LANDWARN: AN OPERATIVE EARLY WARNING SYSTEM FOR LANDSLIDES FORECASTING BASED ON RAINFALL THRESHOLDS AND SOIL MOISTURE

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Outline:

Italian network of functional centers

Landslide risk in Umbria Region

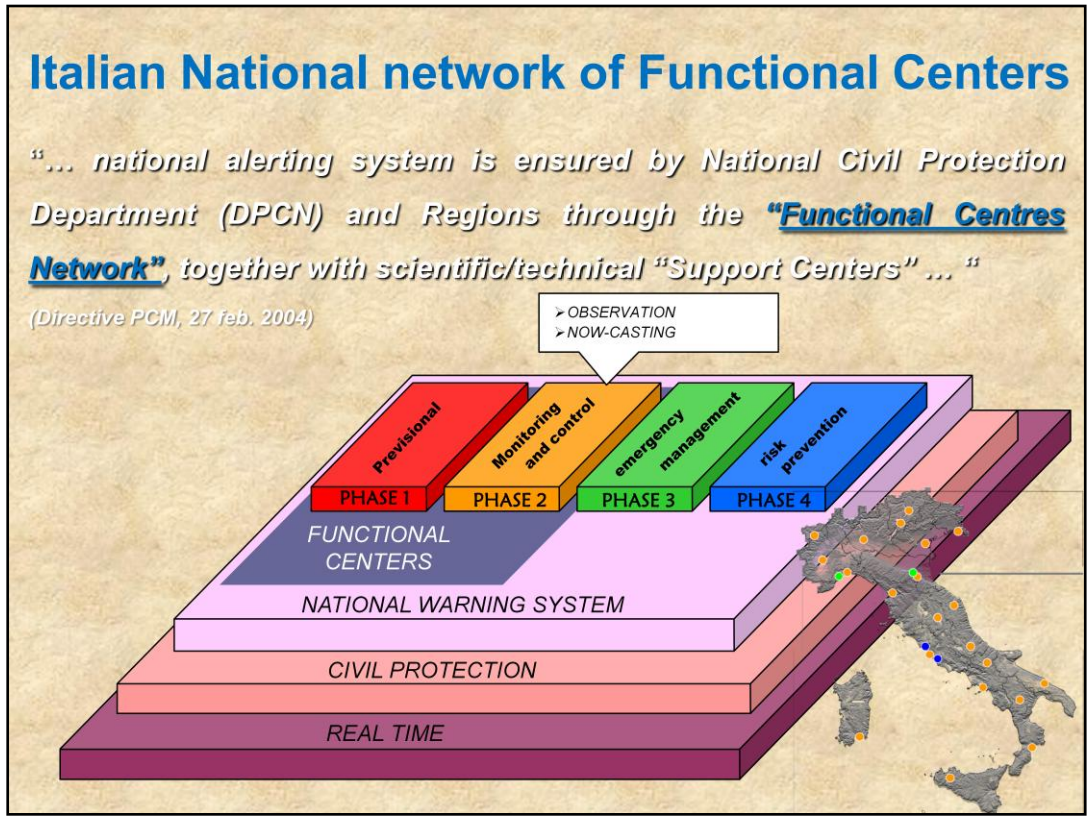
Soil moisture and rainfall thresholds

The Landwarn system

Appl.1 – high risk landslides

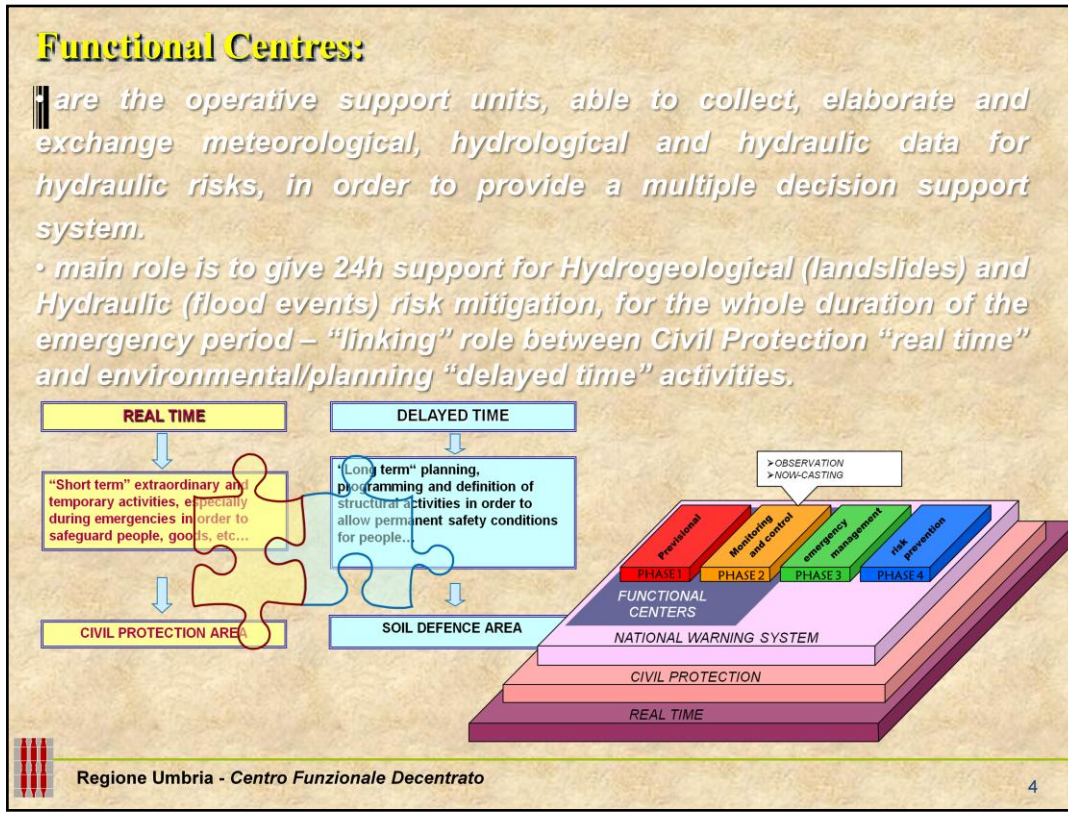
Appl.2 – risk scenario

Appl.3 – the Torgiovannetto rockslide



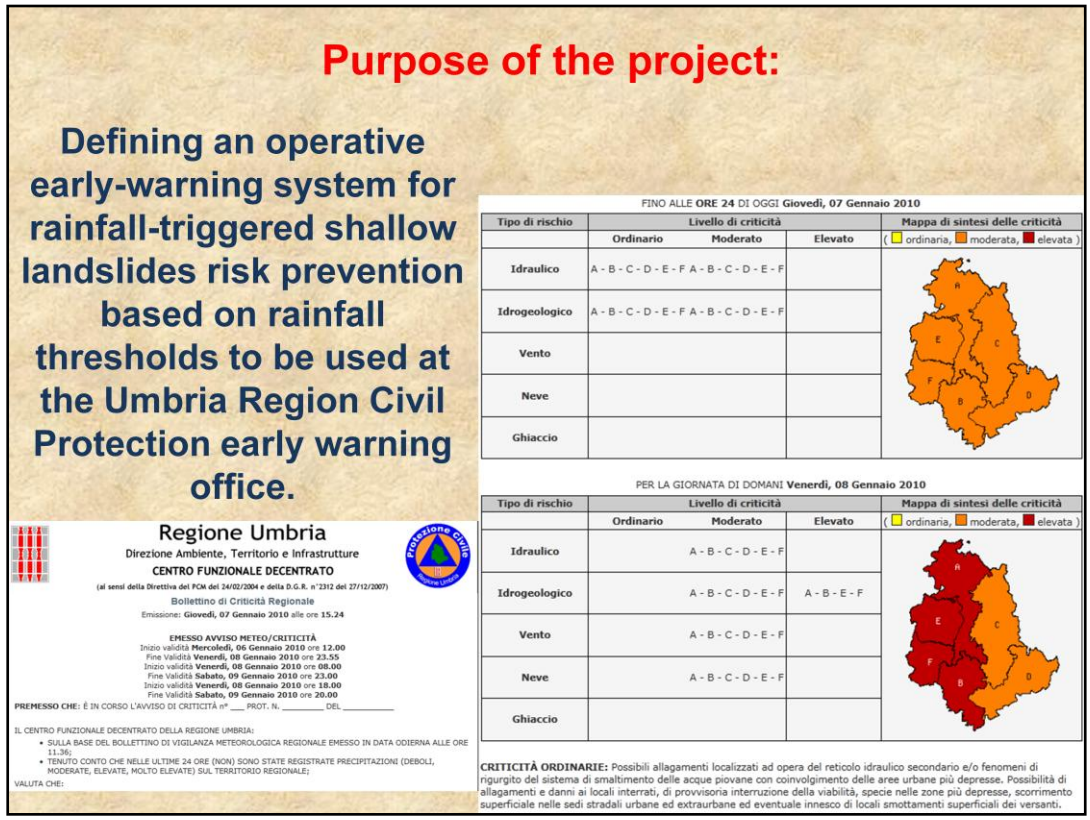
A very short description of the functional center network: regarding the Hydraulic and Hydrogeological risk, the national alert system is ensured by the National Civil Protection Department (DPCN), through the Functional Centres Network, together with scientific/technical Support Centres, named "Competence Centres".

The role of the Functional Center is to support the national alerting system at regional scale, managing the previsional phase and the monitoring and control during the event phase, ensuring the flow of data to the civil protection for the emergency and the management of the event phase.



The CFD is in charge to acquire and collect both real time and quasi-static data: quantitative data from monitoring networks (hydrometeorological stations, meteo radar, ...), meteorological forecasting models output, Earth Observation data, hydraulic and hydrological simulation models, cartographic and thematic GIS data, planning studies, dam managing plans, non instrumental information from direct control of "territorial presidium".

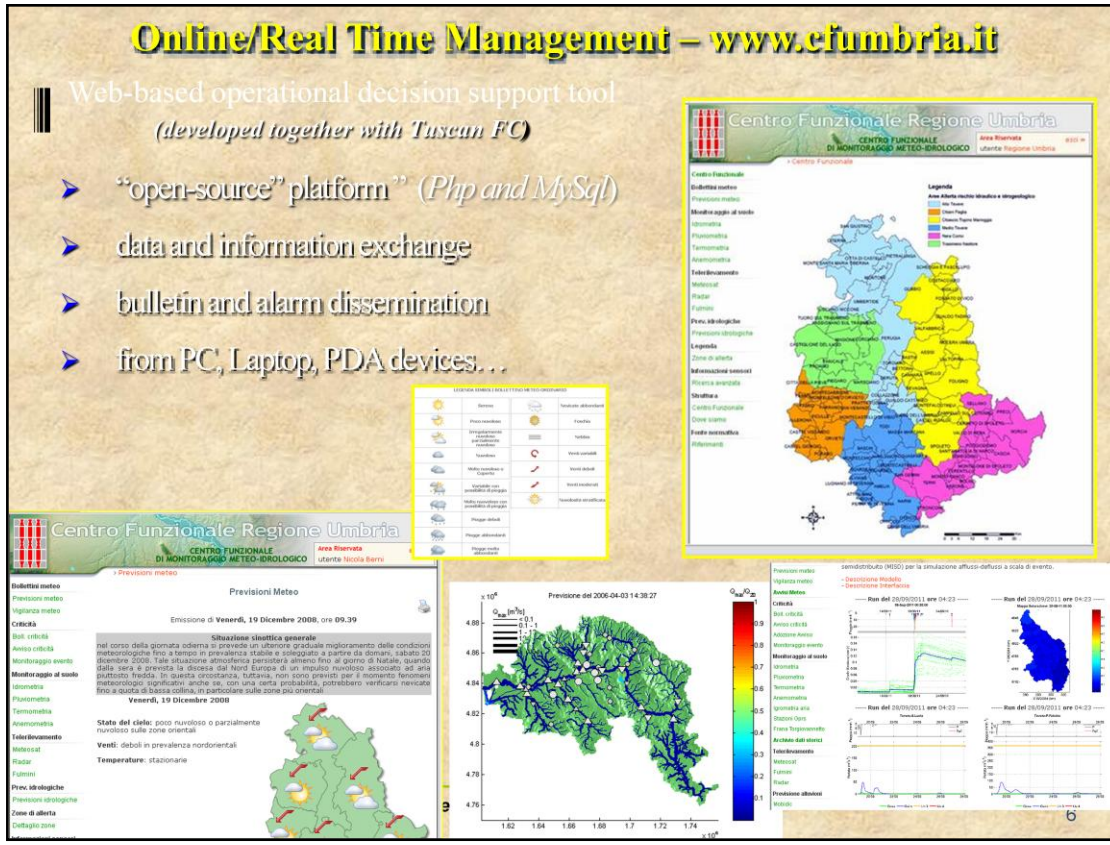
The main role of this office is to manage the previsional phase, furnish 24h support for hydrogeological and hydraulic risk mitigation during the emergency period an to create a "link" between Civil Protection "real time" activities and environmental/planning "delayed time" ones.



The alert procedure is based on three Warning levels, named Ordinary, Moderate and High Criticality specified in Umbria region for 6 sub-areas. Specifically, for each duration (from 1 to 48 hours), the Ordinary, Moderate and High Criticality are assigned to the rainfall values corresponding to a recurrence interval of 2, 5, and 10 years, respectively. These thresholds are compared against rainfall observations .

In few words, the purpose of this work was to define a simple, operative early warning system for the landslide risk assessment and management, that is one of the main goals of the Umbria Region Civil Protection Centre (where the Functional Centre is the operative early warning office).

The system is based on the rainfall thresholds, that represent the main element of evaluation for the early-warning procedures of the Italian Civil Protection System. Anyway, In order to improve the performances of the alert system we applied a continuous physically-based soil water balance model, developed in cooperation with the Research Institute for Geo-Hydrological Protection (IRPI-CNR), aimed to the estimation of soil moisture conditions over the whole regional territory .



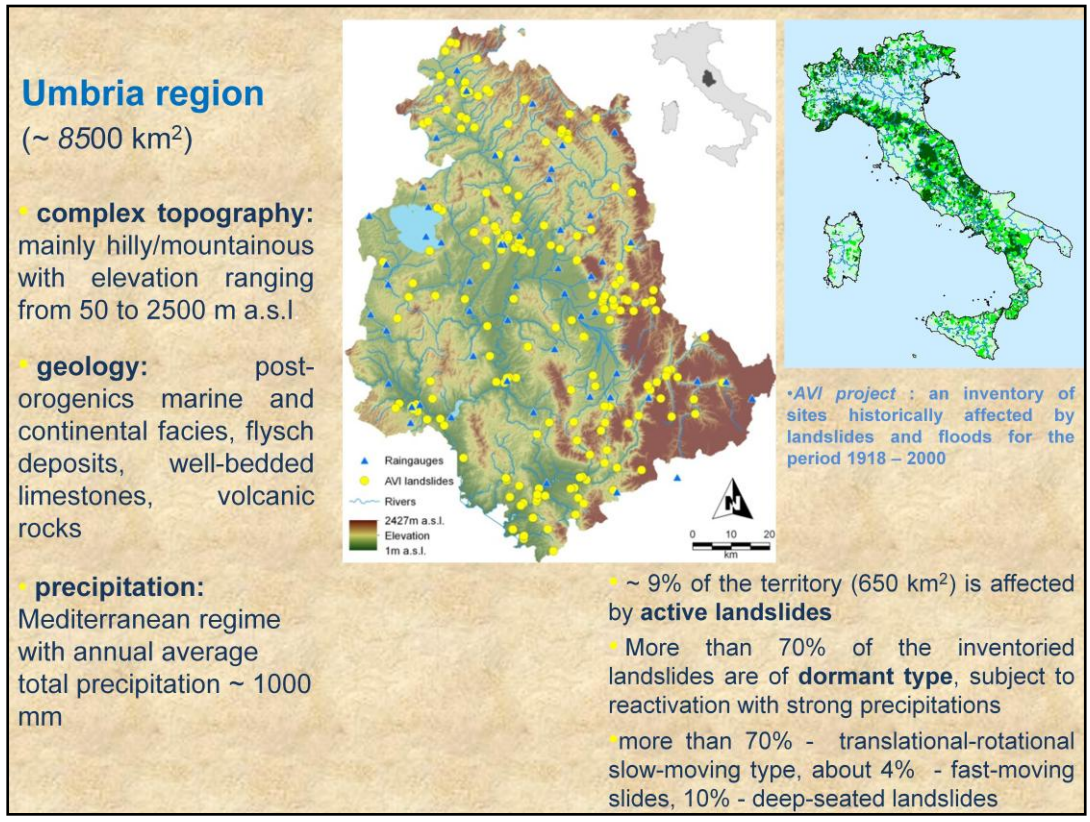
The open-source website www.cfumbria.it represents a fundamental decision support tool for real time data and information exchange with all the administrations and subjects involved.

Our website is able to publish the following sections:

-Alarm zones interactive description

- Meteorological forecasting

- hydraulic and hydrological simulation models

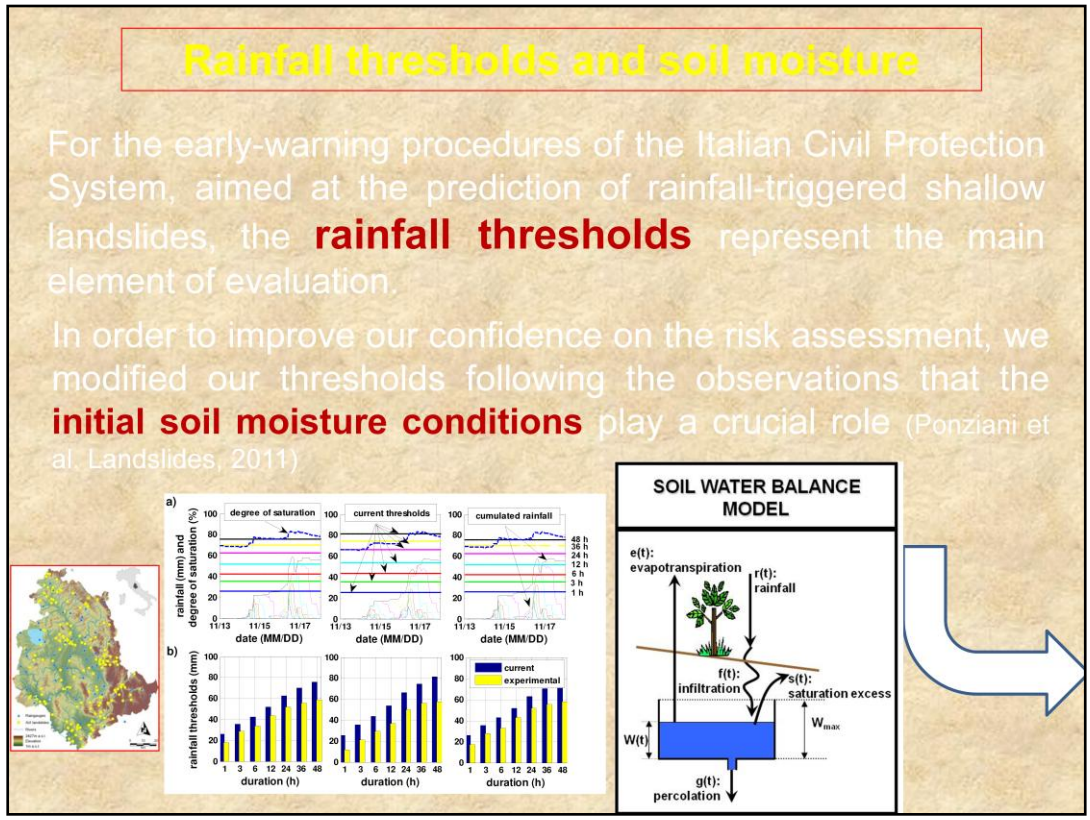


The Umbria Region, located in central Italy, is one of the most prone areas to landslide risk in Italy, being almost yearly affected by landslides and flood events at different spatial and temporal scales.

Located in the central Italy, Umbria is characterized by quit a complex topography. The geology is constituted of post-orogenics marine and continental facies, flysch deposits consisting of clay-schist and clay-marl sediments, bedded limestones and volcanic rocks. All municipalities are prone to hydrogeological risk areas and about 9% of the territory (650 km^2) is affected by active landslides. More than 70% of the inventoried landslides are of dormant type, subject to reactivation with strong precipitations.

The analysis of the landslides type shows that most of them (more than 70%) are of translational-rotational slow-moving type, about 4% are fast-moving slides, and 10% are deep-seated landslides. The precipitation regime can be classified as Mediterranean, with distinct dry and wet seasons. Higher monthly precipitation values generally occur during the autumn-winter period when landslides and floods, caused by widespread rainfall, normally occur. As an example, during a rainfall event that occurred in December 2008, 300 mm of rainfall in 12 days was registered (the mean of maximum monthly rainfall is around 240 mm), with 120 landslides reported to the Regional Civil Protection Office.

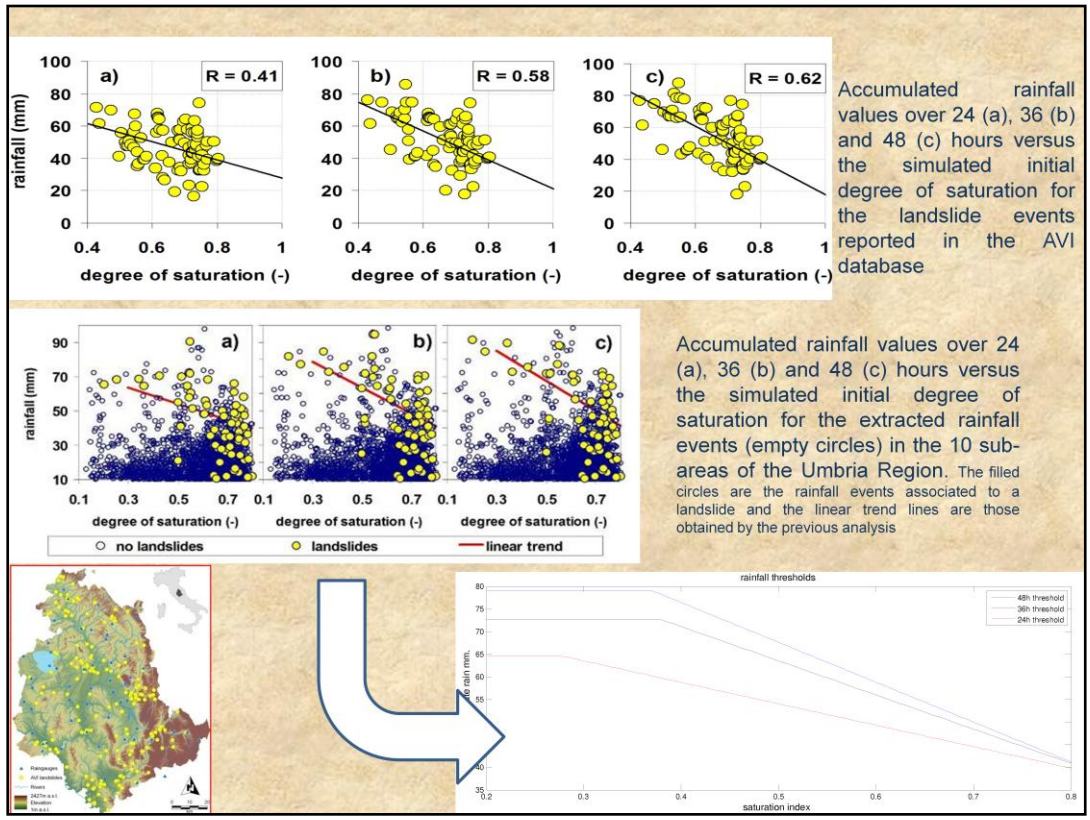
Mean annual precipitation is about 1000 mm; mean annual temperature is 11°C; snowfalls at altitude below 500 m a.s.l. are unusual.



The warning system originates from a previous study, that attempts to define soil moisture (estimated using a soil water balance model) and their correlation with rainfall thresholds, that can be employed for hydrogeological risk prevention by the Functional Centre .

The soil water balance model applied here was developed using soil moisture observations carried out in experimental catchments located in the Umbria Region. In particular, different expressions were considered for the different components of the model, such as infiltration, percolation and evapotranspiration.

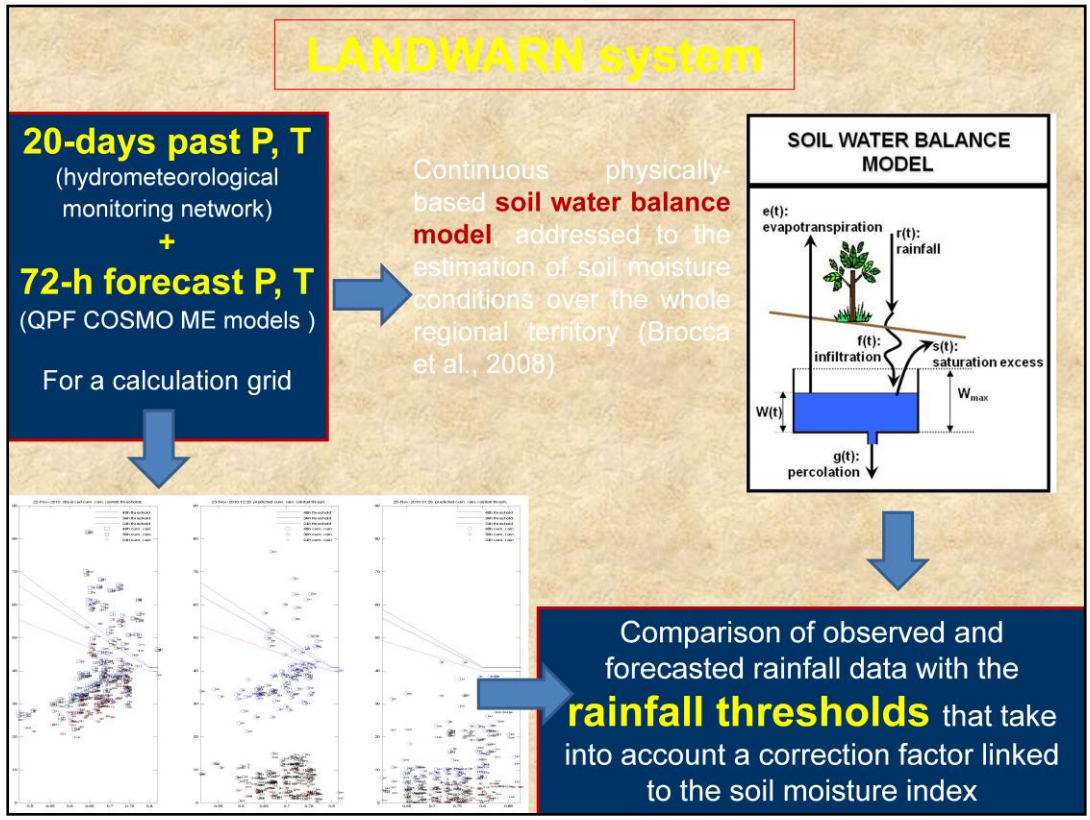
Different analyses were carried out by determining rainfall and soil moisture conditions prior to widespread landslide events that occurred in the Umbria Region and that are reported in the AVI (Italian Vulnerable Areas) inventory for the period 1989–2001.



Based on the analysis of the widespread landslide events available within the AVI database, a linear relation between the rainfall thresholds and the initial soil moisture conditions was found, showing the key role of soil moisture on landslide triggering.

The main result of the analysis is the quantification of the decreasing linear trend between the maximum cumulated rainfall values over 24, 36 and 48 hours and the soil moisture conditions prior to landslide events. This trend provides a mean to dynamically adjust the operational rainfall thresholds used for warning.

Therefore, the correlation established between the maxima cumulative rainfall values and the soil moisture prior to the triggering of landslides allows to dynamically adjust the rainfall thresholds which is of great interest for our warning activities and to the real-time landslides risk assessment for the regional territory, decreasing the uncertainties tied to the application of the rainfall thresholds only.



On these basis, we decided to build the near real tyme system for landslide forecast.

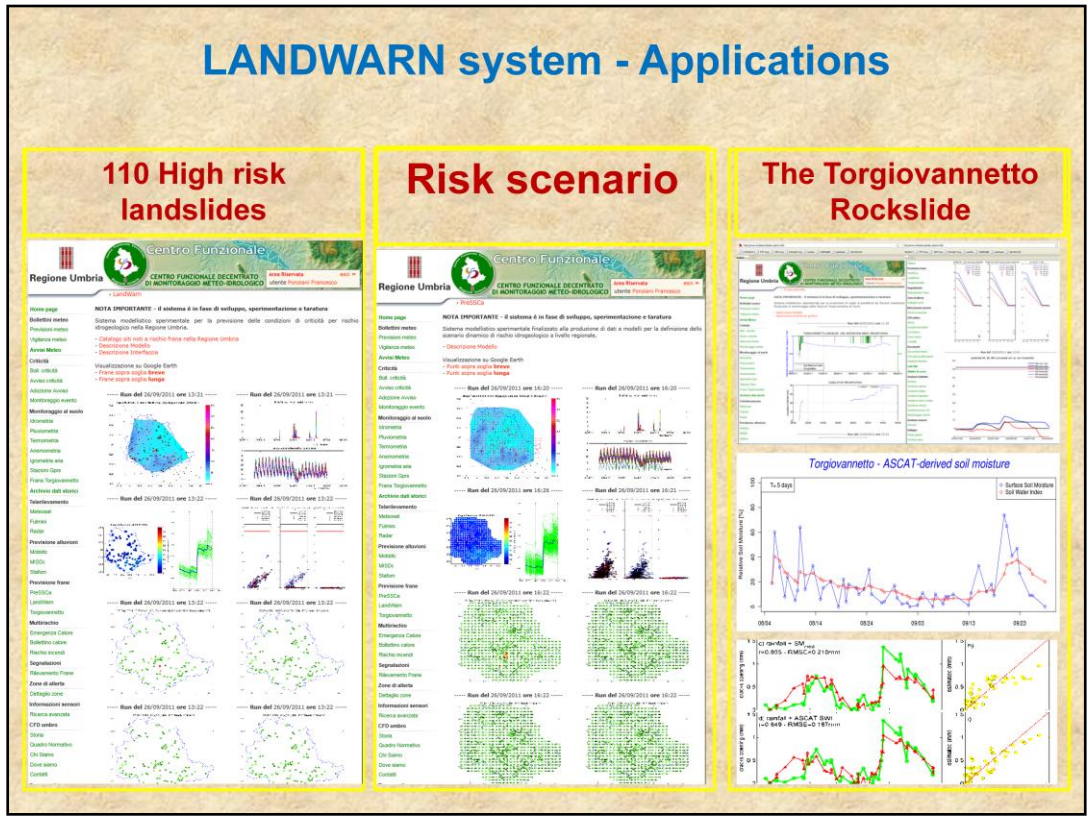
The system performs the following main steps:

- estimation (using spatial interpolation algorithms) of the 20-days past rainfall and temperature together with the 72 h forecast data for every point of a calculation grid (that can be a single landslide, or a number of selected landslides, or a dense grid over the whole territory). This is done by using real-time data from the regional hydrometeorological monitoring network and the results of quantitative weather forecast COSMO ME local scale models for Umbria;

- computation of the soil moisture index through the physically-based soil water balance model;

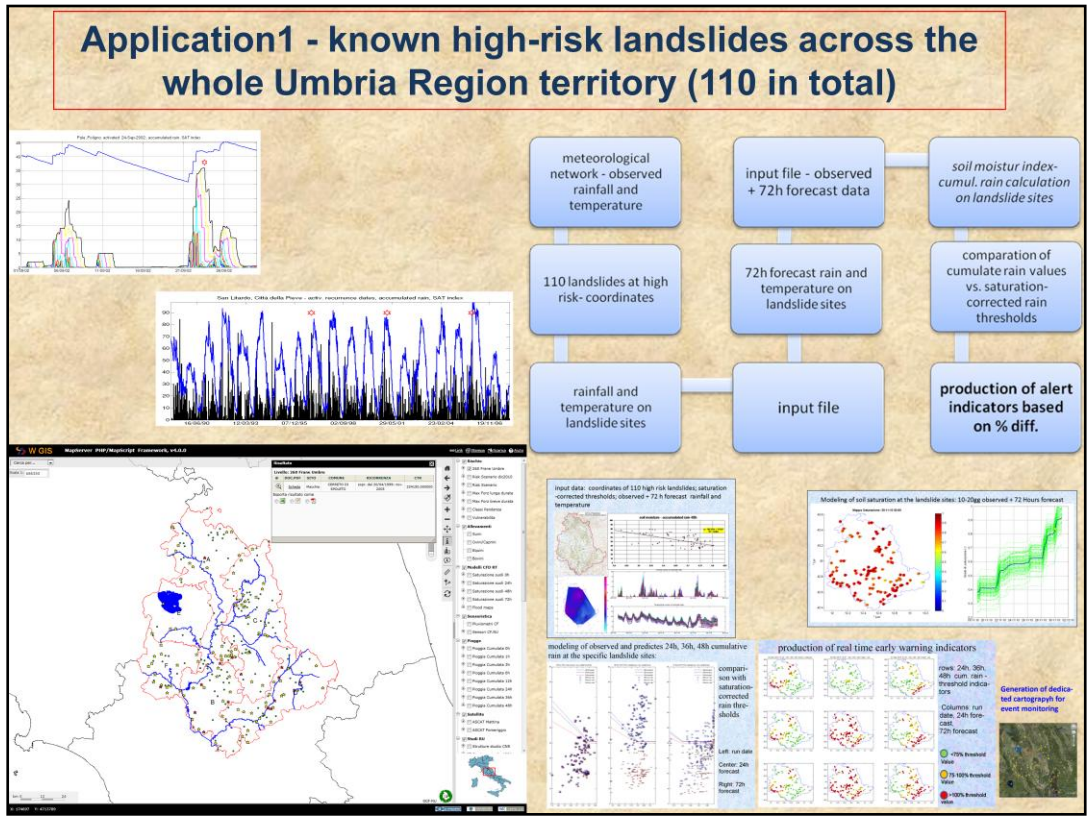
-comparison of observed and forecasted rainfall data with the rainfall thresholds that take into account a correction factor linked to the soil moisture index;

From the comparison, Definition of four early-warning indicators for each grid point (normal, caution, warning, alarm), in compliance with national and regional law.



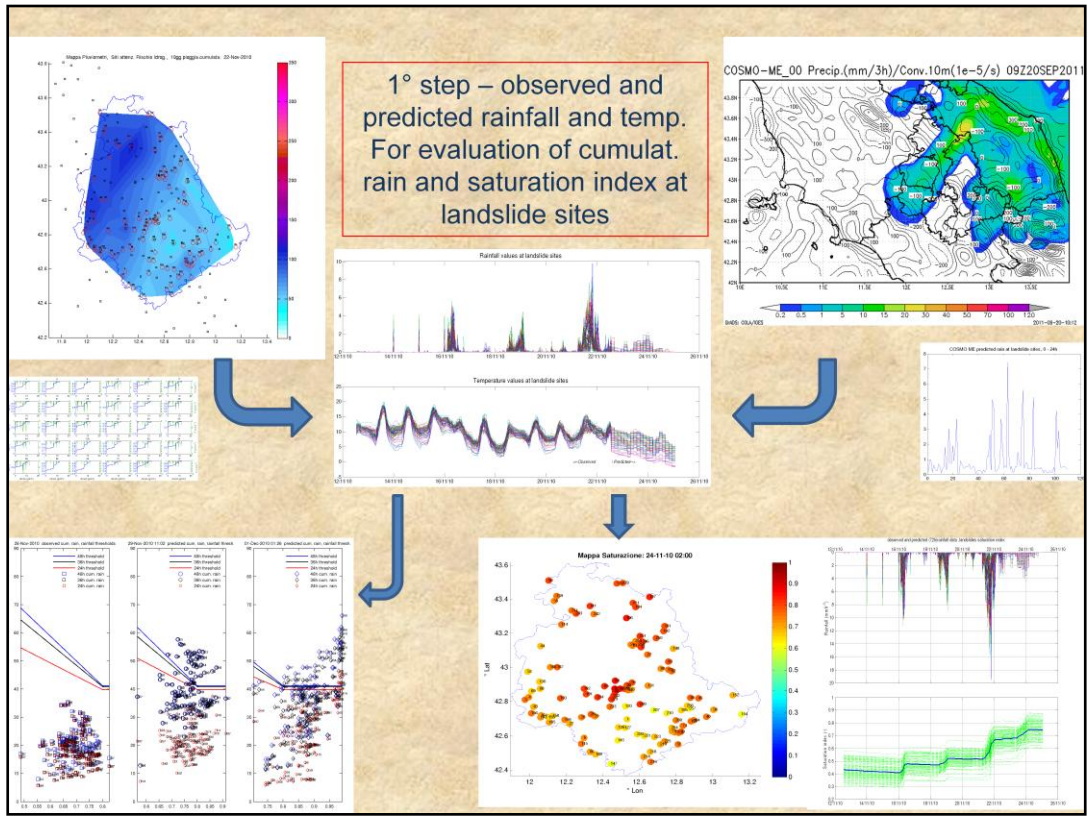
Up to now, we developed the system with three applications:

- a number of known landslides at higher risk previously classified;
- the whole regional territory, with the definition of a WEB-GIS dynamic risk scenario, using susceptibility and vulnerability informations;
- a large rockslide for which a conventional monitoring system is active.

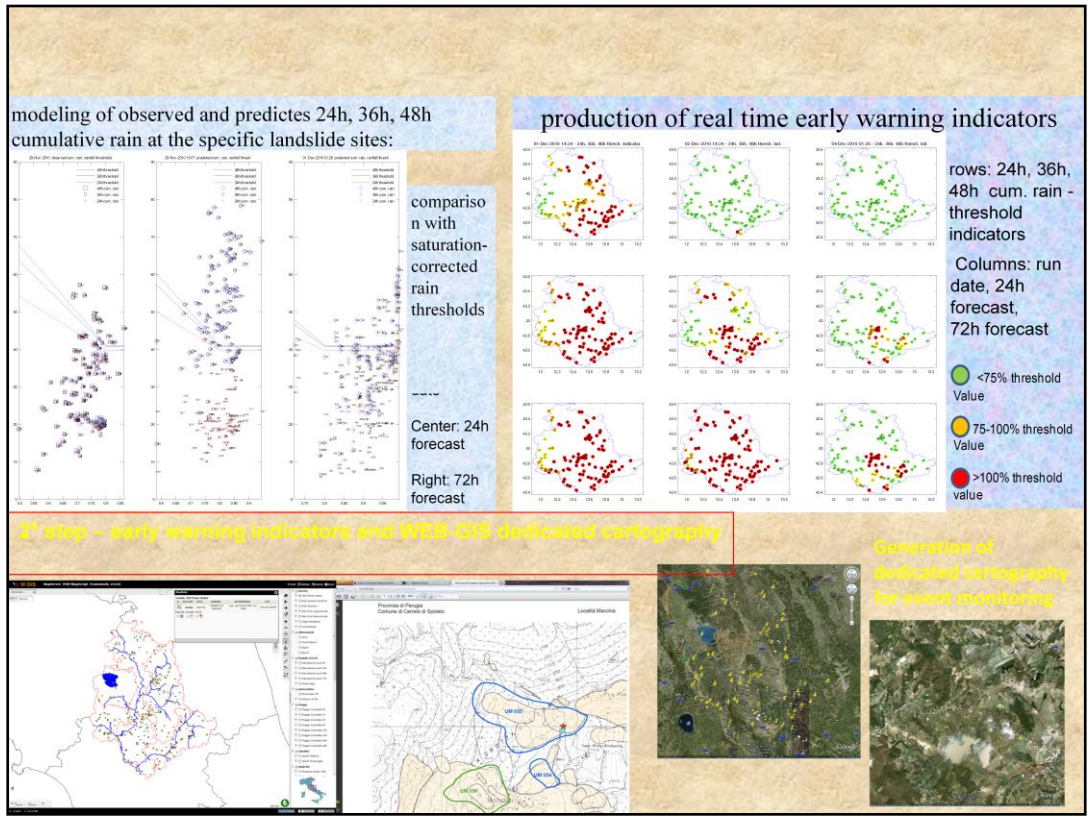


This section of the early-warning system is aimed to the monitoring of 110 landslides at high risk in the Umbria territory: the choice of the sites comes from a preliminary work in which all the known situations at hydrogeological risk were classified.

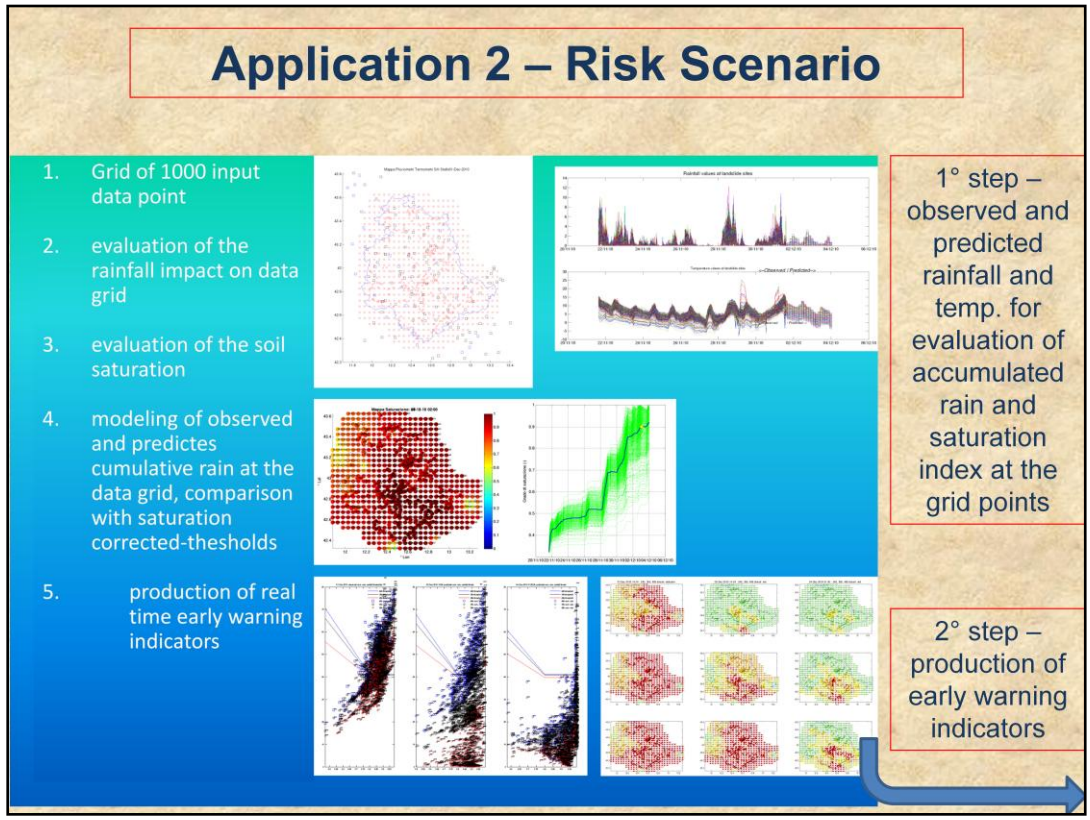
It must be pointed out that the system, up to now calibrated on the landslide dataset recorded during the main rainfall events occurred in the last 20 years in Umbria, is going to be tuned with landslide-specific thresholds, using the analysis of past rainfall, soil moisture conditions, and activation dates available for every landslide, developing specific paramaters for the water balance model too.



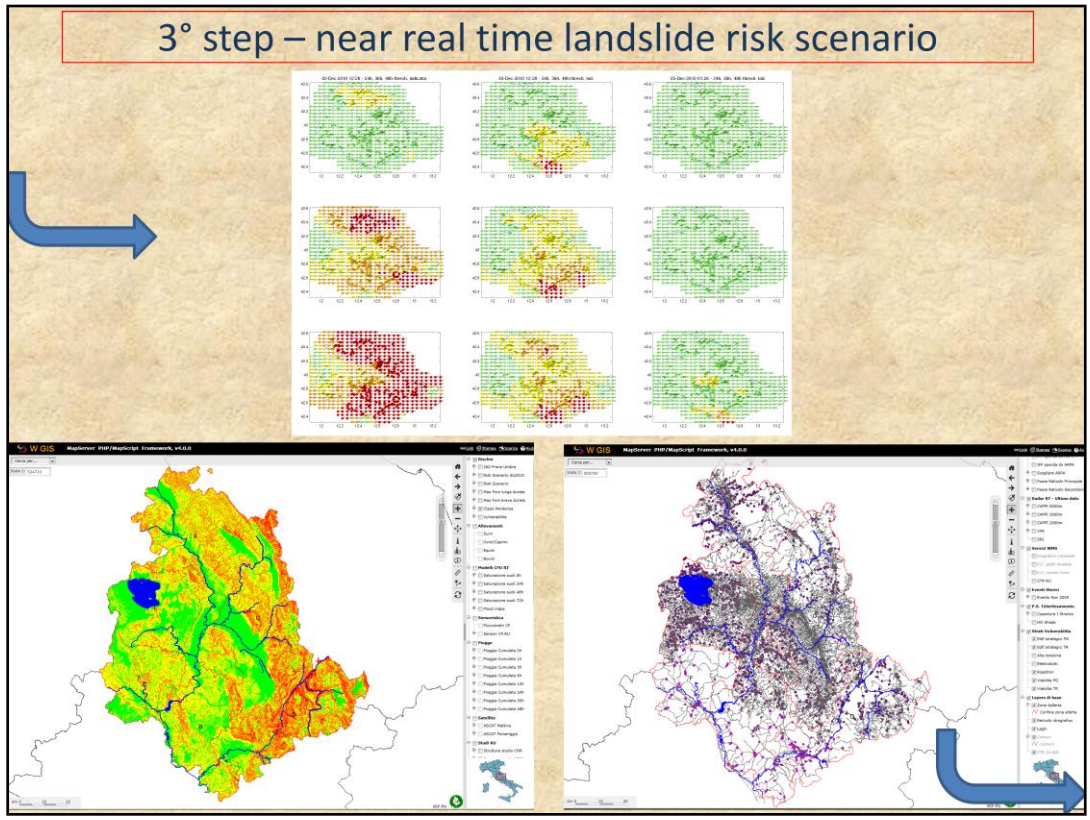
The comparison of accumulate rain, saturation index and correspondent threshold values lead to the production of the early warning indicators for the run date, 24h and 72 hours forecast



and dedicated cartography available through the WEB site



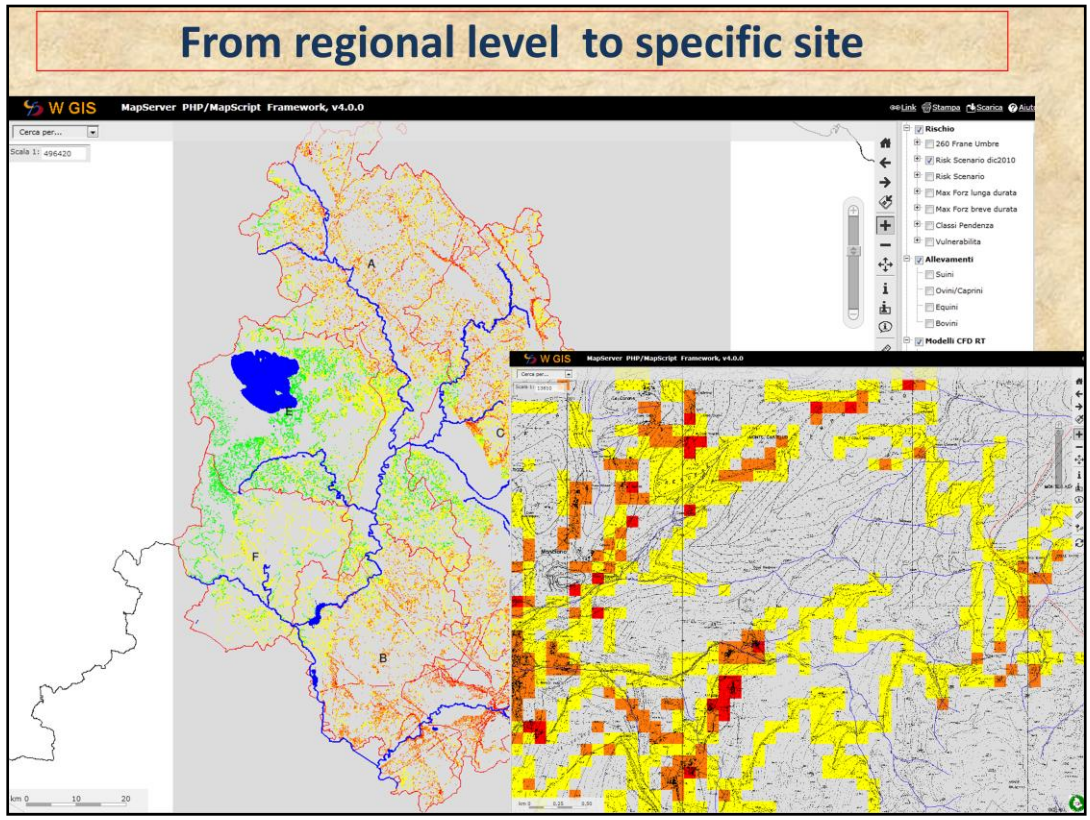
The section is based on the same methodology used for the 110 high risk landslides, but using a dense regular grid, in order to spatially extend the analysis and the monitoring to the whole regional territory.



The indicators are combined with susceptibility and vulnerability layers in order to build a risk scenario on a interpolation grid of 100*100m.

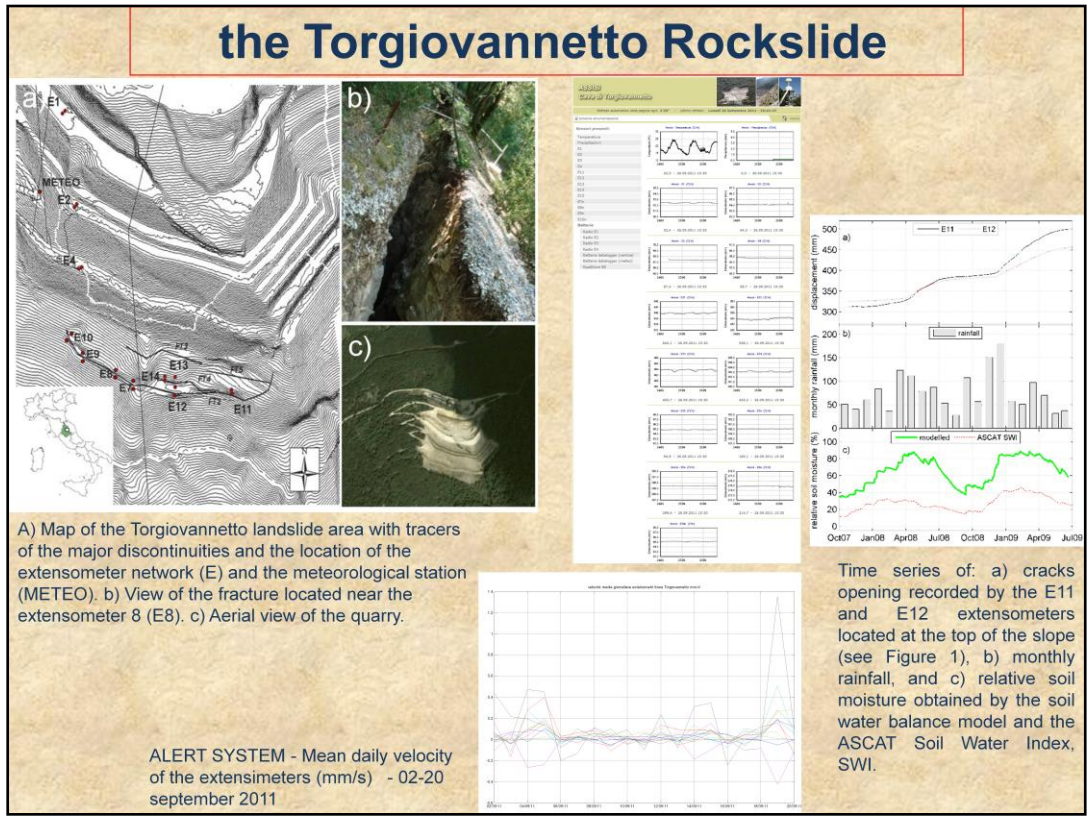
This section is under development, the quality of the scenario is of course strongly dependent by the quality of susceptibility and vulnerability information. Here as example we use as susceptibility layer 4 levels of slope values, obtained by a 20*20m Digital Elevation Model: a susceptibility map is in progress by a cooperation with the CNR IRPI using POR FESR European founding.

Vulnerability data come from all the information we were able to collect form regional and other local Authorities: viability, buildings, infrastructures an so on, and it is regularly updated.



A WebGis platform is so used to build near real-time dynamic scenarios combining the observed and forecasts rainfall (at 24-h and 72-h) with landslide susceptibility and vulnerability data.

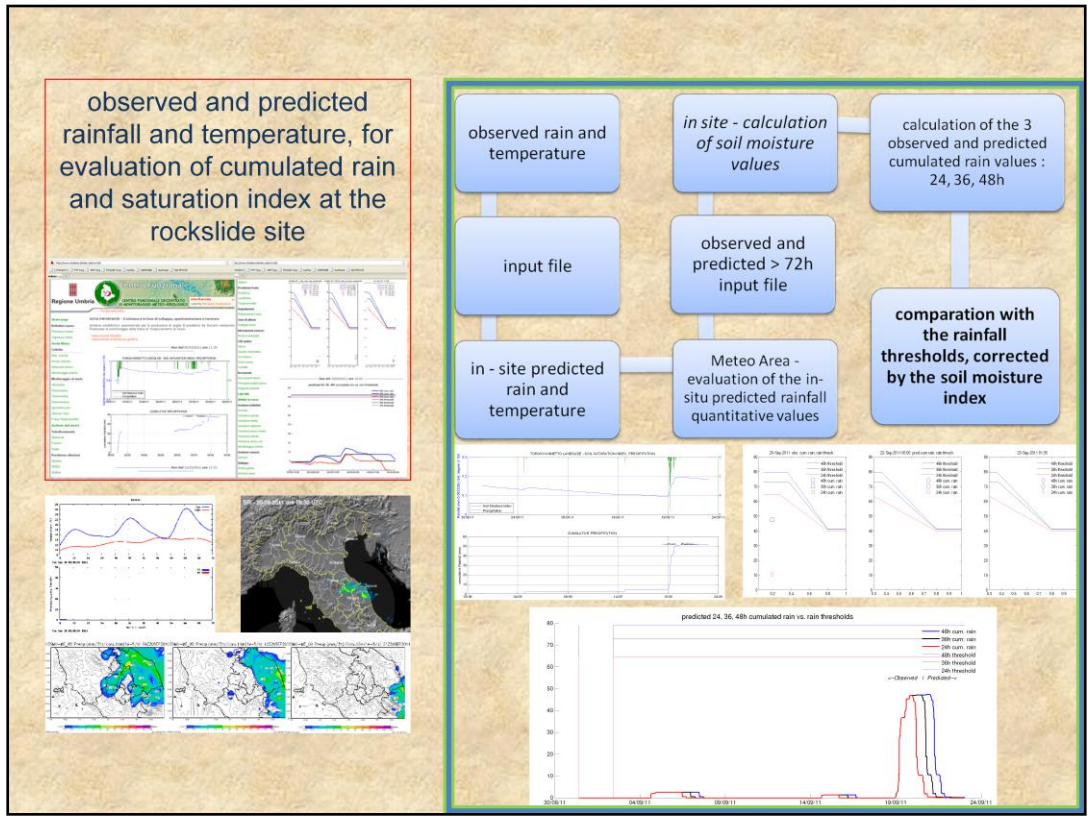
The main result of the analysis is a spatial information on landslide risk, highlighting the areas where local risk situations can emerge due to the interaction of the rainfall-induced landslides with the presence of vulnerability elements. This scenario has a dynamic character because of the re-computation of the rainfalls that are likely to trigger landslides on every dataset updating, during the event phase.



The Torgiovannetto landslide originated from a dismissed stone quarry near the town of Assisi, in Central Italy. The stratigraphy is constituted by stratified limestone with intercalation of thin weak clay layers: the dip of the front of the quarry is about 30° - 38°, similar of that of the limestones bedding planes. A huge sliding rock wedge in the upper part of the quarry has formed, delimited by a big tension crack up to one meter wide and over 100 m long, shoving slow movements after heavy rainfalls, relating the raising of the pore pressure to the reduction of the shear strength on the stratification planes.

The rock wedge threatens two roads at the base of the slope: the landslide is monitored by a meteorological station, an extensometer network and, recently, by a high dynamic accelerometer. The dataset collected up to now demonstrated the clear influence of the rainfall on the rock slide movements.

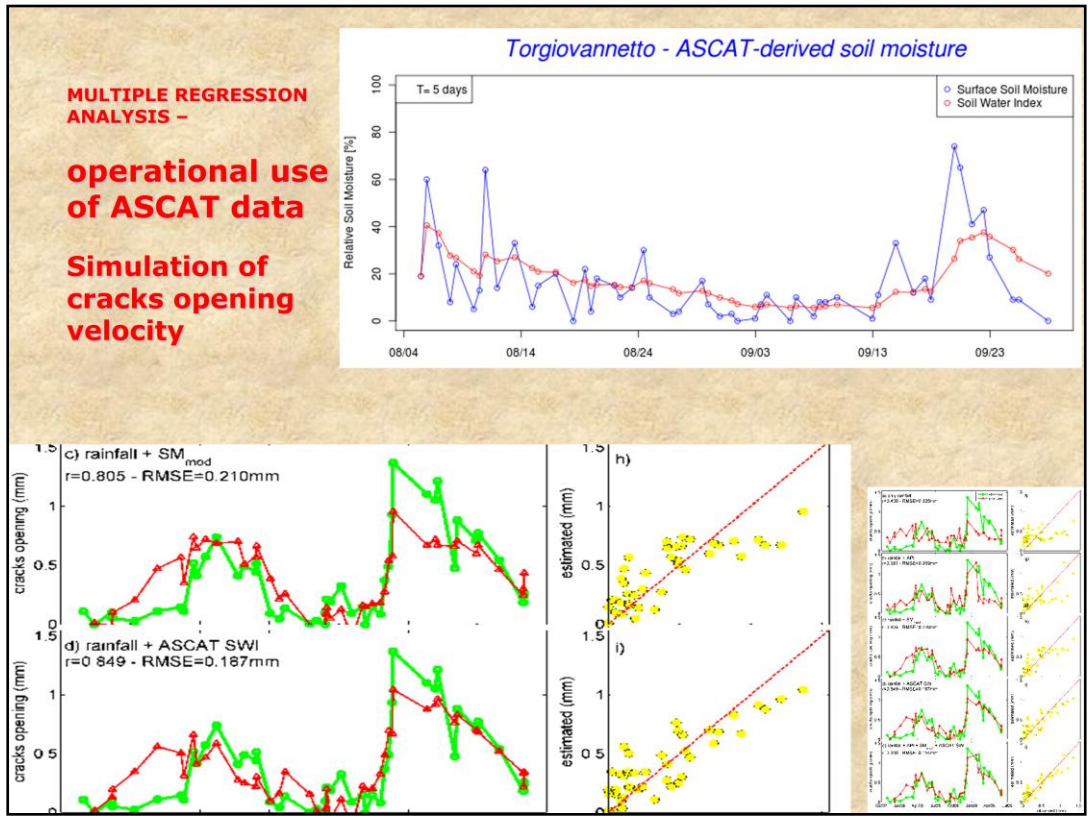
Due to the potentiality of a catastrophic failure that could affect the suburban road passing close to the quarry, the University of Florence is-was is in charge of an alert procedure based upon the observation and prediction of the overtopping of cracks opening velocity (equal to 0.5 or 1 mm/day depending on the location of the different extensometer) detected by the extensimeter network , using three levels of criticity: normality, pre-alert and alert. The alert is declared when at least two extensometers exceed their velocity thresholds (1mm/day or 0.5 mm/day, depending on their position).



The application of the Landwarn system, aimed to the support of the monitoring of the rockslide, performs the following tasks:

- the calculation of the accumulate rain measured by the in-situ meteorological station, and the predicted ones for the three following days using the COSMO-ME local scale prevision models;
- the calculation of the soil moisture content using the balance model above described;
- the comparison between the rain dataset and the rainfall thresholds dynamically adjusted by a correction factor linked to the soil moisture.

The system result is constituted by the real time evaluation of rainfall and soil moisture conditions in the rockfall site and the estimate for three following days; this is used as a pre-alert threshold in case of intense meteorological events, supporting the alert procedure based on the extensimetric network.



Recently, we introduced the use of satellite derived soil moisture data. We are using them at the Torgiovannetto site with the aim of the estimation of the crack openings.

The procedure developed for the forecast of the cracks opening velocity is based on the following tasks:

- the calculation of the accumulate rain measured by the in-situ meteorological station, and the predicted ones for the three following days using -- the COSMO-ME local scale prevision models;

- the calculation of the soil moisture content by the soil water balance model;

- the estimation of the cracks opening velocity through a multiple regression analysis that takes rainfall and soil moisture conditions into account.

The system result is constituted by the real-time evaluation of rainfall and soil moisture conditions for the Torgiovannetto site and the forecast for three following days of cracks opening.

The multiple linear regression equation used for the estimation of cracks opening has been calibrated by analyzing a series of rainfall events that occurred in the period 2007-2009 for which the opening of the tension cracks (as recorded by extensometers) is available. Specifically, besides via the soil water balance model, soil moisture estimates are also retrieved by satellite sensor. The Soil Water Index product obtained by the Advances SCATterometer (ASCAT) on board MetOp (Meteorological Operational) satellite is used for this purpose. Results indicate that the ASCAT SWI can be effectively used for the prediction of the cracks opening of the investigated Torgiovannetto landslide because of the good agreement between the observed and estimated cracks opening. The multiple regression performance decreases if modelled soil moisture data and Antecedent Precipitation Indices are used instead of the ASCAT SWI. The derived relationships are going to be implemented for the alert procedure of Torgiovannetto landslide.

Next Development tasks:

- Definition of **site-specific rainfall thresholds** for the 110 high-risk landslides, along with **more refined calibration** of the soil water balance model parameters, based on **soil moisture measurements.**
- Introducing a **physically-based** model for the **susceptibility analysis at the territorial scale**, which can be integrated with the soil water-balance model and with **ASCAT data**.
- **Operational Use of the ASCAT data** – use of Soil Water Index product for the whole regional territory, not only for the Torgiovannetto rockslide, in order to reduce the uncertainties linked to soil moisture estimation.

PHYSICALLY BASED MODELS

An under-development GIS-based code permits the prediction of the spatial distribution of the minimum rainfall intensity which is likely to trigger shallow landslides and debris flows over a given study area, based on the rainfall duration and the local geometric, hydrologic and mechanical characteristics of the slopes. Once validated, such an approach can be combined with short-time predictions of rainfall data, derived from the CFD real-time meteorological network, with the aim of implementing a new section of the early-warning system.

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