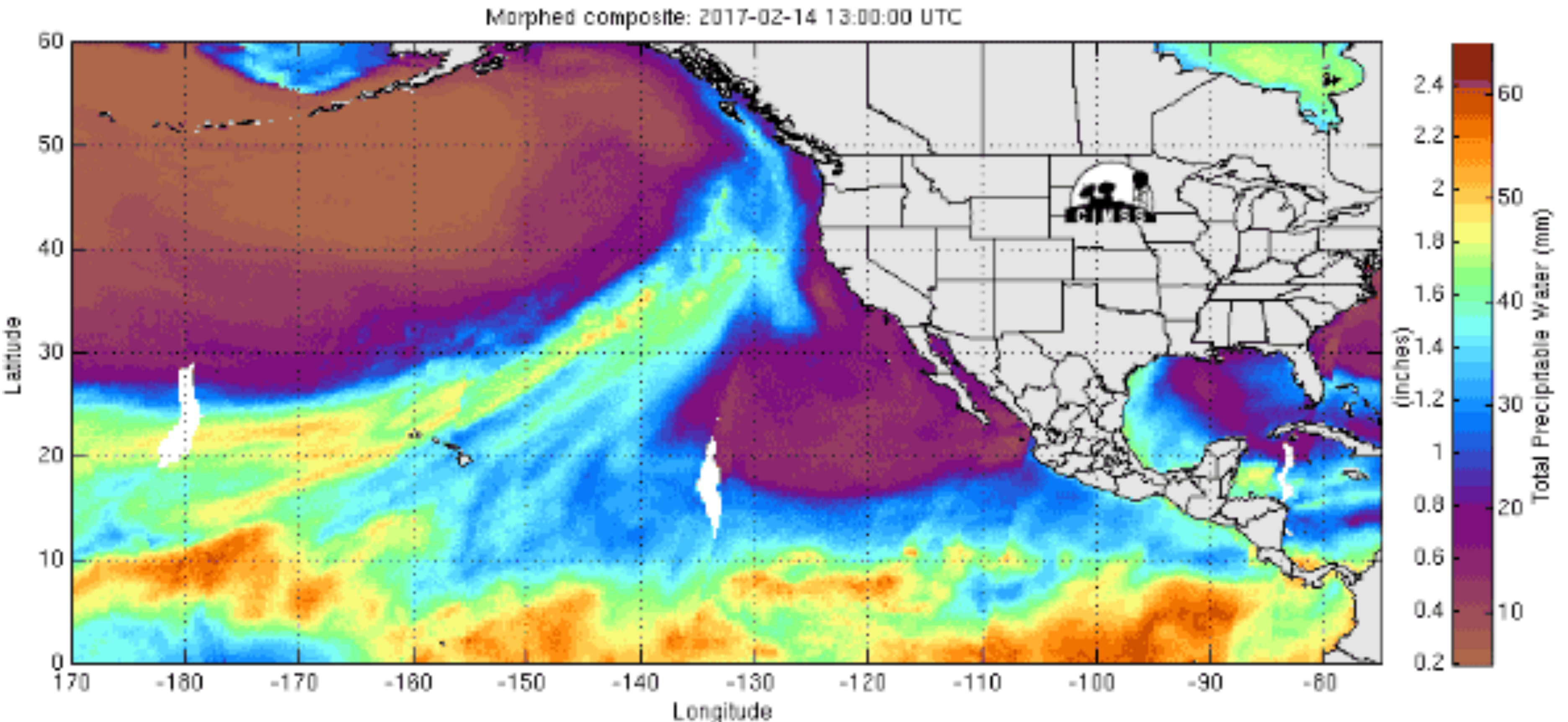
Northern California Coast Range

Drought Maps



- Historic drought 2012 - 2015
- Transition from historic drought to extreme rainfall
- Rapid shifts in precipitation

Atmospheric Rivers



https://phys.org/news/2017-02-atmospheric-rivers-thought.html

- Large changes in rainfall driven in part by atmospheric rivers
- 30-50% of rainfall in California is delivered by landfalling atmospheric rivers (Dettinger et al., 2011)

Atmospheric Rivers

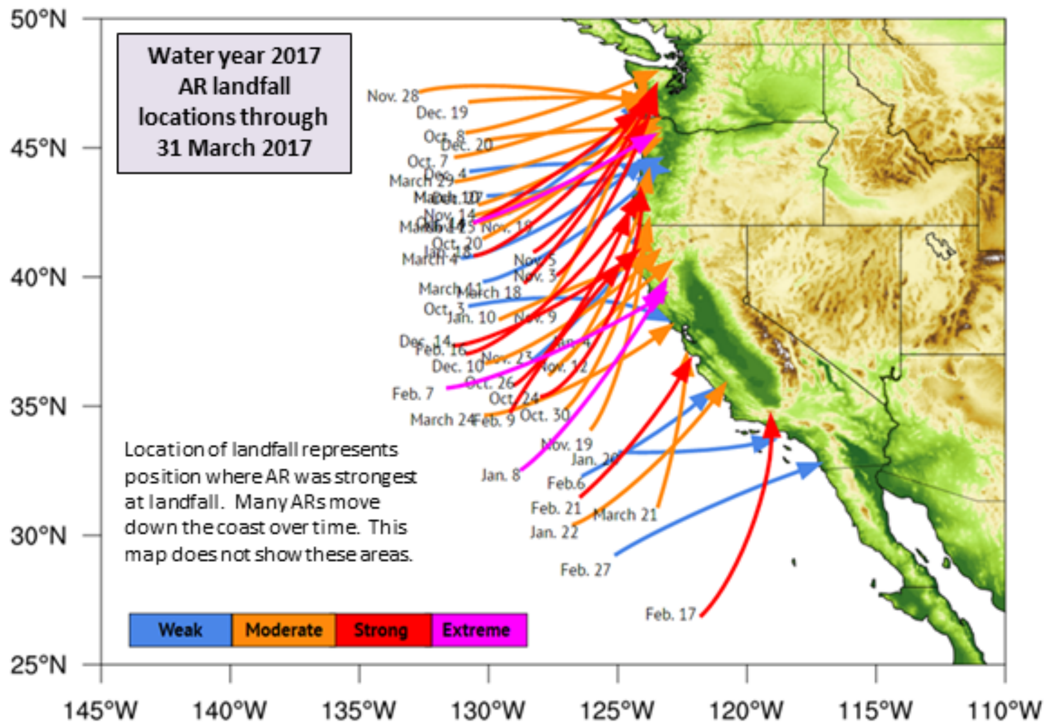
Distribution of Landfalling Atmospheric Rivers on the U.S. West Coast
(From 1 Oct 2016 to 31 March 2017)

AR Strength	AR Count*
Weak	11
Moderate	20
Strong	12
Extreme	3

Ralph/CW3E AR Strength Scale

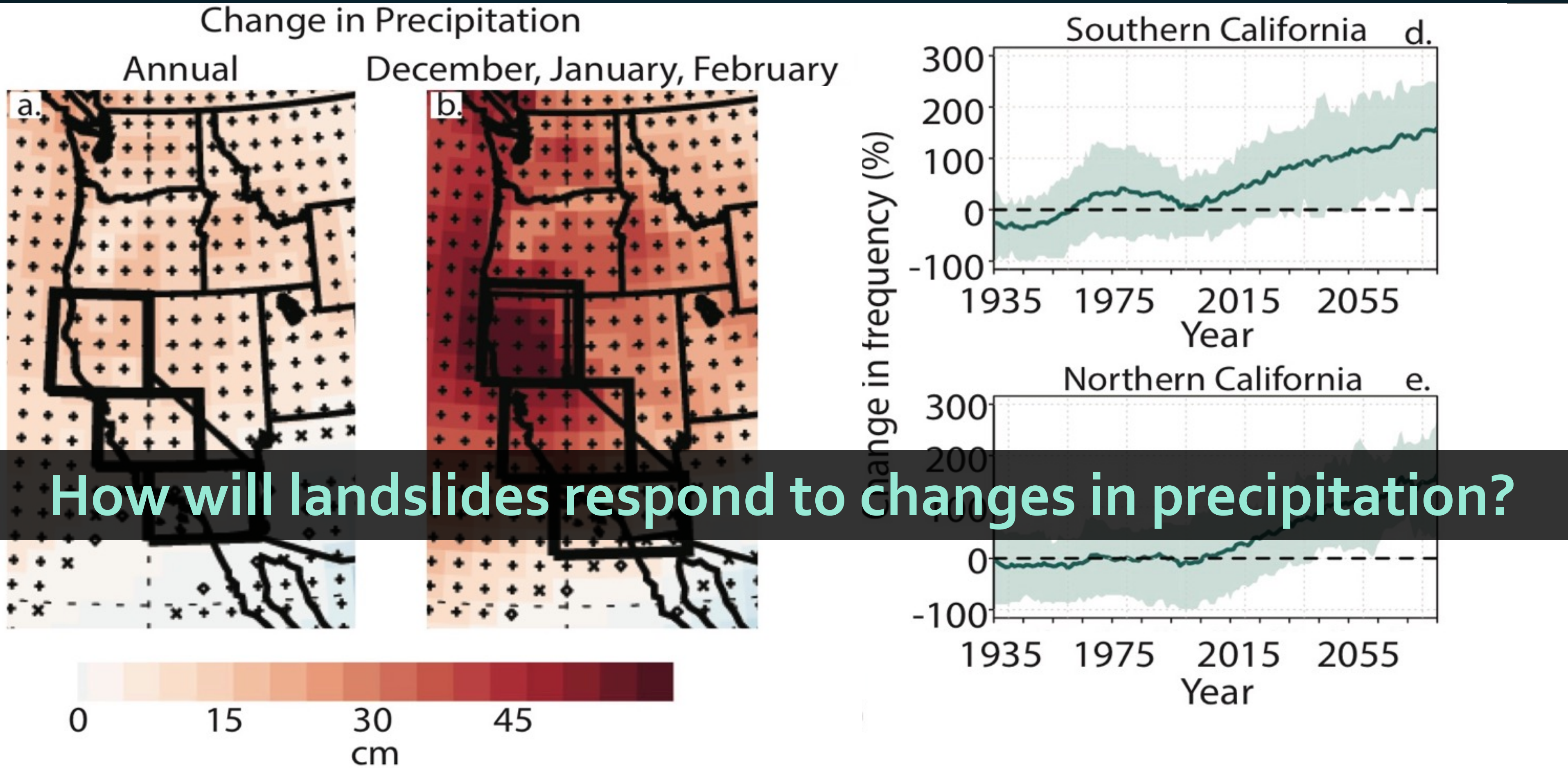
- Weak: IVT=250–500 kg m^{-1} s^{-1}
- Moderate: IVT=500–750 kg m^{-1} s^{-1}
- Strong: IVT=750–1000 kg m^{-1} s^{-1}
- Extreme: IVT>1000 kg m^{-1} s^{-1}

- 45 Atmospheric Rivers have made landfall on the West Coast thus far during the 2017 water year (1 Oct. – 31 March 2017)
- This is much greater than normal
- 1/3 of the landfalling ARs have been “strong” or “extreme”



*Radiosondes at Bodega Bay, CA indicated the 10–11 Jan AR was strong (noted as moderate based on GFS analysis data) and 7–8 Feb AR was extreme (noted as strong)

Northern California Coast Range



How will landslides respond to changes in precipitation?

- Annual mean precipitation increase up to 14 cm in Northern California (Allen and Luptowitz, 2017)
- 25 % to 100% increase in the frequency of dry-to-wet year extremes (Swain et al., 2018)

Satellite and Airborne InSAR

Copernicus Sentinel-1 A/B satellites

- C-band wavelength (5.6 cm)
- Since 2015 data collected every 6-12 days

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

- L-band wavelength
- Since 2009 data collected twice per year

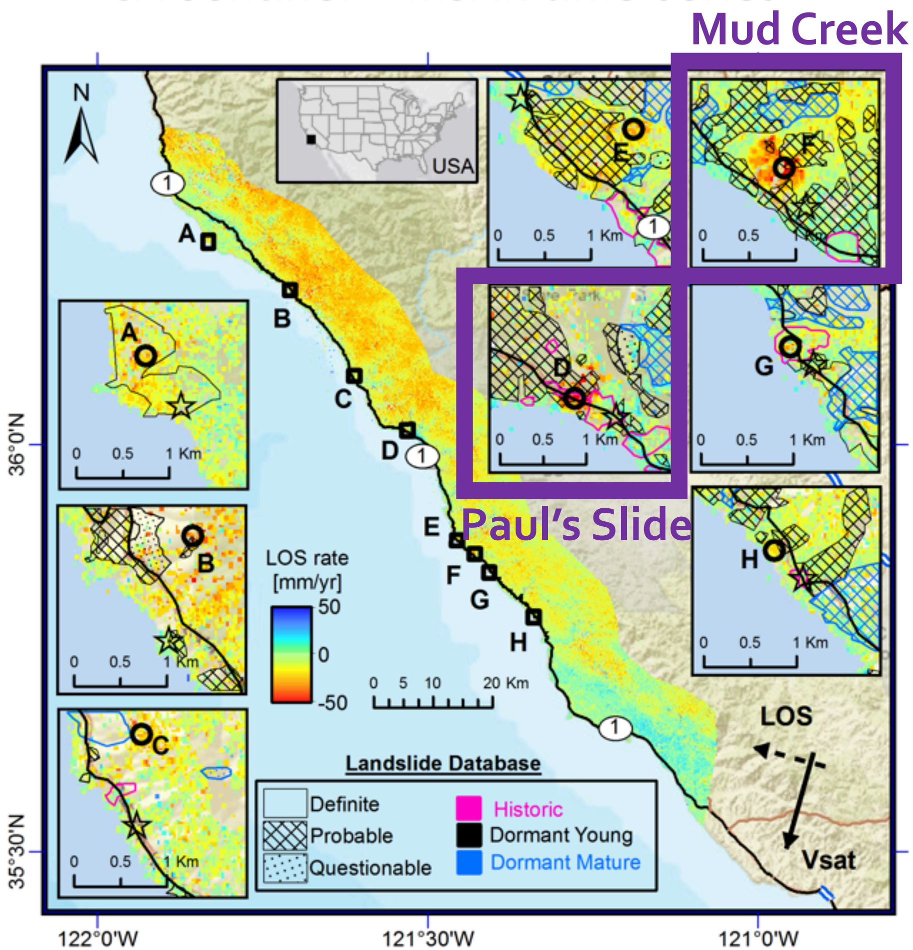
SAR processing and time series inversion

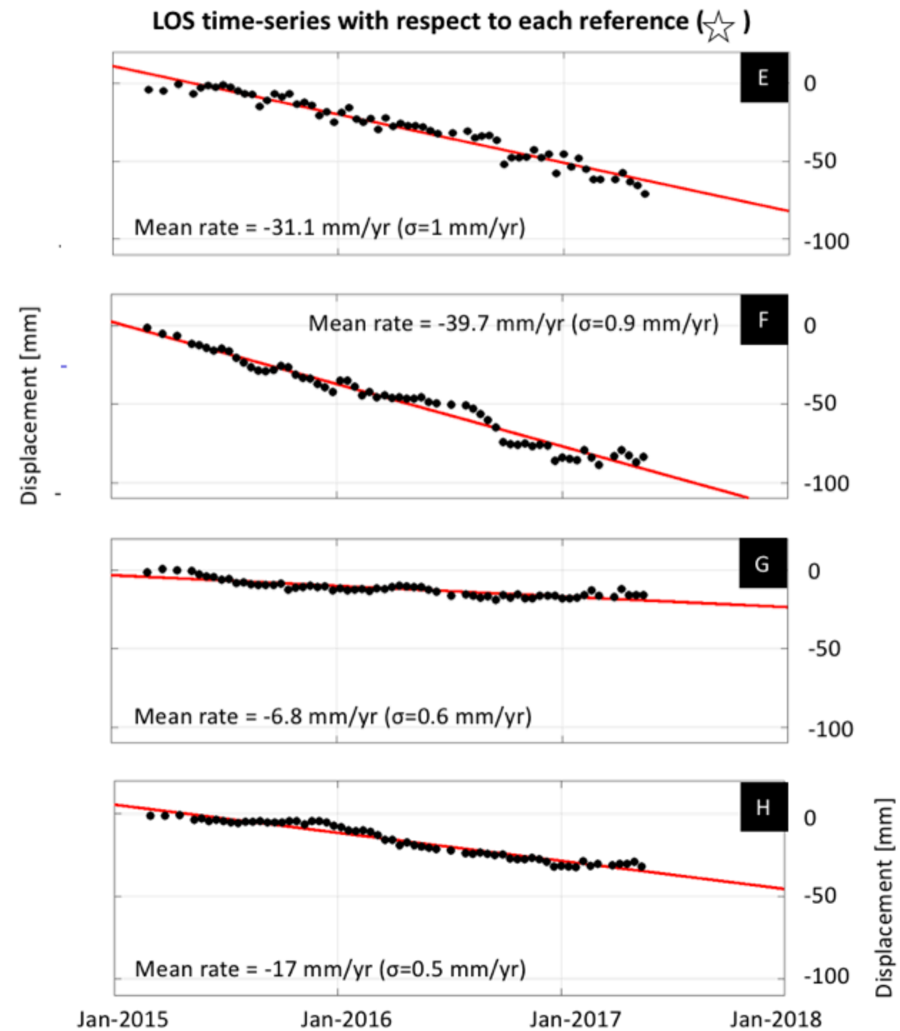
- InSAR Scientific Computing Environment (ISCE) (Rosen et al., 2012)
- Generic InSAR Analysis Toolbox (GIAnT) (Agram et al., 2013)
  - Small Baseline Subset (SBAS) method (Schmidt and Bürgmann, 2003)

Results

2015-2017

CA Sentinel-1 InSAR time-series



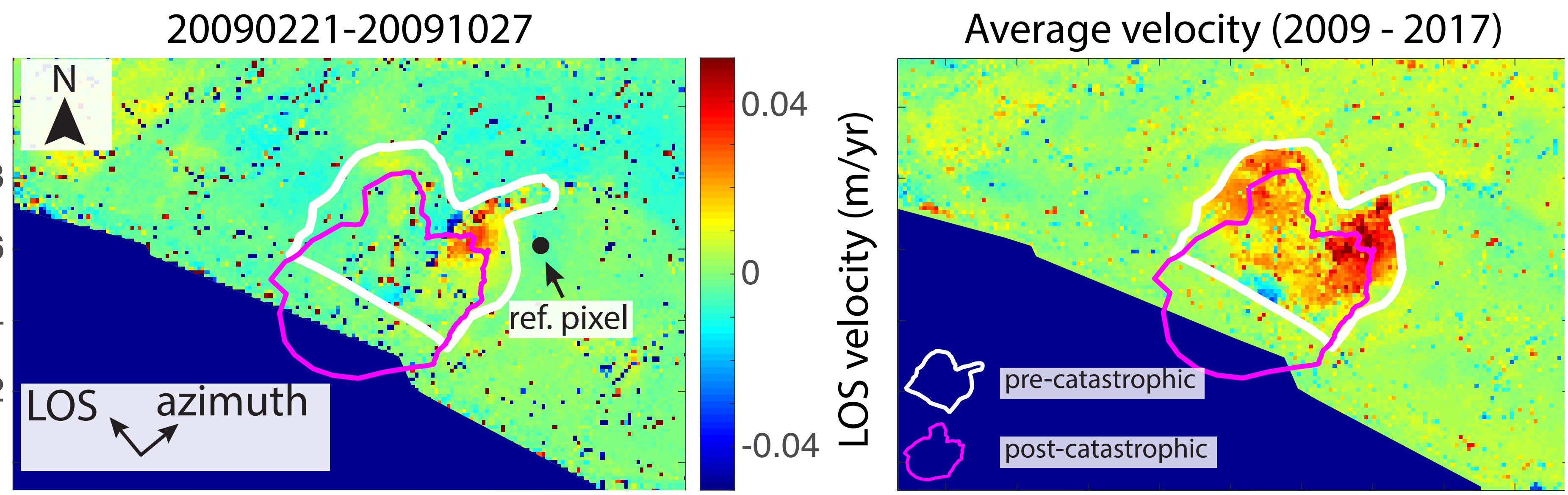


Sentinel-1 available for free under Copernicus program

Slide from David Bekaert, P. Agram, H. Fattahi (JPL)

Results

NASA UAVAR data



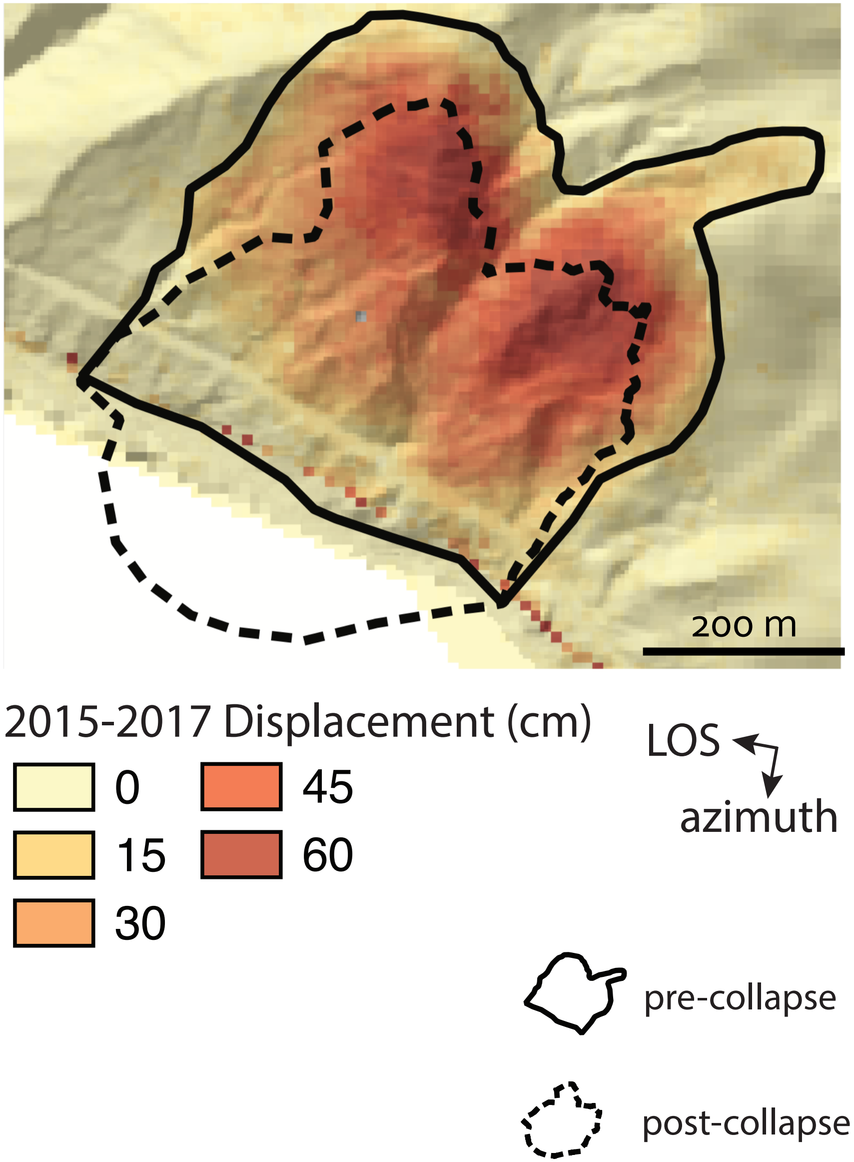
- Landslide was active for a minimum of 8 years prior to catastrophic failure

Handwerger et al. (2019)

Results

Copernicus Sentinel 1A/B InSAR time series

- Moved downslope 80 cm between 2015-2017
- Most displacement occurred near headscarp
- Deformation area larger than failed area

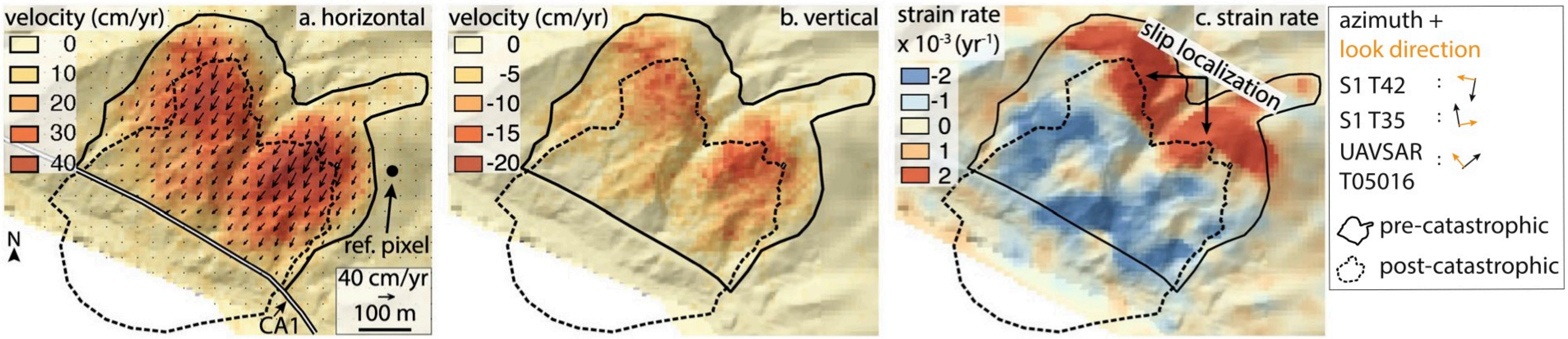


Handwerger et al. (2019)

Results

3D Inversion - NASA UAVSAR and Sentinel 1 A/B data

Avgerage velocity and strain rate (2009 - 2017) of Mud Creek landslide, CA

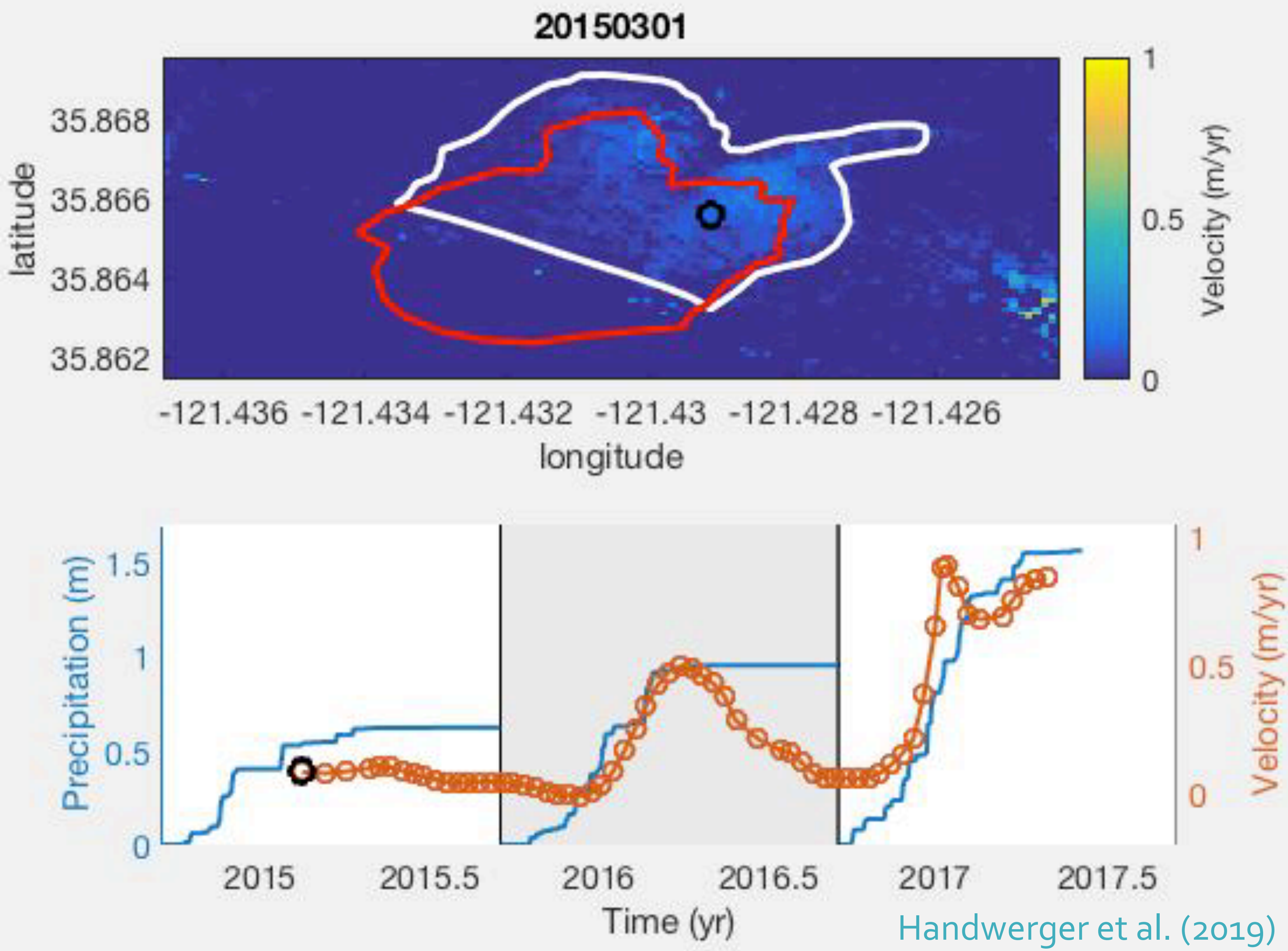


Slip localized onto a different sliding surface

Handwerger et al. (2019)

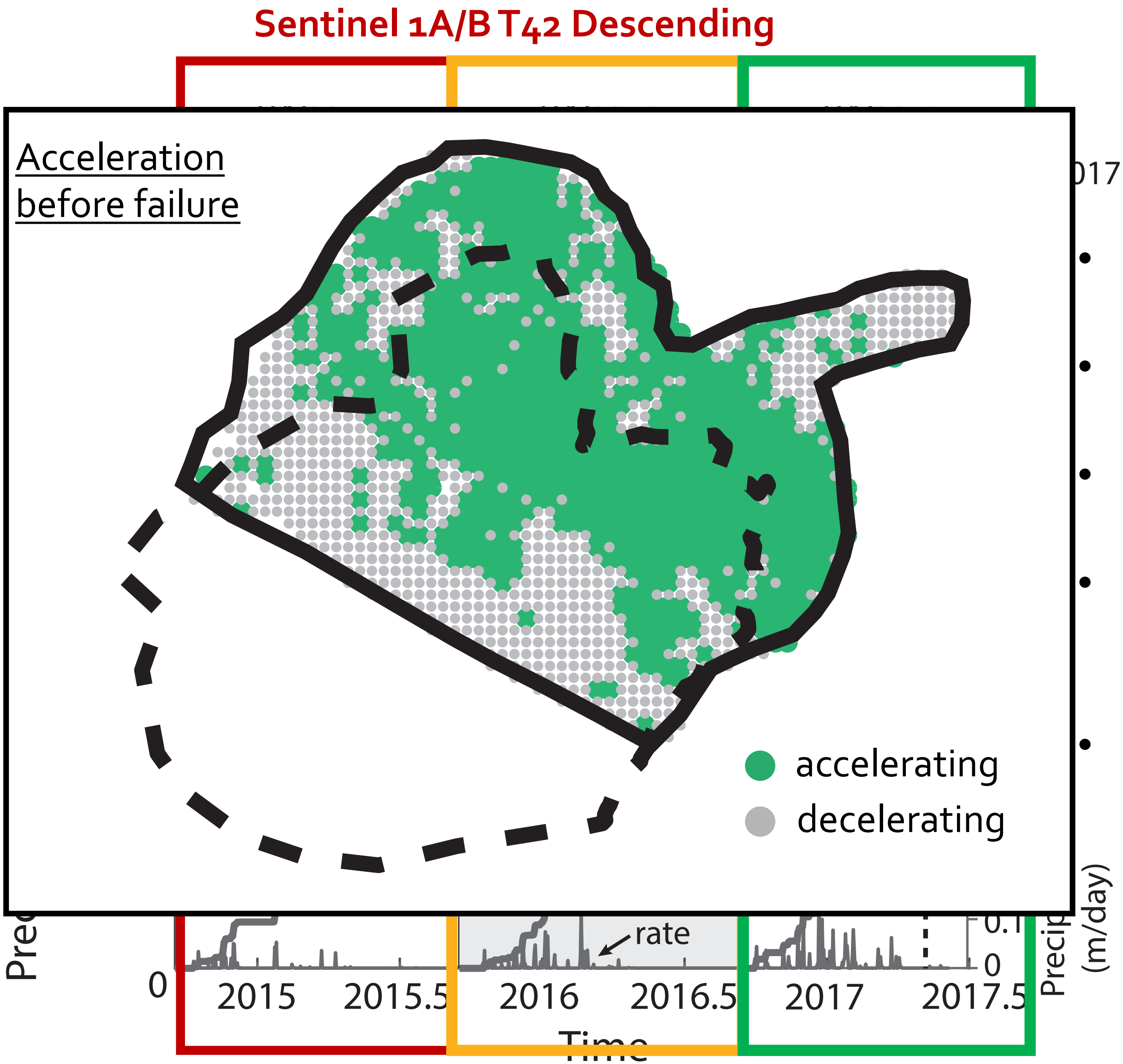
Results

Sentinel 1A/B T42 Descending



Handwerger et al. (2019)

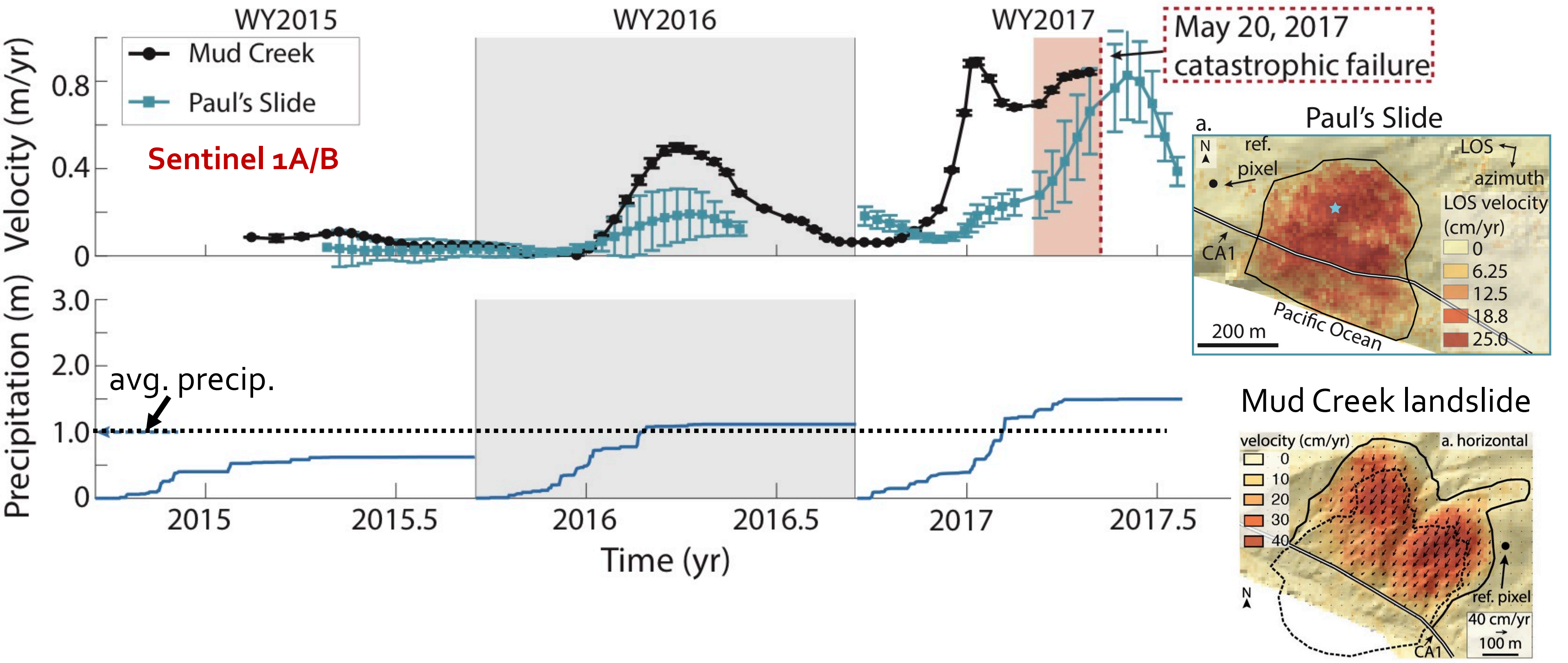
Results



- Moved 80 cm downslope
- Max. displacement occurred near headscarp
- Seasonal motion driven by precipitation
- Displacement and velocity scale with precipitation
- Extreme rainfall caused large increase in velocity and potentially led to collapse

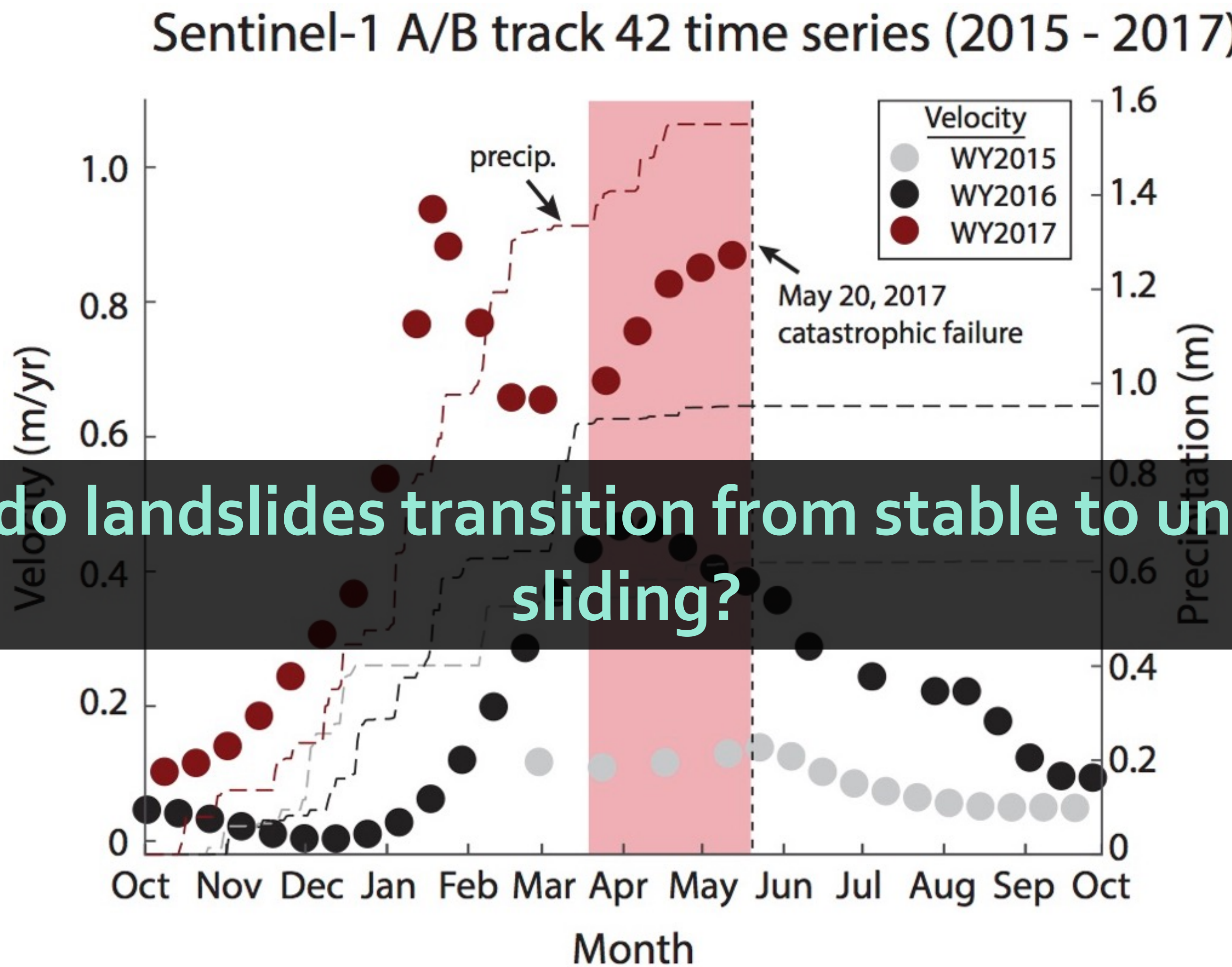
Handwerger et al. (2019)

Results



- These landslides occur in the same lithologic unit and in similar climate
- Landslides display similar velocity pattern during WY2016
- Paul's slide displays a more 'typical' velocity pattern during WY2017

Results



How do landslides transition from stable to unstable sliding?

- Displacement and velocity increase with precipitation
- Divergence from 'typical' seasonal velocity pattern during WY2017 – may suggest a transition occurred

Handwerger et al. (2019)

Mud Creek landslide

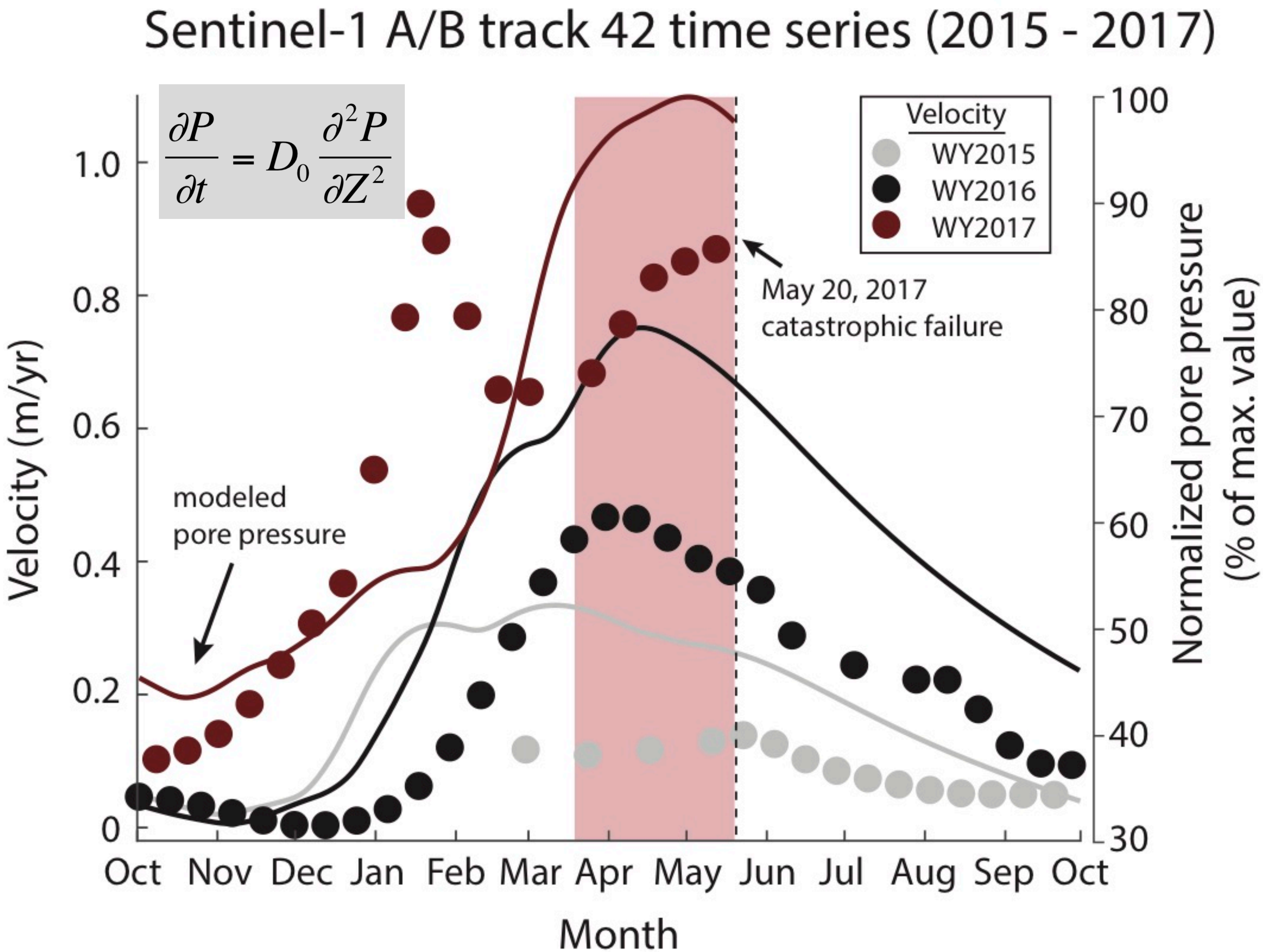
High pore-water pressures

Evidence of high pore-water pressure

- Springs produced darkened areas of soil with downslope seepage
- Water flowing down gullies
- Not caused by overland flow from recent rainfall, because no precipitation occurred at the site during the previous 2 weeks

Warrick et al. 2019

Stable to unstable sliding



Handwerger et al. (2019)

Summary

- Mud Creek landslide moved seasonally for a minimum of 8 years prior to its collapse
- Seasonal velocity changes driven by precipitation-induced changes in pore-water pressure
- Mud Creek shows a divergence from "typical" seasonal velocity pattern during WY2017
- The extreme rainfall of WY2017 likely caused its ultimate failure
- Pore pressure increase can overcome mechanisms that act to stabilize sliding

Summary

- Questions?