Session HS6.3: Remote sensing of soil moisture
6 May 2020

A data-driven model for the assessment of shallow landslides hazard with the integration of satellite soil moisture and rainfall data

Valerio Vivaldi[1], Massimiliano Bordoni[1], Luca Lucchelli[1], Beatrice Corradini[1], Luca Brocca[2], Luca Ciabatta[2], Claudia Meisina[1]

(1)University of Pavia, Department of Earth and Environmental Sciences, Pavia, Italy
(2) Research Institute for Geo-Hydrological Protection, National Research Council, Perugia, Italy

UNIVERSITÀ DI PAVIA

valerio.vivaldi@unipv.it

1. THE PROBLEM

Rainfall-induced shalllow landslides: triggered by short-period but very intense rainfall events; causing significant damages to cultivations, roads and building

27th-28th April 2009 event in Oltrepò Pavese (1639 shallow landslides in about 250 km^2)

2. BACKGROUND

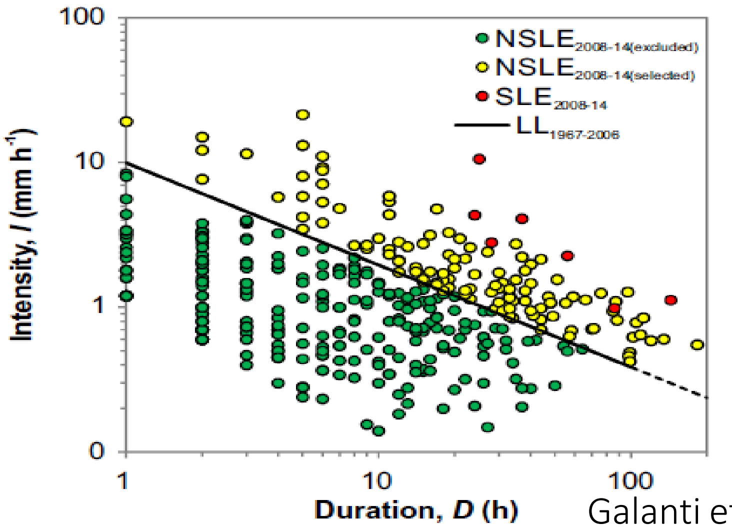
Methodologies for the assessment of spatial and temporal probability of occurrence or hazard of shallow landslides

Rainfall thresholds

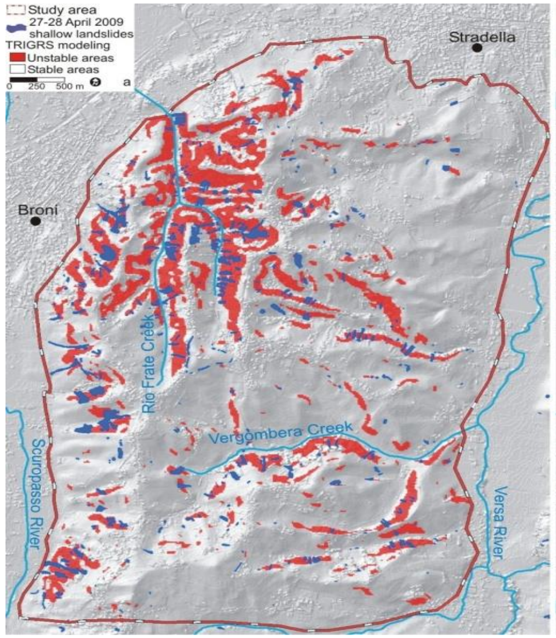
+ Rainfall features representative of the triggering conditions
+ Easily to be implemented at regional scale
- Soil features and geomophological predisposing factors are not considered
- Uncertainties related to the quality and the amount of the rainfall data

Physically-based methods

+ Quantitative analysis of the rainfall triggering conditions leading to the triggering
+ Consideration of the soil hydrological and geotechnical parameters and of the geomorphological attributes
+ Analysis of change in time of stable/unstable areas
- Significant amount of input data, difficult to be implemented at large scale
- Uncertainties on the boundary conditions of the model



Galanti et al., 2018

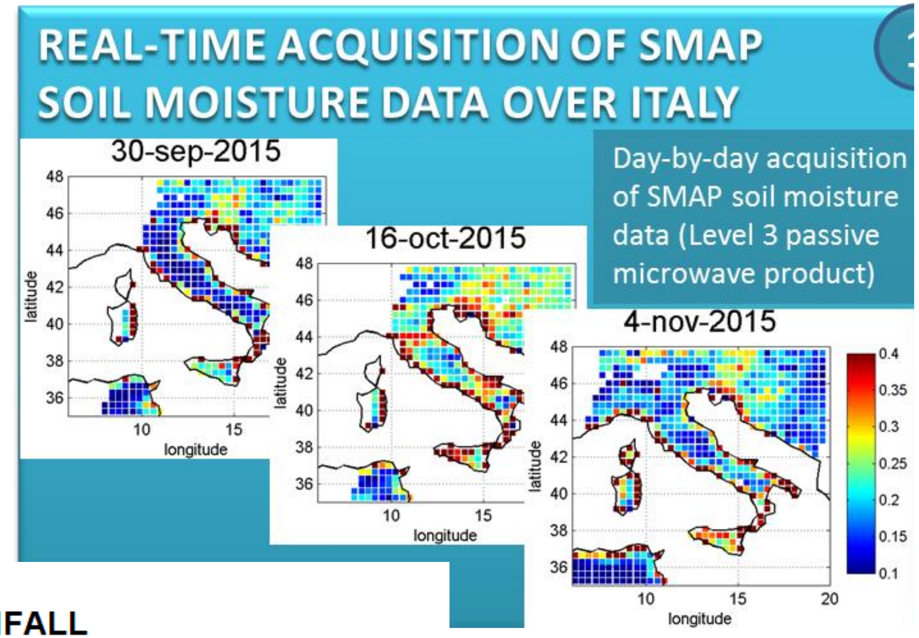


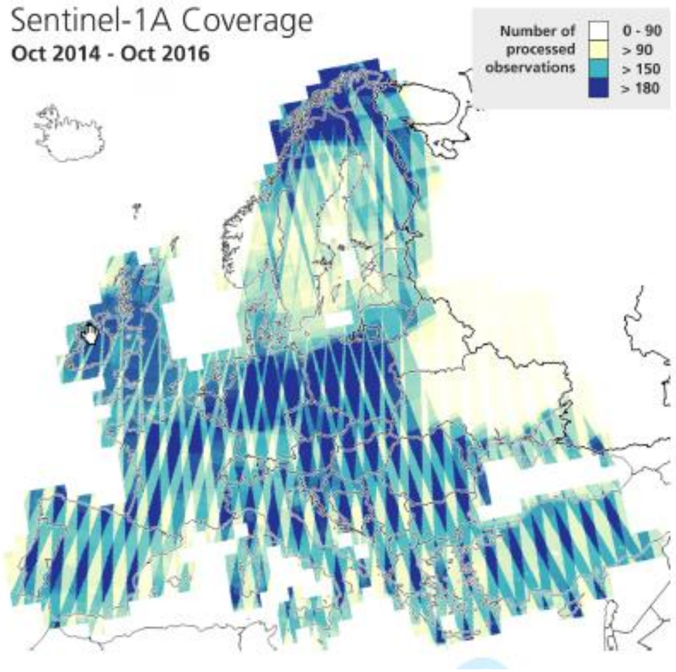
Bordoni et al., 2015

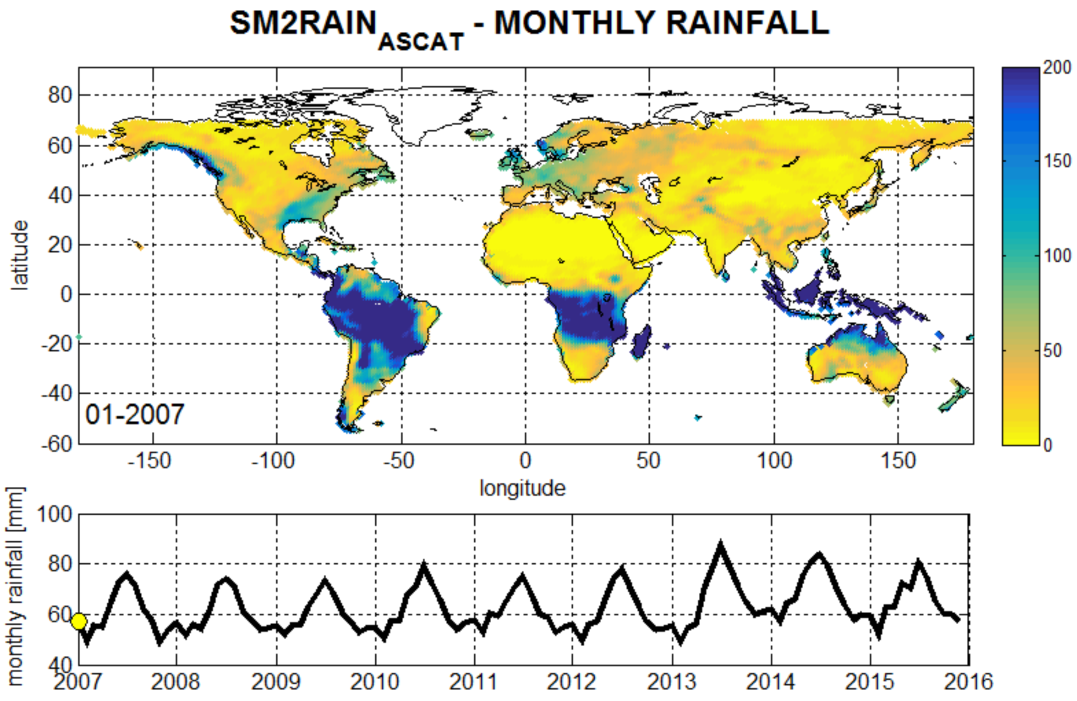
2. BACKGROUND

Satellite soil moisture
for hydrological app

- ASCAT (12.5 km, 12 ore)
- Sentinel-1 (1 km, 2-3 giorni)
- SCATSAR (1 km, giornaliero)
- SMAP, SMOS, AMSR2 (3-9-25 km, giornaliero)







Detecting rainfall from the bottom up: using soil moisture observations for measuring rainfall (**SM2RAIN**) (Brocca et al., 2014)

- GPM-IMERG (10 km, 30 minuti)
- SM2RAIN-derived:
  - ASCAT (12.5 km, giornaliero)
  - SCATSAR (1 km, giornaliero)
- Integrati (GPM+SM2RAIN)

3. OBJECTIVES

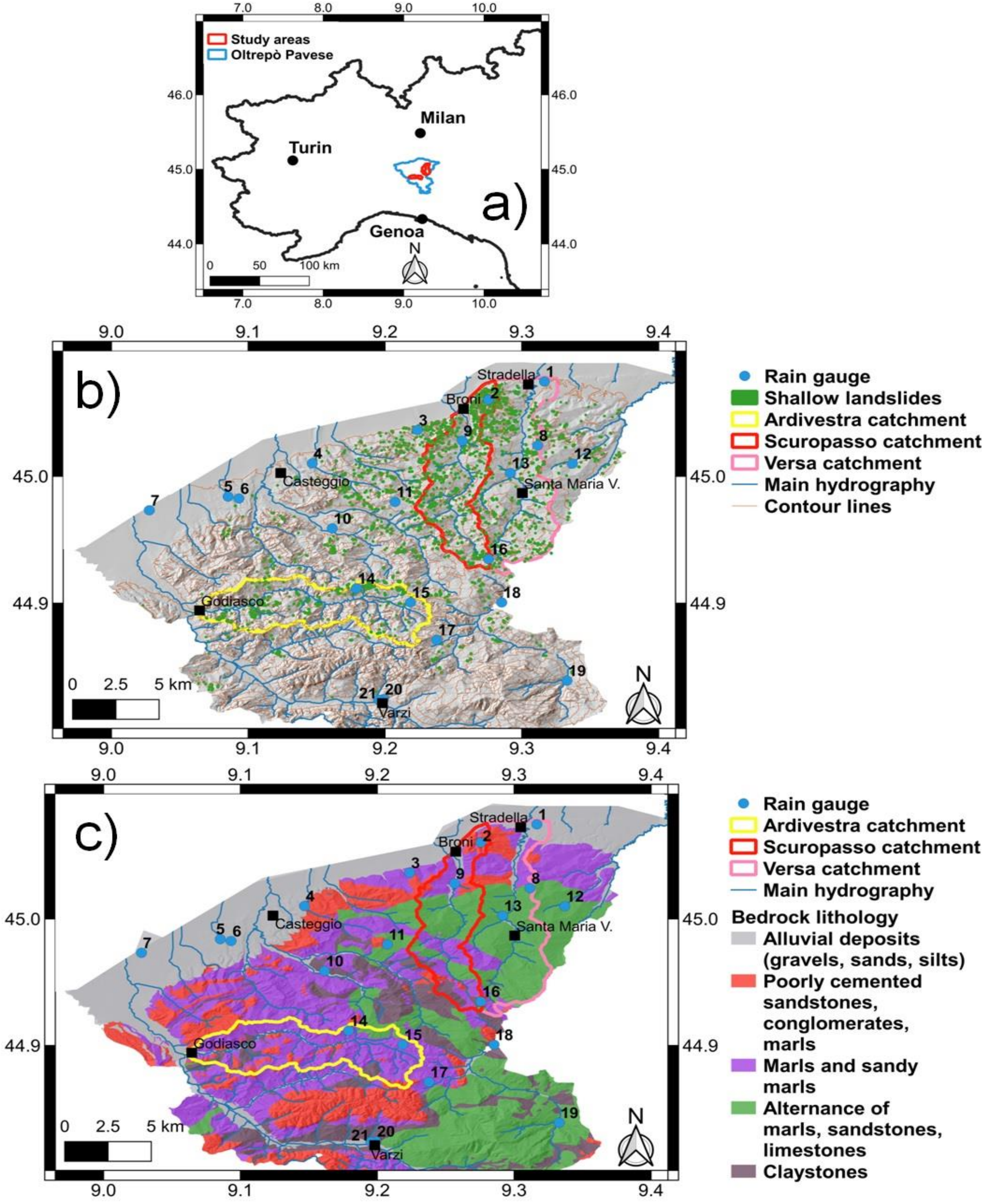
Development and test of a dynamic method for the assessment of spatial and temporal probability of occurrence and hazard of rainfall-induced shallow landslides at large scale (catchement, regional), with the integration of satellite measures of rainfall and soil moisture

The work was realized in the frame of ANDROMEDA project, funded by Fondazione Cariplo and realized by University of Pavia and CNR-IRPI Perugia, which aims to develop a prototypal early-warning system for the assessment of shallow landslides and flood occurrence in Oltrepò Pavese area

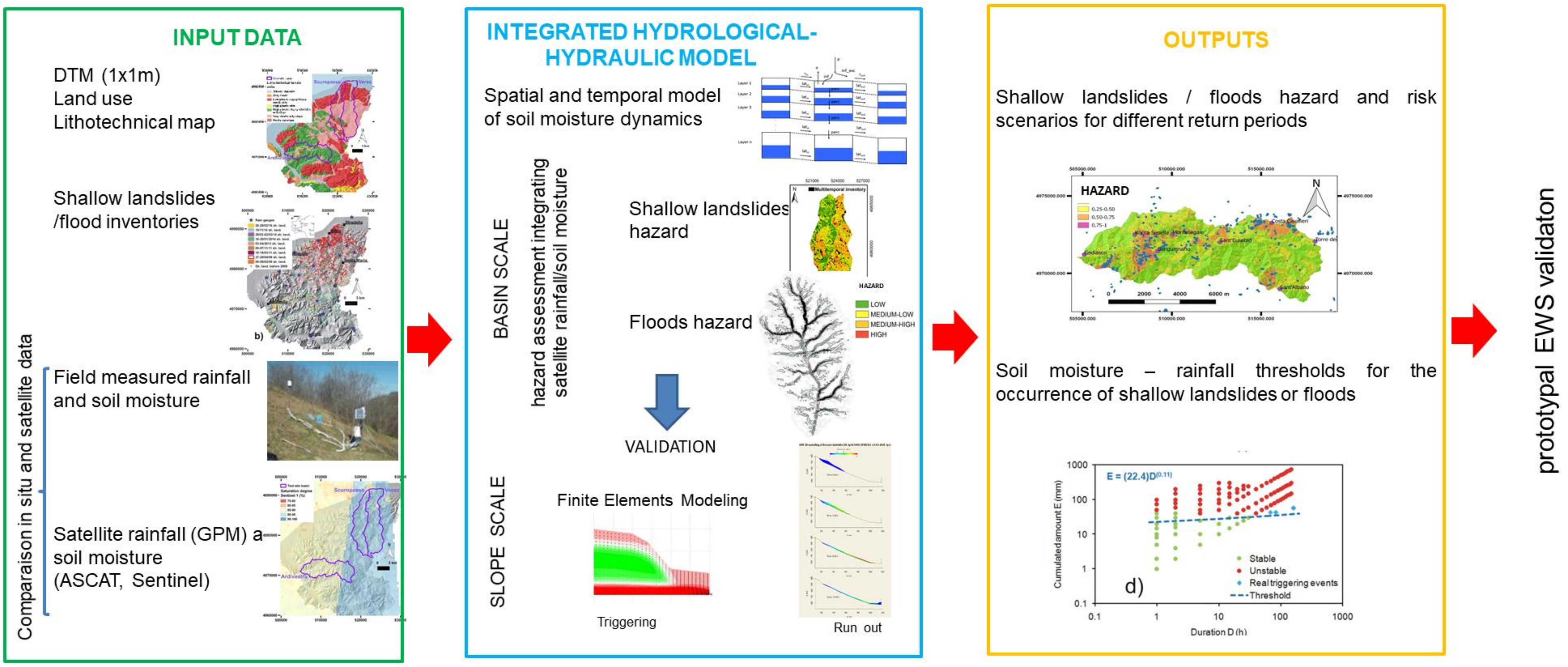
4. STUDY AREAS

Oltrepò Pavese area (720 km²)

Pilot catchments representative of the typical geological and geomorphological settings: **Ardivestra (medium steep slopes, clayey and chaotic bedrocks) Scuropasso-Versa (very steep slopes, marly, areanaceous, conglomeratic bedrocks)**



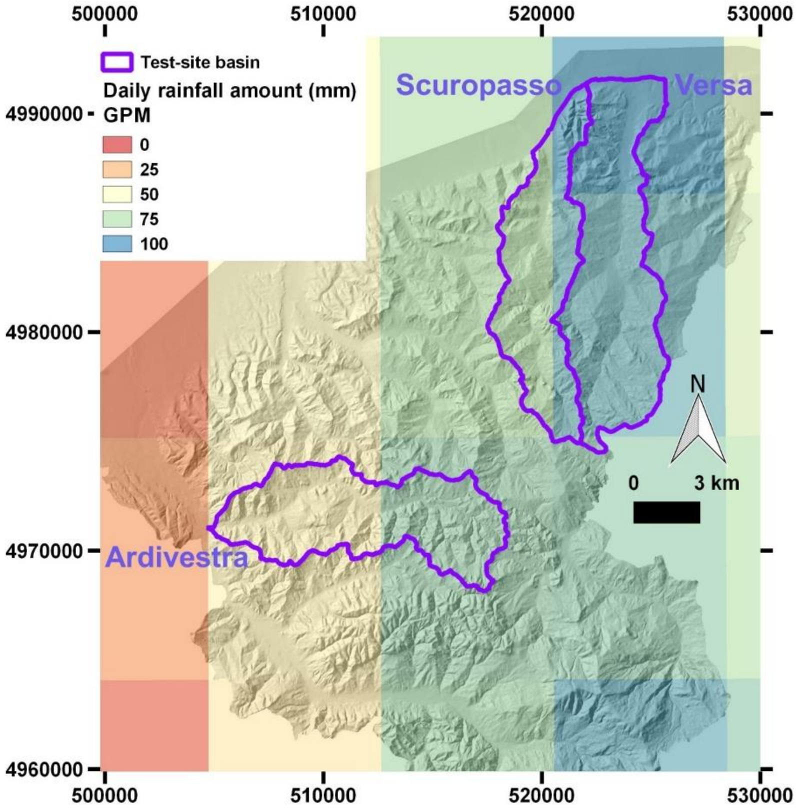
5. METHODS


INPUT DATA
DTM (1x1m)
Land use
Lithotechnical map
Shallow landslides
/flood inventories
Comparaison in situ and satellite data
Field measured rainfall
and soil moisture
Satellite rainfall (GPM) a
soil moisture
(ASCAT, Sentinel)
INTEGRATED HYDROLOGICAL-
HYDRAULIC MODEL
Spatial and temporal model
of soil moisture dynamics
BASIN SCALE
hazard assessment integrating
satellite rainfall/soil moisture
Shallow landslides
hazard
Floods hazard
HAZARD
LOW
MEDIUM-LOW
MEDIUM-HIGH
HIGH
VALIDATION
SLOPE SCALE
Finite Elements Modeling
Triggering
Run out
OUTPUTS
Shallow landslides / floods hazard and risk
scenarios for different return periods
HAZARD
Soil moisture – rainfall thresholds for the
occurrence of shallow landslides or floods
E = (22.4)D^(0.11)
Cumulated amount E (mm)
Duration D (h)
Stable
Unstable
Real triggering events
Threshold
d)
prototypal EWS validaton

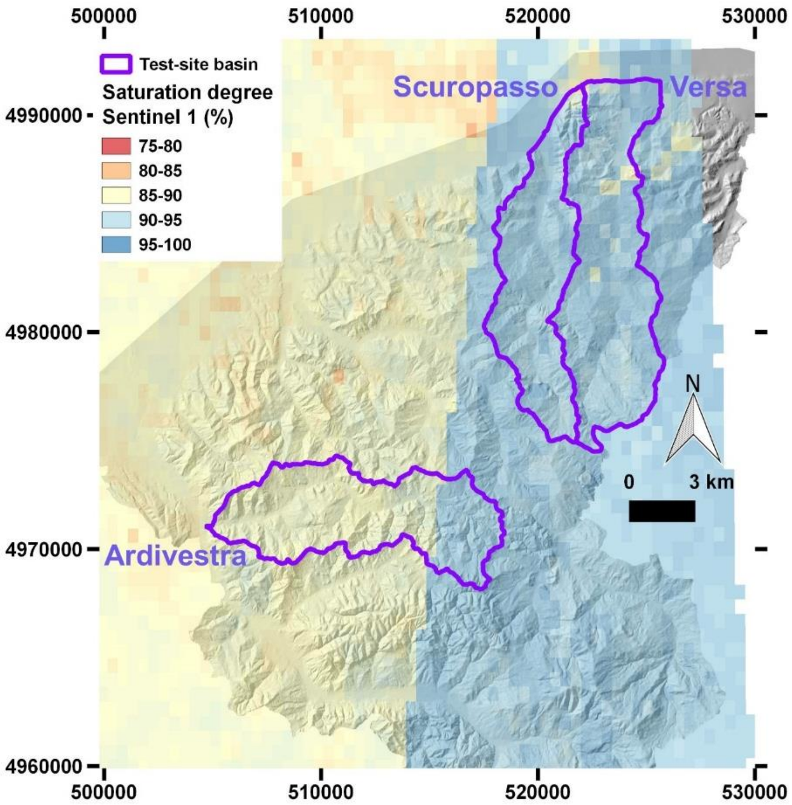
6. RESULTS - COMPARISON BETWEEN FIELD AND SATELLITE MEASURES

Maps of rainfall and soil moisture measured through satellites

Rainfall GPM

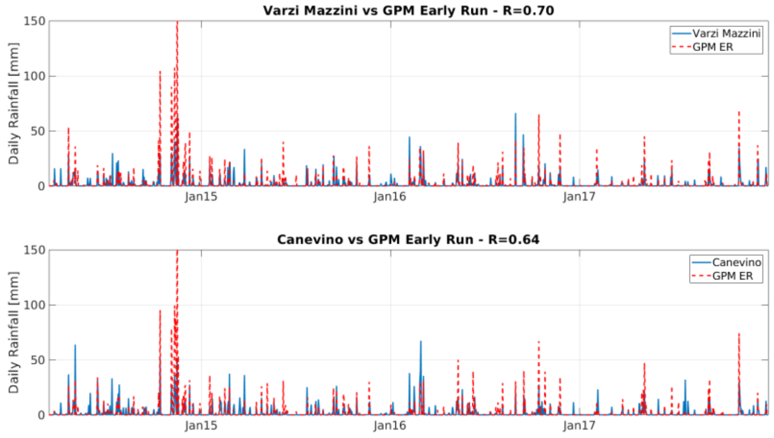


Soil moisture Sentinel 1

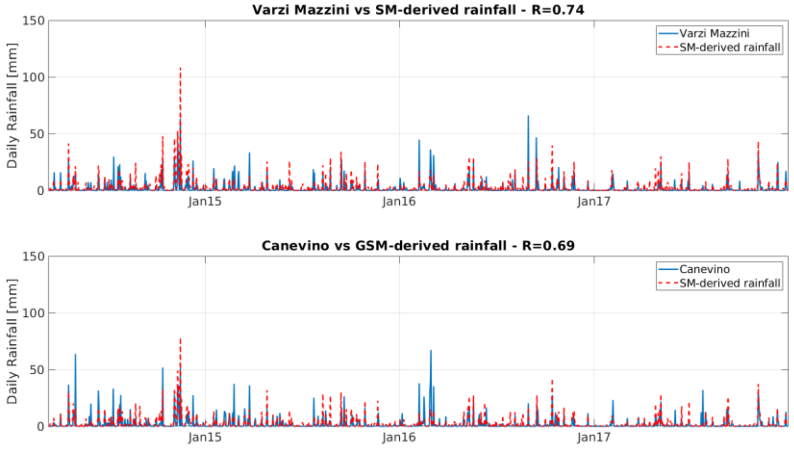


Validation of satellite data through field measures

Rain gauge vs GPM: R=0.64-0.70



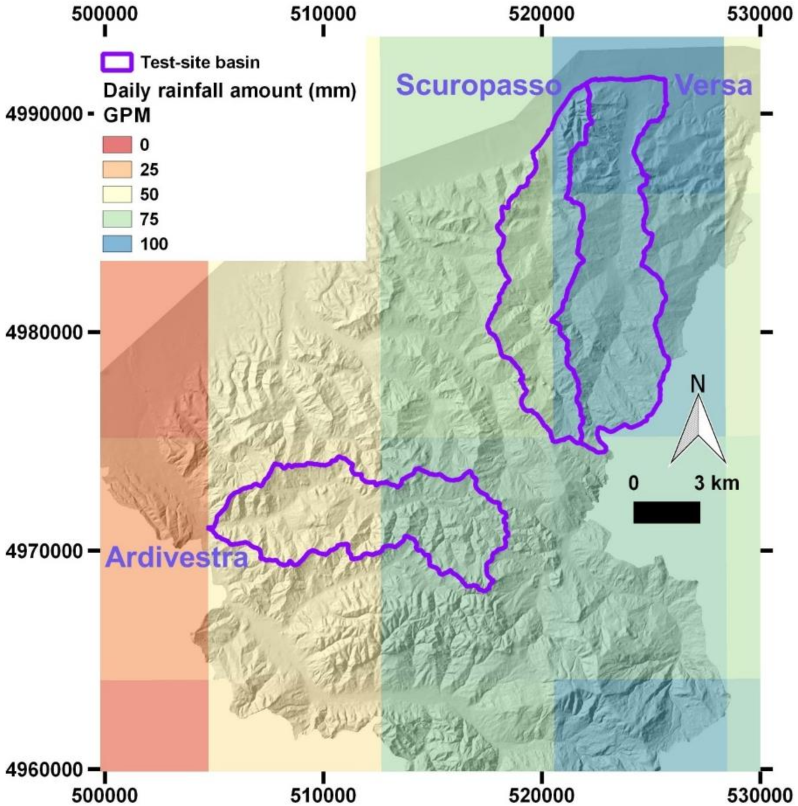
Rain gauge vs SM2RAIN-ASCAT: R=0.69-0.74



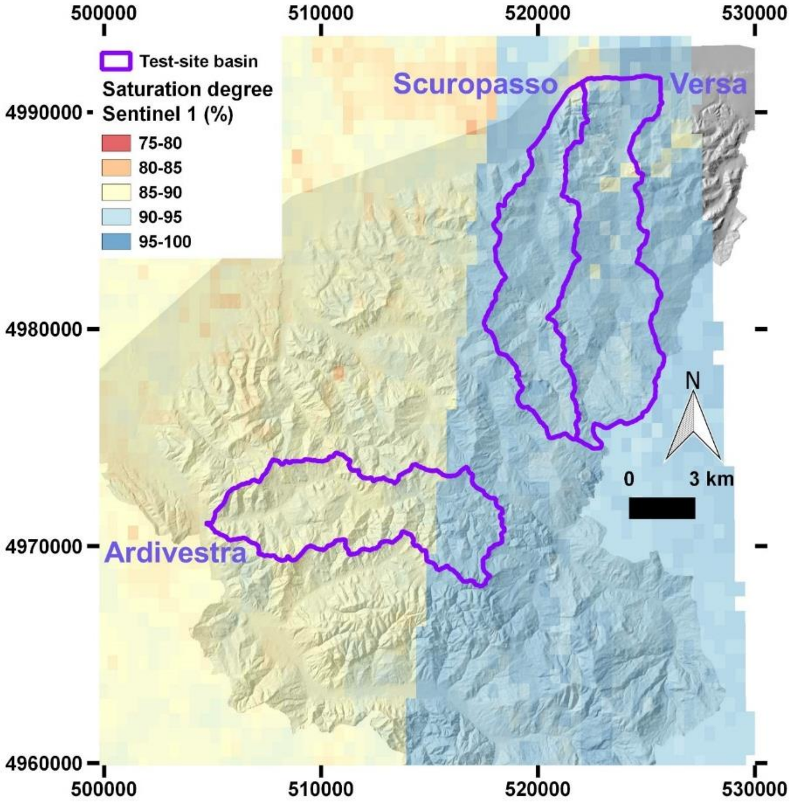
6. RESULTS - COMPARISON BETWEEN FIELD AND SATELLITE MEASURES

Maps of rainfall and soil moisture measured through satellites

Rainfall GPM

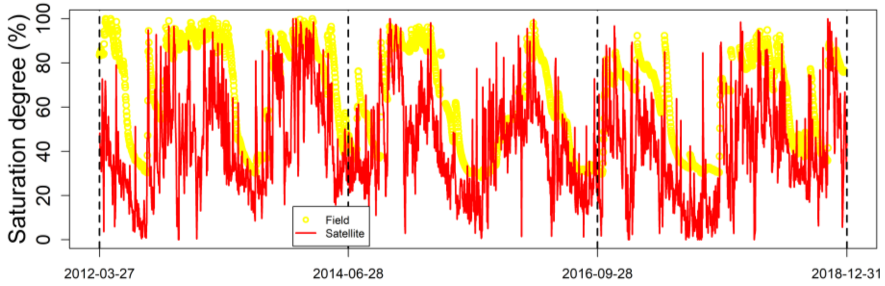


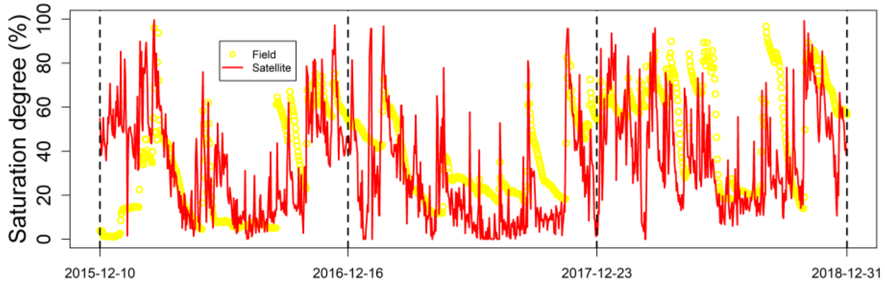
Soil moisture Sentinel 1



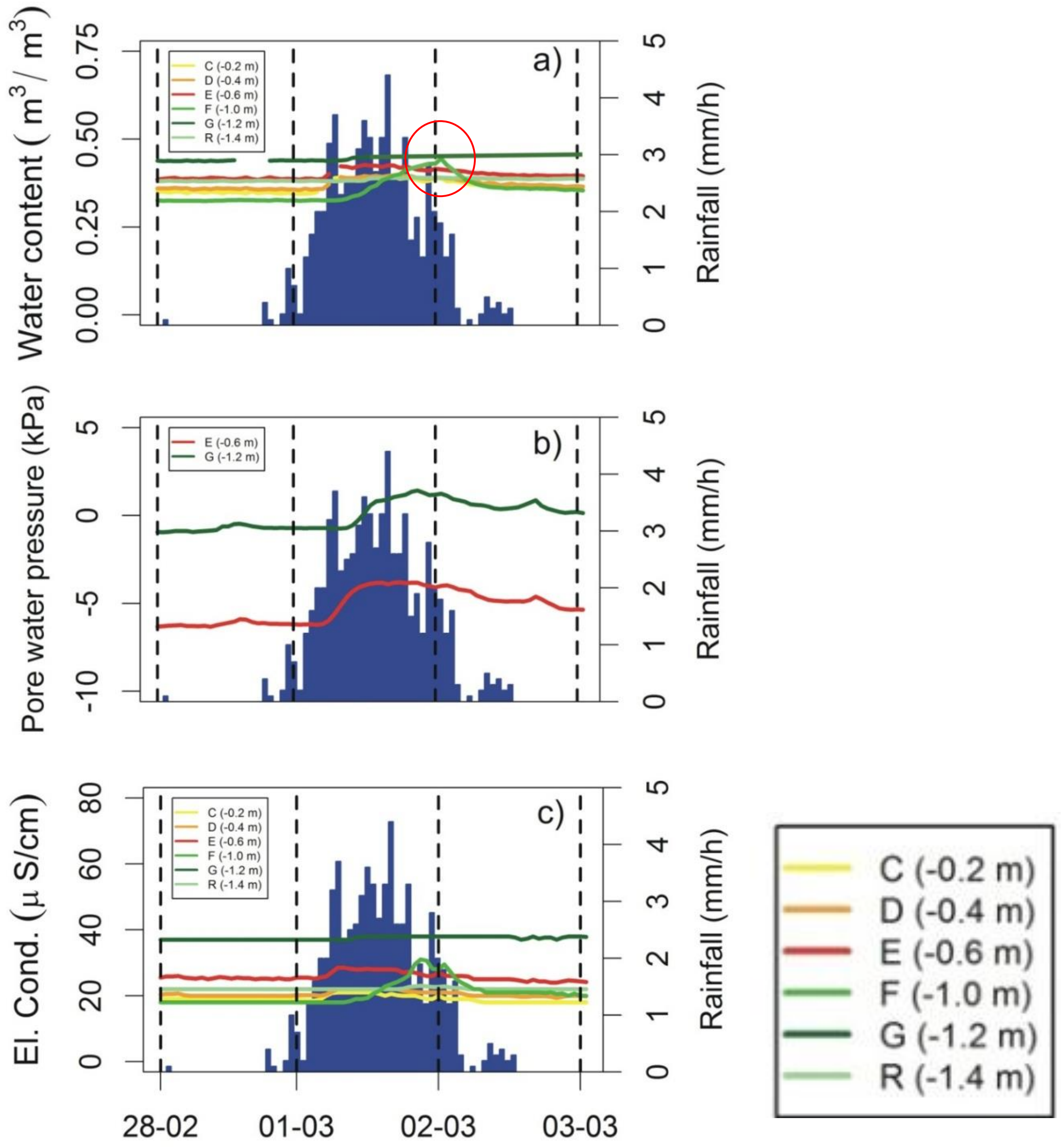
Validation of satellite data through field measures

Field soil moisture vs ASCAT: R=0.64-0.71

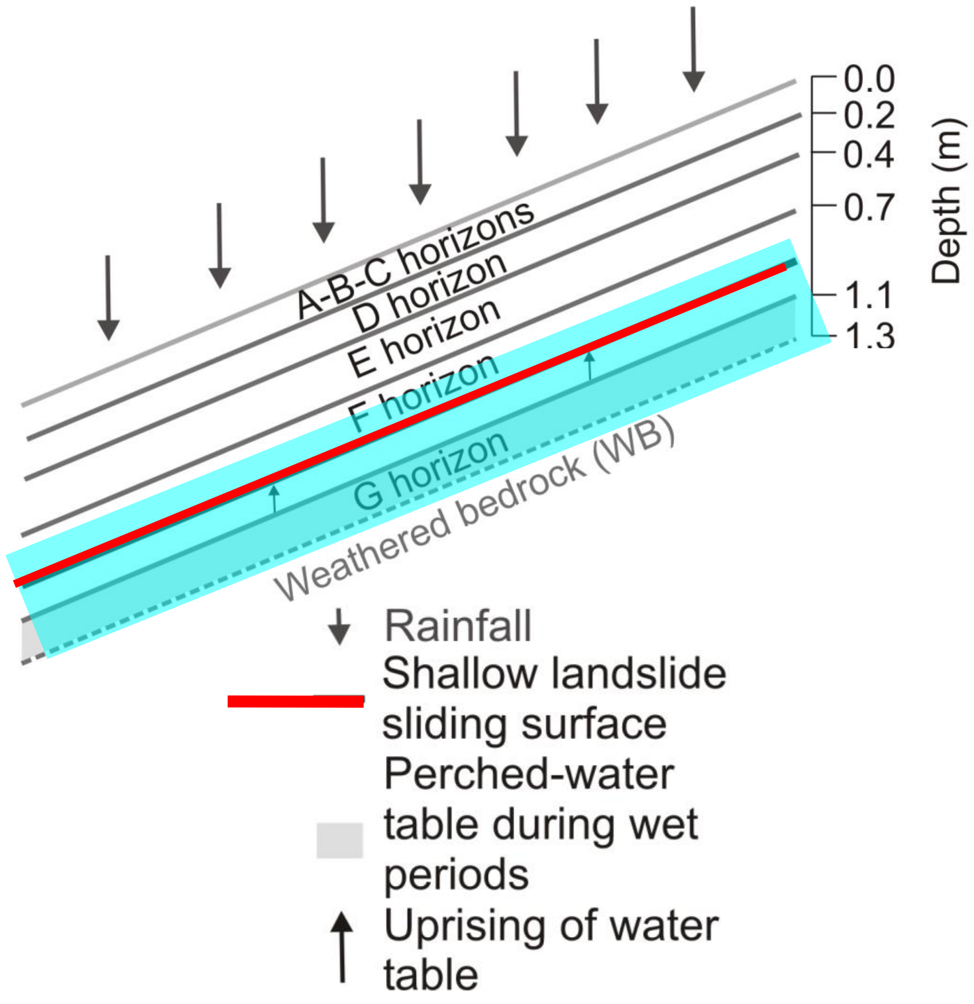




6. RESULTS - TRIGGERING CONDITIONS OF SHALLOW LANDSLIDES THROUGH FIELD MONITORING

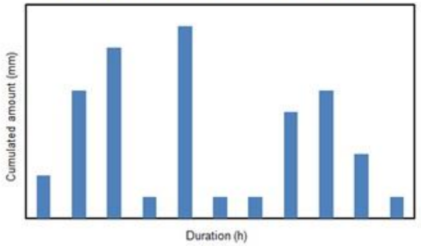


28 February-2 March 2014 event (69 mm in 42 h)



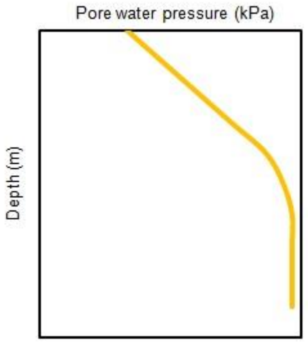
6. RESULTS - RAINFALL THRESHOLDS

Synthetic rainfall events (duration, cumulated amount)



+

Initial pore water pressure conditions



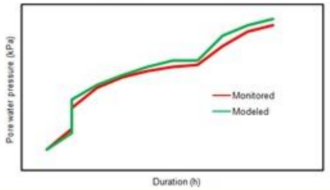
Physically-based modeling at site-specific scale (TRIGRS model)

Boundary conditions:

- Soil hydrological and geotechnical profile
- Impermeable bedrock layer below soil profile
- Uprise of perched water table

Validation of the physically-based model

Comparison between modeled and monitored pore water pressure during past events

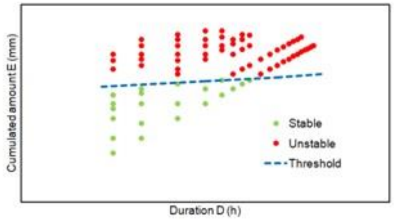


Calculation of slope safety factor (Fs) for each modeled rainfall event (function of duration and cumulated amount)

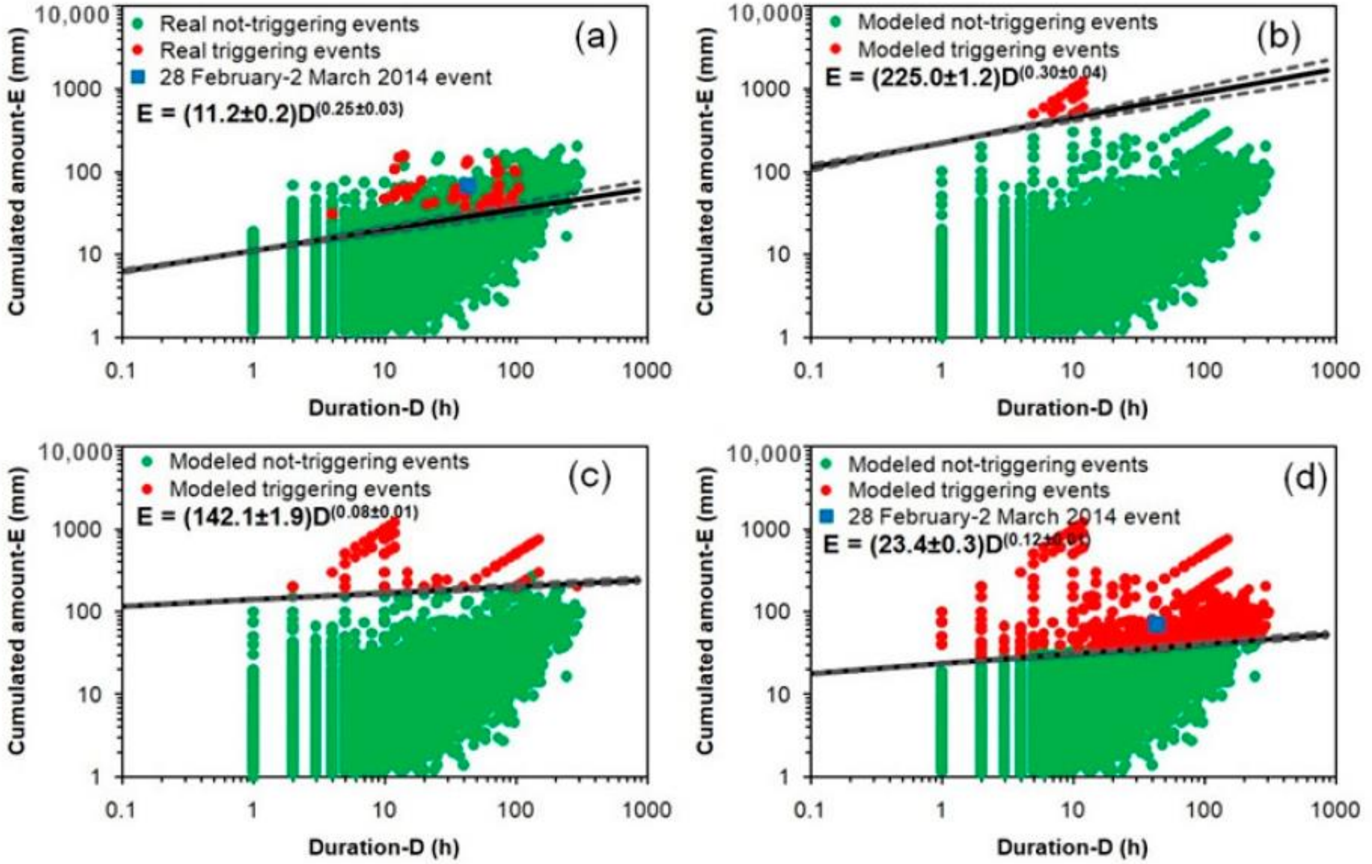
Fs<1 unstable conditions: rainfall event (duration, cumulated amount) is not enough to trigger shallow landslides

Fs>1 stable conditions: moment during the rainfall event (duration, cumulated amount) when shallow landslides can trigger

Rainfall thresholds for triggering of shallow landslides



6. RESULTS - RAINFALL THRESHOLDS



Threshold	TP (%)	TN (%)	FP (%)	FN (%)
Empirical thresholds	95 ± 2	76 ± 3	24 ± 3	5 ± 2
Physicallybased thresholds (−20 kPa) (TRIGRS/−20)	-	100 ± 0	0 ± 0	-
Physicallybased thresholds (−10 kPa) (TRIGRS/−10)	-	100 ± 0	0 ± 0	-
Physicallybased thresholds (0 kPa) (TRIGRS/0)	100 ± 0	93 ± 1	7 ± 1	0 ± 0

- Significant differences on the rainfall cumulated amount between different thresholds

- Significant effects of the initial pore water pressure on the cumulated amount required to trigger shallow landslides

- Low values of triggering rainfall for empirical-statistical thresholds

- Better estimation of rainfall triggering conditions since thresholds reconstructed through physically-based methods

7. FUTURE DEVELOPMENTS

- ❑ Testing the data-driven approach for rainfall events with different features
- ❑ Comparison between data-driven and physically-based methodologies for shallow landslides hazard assessment
- ❑ Reconstruction of rainfall thresholds through satellite data (rainfall, soil moisture)
- ❑ Comparison of the reconstructed thresholds with the official ones (Lombardy region early-warning system) for future events

THANKS FOR THE ATTENTION

References:

Bordoni M., Corradini B., Lucchelli L., Valentino R. Bittelli M., Vivaldi V., Meisina C. (2019). Empirical and physically based thresholds for the occurrence of shallow landslides in a prone area of Northern Italian Apennines. Water 11, 2653. doi:10.3390/w11122653

Bordoni M., Corradini B., Lucchelli L., Meisina C. (2019). Preliminary results on the comparisons between empirical and physically-based rainfall thresholds for shallow landslides occurrence. Italian Journal of Engineering Geology and Environment, 1, 5-10. doi:10.4408/IJEGE.2019-01.S-01

For more information on ANDROMEDA project:

- Prof.ssa Claudia Meisina (Prinicipal Investigator) claudia.meisina@unipv.it
- Massimiliano Bordoni (Responsible of the communication) massimiliano.bordoni@unipv.it
- Valerio Vivaldi valerio.vivaldi@unipv.it

Website: https://progettoandromeda.unipv.it/
E-Mail: andromeda@unipv.it

ProgAndromeda (https://www.facebook.com/ProgAndromeda-1922388478072055/?modal=admin_todo_tour)

@ProgAndromeda