INVESTIGATING THE FATE OF CREEPING LANDSLIDES WITH COMPLEX NETWORK THEORY

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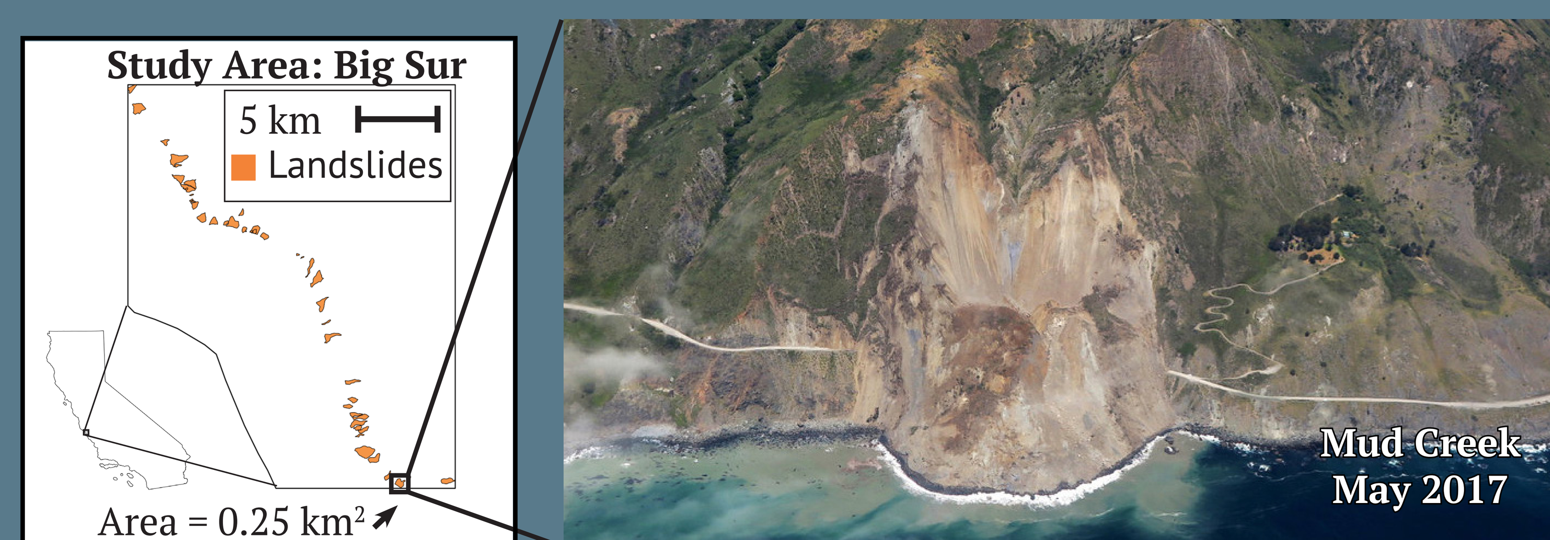
Rainfall-Induced Landslides

Global warming has contributed to an increased risk of California drought due to rising temperatures [1]. Combined with an increased likelihood of wet years in California, slow-moving landslides are more likely to fail due to saturated soils.



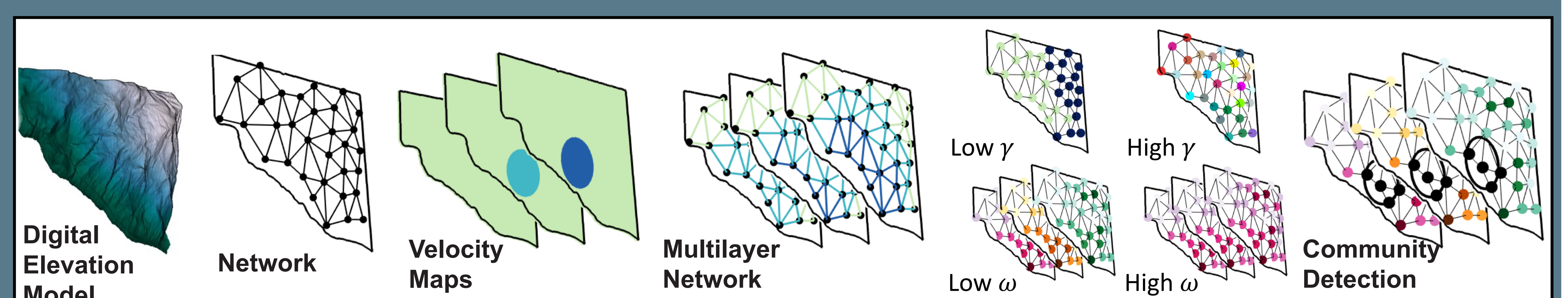
NYT, May 2017

Using satellite InSAR data, we apply techniques from network science to develop methods to investigate spatio-temporal patterns to predict the sudden transition from gradual deformation to runaway acceleration and catastrophic failure.

Network Science Framework

Why a Network?
- Is useful for datasets that are connected through space and time
- Can help mine large datasets for consistent patterns using well-developed toolboxes

A complex network:
- Contains a set of nodes connected by edges that can be weighted and/or directed
- Can represent temporal dynamics via a multilayer network of spatial slices



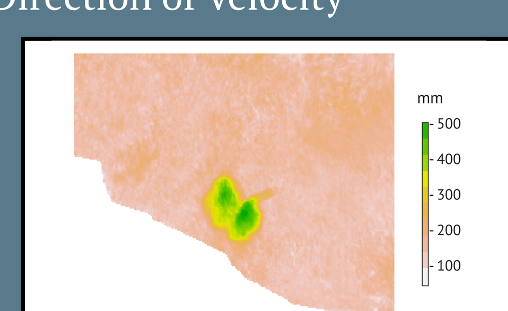
What is Community Detection?
- Identifies clusters of nodes that are more strongly connected to each other than they are to the rest of the network

Which Technique do we use?
GenLouvain - optimizing modularity [3]

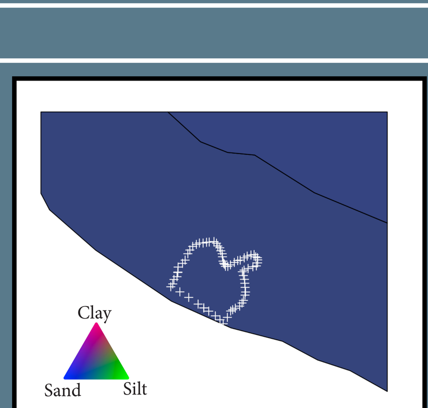
Selecting Variables to Use in Forecasting Failure

DEM Derivatives [4]:
- Elevation, $h(x,y)$
- Position, $\vec{r} = (x,y)$
- Slope, $s = \frac{|\Delta h|}{|\Delta \vec{r}|}$
- Downslope Direction

InSAR Data [2]:
- Cumulative Displacement,
- Incremental Displacement, $u(x,y,l) = U(x,y,l) - U(x,y,l-1)$
- Velocity, $v(x,y,l) = \frac{u(x,y,l) - u(x,y,l)}{\Delta t}$
- Direction of Velocity



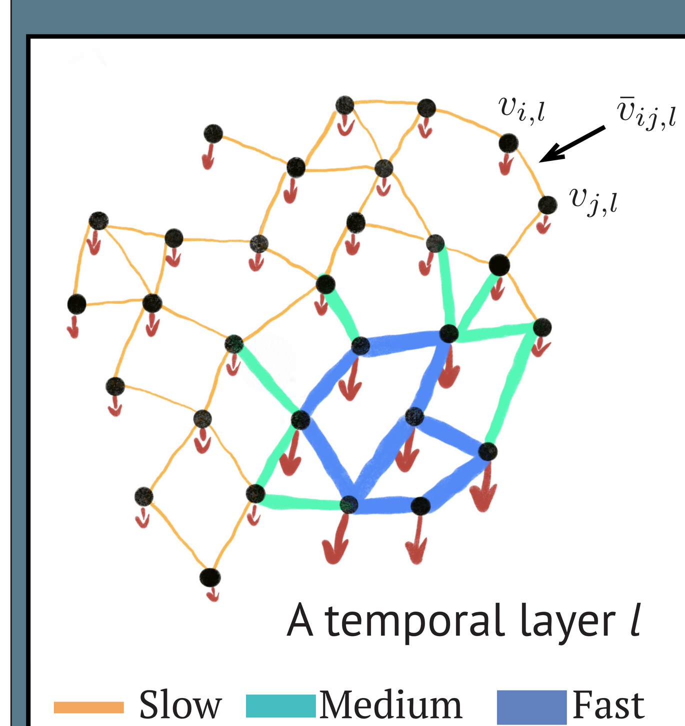
Cumulative displacement over 812 days, where Mud Creek is clearly seen



Soil (Coming Soon) [5]:
- Soil Type
- Soil Moisture

Weights for Multilayer Network

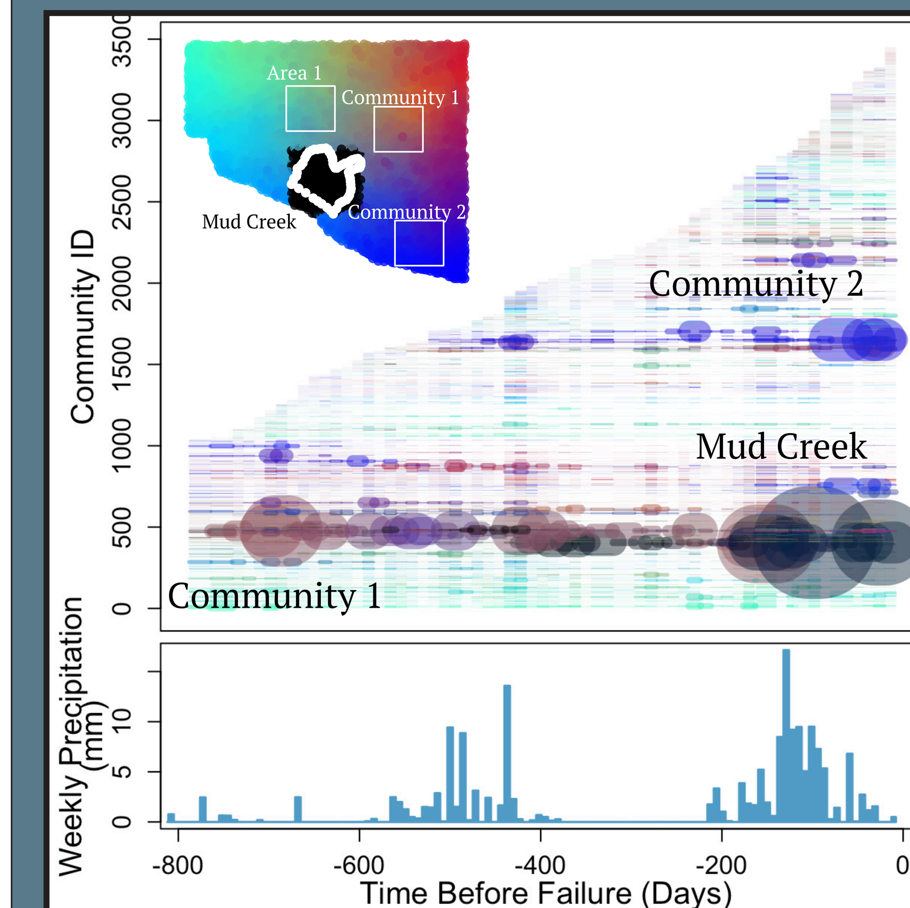
To incorporate the current state of rheology as well as susceptibility of a hillslope, we used velocity, derived from InSAR, and slope from DEM. There are a total of 62 layers from the InSAR data that is taken every 6,12, or 24 days [2].



Calculating Edge Weights
1. We account for the uneven time intervals by calculating velocity for any node i: $v_{i,l} = \frac{u_{i,l}}{\Delta t}$
2. We assign average velocity, $\bar{v}_{ij,l} = \frac{|v_{i,l} + v_{j,l}|}{2}$, as edge weights for any 2 connected nodes
3. We account for both the local slope and recent velocity by defining the adjacency matrix M, as an undirected, weighted multilayer matrix, where

$$M_{ijl} = \begin{cases} \bar{v}_{ij,l} s_{ij} & \text{If nodes } i \text{ and } j \text{ are connected,} \\ 0 & \text{otherwise,} \end{cases}$$

Forecasting Landslides Using Community Detection



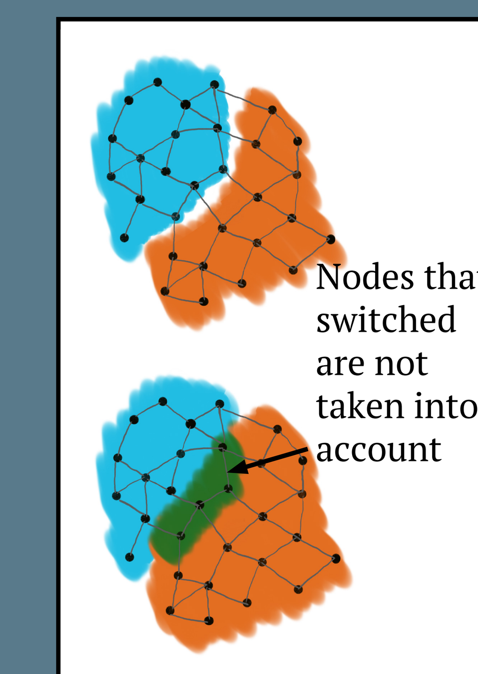
Key Observations:
- GenLouvain consistently identifies Mud Creek as a community
- Several other communities are also identified intermittently, but appear less consistently.

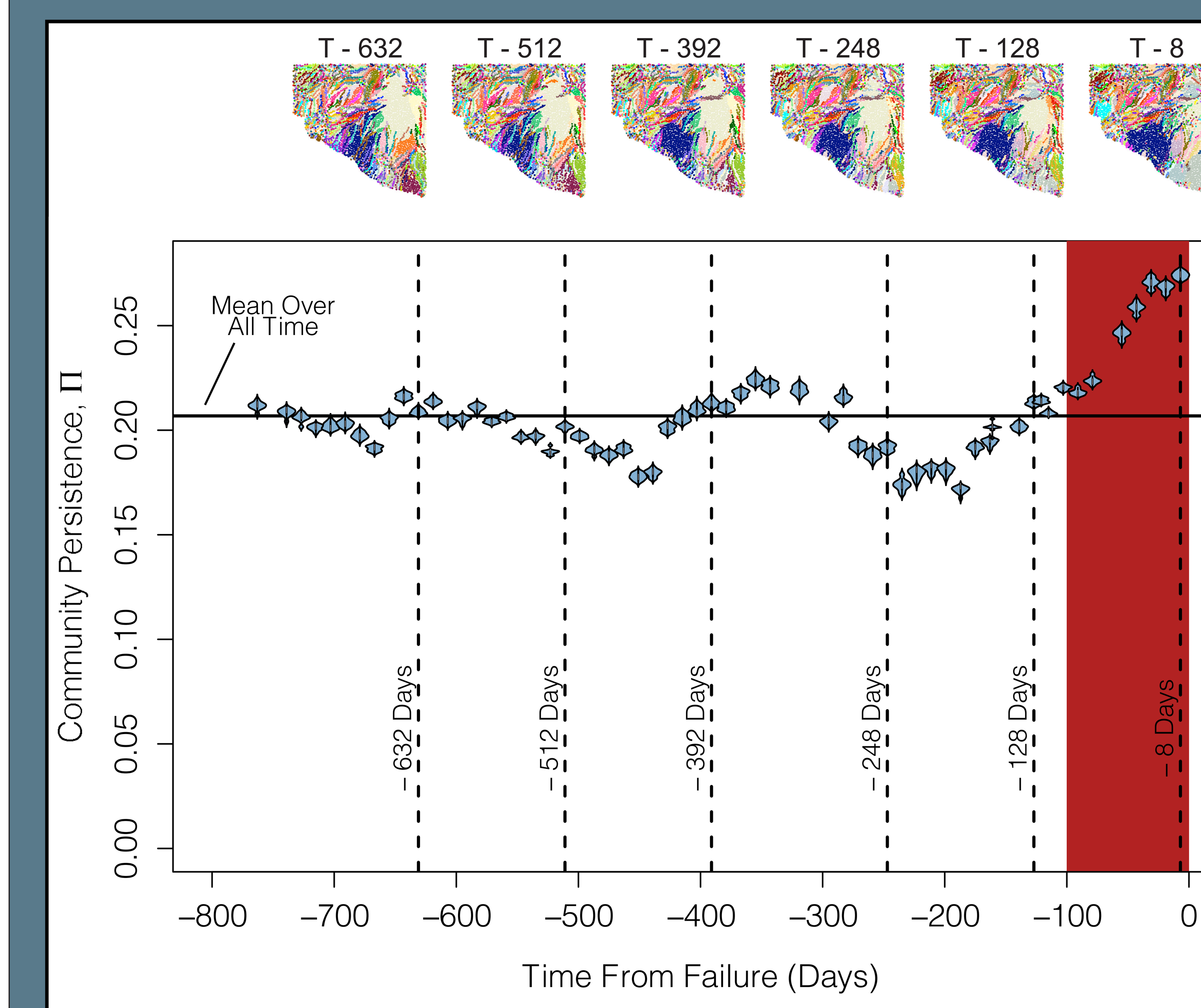
We selected 4 areas for comparison:
- 'Area 1' has similar topography to Mud Creek (at higher elevation), but was never identified as a community
- 'Community 1' & 'Community 2' were repeatedly identified as communities, but did not fail

Community Persistence:
Measures the stability of the nodal composition for each community in relation to the community's size

$$\Pi_l = \frac{1}{N} \sum_c \frac{|c_{l-1} \cap c_l|}{n_{c,l}}$$

N: Total number of nodes
$n_{c,l}$: Number of nodes in community c at layer l
$|c_{l-1} \cap c_l|$: Number of nodes present in community c in both layers l and l-1





- Using community detection, we detect patterns that allows us to forecast Mud Creek's failure in the weeks leading up.
- We are able to distinguish the three creeping landslides found within this study area as stable vs unstable.

References

[1] Swain, Langenbrunner, et al., Nature Climate Change, 8:427-433 (2018)
[2] Handwerger et al., Scientific Reports, 9:1569 (2019)
[3] http://netwiki.amath.unc.edu (open-source)
[4] USGS, 2014, 3D Elevation Program: ARRA-CA Central Coast Z3 2010
[5] C. Li, et al., Natural Hazards Earth System Science, 22, 2317–2345 (2022)