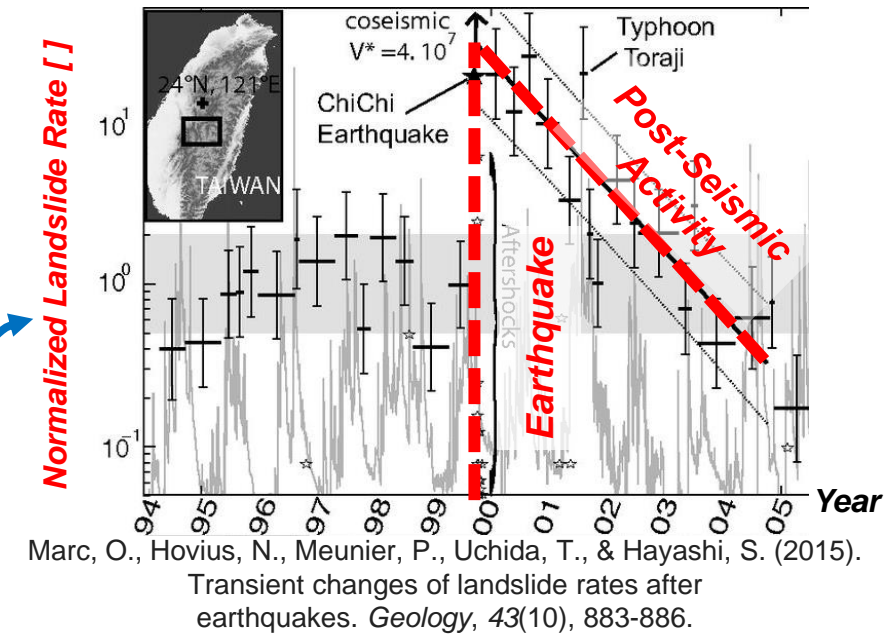# Post-Seismic Shallow Landslide Triggering: Stress States and Hydrology

Ben Leshchinsky[1], Peter Lehmann[2], and Dani Or[2]
[1]Oregon State University, [2]ETH Zurich

Characteristics of Post-Seismic Landslide Activity

- Following major earthquakes, an increase followed by attenuation in landslide activity

- Coseismic hillslope "damage" and subsequent "healing"

- Post-seismic rainfall events activate "damaged" hillslopes

- Difficult to quantify post-seismic landslide patterns

- ***Objective***: To quantify seismicity effects on hillslope "damaged state" with enhanced landslide activity and subsequent healing
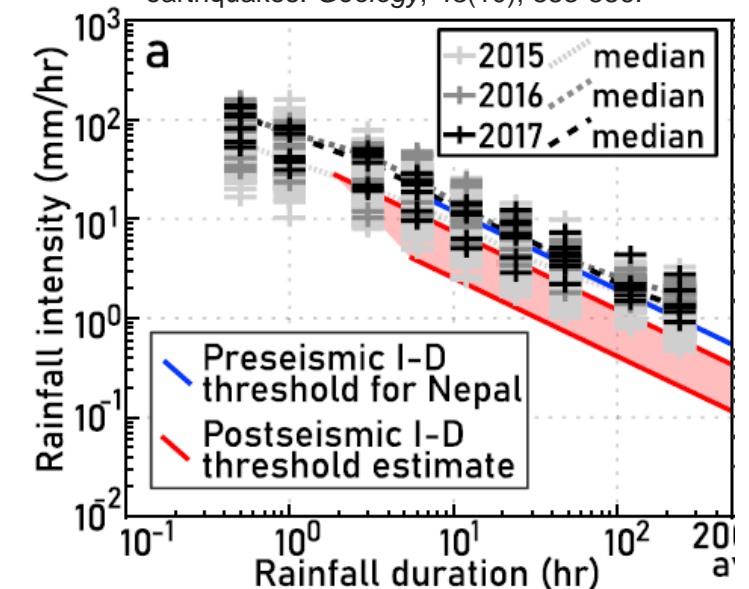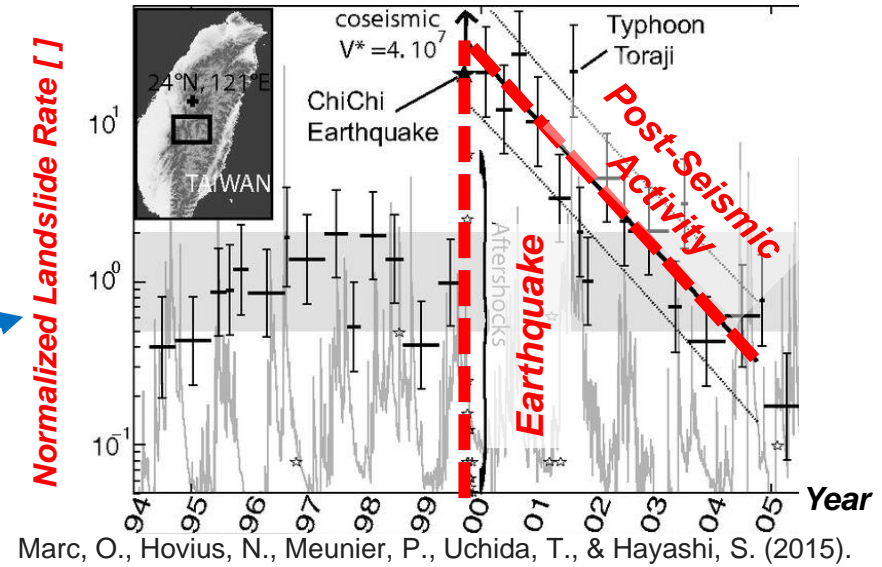

Marc, O., Hovius, N., Meunier, P., Uchida, T., & Hayashi, S. (2015). Transient changes of landslide rates after earthquakes. *Geology*, *43*(10), 883-886.

Fan et al., 2018, Engineering Geology, 243, 128-144

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Dahlquist, M. P., & West, A. J. (2019). Initiation and runout of post-seismic debris flows: Insights from the 2015 Gorkha Earthquake. *Geophysical Research Letters*, *46*(16), 9658-9668.

Hydromechanical Model

- Model discretized into:
  - Columns: *boundaries of compression.*
  - Layers: *boundaries of shear.*

- Cumulative downslope deformation function of shear, compression between boundaries. Compression may remain after disturbance.

- Yield → Compression exceeds passive resistance.

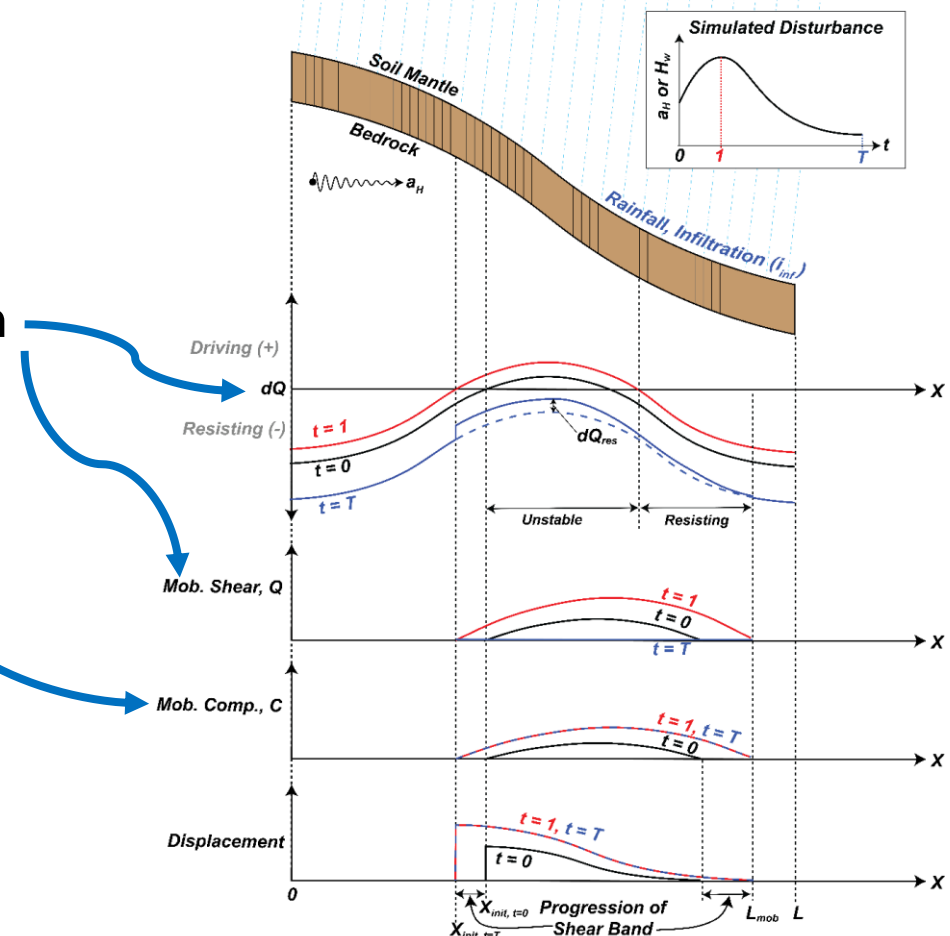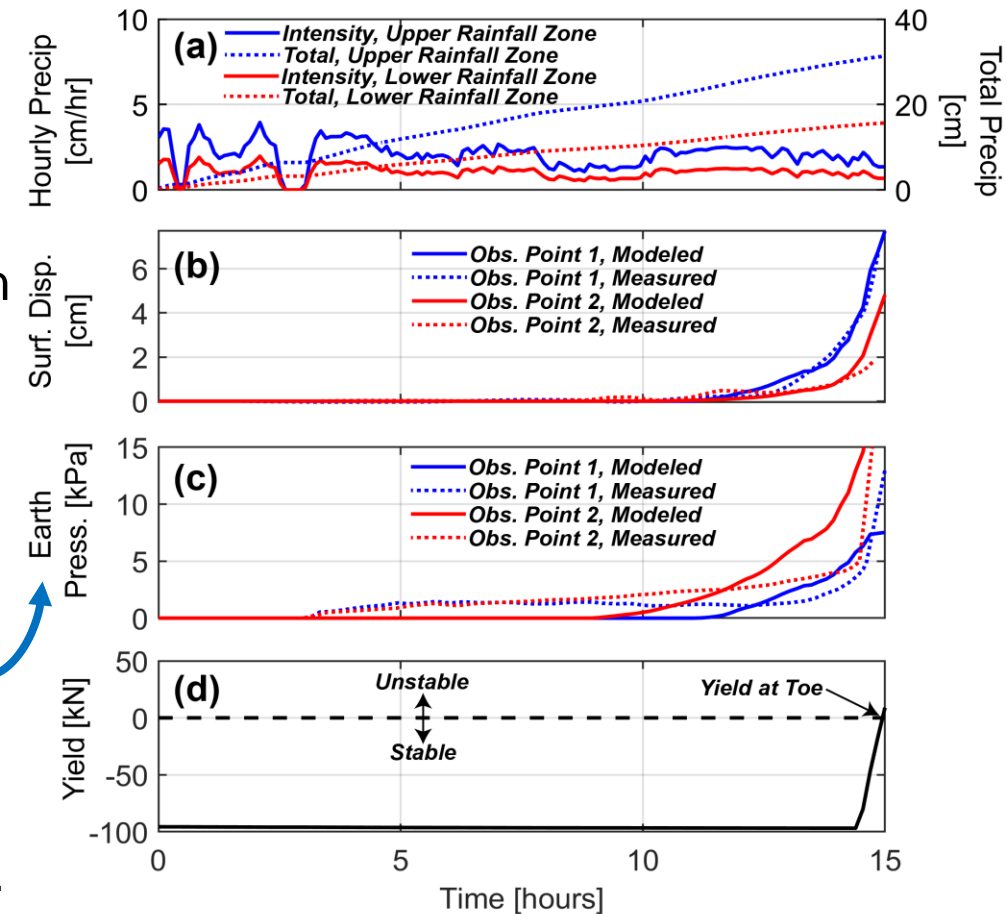 ### Governing Physics:

  Seismic Inertial Load: $k_H(t)W$
  Mohr-Coulomb Failure Criteria: $S = c' + \sigma' tan\phi'$
  Climate: infiltration (i)
  Hydrological: $n, \alpha, k_{sat}, \theta_{res}, \theta_{sat}$, initial VWC ($\theta_o$)
  Vegetation: Root Fiber Bundle Model

- Modeled time of triggering, internal compression and deformation response matched observations from the Ruedlingen landslide (well-instrumented failure where compression and deformation measured).

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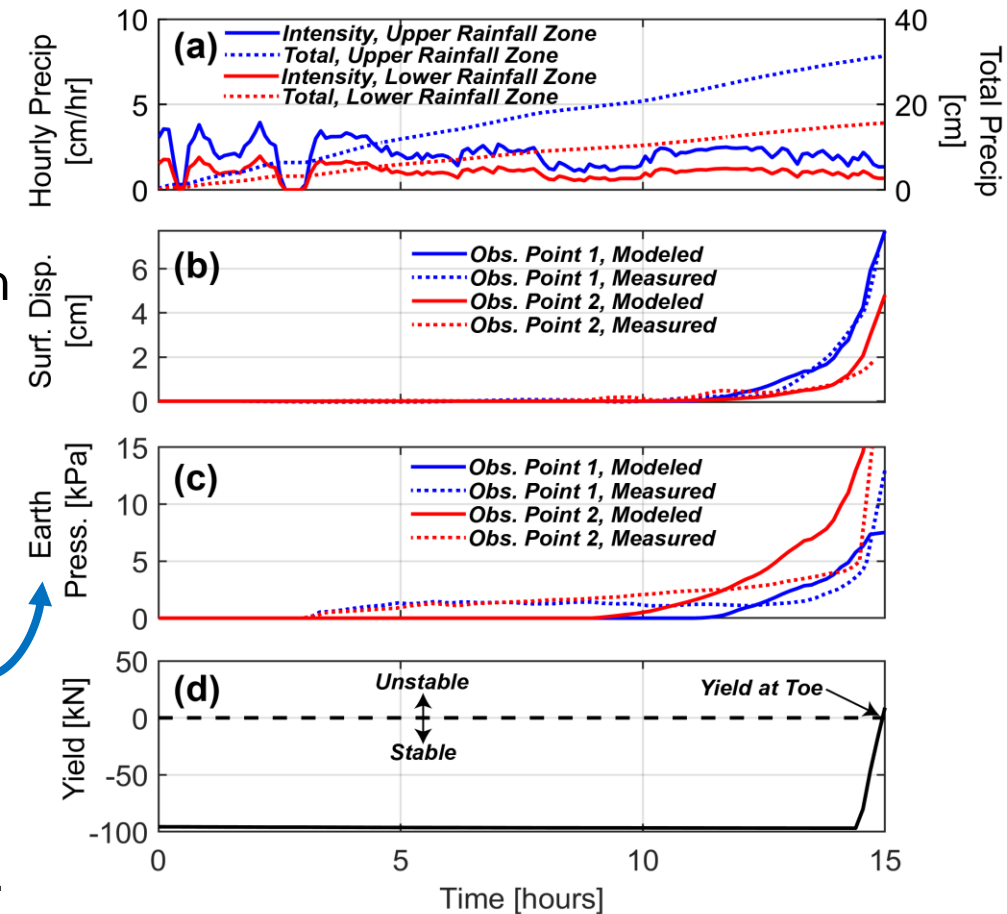
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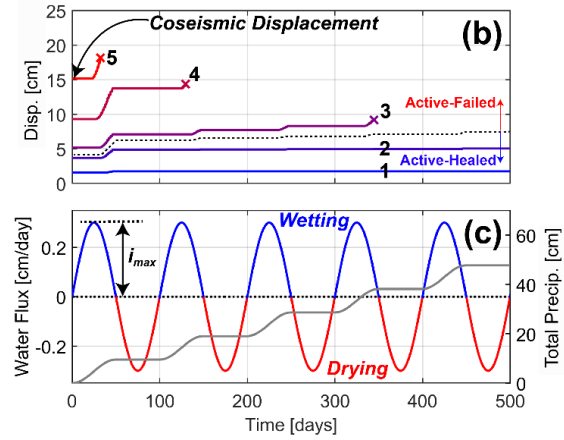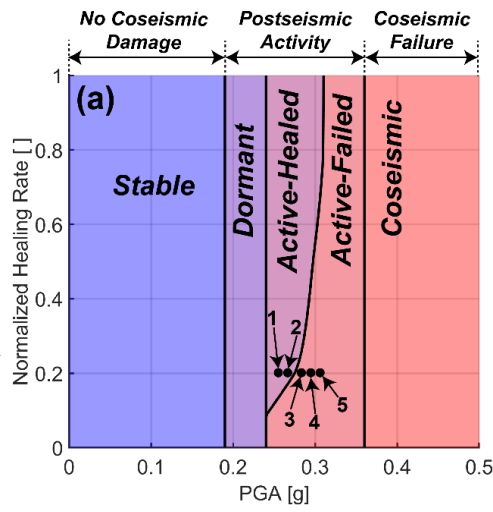

Hillslope Damage and Triggering

- The relationship between coseismic damage (compression, weakening) for PGA and post-seismic triggering rainfall were established, consistent with prior observations (a).

- *Damage Curve*: No damage below yield accel., coseismic failure for large PGA - triggering rainfall due to damage (b)
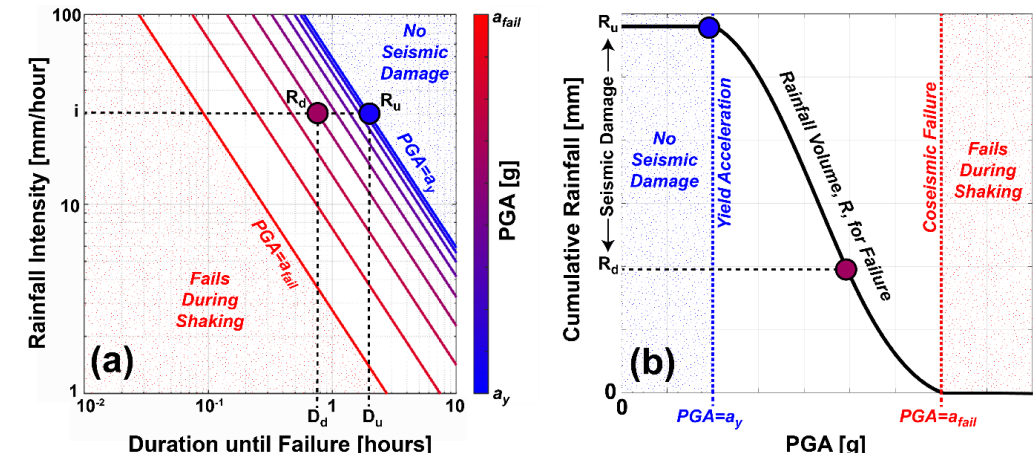
Post-Seismic Failure and Dormancy

- May consider cycles of wetting and drying (c) and the progression of shear banding, residual compression.

- Healing of soil (reconsolidation, shrinkage) and roots (revegetation) influence whether damaged hillslope exhibits post-seismic triggering or dormancy (a).

- Bifurcation in post-seismic landslide behavior with increasing PGA (dormancy or triggering) – (b).

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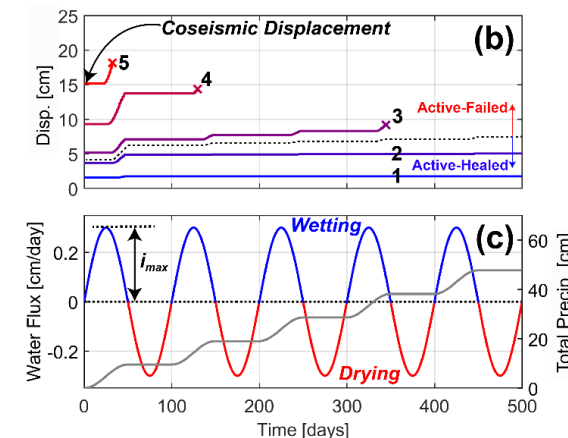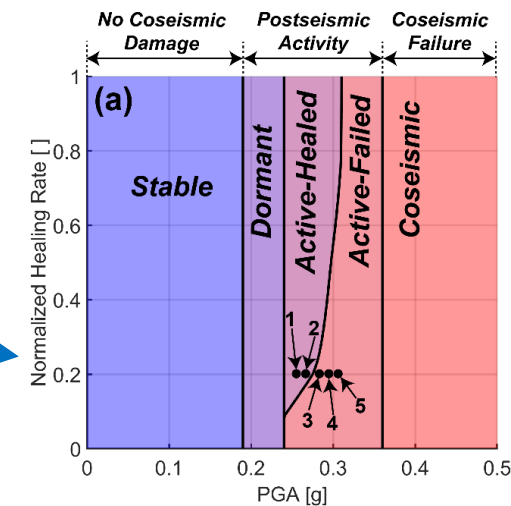
Implications for Post-Seismic Activity

- Take hypothetical distribution of hillslope geometries (a) and apply PGA (here, 0.25g).

- Coseismic failures are compared for soil weakening, vegetated conditions, soil healing and no soil healing (b). Eventual plateau in post-seismic landslide volume.

- This is reflected in landslide rates (c), where decay is observed for all cases. Rates are smallest for vegetated conditions, but most prolonged.

- Dormancy is also considered (d), where vegetated conditions reflect maximum dormancy of damaged hillslopes, shear softening the least.