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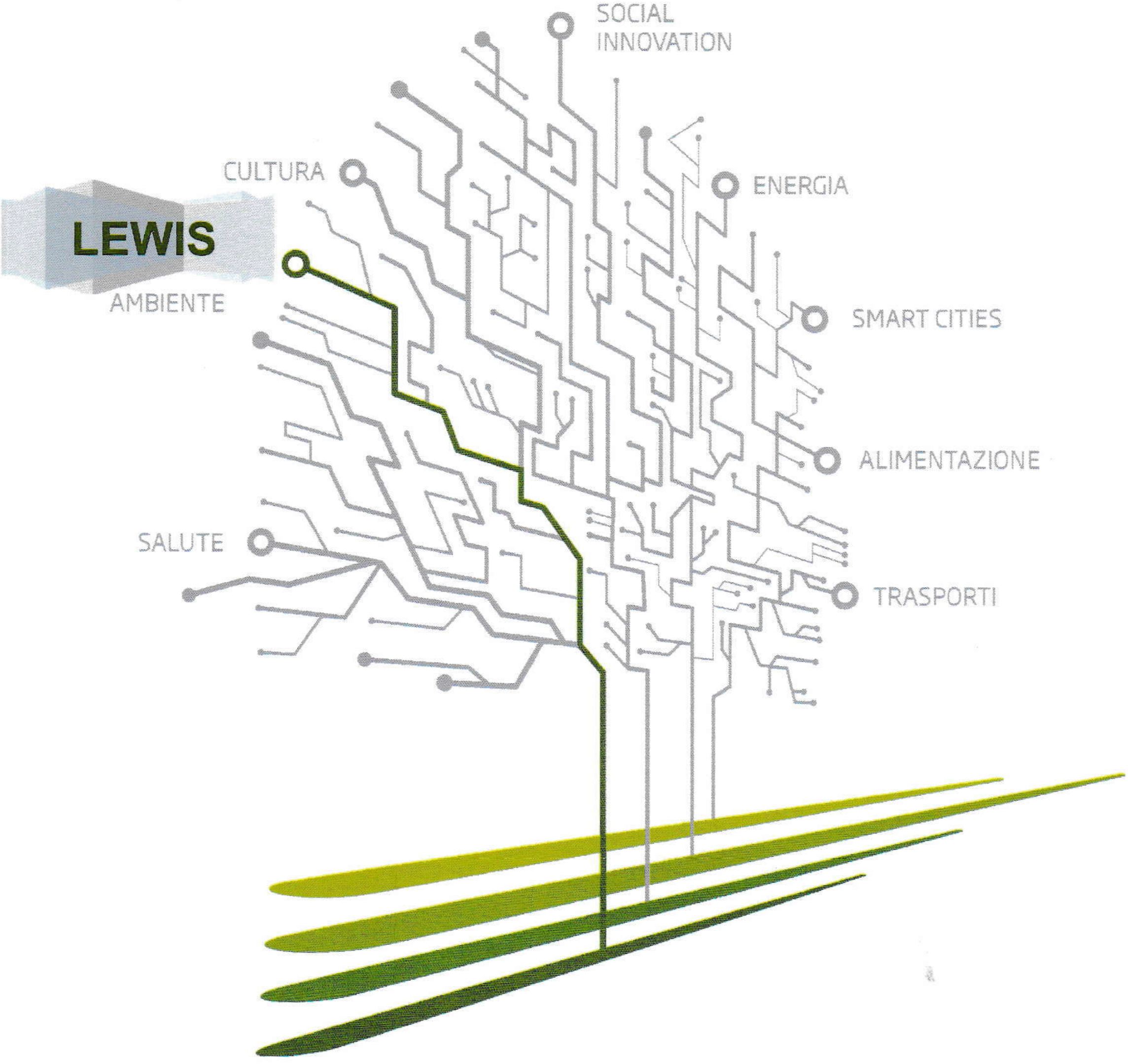
"INTEGRATED SYSTEMS FOR HYDROGEOLOGICAL RISK MONITORING, EARLY WARNING AND MITIGATION ALONG THE MAIN LIFELINES"

PROGETTO PON01_01503



Laboratorio di **C**artografia **A**mbientale e **M**odellistica **I**drogeologica

UNIVERSITÀ DELLA CALABRIA

PON01_01503 "Sistemi integrati per il monitoraggio, l'early warning e la mitigazione del rischio idrogeologico lungo le grandi vie di comunicazione. Discutiamo i risultati"
Cosenza 25-28 Novembre 2014

AN INTEGRATED SYSTEM FOR LANDSLIDE MONITORING, EARLY WARNING AND RISK MITIGATION ALONG LIFELINES

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1. INTRODUCTION *(P. VERSACE)*

In areas where landslide risk is very high, and financial resources are scarce if compared with the necessary ones, an integrated approach that combines structural and non-structural measures is necessary. In such areas, a complex strategy needs to be carried out. It includes qualitative and quantitative risk analysis, monitoring, advanced early warning systems, mathematical modelling of rainfall-landslide relationship, decision making procedures, a strategy for risk reduction measures, and plans for emergency management, works and maintenance.

In recent years, attention has been focused more and more on early warning systems, by developing both single components and integrated systems.

An early warning system aims to ensure the provision of timely and effective information that allow exposed people to make decisions in order to avoid or reduce damages and the loss of life. The safety actions are efficient when they are developed during the "lead-time", that is the time interval between the moment of the event prediction and the moment of the landslide impact.

An early warning system is composed by: landslide susceptibility maps for the investigated areas; scenarios for event impact on exposed people and goods; monitoring of key parameters; real time data transmission; mathematical models and data processing for both current hazard evaluation and future hazard forecasting; a warning model; an emergency plan in order to avoid or reduce the damages and the loss of life; a decision making procedure.

In the design of these systems the velocity of the expected landslides plays a very important role, in fact it affects not only landslide destructiveness but also the procedures for risk mitigation, as it can range from some tens of meters per second to some millimeters per year.

From a general point of view, there are four crucial moments in landslide early warning systems: precursor forecasting (t_1), precursor occurrence (t_2), event onset (t_3) and impact on people and goods (t_4).

Early warning systems are quite efficient when the time intervals (t_4-t_3) is sufficiently long to make decisions and take actions such as evacuation or protection of structures and infrastructures.

When the time between the event onset and its impact (t_4-t_3) is extremely short, the early warning procedure must be based on precursor measurements. This is the case of rapid landslides, as the time elapsing between the onset of slope failure and its impact on exposed goods is typically in the order of tens of seconds or few minutes. When the time between precursor occurrence and event onset (t_3-t_2) is also short the forecasting of the precursor becomes essential. This is the case of shallow landslides, for which the difference (t_3-t_2) is in the order of tens of minutes or few hours.

Then, depending on the landslide velocity, the system can be addressed to the movement detection for “slow” landslides or to the forecasting, with mathematical models, of the movement onset for “rapid” landslides.

This paper describes an integrated system for landslide early warning that considers both slow and rapid movements, develops original component, achieves their integration in a flexible system that can be adapted to different environmental contests.

2. LEWIS PROJECT *(P. VERSACE)*

In the framework of the National Operational Programme 2007-13 “Research and Competitiveness”, co-funded by the European Regional Development Fund, the Ministry of Research (MIUR) financed the project “An Integrated System for Landslide Monitoring, Early Warning and Risk Mitigation along Lifelines”, with acronym LEWIS (Landslides Early Warning Integrated System).

The project includes industrial research, at site tests and training activities with a two year master programme at postgraduate level.

University of Calabria and Autostrade Tech are the main partners of the project, Strago and TD Group are the other industrial partners, together with Universities of Firenze and Catania as research partners, and the Interuniversity Consortium on Hydrology (CINID) as partner in the Master organization.

The project aims to develop an integrated, innovative and efficient solution to manage risk issues associated to landslide prone infrastructures, by developing and testing a system able to timely identify potentially dangerous landslides, and to activate all needed measures for impact mitigation, including the information delivery.

The system includes many components: standard criteria for evaluation and mapping landslides susceptibility; monitoring equipment for measuring the onset of landslide movement; telecommunication networks; mathematical models for both triggering and propagation of landslides induced by rainfall; models for risk scenario forecasting; a centre for data acquisition and processing; a traffic control centre.

In Fig. 1 the flow chart showing the interrelation among the different research components is outlined.

The integration of the system allows for maximizing its operational flexibility as each developed component provides different interchangeable technological solutions. Therefore, the final system may assume many different configurations from the simplest to the most complex, to deal with different scenarios. The flexibility depends essentially on the wide range of monitoring equipment, both traditional and innovative, that have been considered and on the different kind of mathematical models that have been realized.

In particular, the adopted monitoring devices are six: three “point” systems, made up of a network of sensors that locally measure the start of shallow or deep displacements, and three “area” systems that remotely measure the movement of large slopes. All the monitoring systems are fully integrated and are connected to a unique data transmission system.

Concerning the mathematical models for landslide triggering, the system includes both empirical and complete ones. The empirical or hydrological models are simple relationships, obtained by linking the antecedent rainfall and the occurrence time of landslide. On the contrary, the complete models take into account the hydrological and geotechnical processes involved in slope scale and affecting stability. The complete models, adopted in this research, include local models and areal models.

The compactness of the whole system is mainly based on standardized and shared procedures for the identification of risk scenarios, for the surveys to be carried out, for the procedures for each type of on-site testing, for the data assimilation techniques, for the presentations of results, such as risk maps along the highway, landslides susceptibility maps and so on.

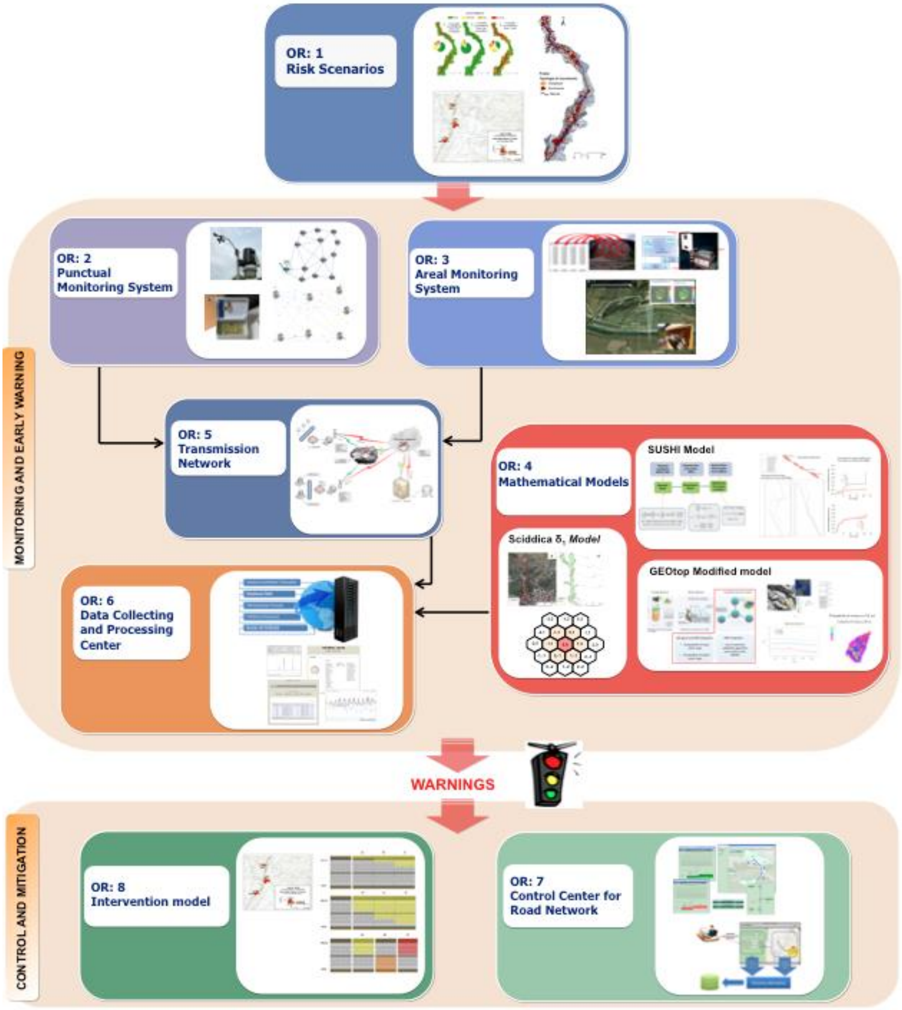


Figure 1. Interrelation among the different research components

The setting up of the data acquisition and processing centre and of the traffic control centre are the core of the integrated system. The CAED (“Centro Acquisizione ed Elaborazione Dati” – Data Collecting and Processing

Center) acquires and processes data that are tremendously variable in intensity, dimensions, characteristics and information content. The Control Center for Road Network (CCC) is meant to integrate the scientific and the management aspects of hydrological risk monitoring and early warning.

The tests for experimentation and validation of the system are being carried out in three highway sections, related to Campania, Basilicata, Calabria and Sicily, that are italian Regions interested by the Community Support Framework.

In the following chapters the LEWIS components will be described:

- Landslide susceptibility assessment
- Displacement measurement
- Measurement of transmission and data acquisition
- Intervention model
- The integration of Monitoring with the Control Center for Road Network (CCC)
- Experimental activities
- The Training Program.

3. LANDSLIDE SUSCEPTIBILITY ASSESSMENT *(F. MUTO, M. CONFORTI, V. RAGO)*

In this paragraph, a methodology for the landslide susceptibility assessment is presented, which was applied in the test areas of the Research Project. The results of a case study along a section of motorway in Calabria (southern Italy), where also presented.

3.1 METHODOLOGY

In landslide susceptibility analyses, the main phases are the collection of data and the construction of a spatial database (Lan et al. 2004; Conforti et al. 2012, 2014). The construction of the spatial database, comprising several maps, was based on three different tasks: digitizing and editing of previous cartographic information, multi-temporal air-photo interpretation and field survey. Database include the geological, topographical, geomorphological, land use/cover information and detailed landslide inventory map. These data were included into the GIS system, which was used as the basic analysis tools for spatial management, data integration and susceptibility analysis phase.

The geo-environmental features of an area have different effect on the occurrence of landslides, and can be utilized as predisposing factors in the prediction of future landslides (VanWesten et al. 2008). In this study, the predisposing factors were selected among the most commonly used in literature and in according with the geological and geomorphological settings of the study areas. All data layers were transformed in raster format.

The landslide susceptibility was performed on the basis of ‘Conditional Analysis’ statistical method applied to a subdivision of the territory into Unique Condition Units (Carrara et al. 1995) (Fig. 2). In this method landslide susceptibility is expressed as landslide density in correspondence with different combinations of predisposing factor classes (Clerici et al. 2006).

The thematic layers were crossed in order to obtain all the possible combinations of the various classes of the different predisposing factors. Each specific combination represents a Unique Condition Unit (UCU). Their number and size depend on the criteria used in classifying the predisposing factors. Subsequently, the landslide presence, represented by the landslide area, is determined within each UCU and the landslide density is computed. Assuming as principle that it is more likely that landslides occur under those conditions which led to slope-failure in the past, the computed landslide density is equivalent to the future probability of occurrence. The conditional probability is given by:

$$P(L|UCU) = \text{landslide area} / \text{UCU area} \qquad (1)$$

i.e. the probability of landslide occurrence (L), in an unique combination of factors (UCU), is given by the landslide density in that specific UCU. Landslide density in each UCU was computed and the susceptibility map was realized.

The validation of the susceptibility model, obtained using the landslides of the training set (Fig. 2), was carried out through the validation set (not used in the training phase). Validation allows the export of models in other zones with similar geo-environmental features. Therefore to quantify the performance of the statistical method and evaluate its predictive capability, the prediction-rate curve was developed and the area under curve (AUC) was calculated (Beguería 2006; Chung & Fabbri 2003).

3.2 AN APPLICATION ALONG A SECTION OF MOTORWAY IN CALABRIA (SOUTHERN ITALY)

The case study was conducted along a section of motorway “A3, Salerno-Reggio Calabria”, between Cosenza Sud and Altilia, northen Calabria (Italy) (Fig. 3).

From a geological point of view, the study area is characterized by a sequence of nearly flat-lying nappes including Paleozoic methamorphic and plutonic rocks, and Mesozoic to Paleogene ophiolitic, meta-sedimentary and sedimentary rocks (Tansi et al. 2007). These rocks are unconformably covered by Miocene to Quaternary deposits. The main thrust fault crops out in the upper portion of the study area, where gneiss tectonically overlies the schist and the phyllite. Neogene normal and strike-slip faults abruptly increased tectonic uplift, and conditioned the orientations of drainage channels.

Geology and tectonic setting, have strongly controlled the geomorphology of the study area, which is dominated by a mountainous landscape characterized by steep slopes, more than 30° in average, and a high local relief due to the rapid uplift of the Coastal Range deeply dissected by V-shaped valleys, which are locally fault controlled. Where phyllitic schists predominate, the ridges show a sharp crests and the slopes are affected by widespread slope instability (Le Pera & Sorriso-Valvo 2000). Therefore, in the study area the dominant slope processes are related to landslides and running-water processes that essentially control the present-day morphological evolution of the reliefs and are responsible for serious damage to property and infrastructure.

Landslide inventory map at the 1:10000 scale was carried and a total of 835 landslides were mapped (Fig. 4). The type of movement are represented mainly by slides and complex and subordinately flow. Most of the observed landslides are active; as for the evolutionary trend of slope movements in the area, retrogressive evolution generally prevails. In order to estimate and validate landslide susceptibility map, the landslide inventory was randomly divided in two groups. One group (LS-training set) was used to prepare susceptibility map and the second group (LS-validation set) to validate the susceptibility map.

In this study, seven predisposing factors (PFs) were selected among the most commonly used in literature to evaluate landslide susceptibility; in particular, the results of field surveys and air-photo interpretation suggested that lithology, faults, land use and a series of topographic factors as slope, aspect, plan curvature and stream power index (SPI), match very well with landslide distribution in the study area (Fig. 4). Lithologies and faults were derived from the geological map. The land use was classified through air-photo interpretation and Corine Land Cover project maps. Slope, aspect, slope curvature and SPI were automatically derived from DEM with a resolution of 20 x 20 m pixel size.

To evaluate the landslide susceptibility the PF maps were crossed, in a GIS environment, in order to obtain a UCUs map containing all the class combinations present in the study area (Fig. 4).The number of potential UCUs in the study area, i.e. the possible combinations of the different classes of the seven PFs, is 28800 (Fig. 4). Of these, 7030 are present in the study area. Then, the landslide density within each UCU, which represent the susceptibility values, was calculated overlapping the LS-training set with the UCUs map.

These values were classified into four susceptibility classes: low, moderate, high, and very high (Fig. 5a). The results showed that the 38% of the study area is characterized by susceptibility high and very high (Fig. 5b).

The overlay of susceptibility map and LS-training set showed that 82% of the landslide were correctly classified, falling in high and very high susceptibility classes.

To evaluate the predictive power of the landslide susceptibility model, the independent subset of landslides (LS-validation set) was used and prediction-rate curve was computed. The results showed that the 78% of the LS-validation set falls within the most susceptible areas and an AUC value of 0.83 (Fig. 5b) attesting a good performance of the susceptibility analysis. These results suggest a good reliability of the adopted statistic method and of the selected predisposing factors.

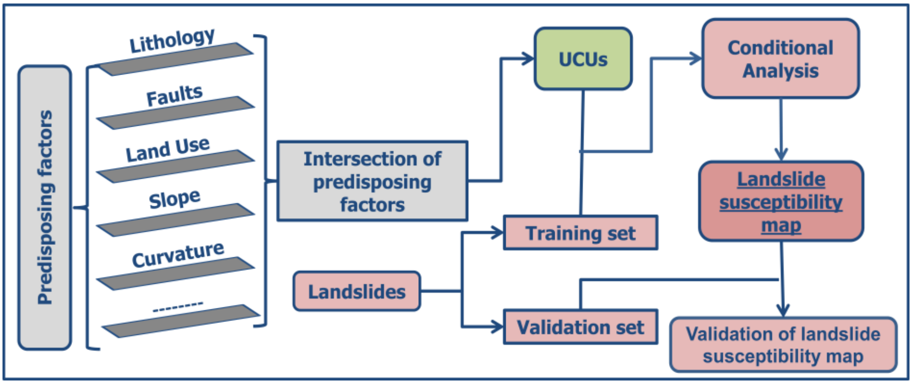


Figure 2. Flow diagram showing the landslide susceptibility method

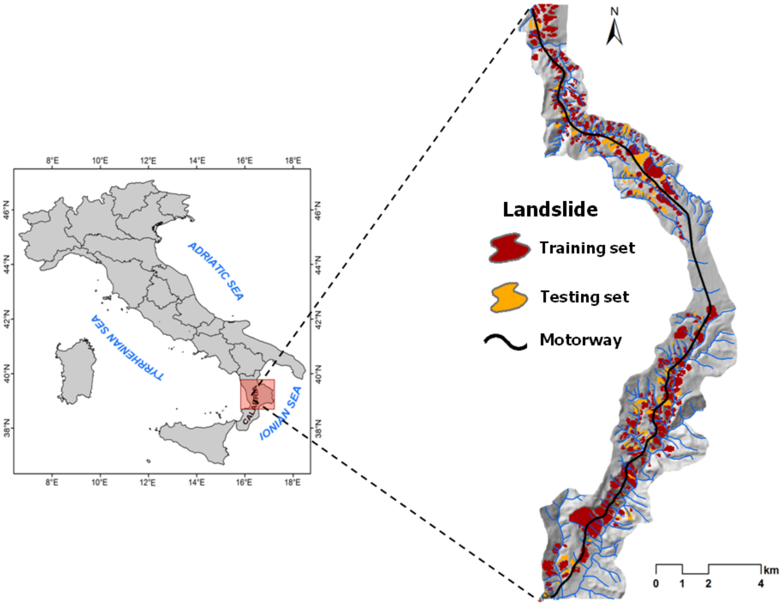


Figure 3. Location and landslide inventory map of the of study area

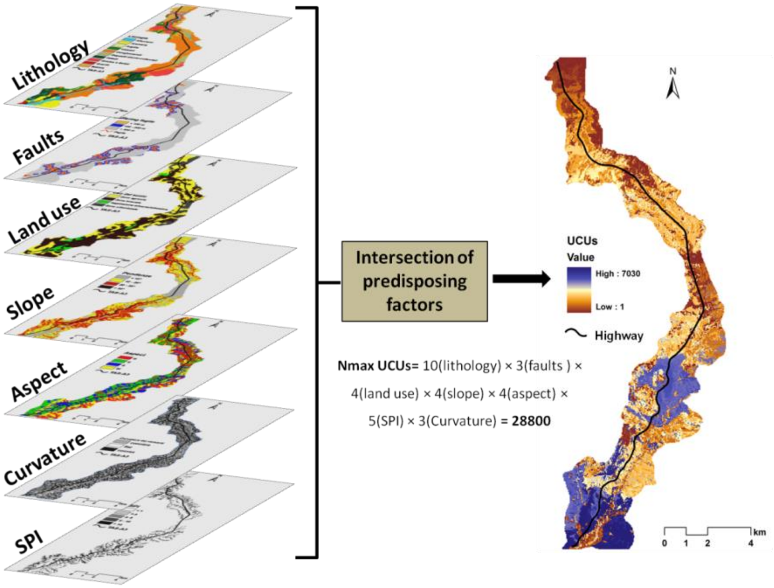


Figure 4. Location and landslide inventory map of the of study area

4. DISPLACEMENT MEASUREMENT

4.1 AREAL MONITORING SYSTEMS

Areal monitoring activities, performed in the framework of a national project on “Landslides Early Warning”, are described in this section. Two compact and low-cost radar configurations, the first one based on the adoption of a software radio platform, the second one using a compact Vector Network Analyzer as SFCW scatterometer module, were developed by Microwave Lab at University of Calabria, while a portable and versatile Ground-Based Interferometric Synthetic Aperture Radar (GB-InSAR) was proposed by Department of Earth Sciences at University of Firenze . Experimental results were carried out as validation tests to demonstrate radar range detection capabilities for both software defined platform and scatterometer, while displacement maps, calculated from an interferogram obtained through a 3 days long measurement campaign, were performed to experimentally validate GB-InSAR features.

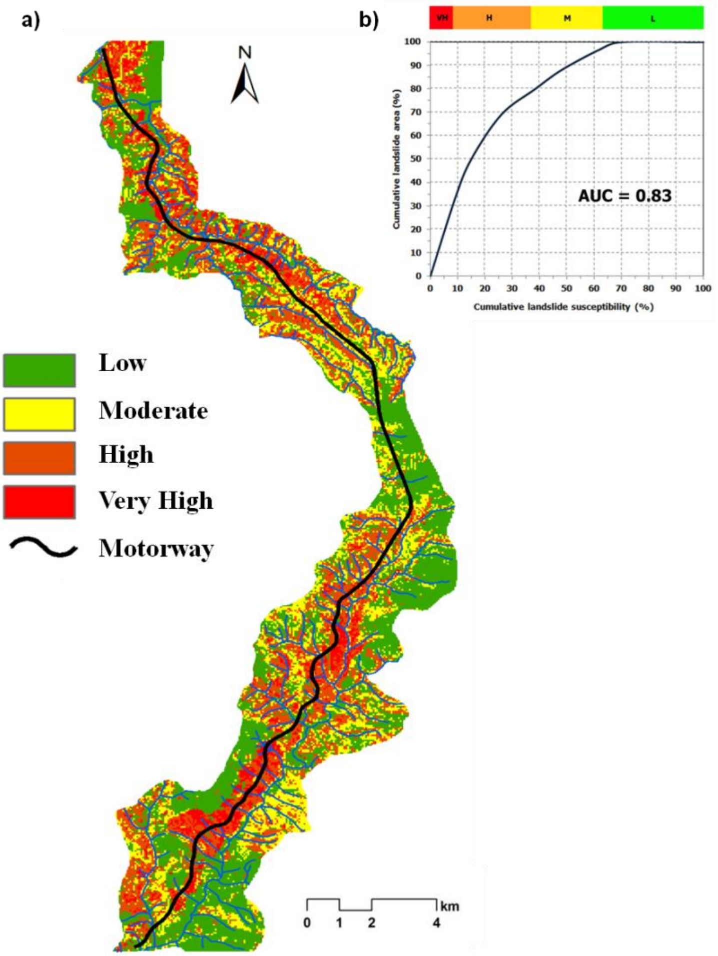


Figure 5. a) Landslide susceptibility map of the study area; b) Prediction-rate curve corresponding to landslide susceptibility model

4.1.1 L-Band Software Defined Radar *(S. Costanzo, G. Di Massa, F. Spadafora, A. Raffo, A. Costanzo, L. Morrone, A. Borgia, D. Moreno)*

The primary goal in the design of the L-band radar system is the possibility for the radar signal to go over the possible vegetation layer on the mountain under observation; this justifies the choice of the L-band, able to realize the wave penetration feature. An antenna rotor is used in order to perform the complete scanning of the area under analysis and an amplification circuit, with a power amplifier and a low noise amplifier, is adopted in order to improve the capability of the radar to detect the signal. Data acquisition, signal processing, and the broadcast of the radar data to a possible acquisition centre is performed by a LabView application on an integrated PC with I5 processor (MXE5302). The antenna used in transmission is a standard gain horn antenna, while the receiver antenna is an array of 8x4 elements specifically designed in the framework of the project.

The totally remote control of the radar system is implemented with a single board computer RaspBerry and a GSM module for the reception of sms, e_mail command or wireless control.

The entire block diagram of the L band radar system is shown in Fig. 6.

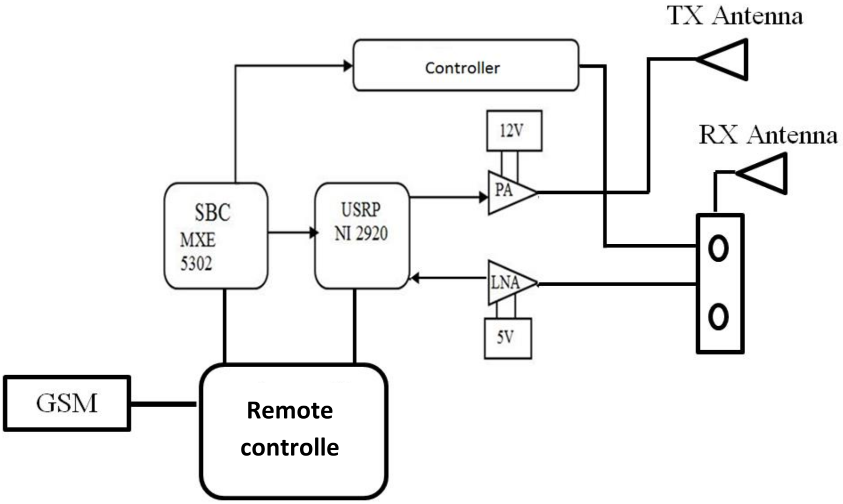


Figure 6. L-Band Software Defined Radar system

The main features of the software application for the entire management of the system are the following:

- friendly Grafic Interface User;
- possibility to save both the raw and the processed data;
- setting of the main radar parameters;
- possibility to divide the scene under analysis in two or more sector;
- setting of the parameters relative to the antenna rotor (n° scan and degree for every scan);

- autosave of the data;
- transmission of the data to an acquisition and elaboration centre.

A printed microstrip antenna, composed by a rectangular slotted patch and fed by a coaxial pin, has been considered as the elementary radiating element for the array supporting the receiving channel of the Software Defined Radar System, while a standard WR-430 Horn antenna, operating in the frequency range 1.7GHz-2.6GHz, performing 20dB gain, has been used in the transmitting one. A picture of the array, mounted in the far field tests, is shown in Fig. 7.

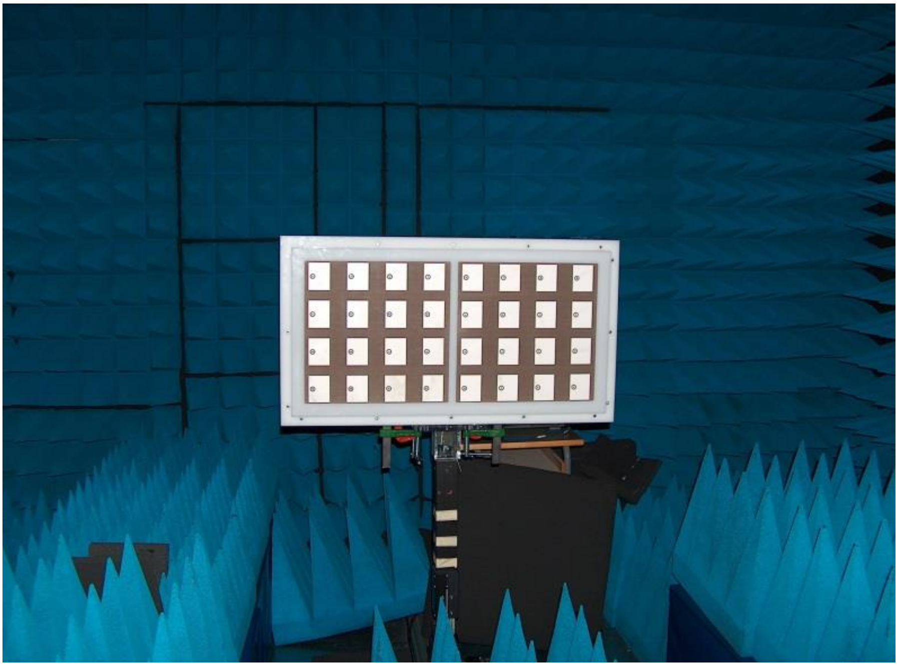


Figure 7. Proposed microstrip patch array for radar application (far-field test)

The adopted radar signal processing is a particular pulse compression technique called Stretch Processor, generally used for target detection. The transmitted signal is a chirp waveform and the corresponding radar slant resolution is equal to $c/2B$, where c is the free-space velocity and B is the signal bandwidth. According with the USRP 2920 hardware, the slant range resolution results to be equal to 6m.

The processing consists in four distinct steps: first, the radar Rx signal is mixed with a replica of the transmitted waveform; then Low Pass Filtering (LPF) and coherent detection are performed in order to avoid the high frequency response achieved at the mixer output. Afterwards, Analog to Digital (A/D) conversion in performed and finally the Fast Fourier Transform is used to extract the tones proportional to the target range. A block diagram for a stretch processing receiver is illustrated in Fig. 8.

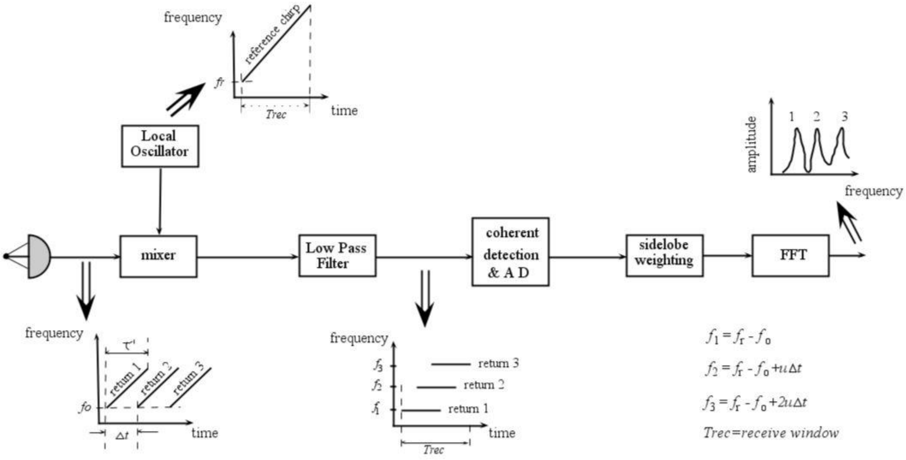


Figure 8. Stretch processor block diagram

In order to validate the L Band radar system and the signal processing tecnique, both free-space and indoor tests have been performed. The radar hardware was assembled in a dedicated case for instruments, and a picture of the entire system is depicted in Fig. 9.

The aim of the experiments was the detection of a metallic sheet at several distances, and the relative measurement setup are shown in Figure 9. In the test, foliage penetration using L-band signal with horizontal polarization was verified hiding a metal plate behind the trees. An example of the the radar response is reported in the graph of Fig. 10.

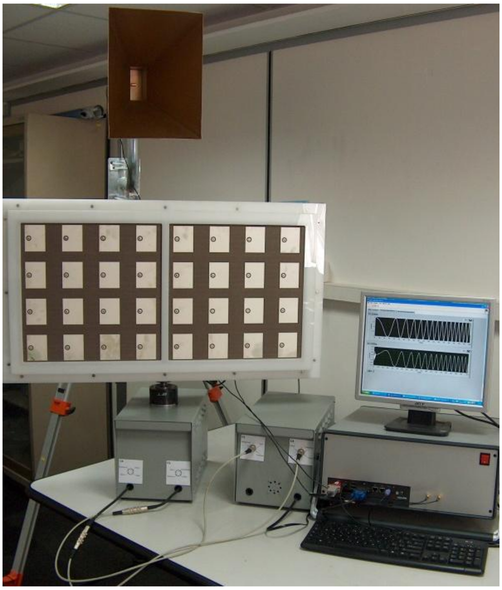


Figure 9. L-Band radar system

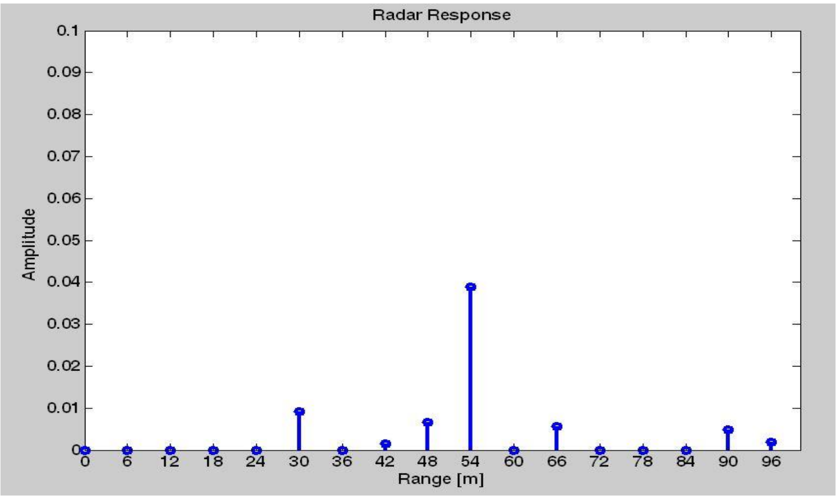


Figure 10. Radar system response with a target detection approximately 54m

4.1.2 STEPPED FREQUENCY CONTINUOUS WAVE RADAR *(S. COSTANZO, G. DI MASSA, F. SPADAFORA, A. RAFFO, A. COSTANZO, L. MORRONE, A. BORGIA, D. MORENO)*

A Stepped-Frequency Continuous-Wave (SFCW) radar has been realized by adopting a compact Vector Network Analyzer, controlled by a C# .NET interface, and connected through a switch module and a Butler matrix to transmitting and receiving microstrip array antennas, in order to realize an azimuthal scanning capability able to select a specific investigation area.

To capture an entire scene, the scan on four different areas, illuminated by the same microstrip array antenna, is required. Since the installation site is not provided for the constant presence of an operator, a framework has been developed for the beam switching in reception and the remote switching on and off of the elements.

This allowed us to create a system able to optimize a wide range of goals, such as reduced power consumption, size limits, performance, reliability and cost constraints.

The block diagram of the C-band SFCW radar is reported in Figure 11.

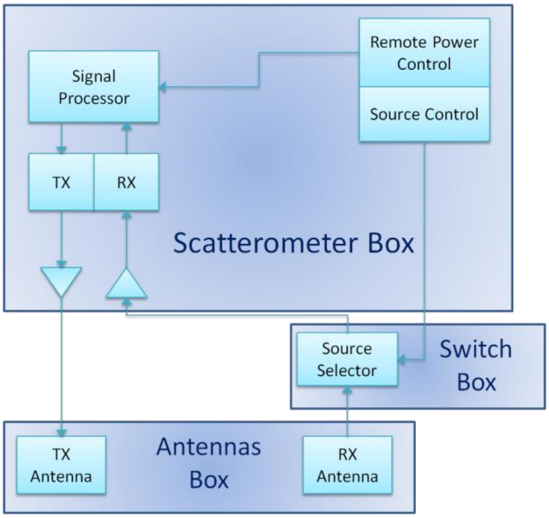


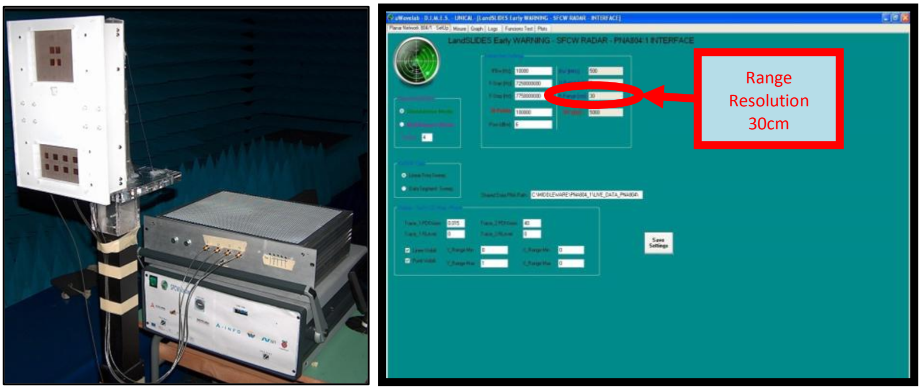
Figure 11. C-Band SFCW radar (top level)

The system is composed of three basic parts:

1. **Scatterometer Box**, which is responsible for the generation and the amplification of RF signals, the acquisition of scattering parameters, the storage and processing operations, and the reconstruction of the HRR Profile. It also incorporates the control block for the beam scanning, the remote activation and the data transfer managing by remote server through socket TCP/IP interface, having its own protocol.
2. **Switch Box**, which contains an RF switch that along with the Butler matrix, located inside the Box Antennas, selects the beam scanning direction.
3. **Antennas Box**, which contains, in addition to the Butler matrix mentioned above, the antennas for transmission and reception.

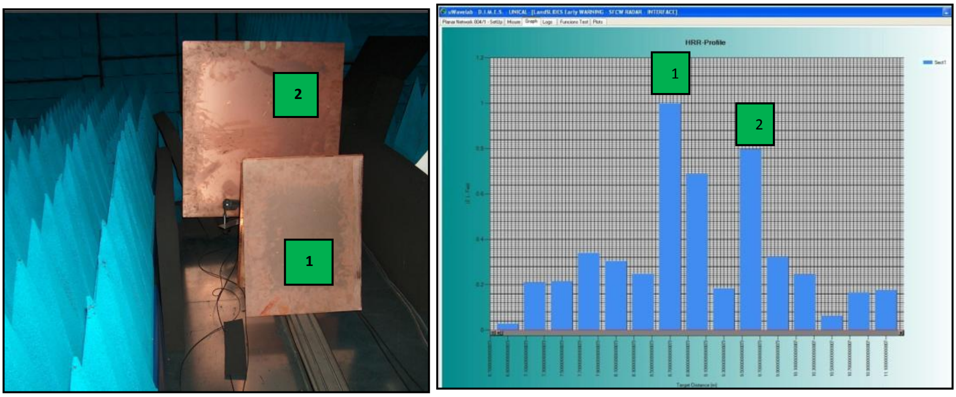
A photograph of the C-band radar system is illustrated in Fig. 12(a), while the software interface is reported in Fig. 12(b).

Experimental tests have been performed to validate the radar range resolution, equal to 30 cm for a bandwidth operation of 500 MHz (Fig. 12(b)). An example of accurate position identification in the presence of two test targets given by two metal plates (Fig. 13(a)) is reported in Fig. 13(b).



(a) (b)

Figure 12. (a) Photograph of C-band SFCW radar and (b) software interface



(a) (b)

Figure 13. (a) Two test targets and (b) proper targets identification by C-band SFCW radar

4.1.3 INTERFEROMETRIC AREAL CONTROL *(F. BARDI, R. FANTI, F. FIDOLINI, E. INTRIERI, N. CASAGLI)*

The Ground-Based Interferometric Synthetic Apertire RADAR (GB-InSAR) adopted in this project is the upgrade realized by Ellegi Lisalab of the apparatus originally developed by the European Joint Research Centre of Ispra (Tarchi et al. 1999); with time, several versions of this tool were applied to monitor landslides (Del Ventisette et al. 2011; Intrieri et al. 2012; Atzeni et al. 2014; Gigli et al. 2014), volcanoes (Di Traglia et al. 2013; 2014; Intrieri et al. 2013a), glaciers (Luzi et al. 2007), buildings and structures (Pieraccini et al. 2000) and archaeological monuments (Tapete et al. 2013).

It is able to detect submillimetric displacements for an areal scenario up to few hectares wide, has been developed and tested. The system is composed of a transceiver, a 2.1 m long linear rail and two antennas moving on it in order to obtain a maximum synthetic aperture of 1.8 m. It is also equipped with an UPS (Uninterruptible Power Supply) to obviate to temporary power supply interruptions. In such a system, transmitting and receiving antennas are mounted beside one another in a quasimonostatic configuration on a mechanical linear rail, which is computer-controlled, synthetizing a linear aperture along the azimuth direction in order to enhance the spatial resolution and to allow the detection of areal displacements. The instrument should be placed in front of the selected target at a distance comprised between a few dozen of meters and few kilometers. Spatial resolution is a function of this distance, while precision is a function of employed wavelength.

The microwave transmitter produces, step-by-step, continuous waves at discrete frequency values, operating in Ku band and extending the bandwidth from 17.0 to 17.2 GHz. Basically, the system emits two microwave signals in two different times; waves reach the target (e.g. the landslide) and are backscattered to the radar, where their amplitude and phase are measured. Whenever any movement occurs between the two acquisitions, a phase difference (called interferometric phase) is measured. By comparing measured phase obtained for each pixel in two different steps, the system computes interferograms, i.e. 2D maps, in which every pixel corresponds to a phase difference, obtaining the current superficial displacement along the line of sight (LOS) of the radar with sub-mm accuracy.

The system is extremely transportable and versatile: it can be installed by two persons in about 30 minutes and it is capable to perform measures in any weather condition. Furthermore, the linear rail can be mounted on adaptable tripods on any type of terrain. Data are stored on two boards with an overall space of 1.8 TiB that can be easily accessed through a remote control.

The ideal landslide scenario for a GB-InSAR investigation should require the following characteristics:

- Minimum vegetation cover, which limits the signal reflectivity and could determine a loss in signal coherence due to seasonal variations;
- Landslide movement velocity comprised in a specific range: displacements should be appreciable in the acquisition campaign time interval, but not faster than a specific threshold over which phase ambiguity and decorrelation occur;
- Deformation type: landslides presenting partial deformations before collapsing are ideal for interferometric monitoring.

Logistic requirements include:

- LOS free from obstacles and aligned as much as possible to the expected direction of movement;
- A stable power supply, especially in case of long-term campaigns;

- Internet connection, if automated data transmission is necessary.

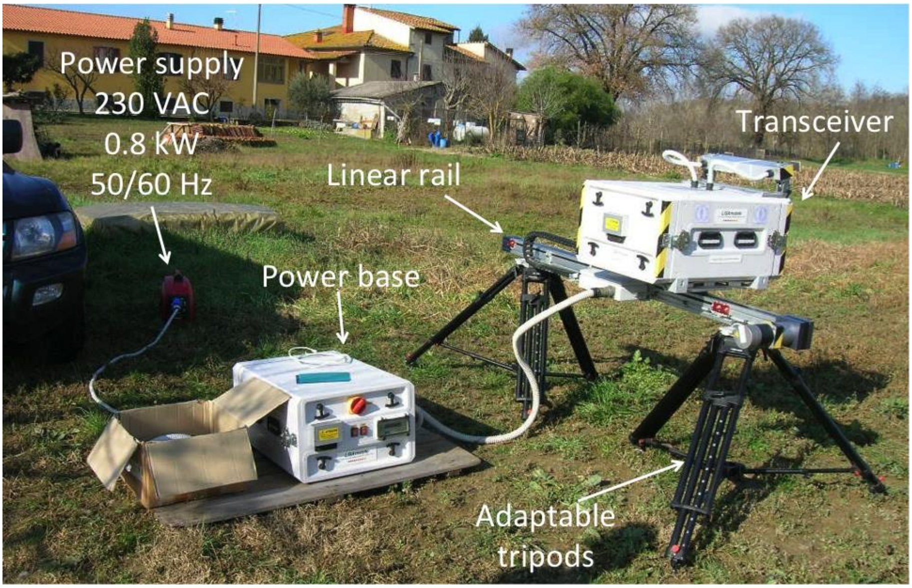


Figure 14. Main components of the GB-InSAR system

4.2 PUNCTUAL DISPLACEMENT MEASUREMENT SYSTEMS

Displacements of terrain and/or other structures in selected points can be monitored, for landslides early warning purpose, trough underground and surface punctual measurement systems. Significant information can be obtained by using a wide range of instruments (total stations, GNSS receivers, opto-mechanical systems, MEMS sensors); underground systems, in particular, imply the drilling of soil and the installation of inclinometric tubes for every monitored point.

For the LEW project, both conventional and innovative techniques has been used.

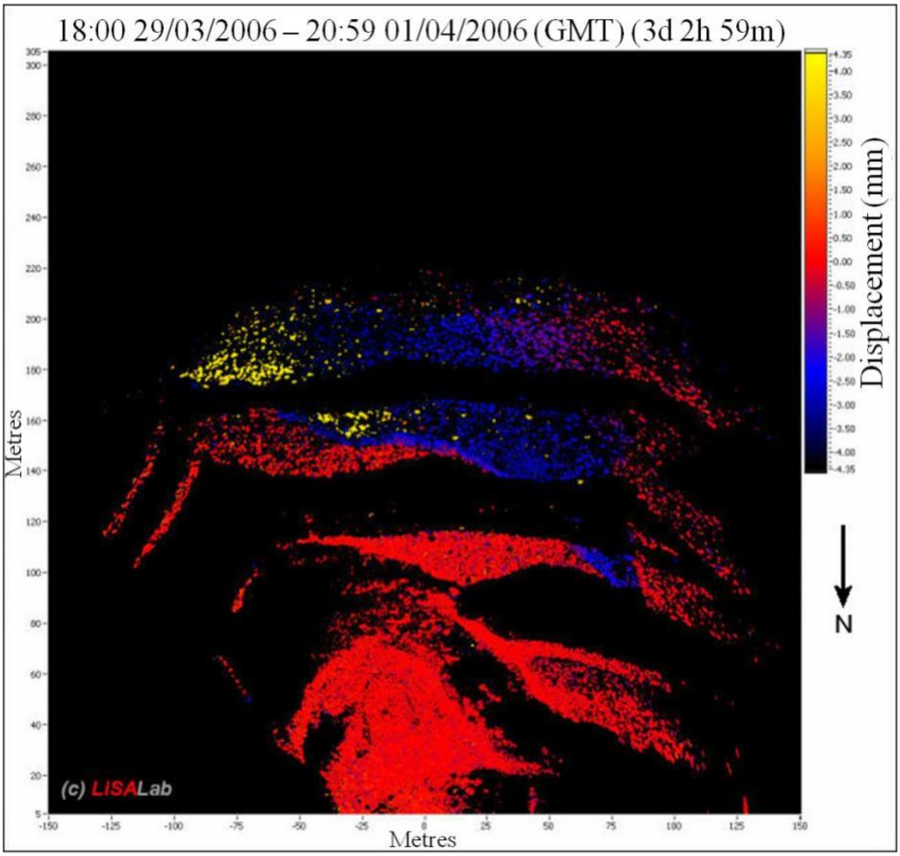


Figure 15. Example of displacement map calculated from an interferogram obtained on a 3 days time interval. Red color indicates stable areas, while blue and yellow zones represent areas respectively approaching and moving away with respect to the radar system

A commercial system, realized by STRAGO company and based on MEMS accelerometers, has been optimized in the project framework. All system components (hardware, firmware and software) have been improved, increasing computing power and energy saving.

An integrated sensor for the measurement and monitoring of position and inclination, characterized by small size, low weight, low power consumption and low costs has been realized at the Geomatics Lab of the University of Calabria. It is a fully automated monitoring instrument, able to send data acquired periodically or upon request by a control center through a bidirectional transmission protocol.

The instrument is composed by an optoelectronic Inclination measurement system, a GNSS receiver, a Data Processing System and a Data Transmission System, assembled on a Support frame.

Conventional measurements have been executedby using typical geotechnical methods.

4.2.1 THE SWAN NETWORK *(G. MANNARA, M. AUTIERO)*

In the context of the LEWIS project, STRAGO started by a version of a wireless network, named SWAN, consisting of inclinometer units based on MEMS technology (SMAMID unit) for continuous monitoring of landslides surveys surface movements with the purpose of warning / alarm in case of critical events (Italian patent N 0001393752 "System and method for landslide risk monitoring " owned by IVM Ltd.). During LEWIS project, research activities have been carried out performing the following key points:

- system optimization and overcoming performance limits from a technological point of view, related to consumption and wireless transmission efficiency, and limiting the system operation autonomy, were achieved. In these activities studies and systematic tests in the laboratory relative to consumption and wireless transmission were carried out in order to achieve a SMAMID redesign from the components analysis (sensor, memory in primis) until the firmware revision. A new SWAN version was so designed, fabricated and tested in both the laboratory and in the operative scenario under the supervision of skilled technicians, ; the operational autonomy time achieved in the new SWAN version doubled in respect to the existing version one, leading to a greater flexibility in the measurement points spatial pattern.
- SWAN integration into the LEWIS system (Fig. 16), by designing and implementing data communication software from the website (lab / field) to the CAED, through a middleware node concentrator, was implemented. The system acquires with specified frequency and duration, which are configurable remotely by both technicians and CAED, also according to the current relief status, and sends a data

file containing information about each inclinometer measurement point and landslide status, according to criteria modified by remote control (as well as temperature and power state of the single SMAMID).

- The study of the displacement measurement, in which the performances of the monitoring system (point measurement depth, sensor specifications, number and density distribution of the measurement points, mode / purpose alarm, integration with trigger parameters data) are related to both the features of the site (size and position, landslide kinematics depth, vegetation presence and type, landslide directionality, spatial distribution, trigger parameters, level and type of human activities) and the monitoring scope (relief evolution study, alarm / alert, securing infrastructure downstream, etc.). The combination of a tensiometric measure with the one produced by the inclinometer will be the subject of further development for researchers.
- In collaboration with DIMES (University of Calabria), an investigation for possible alternatives electronic architectural solution on SMAMID were carried out, analyzing various options (advanced microcontroller, ASIC, FPGA), in order to develop a master unit with higher computational power able to incorporate the functions of the PC host, and in order to improve the SMAMID system hardware and increase overall computing capacity. The result was a FPGA prototype unit built by DIMES and tested in laboratory with excellent results; the proposed prototype is actually subject of novel developments.

4.2.2 POSITION AND INCLINATION MEASUREMENT SYSTEM *(G. ARTESE)*

An integrated sensor for position and inclination measurement and monitoring, characterized by small size, low weight, low power consumption and low costs, has been realized at the Geomatics Lab of University of Calabria.

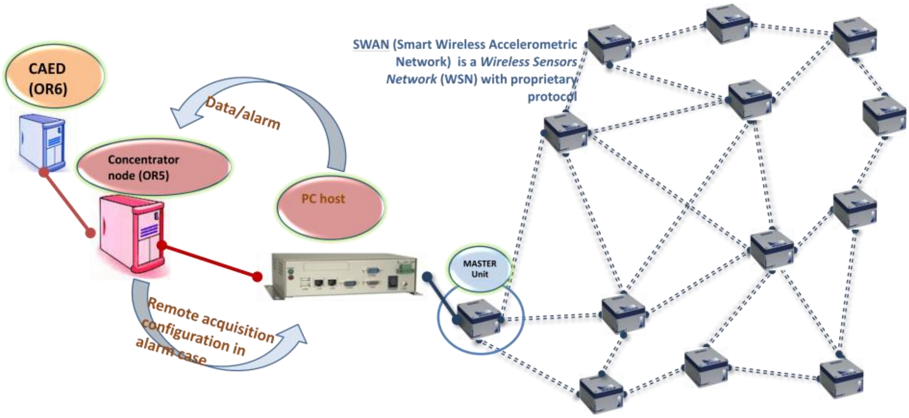


Figure 16. SWAN system general scheme - communication with CAED via concentrator node

The design of the prototype was developed in order to realize a fully automated monitoring instrument, able to send data acquired periodically or upon request by a control center through a bidirectional transmission protocol. The system is provided with a computer, which can be programmed so as to independently perform the processing of collected data, and to transmit, consequently, alert signals if the thresholds determined by monitoring management are exceeded. Bidirectional transmissions also allow to vary the parameters set (time of acquisition, duration of satellite acquisitions, thresholds for the observed data).

The instrument is composed by four main subsystems mounted on a support frame.

Inclinations measurement system

To reveal the inclinations, the images of two glass spirit level vials arranged with mutually orthogonal axes are captured. The images are captured using a camera (Raspberry Pi Camera Module Rev 1.3 from 5 Mpixels) connected to the data processing system (512 MB Raspberry Pi B). A custom software also manages the apparatus of LED lighting with diffusers. Glass bubble vials having a sensitivity of 60 "/ 2mm, which allow to reach the accuracy of 0.001°, have been employed. By choosing bubble vials with different characteristics, one can opt for higher accuracies and lower acquisition ranges or vice versa.

The positioning system

The positioning is performed via a GNSS receiver. Ublox NEO-6M device, able to receive the EGNOS correction, has been employed; the absolute positioning is obtained with planimetric accuracy of less than one meter and height accuracy of about two meters. The purpose of the acquisitions is not to obtain a satellite positioning, but to reveal any morphological changes of the monitored surface. This is obtained by checking the changes in the mutual distances (baselines) between the different sensors, for acquisitions repeated in almost identical terms; in this way a decimeter accuracy can be achieved. For this aim, a sensor is considered as a reference, and it is provided with an XBee module acting as coordinator. In this node converge acquired data from the receivers and the calculation of baselines is performed. If the difference between measurements of the same baseline in later times exceeds a predetermined threshold, an alert is sent to the Acquisition Center.

Data Processing System

Data processing system is constituted by a Raspberry Pi B 512 MB. It is a credit-card sized multimedia computer, comprising a processor ARM1176JZ-F at 700 MHz and a co-processor multimedia VideoCore IV, with a RAM of 512 MB, a multi-format card reader, an HDMI output, an Ethernet port and a USB port. Codes for data acquisition, processing metric calibration of cameras, image processing and inclination reading and processing of GNSS surveys were implemented on the board.

Data Transmission

For data transmission, an XBee module has been used. The instrument network uses the ZigBee protocol and is characterized by a set of distributed sensors, connected to a point of data collection where a coordinator node is located. The Raspberry computer constitutes the set of computational resources in order to perform correlations and data processing , status monitoring, communication with the Acquisition Center, etc.

Support frame

The frame was realized using a single molded piece, including openings that make it lighter without compromising rigidity. For all the elements to be inserted (GNSS receiver, XBee, Raspberry, camera, power unit, levels, etc

...), appropriate slots have been designed. The assembled instrument, finally, is inserted in a PVC box that ensures simple installation of the sensor in the area to monitor and weather protection (IP 65). The sensor can be coupled to a support structure that can be fixed both to an artifact to be monitored, either on the support pole to be driven into the ground.

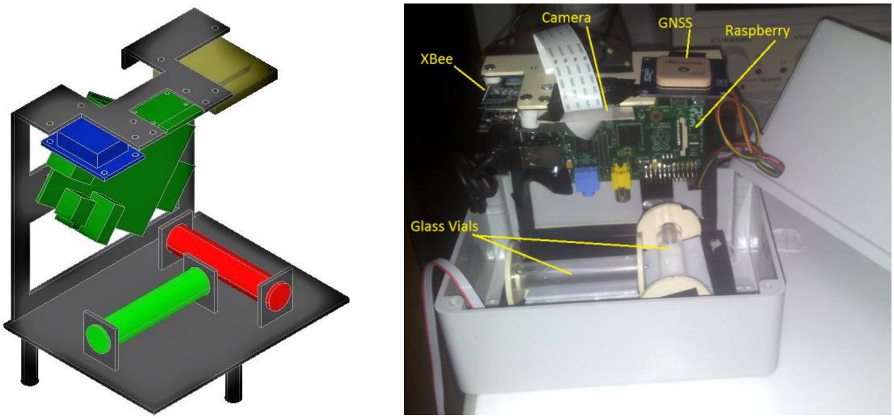


Figure 17. Position and inclination measurement system

4.3 SYSTEM FOR DISPLACEMENTS FORECASTING

4.3.1 AREAL MODEL *(G. CAPPARELLI, G. FORMETTA, R. RIGON)*

In the context of the displacement modeling a section of the project was devoted to the application of hydro-mechanical models. Those models works at different spatial and temporal scales and in this section the areal model and its applications are presented. The areal model couples a hydrological model with a geotechnical model for the computation of the shallow landslide safety factor under the assumption of infinite slope hypothesis (Grahm 1984). The system is integrated with the uDig (http://udig.refractions.net) Geographic Information System (GIS) for the computation of model inputs and visualization of the outputs.

GEOtop (Rigon et al. 2006; Dall'Amico et al. 2011; Endrizzi et al. 2013) was the hydrological model used in this study. It is a three-dimensional (3-

D), physically based, spatially distributed model that performs water and energy budgets at pixel scale. It models subsurface saturated and unsaturated flows, surface runoff, channel flows, and turbulent fluxes across the soil-atmosphere interface (e.g., latent and sensible heat fluxes, soil temperature, etc.). Model results are moisture, soil suction, water table depth maps at different soil depths of the digital watershed model where it is applied.

The geotechnical component uses GEOtop model outputs and parameters such as soil friction angle and cohesion, root cohesion and local slope in order to provide infinite slope safety factor raster maps for each soil layer of the computational domain.

The system's components are integrated by using the modeling framework Object Modeling System 3.0 (OMS, David et al. 2013). OMS includes many model facilities such as tools for model output visualization, algorithms for model parameters calibration and sensitivity analysis. Tools for model parameters calibration are applied in the project in order to estimate parameters of the Van Genuncten soil water retention curve by comparing modeled and measured suction and soil water content.

The system was applied in back analysis along the highways Salerno-Reggio Calabria (South Italy), for two river basins located in Rogliano Calabro (Fig. 18.a). There, landslides occurred in the period from 8 to 10 March 2010.

The climate is sub-humid, the average annual precipitation of 1200 mm with rainfall peaks in the period October–March, and average temperature of 16 °C.

The model was verified in back analysis. Simulation with hourly time-step starts on 01/07/2009 and ends on 11/03/2010. Soil was discretized in six layers as presented in Fig. 18b. The model input data were: raster maps (such as slope, sky-view-factor, land-use, soil-type), meteorological time-series (such as rainfall, air temperature, relative humidity), and parameters (such as Van Genuncten soil parameters, saturated hydraulic conductivity, saturated and residual water content).

Results in terms of comparison of modeled and measured landslided areas are presented in Fig. 19. It shows the evolution of the safety factor in time for the basin B1 (at the top) and B2 (at the bottom), respectively. Pixels in red, presenting instability (safety factor close to 1.0), are located in the black polygons that indicate the actual landslide area.

The system is currently running in near real-time for the test site of the project.

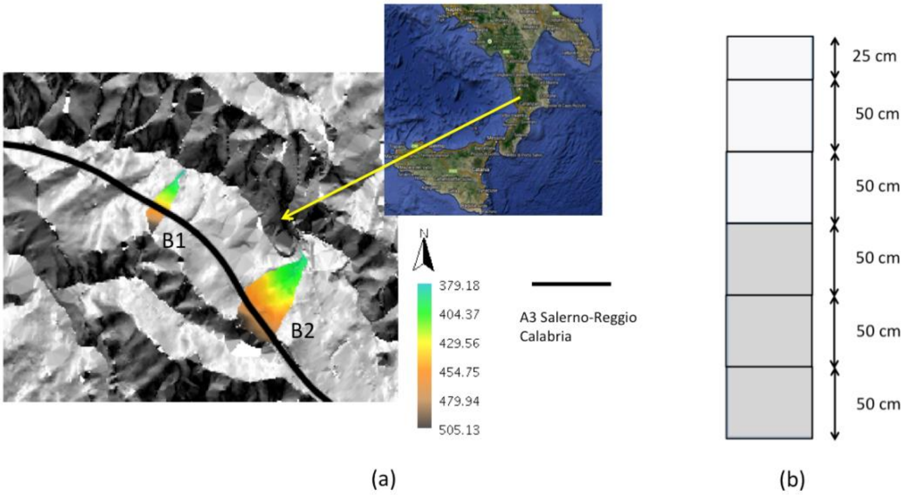


Figure 18. Test sites location and soil discretization

4.3.2 Punctual model *(G. Capparelli, D. L. De Luca, A. Donato, G. La Sala, A. Troncone, M. Vena)*

A landslide is defined as a perceptible downward and outward movement of slope-forming soil, rock, and vegetation under the influence of gravity. Landslides can be triggered by both natural and human-induced changes in the environment. However rainfall is recognized as a major precursor for many types of slope movements. Especially, torrential downpours within short time periods, and resultant excessive increases in groundwater levels, are conductive to extensive these damaging hazards. In fact as a result of rainfall events and subsequent infiltration into the subsoil, the soil moisture can be significantly changed with a decrease in matric suction in unsaturated soil layers and/or increase in pore-water pressure in saturated layers. As a consequence, in these cases, the shear strength can be reduced enough to trigger the failure.

An effective way to develop such an understanding is by means of computer simulation using numerical model.

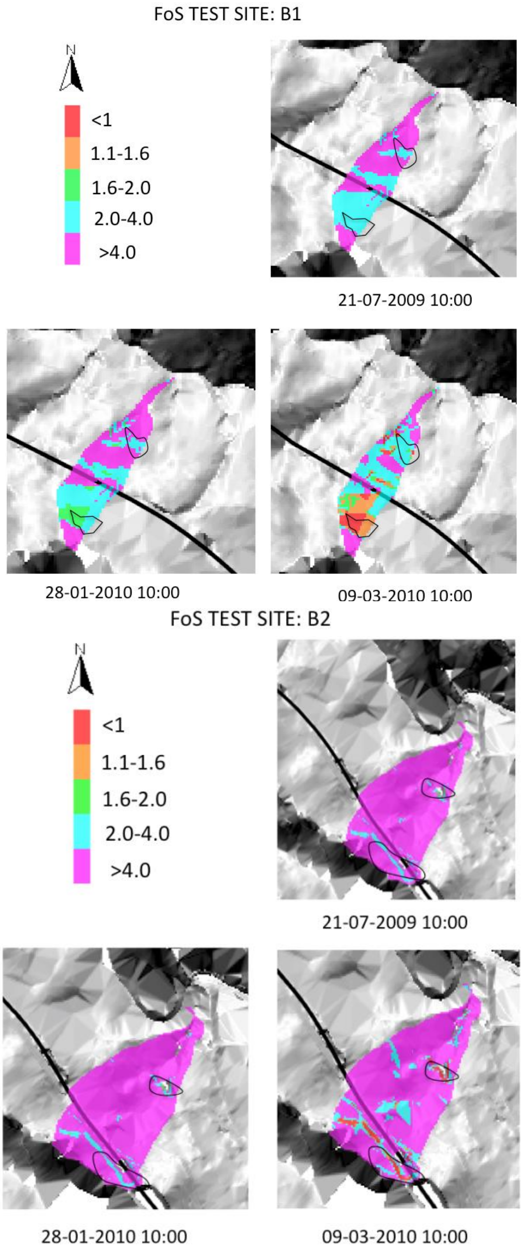


Figure 19. Factor of Safety evolution in time for the basin B1 (at the top) and the basin B2 (at the bottom) for the soil layer at 50 cm depth

As part of the project PON "Integrated Early Warning System" our main objective was just to develop a numerical model that was able to consider the relation between rainfall, pore pressure and slope stability taking into account several components, including specific site conditions, mechanical, hydraulic and physical soil properties, local seepage conditions, and the contribution of these to soil strength. In this work the mechanism behind rainfall-triggered landslides was modeled by using combined infiltration, seepage and stability analyses. This method allows the evaluation of the terrain and its response based on geological, physical, hydrogeological and mechanical characteristics. Moreover the model was developed in order to be suitable for cases with strongly heterogeneous soils, irregular domains and boundary conditions variable in space and time.

The goal was to create a valid instrument to investigate the instability mechanisms behind rainfall-triggered landslides and to use it in an early warning system dedicated to the safeguarding of population in landslide-prone areas.

Practically the implemented software is based on the combined use of two modules: an hydraulic module, to analyze the subsoil water circulation due to the rainfall infiltration under transient conditions and a geotechnical module, which provides indications regarding the slope stability.

With regard to the hydraulic module, variably saturated porous media flows have been modeled by the classical nonlinear Richards equation:

$$\frac{d\vartheta(\psi)}{\partial\psi}\frac{\partial\psi}{\partial t} = C(\psi)\frac{\partial\psi}{\partial t} = \nabla \cdot [K(\psi)\nabla\psi] + \frac{\partial K}{\partial z} \qquad (2)$$

and closed by constitutive relations describing the functional dependence of moisture content C and hydraulic conductivity K on the pressure head ψ. Due to the high nonlinearity in the constitutive relations, analytical solutions to the Richards equations rarely exist except for a limited number of simple configuration. For this reason the flow mathematical equation was solved numerically by using the Galerkin-type finite element method. The discretization of the flow domain is obtained by using quadrilateral finite elements and linear shape function; in particular after discretization in space with the Galerkin weighted residual method, a set of finite element equations was obtained in abbreviated matrix form as follows:

$$M\dot{d} + Kd = F \qquad (3)$$

where M is the system capacity matrix, K is the system conductivity matrix, F is the system flux vector, d is the primary variables and $\dot{d}$ is the time derivative of d. Numerical time integration is then performed by a finite difference scheme. Finally because the problem is highly nonlinear, the solution must be determined iteratively.

Numerical problems are usually manifested by a lack of convergence and/or the presence of undesired oscillations in computed results when sharp moisture fronts are present. Such situations arise, for example, when calculating ponded infiltration in initially very dry soils, particularly when the soil hydraulic properties are highly nonlinear. So several efforts were required to reduce the computational cost and provide more stable numerical solutions.

In the geotechnical module the differential equilibrium equations to be solved are the following:

$$\frac{\partial \sigma'_{ij}}{\partial x_j} + \frac{\partial u_w}{\partial x_i} + \gamma \delta_{iz} = 0 \qquad (4)$$

where σ'_{ij} are the stress components, u_w is the pore pressure calculated from the hydraulic module, γ is the soil unit weight and δ_{iz} is the Kronecker symbol. The linear constitutive equations (plane stress) and strain-displacement relationship must be also taken into account. The displacement formulation is considered in the present approach in which stress and strain are eliminated resulting in differential equations where the displacement are the variables. Then, discretization and application of Galerkin's method leads to the stiffness equations for a typical element. To solve equation over a generic domain an assembly strategy is chosen, leading to global algebraic linear equations $[K_G]\{U\} = \{F\}$ where $\{U\}$ and $\{F\}$ are the nodal variables (displacements) and known force components (gravity loading and seepage loads) respectively. The model take into account the material non linearity using constant stiffness iterations, in which non linearity is introduced by iteratively modifying the loads vector $\{F\}$: the loads vector at each iteration consist of externally applied loads and self-equilibrating loads that have the effect of redistributing stresses within the domain. Mohr-Coulomb criterion was chosen to represent the yield function and associated flow was assumed. Also the self-equilibrating loads were calculated using an initial strain method (Zienkiewicz & Cormeau 1974).

By means of the presented geotechnical module it is possible to assess:

- the safety factor of the slope subjected to gravity loading and to the pore pressure calculated from hydraulic module;
- displacement, strain and stress under the effect of rainfall infiltration.

As test of model validation, the analysis and the representative results obtained for the volcaniclastic covers of Sarno (Campania region - Southern Italy), where dangerous mud flows occurred in May 1998, are described in figures below.

As confirmed by numerical analysis, prolonged rainfall during the first days of May has a greater effect on suction. Fig. 20 shows in fact a sudden increase in suction in the days between the 4th and May 5th; this increase could represent the cause of the occurred slope movements in such a day.

Referring to the FS-time results (Fig. 21), it worth be noticed that the value of safety factor (FS) between 50 and 100 days, decrease and swing close to 1, though it is always maintained slightly above. In this interval of time, the calculated displacements do not present remarkable increases (Fig. 22). In consequence, on the slope the global collapse does not activated as appear at the end of the analysis. In fact, at day 217, the safety factor reaches the value of 1 and the global collapse of the slope is achieved. As a result, the calculated displacement trends (Fig. 22) point out a sudden rise. The displacement evolution next to the failure (after the day 217) has not been fully analyzed, in order to avoid convergence problems.

4.3.3 PROPAGATION MODEL *(G. CAPPARELLI, M. V. AVOLIO, A. CANCELLIERE, S. DI GREGORIO, E. FOTI, V. LUPIANO, D. J. PERES, W. SPATARO, L. M. STANCANELLI, G. A. TRUNFIO)*

This research follows the innovative guideline of Cellular Automata (CA) methodology in order to develop efficient and efficacious models for simulating complex dynamical systems, that evolve mainly on the base of local interactions of their constituent parts.

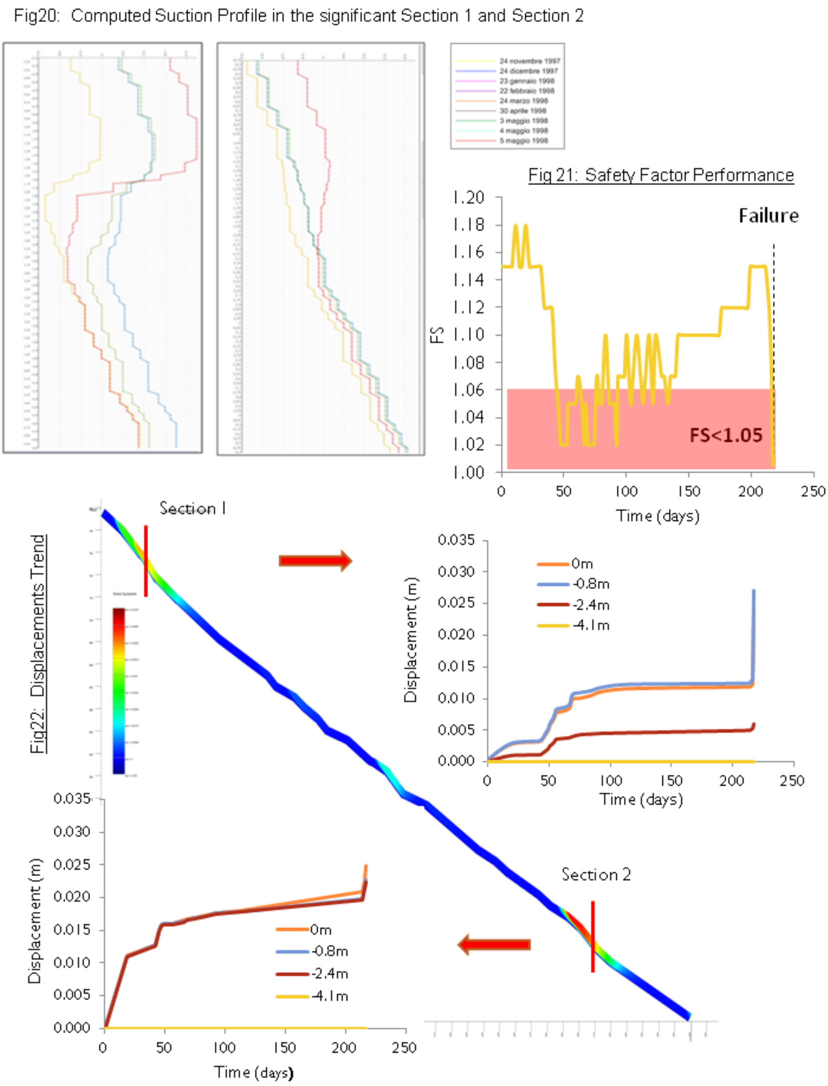


Figure 20. Computed Suction Profile in the significant Section 1 and Section 2
Figure 21. Safety Factor Performance
Figure 22. Displacement Trend

Debris flows may be considered such a type of complex systems, that involve many interacting processes; in summary, they start from soil detachments, that originate surface gravitational flows with mutable rheological properties, furthermore their passing causes soil erosion with inclusion of various matter and induction of secondary detachments. Modelling such dangerous phenomena can supply new tools by computer simulation for evaluating debris flow hazard and effects of possible remedial works in the considered areas, that concern in our application the Giampilieri zone, devastated in October 1st, 2009 by several catastrophic debris flows, further to high intensity rainfall, concentrated in few hours.

SCIDDICA-SS3 ((Simulation through Computational Innovative methods for the Detection of Debris flow path using Interactive Cellular Automata – both Subaerial and Subaqueous ones), is the third model of the SCIDDICA-SS family, that improves decisely approximations regarding momentum conservation; it was a weak point of previous models. Furthermore to model debris flowing inside the urban tissue needs more accurate details in comparison with the dimensions of the cell, different solutions were obtained for such CA challenging problem-

The Giampilieri village is located on the eastern slopes of the Peloritani Mountains on left side of Giampilieri River. It is settled on ancient alluvial fan and is crossed by various creeks, tributaries of the Giampilieri River. During this 2009 alluvial event, from the basins behind the town are mobilized several debris flows (Fig. 23), that reached Giampilieri Superiore. In such a case the mutual interaction between different, nearly simultaneous, debris flows produced dramatic effects in terms of loss of human lives and damages of buildings close to the hill and along the principal streams that cross the town. Crossing the centre the flows killed 19 people, destroyed houses and dragged away what they find on their path.

Simulations were performed for the six debris flows occurred in Giampilieri area (indicated with numbers from 1 to 6 in Fig.23. In particular, the no.2 debris flow was used in calibration phase (Fig. 24, 25), while the five other ones were used for model validation.

Figure 23. October 2009 debris flows occurred in Giampilieri Superiore, obtained by interpretation of aerial photo

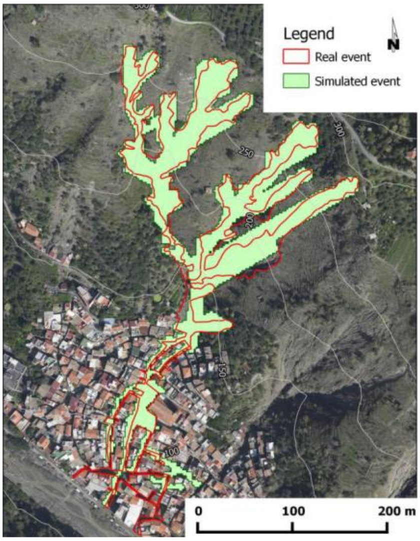


Figure 24. Comparison between Sopra Urno creek debris flows and simulated event

The results show a good capability of the model to simulate the debris run-out, particularly, in the upslope parts of the basins, while in the downslope urbanized area, the reproduction of the real events is less accurate by significant differences due to the lateral spreading characteristics: some streets inundated by the debris in the real event are different from those resulting from simulation.

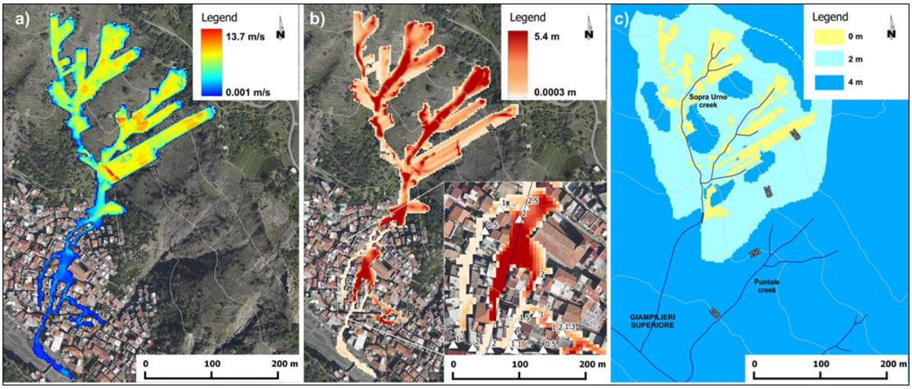


Figure 25 a) maximum velocities; b) maximum detrital thickness; c) eroded regolith

The same set of parameters used to reproduce Sopra Urno debris flow, was used to simulate the other five debris flow run-out in the nearby catchments (Fig. 26). In all considered cases, the application of the fitness function ($\sqrt{((R \cap S)/(R \cup S))}$ where R is the set of cells involved in the real debris flow event and S is the set of cells involved in the simulated event) return acceptable values between 0.70 and 0.78, and the path of the flows is adequately reproduced.

The debris flow, shown in Fig. 26d, was deflected by the presence of the perimeter wall of the primary school (it was not reported in data of morphology. This wall has partially protected the building. In order to simulate this event, a wall was inserted on the DTM as topographic alteration. The simulation was performed in such a modified morphology with an improved result. So SCIDDICA may be used for verifying the validity of the barriers or trenches together with analysing the effects of diverted flows into other areas.

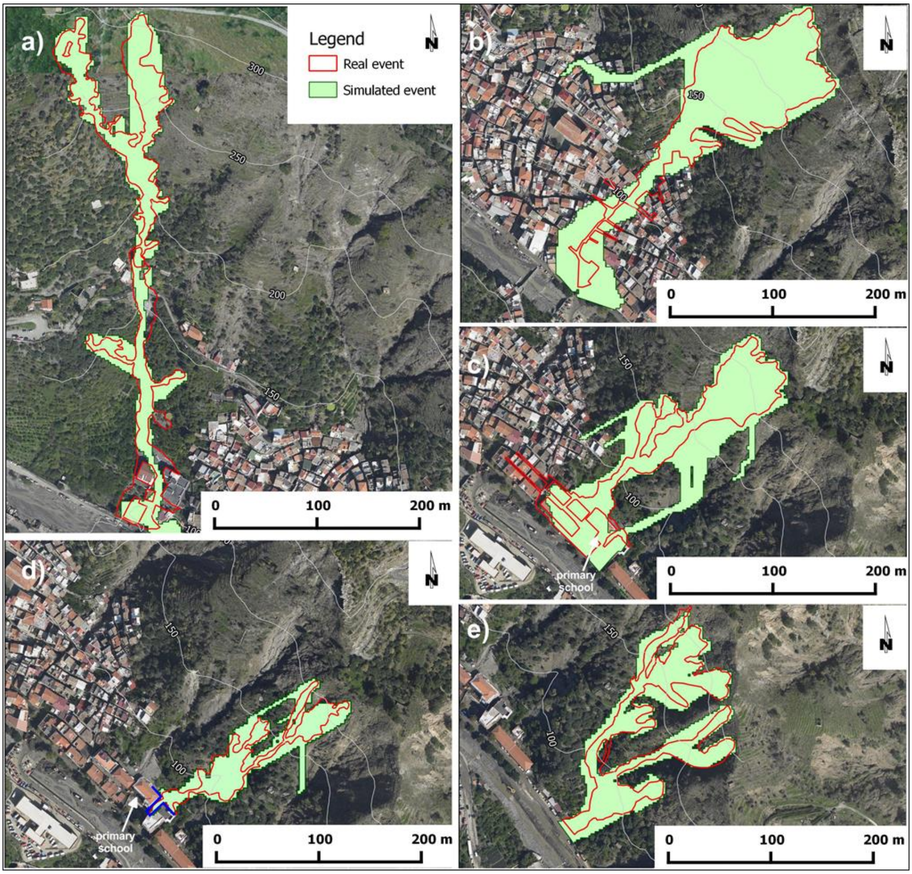


Figure 26. comparison between real debris flows and simulated events. a) Loco creek debris flow; b) Puntale creek debris flow; c) and d) Primary school debris flows (the wall is in blue); e) East Primary school debris flow. (Respectively 1, 3, 4, 5, 6 in Fig. 1)

Simulation results show that SCIDDICA-SS3 is suitable and reliable for simulation of debris flows in the area, especially if one considers that there are unavoidable errors in post- and pre- event data. An accurate study was performed in order to compare data of different sources and to obtain the most accurate reproduction of the observed event. The model behaviour was satisfactory in terms of reproducing global dynamic of the events, such as velocity, debris flow depth, thickness of deposit, and, in particular, the path of debris flows, that show a good correspondence with the real events.The program could be refined in the reproduction of debris flow propagation into highly urbanized areas, where streets are narrow. This improvement may be obtained by a better cell discretization of the computation region, which enables accurate positioning of buildings.

5. MEASUREMENT OF TRANSMISSION AND DATA ACQUISITION

5.1 DATA TRANSMISSION NETWORK *(S. COSTANZO, L. MORRONE)*

A network architecture with hybrid configuration, named LEWARNET (‘Landscape Early WARning NETwork’) is considered to realize a proper data transmission from the various sensors involved in the monitoring (e.g. SDRadar, SFCW scatterometer, interferometer, SMAMID sensors) towards the CAED. The chosen topology can be represented by a three-levels network, as reported in Fig.27, with a connection between the CAED and the monitoring sites through a direct link or by sink nodes.

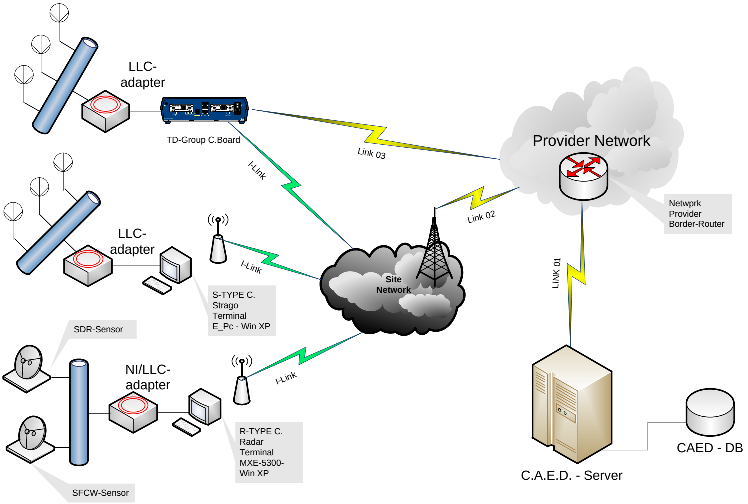


Figure 27. Network architecture

The network framework developed within the project includes:

a) a server component working as a software interface, designed in agreement with CAED specifications;

b) an own middleware, including all software components for the management of the sink nodes, namely the monitoring of the client process, the definition of data structures for the storage and the management of data messages, encryption utility and data compression utility;
c) the client software components for each sensor belonging to a sink node, namely the specific software interfaces established in agreement with the sensors designers.

The middleware is designed as a multi-threads architecture, with the main task (‘Main Process Monitor’) devoted to the management of secondary threads, named as ‘AqServClient’, ‘Radar Sensor Server’ and ‘Graphical User Interface’.

In particular, the ‘Main Process Monitor’ implements the following main functionalities:

- ‘Warm Up’, consisting in the actions relative to the identification of CAED server and active sensors (network and sensor discovery);
- ‘Messages Queue Manager’, devoting to the management of messages queues in input/output from the sensors and towards the CAED;
- ‘Activities Logger’, devoting to the generation of log files reporting all developed activities and activated processes.

Four distinct server modules are implemented and specialized for the four sensors/subnetworks afferent to the middleware, namely the SDRadar server, the SFCW-scatterometer server, the Interferometric-Radar server and the SMAMID-subnet server.

For the radar sensors, the possibility of remote activation is implemented on a custom embedded Raspberry board, in which a GSM communication is adopted for the transfer of remote commands, as illustrated in Fig.28.

The subnet of accelerometric sensors developed by Strago is integrated in the middleware, as illustrated in Fig. 29, where a Wi-fi link is adopted to guarantee the communication of the subnet with its sensors.

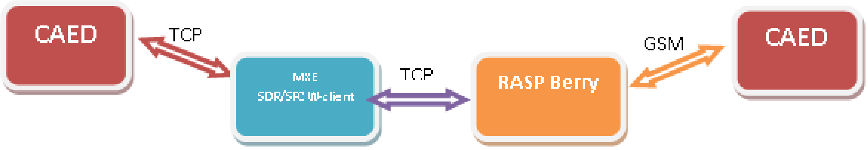


Figure 28. Remote control scheme for radar sensors

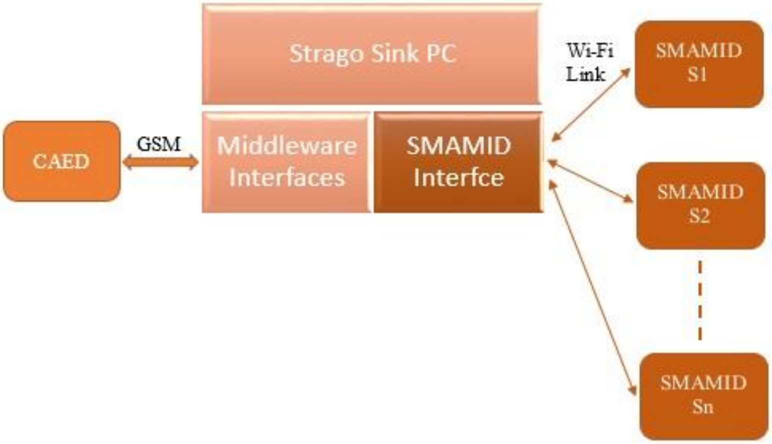


Figure 29. Integration scheme of subnet Strago with the middleware

5.2 THE NODES OF THE TRANSMISSION NETWORK *(M. DE MARINIS)*

The smart sensors of the network are connected to an innovative system for the measurement and transmission of meteorological, hydrological and geophysical data, which allows to monitor in an accurate manner, at programmable intervals and with continuity, the stability and movements of mountain slopes and allows to prepare the input data for mathematical models able to estimate the probability of landslide triggering.

The system is based on wireless networks able to minimizing the energy consumption and that are completely independent from external power sources (public power grid / self-employed alternating generators). A battery pack and a typical 500 mW solar panel represent the only source of energy of the system and of each node. This allows the correct functioning of networks monitoring for an indefinite period of time and the almost total absence of maintenance.

It has been designed and realized an ad hoc HW and FW system, named Software Defined Sensor Interface - SDSI, specifically planned for the management of the large spatio-temporal variability of the factors to be checked and of the huge amount of data processing required to do reliable analysis and predictions.

The SDSI system is a Multi-Core management system for safety critical applications. The Core contains a number of configurable circuits via firmware for a complete adaptability to many application scenarios; It is composed of 3 main parts: Analog Digital Interface that is programmable and includes a microprocessor Core dedicated to signal processing (8051 or 8-bit ARM Cortex-M3 32-bit); Radio receiving/transmitting system, consisting of LGA modules certified according to CE regulations covering bands from VHF (150 MHz) to 2.45 GHz with many types of modulations and transmission protocols, It has been chosen the use of the 868 MHz band cost free with W-MBus protocol; and the Power Management able to feed devices from countless sources of energy.

The main architectural components of the network are: the End-Node, able to adapt itself to the different families of connected sensors through a reconfiguration of its HW and FW interface and able to transmit the collected data to the network along with other functional information about the same node (battery status, temperature, malfunction, etc.); the Coordinator that collects information and manages all the network devices; and the Gateway, called Sink, that hosts a modem in order to communicate with the central server and allows the routing of all the data to the CAED central server via a GPRS / WiFi connection, using TCP/IP on dynamic address. The application protocol follows the AqServ service specifications.

The implemented nodes are: Sink, Station, Weather/Sink, Wells (IPI, piezometers and total pressure cells) Hydrogeological (TDR, tensiometers), Total Pressure, Inclinometer (IPI inclinometers) and Piezometric.

5.3 DATA COLLECTING AND PROCESSING CENTER (CAED) *(G. MENDICINO, A. LUCI)*

Management of information flows, telematic architecture and services for data management is entrusted to the Data Collecting and Processing Center (CAED, namely “Centro Acquisizione ed Elaborazione Dati”).

Fig. a) Fig. b)

Figure 30. Design (Fig. a) and realization (Fig. b) of the hardware board and of the corresponding case for the monitoring system

The CAED has been designed and realized according to a complex hardware and software system, able to ensure the reliability and continuity of the service, providing advance information of possible dangerous situations that may occur.

In the research project, the CAED has to ensure the continuous exchange of information among monitoring networks, mathematical models and the Command and Control Centre (CCC), that is responsible for emergency management. The design and implementation of procedures for the exchange of information among the various components was built according to persistent and stable communication protocols, that are suitable for hardware/software architecture of monitoring devices, for models and for CCC.

Data flow from the monitoring network was managed according to a communication protocol, implemented by the CAED, and named AqSERV. AqSERV was designed by considering the heterogeneity of devices of monitoring and transmission networks (punctual and areal sensors) and the available hardware resources (microcontrollers and / or industrial computers). AqSERV was realized to link CAED database (named LewisDB) and the monitoring networks, after validation for the authenticity of the node that connects to the center. Data acquisition, before the storage in the database, is validated both syntactically and according to the information content. The procedures for extraction of the information content and validation have been realized differently for punctual and areal sensors: the latter require a more complex validation, as they work in a 2D domain.

The complete management of the monitoring networks by CAED has been realized through specific remote commands, sent to individual devices via AqSERV, to reconfigure the acquisition intervals or to activate any sensor, depending on the natural phenomena occurring in real time.

The acquired and validated data are then accessible for the mathematical models through a further service, created ad hoc, which publishes all the acquisitions by sensors on a remote server for sharing.

The configuration of monitoring networks, composed by devices and sensors, of communication protocol used by each network, and of rules for extraction and validation of information content is carried out through a web application that allows for the management of the whole system by the users.

Besides the configuration, the application has been realized to automatically create the tables of interest; automation of the process allows to reduce the acquisition time and the possible human errors which inevitably may occur.

The search in real time of acquisitions is carried out through a WebGIS, specifically designed for wireless sensor network (WSN), but that can be easily extended to classic monitoring networks.

The WebGIS was designed according to the traditional web architecture, client-server, by using network services which are web mapping oriented: 1) web server for static data, 2) web server for dynamic data, 3) server for maps, 4) database for the management of map data.

The static layers provided by the WebGIS are the results produced by geological studies for the identification of event scenarios: geological map, geomorphological map, map of event scenarios. The dynamic layers are the acquisitions in real time by the sensors.

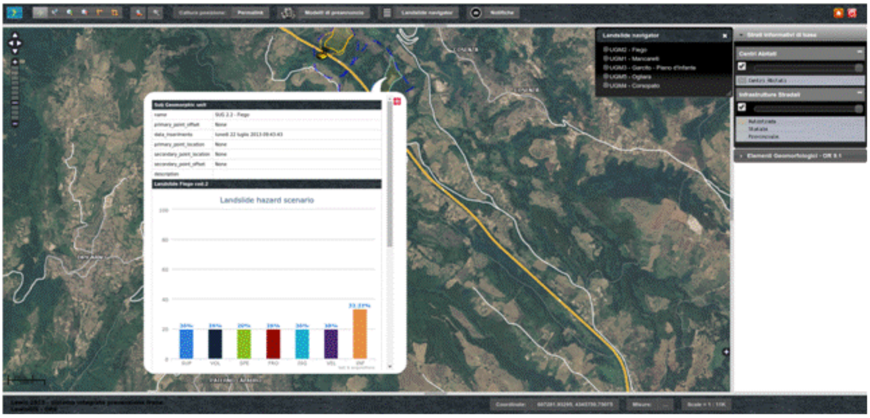
A CAED operator can consult the information provided by each layer via a standard web browser (Figs. 31, 32), verifying the performance of the event precursors and any anomalies in acquisitions.

The information of each sensor and the results produced by the models are used to assess, in each instant t, the occurrence probability of an event scenario in the monitored areas and the possible risk scenarios.

This combination of heterogeneous data was carried out by identifying for each sensor an model a typical information (displacement, precipitation, inclination, etc..), evaluating the state in each instant t, according to a threshold system, and combining this result for all sensors placed in a monitored geomorphological area.

The final result is constituted by the occurrence probability of a event scenario, that is associated with a specific action by CAED. In particular, if the occurrence probability is low, moderate or high it is necessary to issue a notice of criticality (ordinary - Level 1, moderate - Level 2, High - Level 3) to the Command and Control Centre (CCC).

The CAED sends two types of information: 1) criticality state of the single geomorphological monitored unit, 2) criticality state of the whole area. The adopted communication protocol between the two centers for the exchange of information was carried out through a web service provided by the CCC, using the classes and attributes of the methodology named Datex II (which is a protocol for the exchange of traffic data). The use of the web service allowed to ensure the interoperability of data between the two centers, regardless of the used hardware and software architecture, through a persistent service capable of ensuring an immediate restoration of the connections, in case of malfunction and a continuous monitoring between the two centers, even in the absence of criticality.



Sub Geomorphic unit
name: SUG 2.2 - Fiego
primary_point_offset: None
data_inserimento: lunedì 22 luglio 2013 09:43:43
primary_point_location: None
secondary_point_location: None
secondary_point_offset: None
description:

Figure 31. WebGIS for visualization of static layers

Device TDgroup_meteo_2

firmware	tdgroup_meteo_station_stadalone 1.0.2332 [Marco De Marinis - TDGroup]
network_identifier	TDgroup_meteo_2 [22]
est_phi	605539.0
nord_lambda	4358060.0
data_inserimento	mercoledì 12 febbraio 2014 10:11:47
wsn	TDGROUP_LEW_001_DEMO
sink status	TDGroup_test: not connected TDGroup_test_2: not connected

model	SHT15 [14]

Figure 32. Analysis of dynamic layers

6. INTERVENTION MODEL *(P. VERSACE)*

An Intervention model is based on the following elements:

- Event scenarios
- Risk scenarios
- Levels of criticality
- Levels of alert

Event scenarios describe the properties of expected phenomena in terms of dimension, velocity, involved material and occurrence probability.

Occurrence probability depends on the associated time horizon, which should be equal to few hours at most, in the case of Early Warning Systems. Evaluation of occurrence probability is carried out by using information from monitoring systems and/or from outputs of adopted mathematical models for nowcasting.

All the properties, to be analyzed for event scenarios, are listed below; a subdivision in classes is adopted for each one:

- Landslide velocity (5 classes from slow to extremely rapid)
- Landslide surface (5 classes from very small to very large)
- Landslide scarp (5 classes from very small to very large)
- Landslide volume (5 classes from extremely small to large)

- Thickness (5 classes from very shallow to very deep)
- Magnitude (3 classes: low, moderate, high), which combines the previous information
- Involved material (mud, debris, earth, rock, mixture of components)
- Occurrence probability (zero, low, moderate, high, very high, equal to 1)

An example of map for event scenarios is reported in Fig. 33.

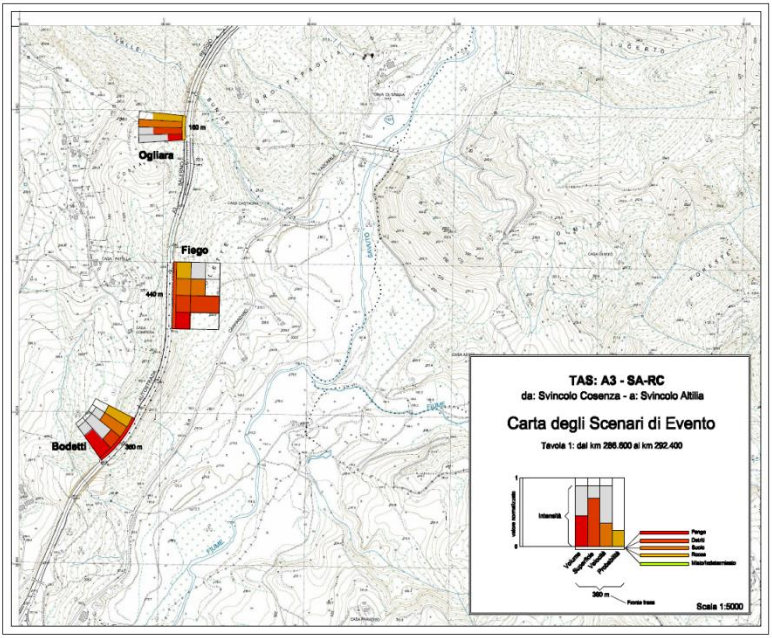


Figure 33. Example map for event scenarios

Risk scenarios can be firstly grouped in the following three classes:

A. Mud and/or debris movements which could induce a friction reduction and facilitate slips
B. Road subsidence induced by landslides that could drag or drop vehicles
C. Falls of significant volumes and/or boulders that could crush or cover vehicles and constitute an obstacle for others vehicles.

For each previous risk scenario, six sub-scenarios can be identified on the basis of the number of potentially involved infrastructures, carriageways and lanes (a. hydraulic infrastructures and/or barriers, b. only emergency lane, c. lane, d. fast lane, e. fast lane of the opposite carriageway, f. lane of the opposite carriageway)

Thus, all possible risk scenarios are 18 (Figure 34), which are indicated with a couple of letters (Capital and small)

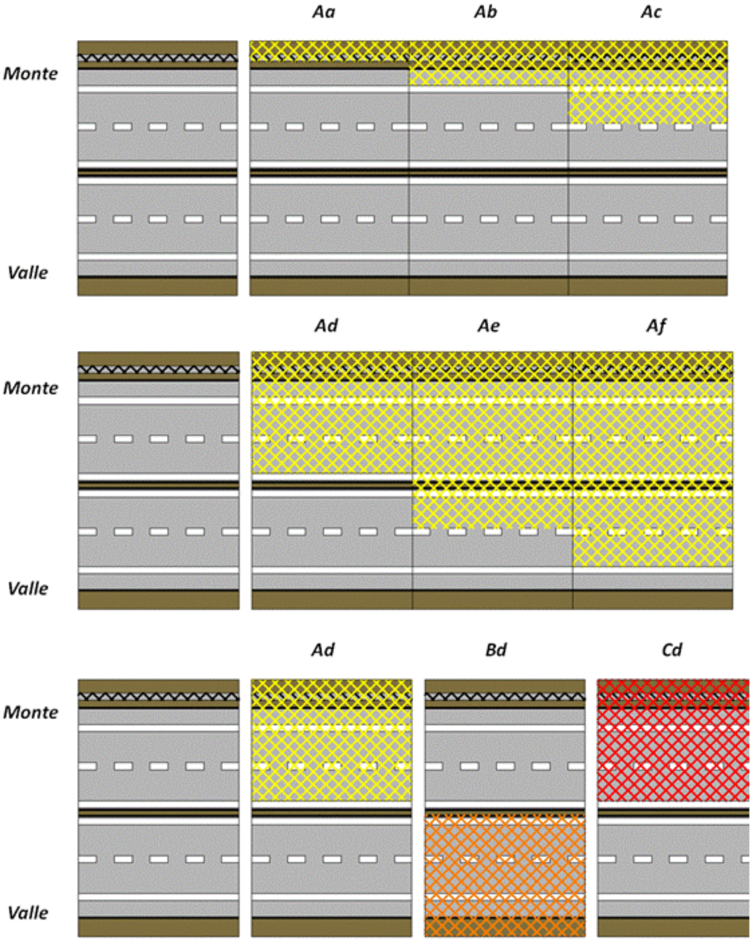


Figure 34. Risk scenarios

The following information is provided to CAED:

- Measurements from sensors

- Model outputs

and four states are identified for each of them:

- state 0 = no variation
- state 1 = small variation
- state 2 = moderate variation
- state 3 = high variation.

Besides information from sensors and models, other information is obtained by meteorological and hydrological models (named as indicators).

Indicators comprise weather forecasting and output of FLaIR model on the basis of observed and predicted (for the successive six hours) rainfall heights.

Two states are defined for indicators:

- state 0 = no variation or not significant
- state 1 = significant variation

To sum up, CAED has the following information in any moment:

- state (0, 1) of indicators (IND)
- state (0, 1, 2, 3) of sensors and models running for the specific highway section (SEN)

and, on the basis of these states, four different decisions can be made by CAED, one of which with three options.

All the possible decisions are illustrated in Table 1, in which the weight of the several sensors is assumed to be the same.

Based on the notices of criticality levels provided by CAED, and on its own independent evaluations, the CCC issues the appropriate warning notices (Surveillance, Alert, Alarm and Warning) and makes decisions about the consequent actions (Fig. 35).

7. THE INTEGRATION OF MONITORING WITH THE CONTROL CENTER FOR ROAD NETWORK (CCC) *(F. PAOLETTI)*

The Landslide Early Warning Project aim at monitoring high impact hydrogeological risk zone with the objectives to enhance safety of the sites, with specific attention to motorway infrastructure impact in order to enhance safety and grant travelers and goods to reach their destination in time and on safe condition . The CAED (“Centro Acquisizione ed Elaborazione Dati” –

Data Collecting and Processing Center) collects and processes the data monitored by the specific sensor network and deliver the outcomes of the processing to the Center which is devoted to Road Infrastructure Monitoring and Management (CCC, namely “Centro di Comando e Controllo”).

State of sensors and/or models	**CAED decisions**
All INDs and SENs are S0	0 - no decision
At least one IND is S1 and all SENs are S0	1 – SOD activation
At least one SEN is S1	2 – to intensify the presence up to 24 hours/day
At least *n* SENs are S1 or at least one SEN is S2	3/1 – to issue a notice of ordinary criticality (level 1)
At least *n* SENs are S2 or at least one SEN is S3	3/2 - to issue a notice of moderate criticality (level 2)
At least *n* SENs are S3	3/3 - to issue a notice of high or severe criticality (level 3)

Table 1. CAED possible decisions

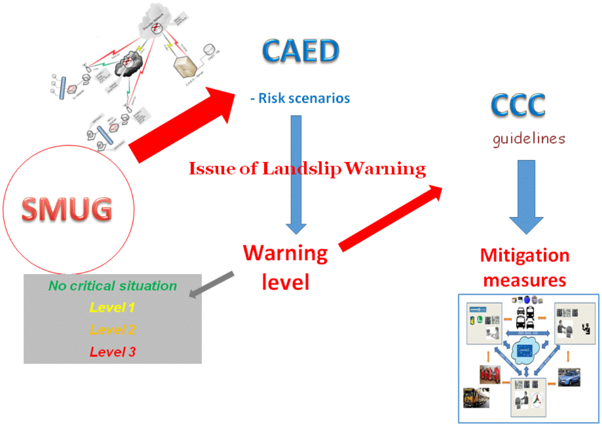


Figure 35. Relationship between LEWIS components

The concept behind the design of the CCC, implemented by Autostrade Tech in the framework of the PON LEW project, is to set up a monitoring and

supervising system which is responsible to integrate data from hydrogeological risk monitoring and traffic and road condition information, consider relevant alerts, and, initiate road maintenance and traffic management operations based on global situation evaluation, which will act based on specifically designed management rules and procedures, derived from Emergency plan. The CCC is able to activate communication channels with the operating and rescue teams in an automated way, after operator validation of the danger situations recognized by systems. Besides, it may easily interacts with other operating centers responsible for road managing and safety (such as Authorities, Road Police, Civile Defence, Viability Patrols, etc.). Automatic Communication has been implemented by machine generated messages, both on traditional communication means (such as mail, telefax, SMS, speech) and by a specific innovation in this framework, by means of DATEX, up-to-date technology and machine readable protocol.
The functions performed by the CCC are:

- Check the environmental conditions;
- Monitors traffic status;
- Detect eventual abnormal conditions and situations;
- Find out the intervention/information procedures to be applied against certain situations;
- Triggers the intervention/information procedures (whether directly or actively involved in the operation);
- Check the progress of the interventions;
- Check the information delivered on different media.

The organizational and procedural model provides a broad vision of the problem showing several operations centers (police, rescue organizations, road operators) that are able to interact with other operational centers through traditional and up-to-date technology communication means.
CCC can operate acting as an road operational centre that directly activates the emergency rescue teams and patrols as well as it may implement the actions required to manage the critical situation. Otherwise it can operate as a supervisory central which gets information from other operating centres to oversight and coordinate several collaborating operating centers, monitoring and triggering management risk and initiating specific rescue and management operations.

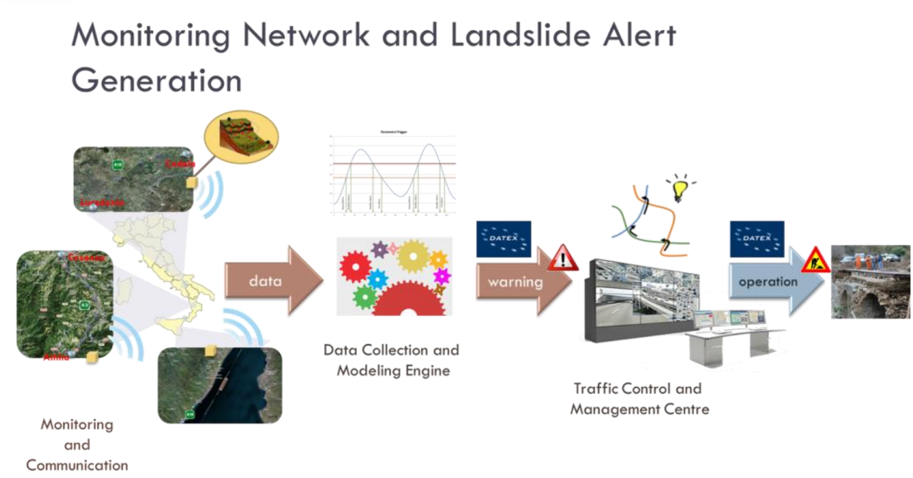


Figure 36. PON LEWIS Architecture

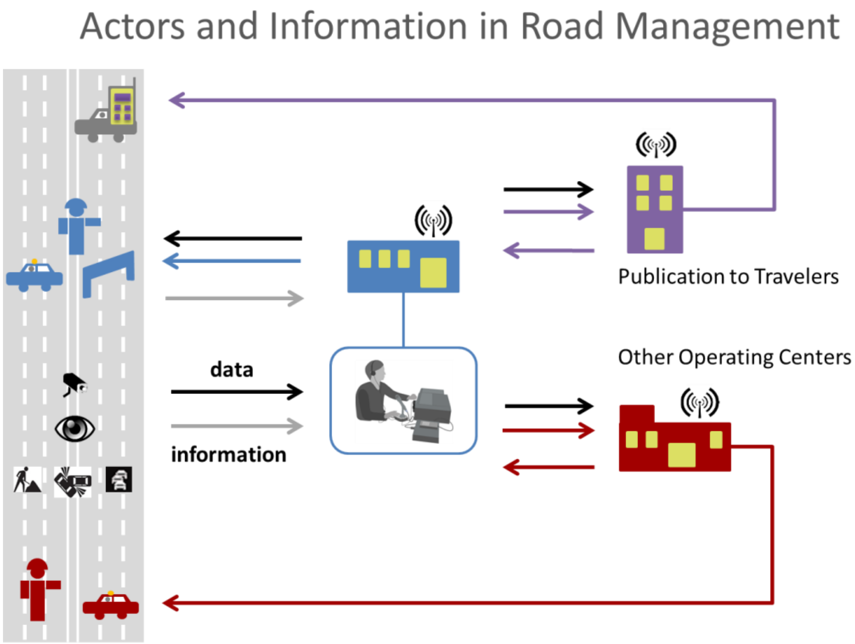


Figure 37. Actors and Information Flows in CCC Traffic Control Centres

The DATEX protocol (www.datex2.eu) has been developed along last ten years by several EU initiatives in the Intelligen Transportation System and Services (ITS) field. The scope of this protocol is to ensure reliable and timely Traffic Information exchange among centres, to inform about traffic situations in the road network and has been leveled up to CEN Technical Specification in 2012 (CEN TS-16157). Based on its common services platform and road and traffic dictionary, it has been extended and harmonized among motorway operators and in the framork of the LEWIS project, a pilot has been developed to implement coordination and best cooperation of Road Emergency Operator in Emergency situation management. Deployment Guideline for Traffic Managemente Systems deployed in Easyway Program in 2012 have helped to set up a management procedure based on requirements and vision which are valid among a larger ITS stakeholder community.

In order to take best actions to manage road network and ensuring best safety and service levels, information about Traffic and Road is needed as well as other Environmental and Wheather conditions information. These information are received by CCC via DATEX messages flows set with other centres: DATEX link from Autostrade per l'Italia motorways operator has set up in order to be informed about specific situation and receive Traffic Level of Services elaborated by traffic Sensors and Travel Time Information Elaboration, mostly based on Floating Car Data (i.e. position of vehicles which drives along the road network which may be processed to find current average speed and travel time). Information about Exceptional Load Vehicles and Specific high risk sites as Tunnels which are near hydrogeological risk sites are monitored and managed in the system, allowing the TCC operators to best evaluate the current network situation and to manage operations in case of increased risk or real event. The Information Delivery system is able to convey all collected information to specific information channels to be broadcasted directly to travelers by means of websites, RDS-TMC radio channel, and native speaker multilingual messages on radio and tv channels.

By means of “ extension mechanisms” and based on the LEWIS projects requirements, the standard DATEX protocol and information model has been enriched addressing specific information related to landlside, in a perspective to describe hydrogeological characteristics and the potential impact on the road network, as well as operational needs to manage and reduce risk conditions and fast return potentially damaged or risky zones to standard conditions.

A further extension has been implemented as an operational Workflow to help centres to manage road by means of specifically designed Traffic Management Plan (TMP) operation, i.e. specific network configuration which have been designed and agreed with all involved authorities and organizations. Specific TMP messages have been implemented as weel as TMP Feedback messages to manage a cohordinated setting of operation to enable specific road configuration as carriageway reduction and deviation, and specific alternative paths for different kind of vehicles. The specific implemented extension have been agreed among the motorway companies in Italy under AISCAT umbrella and the extension have been published as achievement to the DATEX website: www.datex2.eu/d2-extension)

Resuming the overall management flow, by means of CCC system fed by the CAED system and Traffic Information received by surrounding Traffic Control Centres, CCC operators are able to evaluate detail information about hydrogeological conditions. They may check if the monitoring system is running and alert information is correct to validate risk alerts derived from the CAED system. Decision Support System (DSS) will help operators to recognize management effective risky condition in order to promply deliver messages which will be reliably shipped via traditional communication channels to patrol and rescue teams. On the meanwhile further machine readable messages via DATEX are shipped to other centres for informational purposes. Traffic Management Plan eventually needed are suggested and acknowledged among operators via the TMP DATEX Extension. Ongoing operation monitoring is enabled to ensure the efficiency of road management operation and prevent communication mistakes. Traffic Conditions are continuously monitored via all available channels till the risky condition are off or any damage to road infrastructure are repaired. Information on the ongoing situation may be broadcasted to drivers by various public Information channels in multilingual messages.

8. EXPERIMENTAL ACTIVITIES (G. VIGGIANI, E. CONTE, O. CIANCIOSI, A. CARUSO, A. CANCELLIERE, D. J. PERES, L. CAVALLARO, E. FOTI, M. CAPUOZZO, D. DE SANTIS)

Extra-laboratory experimental activities have currently been carrying out. For practical purposes, experiments are classified in two categories, namely slope monitoring and landslide effects on highway structures monitoring.

Slope monitoring is carried out by:

- Geotechnical investigations (including in-situ testing, subsurface sampling and laboratory testing) and piezometers, inclinometers and stress cells.
- Hydrological investigations (tensiometers and Time Domain Reflectometry – TDR).
- Meteorological investigation (rainfall, temperature, humidity, wind and radiation).
- 2-dimensional analysis (Radar, Scatterometer, Interferometer).
- Mathematical models for landslide triggering and propagation, supported and validated by geotechnical and hydrological investigations.

Landslide effects monitoring is based on:

- POIS system for structures monitoring (abutments, tunnels, retaining walls).
- SMAMID for edge break, wearing surface cracking or fore/backslope monitoring.

A3 Highway monitoring

Experimental activities across Highway A3 Salerno-Reggio Calabria have been planned in three sites, namely Mancarelli, Fiego and Piano d’Infante sites.

In the Mancarelli site the greatest number of devices has been planned (Fig. 38), with a Weather station, three Borehole stations (piezometer+inclinometer+stress cells) and two Hydrogeological stations (tensiometer+TDR), whose measures are useful as input for the one-dimensional mathematical model.

The slope in front of Mancarelli has been selected to install the Radar, at a distance of about 500 m from roadway and at the same height.

Similar devices have been planned for Fiego site, where the two-dimensional mathematical model is more appropriate.

In the Piano d'Infante site a deep-seated landslide causes shows retaining walls movements and wearing surface cracking. Therefore, this site has been selected for structures monitoring (POIS system, SMAMID).

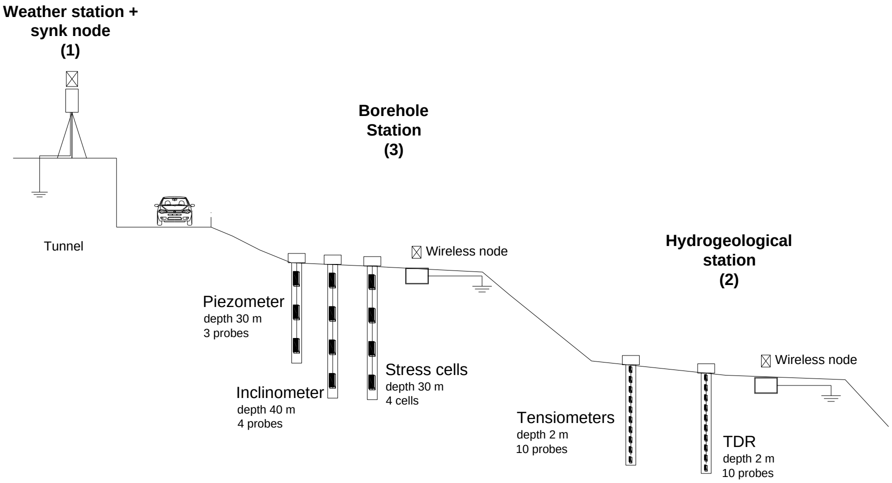


Figure 38. Mancarelli site experimental stations

A16 Highway monitoring

Experimental activities across Highway A16 Napoli-Canosa have been planned in three sites, that are located at km 112+400, km 122+500 and km 97+500.

The main disruption affecting A16 area have been caused by gravitational phenomena which have developed in recent clay-sandy, resulting in phenomena of surface instability (landslides and lens distortion for flow) and deep instability related to the scale.

In the first site, interferometric radar and SMAMID system have been installed. The monitoring will be completed with a Borehole station (piezometer+inclinometer+stress cells) and an Hydrogeological station (tensiometer+TDR).

A Berehole station and a Hydrological station will be located in the second site too.

Figure 39. A3: Edge break in the Mancarelli site

Figure 40. Piano d'Infante site: concrete panels between roadways to be equipped with SMAMID and POIS system

Finally, the wide area of instability at km 97+500 (with its deep sliding surface) will be monitored by inclinometric and piezometric devices.

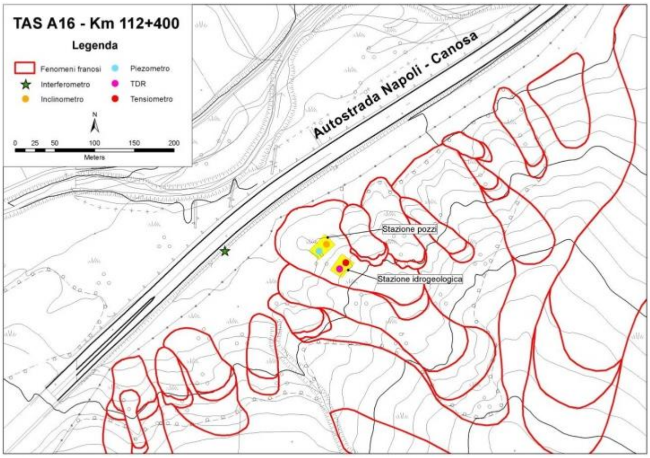


Figure 41. Highway A16 Napoli-Canosa

Figure 42. A16: km 112+400 site

A18 Highway monitoring

Experimental activities across Highway A18 Messina-Catania have been located in two sites between Roccalumera and Messina Sud.

Selected sites differ substantially since the first one is prone to shallow rapidly moving landslides (mudflows) while the second is more prone to slow and deep-seated landslides. This area has recently experienced highly-damaging landslide events; on the 1st October of 2009, a diffused debris flow event in the area caused 37 victims, about hundred injuries and two thousand of evacuated people.

Figure 43. A18: gate conveying mudflow over roadway

The A18 Highway traffic was stopped, with negative impacts on the promptness of rescue operations.

In order to analyse the rapidly-moving landslide, four mathematical models have been applied: FLaIR (Capparelli & Versace 2011), TRIGRS model (Baum et al., 2008), SCIDDICA (Avolio et al. 2013), FLO-2D model (O' Brien et al. 1993). It is noteworthy to highlight that this site the only experimental site of the project in which rapidly-moving landslides occur, thus increasing relevance of early warning.

Slow and deep-seated landslide has planned to be monitored by a Borehole station (piezometer+inclinometer) and an Hydrogeological station (tensiometer+TDR).

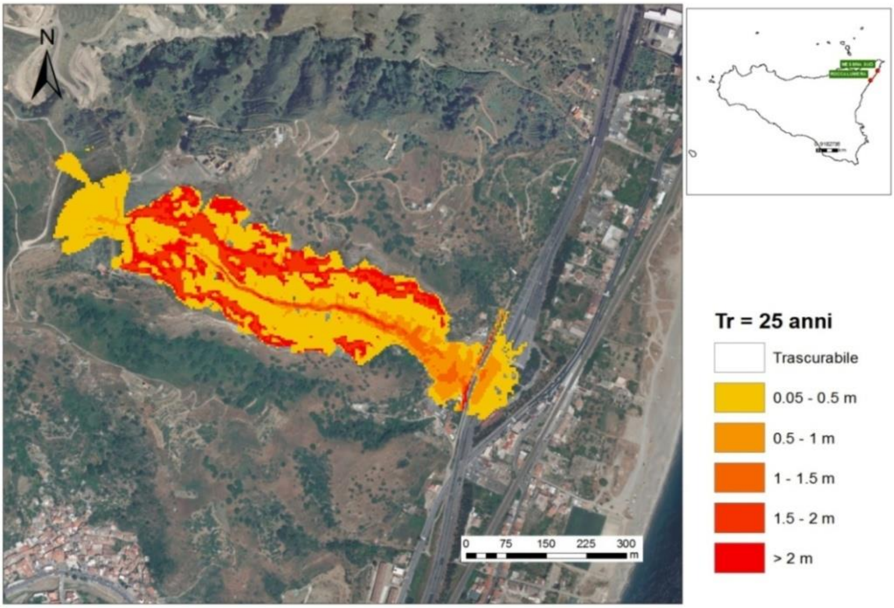


Figure 44. A18: graphical results from integrated mathematical model (hydrological landslide + mudflow run-out models)

9. THE TRAINING PROGRAM *(D. MALETTA, T. MUNGARI)*

“Enduring learning for knowledge, creativeness and innovation”. The entire reference politic of the “Lisbon Agenda” is based on the previous sentence and it was used in the training project of the PON01_01503 in order to reach “training success” as wide as possible in its different components. Training has been interpreted as a tool of excellence that has combined the strength of traditional academic learning type with professional training, in a context of an integrated program that enhances the transmission mechanism of the "informal knowledge" generated in the company.

An high post-graduate educational pathways was established: the two-year second level Master in "Expert in Forecast / Prevention of Hydrogeological

Risk (ESPRI)". This was the result of a partnership between the University of Calabria, the Inter-University Consortium Hydrology and three companies of national importance: Autostrade Tech, TDGroup and Strago.

The design idea of the Master was born to satisfy a dual requirement: 1) prepare and train on the territory qualified professionals in the field of Prediction / Prevention / of hydrogeological risk, 2) provide advanced and specific training to young talents residents in Convergence Areas for creating trained and competitive professionals both at local and at national and international level. The training was aimed at the formation of two new professionals: Expert in monitoring the hydrological risk and Expert Systems Early Warning and numerical modeling of hydrogeological disasters.

The two professional profiles identified received specific skills and knowledge relating to the entire process of environmental monitoring (monitoring, early warning, hydro-geological risk mitigation and environmental protection) crucial to operate within the hydrogeological risk field and to prevent, anticipate and solve critical situations through the application of innovative techniques of remote sensing monitoring in conjunction with accurate models for forecasting and risk prevention.

On one hand, the “professional expert in monitoring the hydrological risk” profile of has been focused on know-how acquisition for the design and management of systems for monitoring landslide risk through the analysis of point sensors, remote sensor, and of systems for data processing and transmission both in real time (early warning) in deferred time (transmission time intervals periodicals).

On the other hand, the professional “Expert Systems in Early Warning and numerical modeling of hydrological disasters” profile was focused on notions concerning the Early Warning systems (design, management, procedures for alerting, etc.) and the mathematical modeling and simulation of the phenomena related to the hydro-geological risks (identification, characterization and mapping of areas at risk, etc.).

Environmental Engineering and Geological Sciences and Technologies graduate students and professionals of the fields attended the Masters, for a total duration of 3000 hours in 24 months.

During this period students have achieved a highly specialized training experience through the illustration of specific topics in order to promote their inclusion in specialized fields of expertise and rapid professional growth.

The entire training program was organized in fact to prevent the skills obsolescence and ensure an adequate level of education and qualification in accordance with the Lisbon Strategy.

The courses have been carried out by a succession of university teachers (belonging to the University of Calabria, University of Padua, at the Polytechnic of Turin, the Politecnico di Bari, University of Basilicata, University of Florence , University of Catania, ICAR-CNR, the Consortium Wisdom and Innovation) and a number of professionals and technicians (relating to Autostrade Tech, Autostrade in Italy, the Company SPEA Ingegneria Europe, the Infoblu, the Ministry of Infrastructure and Transport, the company Strago and TDGroup, Arti Puglia, as well as experts and professionals of national and international significance). They have focused their lessons on scientific and technical aspects of monitoring hydrogeological risk, Early Warning systems, hydrological disasters modeling, and management of research projects.

Classes were hosted at the University of Calabria in a training program that was made by both knowledge communication and practical experiences presented by professionals who have transmitted to the students not only "know", but also "know-how ". Theoretical activities have been balanced by practical activities, guided tours, tutorials, workshops, working-groups and simulations of real cases. This has made classes more dynamic and has encouraged the learning project.

Taking into account the European strategy that focuses on Lifelong Learning, an innovative training chain has been introduced. This aims to consolidate knowledge through the implementation of learning object able to meet the challenge of the current changes both in terms of technology and in strengthening of professional expertise operating in the territory, starting from the master ESPRI students.

Through multimedia objects would also be possible to support continuous and permanent training not only for students of master ESPRI but also for all those involved in the educational process. In particular, the multi-media object designed, and used as a demo, was modulated for the Civil Protection Class granted during the master. The structure is hierarchical and at the fourth level are the Learning Object, ie the minimal units in which teaching units are articulated in. In practice they corresponds to the contents organized into precise shapes. The key element of the LO is the indexed Video lesson: a lesson in the form of video, accessible in an asynchronous way on web, which is introduced in the classroom by a tutor. This requires the presence, in a single user interface, of an audio / video data stream (the teacher) synchronized with the slides projected (regarding educational content). The LO is integrated by:

- self-assessment tests to allow the learner to verify the achieved level of learning;
- Normative References on the subject such as laws, decrees, directives, manuals, etc.;
- Essays and scientific publications;
- Recommended Links (web links) to explore topics relating to the subject of the lesson;
- PowerPoint presentations related to the topic presented;
- Movies on to the subject of the lesson.

In addition to the asynchronous self-learning mode, through the use of contents available on the platform, the integration of learning resources is ensured through the use of different modes, such as synchronous learning mode, videoconferencing, virtual classrooms, and collaborative learning through activities in virtual communities.

Moreover, the formative pathway include a training period both in University (University of Calabria, University of Florence, University of Basilicata) and in companies and organizations involved in the project (Autostrade Tech, Strago, TDGroup, CINID). The internship activities were carried out in suitable facilities in advance identified by crossing the trainees skills and aspirations with the companies and / or universities features in order to ensure the best combination that could enhance the curriculum, the personal and the professional growth.

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