# Multimethod approach for landslide hazard monitoring

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# Content

**New approach to monitor shallow slow-moving landslides**

**Objectives** :
1) Where are the high-risk areas?
2) What are the reactivation mechanisms and their factors of control?

**Methods:**

1) **Estimate the hazard**:
    - PoF => Hydro-geomechanical model
        - Extract critical parameters
        - Estimate their spatial variability (Geophysics + remote sensing)

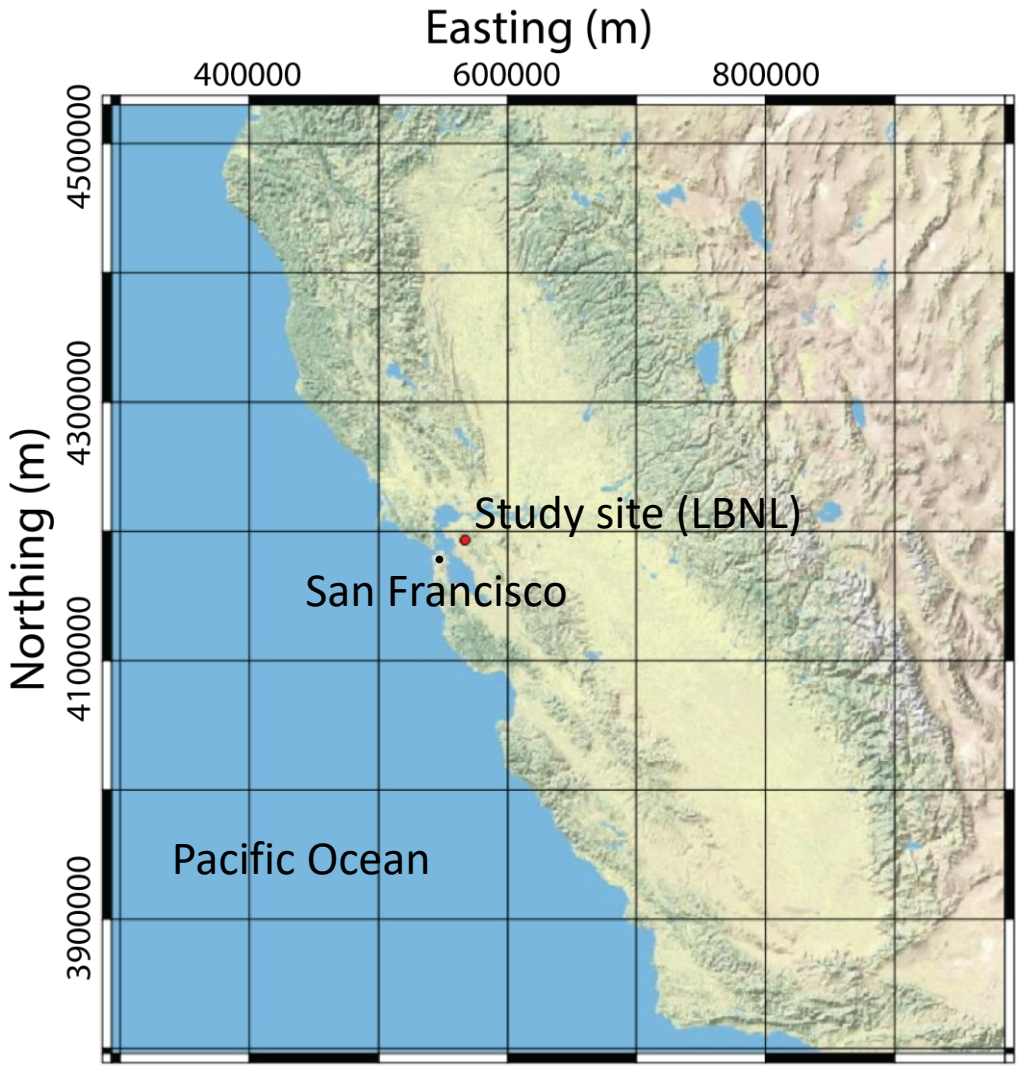
2) **Characterize and monitor areas at risk**:
    - Multimethod approach (geophysics, geotechnics, hydrology and meteorology)

La Conchita landslide, 2005, California, USA.

# Study site

Berkeley Hills (California, USA) :

- Urban site
- Highly prone to landslide
  - Numerous paleolandslides
  - Some active(s)
- Areas monitored by GPS stations
- Numerous geotechnical surveys (linked to constructions and retrofitting)



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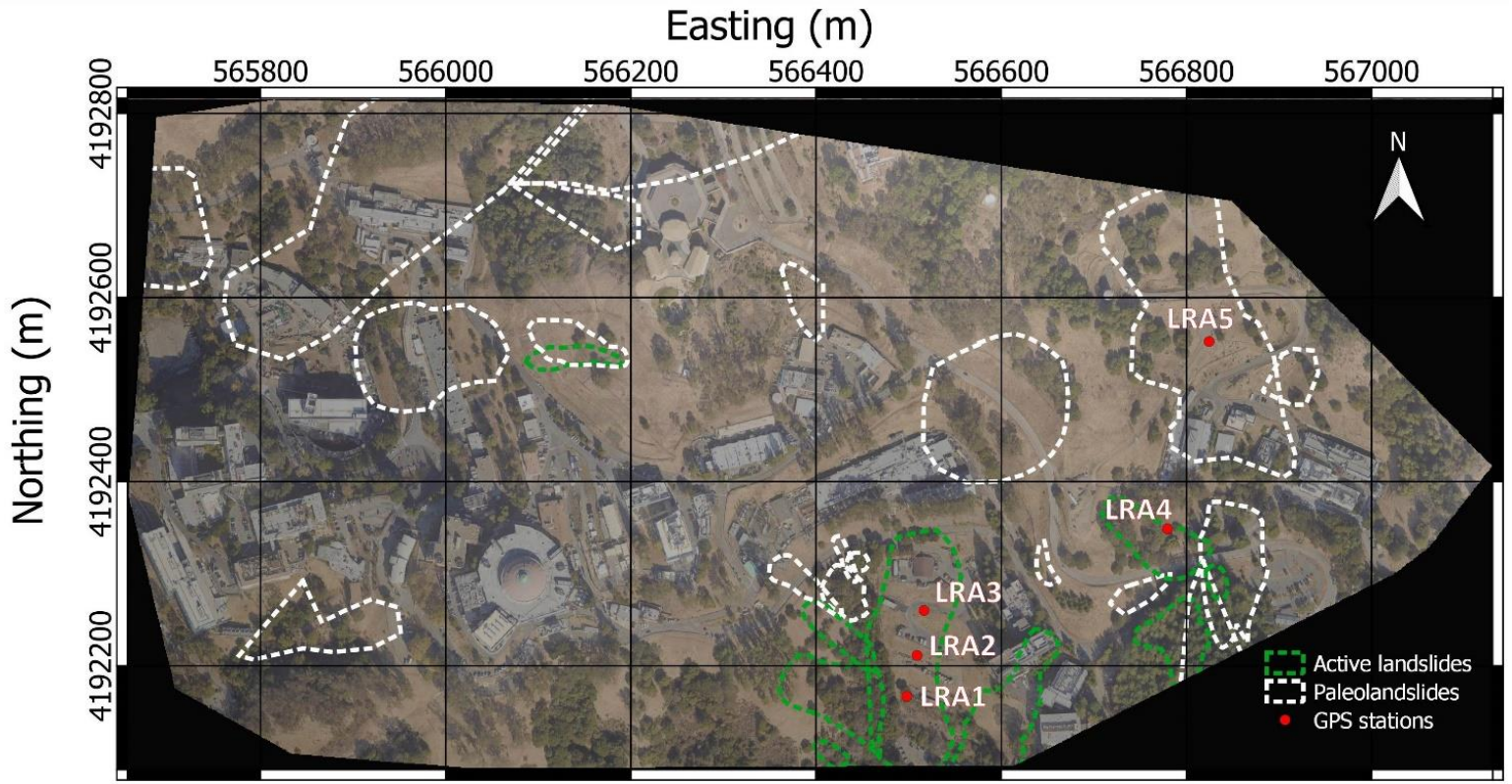
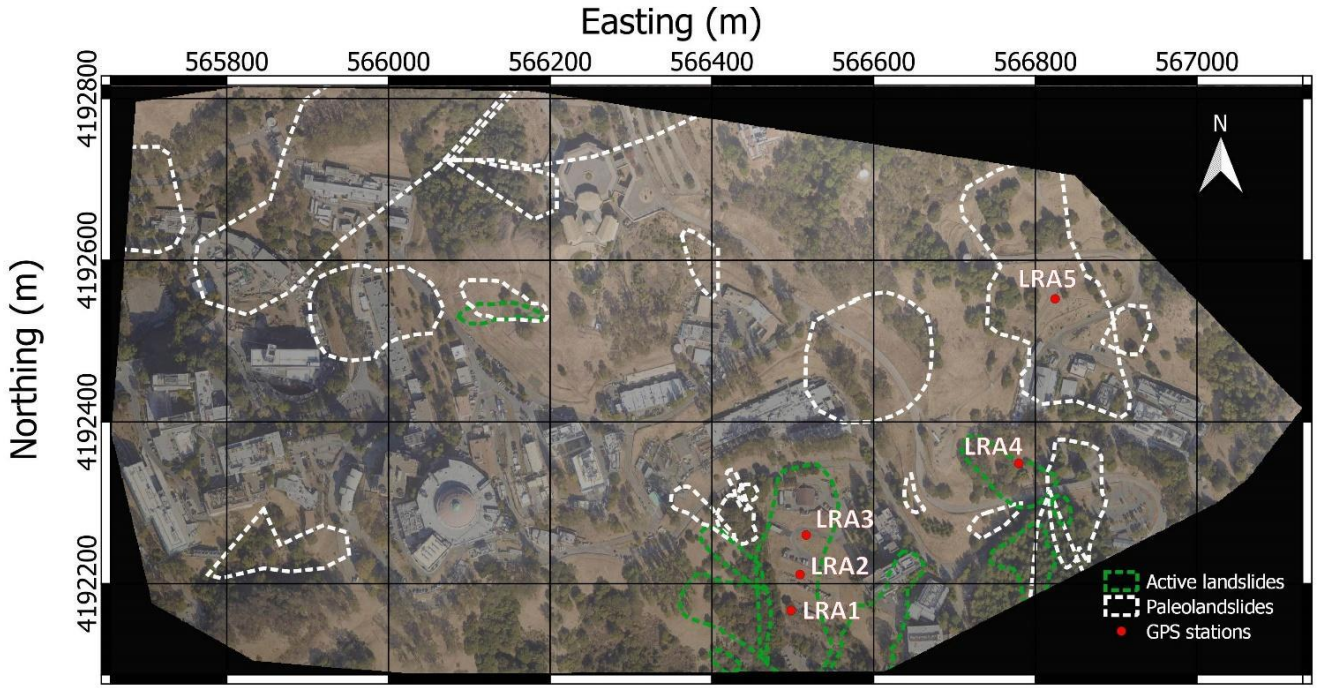


# Estimate the hazard

**Where are the high-risk areas?**

PoF from hydro-geomechanical model:

How to take into account spatial variations of critical parameters?



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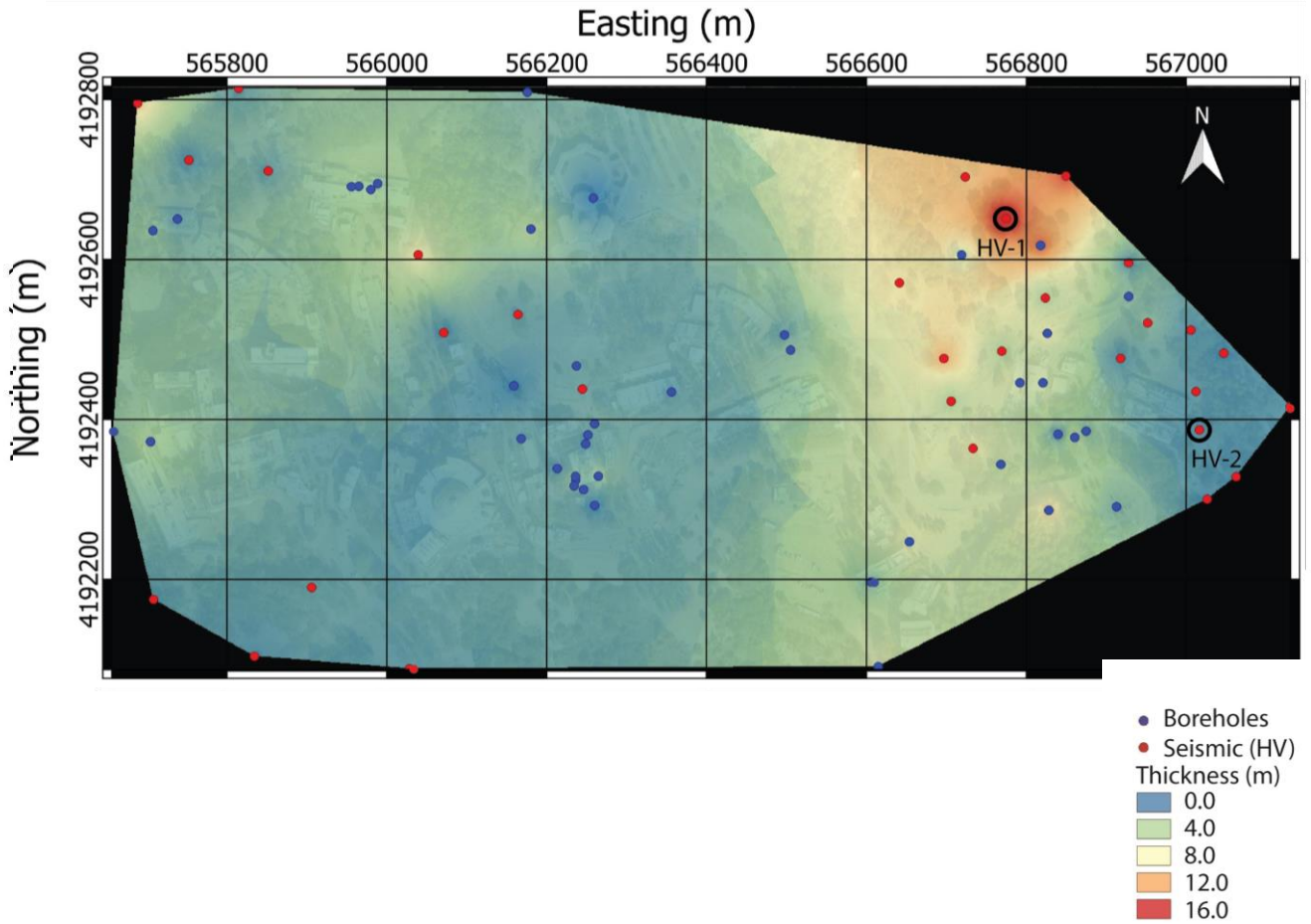
- Geotechnical campaigns (boreholes).
- Improve coverage with Passive seismic (H/V)



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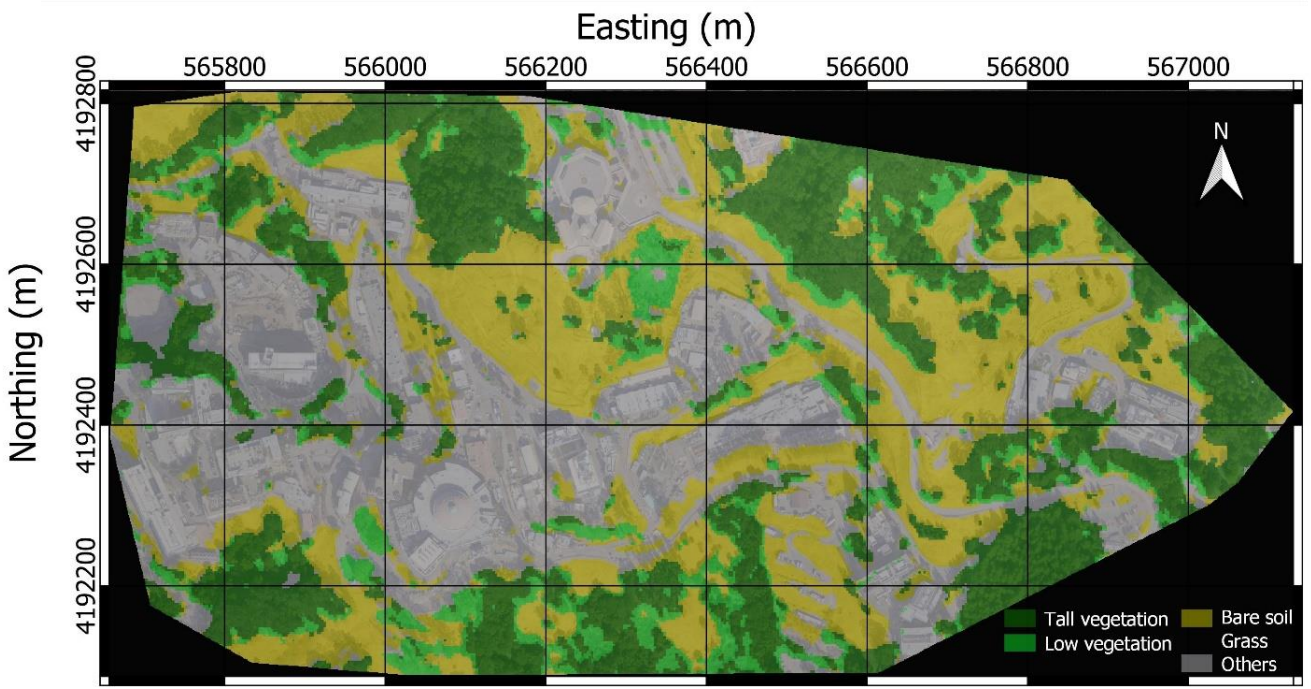
**Where are the high-risk areas?**

PoF from hydro-geomechanical model:

How to take into account spatial variations of critical parameters?

- Geotechnical campaigns (boreholes).
- Improve coverage with Passive seismic (H/V)
- Remote sensing (classification)

  => extract vegetation => root cohesion

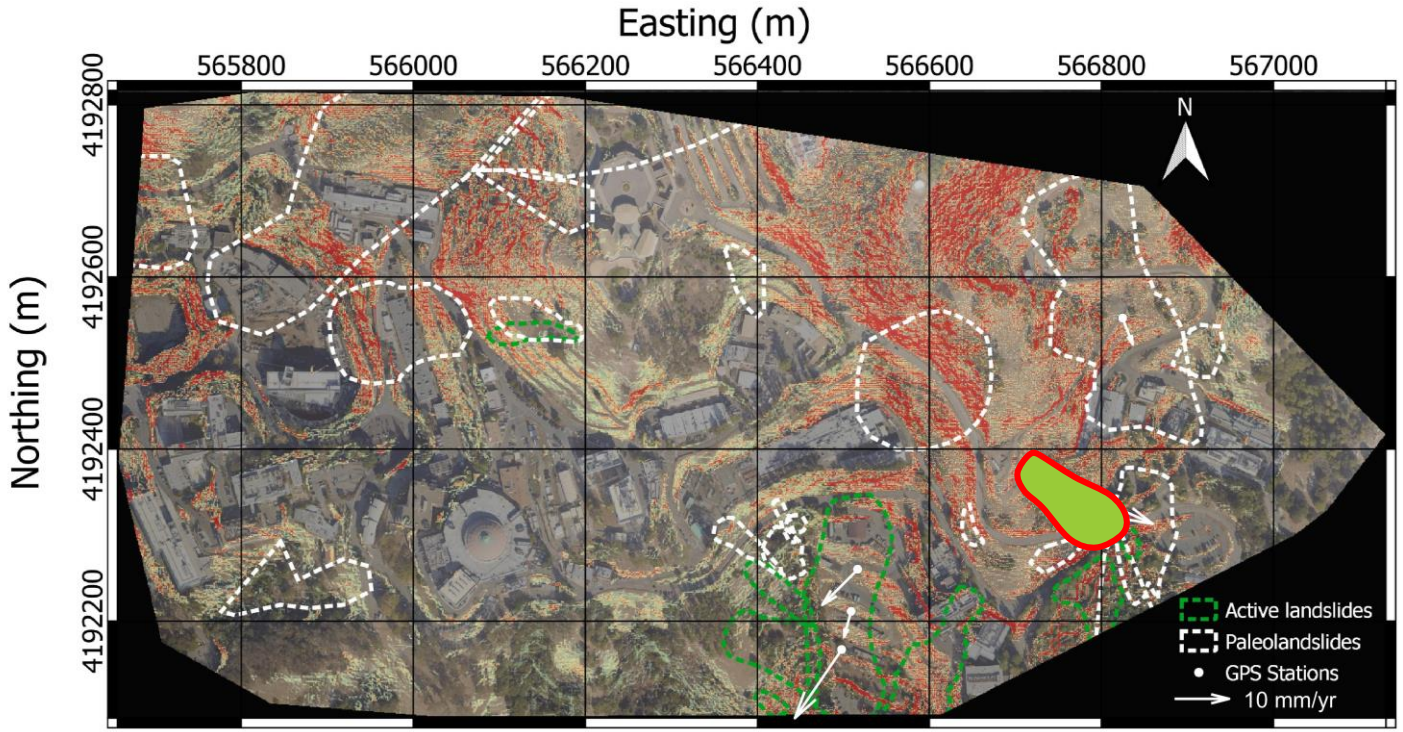


# Final Probability of failure map

- Taking into account soil thickness and vegetation lead to a more accurate estimation of PoF
  - High PoF in moving areas (GPS stations) or paleolandslides areas
  - Small to zero PoF in retrofitted areas (build)

**What are the reactivation mechanisms and their factors of control?**

- Concentration on a high risk area endangering a bridge

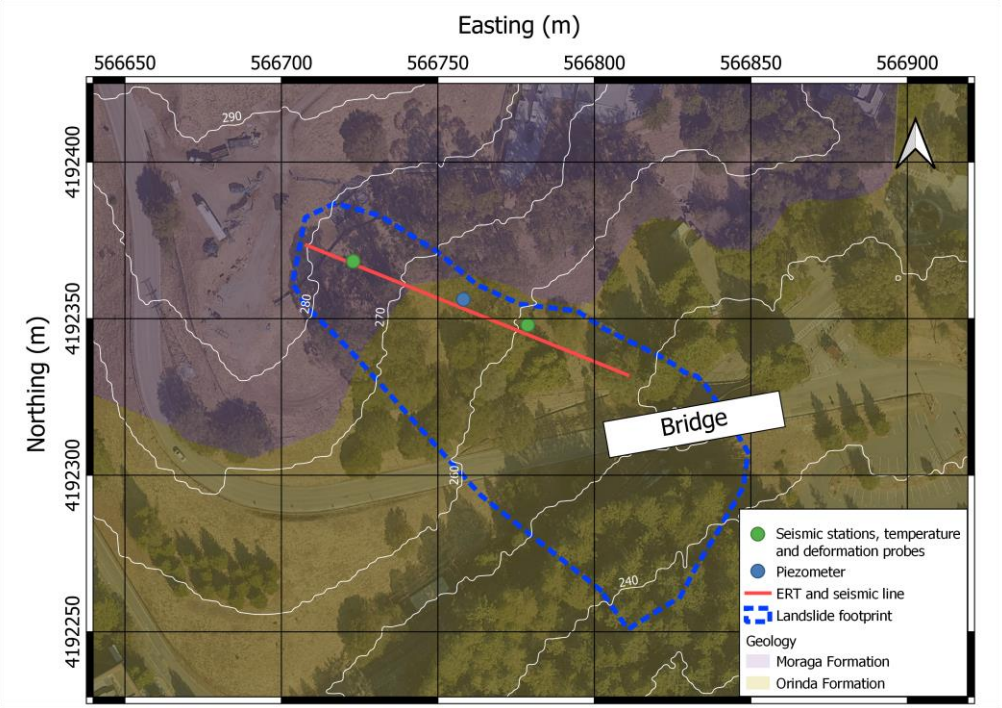


# Characterize and monitor an area at risk

Combining geophysics, geotechnics and hydrology

Characterization:

- Borehole + joint SRT/ERT: landslide structure



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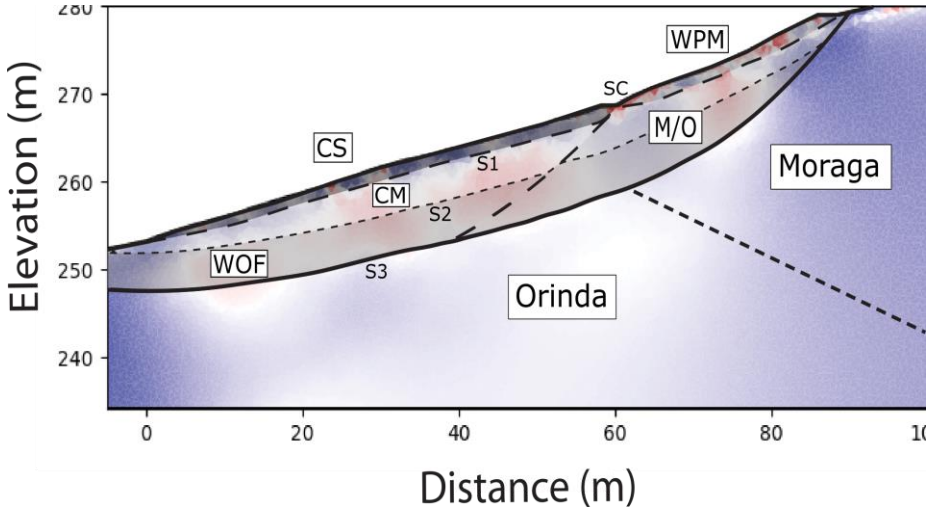

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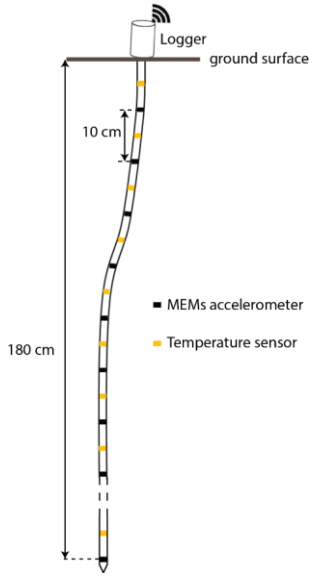
Monitoring:

- inclinometer/temperature
- Ambient seismic noise  (3C / 4.5Hz)
- meteorological station and piezometer

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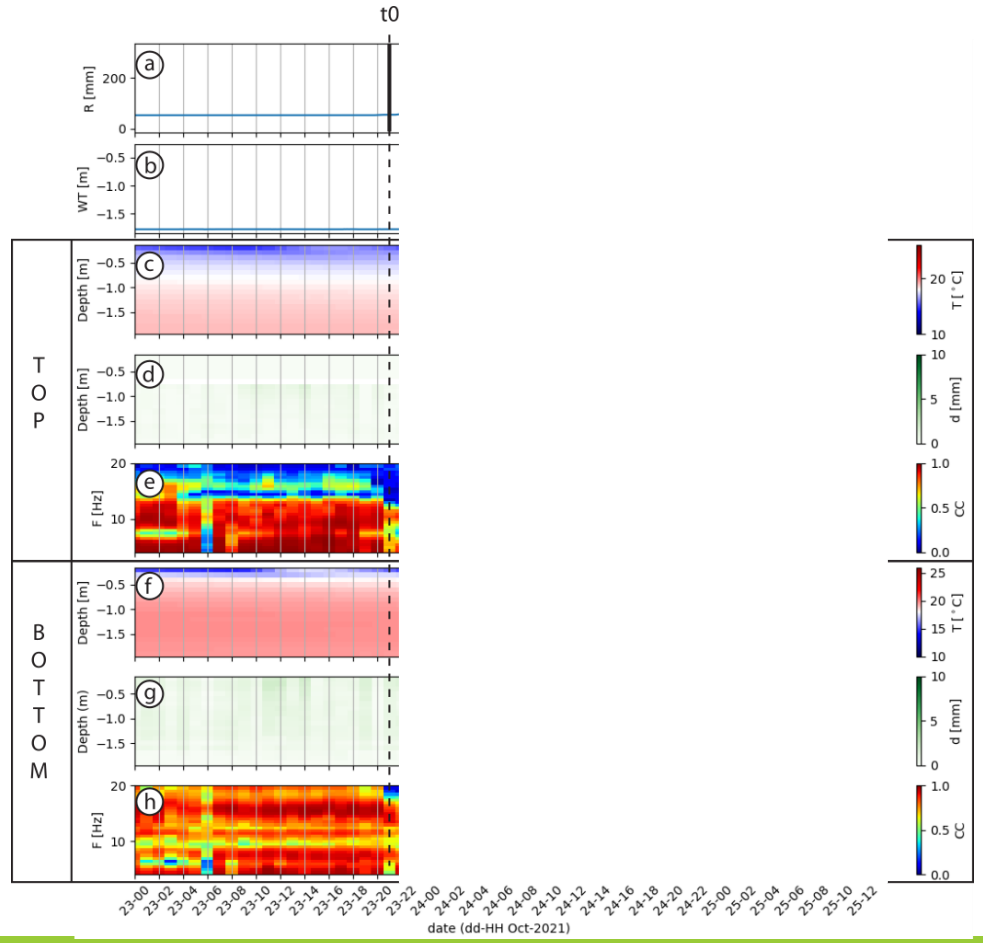
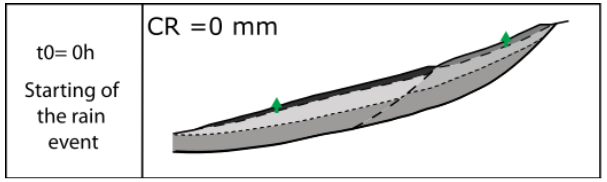
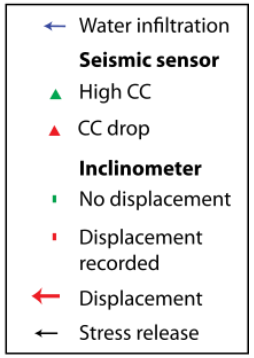
# Characterize and monitor an area at risk

Monitoring of small reactivation during rainstorm event:



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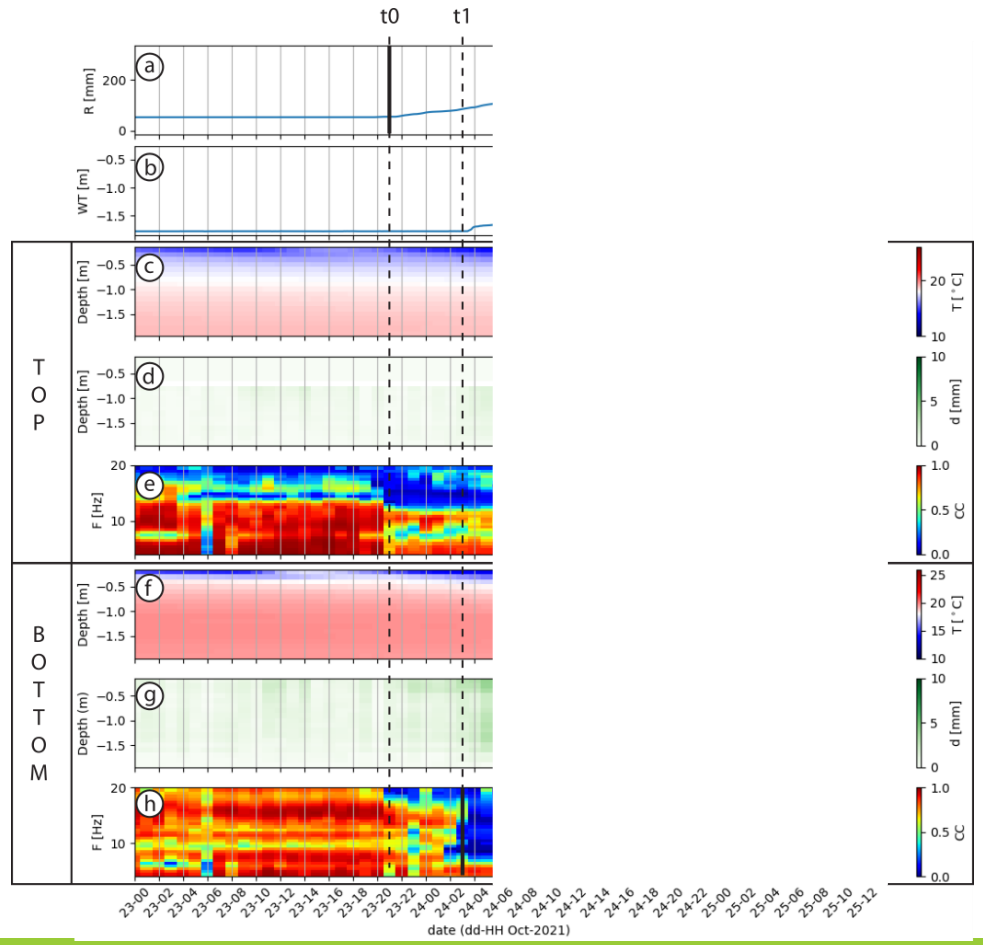


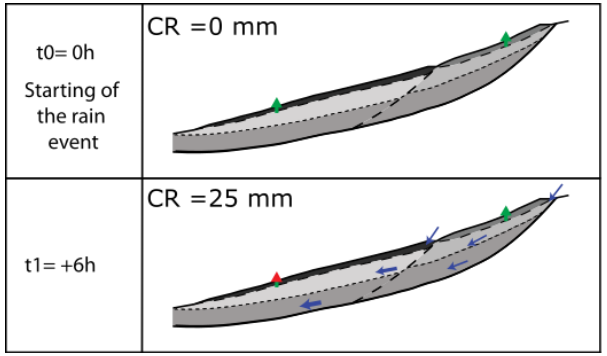


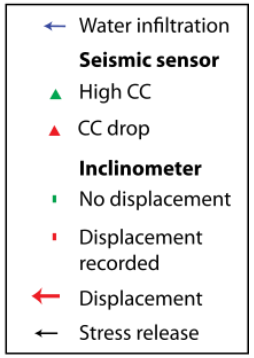

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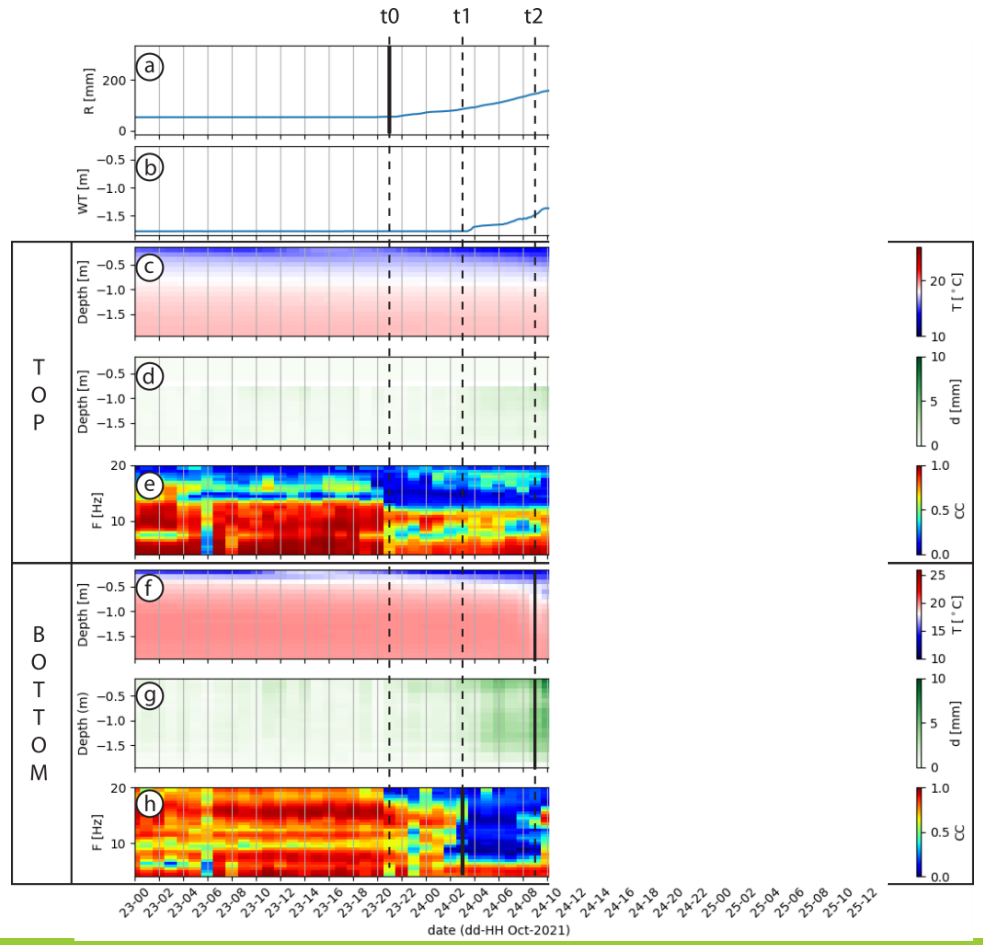


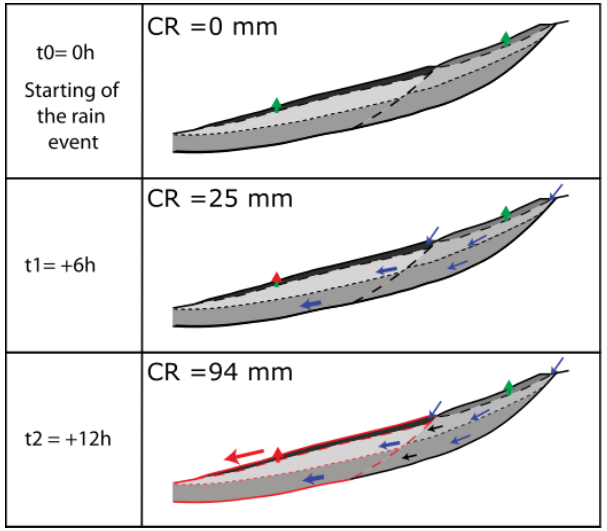


Water infiltration

**Seismic sensor**

High CC

CC drop

**Inclinometer**

No displacement

Displacement recorded

Displacement

Stress release

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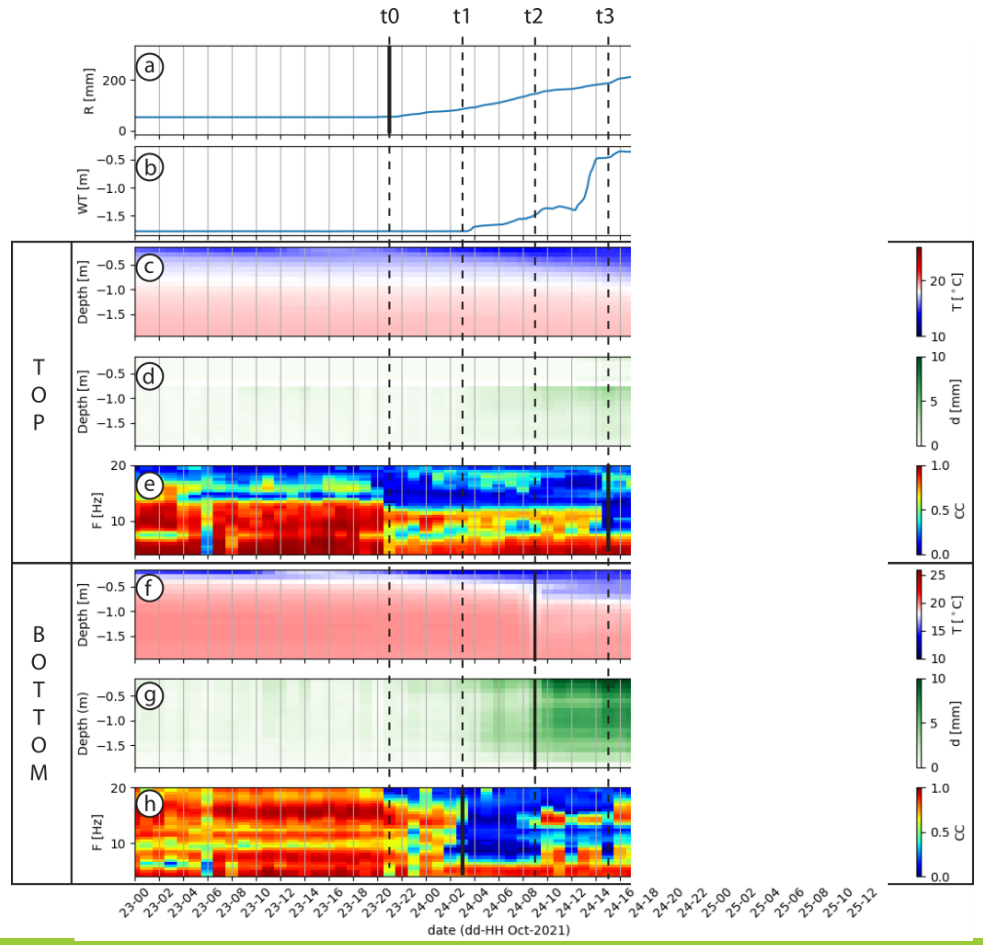


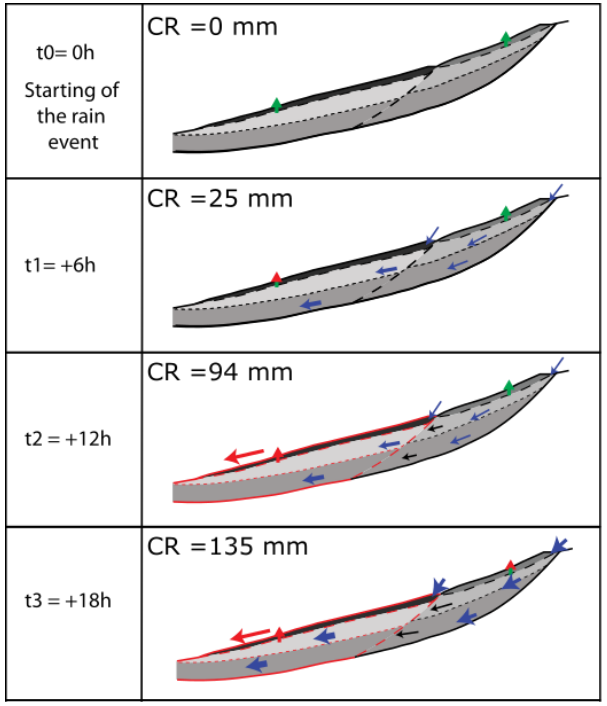


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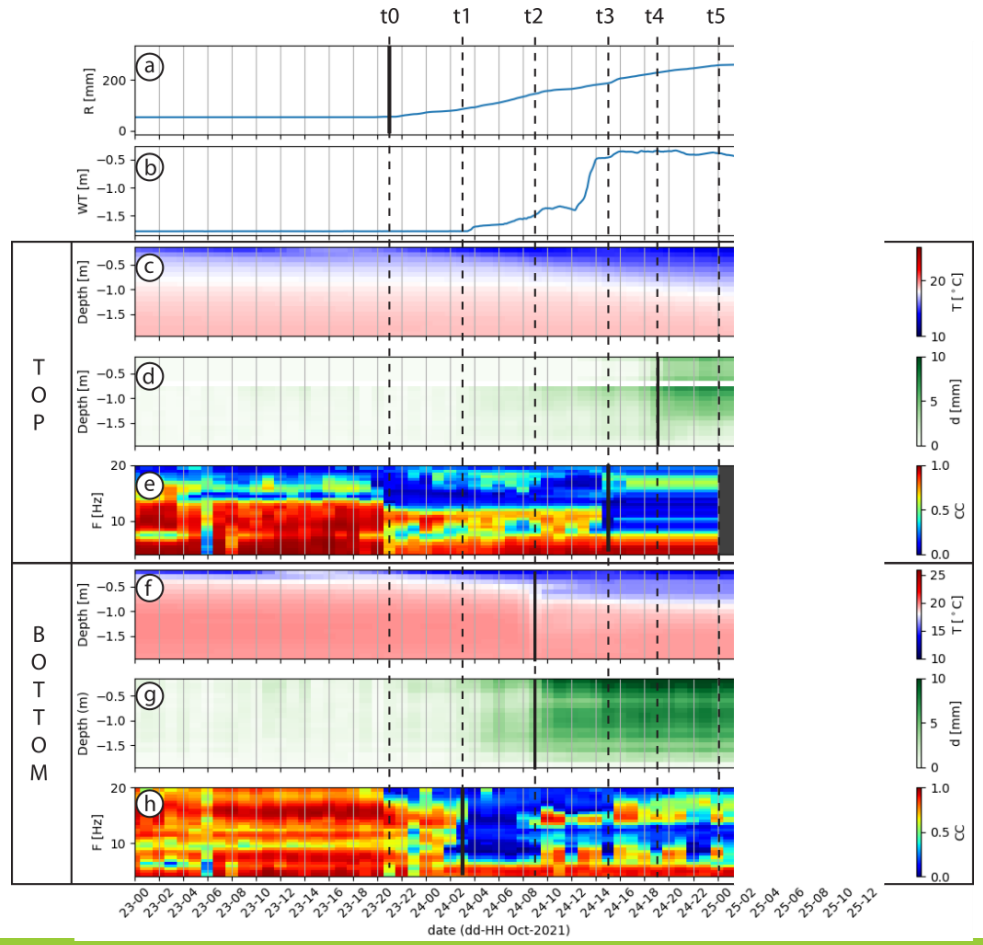


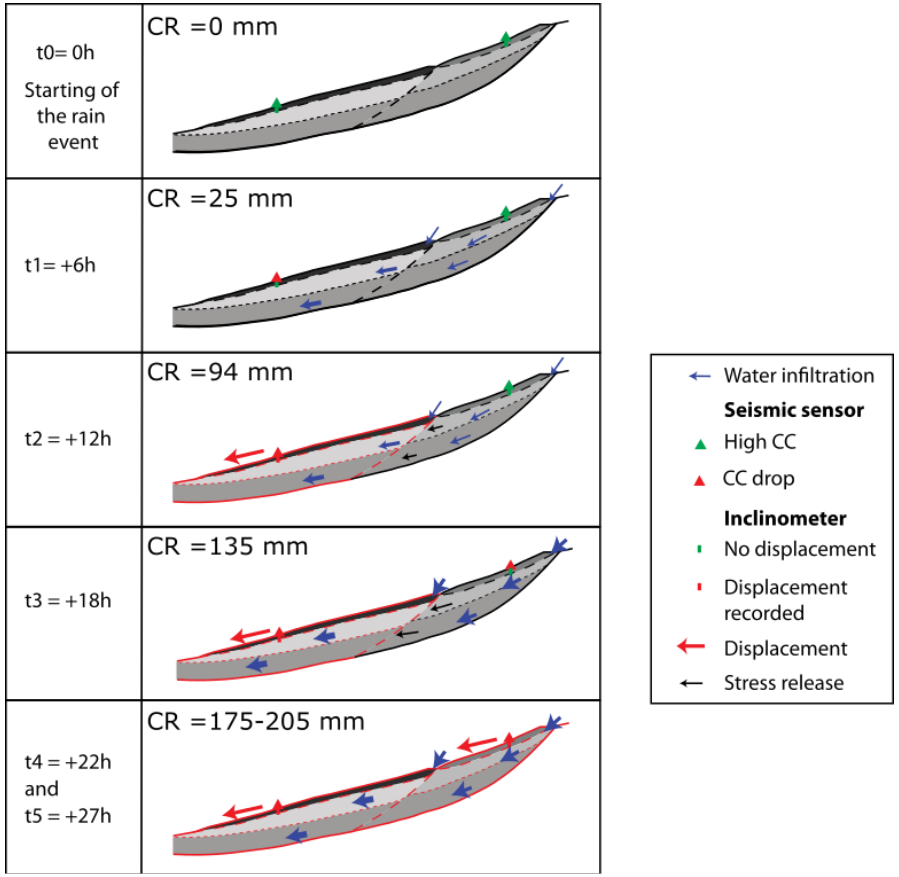

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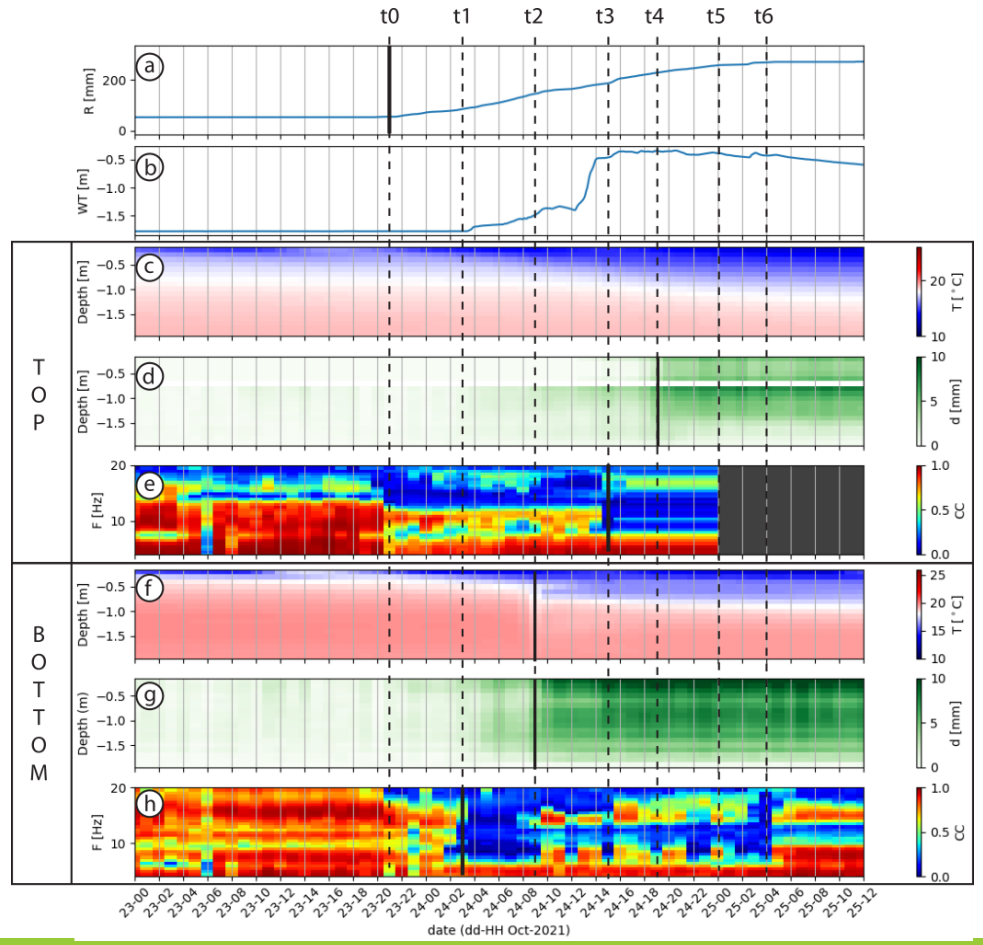


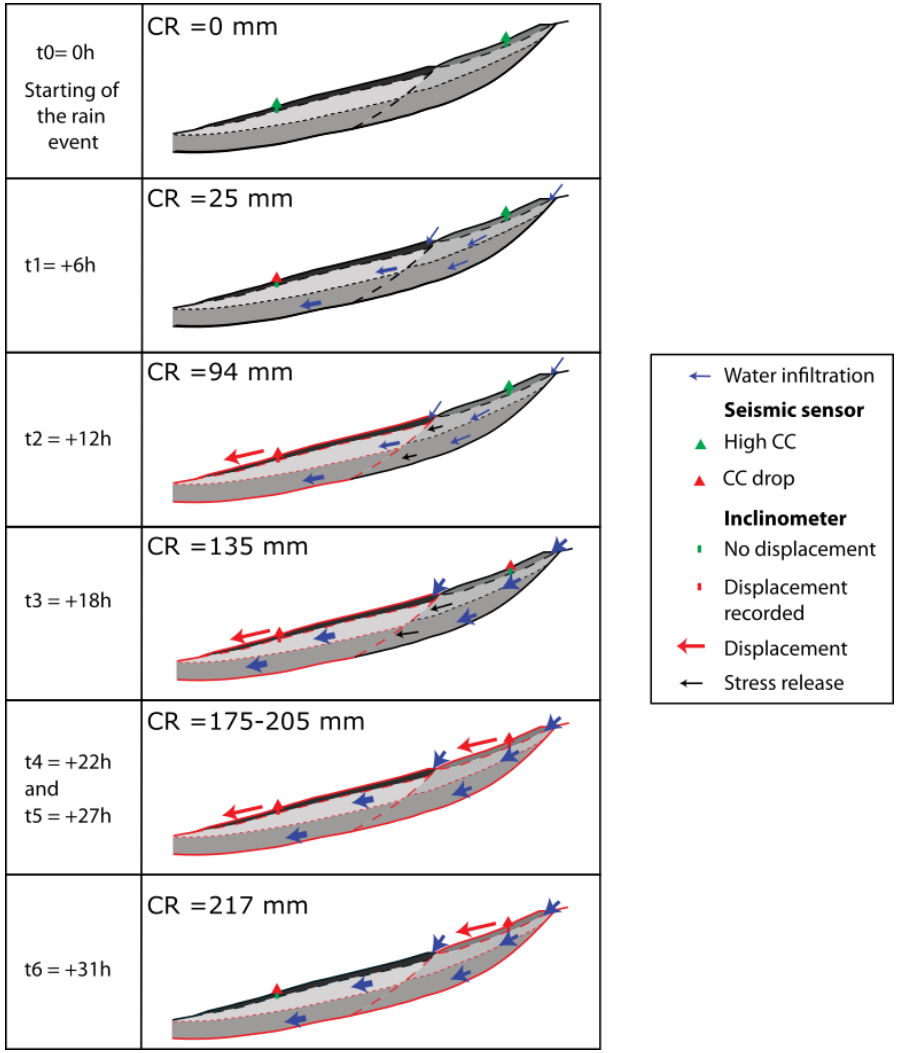

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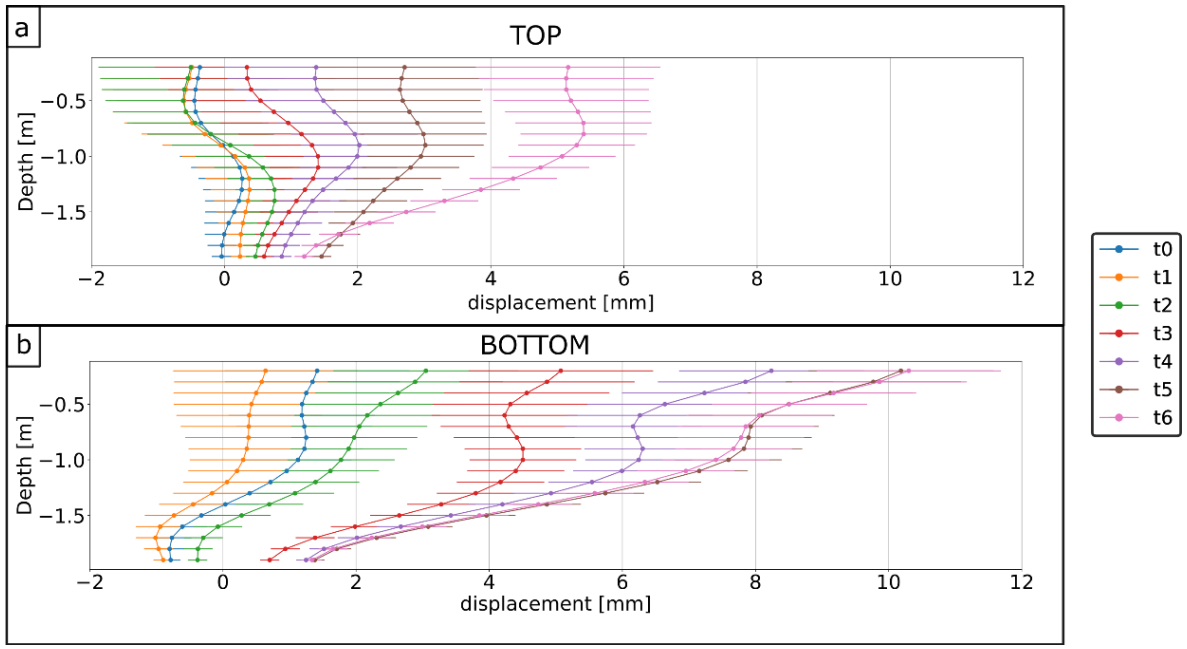
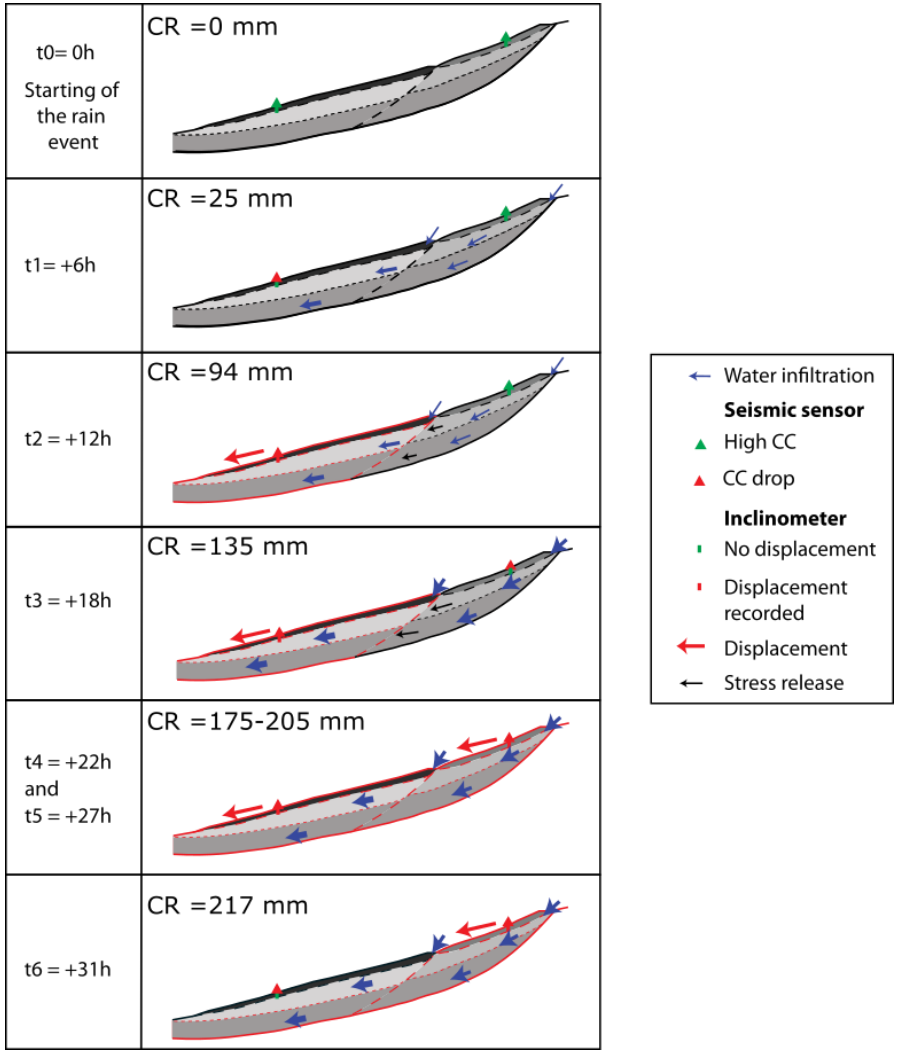
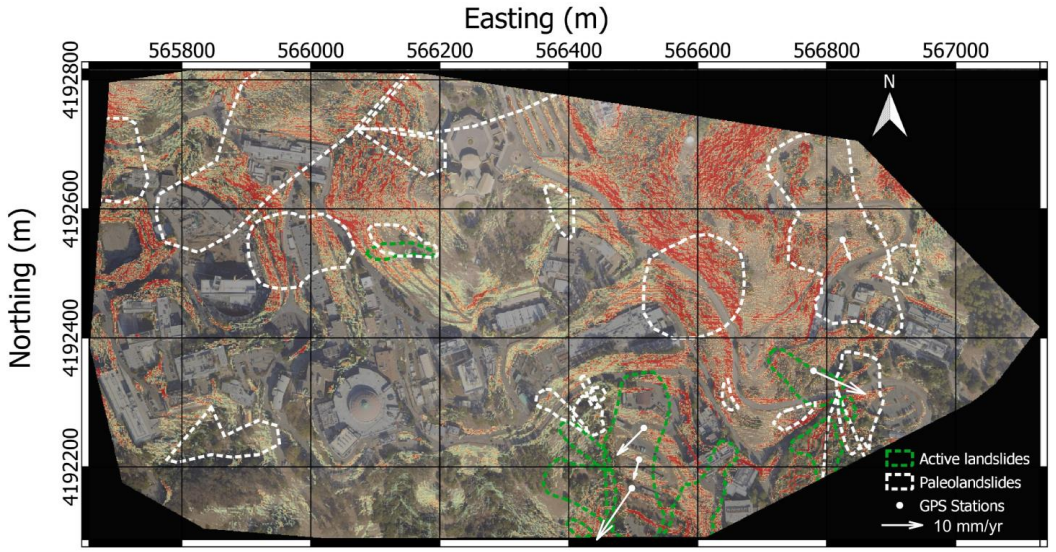


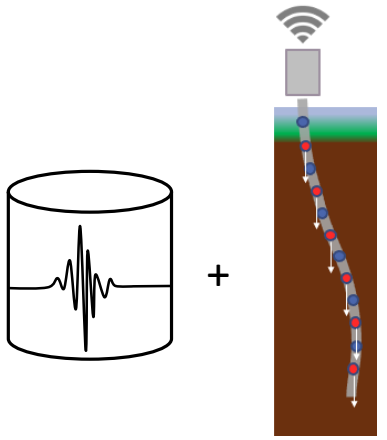



# Conclusion

- Key steps for assessing slope instabilities hazards
  - Taking into account variations of critical parameter.
  - seismic to determine the soil thickness distribution.
  - remote sensing to allow monitoring of the PoF.

- Key steps/combinations for monitoring landslide hazards
  - Seismic => precursory
  - Inclinometer / temperature => track deformation to better capture the mechanisms



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# Thank you for your attention!

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# Parameters impacting on the Probability of Failure (PoF)

Probability of failure using Monte-Carlo approach on Factor of Safety ($FS$):

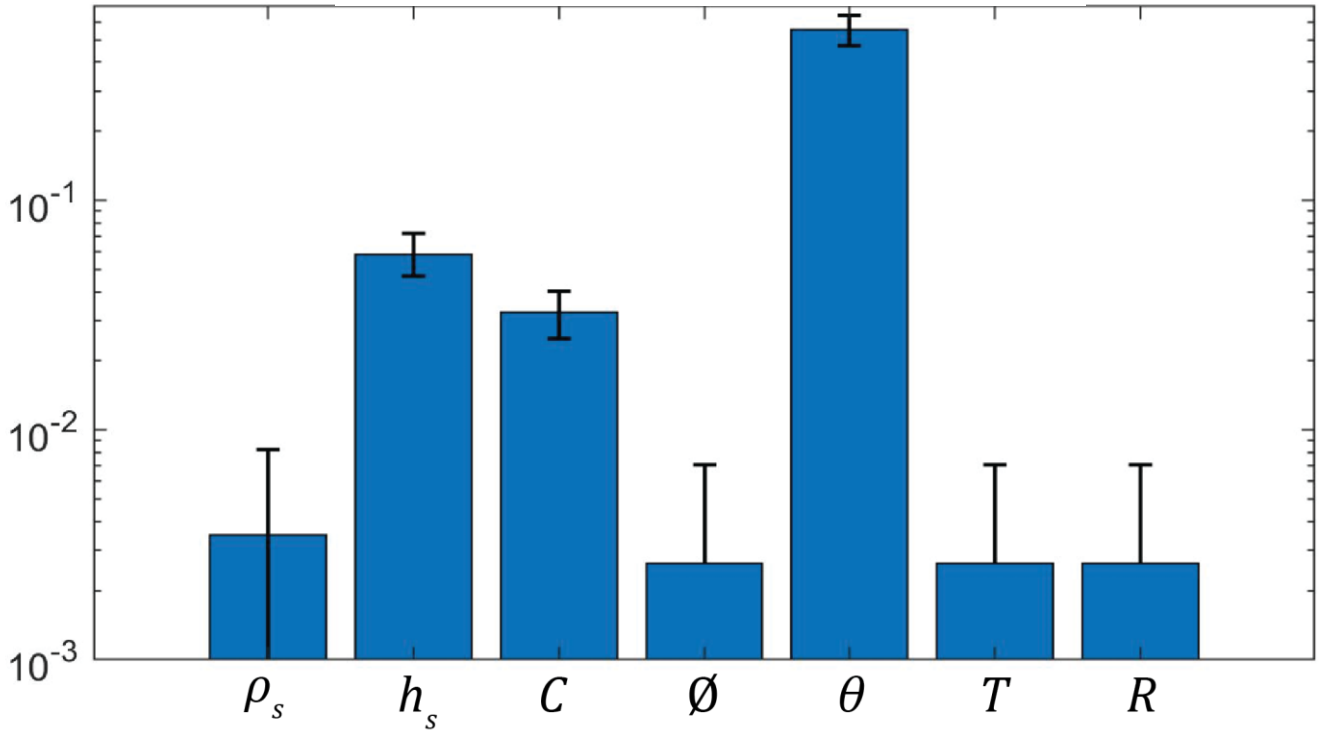
$$FS = \frac{(C_s + C_r)/h_s \rho_s g}{\sin\theta} + \frac{\cos\theta \tan\emptyset\,(1 - R_w \rho_w/\rho_s)}{\sin\theta}$$

- Soil density ($\rho_s$)
- Soil thickness ($h_s$)
- Cohesion (soil and root cohesion, $C = C_s + C_r$)
- Friction angle ($\emptyset$)
- slope angle ($\theta$)

$$R_w = \min\left(\frac{R\ a}{T\ sin\,\theta}, 1\right)$$

- Soil transmissivity ($T$)
- Water recharge ($R$)

**Sobol first order indices**
**(variance based sensitivity analysis)**




How can we easily extract relevant parameters?

# Use of remote sensing to extract vegetation cover

Classification with SVM classifier

↓

Extraction of tall vegetation

↓

Computation of the min, max and mean root cohesion (considering most represented tree species)

$$Cr = 0.48 * Tr * \mathrm{RAR}$$

with $Tr$ average tensile strength of roots and $\mathrm{RAR}$ the root area ratio

↓

$$C = C_s + C_r$$