UNIVERSITÀ DEGLI STUDI
DI SALERNO
Dipartimento di
Ingegneria Civile

CORSO DI
DOTTORATO DI RICERCA IN
Ingegneria Civile per
l'Ambiente ed il Territorio

Risk and Sustainability in Civil Engineering, Environmental and Construction

Early warning systems for rainfall-induced landslides: a multi-scale approach

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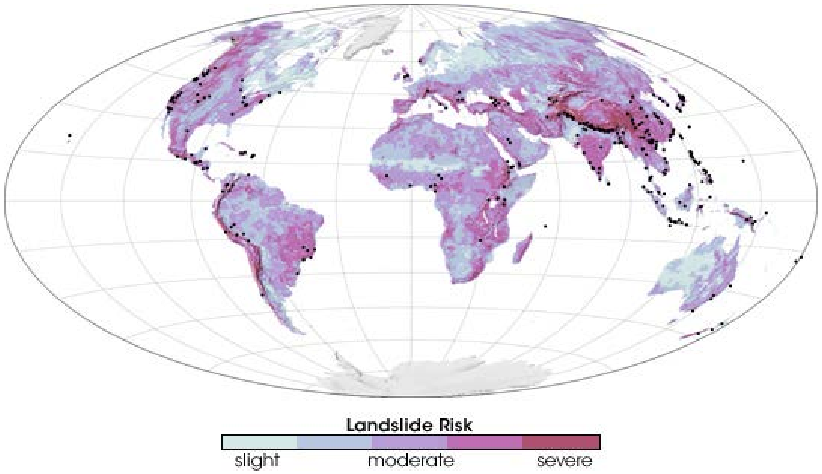
Tutor:
Prof. Michele CALVELLO

XXXI Cycle - Coordinator: Prof. Ciro FAELLA

Fisciano, 28th June 2017

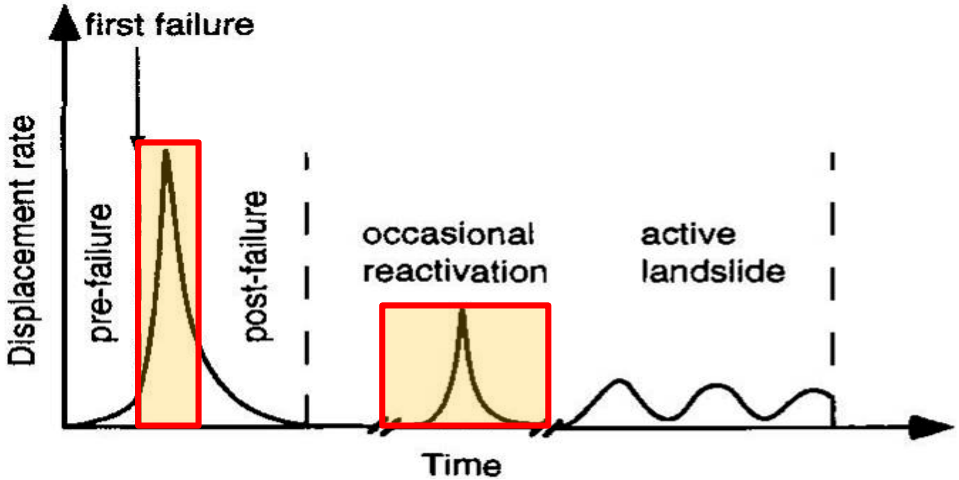
Introduction

Landslides are **natural phenomena** related to **landscape evolution** and represent one of the most important and significant **geomorphological processes.** **Slope stability** is based on the equilibrium between two types of forces, **driving forces** and **resisting forces.** When **driving forces** overcome **resisting forces,** the slope is unstable and results in mass wasting



Source: http://earthobservatory.nasa.gov/IOTD/view.php?id=7783

Leroueil et al. (1996)



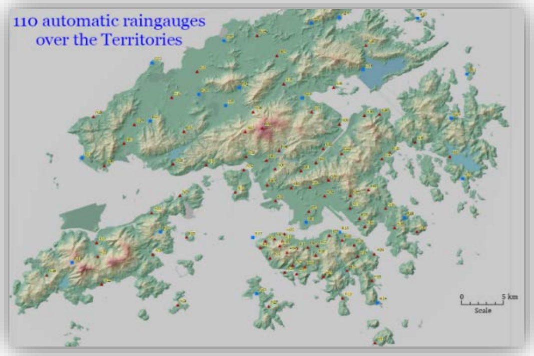
Triggering Factors – Schuster et al. (2002)

- ❑ Human activities
- ❑ Vibrations caused by earthquakes
- ❑ Erosion
- ❑ Volcanic eruptions
- ❑ Failure of natural dams
- ❑ Change in surface levels of water bodies
- ❑ Rainfall

Landslide Early Warning Systems

- Large regions **(REGIONAL scale)**

HONG KONG

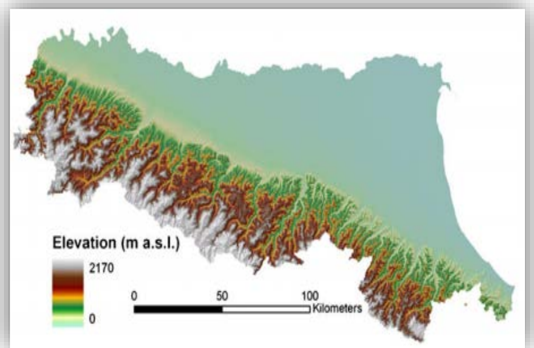


Cheung (LARAM 2013)

BRAZIL – Rio de Janeiro

Source: Geo-RIO

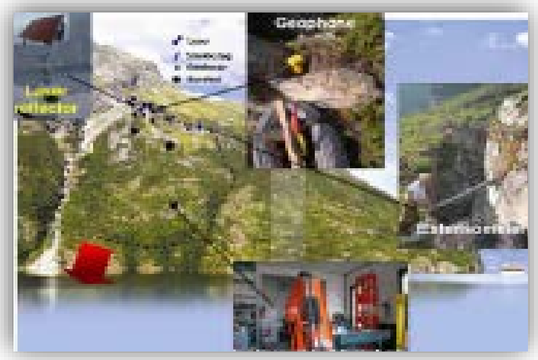
ITALY – Emilia-Romagna



Martelloni et al. (2012)

- Single slopes **(LOCAL scale)**

NORWAY – Åknes rockslide

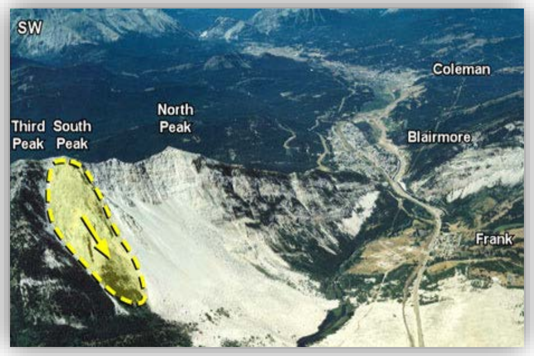


Blikra (2008)

Central ITALY

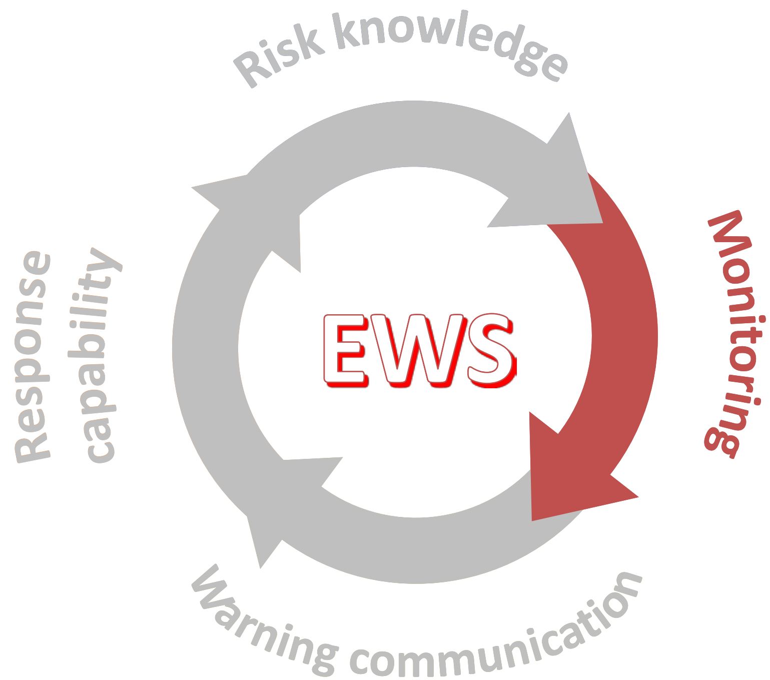
Intrieri et al. (2012)

CANADA – Turtle Mountain



Moreno and Froese (2009)

Open issues at regional and local scale



Modified by UNISDR, 2006

1. *How to improve **landslide data collection, storage and distribution?***

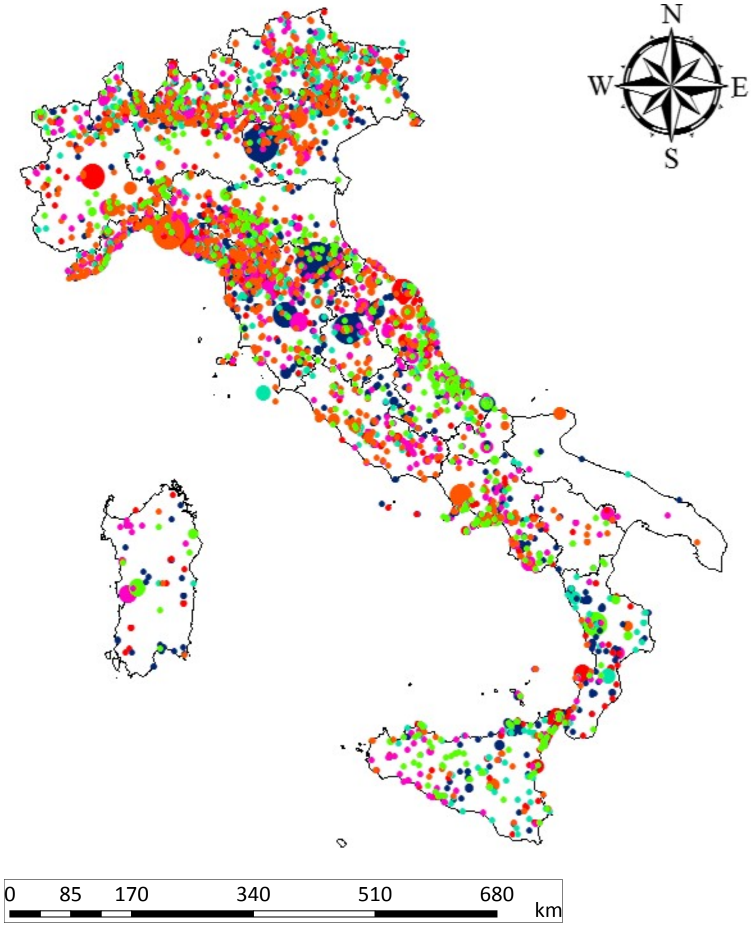
2. *What are **the most relevant variables** to forecast the activity of different landslide types?*

3. *How to best incorporate **remote sensing data** into current land-based monitoring networks?*

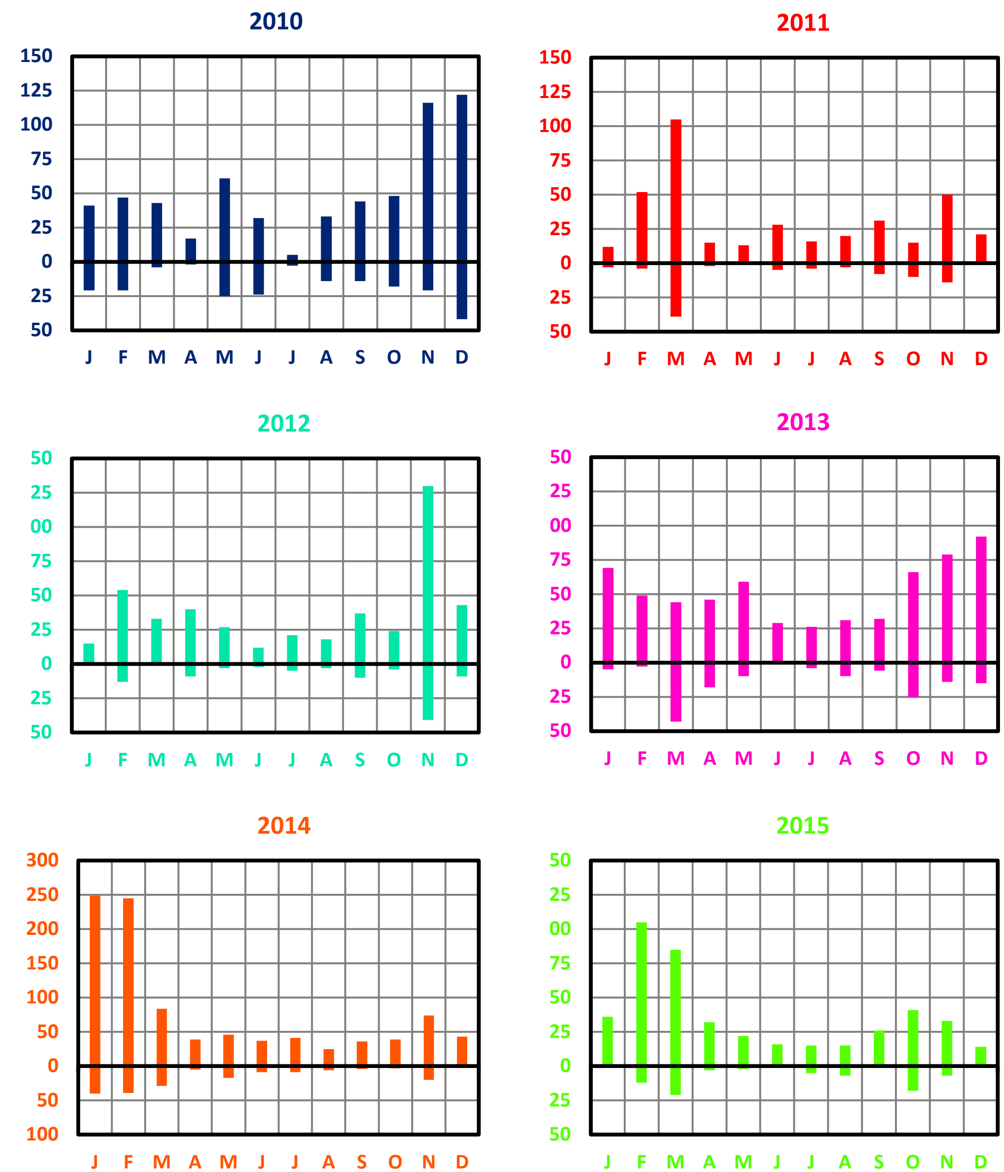
4. *How does the accuracy of **regional and local landslide models** change according to lead-time and spatial scale?*

5. *How can monitoring data coming from **local LEWSs** be profitably used within warning models at **regional scale** and **vice versa?***

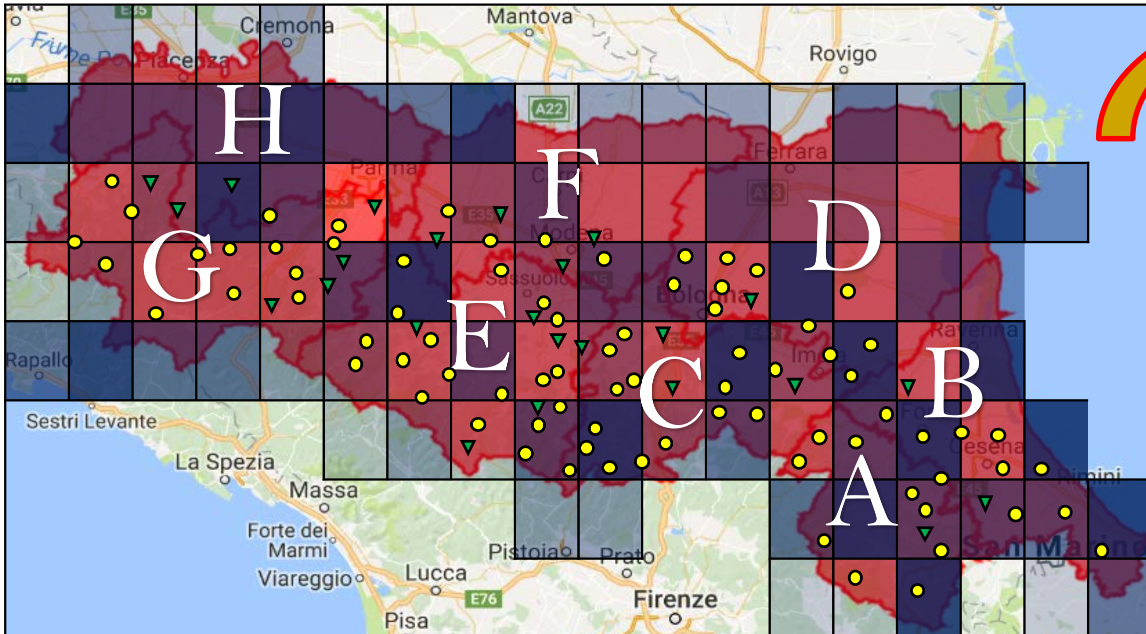
The "*FraneItalia*" database



TOTAL EVENTS	C1	C2	C3
Single Landslide Events	65	445	2955
Areal Landslide Events	14	163	638



Case study at regional scale: *"Emilia-Romagna"*



EMILIA-ROMAGNA region

Legend:

Single landslides   Areal landslides   Rainfall [mm]   0   0 - 1   1 - 2   2 - 3   > 3

- GPM rainfall dataset managed using Google Earth Engine *(Huffman et al., 2017)*
- Rainfall-induced landslides from FraneItalia database
- Spatial discretization: 8 weather alert zones defined by Regional Law 1427/2005
- Period of analysis: March 2014 – December 2015

Pecoraro and Calvello
Poster EGU (2017)

Correlation between landslides and rainfall

(March 2014 – December 2015)

- **1029 rainfall events**

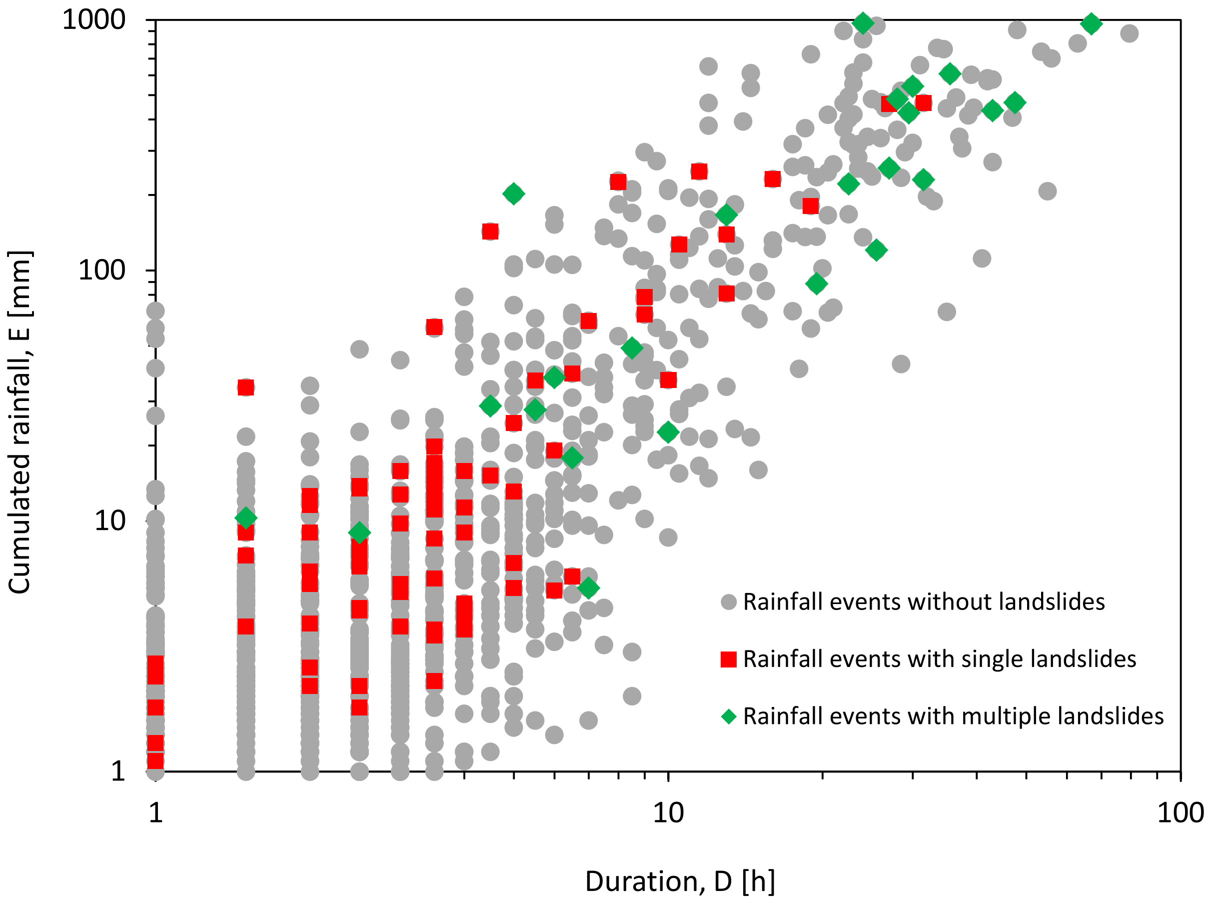
  (a set of hourly rainfall in a row exceeding a pre-defined threshold: 1 mm/hour)

- **78 single landslide events**

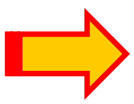
  (one landslide)

- **24 areal landslide events**

  (more than one landslide)



There is no clear difference between critical and non-critical rainfall



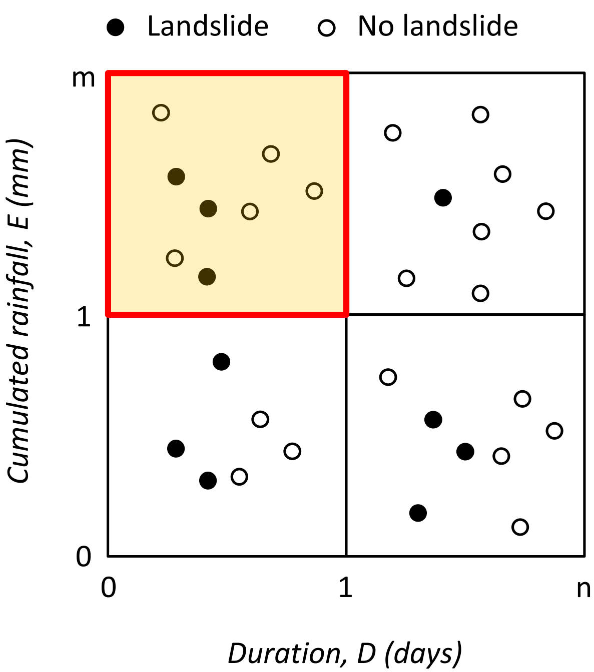
It is not possible to draw any line of distinction between triggering and non-triggering rainfall

Two-dimensional Bayesian probability

Posterior landslide probability

$$P(A \mid E, D) = \frac{P(E, D \mid A) \cdot P(A)}{P(E \mid D)}$$

(Modified from Berti et al., 2012)



In the upper-left cell:

P(A) = prior landslide probability ⇒ $\frac{10}{30} = 0.33$

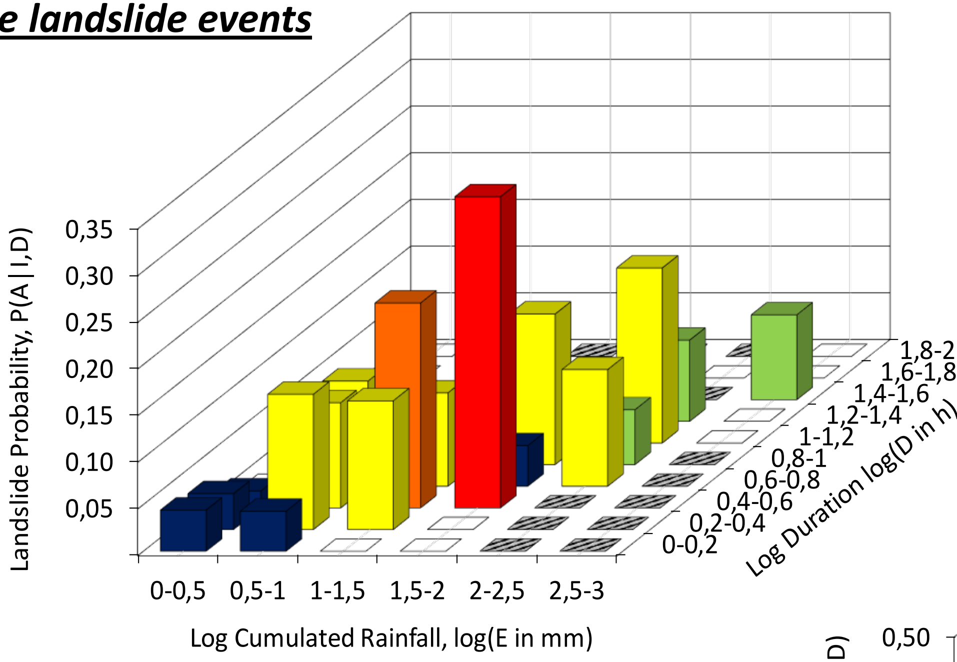
P(E,D|A) = probability of having a cumulated rainfall E with duration D, given the occurrence of a certain number of landslides ⇒ $\frac{3}{10} = 0.33$

P(E|D) = probability of observing a cumulated rainfall E, given the duration D ⇒ $\frac{8}{30} = 0.27$

P(A|E,D) = posterior landslide probability ⇒ $\frac{0.33 \times 0.33}{0.27} = 0.40$

Two-dimensional Bayesian probability

Single landslide events

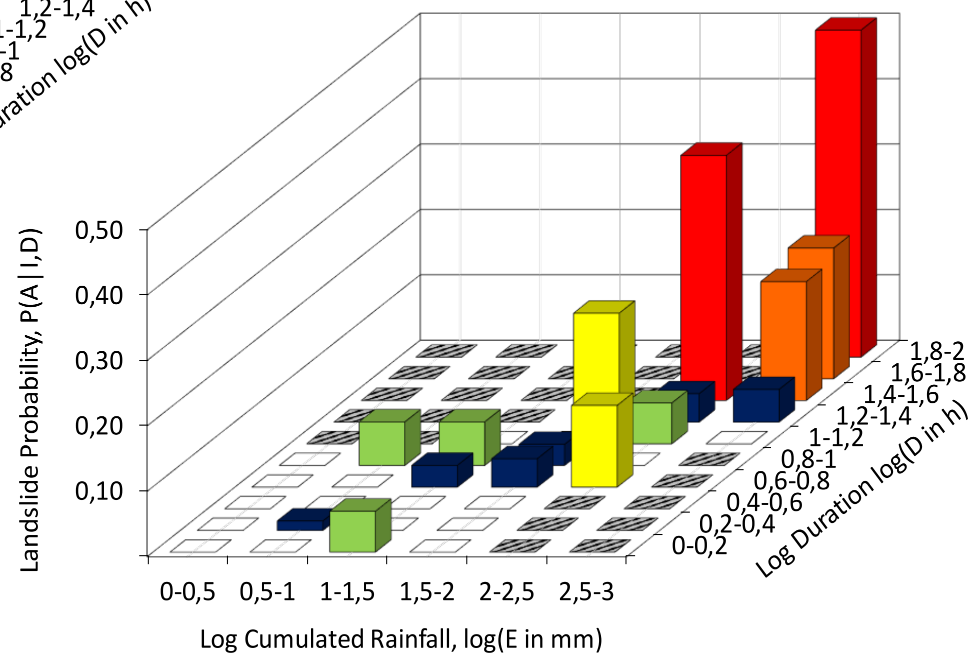


Before Bayesian analysis:

P(A) = prior landslide probability

- Single events: 0.076
- Areal events: 0.023

Areal landslide events



Two-dimensional Bayesian analysis *clearly showed the* ***critical levels of rainfall*** *beyond which we observe a* ***radical change of state of the system,*** *in order to define the* ***rainfall thresholds***

No data | No landslides | 0 – 0.05 | 0.05 - 0.1 | 0.1 - 0.2 | 0.2 - 0.3 | > 0.3

Research working plan at NGI (Oslo, NORWAY)

NGI KLIMA2050

RISK REDUCTION THROUGH CLIMATE ADAPTION
OF BUILDINGS AND INFRASTRUCTURES

Supervisor: Dr. José Mauricio Cepeda

WORK PACKAGE 3 – **Landslides triggered by hydro-meteorological processes**

RESEARCH TASK WP3.4 – **Early warning systems (EWS)**

Scheduled activities:

→ Calibration and validation of warning models at through back-analysis of early-warning scenarios in Norway using different spatial and time scales and input datasets

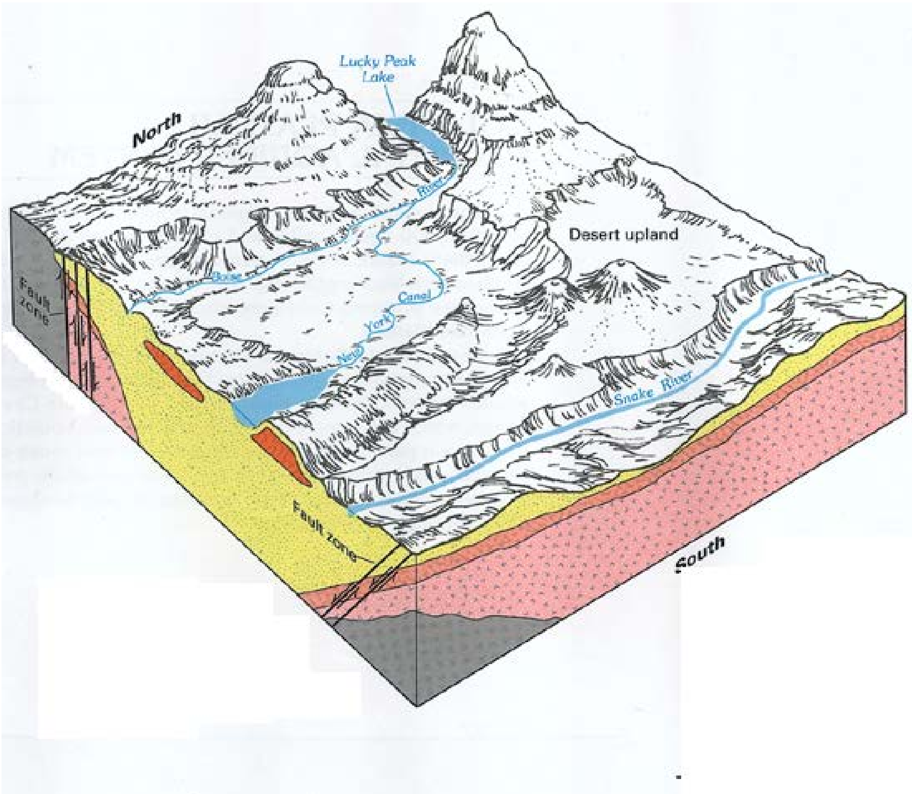
Working phases:

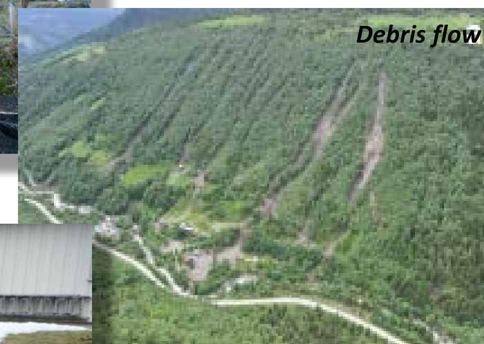
→ Data collection

→ Definition of a methodology

→ Results and Analyses

Landslides in soils in Norway





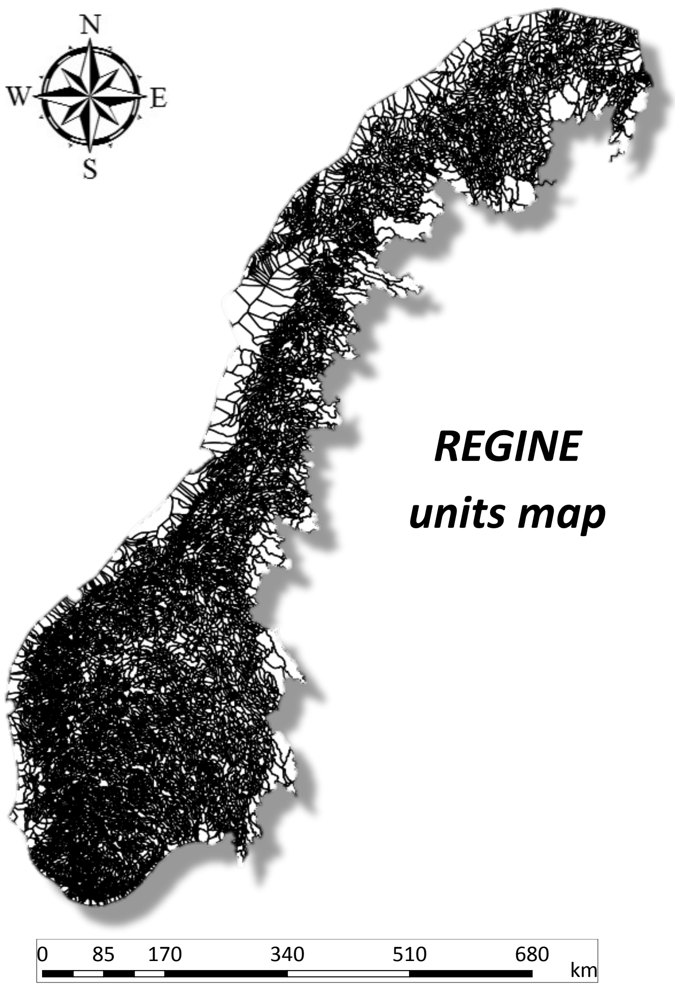
- Many ***shallow soil slides, debris slides/avalanches*** and ***debris flows*** in recent years (e.g. 2000, 2005, 2008, 2011, 2012, 2013, 2014)
- Triggered by rain, rapid snowmelt or a combination
- Steep slopes where loose deposits (tills deposit, alluvial and colluvial deposits, marine clay, weathered rocks) are in contact with bedrock materials

Devoli (2014)

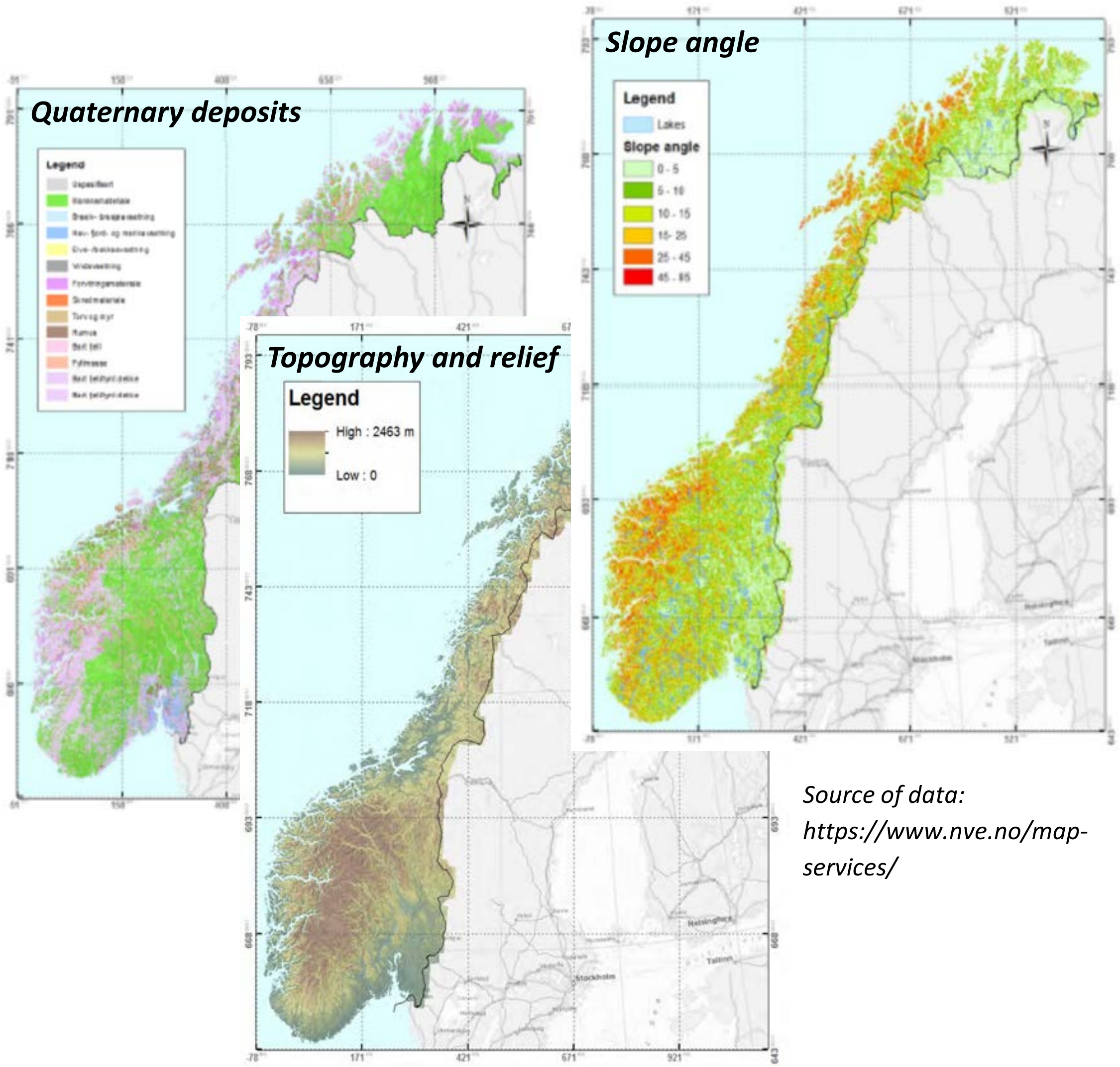
Datasets for analyses- 1

Scale of analysis:

CATCHMENT SCALE



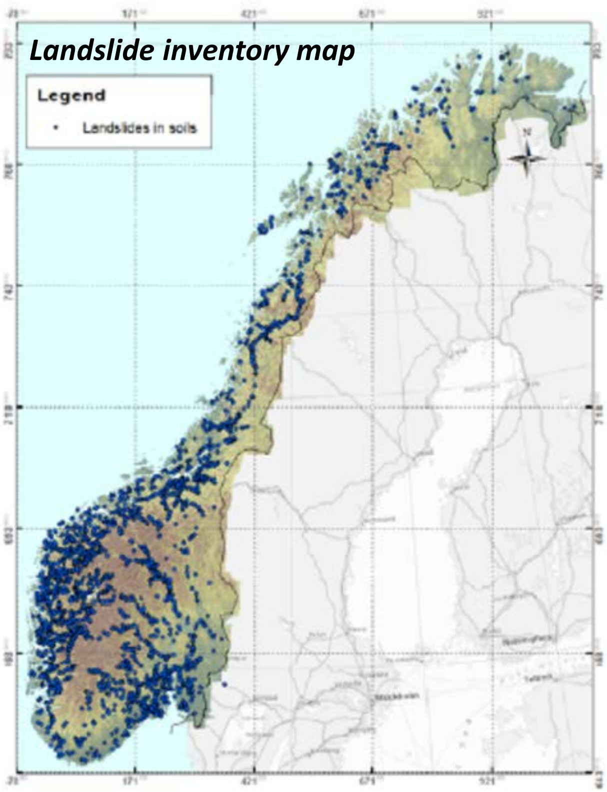
THEMATIC MAPS



Source of data: https://www.nve.no/map-services/

Datasets for analyses - 2

LANDSLIDE INVENTORY

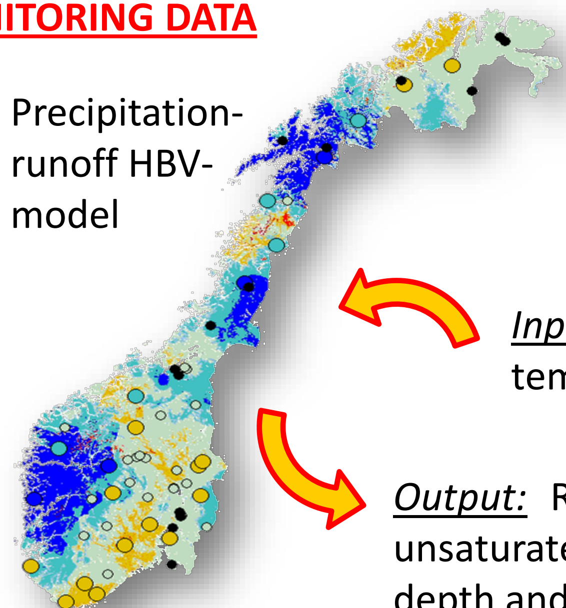


- > 60,000 landslide events
- Time period: 1100 - 2017
- Developed by: NGI, NVE, NGU, SVV, and regional observations

MONITORING DATA

Gridded data

Precipitation-runoff HBV-model



GRIDDED DATA from xgeo:

- 1x1 km^2 grid
- 330,000 cells
- 9-days prognosis

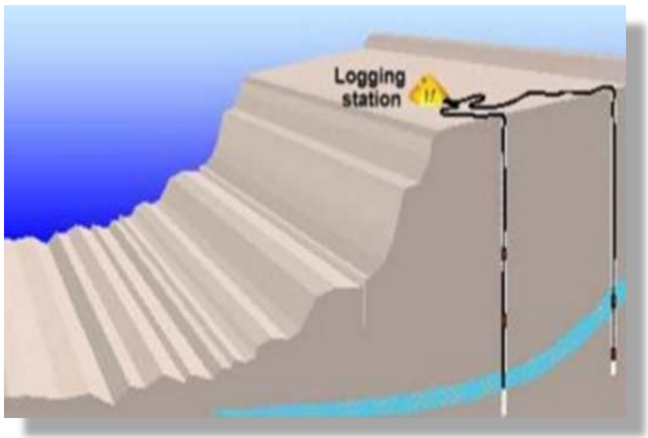
Input: Daily values of air temperature and precipitation

Output: Runoff, groundwater volume, unsaturated storage capacity, soil frost depth and snow depth

Local data

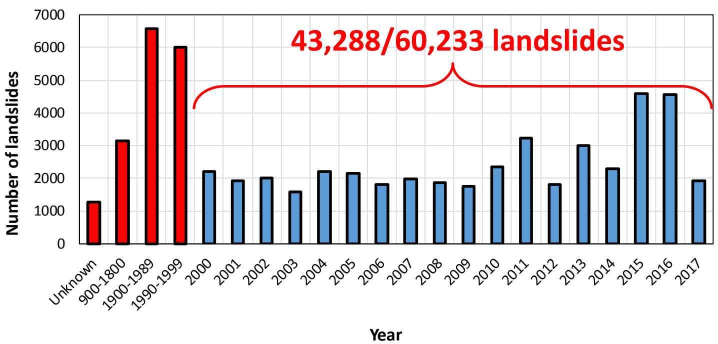
NGI

Pore water pressure measurements from NGI projects in Norway



Methodology: Data selection

SELECTION CRITERIA



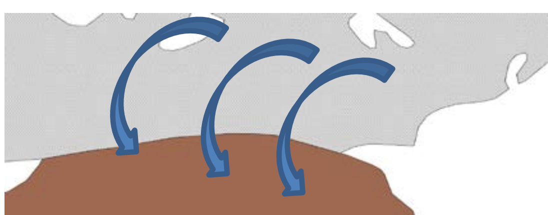
WEATHER-INDUCED LANDSLIDES

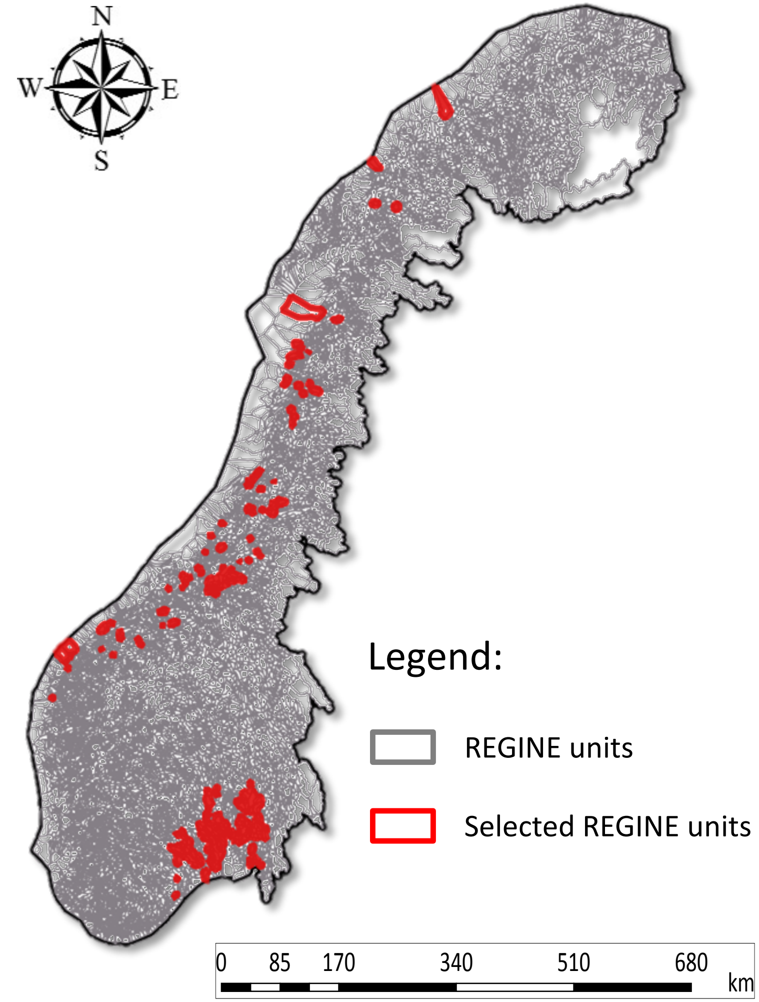
- Debris flows
- Debris slides
- Shallow slides
- ...

CONTACT BEDROCK-SOIL

Bedrock

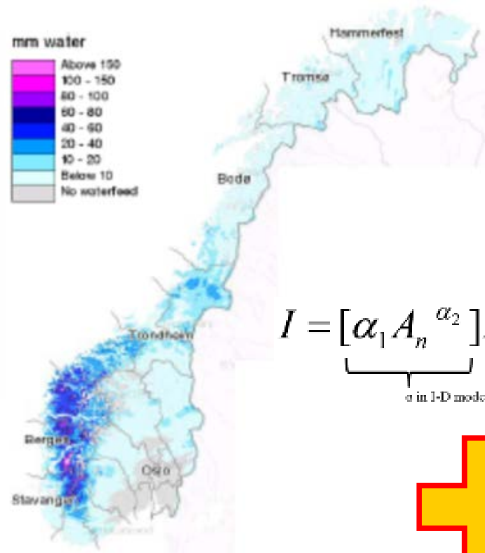
Loose soil





> 200 catchments *affected by weather-induced landslides in loose soils in direct contact with bedrock in Norway*

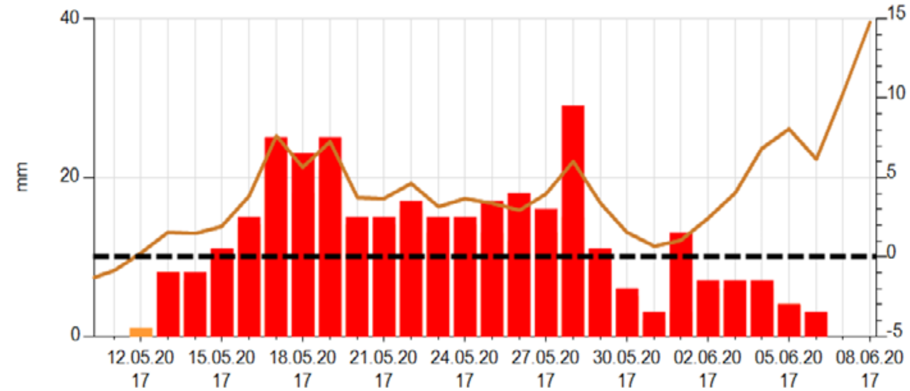
Methodology: Correlation between gridded and local data



Source: http://www.xgeo.no/

$$I = [\alpha_1 A_n^{\alpha_2}] D^{\beta}$$

α in 1-D model



Critical pore water pressure:

$$u_{w,c} = z \times \gamma_t \times \left(1 - \frac{tan\theta}{tan\varphi}\right)$$

Modified from Keller et al. (1987)

Simplified hyphoteses:

- Cohesionless material (c=0)
- Slip surface parallel to ground surface
- Piezometric surface parallel to ground surface

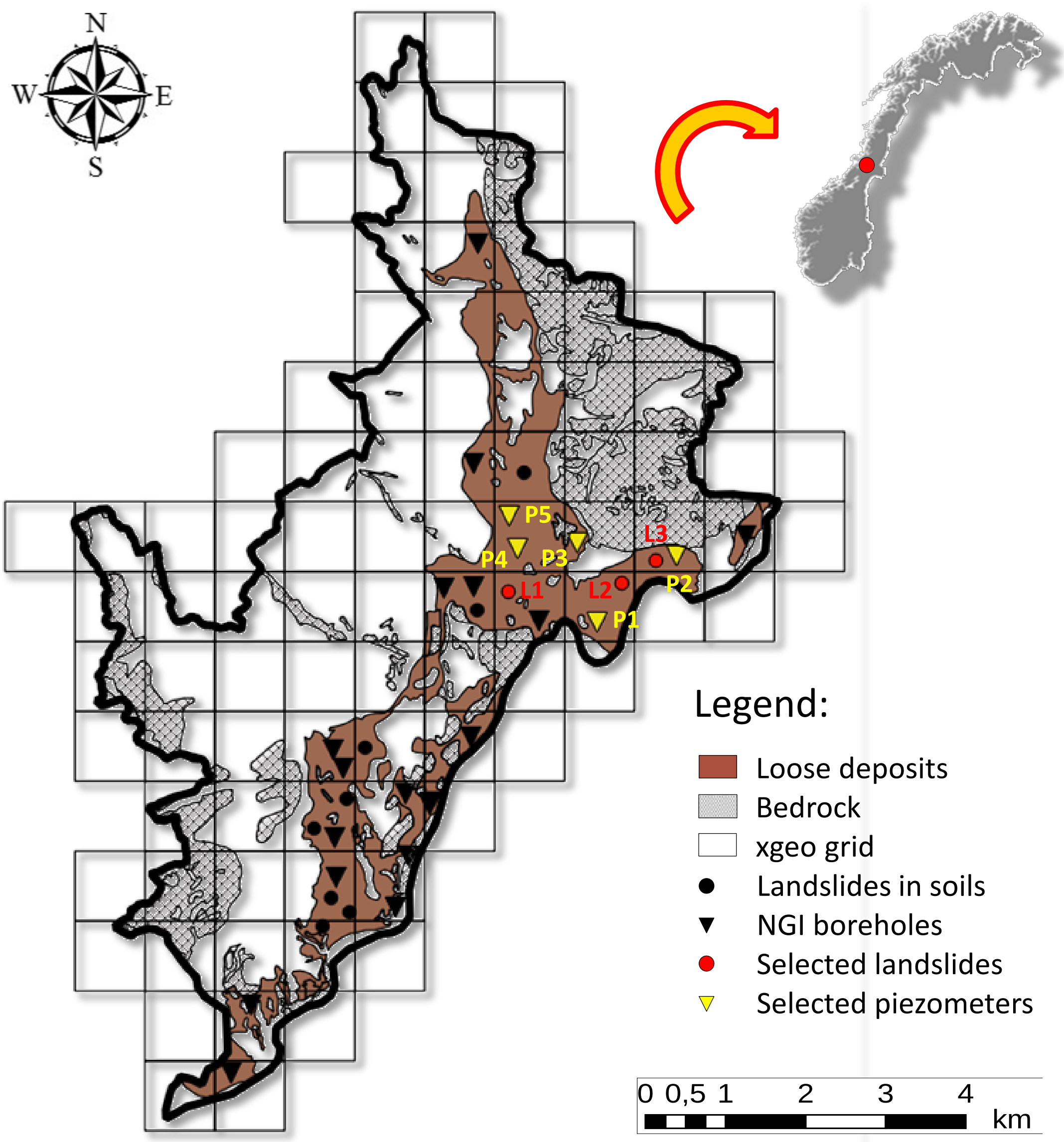
MULTIPARAMETRIC EW THRESHOLDS based on gridded data and pore water pressure data

1st case study: the *"Namsen basin"*

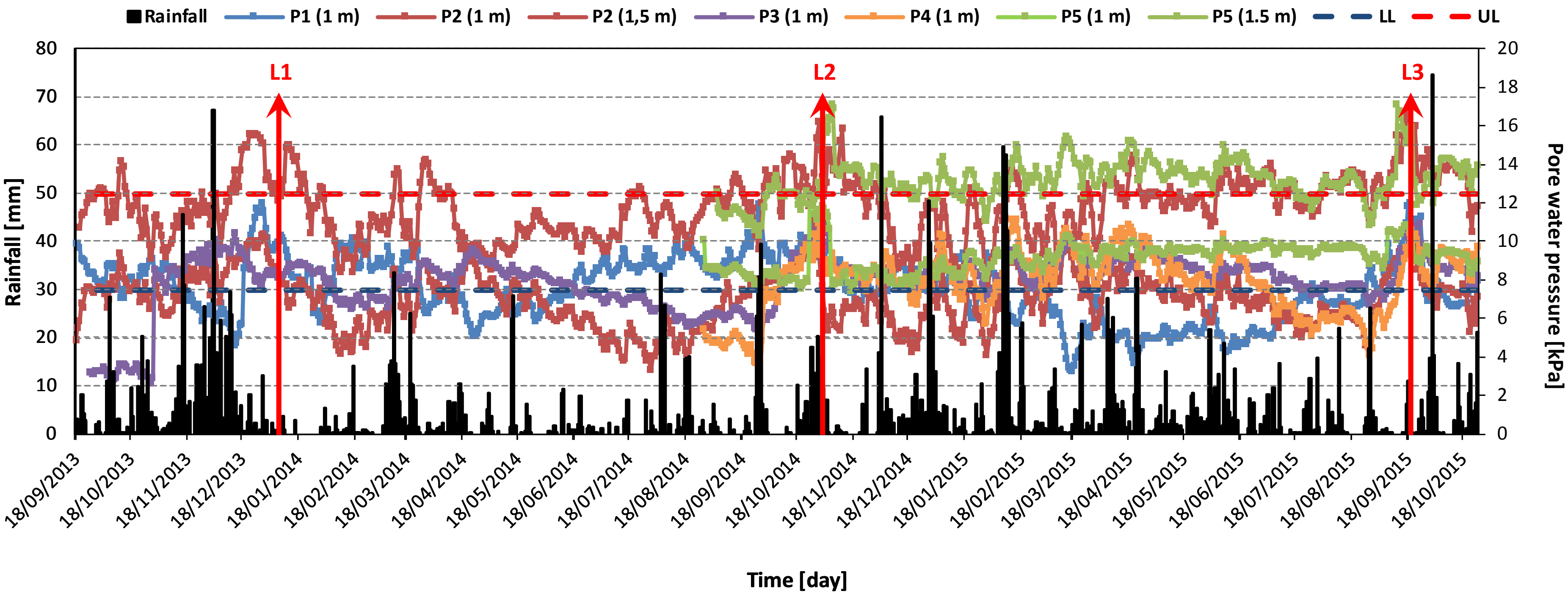
"NAMSEN basin" – Summary sheet	
ID (Identification Code)	6460
Total Area [km²]	56.512
Number of landslides	11
LI (Landslide Index)	56.238
Loose deposits [km²]	12.712
Bedrock [km²]	12.649
Selected landslides	L1 – 2013/12/30 L2 – 2014/10/28 L3 – 2015/09/19
Available piezometers	5

Geotechnical parameters		
Loose material	Silty sand	
Layer thickness (z)	1 – 1.5	m
Total unit weight (γ_t)	16.92 – 18.14	Kn/m³
Friction angle (ϕ)	34.55 – 40.53	°
Slope angle (θ)	18.35	°

Data from NGI in-situ tests



Preliminary results and Analyses



$$u_{w,c} = z \times \gamma_t \times \left(1 - \frac{tan\theta}{tan\varphi}\right)$$

$$u_{w,c} = 9.96\ kPa$$

$u_w(Lower\ limit) = 7.47\ kPa$

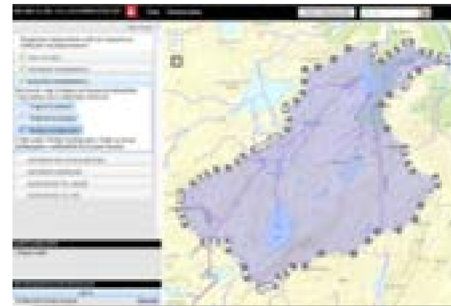
$u_w(Upper\ limit) = 12.45\ kPa$

(± 25% $U_{W,C}$ to take into account uncertainties about the depth of slope failure surface)

WARNING LEVEL	CONDITION
ORDINARY	*I/D equation not satisfied* AND $U_w \leq 7.47$ kPa
ATTENTION	*I/D equation satisfied* AND 7.47 kPa < U_w < 12.45 kPa
ALARM	*I/D equation satisfied* AND $U_w \geq 12.45$ kPa

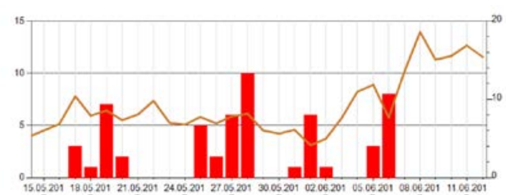
Future developments

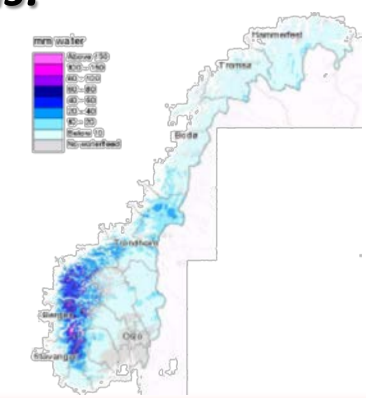
- ***Further applications to case studies in Norway***



- ***Identification of the most relevant variables for each type of landslide***

- ***Different monitoring variables within EW models:***
  - ***Water supply***
  - ***Soil water content***
  - ***…***





Time schedule

Activity	Months					
	0-6	6-12	12-18	18-24	24-30	30-36
Literature review						
Regional scale						
Local scale						
Case studies						
Thesis						

Thank you for your kind attention

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