SLAM, the development of an EO Service to support the legal obligations of Swiss and Italian Geological Risk Services in landslide risk forecasting and prevention

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Abstract — **The necessity to identify and monitor slope movement is of paramount importance to reduce the socio-economic toll that every year is paid in developing as well as in developed countries. From the late 80's Italian and Swiss legislations regarding hydro-geological risks, have identified landslide hazard maps as essential tools to mitigate the risk associated to landslides. Several projects funded by the European Space Agency within the framework of its Data User Program (DUP), have investigated the feasibility and the operational applicability of spaceborne imagery to respond to the needs of governmental institutions that have a mandate in landslide analysis and prevention. Techniques based on SAR interferometry and on the combination of state of the art Remote Sensing observations with GIS modeling have been analysed in order to assess the contribution of Satellite Remote Sensing information in support to the practices of the Geological Risk Services Agencies.**

Keywords: Earth Observation, landslides, natural hazards.

I. LEGISLATIVE FRAMEWORK

Ground Instabilities are among the most widespread geological hazards on Earth: thousands of deaths and injuries, and enormous economic loss are regrettable evidences of worldwide slope instabilities. They form an increasing threat taking into consideration the world population growth, the intensive land use and the climatic change. Destructive effects have been reported in recent years in developing countries (approximately 1,000 deaths per year), but even in developed countries the annual death toll paid is fairly large (25 to 50 deaths annually in the USA and almost twice in the EU). In the late 80's a strong and responsible political action was started in Italy and in Switzerland, as a result of the increased awareness of the risk factors for the population exposed to landslides.

In Switzerland, the legislation regarding natural hazards mapping is contained in the Federal Law for Flood Protection, in the Federal Law of Forest and in the Federal Law of Land Use Planning. In particular the 1991 Federal Law on Forest and Water Management sets out the legal requirements for hazard mapping and land use planning. Local and regional authorities (i.e. the Swiss Cantonal Authorities) have the responsibility to map and monitor slope instabilities that may present a danger to lives and properties. The main legal instruments used in this context are the hazard maps and the zonal plans that are to be produced by the Cantons following the guidelines provided by the Federal Office for Water and Geology (FOWG).

In Italy the Law 183/1989 has assigned to national, inter-regional and regional River Basin Authorities the coordination of all issues related to the hydro-geological risks. The difficulties related to the elaboration of the Basin Plan - the legal instrument to address territorial planning and management activities - drove the Government to the promulgation of further legislation to enable adoption of elements of the Basin Plan: the Sector Plans "*Piano Stralcio*". The Sector Plan related to the hydro-geological system is the P.A.I plan "*Piano per l'Assetto Idrogeologico*" that contains all the technical information regarding land use for very high (R4), high (R3), moderate (R2) and low risk (R1) areas of the hydrographic basins. The P.A.I. plan determinates the necessity to study and monitor the territory. In the areas characterized by a very high level of risk (R4), the Basin Authority must elaborate the Extraordinary Plan of intervention "*Piano Straordinario*" that contains the risk reduction and protection measures to be adopted. With the DL 112/1998 the State (i.e. the Italian Ministry of Environment) maintains functions as coordinating organism, while the regional authorities are involved in the planning and in the implementation of the interventions: the Basin Authorities to plan and control, and the regions and local entities to fulfill the Plans. Finally, the Department of Civil Protection, instituted by the Law 225/1992, has a mandate in forecasting, prevention, assistance and recovery. Forecasting and prevention actions in the case of the hydro-geological calamities are described in the Prevention and Prevision Program "*Programma di Prevenzione e Previsione*" that is elaborated in collaboration with the Basin Authorities and with the Regions. This document, updated every 3 years, constitutes the reference for the description of priority areas and risk mitigation actions.

This work has been carried out under five European Space Agency (ESA) contracts within the DUP Service for Landslide Monitoring (SLAM) Initiative. Further information about DUP and results of the SLAM projects can be found at: http://dup.esrin.esa.it/

II. SLAM INITIATIVE

The European Space Agency started the SLAM (Service for Landslide Monitoring) initiative in 2001 to develop an EO Service that could support the forecasting and prevention activities of Italian and Swiss Geological Risk Services involved in Landslide risk mitigations. A total of 5 projects - carried out by consortia belonging to the four ESA Member States that have subscribed to the DUP program (Italy, Switzerland, Belgium and Holland) have been sponsored by ESA along 3 consecutive sets of activities:

1. a *SLAM Service Feasibility project* to study, critically review and assess the possibility to use RS technologies within Landslide monitoring and risk assessment;
2. Some *SLAM Service Definition projects* to carry out, with the close collaboration of user organizations, all preliminary tasks that would build the foundation for the implementation of a wide scale SLAM information service: the identification and engagement of user organizations based on their statutory mandate, and the definition and specification of SLAM information products and services well targeted to their specific needs;
3. a *SLAM Small Scale Demonstration project* focused on the specification, on the production and on the qualification of demonstration products and services.

All these activities aimed principally at preparing the development of a *Service Demonstration project* to implement and demonstrate a SLAM end-to-end service chain on a large-scale basis with a representative user community.

III. METHODS

Different approaches to the mapping and the monitoring of landslides, and related susceptibility and hazard, have been analysed by the consortia, in various case studies.

- Standard techniques based on image interpretation of high and very high resolution imagery (HR/ VHR), as input to slope instability information extraction;
- DinSAR to extract information about location and quantification of mass movements;
- Advanced multi-interferometric techniques (e.g. Permanent Scatterers) to derive deformation rate vs time;
- Standard RS techniques to create land-cover maps and DEMs, as input to landslide conditioning factors derivation;
- Analytic tools in GIS environment to extract relationships between causative factors (derived from Remote Sensing) and landslides occurrences.

In overall, a comparison between all InSAR methodologies applied have shown that, even if the limitations of the techniques based on C-band SAR interferometry (e.g. target visibility, landcover and rate of motion) influence the amount of observations, the use of multi-interferometric techniques with integrated datasets (10-year ERS archive, ascending / descending) can substantially improve their applicability.

IV. TEST CASES RESULTS

MASMOV (Fig. 1) focused on Southern Italy (Cosenza province), where the Permanent Scatterers technique has enabled the identification of deformation trends during the time-interval 1995-2000.

ALPS (Fig. 2) aimed to the demonstration of capabilities and analysis of limitations of conventional InSAR techniques to detect unstable slopes and measure the displacement rate over test areas in Switzerland and Northern Italy.

SLAM-1 (Fig. 3) built on the results already achieved by MASMOV and demonstrated integrability of PS-derived information about unstable slopes and rate of deformation into GIS systems and related databases.

SLAM-2 (Fig. 4) demonstrated the advantages of a joint exploitation in a GIS of EO-derived products (mainly from SAR observations) and other sources of information to achieve a landslide susceptibility map over a test area in Switzerland

ALPSLOPE (Fig. 5) is aiming at the integration of interferometrically-derived information about 2 known landslides in Northern Italy into the end-user GIS.

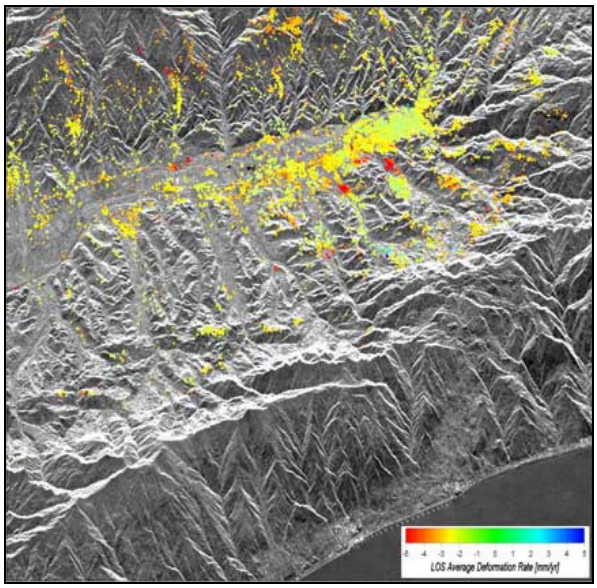

Figure 1. **MASMOV**: PS LOS average deformation between 13 November 1995-21 January 2000. Dataset: 46 scenes

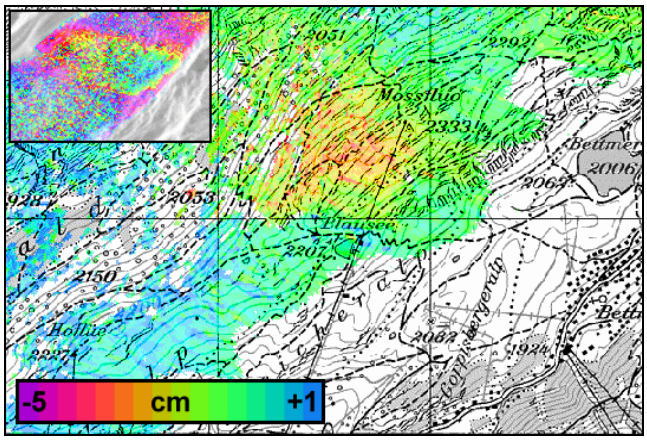

Figure 2. **ALPS**: Displacement map of a rock-fall above the Aletschglacier along line-of-sight (105 days temporal baseline, 5 m perpendicular baseline). The inset shows the differential interferogram.

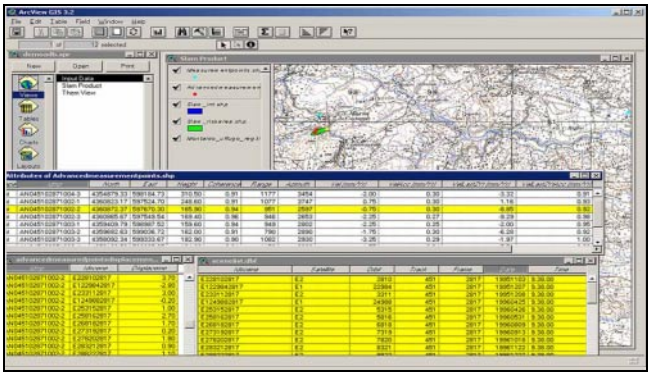

Figure 3. **SLAM-1**: Deformation rate measured by means of the PS technique, integrated in a GIS depicting unstable areas.

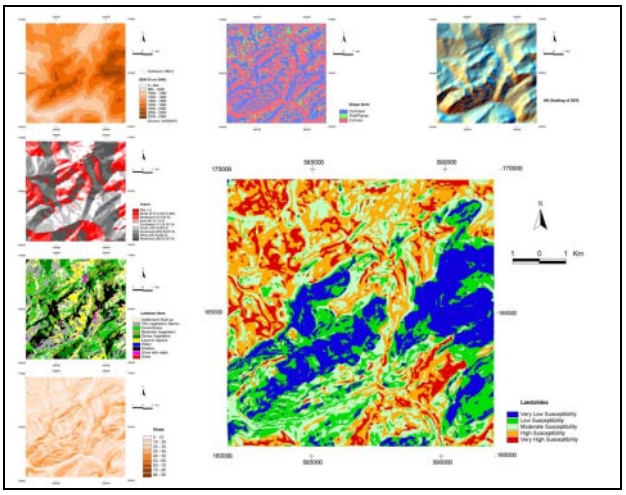

Figure 4. **SLAM-2**: Statistic bivariate landslide susceptibility map obtained by combining in a GIS input layers (small insets), mainly derived from InSAR

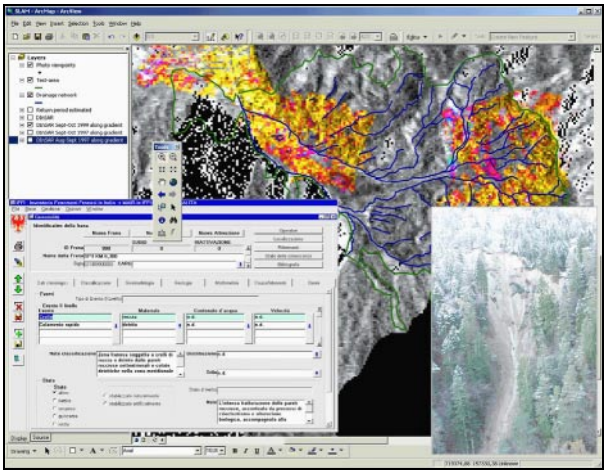

Figure 5. **ALPSLOPE**: Screenshot of a GIS merging interferometric information with other information sources

V. PRODUCTS AND SERVICES

The *SLAM Feasibility and Definition projects* resulted in the identification and in the specification of three EO-derived products that should respond to the needs of the Geological Risk Services Agencies:

A. Landslide motion survey

A motion reconnaissance service to identify, within a large Area Of Interest (i.e. 1,000 - 10,000 km^2), the areas / points where deformation takes place. The service carries out a screening of the AOI in order to identify areas affected by slope motion. The minimum content of such a product is the location of the movement, the extent and contour, and an approximate estimation of the deformation velocity. Standard Interferometric techniques are used to derive the needed information. This product is requested to support the geological risk service agencies in their activities related to the update of landslide inventories and activity maps, and in the planning of ad-hoc field works. The product can also be an input to Landslide susceptibility and hazard mapping.

B. Landslide displacement monitoring

Landslide activity products to be delivered on a regular basis to precisely quantify the rate of motion of areas / points within a small Area Of Interest (i.e. 50 - 1,000 km^2). The objective is to accurately measure the displacement fields of known landslides. The service could be used for monitoring the efficiency of structural interventions and areas that have been classified as high risks. Advanced Interferometric techniques are used to derive the needed information. This product can be used by end-user organizations to qualify existing landslide inventories, to analyze risk mitigation issues and to validate existing risk-zones areas. The product can also be an input to Landslide susceptibility and hazard mapping.

C. Landslide susceptibility mapping

Products derived from EO data to be integrated and used as intermediate layers in support to landslide susceptibility mapping (at scales imposed by the resolution of the EO data and the needs of the end-users). Techniques to derive the information may account for visual interpretation of HR/VHR satellite imagery (mono and stereo), multi-spectral analysis and interferometry (to produce DEMs or to qualify/quantify movement rate). Landslide Hazard Maps are the products to be produced by Law, by the Geological Services and are intended for land use planning and environmental impact assessment.

VI. FOLLOW ON

The “large scale” SLAM *Service Demonstration project* has been kicked off by ESA in April 2003. This 22-month project aims to respond to the operational needs of the local authorities that have an institutional mandate in hydro-geological risk mitigation in Switzerland and in Italy, and has been organized in cooperation with there national agencies: the Italian Ministry of Environment that federates the Italian Basin Authorities and can act on policy issues; the Italian National Research Council Group for Hydro-geological Disaster Prevention (GNDCI) that federates the major Italian Research Centers involved in Slope Instabilities assessment; the Swiss Federal Office for Water and Geology (FOWG) that federates the Geological Risk Services of the Swiss Cantons. These national organizations have been instrumental in fostering the active participation of several local institutions that are the real recipients of the SLAM products and that have the statutory mandate to assess slope instability hazard.