A regional-scale Landslide Activation Index (LAI) based on hydrological stress index, for shallow landslides and debris flow forecasting.

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ABSTRACT

Inundations, landslides, debris flows and stream floods are common natural processes in Italy. Almost 90% of the national territory is affected by landslide processes, being one third classified as rapid processes triggered by heavy or persistent precipitation. Early Warning Systems are increasingly applied to mitigate the risks posed by natural hazards. As commonly recognized by the scientific community, heavy and sudden precipitation events are increasing in the last decades, due to global warming: therefore we can expect increasing rates and increasing population exposure to this kind of hydrogeological risk, consequently. Landslides triggered by rains represent a high threat to life and human properties, therefore, predicting their spatial and temporal occurrence is an important scientific and operational-issue. For this reason, many landslide forecasting techniques have been developed at regional scale, especially for shallow landslides and debris flows that are generally activated by severe precipitation events. The forecast is based on rainfall quantification, which represents the most easily detectable physical quantity. Then, forecasting landslide models are usually based on rainfall empirical thresholds, that needs to be locally defined and often revised for each element at risk, according to historical data that are not always available. Their occurrence can be correctly assessed in space and time only through a sound basis of knowledge to be acquired through the scientific use of many historical documents.

In this work, the same approach useful for flood and flash flood index forecasting was used. Starting from the rainfall spatialization techniques, available in the CHyM hydrological model, we propose a new index to forecast the shallow landslides and debris flow: Landslide Activation Index (LAI). This index considers the drained rainfall in each point of the rebuilt drainage network during the runoff time and can be used to predict landslide risk over wide areas, by using a unique threshold over slopes, susceptible to collapse.

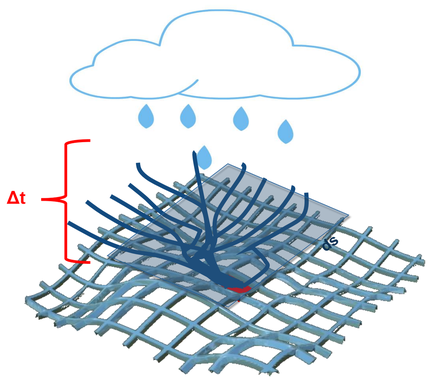
Preliminary results show as the LAI index is able to identify main areas at landslide risk for different meteorological events, including scenarios where activation of debris flow and shallow landslides is due to rapid snowmelt.

CETEMPS Hydrological Model – CHyM

Developed by M. Verdecchia, B. Tomassetti and E. Coppola since 2002.

- Grid distributed physically-based hydrological model in which standard processes such as surface runoff, infiltration, evapo-transpiration, percolation, and melting and return flow are simulated;
- Based on the kinematic wave approximation of the shallow water wave; the continuity and momentum conservation equations are used by the CHyM model to simulate the surface routing overland and channel flow;
- It includes an explicit parameterization of different physical processes contributing to the hydrological cycle;
- Different sets of precipitation data can be assimilated and merged in a hierarchical way at each hourly time step;
- It runs on any geographical domain with any resolution up to the DEM resolution, drainage network is extracted by a native algorithm implemented in the CHyM code;
- Interpolation methods for DEM smoothing and meteorological variables spatialization based on Cellular Automata-based algorithm.

LAI *Landslides Activaction Index*



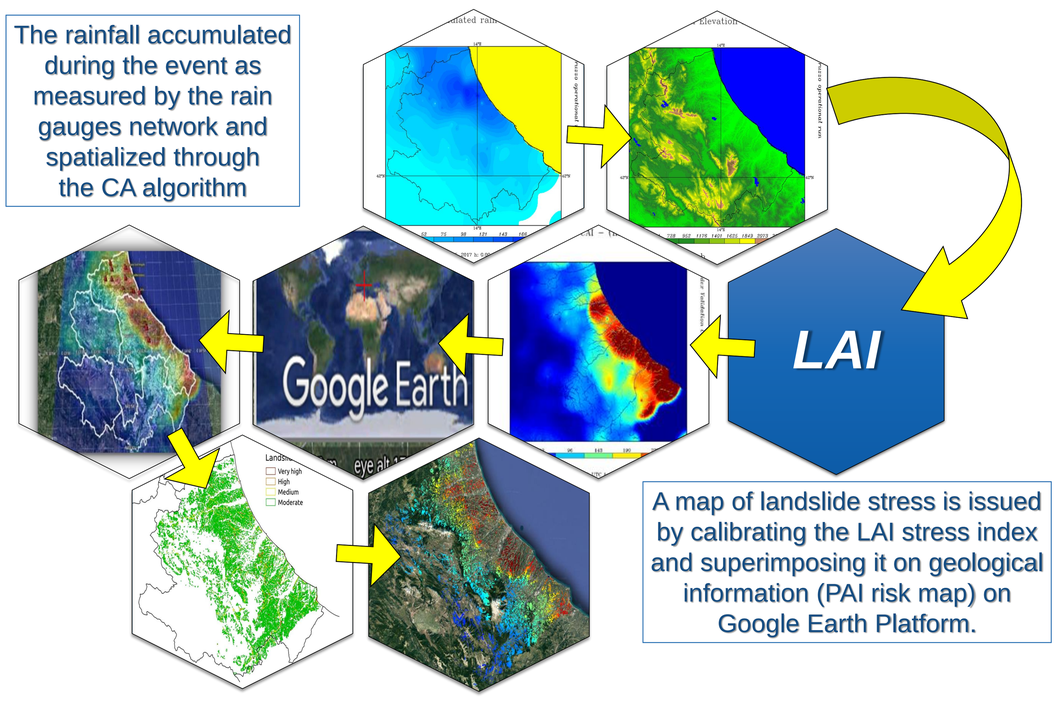
$$LAI = \frac{\int_{t-\Delta t_i}^{t} \int_{Up_i} P(t,s)\,dt\,ds}{\int_{Up_i} ds}$$

mm/day

LAI index is the ratio between the total precipitation drained by a grid-cell and the total drained area. Namely, it represents the average of the drained rainfall during a time interval corresponding to the mean runoff time. The LAI index is an evolution of the rainfall thresholds whose approach is used in various scientific works. It identifies areas under stress due to heavy rains and can therefore be used to predict the risk of landslide using a single threshold on the identified slopes, susceptible to collapse.

METHODS

The rainfall accumulated during the event as measured by the rain gauges network and spatialized through the CA algorithm

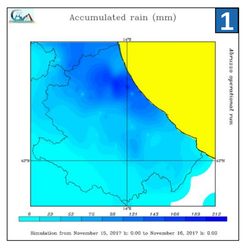


A map of landslide stress is issued by calibrating the LAI stress index and superimposing it on geological information (PAI risk map) on Google Earth Platform.

- CHYM Model is forced with observed rain gauges data spatialized through the CA algorithm, and then the LAI index is calculated for each grid point of the domain considered. If we combine the map of LAI and the PAI map risk on Google Earth platform, we can identify the area most susceptible to risk for an event.
- To test the use of this new index, case studies were identified considering landslides events of which we knew the geolocation and the time of event. We identified new empirical stress thresholds keeping the warm colors for stressful and cold colors for stationary conditions, conforming to the color scale adopted in the criticality bulletins issued by the Abruzzo Regional Functional Centre.

CASE STUDIES AND ANALISYS

Case study 15th November 2017

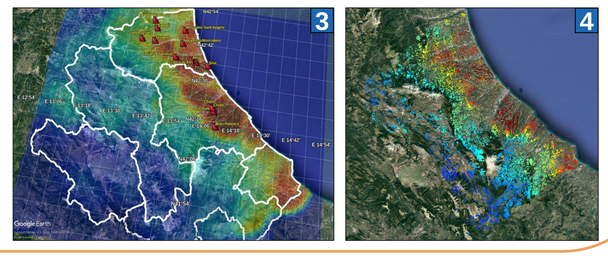


1 24 hour Accumulated Rain. Typically autumnal perturbation characterized by abundant rains with cumulations above 200mm/24h.

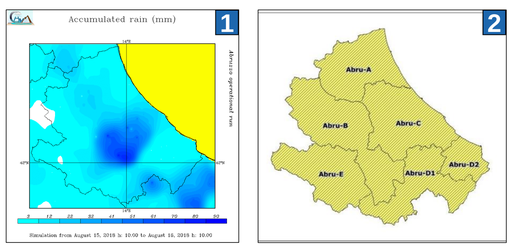
2 Hydrogeological criticality bulletin issued by the Abruzzo Region Functional Centre on the morning of 15th November 2017.

3 LAI Map (worst in 24 hour) on Google Earth. The red symbols indicate the geolocation of the main landslides that occurred.

4 LAI Map combines with the PAI map risk on Google Earth.



Case study 15th August 2018

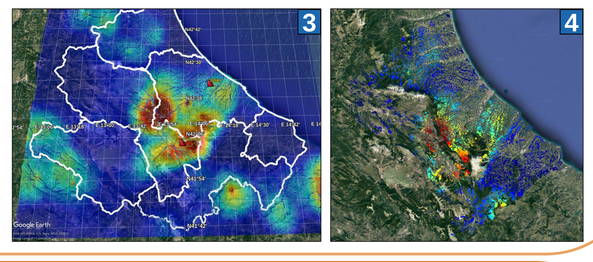


1 24 hour Accumulated Rain. Rapid, intense and very localized event, typical of summer convective phenomena.

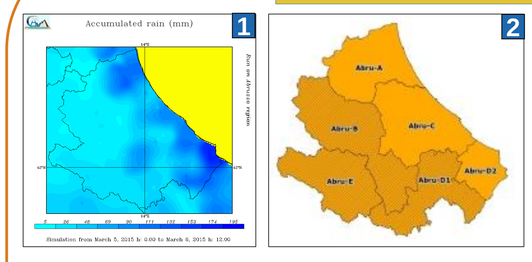
2 Hydrogeological criticality bulletin issued by the Abruzzo Region Functional Centre on the morning of 15th August 2018.

3 LAI Map (worst in 24 hour) on Google Earth. The red symbols indicate the geolocation of the main landslides that occurred.

4 LAI Map combines with the PAI map risk on Google Earth.



Case study 5th March 2015



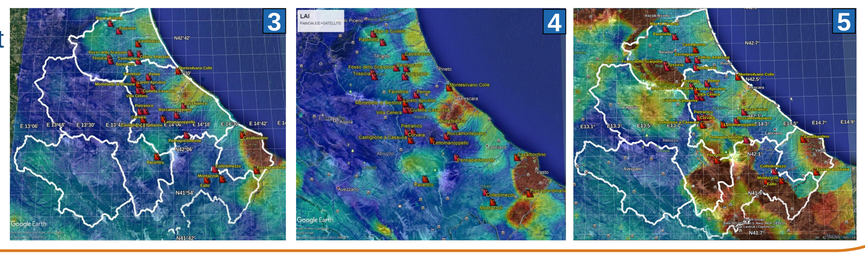
1 24 hour Accumulated rain. Intense and widespread precipitation, even snowy ones above 500 m a.s.l..

2 Hydrogeological criticality bulletin issued by the Abruzzo Region Functional Centre on the morning of 5th March 2015.

3 LAI Map (worst in 24 hours) rebuilt forcing CHyM model with raingauges data.

4 LAI Map (worst in 24 hours) rebuilt forcing CHyM model with raingauges and satellites data.

5 LAI Map (worst in 24 hours) rebuilt forcing CHyM model with raingauges data and using melting module.



CONCLUSIONS

- This preliminary study on the performances of the LAI index indicates that this could be an excellent tool for identifying areas stressed by the probable triggering of landslides in case of severe events.
- In order to make up for any shortcomings in the spatial and/or temporal coverage of the rainfall data, during the spin-up phase of the model, the radar and/or satellite data must also be assimilated.
- The assimilation of the amount of water derived from the melting of the snowpack is of fundamental importance and it can be obtained from a SNOWPACK model.
- The LAI thresholds must be "calibrated" more and more precisely on the basis of a significant number of landslides and above all the results of the modeling must be compared with the geological conditions of the area.
- For the validation of the thresholds, we have already carried out about 20 years of simulations (from 2000 to 2019) on the Abruzzo region: therefore we only need to extrapolate the analysis of the case studies regarding landslides that we are cataloging.

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