European Geosciences Union
General Assembly 2011
Vienna | Austria | 03 – 08 April 2011
EGU.eu

AN INTEGRATED APPROACH FOR AN OPERATIVE EARLY WARNING SYSTEM APPLIED TO HIGH RISK LANDSLIDES BASED ON RAINFALL THRESHOLDS AND SOIL MOISTURE ASSESSMENT

Ponziani F.[(1)], Berni N.[(1)], Pandolfo C.[(1)], Stelluti M.[(1)] Brocca L.[(2)] and Moramarco, M[(2)]
(1) Umbria Region Functional Centre, Via Romana Vecchia, 06034 Foligno (PG), Italy centrofunzionale@regione.umbria.it
(2) Research Institute for Geo-Hydrological Protection, CNR, Via Madonna Alta 126, 06128, Perugia, Italy

INTRODUCTION

The Umbria Region, located in central Italy, is one of the most landslide risk prone areas in Italy, almost yearly affected by landslides and flood events at different spatial and temporal scales. For early warning procedures aimed at the assessment of the hydrogeological risk, the rainfall thresholds represent the main component of the Italian Civil Protection System. A more accurate and reliable methodology for the landslide risk assessment and management is one of the main objectives of the Umbria Region Civil Protection Centre (where the "Decentralized Functional Centre" – CFD is the operative early warning office), in order to fill the gap between landslides prediction tools and the good performances obtained for flood predictions ones. It is well known that soil moisture conditions at the onset of a storm event play a critical role in triggering slope failure (PANEL 1). In order to improve the performances of the alert system for the landslide risk, Umbria Region CFD, in cooperation with the Research Institute for Geo-Hydrological Protection (IRPI-CNR), developed and tested a continuous physically based soil water balance model, addressed to the estimation of soil moisture conditions over the whole regional territory. Acting on the pore water pressure, soil moisture modulates the strength-stress ratio in soils and so is a significant precondition for the triggering of landslides; maybe as important as thresholds based on accumulated rain values, following the observation that the triggering of several large landslide events occurred in the region is strongly influenced by the initial soil moisture.

The combined soil moisture (computed through a soil water balance model) and rainfall thresholds are implemented in the new Early Warning System for landslide risk prevention of the CFD, named LANDWARN, that is under development on three different tasks:

1— (PANEL 2) Application on 110 known high risk landslides across the whole regional territory, for which the soil moisture evaluation is done by the interpolation of experimental data coming from the regional hydrometeorological network and 72h forecast local scale meteorological model;

2— (PANEL 3) Application on a case study rockslide (Torgiovannetto Rockslide), for which the computation of soil moisture is done by data coming from a onsite meteorological station, and a simulation of the movement of the rock wedge is compared with a real time extensimeter network;

3— (PANEL 4) Application on the whole regional territory by a dense computation grid, aimed at the development of a real time landslide risk scenario expanded to 72h forecast.

PANEL 1

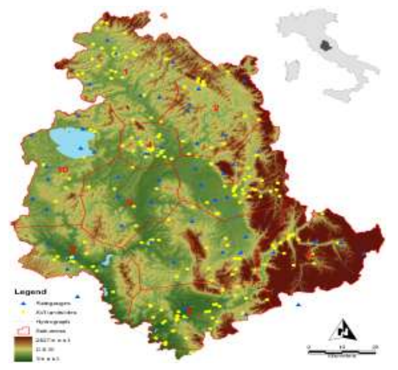


Figure 1 – Morphology and hydrometeorological network of the Umbria Region. The location of the landslides reported in the AVI inventory is also shown.

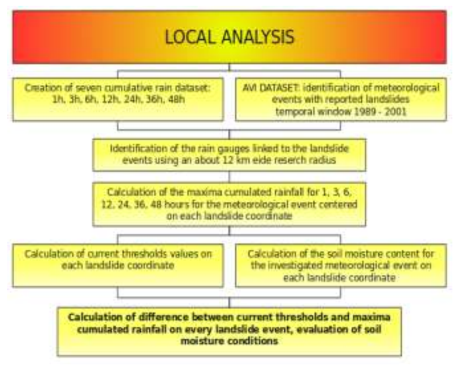


Figure 2 – Flux diagram of the local analysis (Ponziani et Al., 2011)

Based on the analysis (Figure 2) of the widespread landslide events available within the Italian AVI Landslide database, a linear relation between the rainfall thresholds and the initial soil moisture conditions (figure 3) was found (Fig. 4, 5) with correlation coefficients up to 0.60 showing the key role of initial soil moisture conditions on landslide triggering. 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 paramount interest for warning activities. Indeed, these results should provide a significant contribution to the real time landslides risk assessment for the regional territory, decreasing the uncertainties tied to the application of the rainfall thresholds only.

Moreover, the obtained results confirm the capability of the hydrological monitoring for setting up early warning systems for real slopes. In fact, collected data can be used both for the effective calibration of physically based models of infiltration and for establishing correlations for empirical models of landslides triggering.

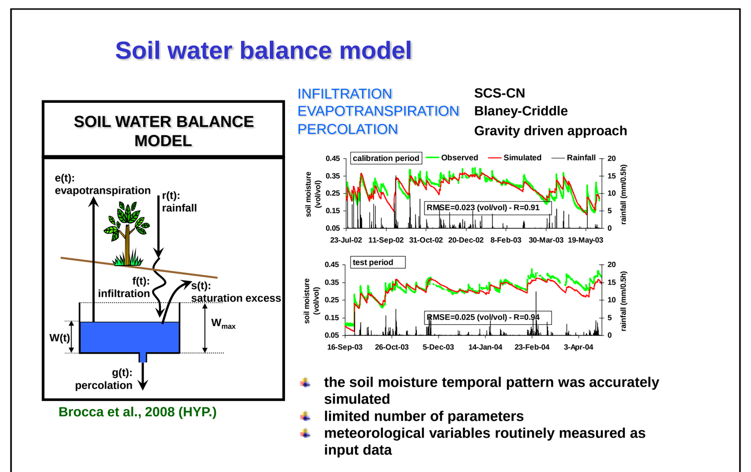


Figure 3—Specifically, the soil water balance model was obtained by comparing different formulations of the main processes involved in the soil moisture simulation, i.e. infiltration, evapotranspiration and percolation. The model was found reliable also considering the calibration both with a short soil moisture time series and with time spot measurements (the figure shows the comparison between simulated and observed soil moisture). The model incorporates a limited number of parameters and requires as input data the meteorological variables routinely measured.

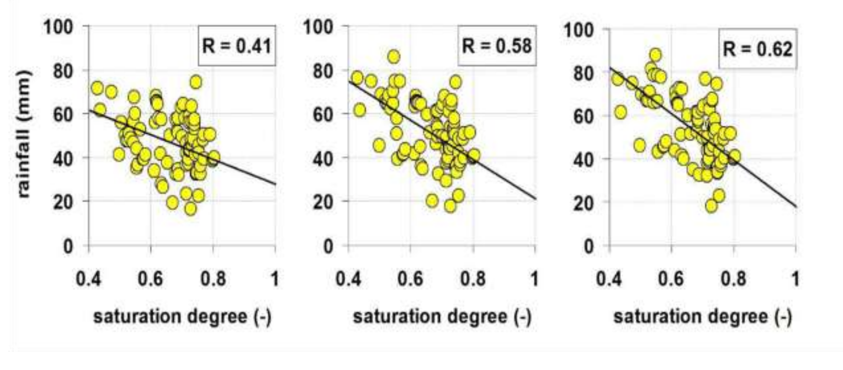


Figure 5 – Cumulated rainfall values over 24 (a), 36 (b) and 48 (c) hours versus the simulated saturation degree for the landslide events reported in the AVI database and considering the period 1991-2001.

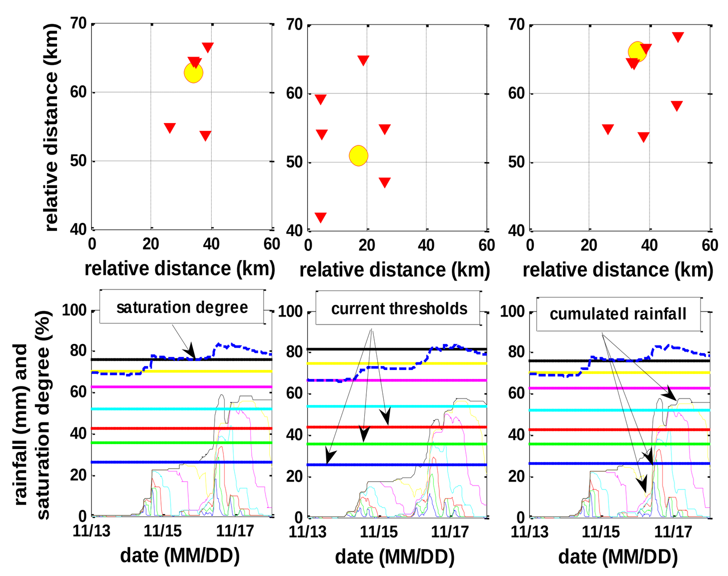


Figure 4 – Analysis of three landslides occurred during the rainfall event of 16th November 1991. On the first row of the figure the location of the landslide event (circle) and of the raingauges (triangles) used for the computation of the experimental rainfall thresholds is shown. In the second row the cumulated rainfall for the different durations is reported along with the corresponding current thresholds and the saturation degree simulated by the soil water balance model.

REFERENCES

Baum, R.L. and Godt, J.W. (2009). Early warning of rainfall-induced shallow landslides and debris flows in the USA. *Landslides*, 7(3), 259-272.

Brocca, L., Melone, F., Moramarco, T. (2008). On the estimation of antecedent wetness condition in rainfall-runoff modeling.. *Hydrological Processes*, 22, 629-642.

Guzzetti, F., Peruccacci, S., Rossi, M., and Stark, C. P. (2007) Rainfall thresholds for the initiation of landslides in central and southern Europe, *Meteorol. Atmos. Phys.*, 98, 239-267.

Iverson, R.M. (2000). Landslide triggering by rain infiltration, *Water Resour. Res.*, 36, 1897–1910.

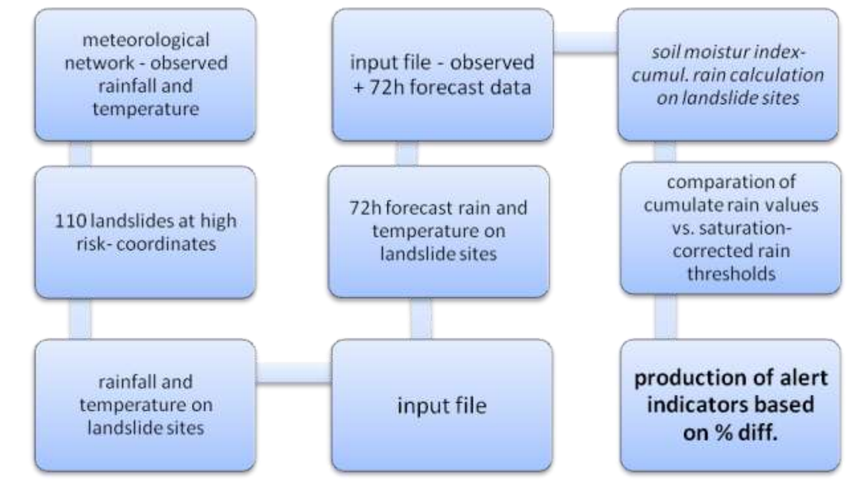
Ponziani F. , Pandolfo C. , Stelluti M. , Berni N. , Brocca L. , Moramarco T. (2011). Soil moisture and rainfall thresholds assessment for hydrogeological risk prevention in a regional operational warning centre. *Landslides*, in press.

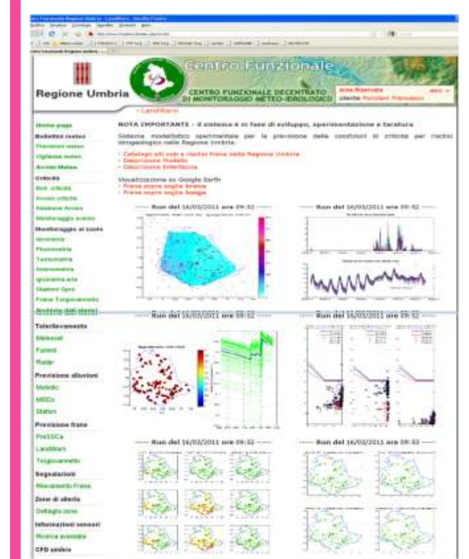
Ray, R.L. and Jacobs, J.M. (2007). Relationships among remotely soil moisture, precipitation and landslide events. *Natural Hazards*, 43(2), 211-222.

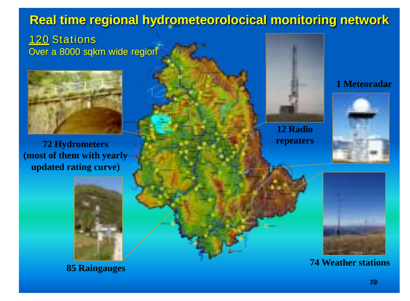
Panel 2

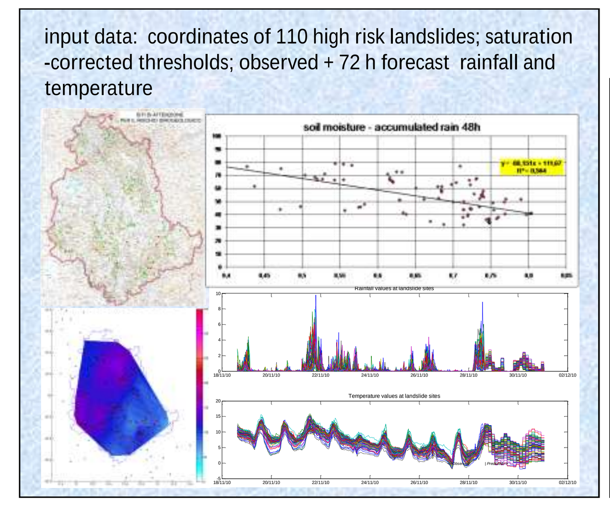
LANDWARN: AN EARLY WARNING SYSTEM APPLIED TO HIGH RISK LANDSLIDES

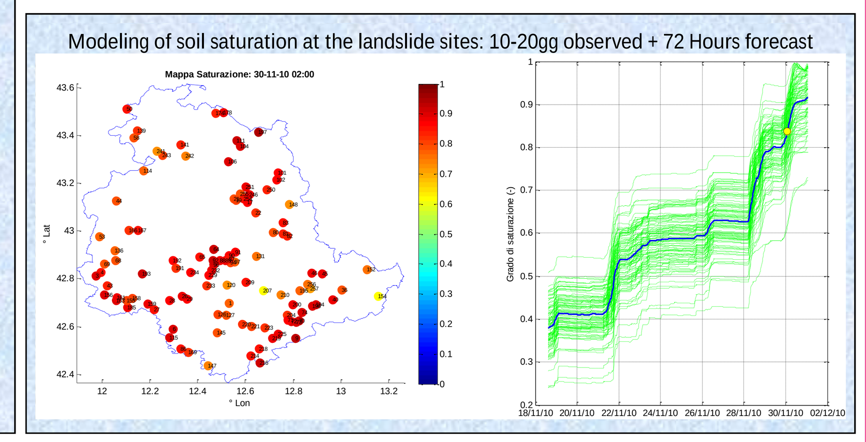
The WEB-based System is aimed to the monitoring of 110 landslides at high risk in the Umbria territory: observed and 72h predicted rainfal is evaluated toghether with a continuous physically based soil water balance model, addressed to the estimation of soil moisture conditions on the landslide sites. It must be pointed out that the system, calibrated on the landslide dataset recorded during the main pluviometric events occurred in the last 20 years in the Umbria territory, it works as a monitoring system able to evaluate the landslide hazard in larger areas around the landslide sites, so with a higher detail with respect to the 6 territorial zones of the current alert system.

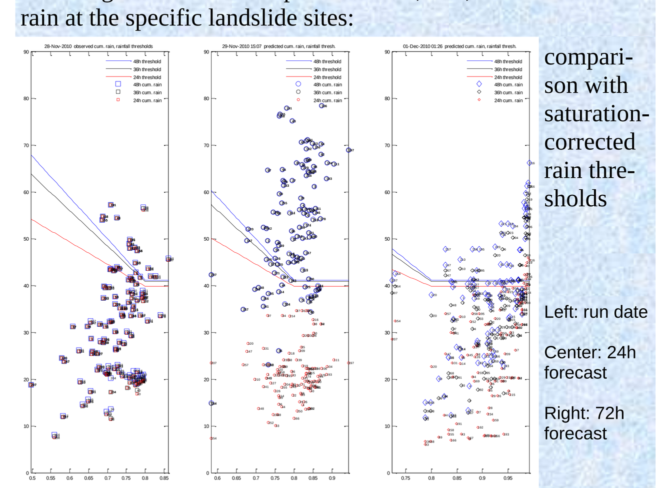


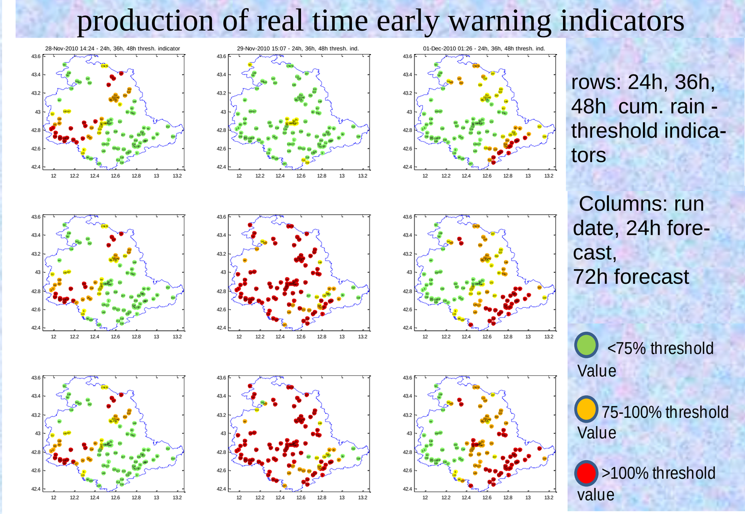


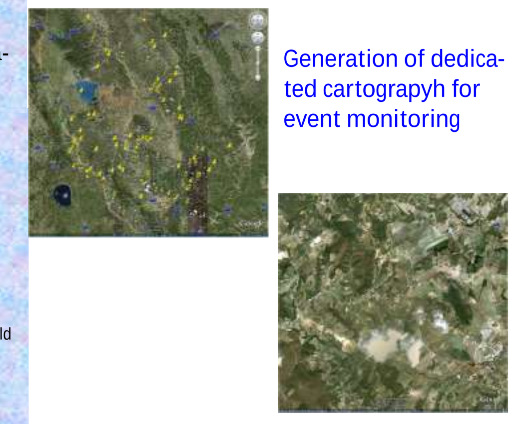












Generation of dedicated cartograpyh for event monitoring

Early Warning monitoring of a specific site : the Torgiovannetto Landslide

Panel 3

The pre–alert system

The University of Florence—Earth Sciences Department is in charge for the alert procedure based upon the overcoming of velocity of cracks opening detected by the extensimeter network (Fig. 1), using three levels of criticity: normality, pre-alert and alert. The alert is declared when at least two extensimeters exceed their velocity thresholds (1mm/day or 0.5 mm/day, depending on their position).

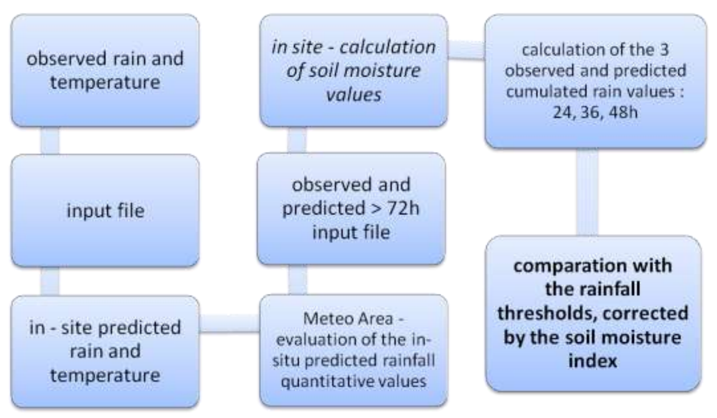
The system developed by the CFD, aimed to the support of the monitoring of the rockslide, performs the following tasks (Fig. 7):

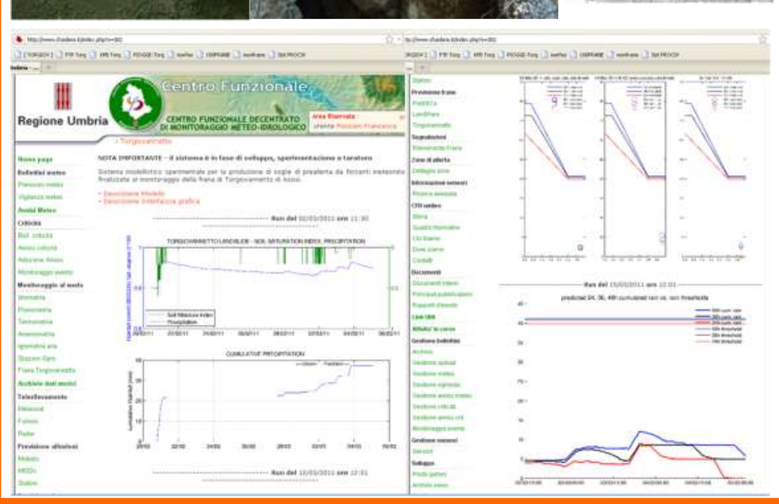
- the calculation of the accumulate rain measured by the in-situ meteorological station, and the predicted ones for the three following days using the COSMO-ME local scale prevision models;

- the calculation of the soil moisture content using the balance model above described;

- the comparation between the rain dataset and the rainfall thresholds dynamically adjusted by a correction factor linked to the soil moisture.

The system result is consituited 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.





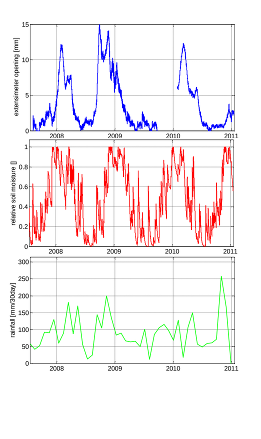
MULTIPLE REGRESSION ANALYSIS

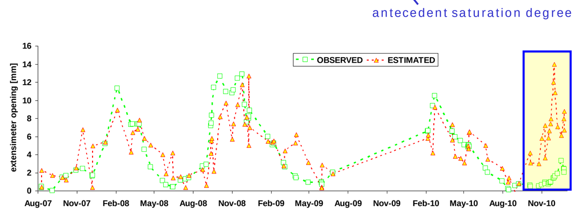
Based on the previous study (Ponziani et al., 2010) indicating the significant effect of initial soil moisture conditions on landslide triggering, the relationship between rainfall, modeled soil moisture and extensimeter opening was investigated. It was found that also for Torgiovannetto Landslide extensimeter opening is strictly linked to rainfall and initial soil moisture conditions.

Considering the whole period (from July-2007 to January 2010), the more significant rainfall events (rainfall > 10 mm) are taken out. For each rainfall events, the rainfall characteristics (total, maximum, ...), the antecedent soil moisture conditions estimated by the soil water balance model and the corresponding observed extensimeter opening are computed. Then, a multiple regression analysis to estimate the quantitative opening of the tension cracks, dHest, was carried out considering different sets of predictors:

$$dH_{est} = \alpha_1 P_{tot} + \alpha_2 P_{max\ 1h} + \alpha_3 P_{max\ 3h} + \alpha_4 P_{max\ 6h} + \alpha_5 P_{max\ 12h} + \alpha_6 SD + \alpha_7$$

(total rainfall: P_{tot}; maximum rainfall over 1h: $P_{max\ 1h}$; antecedent saturation degree: SD)





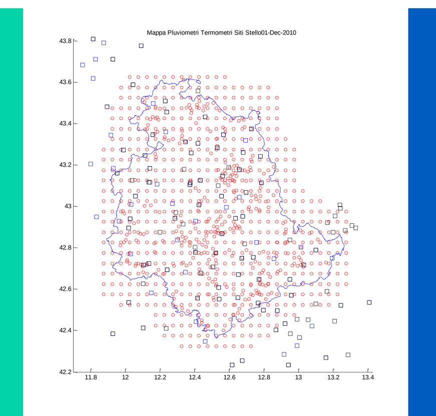
The main results are the following:

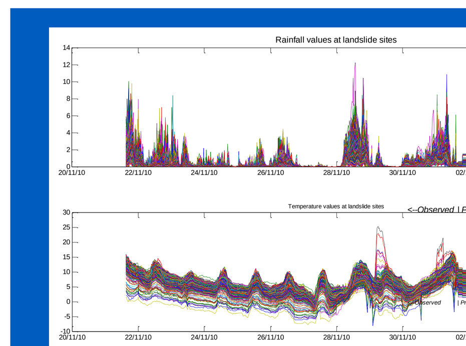
1.By analyzing the coefficients of the multiple regression it is obtained that the antecedent soil moisture conditions are the more important factor affecting the extensimeter opening
2.The estimated extensimeter opening is in good accordance with the observed one until August 2010 with a correlation coefficient equal to 0.77.
3.For the period September 2010 - January 2011 (yellow rectangle) the estimated extensimeter opening is significantly higher than the observed one, likely due to change of the landslide friction forces.

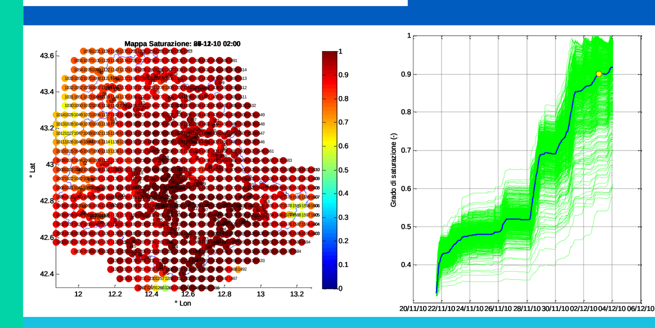
Panel 4

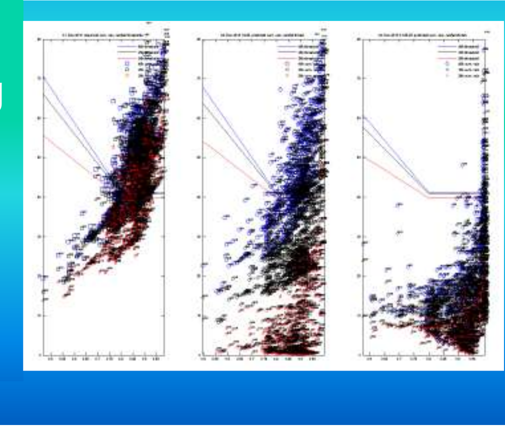
Risk scenario: Early Warning from regional level to specific site

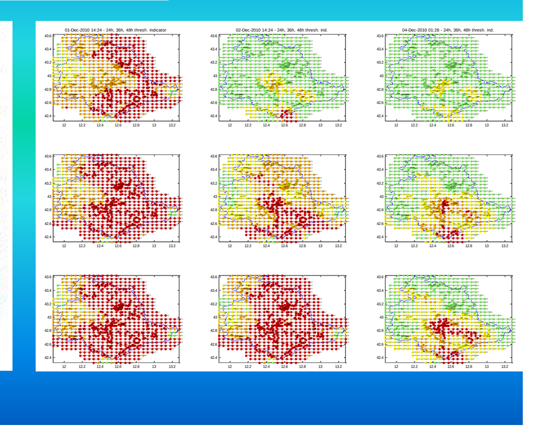
1. Grid of 1000 input data point
2. evaluation of the rainfall impact on data grid
3. evaluation of the soil saturation
4. modeling of observed and predictes cumulative rain at the data grid, comparison with saturation corrected-thesholds
5. production of real time early warning indicators

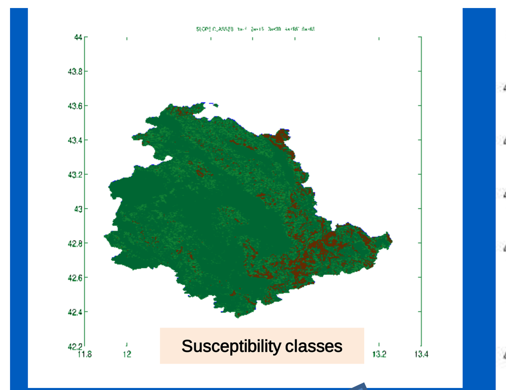


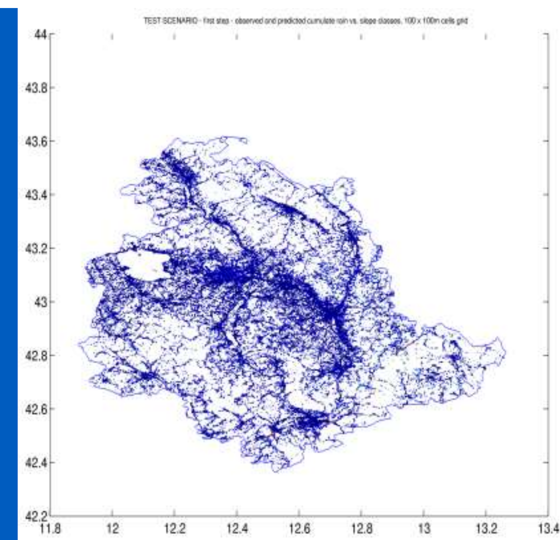


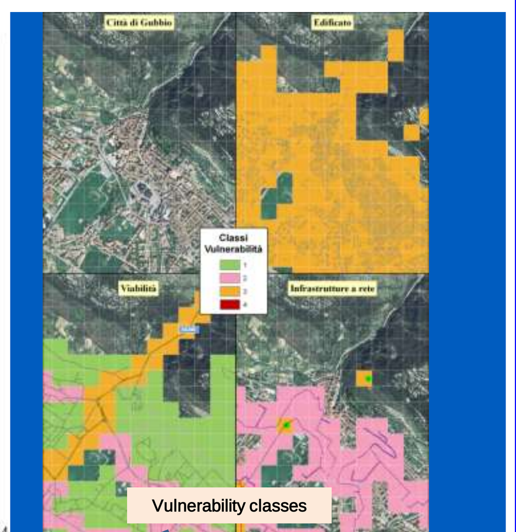






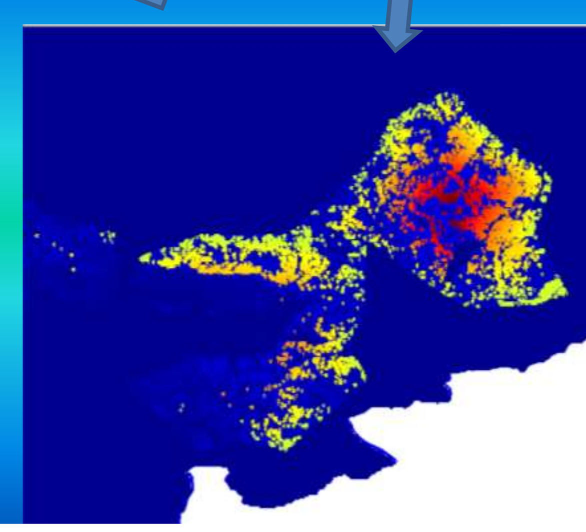


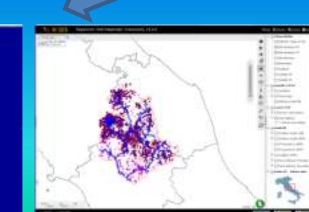




6. Interpolation of results on a regular 100 x 100m data grid;

7.Combination of indicators, susceptibility and vulnerability : risk matrix 100 x 100m data grid





WEB GIS risk scenario