PIEMONTE

Arpa

Agenzia Regionale
per la Protezione Ambientale

Dipartmento Sistemi Previsionali*
Area Funzionale Tecnica**

EWS for rainfall-induced slope phenomena: shallow landslides and channelized debris flows in Piemonte, Italy

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PROTEZIONE CIVILE
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Interreg ALCOTRA
Fonds européen de développement régional
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UNION EUROPÉENNE
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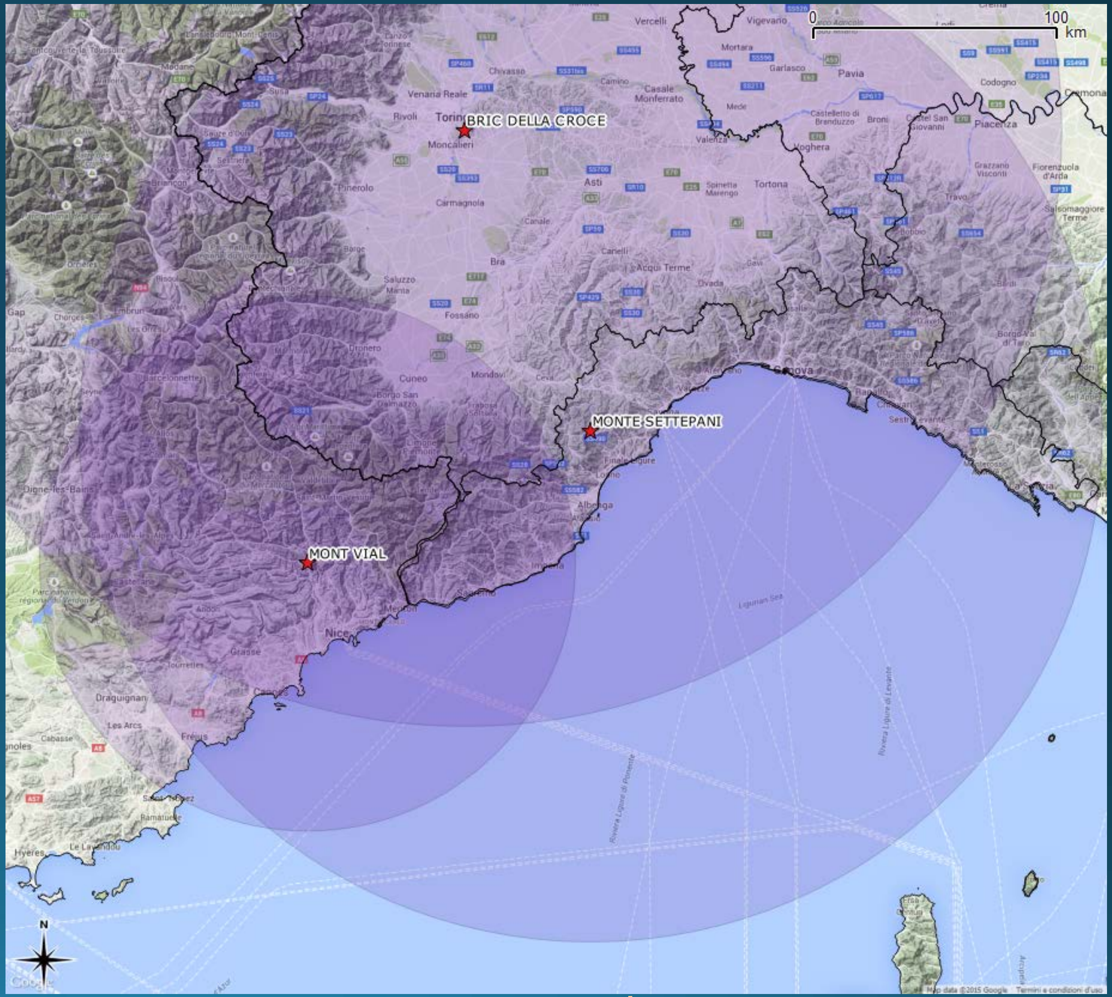
Project n. 477 URAMET- Union des RADar METeorologiques Elaboration des données radar et diffusion en temps réel aux citoyens des informations sur fortes averses orageuse et pluies intenses

- EU Funded project ALCOTRA IT-FR 2014 – 2020
- Partners: ARPAP, Reg. Liguria, ARPAL, Novimet
- 24th Feb 2016 – 24th Aug 2016
- Warnings on severe weather diffusion to citizens (by App, Social Media, emails)
- Weather radar-based QPE improvement
- System upgrades and real time data sharing Italy – France
- Nowcasting: rainfall, floods in small basins, torrential processes and shallow landslides
- Overall budget: **1,208,905.00 €**



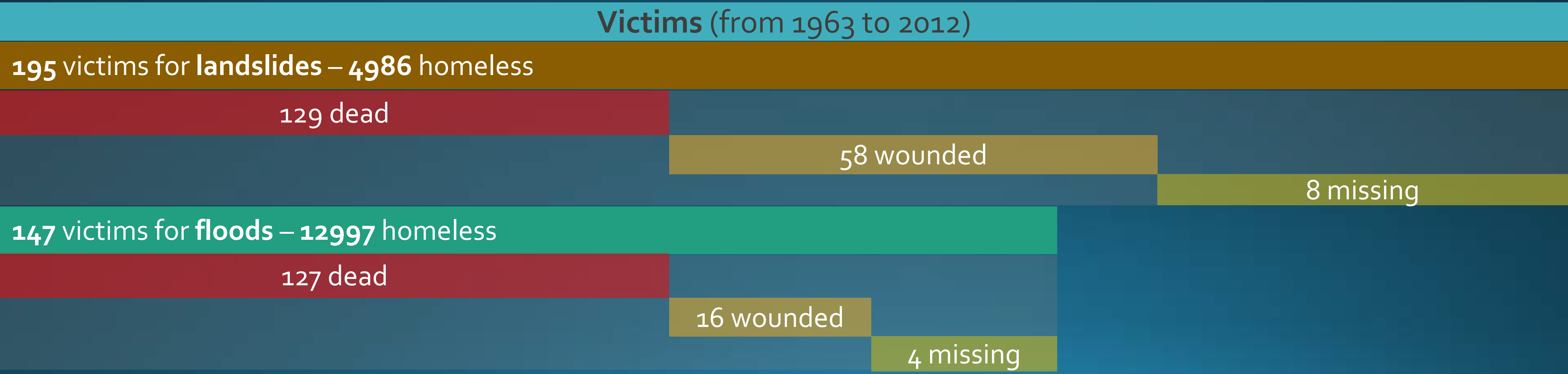
www.interreg-alcotra.eu

Overview of natural hazards in Piemonte

In 50 years floods and landslides caused 256 deads, 160 wounded and about 28,0000 homeless in Piemonte. In an area characterized by a delicate water balance - mountains occupy 45% area, and there is one calamitous event every 18 months on average – urbanized surface increased by 74% between 1960 and 2009.

In Italy, the province of Torino is second only to the province of Naples for the population living in areas with high landslide risk. A critical framework that involves 87% of municipalities and 12.7% of residents: these values highlight the importance of an enhanced regional warning system operating in Piemonte.

From 1800 to 2013 Piemonte was hit by about 115 flood/landslide events – one event every 18-20 months. 12.2% of Piemonte territory is classified as affected by high geo-hydrological risk.



[Source: CNR-IRPI ; Arpa Piemonte]

Most danderous slope phenomena

- **Shallow landslides** (Varnes, 1978) are considered extremely dangerous, despite their relatively low volumes (generally <1000 m^3), due to: the high velocities (> 5 m/s - Cruden and Varnes, 1996); the rapid evolution; the capacity of propagation even in presence of obstacles; the disposition to the combination of the scars and to the coalescence of the mobilized soil; the high density of slides per unit area of terrain in a single rainfall event.

Shallow landslides are responsible for 50% of the casualties caused by landslides in the last 100 years in Piedmont region.

- **Debris flows** are rapid or very rapid sediment water mixtures flows, with high solid concentration (Jakob and Hungr 2005) occurring in the small alpine catchments. They frequently occur and they often are characterized by very high magnitude.

Debris flows are responsible for 36% of casualties in the Italian alpine regions in the last century.

The obvious forecasting questions …

Where?

(…also called "predisposing factors")

&

When?

(…also called "triggering factors")

Shallow landslide Early Warning System

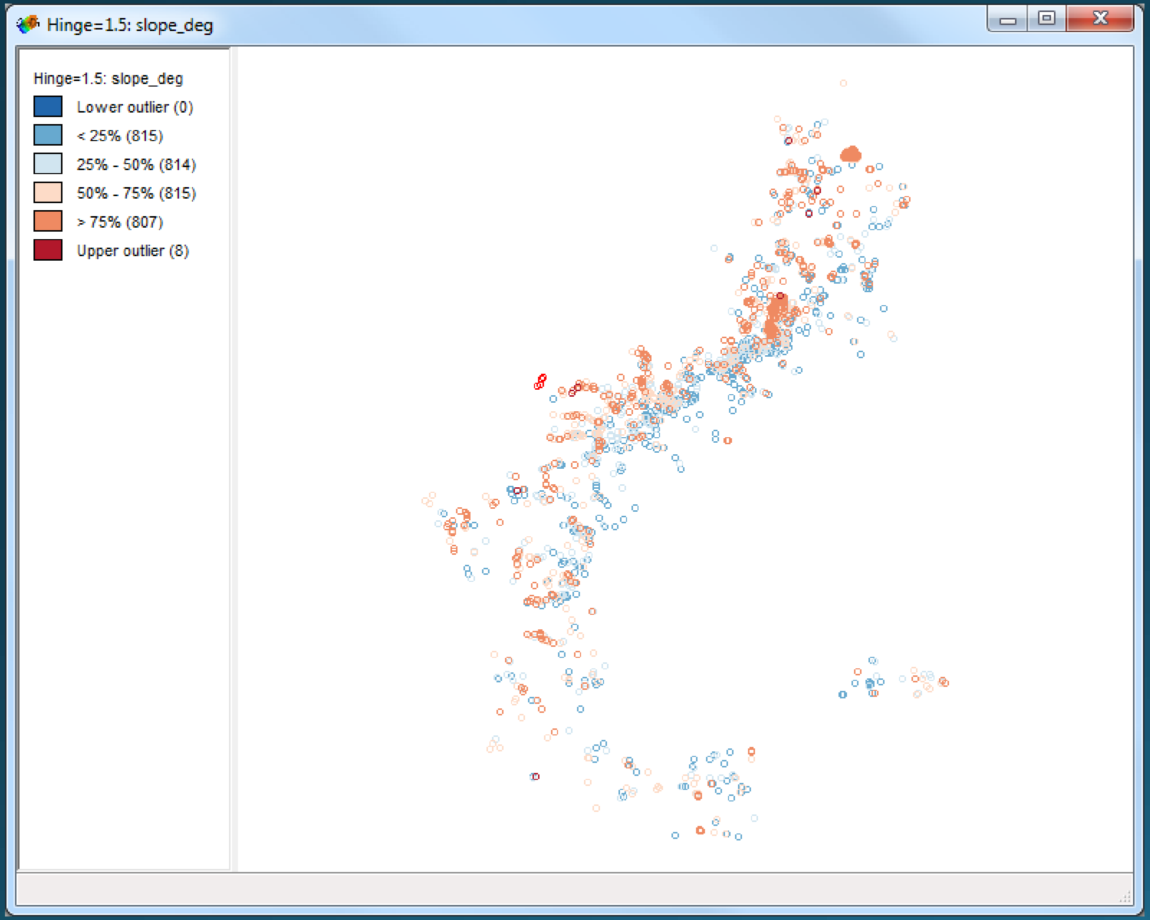
S.M.A.R.T.

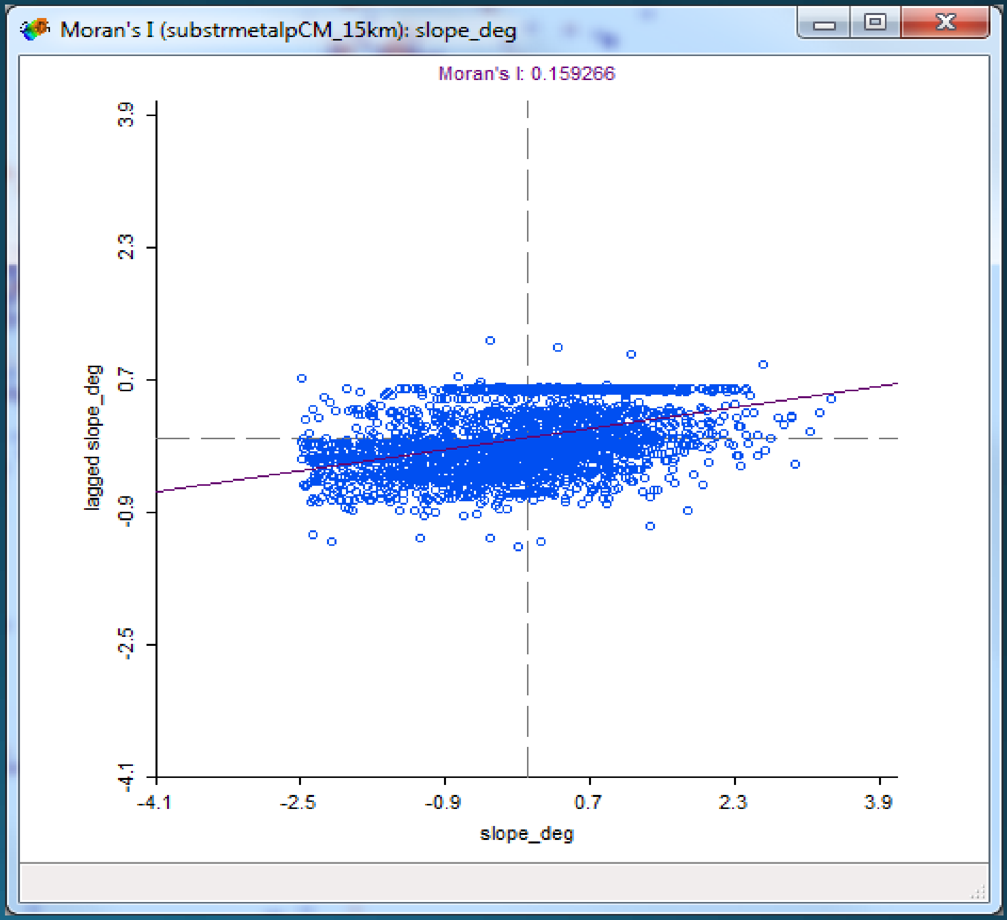
S*hallow landslides* ***M****ovements* ***A****nnounced through* ***R****ainfall* ***T****hresholds*

SMART is an empirical model based on the identification of rainfall (water) thresholds which constitute the quantitative indicator of the induced hazard. It works by the statistical relationship between causes and effects.

Shallow landslide EWS: where?

The approach is based on multivariate statistical analysis considering territorial parameters (lithology, soil, curvature, elevation, climate, aspect, slope, land use, MAP, etc.) and shallow landslides distribution.





e.g. Low correlation with slope in alpine environment

Shallow landslide EWS: where?

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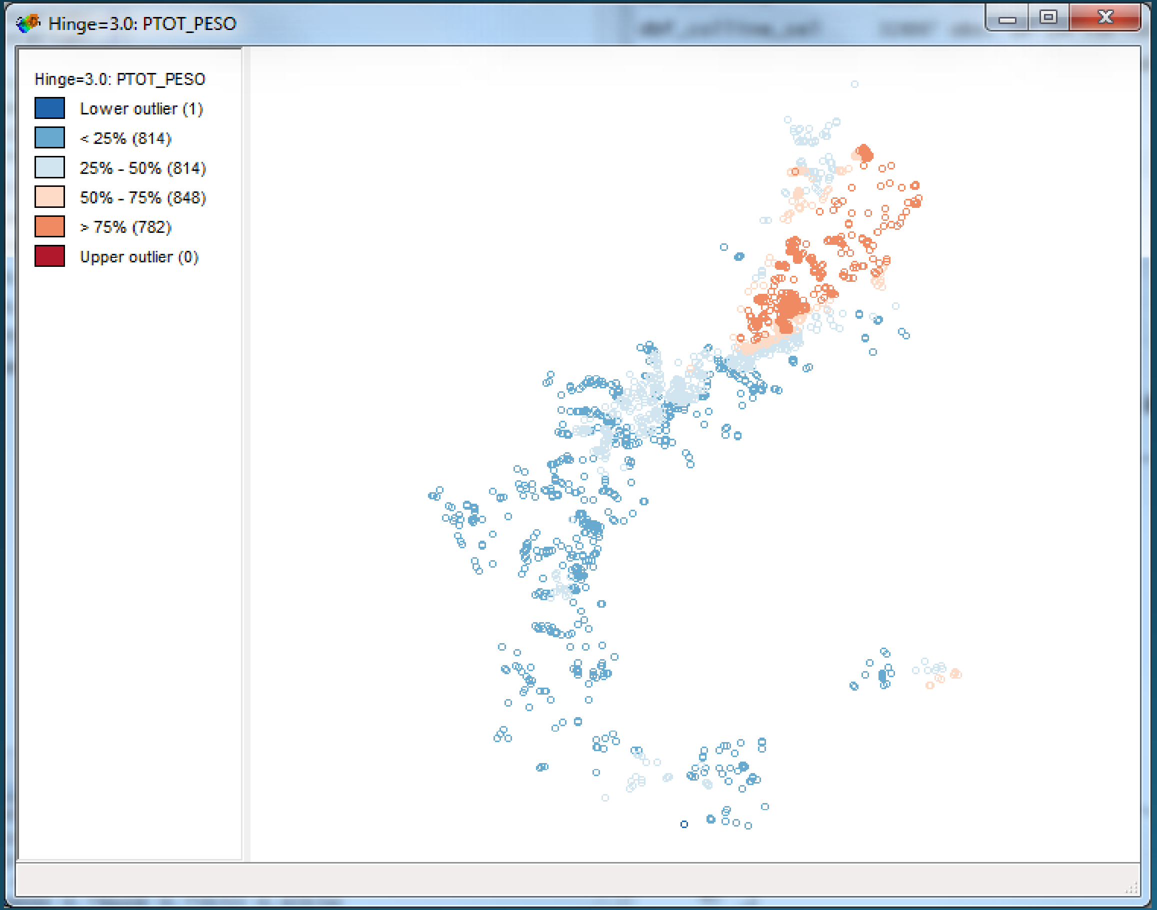
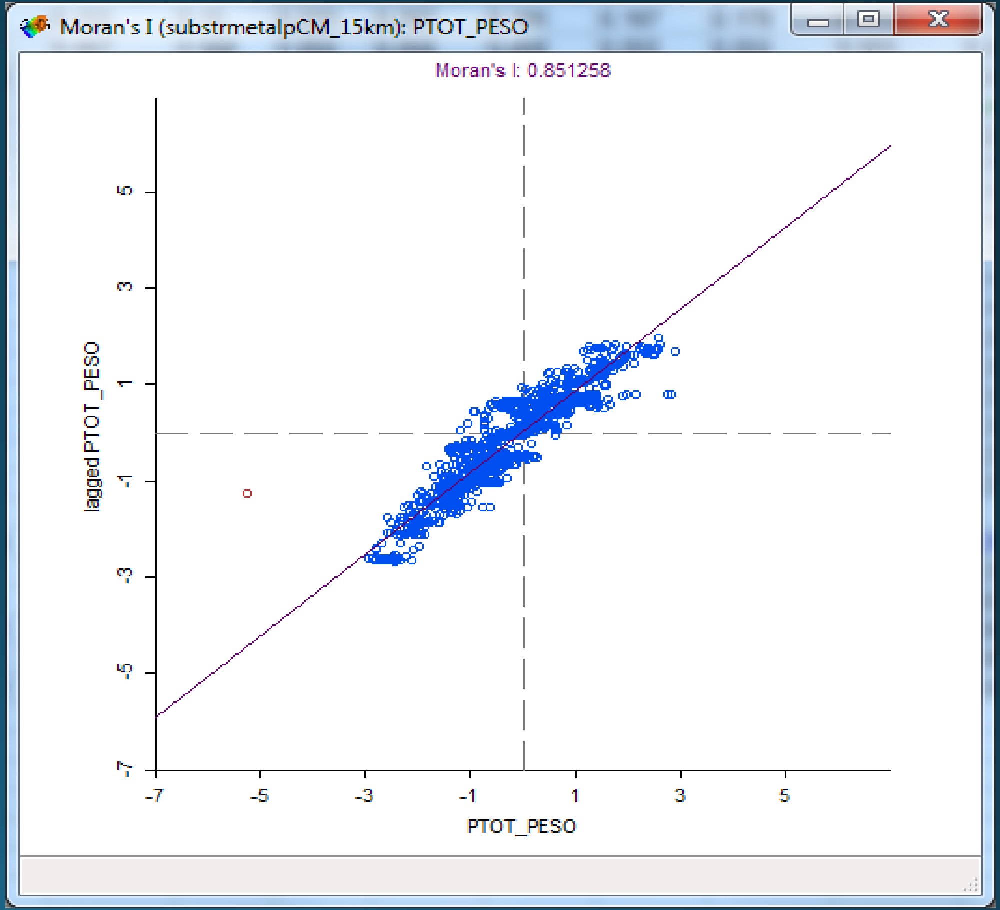
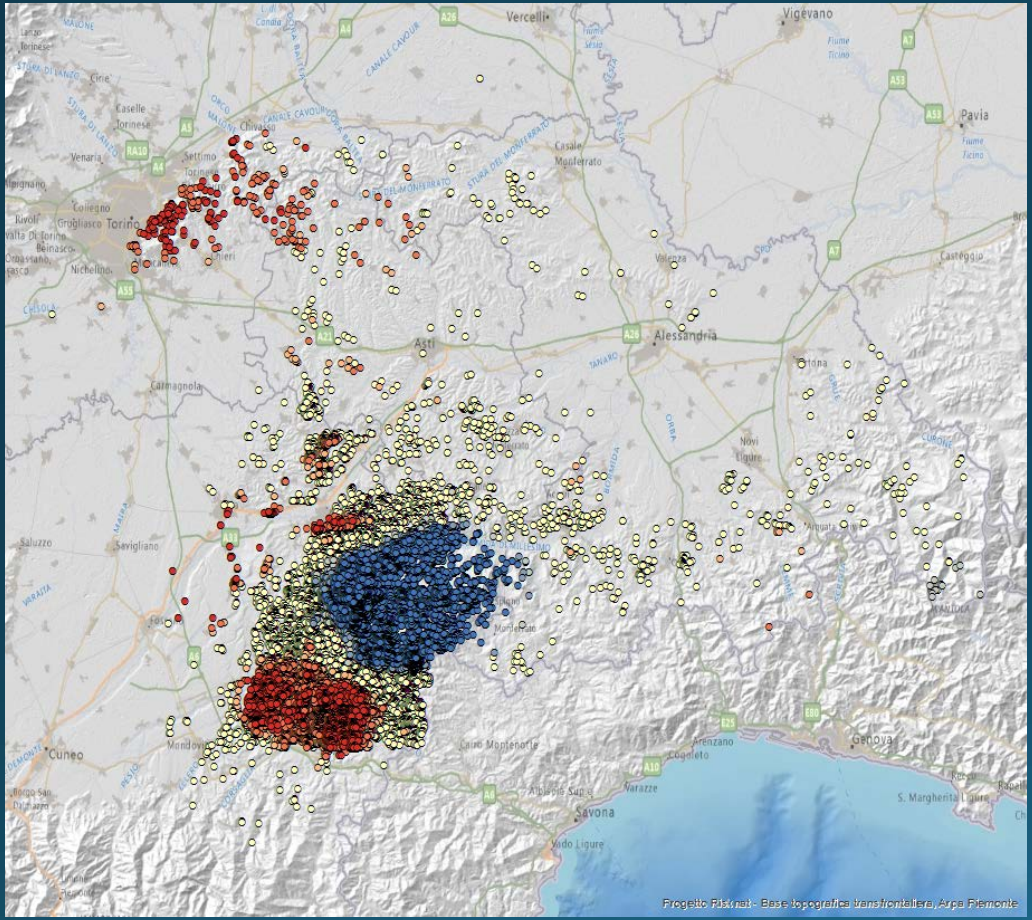




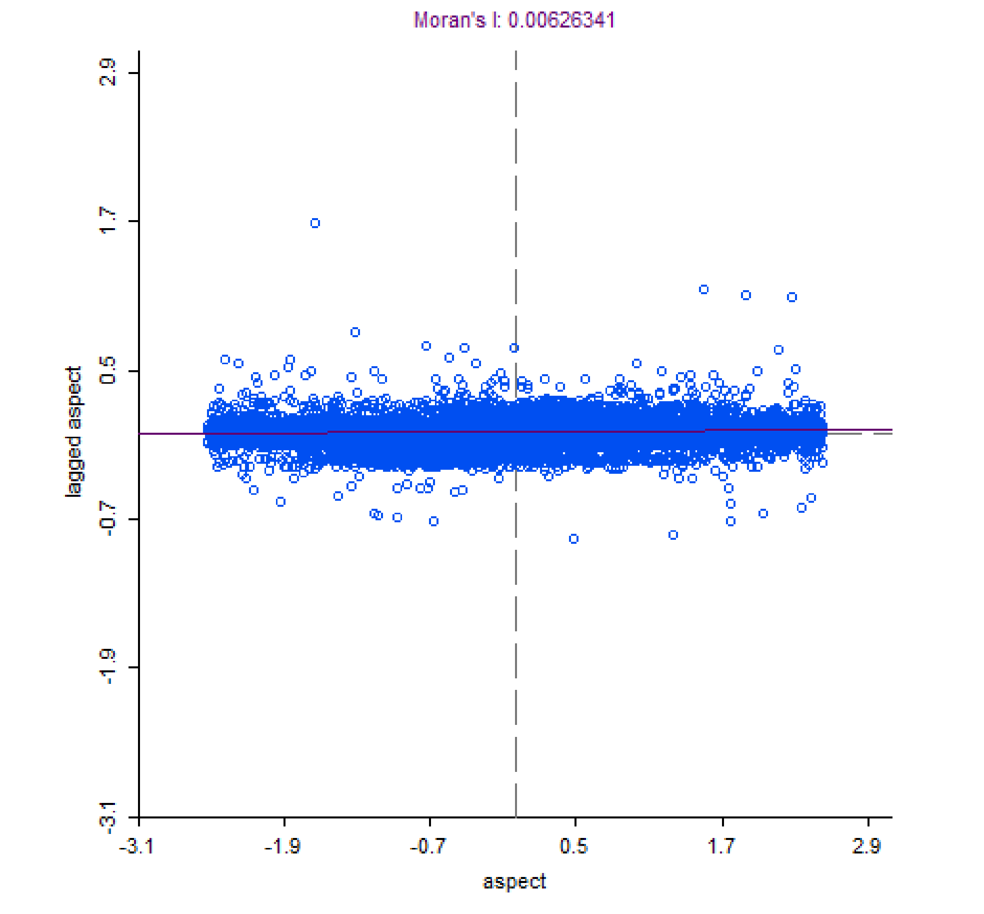
e.g. High correlation with MPA in alpine environment

Shallow landslide EWS: where?

The approach is based on multivariate statistical analysis considering territorial parameters (lithology, soil, curvature, elevation, climate, aspect, slope, land use, MAP, etc.) and shallow landslides distribution.

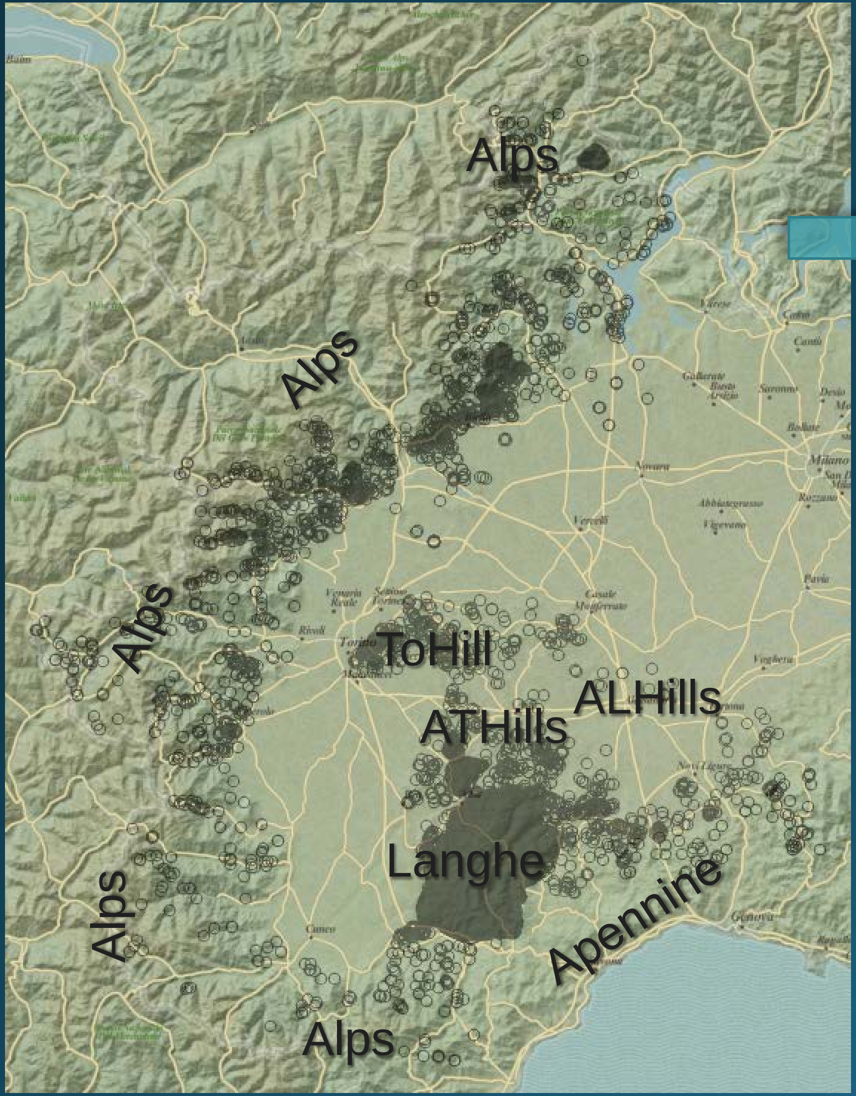


e.g. High correlation with curvature in hilly environment

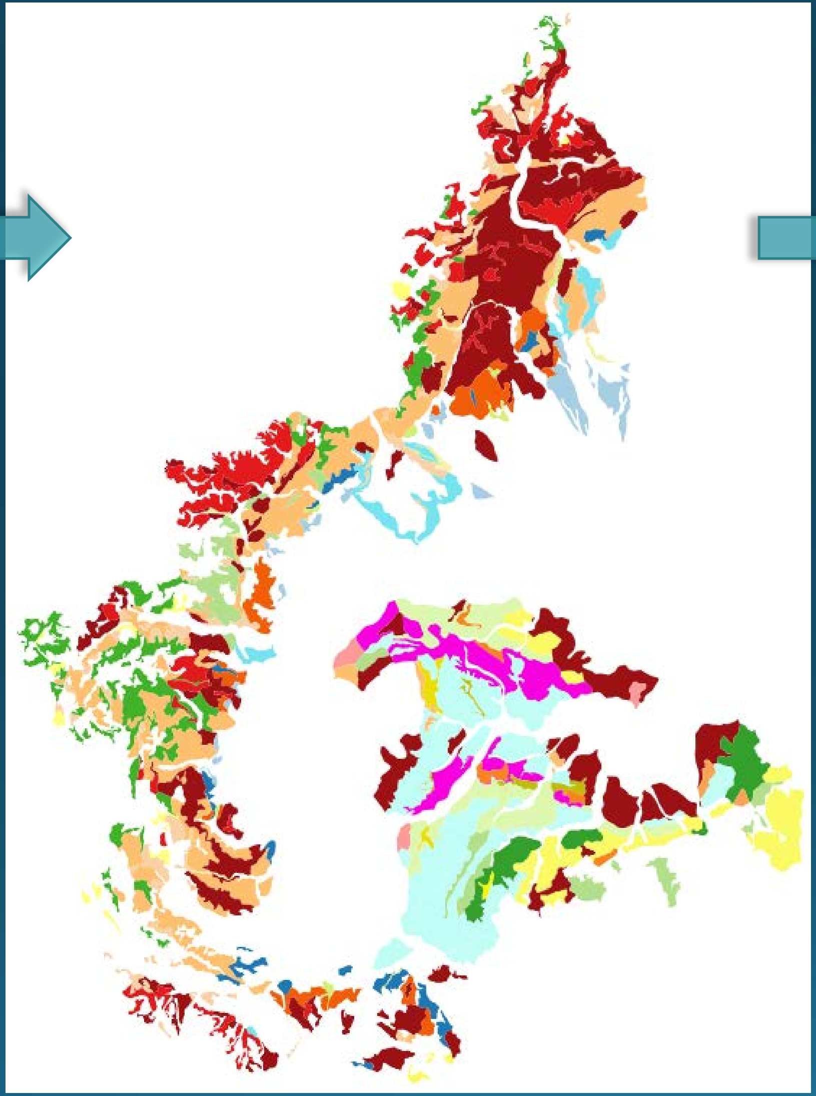


e.g. No correlation with aspect in hilly environment

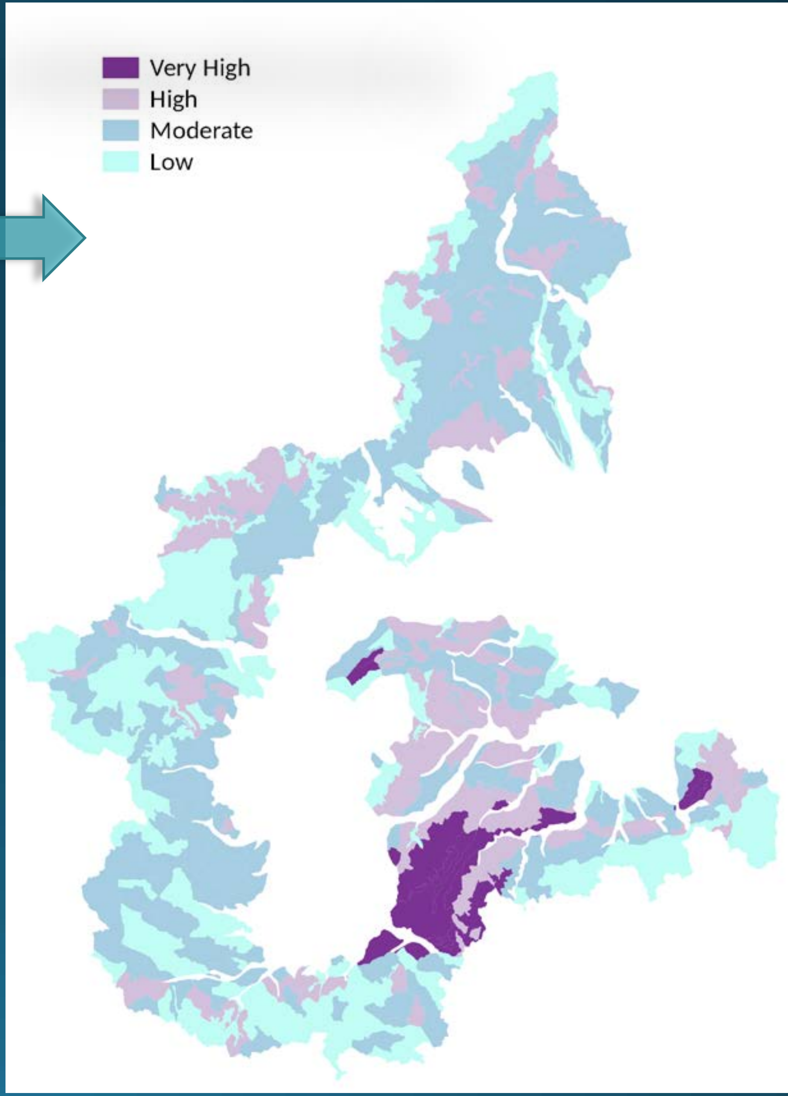
Shallow landslide EWS: Where?



Shallow landslide density distribution based on about **35,000** landslides



Zonation from correlation of territorial parameters and SL density



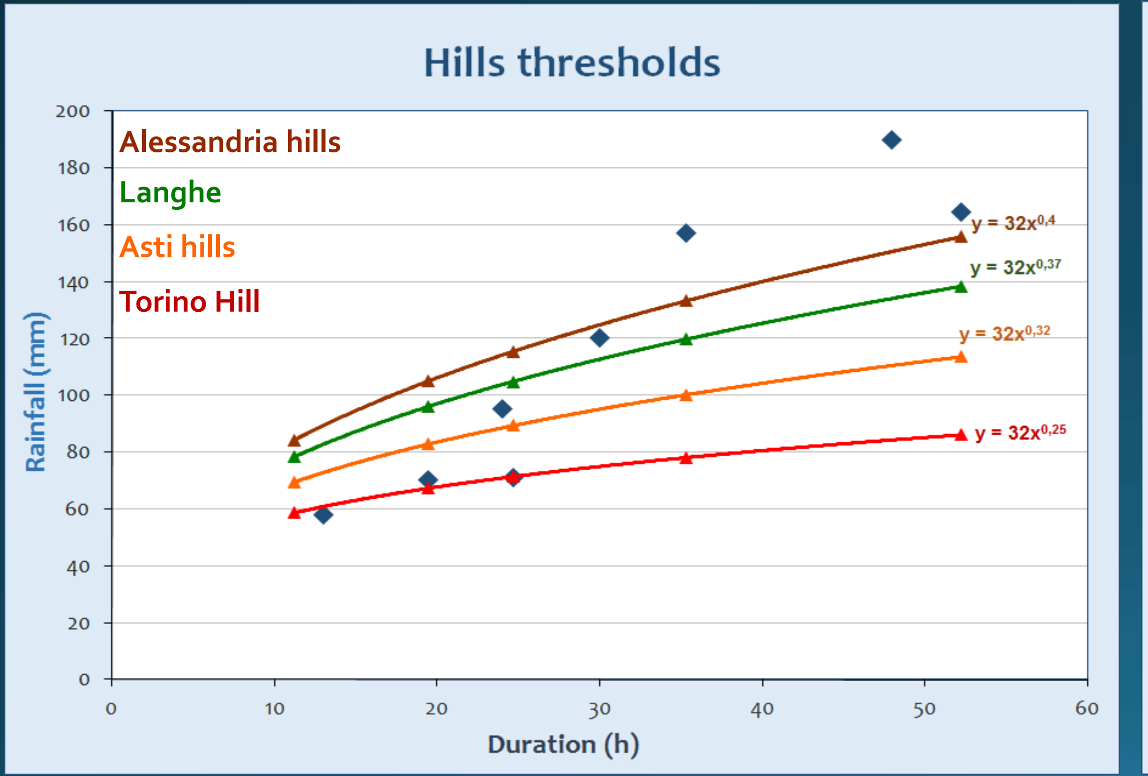
Resulting **susceptibility map** (probability of wide SL event occurrence)

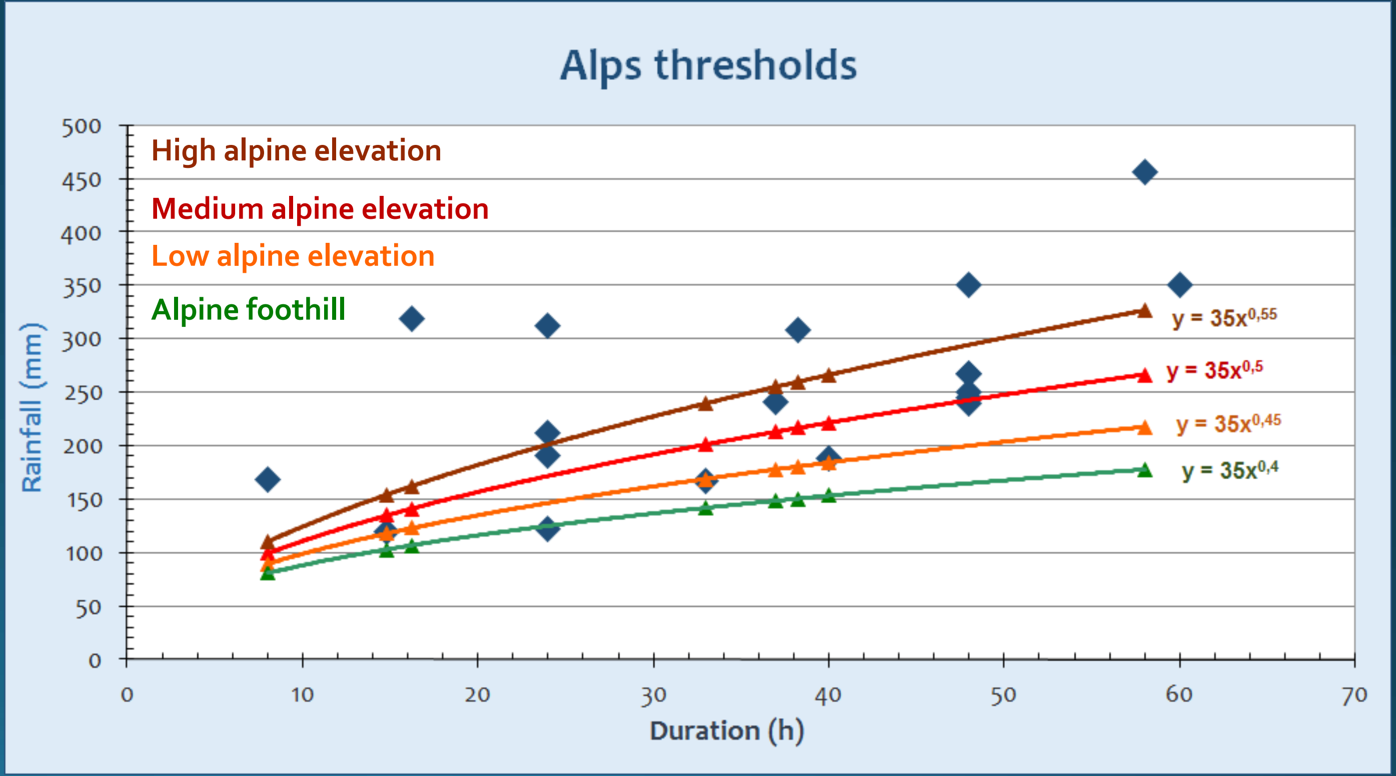
Shallow landslide EWS: When?

Recorded landslides (500 having info on triggering time) and related critical rainfall are lumped into a single value of critical rainfall, calculated as the mean duration and mean cumulative rainfall. This value is used to represent the whole wide landslide event. Following this simple procedure, each marker in the *I-d* plot is representative of all the landslides triggered during a single rainfall event ("Pragmatic thresholds" Tiranti and Rabuffetti, 2010). The general expression of the rainfall threshold is:

$$I = a \cdot d^{n-1}$$

where "*n*" is the Montana coefficient (Estorge et al., 1980) characteristic of the intense rainfall in the studied area (Boni et al., 2001). So that, in the calibration process, the variability ranges of "*n*" in each area is fixed while "*a*" remains the only free (experimental) parameter.

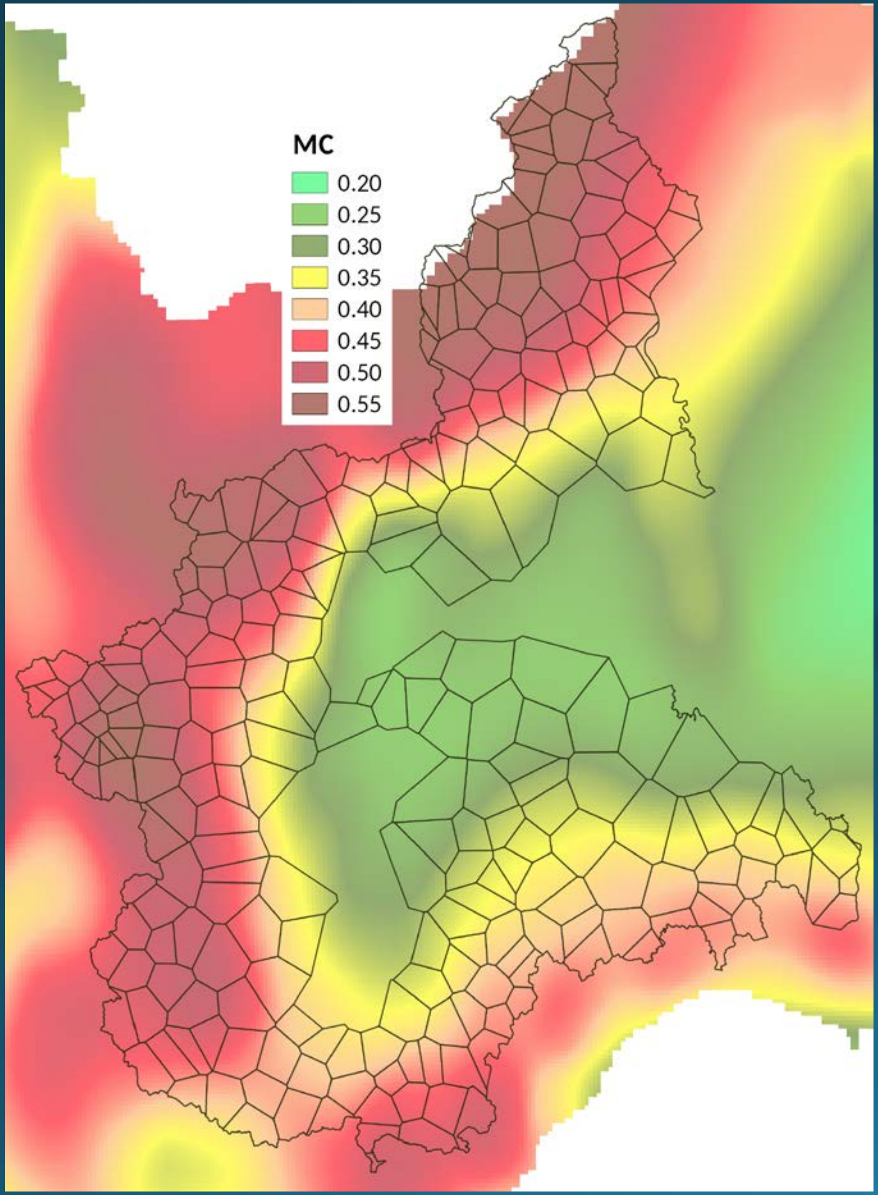


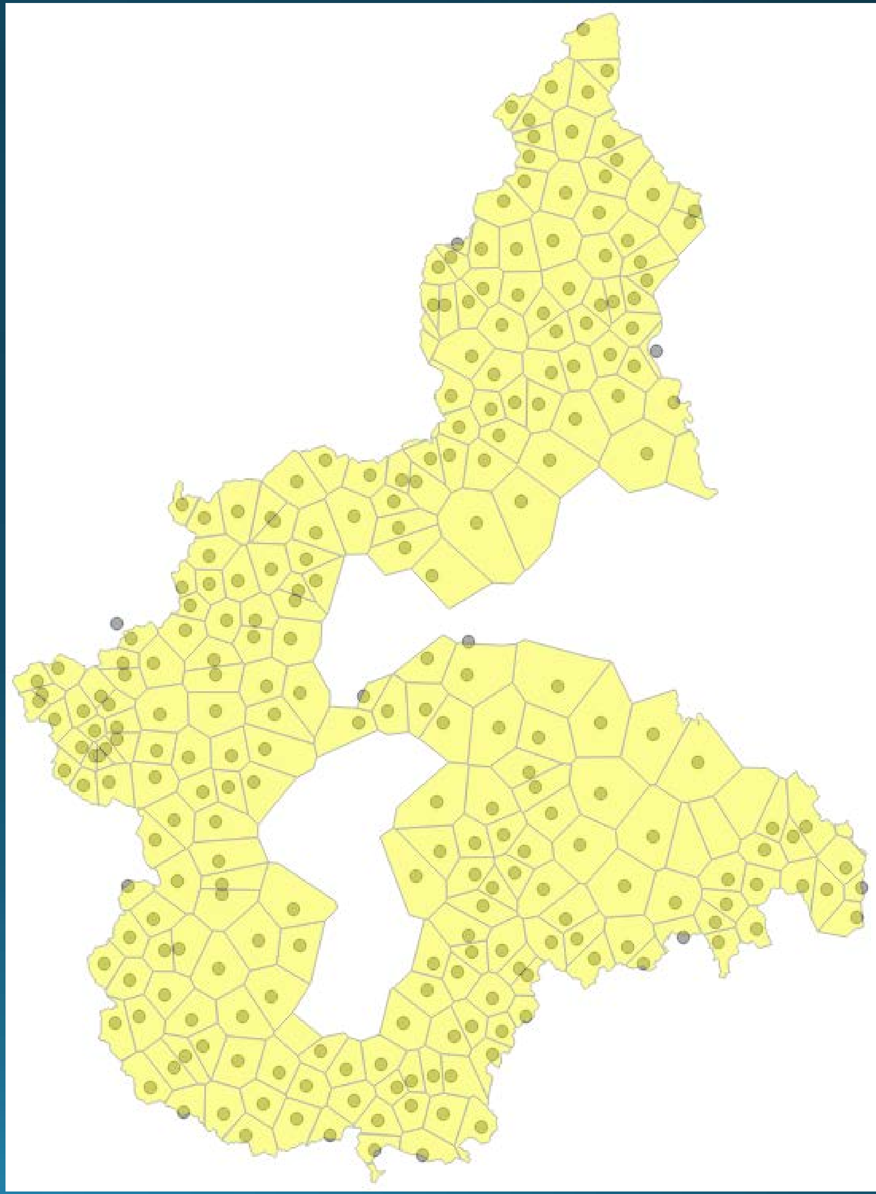


Based on landslide events mean triggering rainfall values distribution, different threshold were identified for each alpine and hilly environments.

Shallow landslide EWS: When?

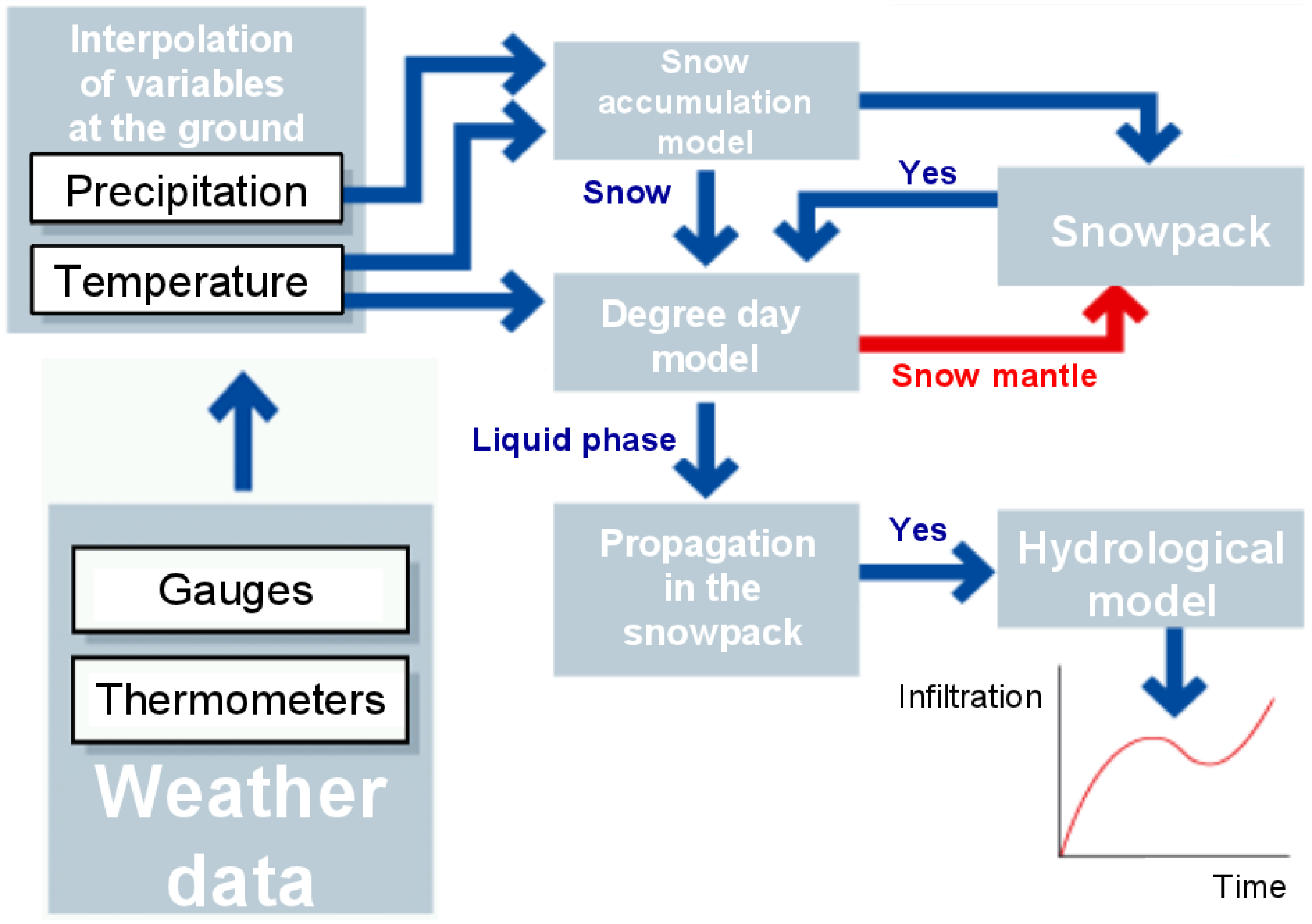
Thresholds, differentiated by MC index and experimental results, have been linked to each raingauge according to different environments, using Thyssen polygons.



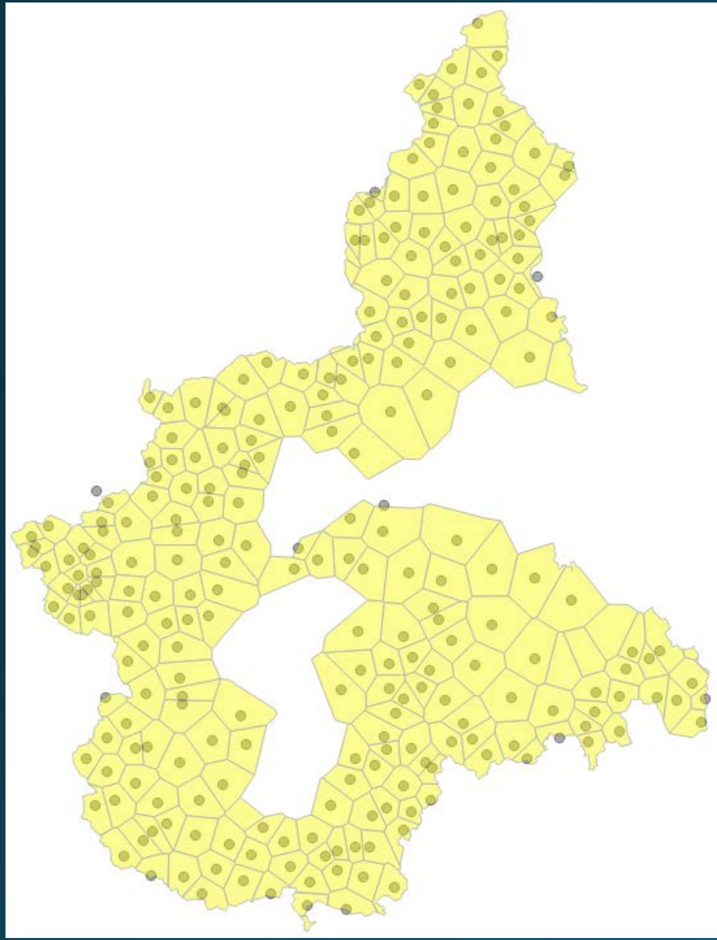


Shallow landslide EWS: When?

Moreover, for each Tyssen poligon the T_o condition (soil moisture derived from previous 24-hours rainfall or snowmelting accumulation) is calculated by a distributed hydrological model every day.



Shallow landslide EWS: Where & When



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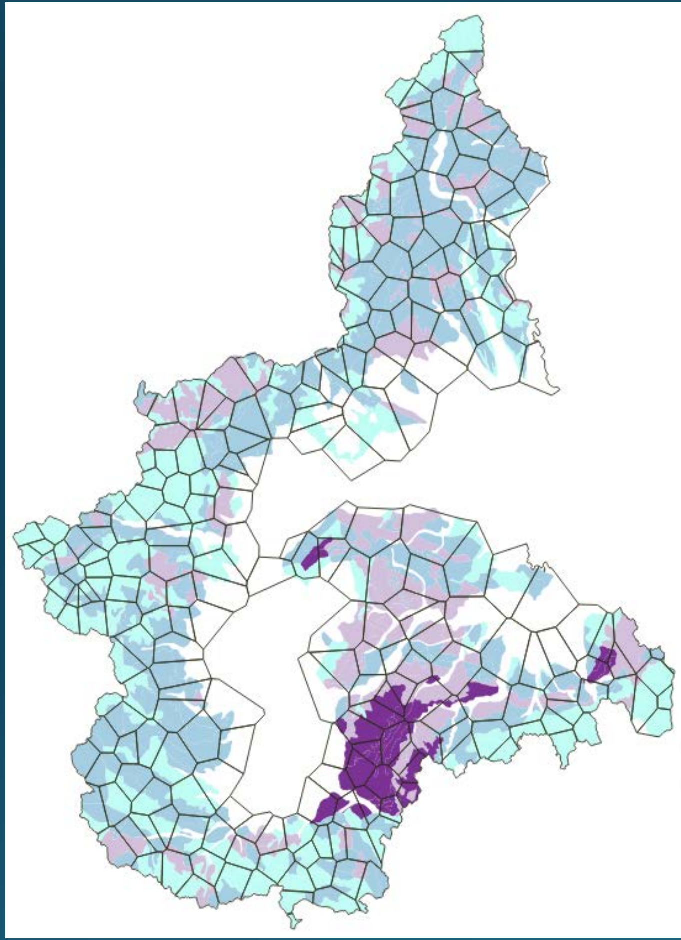

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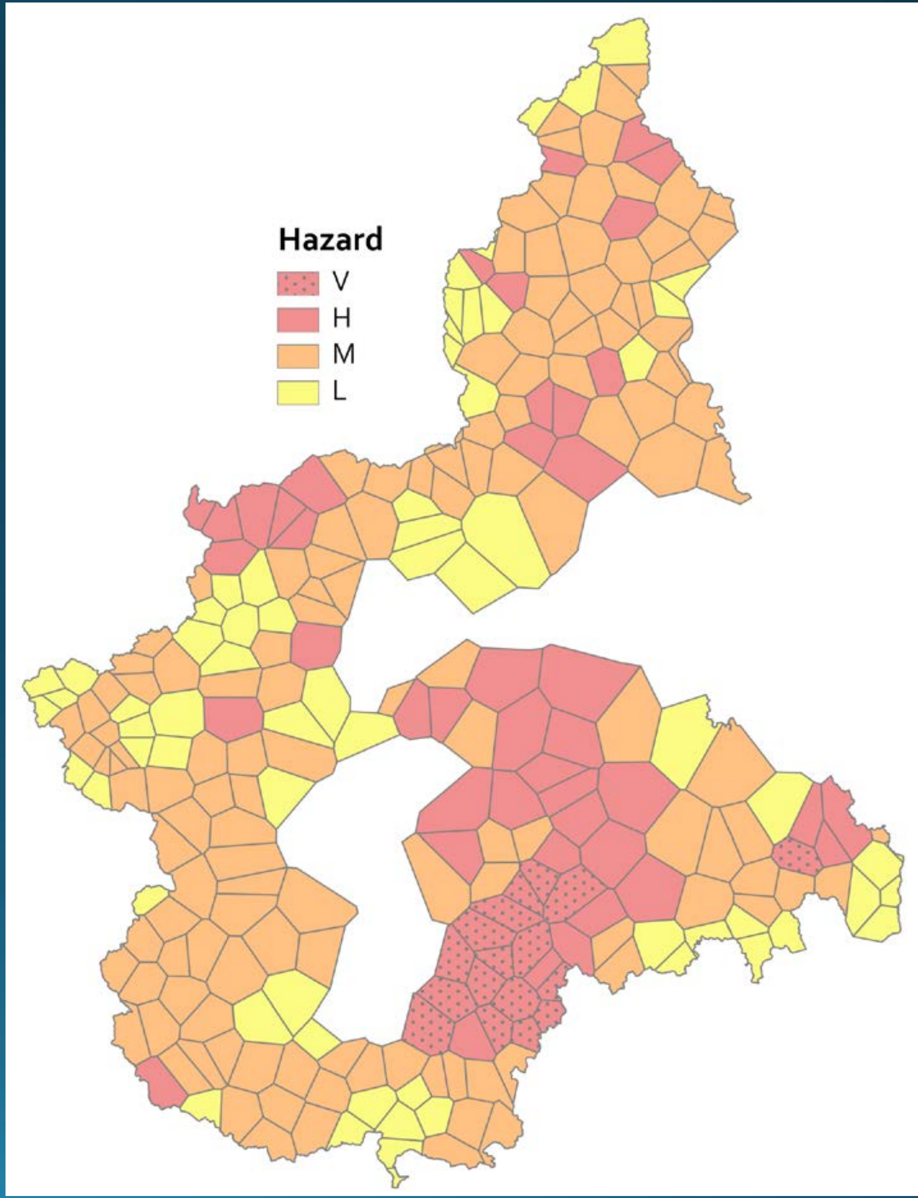


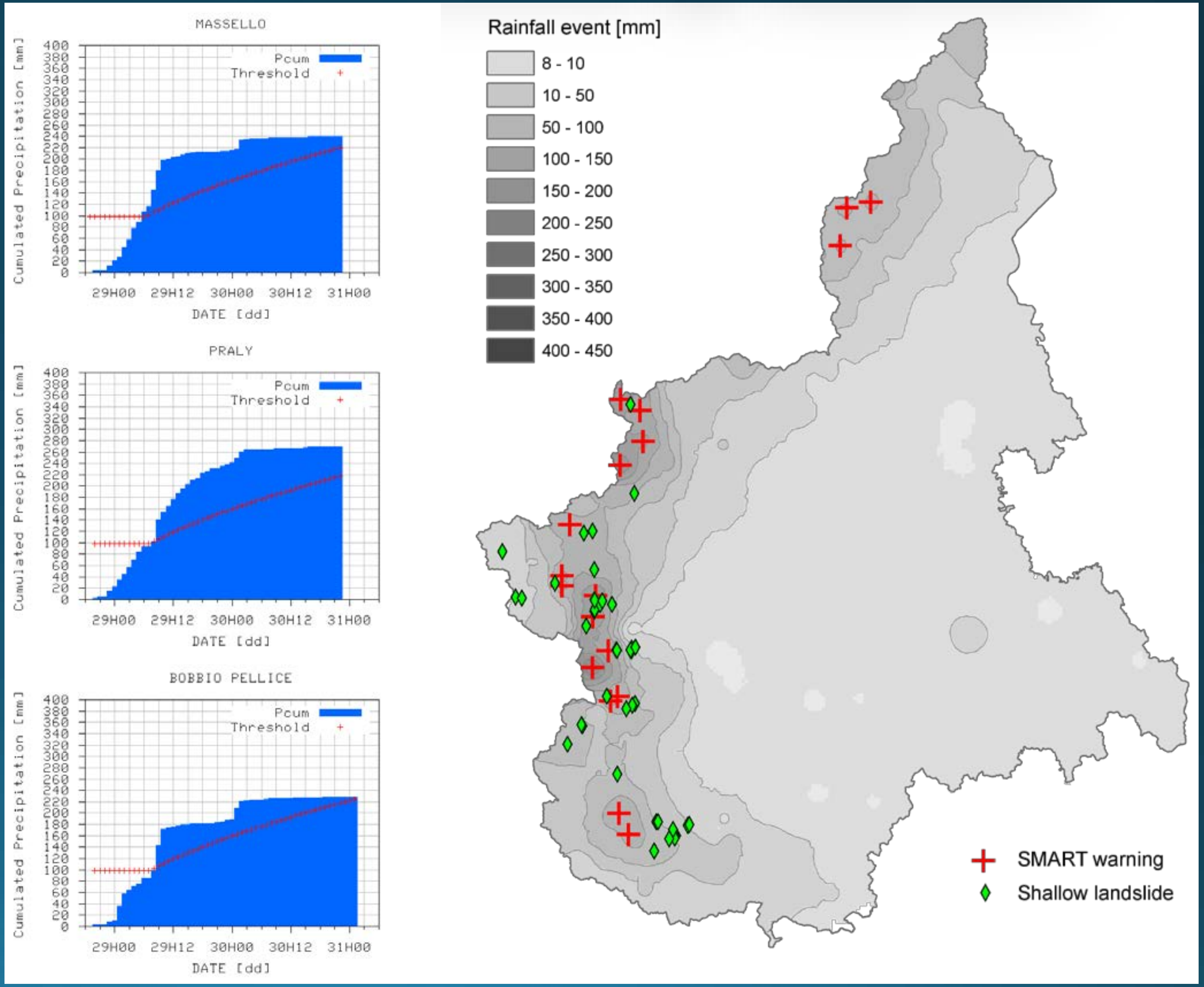
By the intersection between Thyssen polygons and susceptibility map, an EWS hazard zonation for shallow landslide activations was obtained. So, when a threshold is exceeded in a polygon, we get also a direct information about the likely number of triggers per km². So, we answered also to the question "**How many?**"!

Shallow landslide EWS: Where & When

A dedicated tool "Shallow landslides Movements Announced through Rainfall Thresholds" (**SMART**) is set up to elaborate rainfall time series for each rain gauge in real-time.

After setting a threshold of interest, **SMART** is able to identify the complete set of critical rainfall events for each gauge station (i.e. cumulative rainfall is greater than the threshold value for the specific duration).

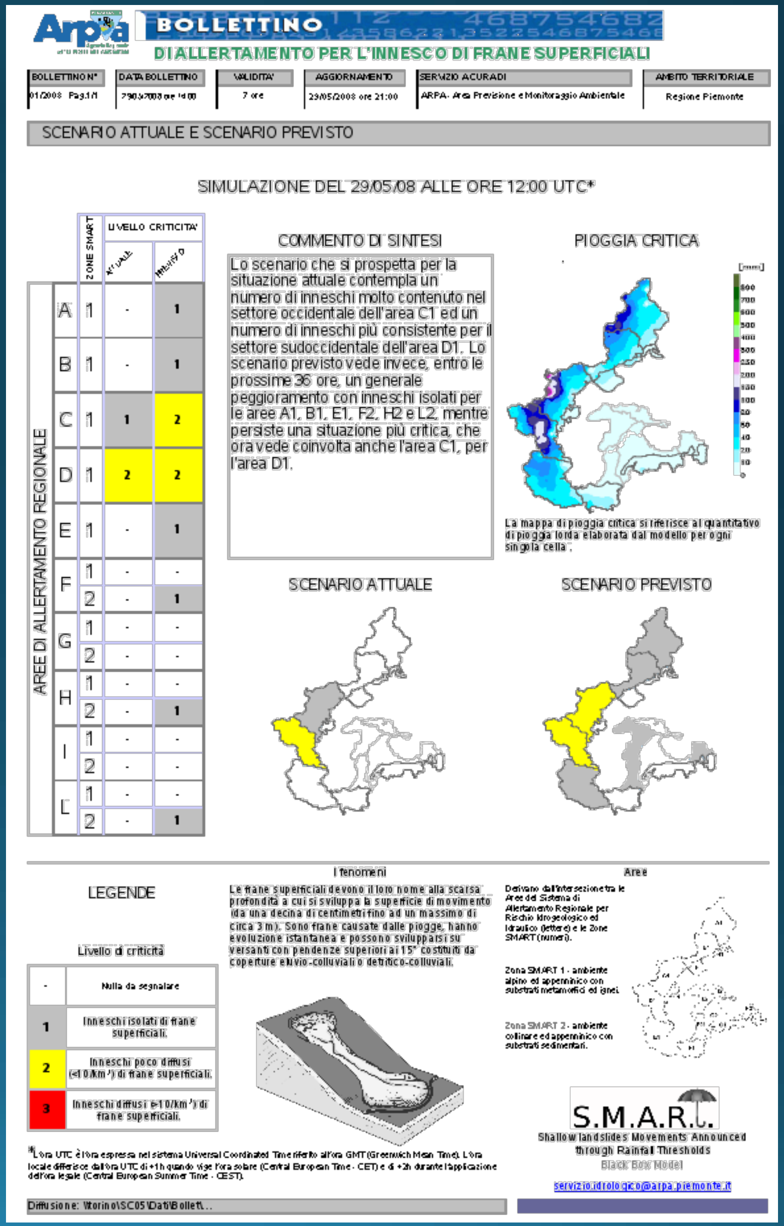
The tool identifies the beginning of a rainfall event, defined as 12 hours of continuous rainfall, with interruptions not exceeding 6 hours.



How to communicate?

- The **SMART** warning bulletin is released every day. The extraordinary emissions according to the alert degree.
- Real-time and forecasted scenarios are summarized using a simple and immediate layout.
- Bulletins are diffused by our institutional website:

http://www.arpa.piemonte.it/rischinaturali/rischi/rischio-idrogeologico/frane-superficiali/scenario-attuale.html



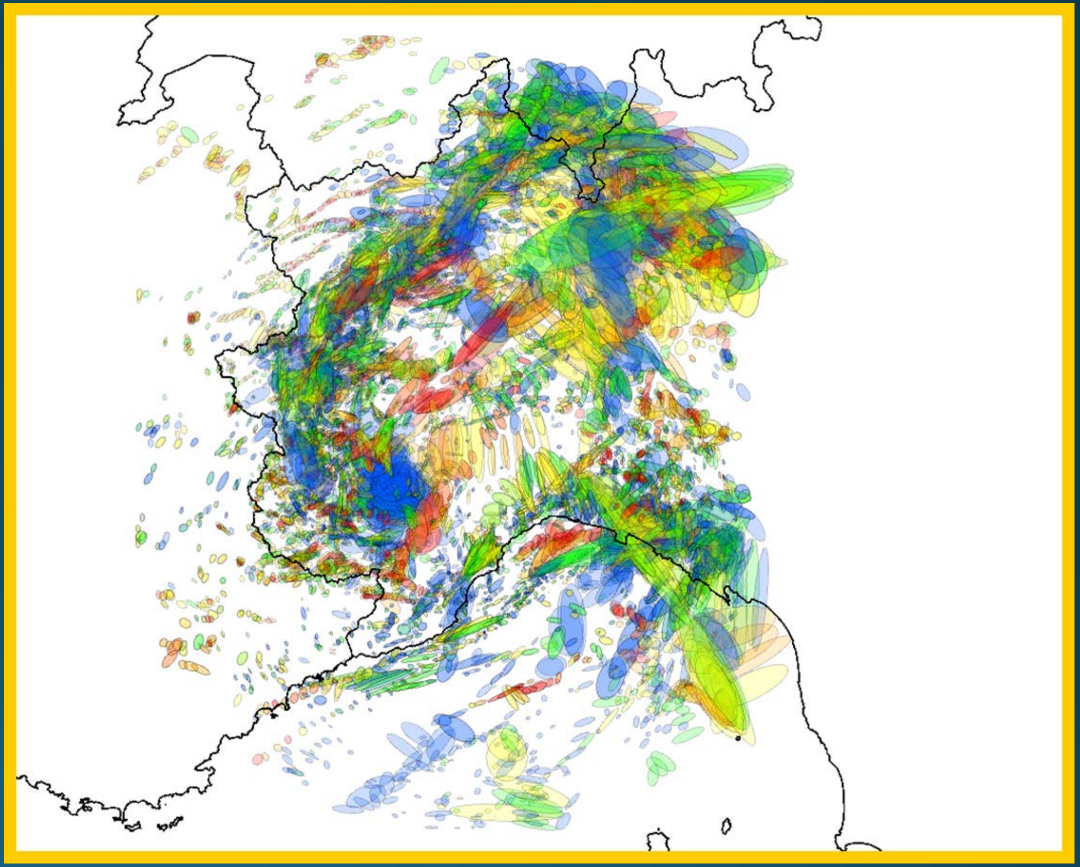
Debris flow Early Warning System

DEFENSE

DEbris **F**lows triggEred by storms - **N**owcasting **S**ystEm

"When?" and "Where?" are no longer sufficient...
Another new fundamental question is:

What?



Geological model + Radar Storm Tracking

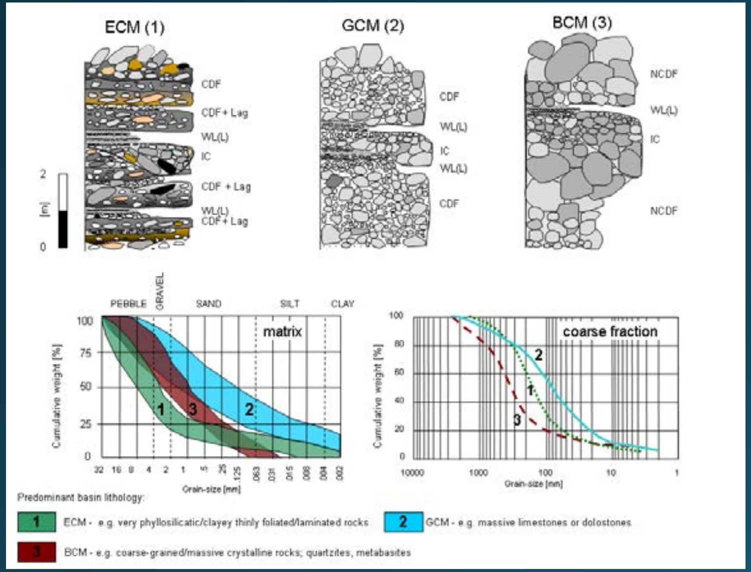
Debris flow EWS: What?

The geological model is based on the dominant lithofacies of the catchment bedrock that affects the characteristics and behavior of torrential processes and architecture of alluvial fans (Tiranti et al., 2008; 2014, Tiranti and Deangeli 2015, Tiranti et al., 2016). Catchments were classified into three main classes of catchment lithology through the **Clay Weathering Index (CWI)** which indicates the propensity of lithofacies to weather into clay or other fine minerals with clay-like rheology behavior (e.g. other phyllosilicate groups):

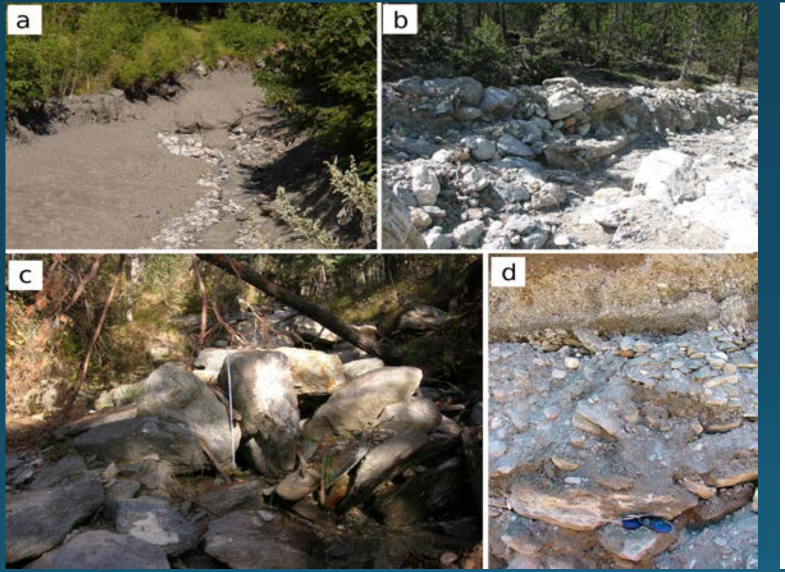
- Excellent Clay-Maker (ECM) catchments are mainly formed by rocks having a very high propensity to weather into clay or clay-like minerals (e.g. thinning-foliated and phyllosilicates-rich metamorphic rocks);
- Good Clay-Maker (GCM) catchments are mainly formed by rocks having a good propensity to weather into clayey silt and clay (e.g. massive carbonate rocks);
- Bad Clay-Maker (BCM) catchments are mainly formed by rocks having a bad propensity to weather into clay or clay-like minerals (e.g. massive crystalline rocks).

Debris flow EWS: What?

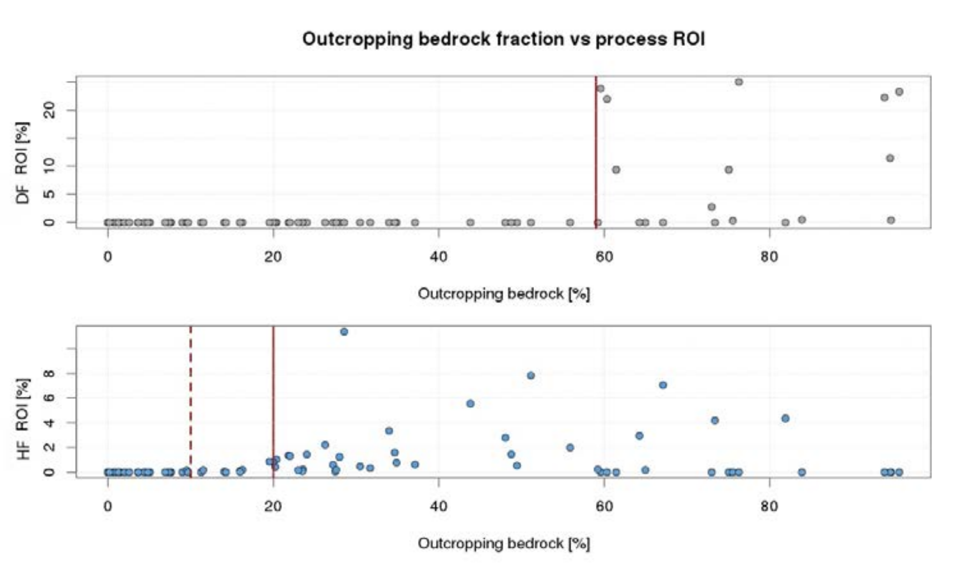
The characterization of rocks and derived shallow deposits is useful for the identification and evaluation of potential source areas. What is evident is a different amount of unconsolidated material production, both in terms of abundance and grain-size, depending on the catchment lithologies. The unconsolidated material in the catchment area affects the depositional style of debris flows and is directly linked to the rheology. Depositional styles are easily identifiable for each catchment class through direct field observations in channel beds and in alluvial fan areas.



Each CWI class identify different sedimentological characteristics



depositional style

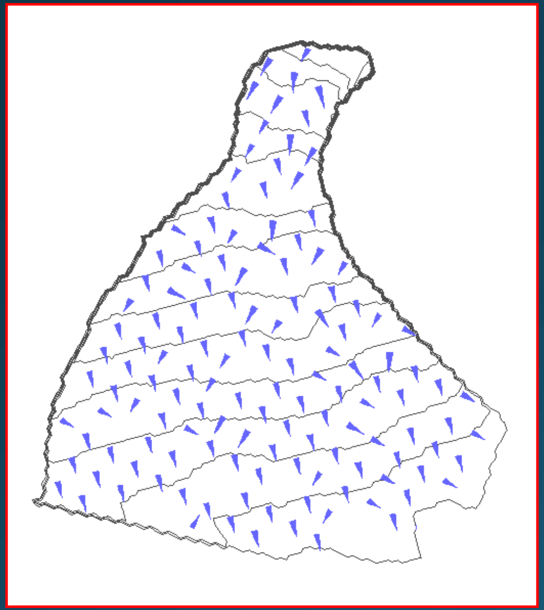


the torrential process type (water, hyperconcentrated and debris flow) is driven by the percentage of outcropping bedrock in a catchment.

Debris flow EWS: What?

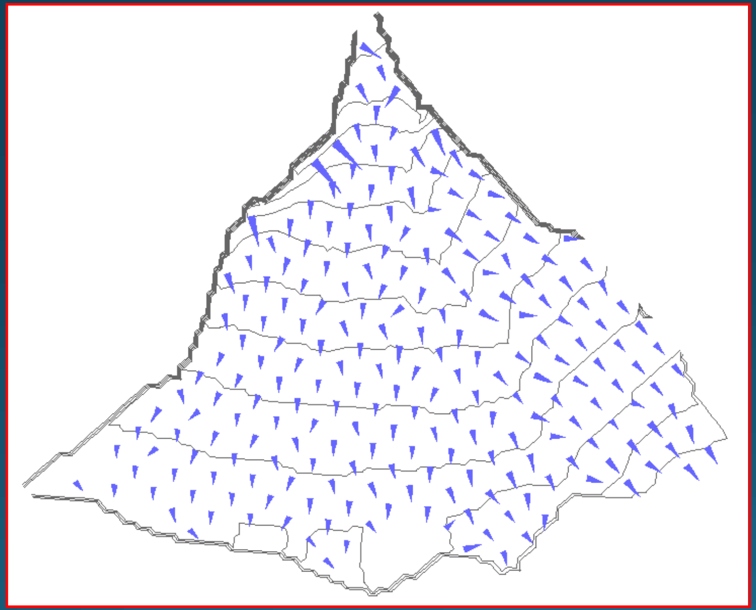
CWI classes also describe the alluvial fans characteristics: size, shape, morphology and grain-size distribution.

ECM
areafan/areabasin = 5%



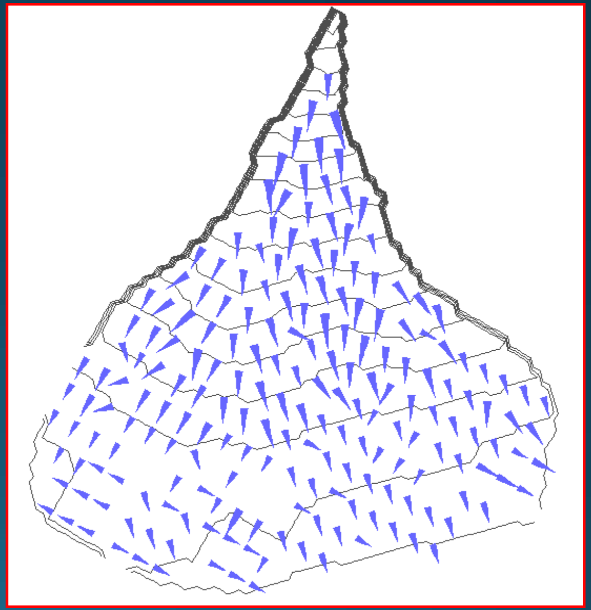
characterized by moderate slope and an irregular geometry.

GCM
areafan/areabasin = 20%



characterized by regular geometry (fan-shaped) and gentle slope.

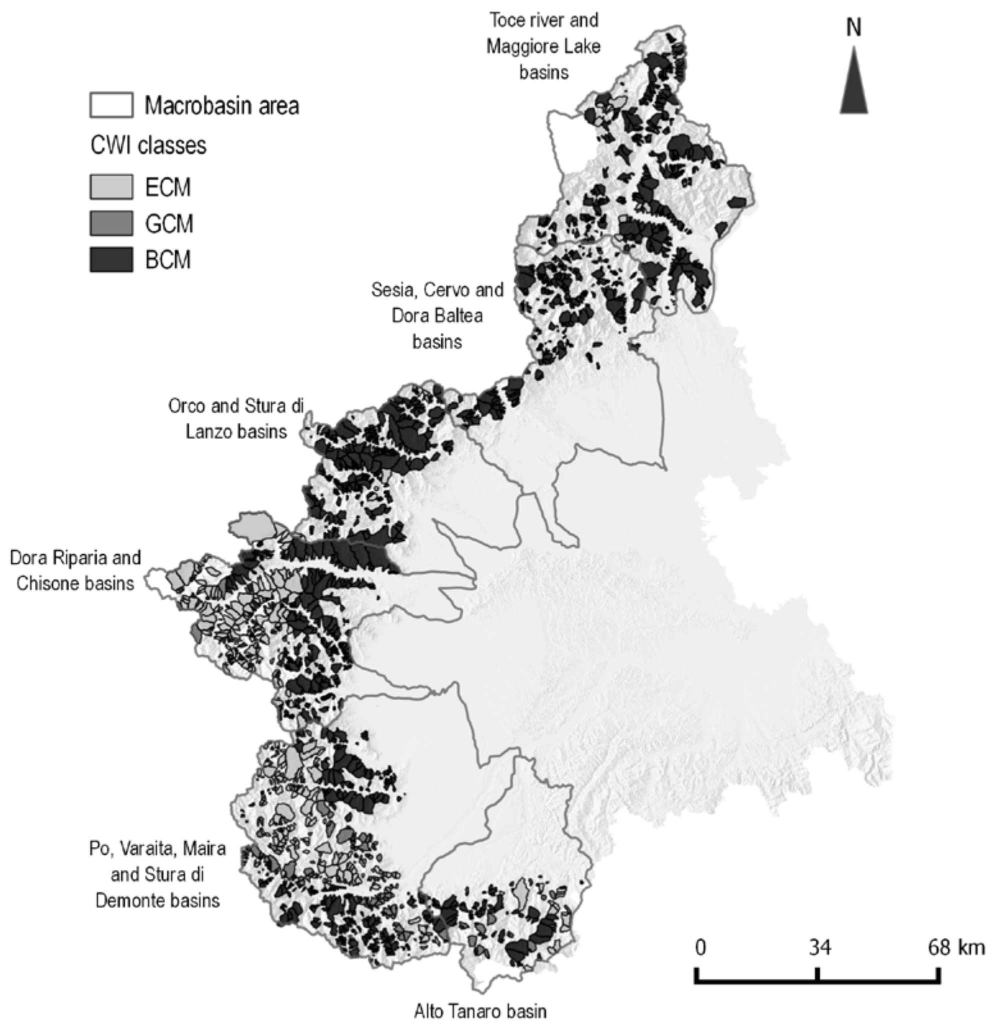
BCM
areafan/areabasin = 5%



characterized by lobe-shaped geometry and high slopes particularly at the apex of the fan.

Debris flow EWS: Where & When?

Answer to "Where?" is simple... But, to solve the problem "When?" 2,100 basins and all the recorded events from 1728 to 2015 were analyzed.



CWI basin class	Dominant rheology	Minimum triggering recurrence [years]	Minimum triggering rainfall type	Main occurrence season
ECM	CDF (viscoplastic)	2	storm of moderate intensity (≥ 20 mm/h)	summer
GCM	CDF (viscoplastic)	5	storm of high intensity (≥ 30 mm/h)	late spring
BCM	N-CDF (frictional/collisional)	20	storm of very high intensity (≥ 50 mm/h)	autumn and spring (rarely in summer)

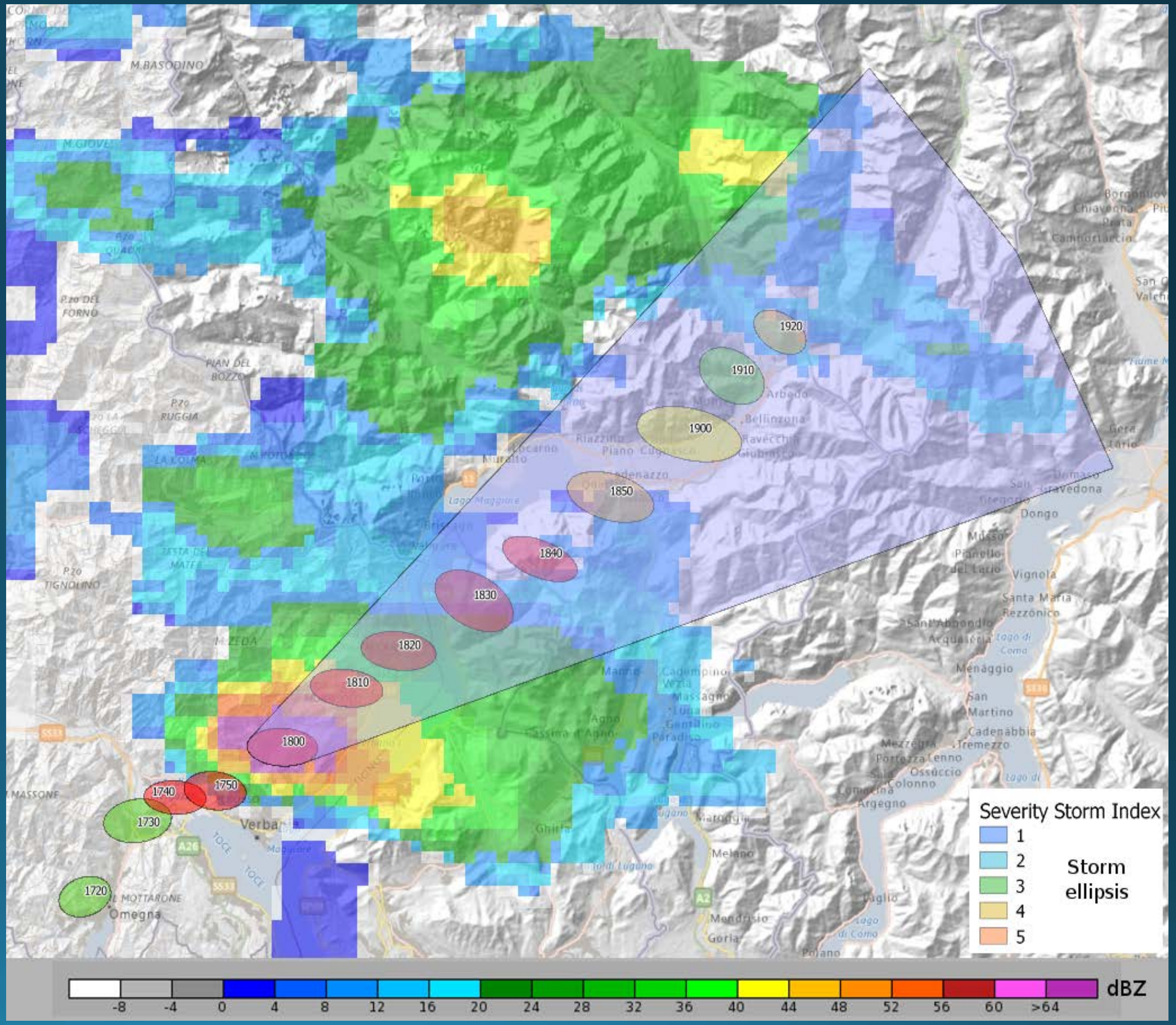
Debris flow EWS: When?

From historical debris flow events results clearly that debris flows are mainly initiated by short and intense rainfall (rainstorm or high intensity peaks during a prolonged rainfall event).

Rain gauge networks often miss localized and intense precipitation events (Duncan et al., 1993), while weather radars allow the monitoring of rainfall over large areas, with a high spatial and temporal resolution, if the radar echo exceeds the minimum detectable signal.

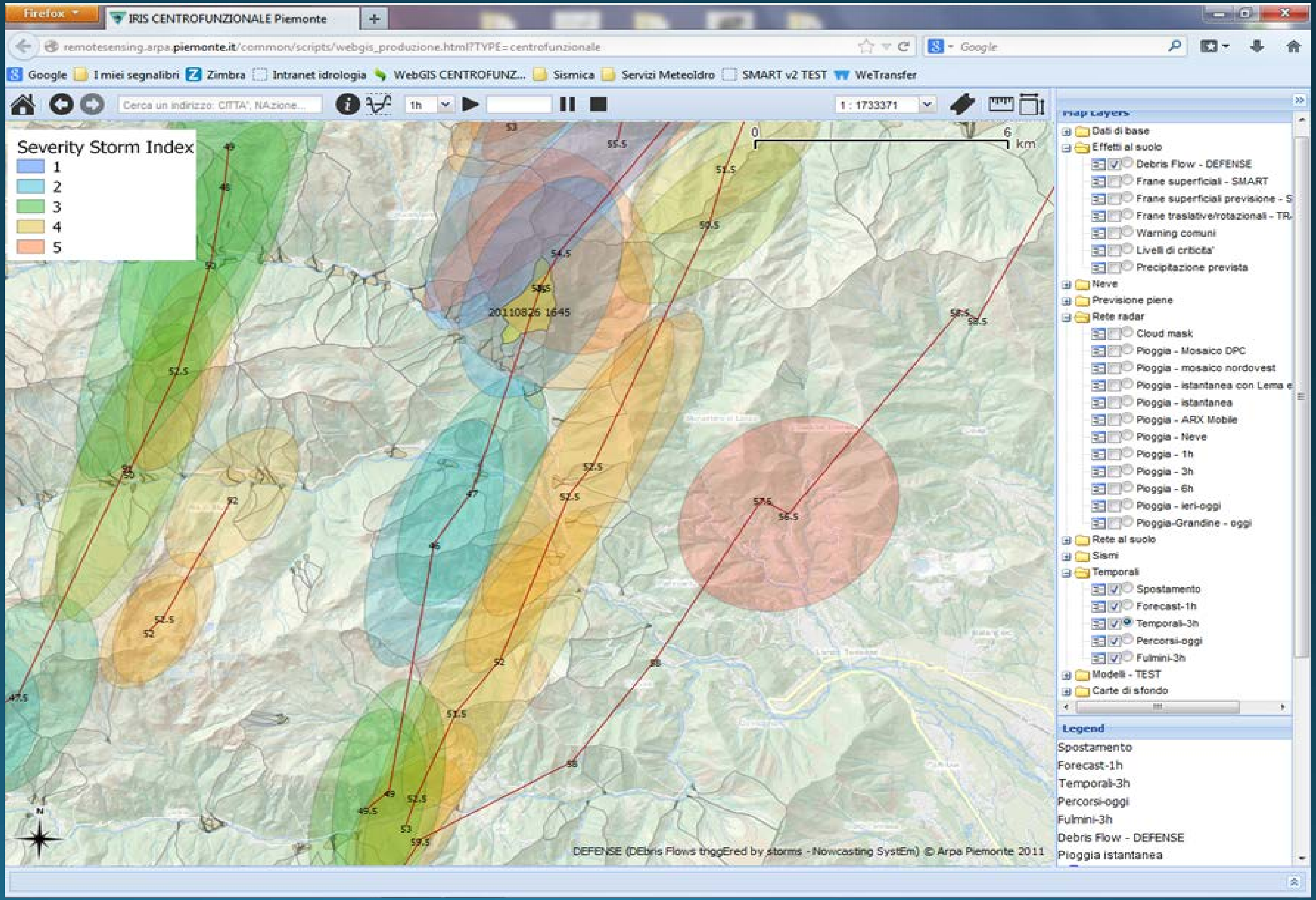
In order to identify convective precipitation cells, a storm identification and tracking algorithm was employed. The storm-tracking algorithm detects convective events with a maximum reflectivity larger than a given threshold (40 dBZ) and tracks them in space and time.

Every five minutes **DEFENSE** analyses weather radar and satellite data, localizing potential damaging storms, and it produces a georeferred dataset with relevant storms parameters (i.e. position, displacement velocity, severity). The expected ground effects of the storms are evaluated performing geographical operations by a spatial database and GIS functions.



Debris flow EWS: What, Where & When

DEFENSE identifies, among all storm, severe storms (i.e. storm severity index greater than three), whose area is over or it will impact in the following 60 minutes upon CWI pre-classified basins; automatic warnings for debris-flow occurrence are then produced (e-mails and SMSs to experts and stakeholders).



Highlights

- ✓ SMART works using rainfall values recorded by raingauges network and traditional weather forecasting (weather radar data in a near future);
- ✓ SMART's warnig is disseminated as a bullettin by institutional WebSite everyday (public);
- ✓ DEFENSE works using only the observations by weather radars in real-time and in nowcasting;
- ✓ DEFENSE's warnig is disseminated by e-mail and SMS messages when a critical situation is identified (stakeolders and experts only).

Thanks for your attention!

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