A framework for the territorial landslide early warning system implementation: applications, lessons learnt and future challenges

Mauro Rossi

Ivan Marchesini, Maria Elena Martinotti, Maria Teresa Brunetti, Silvia Peruccacci, Vinicio Balducci, Fausto Guzzetti

CNR IRPI, via Madonna Alta 126, 06128 Perugia, Italy

e-mail: mauro.rossi@irpi.cnr.it

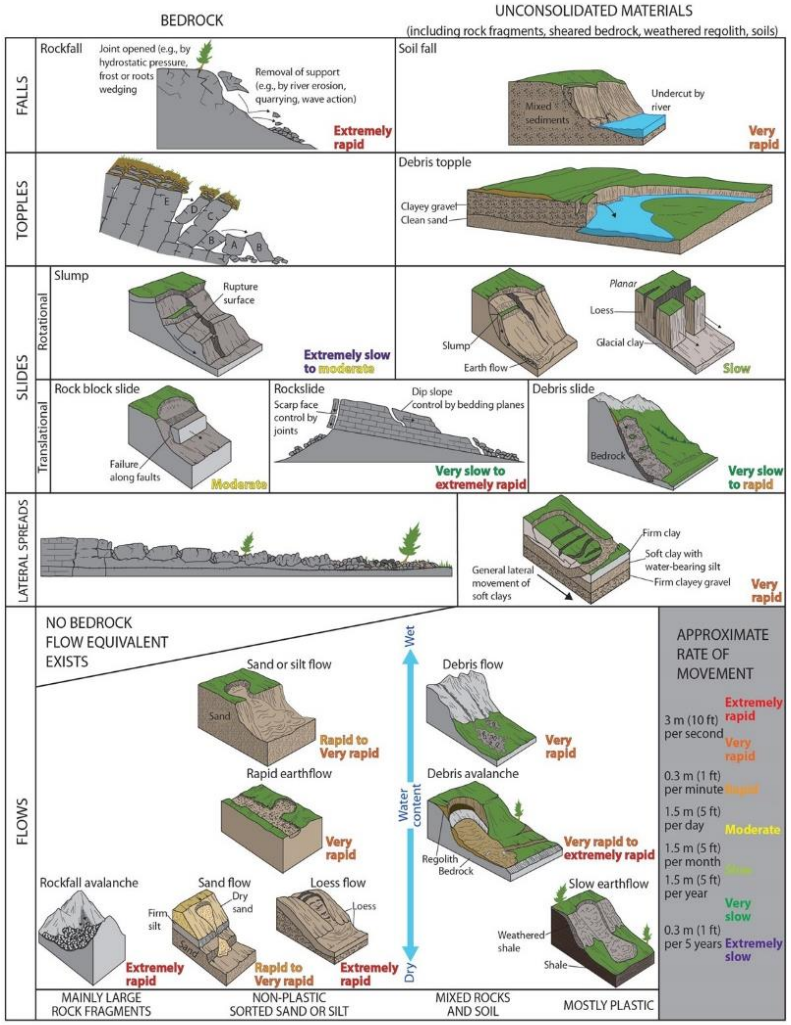
Brief LEWS history

Rainfall is the **primary trigger** of **landslides** in Italy **occurring every year**, **claiming lives** and **causing economic** damages.

Italian Civil Protection Department asked CNR IRPI to **develop** a **landslide EWS** for the **entire Italian Territory**. **Successively** other **national** and **regional administrations in Italy and India asked to implement systems** at **different scales** and for **different purposes**.

Following this request we **designed** and **realized** a **framework** to **implement early warning systems** to **forecast rainfall-induced landslides**.

Landslide types



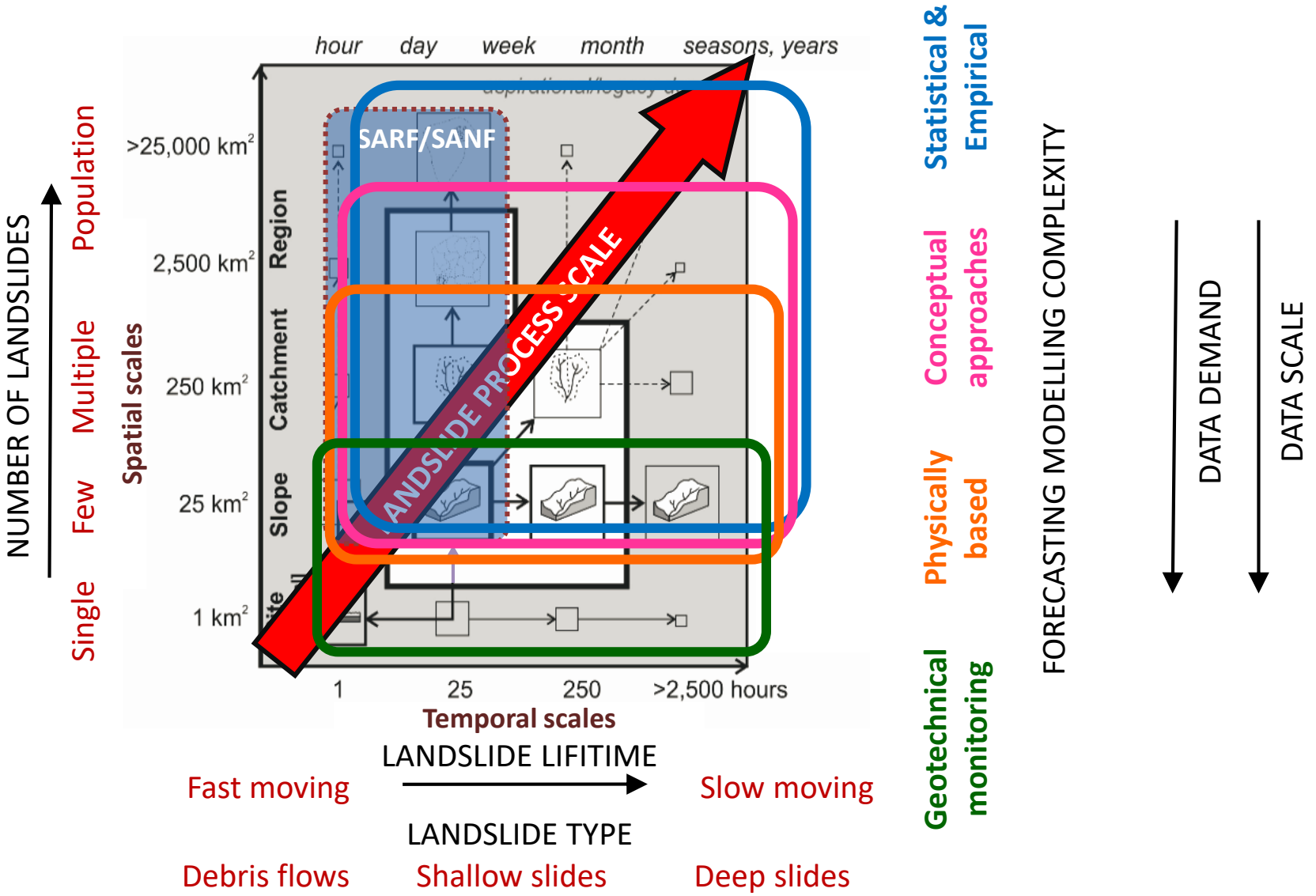
© Trista L. Thornberry-Ehrlich, Colorado State University. Modified from Varnes, D. J. 1978. Landslides: analysis and control.

Different **schemas** in the literature **classify landslides based on:**

- **type** of **material**
- **type** of the **movement**
- **rate** of **movement**
- **moisture** content

Landslide are heterogeneous processes and it is difficult (even if impossible) to find a unique forecasting approach.

Forecasting VS scales



Implementation History

	TIME														
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
National LEWS: Civil Defence Authority			**V0.1**		**V0.2**		**V1.0**		**V2.0**		**V3.0**		**V3.1**		**V4.x**
National LEWS: RFI Railway Network									**V2.0**			**V3.0**	**V3.2**		**V4.x**
Regional LEWS: Liguria Region									**V2.0**			**V3.0**	**V3.1**		**V4.x**
Regional LEWS: Sardegna Region												**V3.0**	**V3.1**		**V4.x**
Regional LEWS: Puglia Region												**V3.0**	**V3.1**		
District level LEWS in INDIA: Darjeeling in West Bengal and Nilgiris in Tamil Nadu. Funded by UK NERC SHEAR LANDSLIP Project.											**Prototype**				

LEWS Key concepts

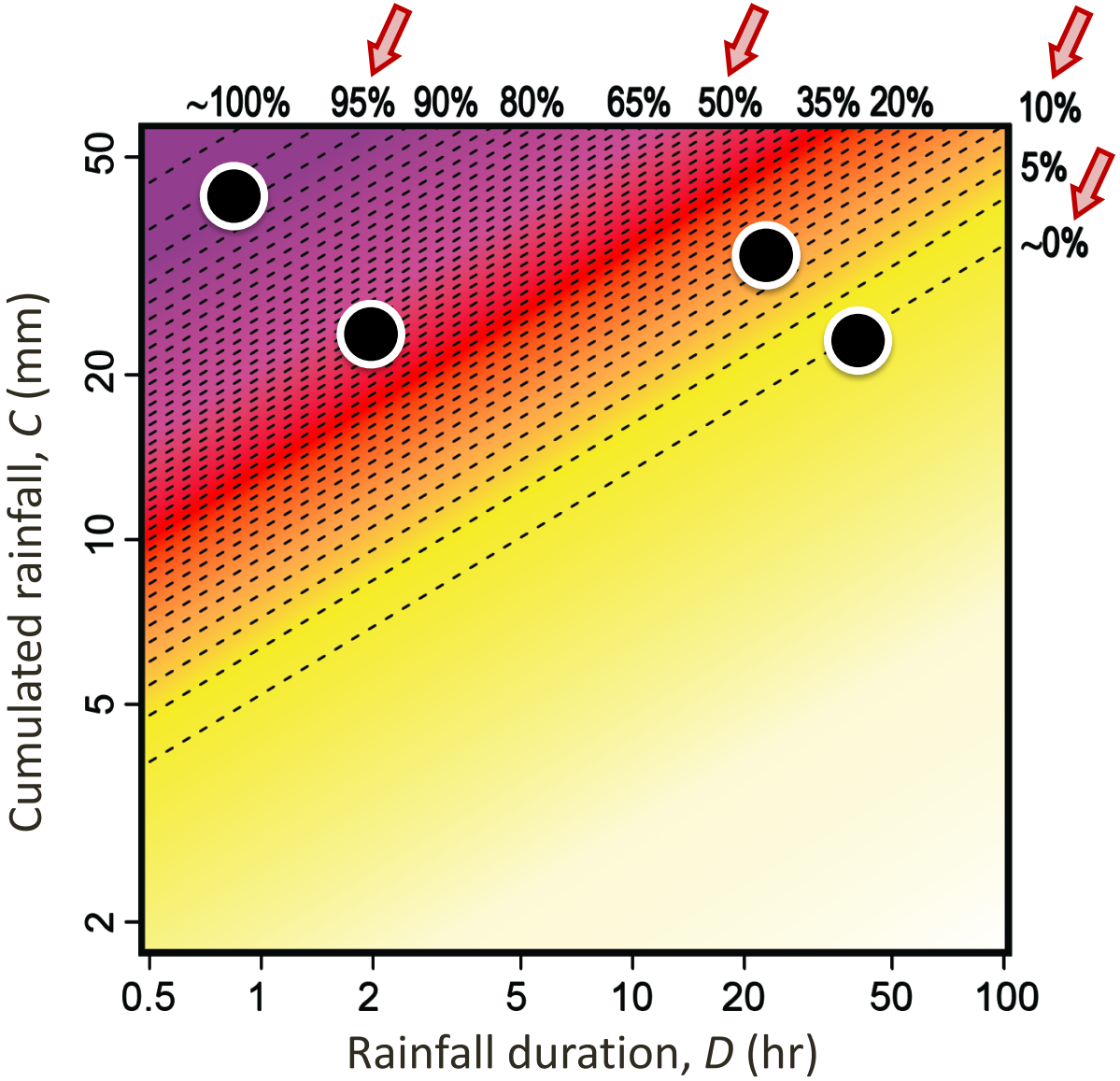
- **SANF/SARF forecasts landslides** with a **trigger mechanism directly related** to **rainfall** (i.e. shallow slides and flows)
- **SANF/SARF are based on** the **comparison between rainfall** data and landslide empirical **rainfall thresholds models**
- **SANF/SARF are probabilistic models** returning the probability of given rainfall to trigger landslides
- **SANF/SARF provide landslide nowcasts** (using rainfall measures) and **forecasts** (using rainfall forecasts) **hourly**
- **SANF/SARF use** a **statistical susceptibility models** to account the landslide propensity of a the territory

Landslide NEP: the LEWS cornerstone

The **LEWS forecasts rely upon a probabilistic model able to estimate** the **landslide** occurrence **Non-Exceedance Probability (NEP) associated to any** specific **rainfall conditions** (i.e. rainfall duration and cumulative).

The **model takes** its **scientific foundation** on the **concept** of **landslides empirical rainfall thresholds**, a **landslide forecasting approach largely verified in** the **literature**.

The **NEP model is calibrated using data** on the past **spatial-temporal occurrence** of **landslides and** on the **associated rainfall data**.



LEWS Algorithms

Average NEP

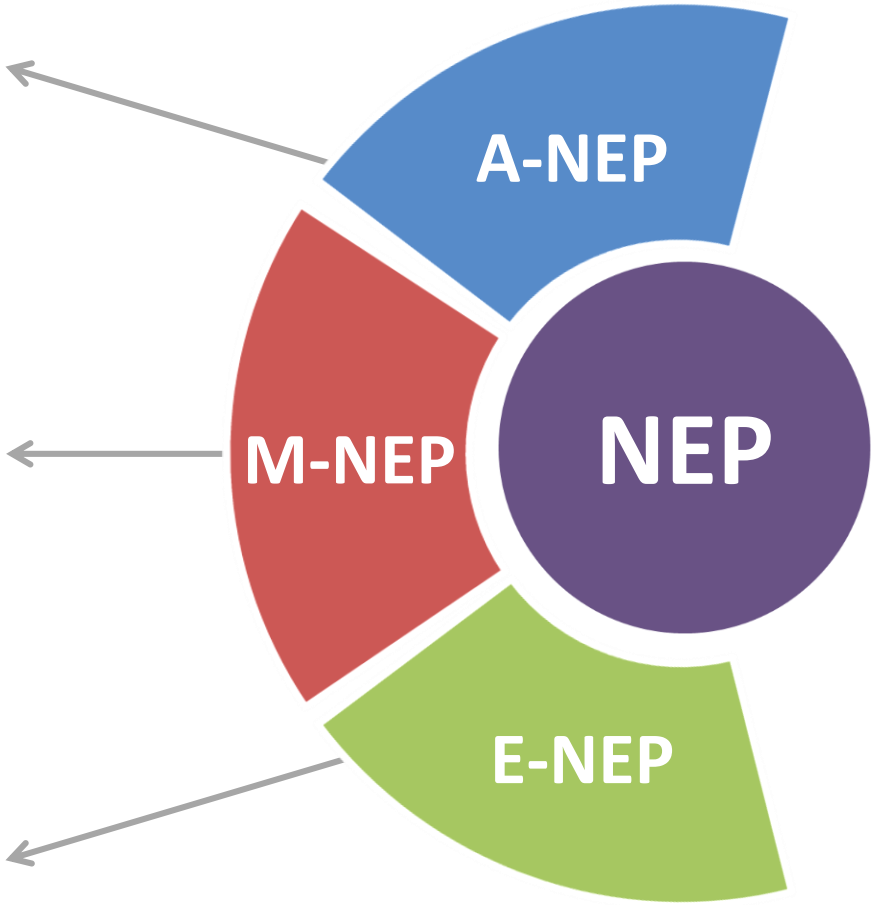
Landslide Nowcasts/Forecasts calculated **as** the **average** of **NEP values** estimated **for cumulative rainfalls** over **different antecedent/subsequent periods**.

Maximum NEP

Landslide Nowcasts/Forecasts calculated as the **maximum** of **NEP values** estimated **for cumulative rainfalls** over **different antecedent/subsequent periods**. The algorithm tracks the period corresponding to the maximum NEP.

Ensemble NEP

Landslide Nowcasts/Forecasts calculated as the **n^{th} statistics** of the NEP values estimated for **cumulative rainfalls** over **all the possible antecedent/subsequent periods**. The algorithm tracks the 50^{th} and 100^{th} NEP percentiles, their difference and the period corresponding to the maximum NEP.



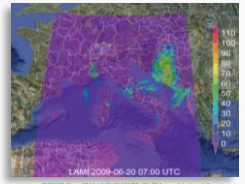
SANF/SARF Inputs & Outputs

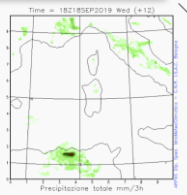
RAINFALL INPUTS

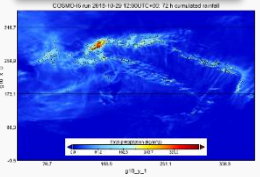
Rain Gauge
Measures

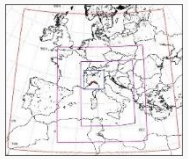
Merged RADAR
Rainfall Estimates
(Gauge + RADAR)

Rainfall
Forecasts
(COSMO-I7, COSMO-I5, BOLAM by ARPAS, WRF by CNR IMAA, ARPAL Poor's Man Ensemble, NCMRWF's global and regional deterministic model)

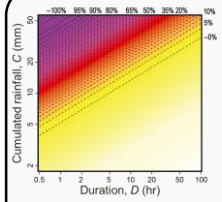


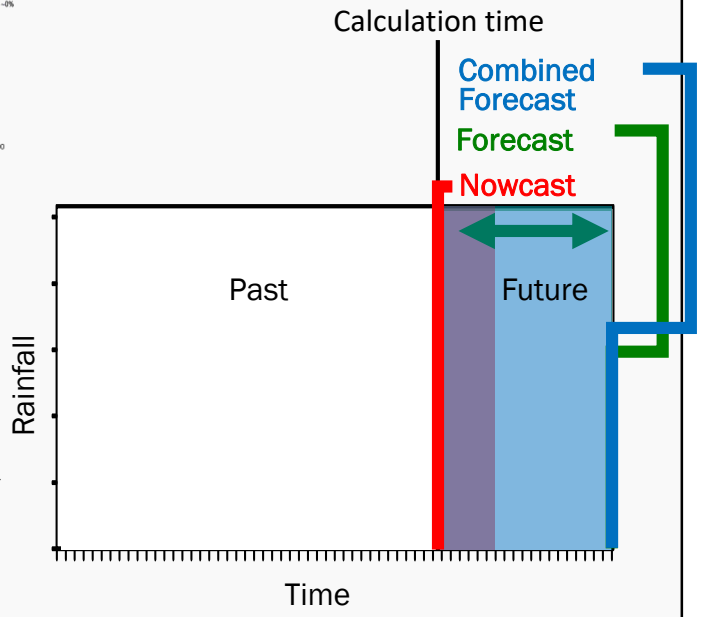






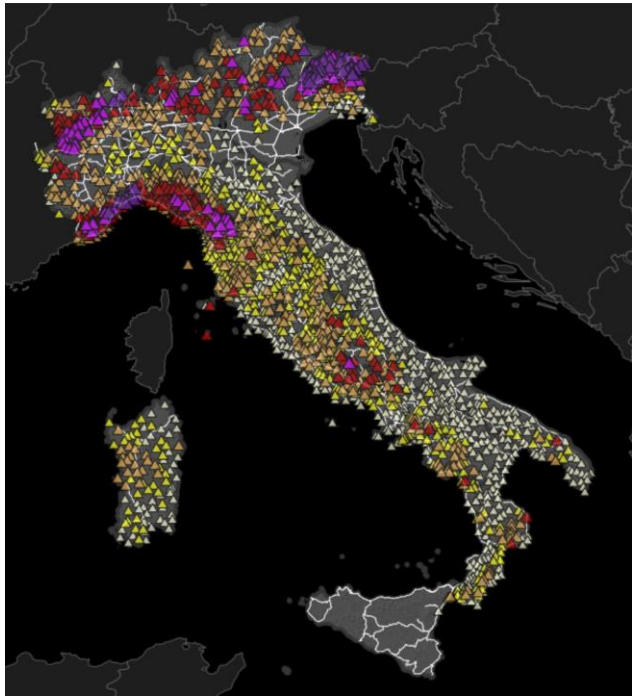
LANDSLIDE FORECASTS



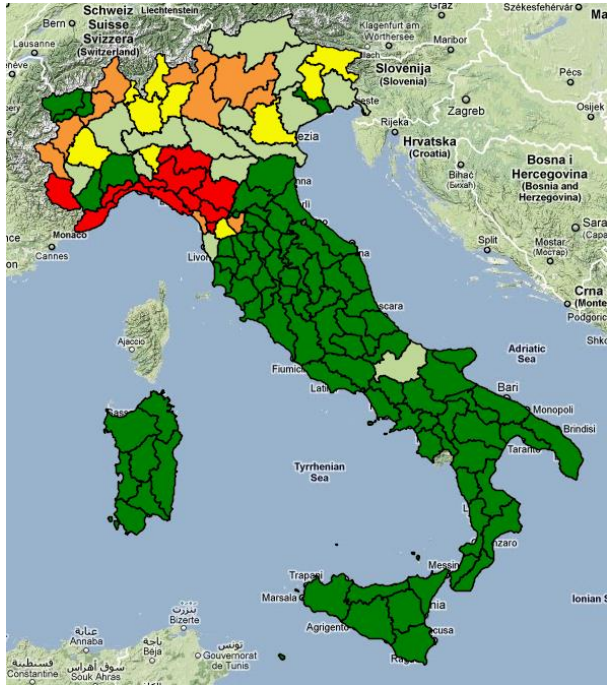


LEWS forecasts Spatial Granularities

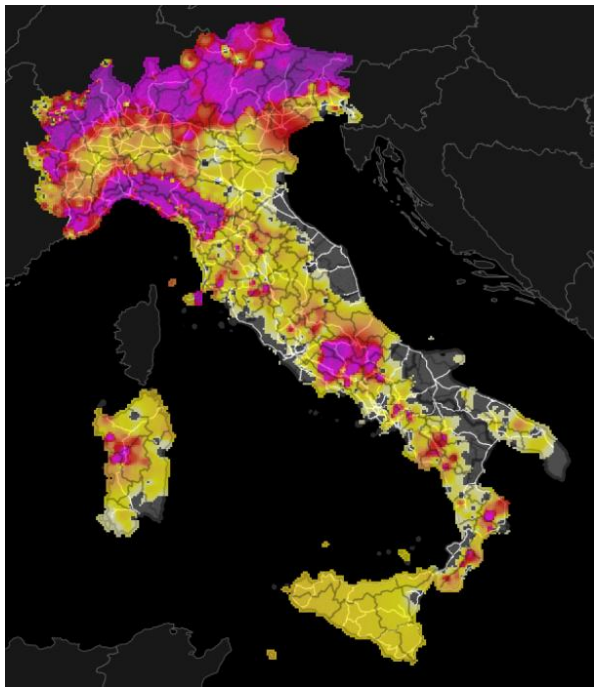
Nowcasts/Forecasts over
Rain gauges
(using data from rain gauges network)



Nowcasts/Forecasts over
Alert Zones
(aggregation of rain gauges forecasts/nowcasts)



Nowcasts/Forecasts
Interpolated
(interpolation of rain gauges forecasts/nowcasts)

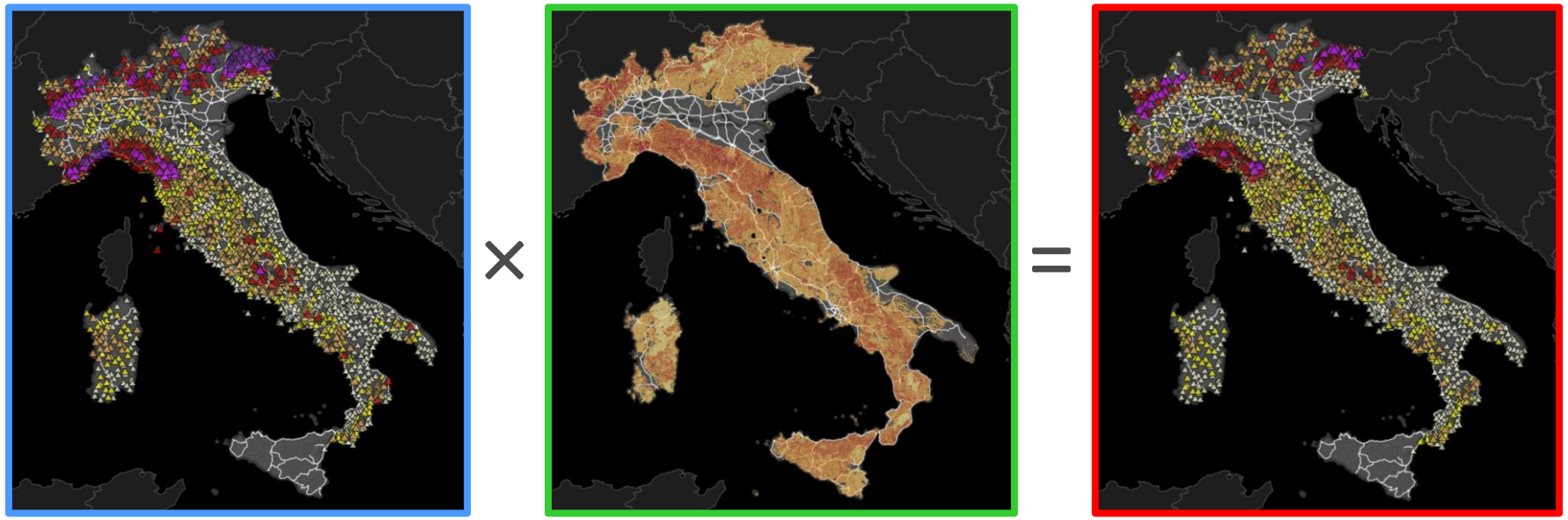


NEP & Landslide Susceptibility

LANDSLIDE NON-EXCEEDANCE PROBABILITY (NEP)

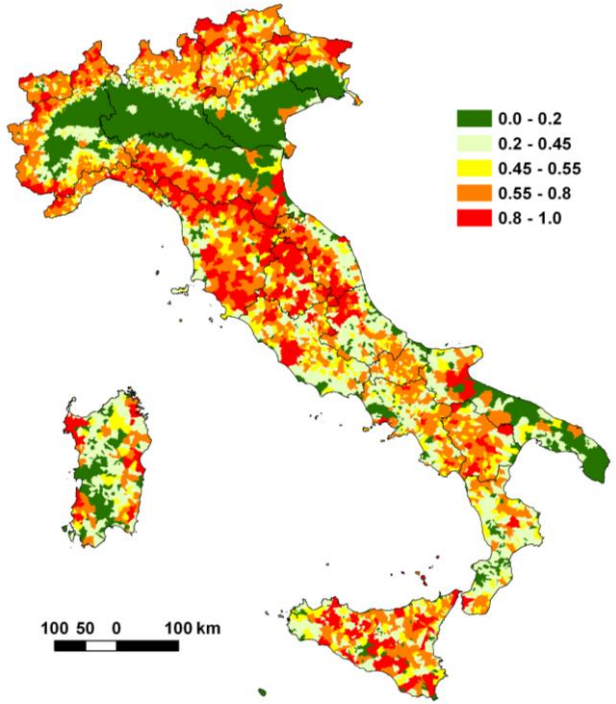
LANDSLIDE SUSCEPTIBILITY ESTIMATES (S)

NON-EXCEEDANCE PROBABILITY CONSIDERING SUSCEPTIBILITY (NEP × S)

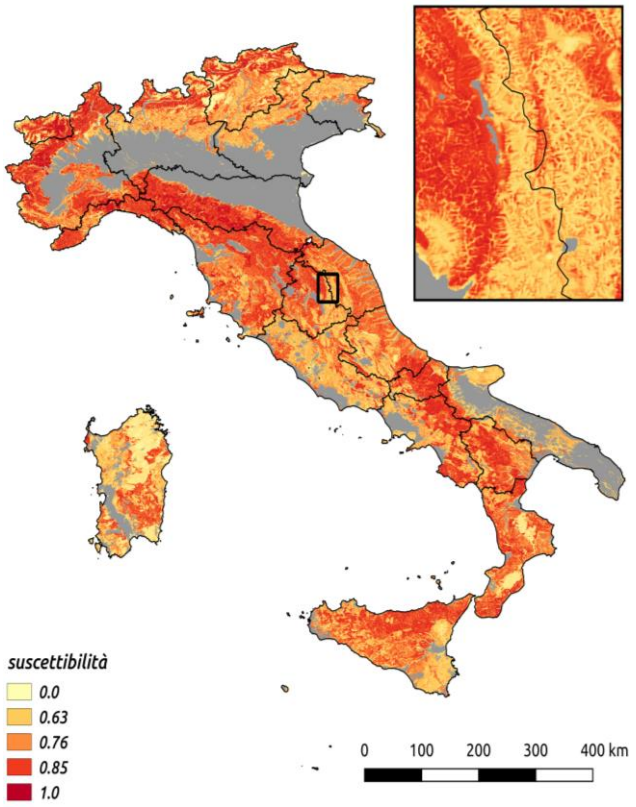


Landslide Susceptibility Models

Model @ admin level based on **landslide AVI catalogue**



Model @ pixel level based on **CNR IRPI landslide inventories**



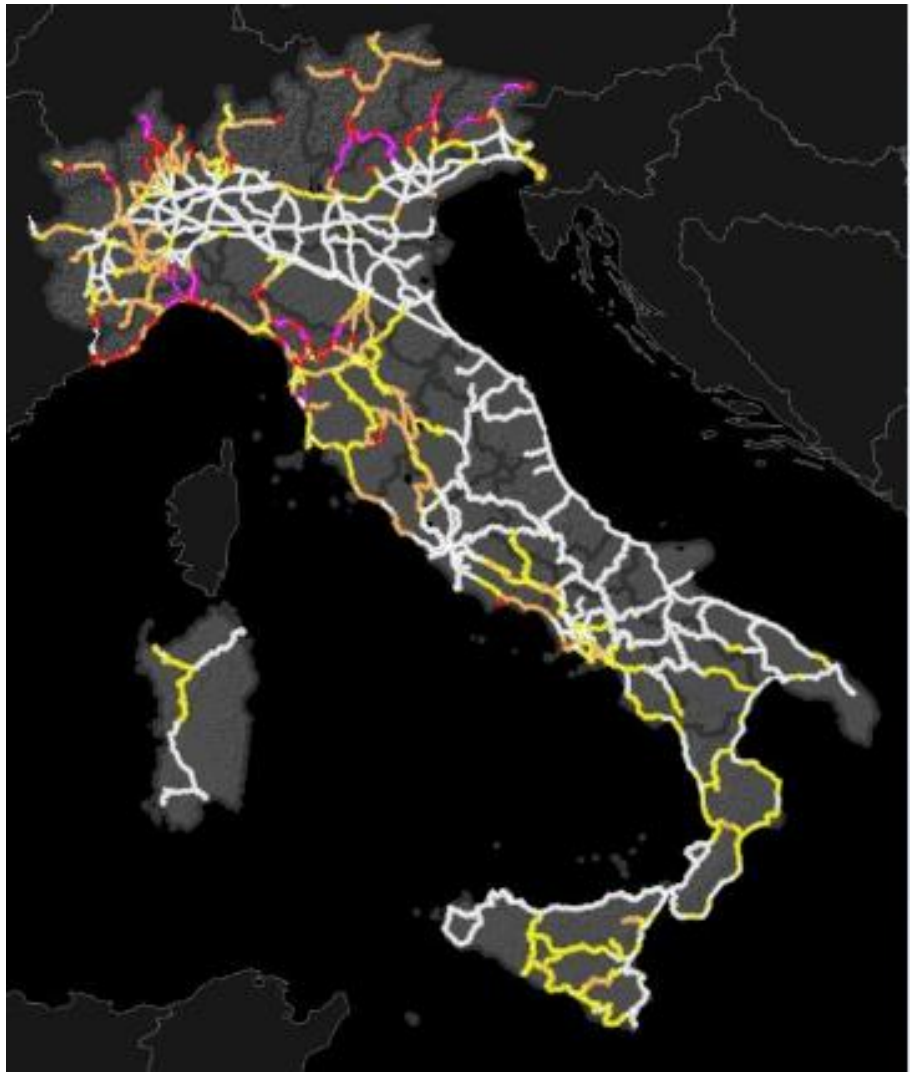
For both models the following **information** are **available**:

- **Evaluation** of **calibration performances**
- **Evaluation** of **validation performances**
- **Evaluation** of **model uncertainty**
- **Error Maps**
- **Uncertainty Maps**

LEWS Forecasts along Linear Infrastructures

A **specific LEWS version** was **developed** for the **Italian Railway Network**. The system **produces** **nowcasts/forecasts** by **overlapping** the **interpolated NEP nowcasts/forecasts to** the **railway track**.

Such **nowcasts/forecasts** **are** then **weighted** for the **railway network exposure** to **different landslide types** (namely Falls, Flows, Slides) **derived with** **diversified modelling approaches** in the **railway** track **proximity**.

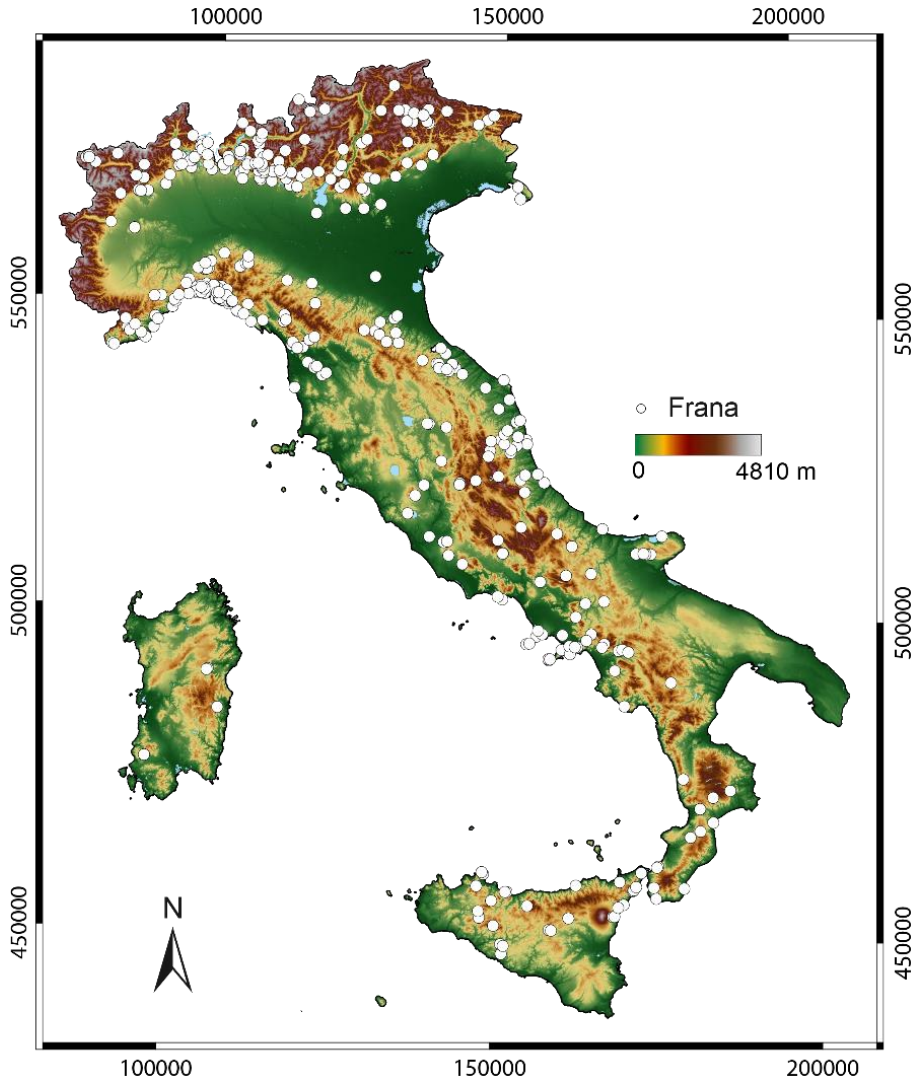


LEWS Evaluation

Procedures for the **validation** of the **system**, **can be executed on demand to assess** the system performance in terms of:

- **Operational efficiency** (proper and regular system functioning)
- **Forecasting capabilities** (degree of success of the system to predict landslide events)

The system integrates interfaces for **validation data collection** and **procedures to be used** for the **forecasting capabilities evaluation**.



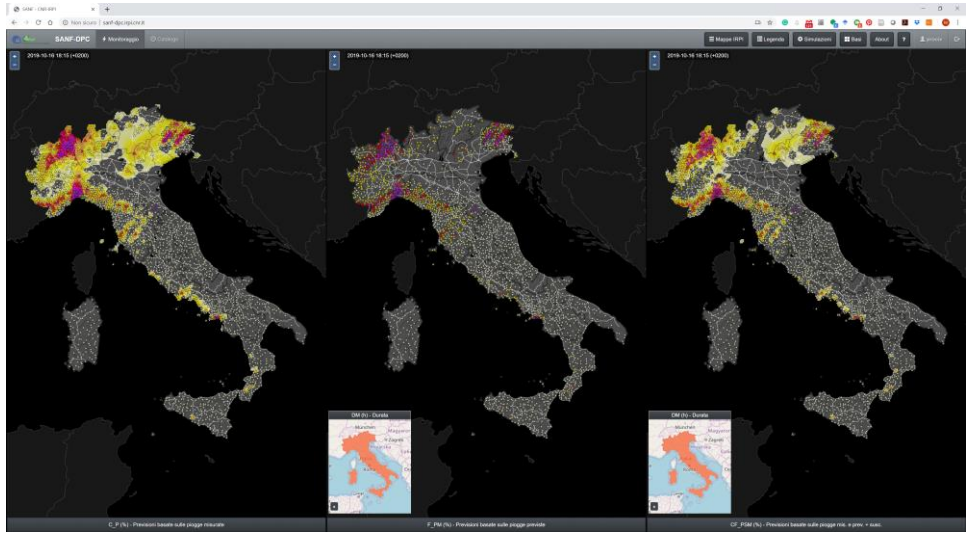
From Forecast To Warning

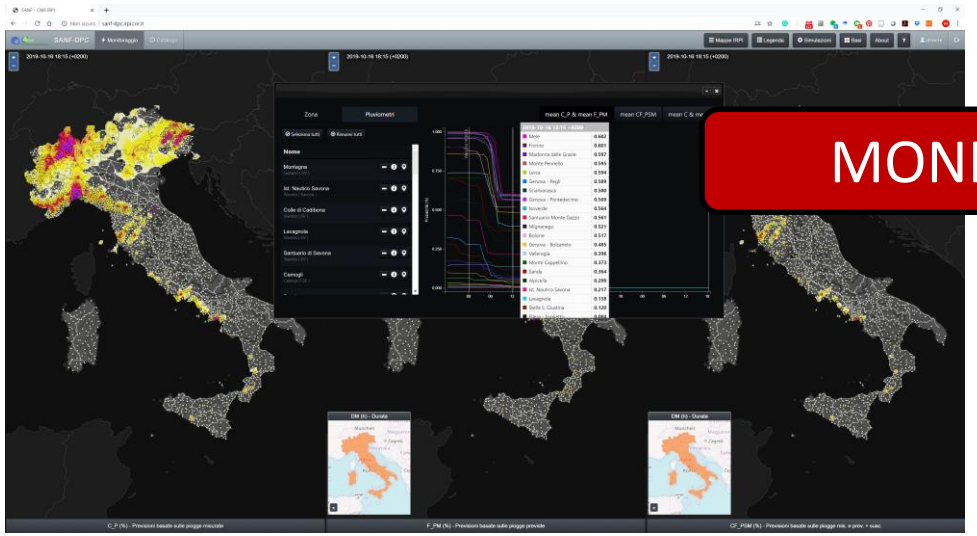
The **system does not use** a **forecasts-to-warning automatic translation** (even if in the past automatic bulletins preparation procedures were tested).
The **system offer** a **web-based interface to be used** as a **Decision Support System** (DSS) **to facilitate** a **consensus-based warning levels identification**.

Standard Operative Procedures (SOPs) **need to be defined** for this purpose and **must take into account** the **needs** and **specificities** of the **LEWS user** and the **specific institutional settings**.

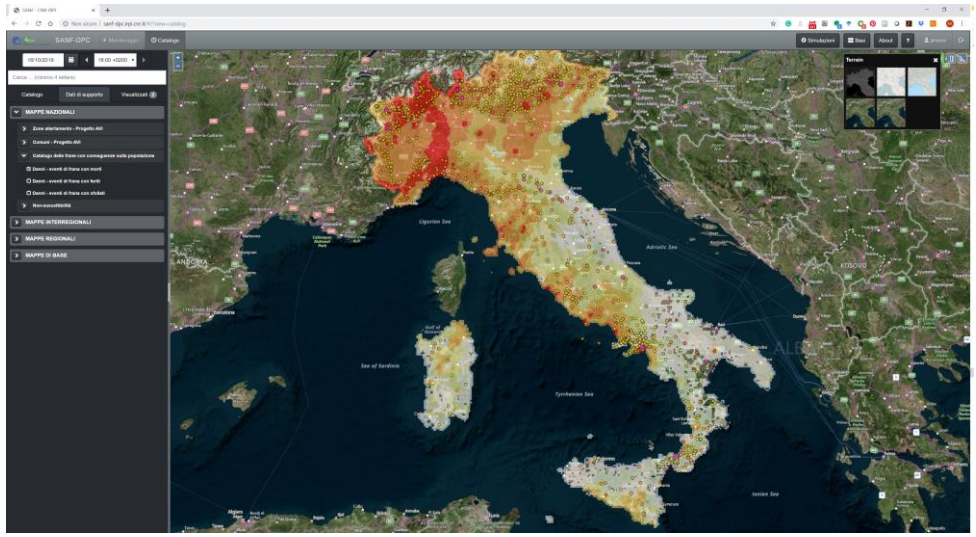
A specific **methodology was drawn to define specific SOPs**, **identifying** the **responsibilities**, the **activities**, the **products** and the **related forecast threshold levels to be considered** when **selecting landslide forecast scenarios** and **to take** the **corresponding actions**.

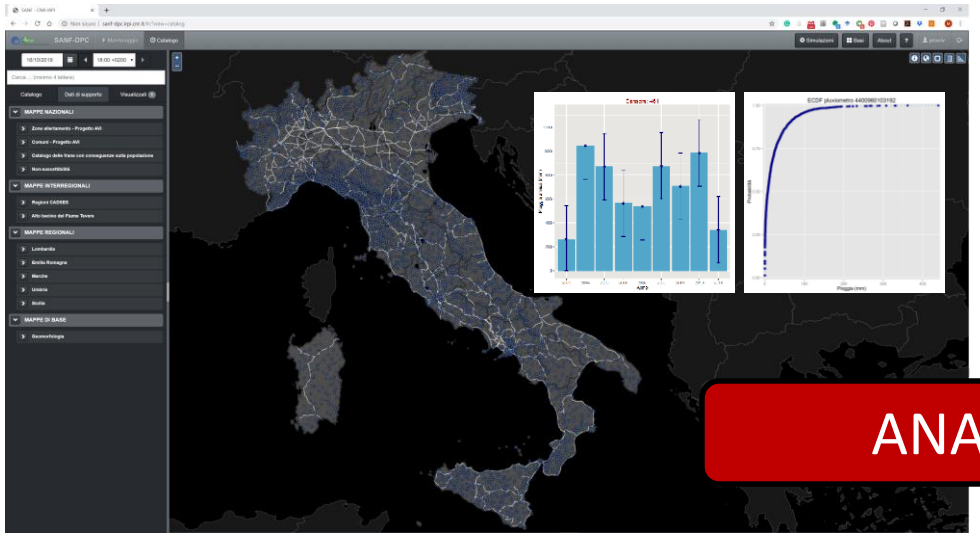
LEWS Web-Based Interfaces





MONITORING





ANALYSIS

LEWS Hardware Architecture

LEWS HW Infrastructure

DPC Experience node

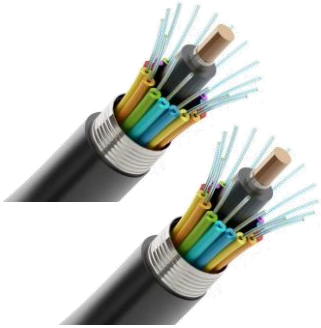
samba

Java

Backup Diesel Power Generator

Redundated UPS

Redundated fibre connection



Redundated Conditioning

LEWS Software Architecture

ubuntu

CentOS

vmware ESXi

VM LEWS-forecast

R

PostgreSQL

PostGIS

Spatial PostgreSQL

GDAL

NCL

NCAR Command Language

VM LEWS-interface

MapServer

open source web mapping

APACHE HTTP SERVER

python

GeoServer

django

ubuntu

CentOS

Lessons Learned

- **LEWS theory different from practice**
- **LEWS are complex tools** and their **implementation**, **running** and **maintenance is difficult**
- **LEWS require dedicated competences** (not only scientific)
- **LEWS benefit from multiple forecasting approaches**
- **LEWS must be continuously evaluated** (both forecasting and operational performances)
- **LEWS system users need to interact continuously with system developers** for a proper system usage
- **LEWS are live systems** (evolving in time)

Future Challenges

- **Filling** the **gaps existing** when **translating forecasts to warnings**
- **Finding a balance** between the **unavoidable LEWS complexity** and the **easy-to-use demand from users**
- **Establishing** the **appropriate LEWS accuracies in relation to** the **forecast scales**
- And many others …

Mauro Rossi

mauro.rossi@irpi.cnr.it

THANK YOU!