# Controls on slow-moving landslides revealed by satellite and airborne InSAR

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# Motivation

**1) How do slow-moving landslides respond to seasonal and multi-year changes in rainfall?**

- We use InSAR to quantify velocity changes in response to changes in precipitation

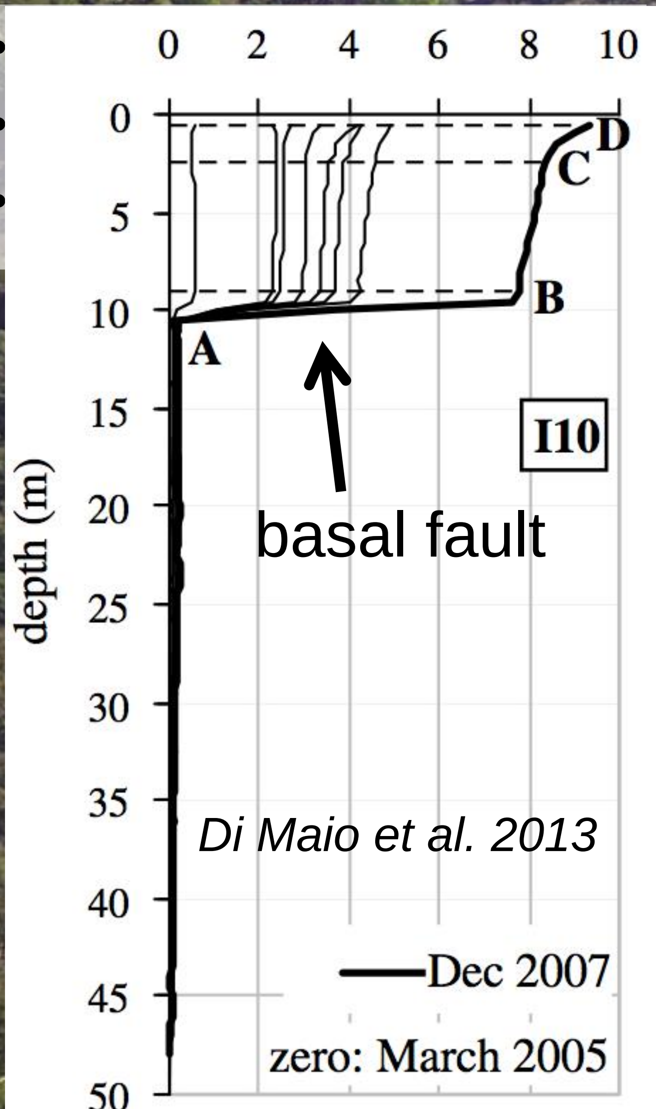
- Landslides display both seasonal and annual variations

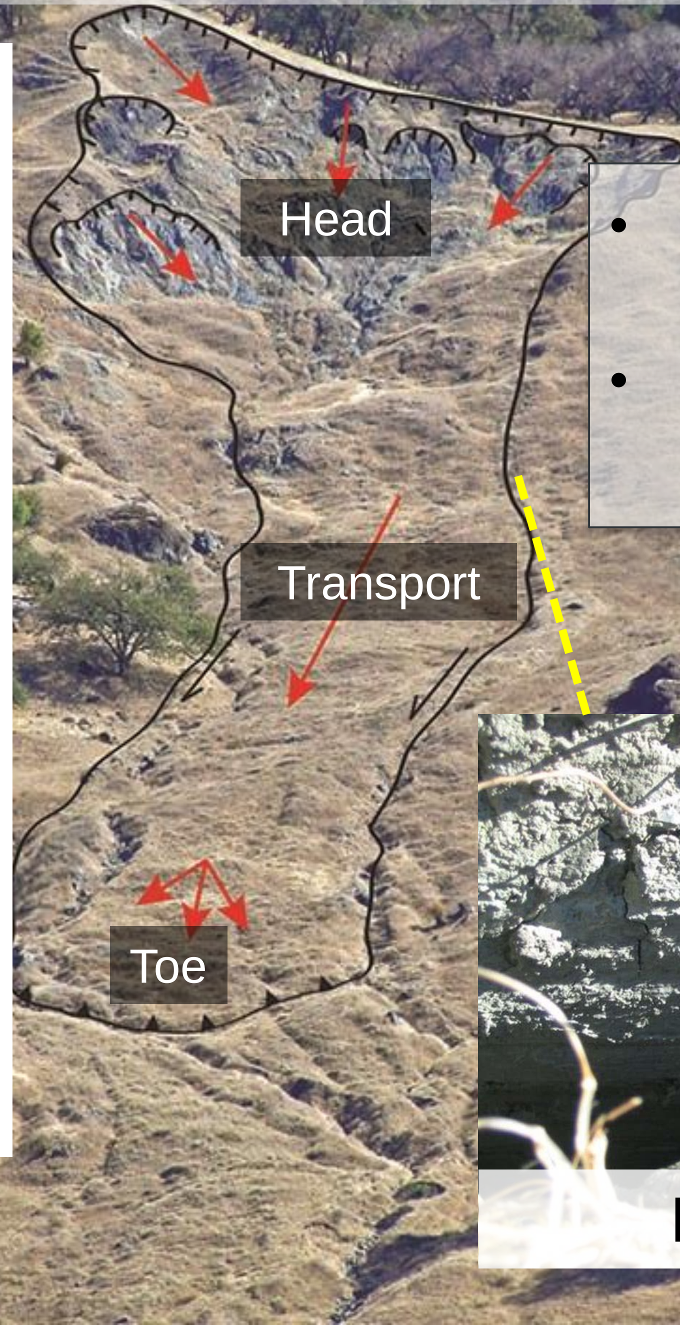
**2) What does the basal slip surface look like and how does it influence landslide motion?**

- We use 3D velocity from NASA UAVSAR and mass conservation to infer basal thickness and geometry

- Thickness is highly variable and basal slip surface is bumpy and irregular

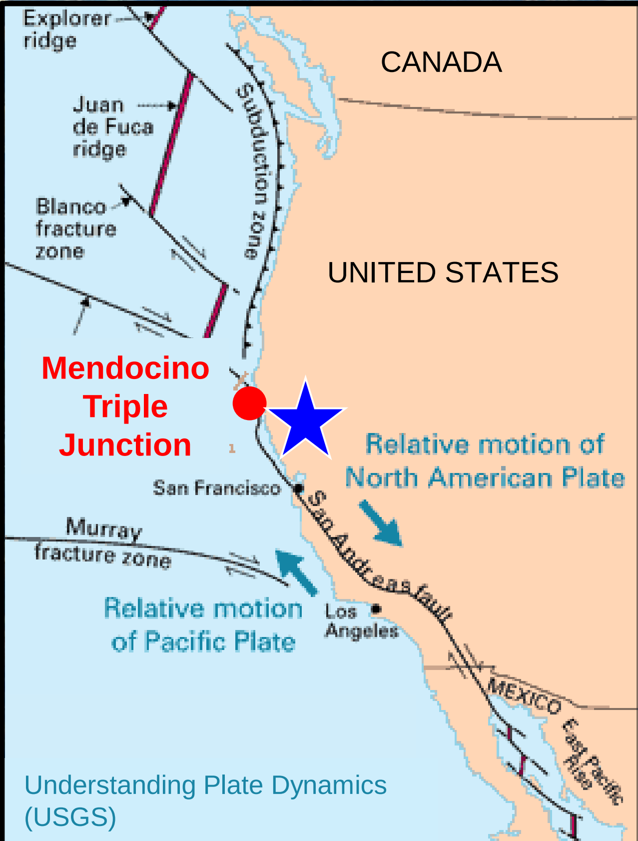
# Slow-moving Earthflows




- Distinct kinematic zones
- Sliding along basal and lateral faults

# Northern California Coast Range



Understanding Plate Dynamics (USGS)

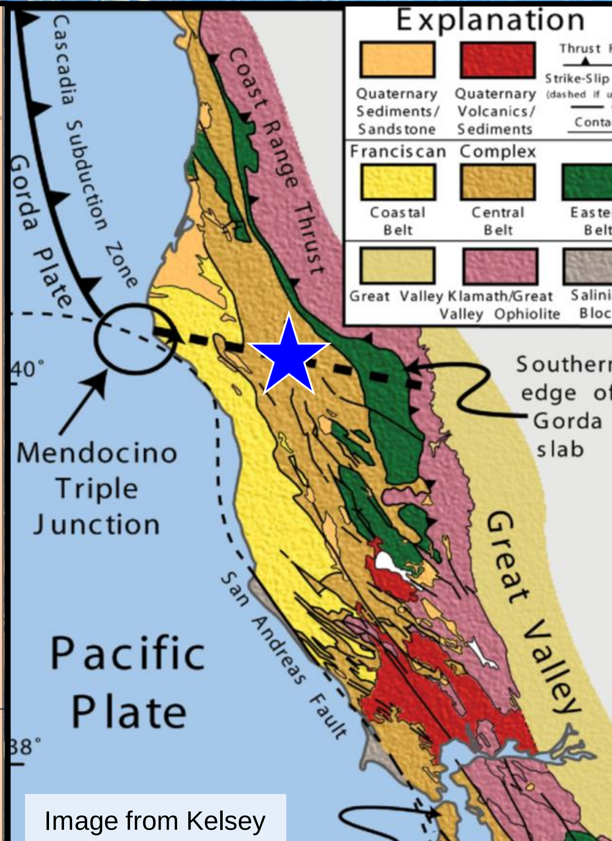
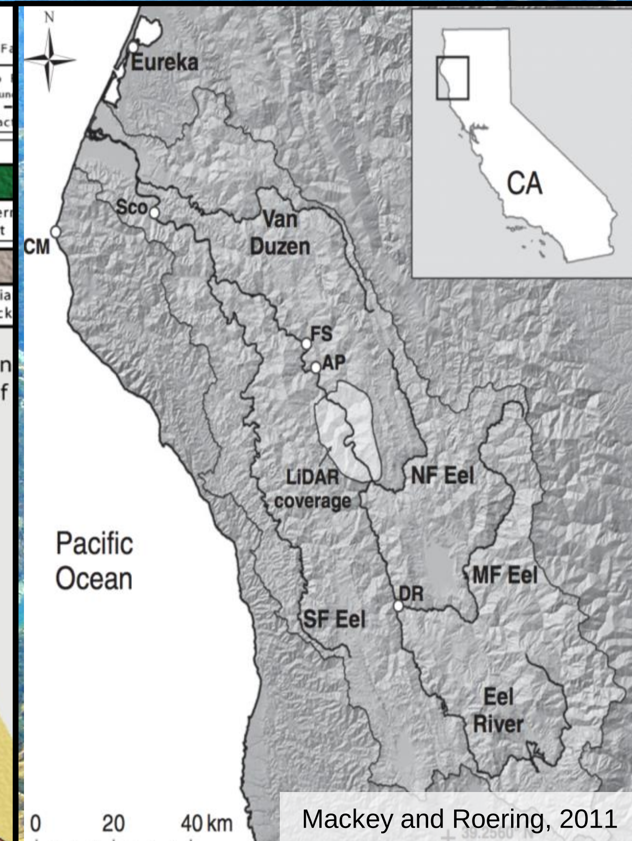


Image from Kelsey



Mackey and Roering, 2011

## Tectonics

- Mendocino Triple Junction
- Uplift rates ~ 1 mm/yr

(Lock et al., 2006)

## Lithology

- Franciscan mélange
  - Accretionary prism complex
  - Argillaceous matrix

(Kelsey 1978; Mackey and Roering, 2011)

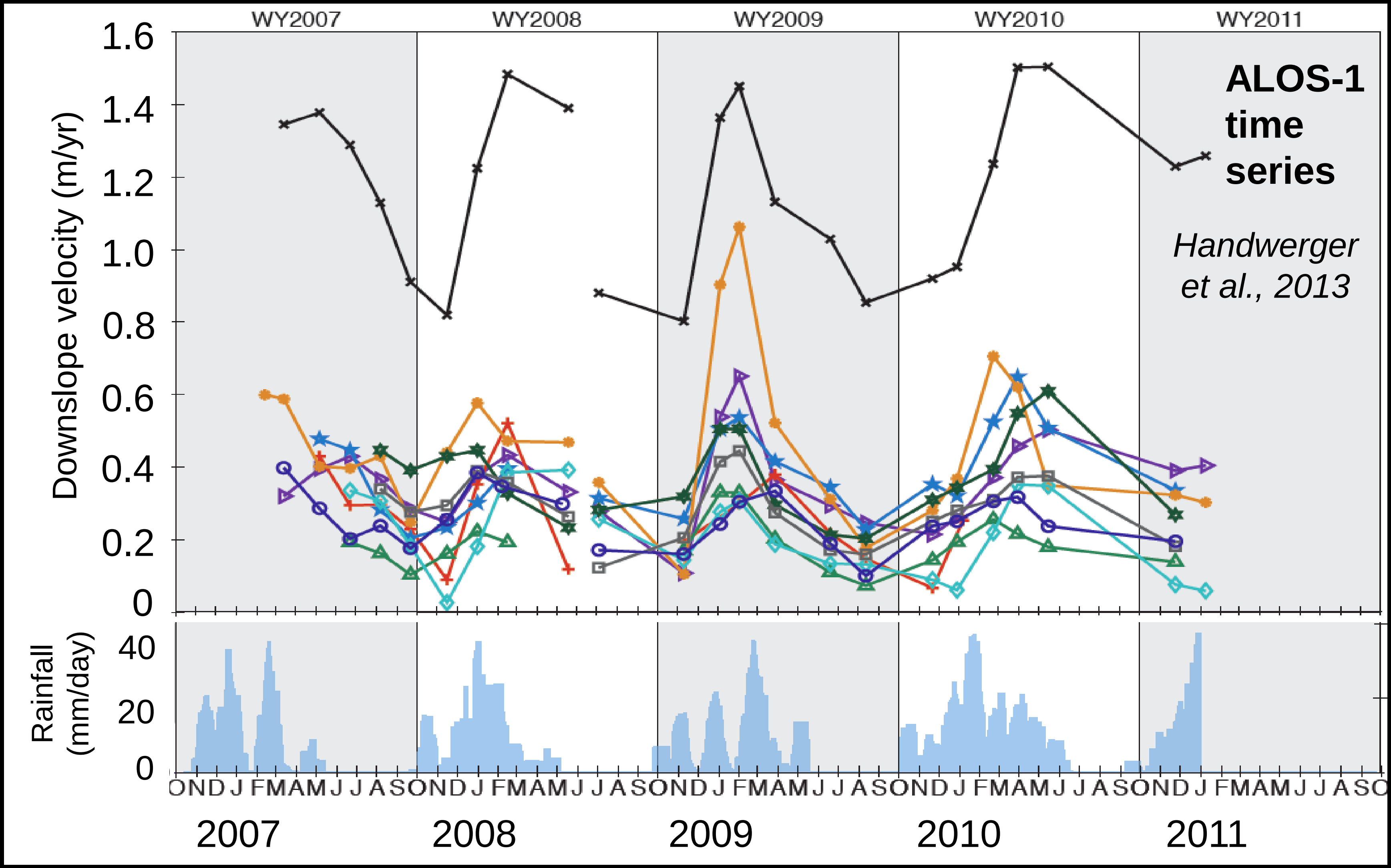
## Eel River Catchment

- Precip. = 1.4 m/year
- 80% between Oct & May
- High erosion rates ~ 0.9 mm/yr

(Wheatcroft and Summerfield, 2005)

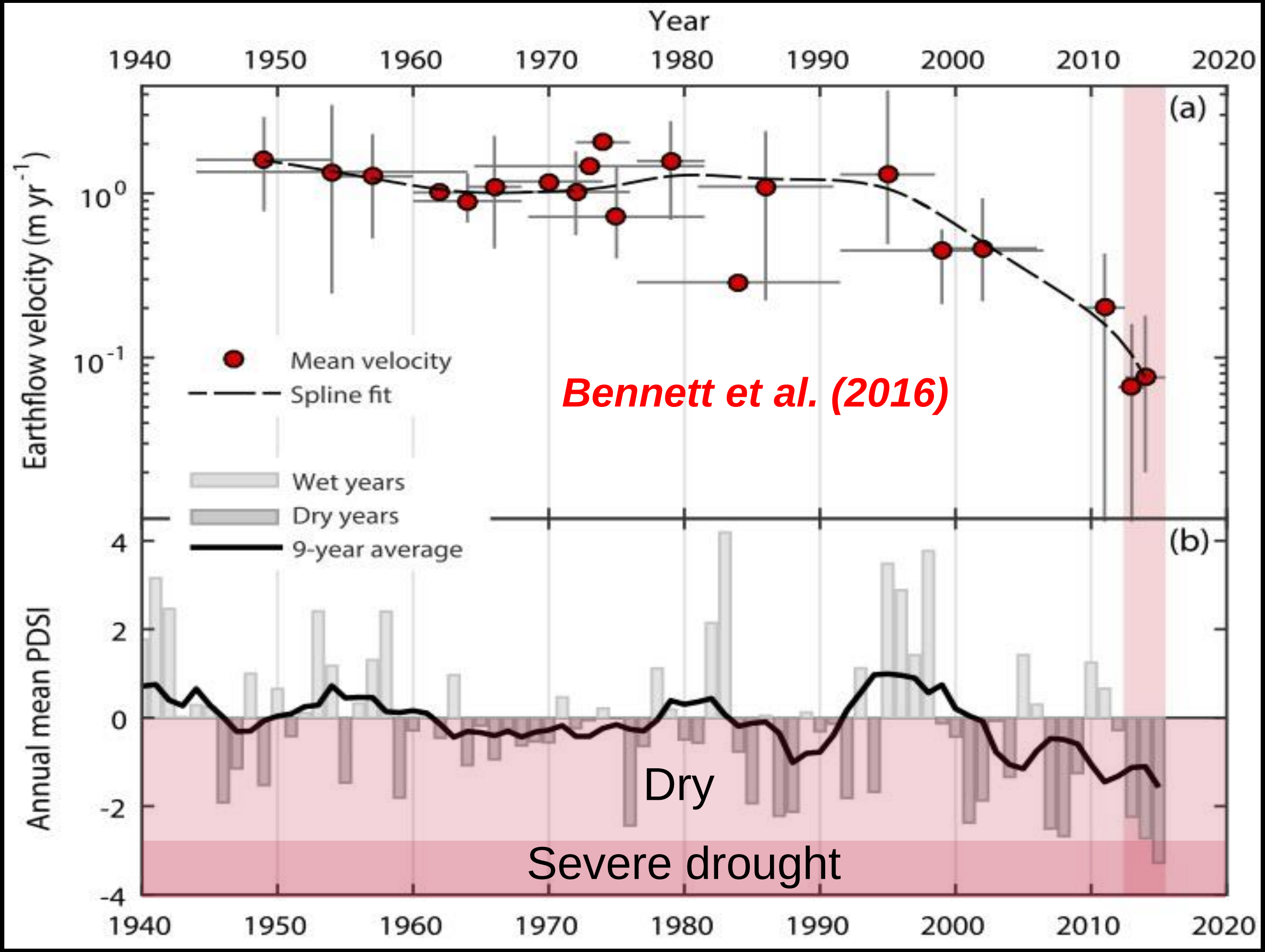
# Seasonal Kinematics

- Seasonal velocity changes
- Driven by precipitation-induced changes in pore-water pressure
  (Terzaghi, 1950; Iverson and Major, 1987)



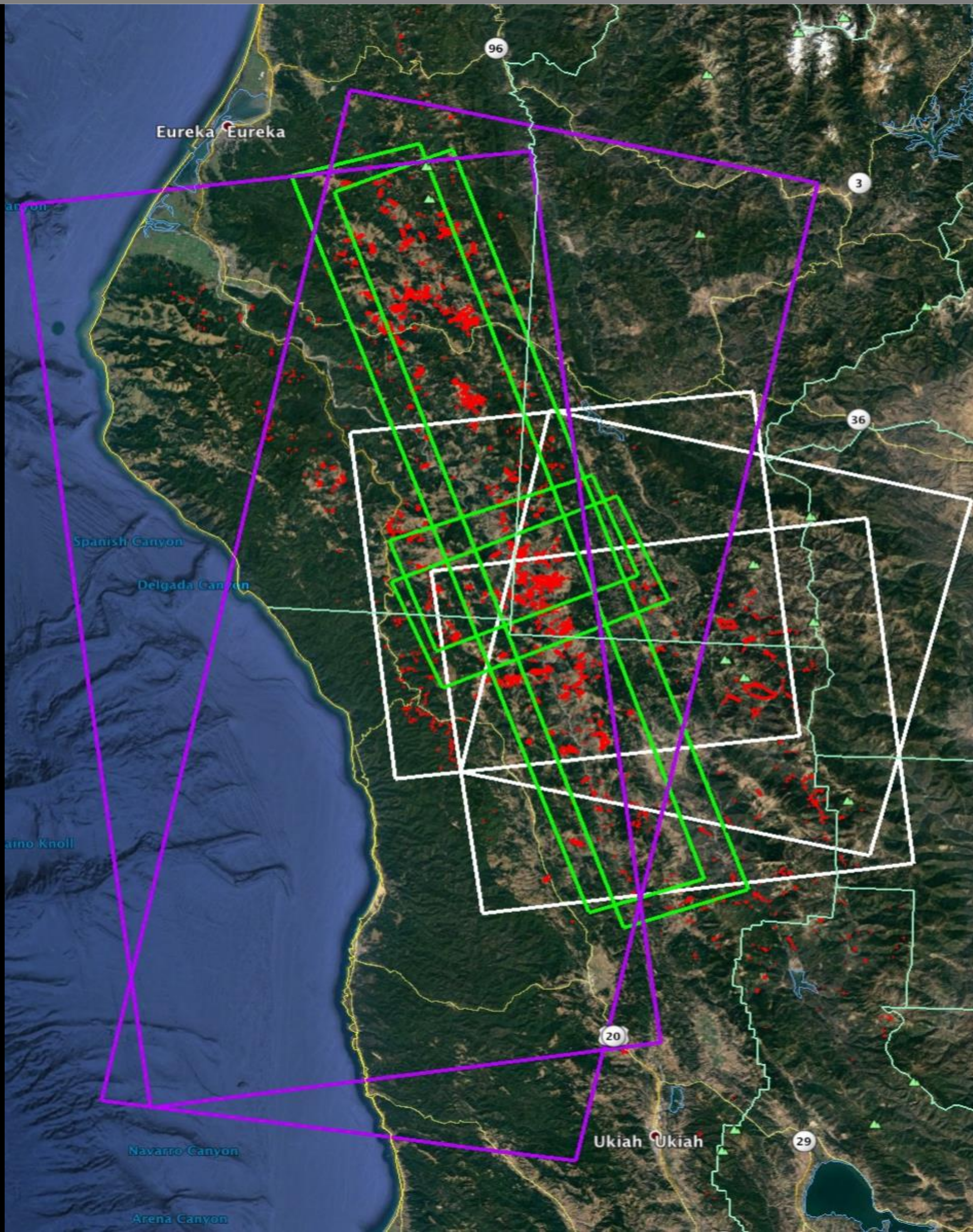
# Multi-year Kinematics

- Multi-year velocity changes
- Average landslide velocity has decreased in response to long-term moisture deficit (98 landslides analyzed)




- PDSI = Palmer Drought Severity Index
- Accounts for antecedent moisture conditions, precipitation, and evapotranspiration

# SAR satellite coverage

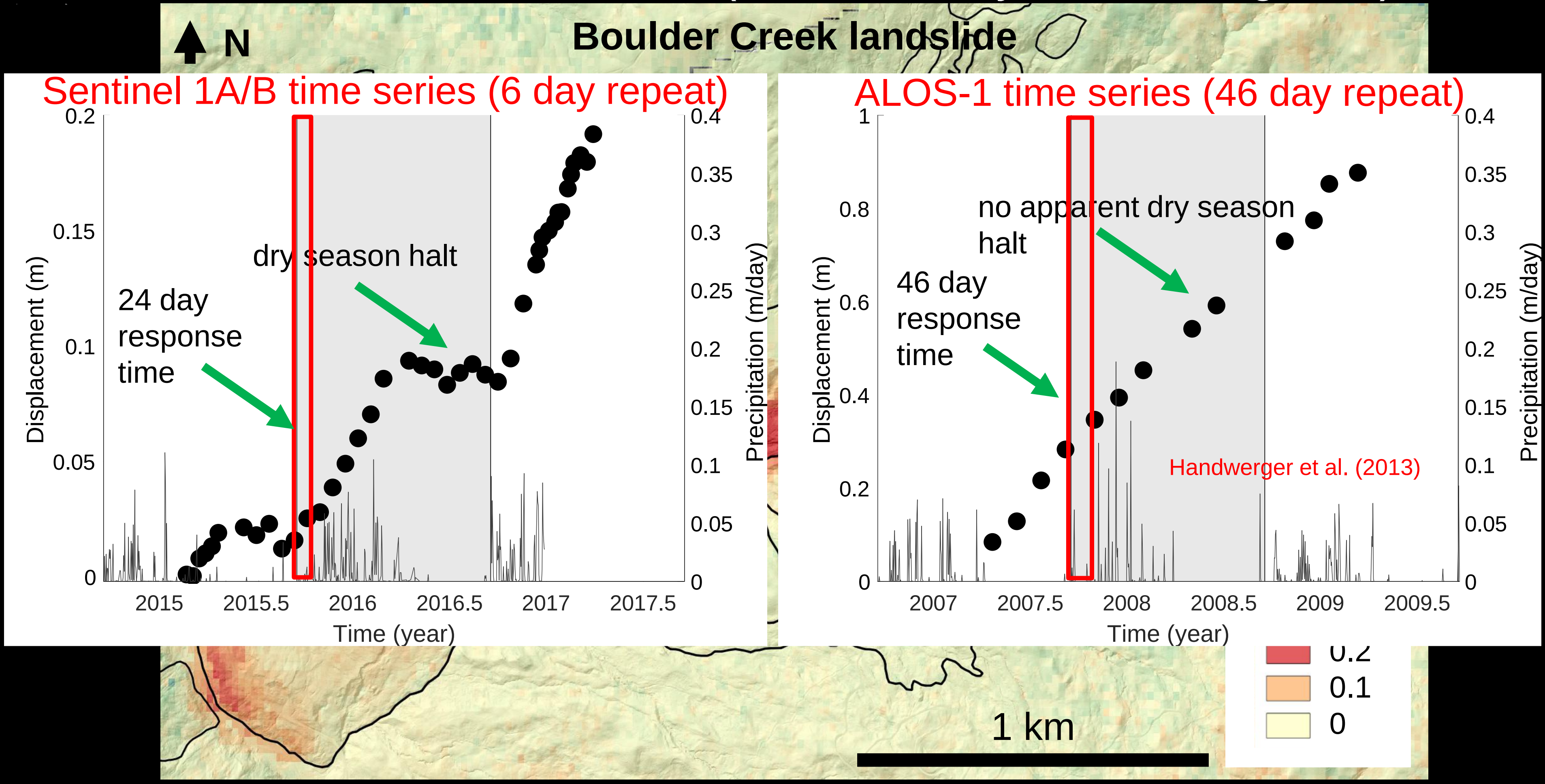



- Purple = ESA Sentinel 1A/B
  - 6 day minimum acquisition
- White = JAXA ALOS2
  - 14 day minimum acquisition
- Green = NASA UAVSAR
  - irregular acquisition interval

Red polygons = landslide inventory (Mackey et al., 2011; Handwerger et al., 2015; Bennett et al., 2016)

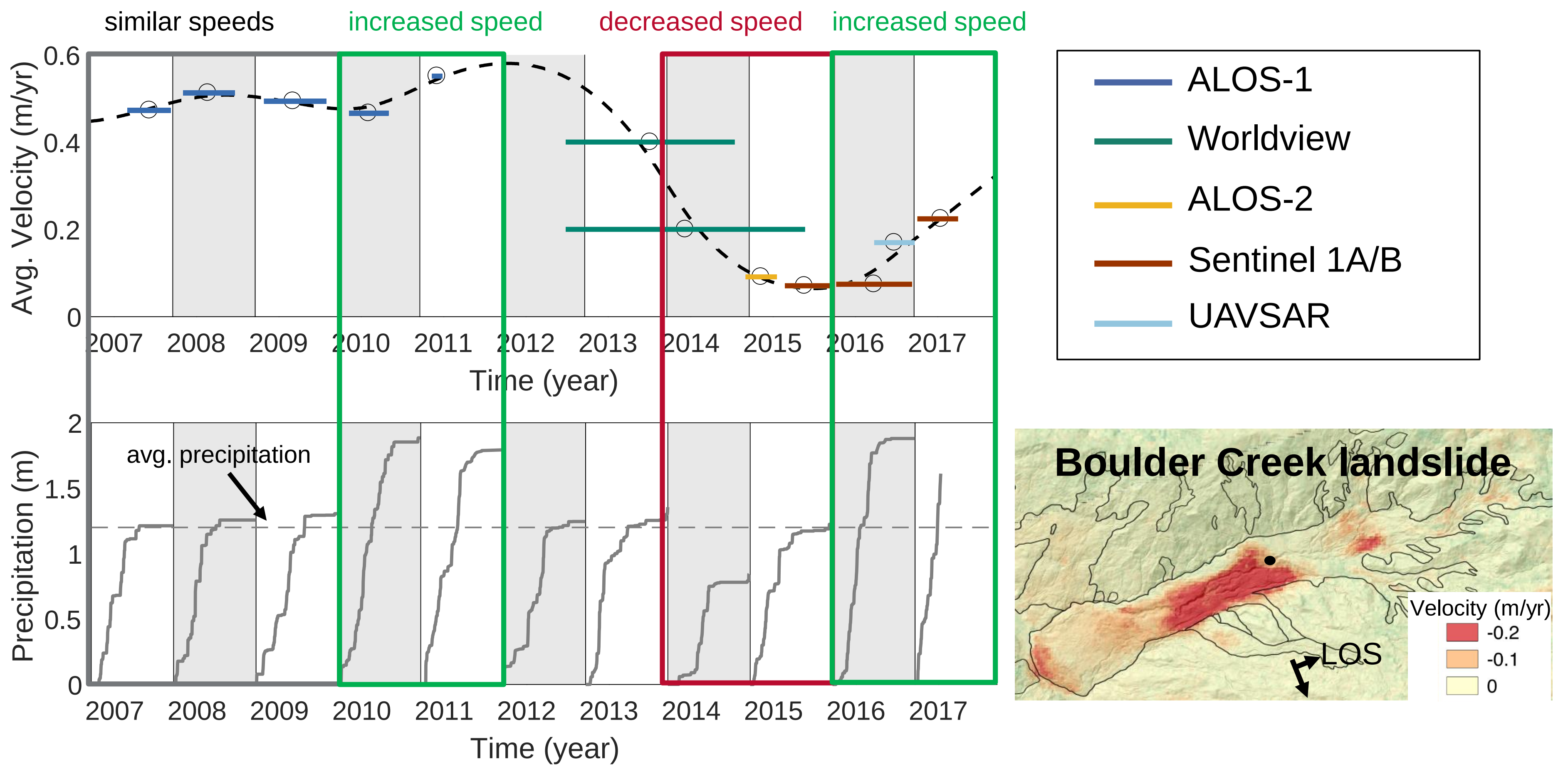
# Results

- Sentinel 1A/B and ALOS-1 time series
- Landslides continue to show seasonal displacement
- Total displacement significantly lower due to recent historic drought
- Now can better resolve motion (i.e. halt in dry season, lag time)



# Results

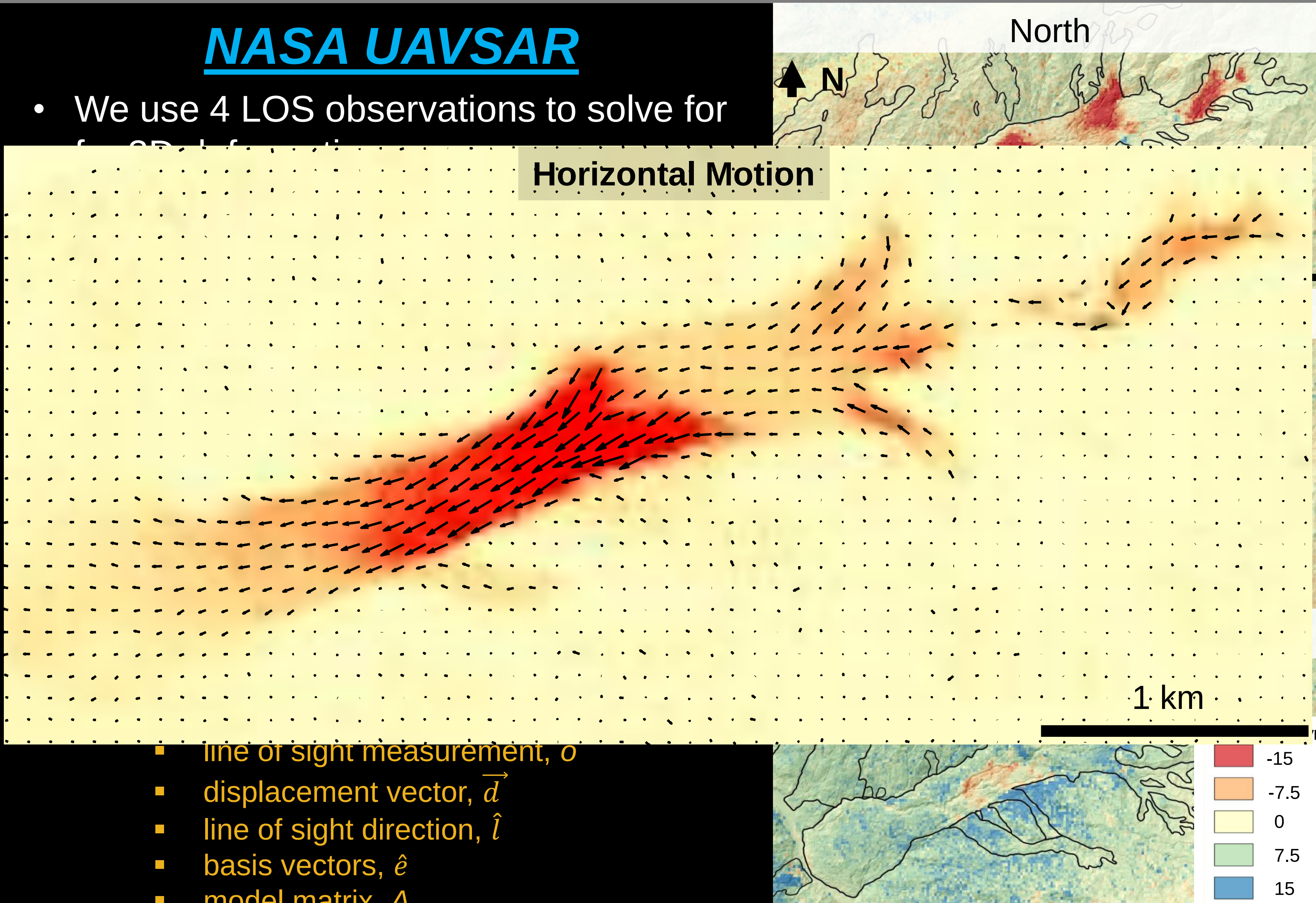
- Multi-year velocity changes
- Changes in annual precipitation (i.e. pore-water pressure)
- Slow down associated with 2014-2015 drought
- Apparent velocity increase following above average rainfall



# Results

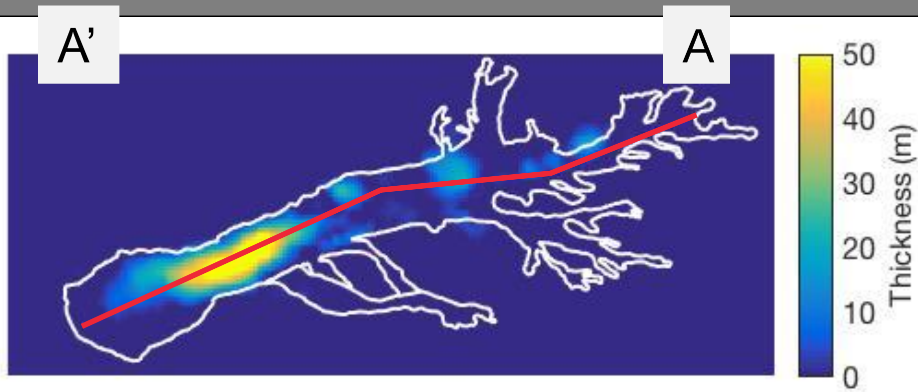
## *NASA UAVSAR*

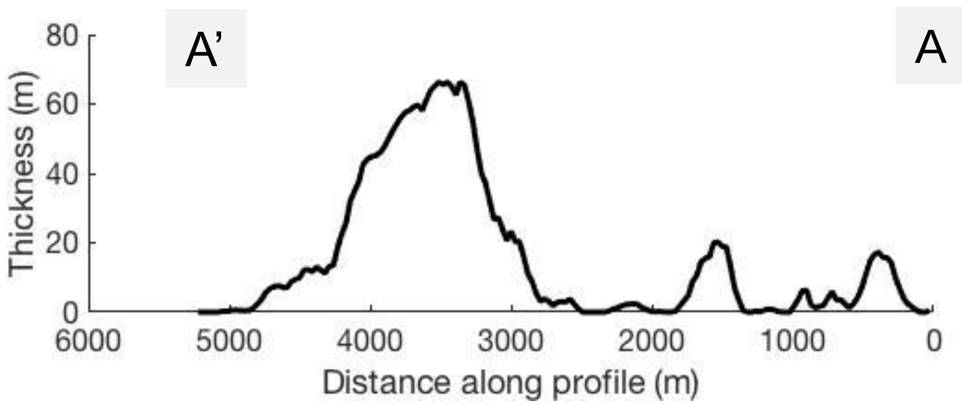
- We use 4 LOS observations to solve for

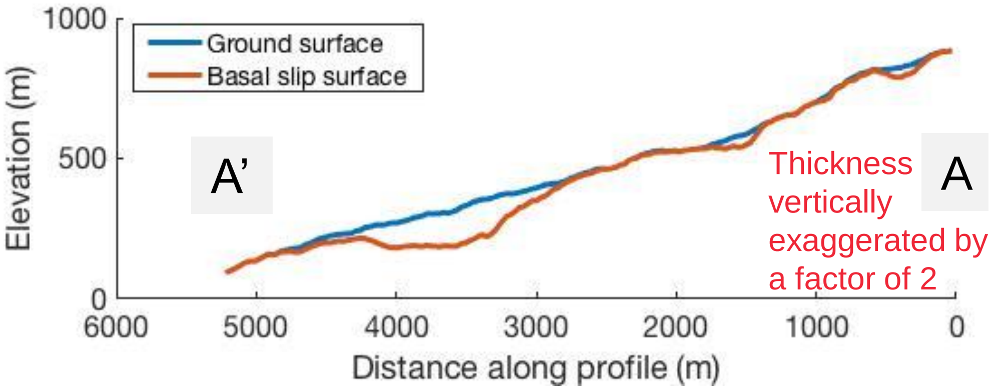



  - line of sight measurement, $o$
  - displacement vector, $\vec{d}$
  - line of sight direction, $\hat{l}$
  - basis vectors, $\hat{e}$
  - model matrix, $A$

# Results




## Mass conservation

$$\frac{\partial h}{\partial t} = -\nabla.(h\bar{\mathbf{u}})$$

variables
- landslide thickness, *h*
- time, *t*
- depth averaged landslide velocity, *u*

Assumptions
- constant density
- basal slip surface elevation does not change
- changes in thickness are responsible for observed 3D deformation

## ***Findings***

- Landslide thickness is highly irregular
- Basal slip surface is rough and bumpy
- Implications for long-term kinematics

Booth et al. (2013); Delbridge et al. (2016)

# Concluding Remarks

- Recent SAR data provides opportunity to quantify landslide kinematics over a period of < 1 week to multiple years
- We find landslide velocity is sensitive to changes in seasonal and multi-year rainfall
- Landslide thickness is highly variable
- The basal slip surface is irregular and bumpy, which may have implications for kinematics