



## Research Paper

# A nation-wide system for landslide mapping and risk management in Italy: The second Not-ordinary Plan of Environmental Remote Sensing



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## ABSTRACT

Landslides are frequent events that may cause human casualties and injuries as well as damage to urban and man-made structures, with extensive loss of economic resources. For this reason, landslide mapping is a primary tool for hazard and risk assessment. Italian Ministry of Environment, thanks to great availability and functionality of Synthetic Aperture Radar (SAR) data promoted the Not-ordinary Plan of Environmental Remote Sensing (Piano Straordinario di Telerilevamento Ambientale, PST-A in Italian) in 2008, as to constitute a national database of active or potential instability phenomena affecting the Italian territory, based on the exploitation of interferometric products (ERS and ENVISAT). In this paper, the PST-A-3 is described. A procedure based on the integration of engineering-geological approaches and SAR interferometry data belonging to COSMO-SkyMed constellation (100 frames 40 × 40 km) has been here implemented over 7,400 km<sup>2</sup> of the Italian territory. First, landslides have been mapped by field geologists, defining type and state of activity. Simultaneously to field surveys, remote sensing data have been analyzed as to detect areas with considerable displacement registered by the satellite. Both products have been overlaid, also quantifying the coincidence between the events reported according to the two detection methodologies and subtracting those landslide not recordable by the satellite, finally obtaining an updated landslide inventory map with 4,522 newly detected phenomena. Therefore, PST-A-3 proves to be a valuable system for local authorities, in order to provide a contribution to risk management but also for the forecasting of landslide events, as testified by two case studies selected. Thanks to the PST-A experience, the use of such strategy to other countries could represent a valid contribution to land management at worldwide scale.

## 1. Introduction

Landslides are recurrent and widespread phenomena, which, depending on their velocity and their magnitude, may endanger people, causing human casualties and injuries as well as damage to private and public properties, with considerable loss of economic resources. Indeed, slope instabilities represent one of the main causes of death caused by natural hazards (Guzzetti et al., 2012). Therefore, mapping such phenomena represents a leading task for landslide hazard assessment (Cubito et al., 2005; Martha et al., 2013; Di Martire et al., 2016a). Landslide inventories are an essential part of any landslide zoning and represent a key factor to understand the evolution of landscapes and are conceived and prepared for different purposes (Galli et al., 2008; Guzzetti et al., 2012): i) to show the location and type of landslide

movement in a territory (Cardinali et al., 2001; Antonini et al., 2002; Novellino et al., 2015; Diodato et al., 2017); ii) to show the slope response to certain triggering events, such as an intense rainfall event (Bordoni et al., 2015; Confuorto et al., 2017; Tessari et al., 2017), an earthquake (Bozzano et al., 2011; Huang et al., 2017) or snowmelt (Naudet et al., 2008); iii) to show the great quantity of mass movements (Albano et al., 2015; Kenner et al., 2016; Novellino et al., 2017); iv) to determine the frequency of landslide events (Guzzetti et al., 2002; Brardinoni et al., 2003; Guthrie and Evans, 2004a, 2004b; Malamud et al., 2004; Wooten et al., 2016); and v) to evaluate landslide susceptibility (Soeters and van Westen, 1996; Guzzetti et al., 1999; Trigila et al., 2015) or hazard (Parise, 2001; Guzzetti et al., 2005; Guzzetti et al., 2006a, 2006b; Lari et al., 2014) models. Among the several methodologies developed to define location and geometry of landslide,

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photogrammetry (Li et al., 2016), LiDAR (Light Detection and Ranging) (Van den Eeckhaut et al., 2011; Jaboyedoff et al., 2012) and GPSs (Global Positioning System) (Guerriero et al., 2014; Di Martire et al., 2015) are worth mentioning, nevertheless considering the necessity to couple the above-mentioned techniques with field surveys aiming at the inspection of the morphology and the identification of the main features of a landslide (i.e. main scarp, flank, toe, etc.). The enhancement of new technologies made landslide investigation easier, with, for instance, the development of remote sensing techniques, such as Synthetic Aperture Radar (SAR) interferometry and the specific class of Multi Temporal Interferometry SAR (MTInSAR, Wasowski and Bovenga, 2014). The latter enabled the measurement of ground deformation down to the order of millimeters from satellites (Bamler and Hartl, 1998; Rosen et al., 2000; Ferretti et al., 2000). In particular, with recent improvements in resolution of the new SAR missions, such as COSMO-SkyMed or TerraSAR-X stripmap images ( $< 3 \times 3$  m) and with the reduction of the revisit time (4–12 days, COSMO-SkyMed, TerraSAR-X and SENTINEL-1A and 1B), a considerable increase in the effectiveness of remote sensing methods for the monitoring and the analysis of natural risks has been recorded. The great availability of SAR images, acquired all over the Italian territory, led the Italian Ministry of Environment and Protection of Land and Sea (MoE) to promote and then issue the Not-ordinary Plan of Environmental Remote Sensing (Piano Straordinario di Telerilevamento Ambientale in Italian, PST-A) since 2008, in order to start, for the first time, the constitution of a national database of active or potential instability phenomena affecting the Italian territory, based on the exploitation of interferometric products. In this framework, SAR products were used, providing PS (Persistent Scatterers) ground deformation measurements of the Italian territory and made them available on a webGIS server (<http://www.pcn.minambiente.it/GN/>). All the collected data soundly contributed to territory management activities, giving support to all ranges of topography, cartography, modelling, GIS and decision-makers activities. The first phase of the PST-A (PST-A-1, 2008–2009) led to the processing by means of interferometric technique (Persistent Scatterers Interferometry SAR, PSInSAR, Ferretti et al., 2001) of SAR images acquired by the ERS1/ERS2 and ENVISAT satellites between 1992 and 2008 throughout the national territory. In the second phase (PST-A-2, 2010–2011), the interferometric dataset has been updated with processing of SAR images acquired by the ENVISAT satellite from 2008 to 2010. In 2011, MoE started and financed a new procedure, based on integration between engineering-geological approach and X-Band SAR interferometry. Newly acquired COSMO-SkyMed SAR data on three study areas, Bologna, Palermo and Venezia study areas were experimentally processed and interpreted. Considering the valuable results obtained in such test areas, the Italian MoE started the PST-A-3 (2013–2016), here described, in order to enhance and update the previous database. In the latter framework, 100 COSMO-SkyMed frames ( $40 \times 40$  km) acquired from ASI (Italian Space Agency) within the MapItaly Project (MIP) (Sacco et al., 2015; Carbone et al., 2016) have been used. The latter has been developed by ASI and the Italian Department of Civil Protection in order to obtain a continuous archive over the national territory. All the SAR data collected have been processed by means of PSP-IfSAR algorithm (Costantini et al., 2008). A procedure developed by Di Martire et al. (2016 b), called LaDIS (Landslide Detection Integrated System), has been adopted in different geomorphological settings over Italian territory in order to map the ground instabilities through the contribution of SAR data. This procedure is structured in 4 stages: i) detection of critical areas to be verified (AV); ii) geomorphological surveys and mapping of landslides; iii) analysis of interferometric data and mapping of significant displacements; iv) update of the landslide inventory map. To this aim, 249 areas (AV) have been selected, spread over the whole Italian territory, and covering about 7,400 km<sup>2</sup>. The final goals of PST-A-3 were to update landslide inventories and the previous PST-A-1 with higher resolution imagery as X-Band. The paper is organized as follows: first, a brief illustration of the PST-A is given. Then, a description of dataset

and methodology applied within the framework of this project is provided. Finally, given results are described and totaled.

## 2. Not-ordinary plans of environmental remote sensing

In order to provide counter-measurements of the extremely high risk to hydro-geomorphological phenomena of the Italian territory, the Italian government, through the article 27 of the Law n. 179/2002, promoted the PST-A (Costabile, 2010). The plan is conceived to support central administrations, whose role is to coordinate the activities for land management (MoE), to manage the consequences of natural events in case of emergency (Civil Protection) and to develop the national capabilities for cartography and security (Defense Ministry) (Costabile, 2010). Consequently, the plan supports also local administrations (Regional, provincial and municipalities), involved in territory and emergency management. The project aims at strengthening the capabilities of observing and controlling the territory using innovative remote sensing techniques, while helping to enrich the technological know-how and to spread its use in Public Administration.

All the data have been reported in the National Geoportal (Geoportale Nazionale—GN) database, in order to share them with administrations and public users (Costabile and Paci, 2017). PST-A-1 was launched in 2008, using interferometric dataset, composed of displacement rate maps, created by means of interferometric processing of ERS-1/2 and ENVISAT imagery. In detail, 304 ERS frames (115 ascending and 189 descending) have been acquired between 1991 and 2000; ENVISAT, which substituted the previous constellation, was active between 2002 and 2010, and in PST-A-1 179 frames (98 along ascending track and 81 along descending) were made available. An amount of about 15,000 images has been computed, leading to the identification of 14 million PS points, with ERS data, and 28 million points with ENVISAT data (Costantini et al., 2016). ERS mission covered the whole Italian territory along the descending track, while along the ascending one, Tuscany and part of Apulia, Sardinia and Sicily were excluded (Fig. 1a). Coverage for ENVISAT imagery was lower than that of the previous mission, totally excluding regions like Sardinia, Emilia Romagna, Apulia, Calabria and Basilicata (Fig. 1b). All the data have been then processed using PS-InSAR (Ferretti et al., 2001) and PSP-DifSAR (Costantini et al., 2008) techniques, considering all the frames made of at least 35 images, in order to have as most reliable results as possible. All the PSs maps contain information about velocities of displacement, coherence, displacement and standard deviation.

Thanks to the availability of COSMO-SkyMed images, the Italian MoE promoted for research purposes an experimental elaboration of PS displacement maps over three test areas, characterized by different phenomena and distributed in different regions of the Italian territory: Venezia and Bologna areas, well known for historical subsidence phenomena, and Palermo, for the analysis of landslide affecting its territory (Fig. 1c). The study carried out in such test areas led to very interesting results, showing the improved performance of COSMO-SkyMed (higher spatial and radiometric resolution, higher accuracy, shorter revisit time, etc.) with respect to the previous SAR systems and the great potential it offers to monitoring and control of instability phenomena, opening the way also to new applications in this field. Venezia case has been briefly described in Costantini et al. (2015), showing how COSMO data enhanced a PS density increase by more than one order of magnitude with respect to those obtained by processing ERS and ENVISAT data. Palermo case has been extensively discussed in Di Martire et al. (2016b), whose work concentrated on the identification of unstable areas, integrating SAR data with field work, introducing the LaDIS methodology. Because of interesting results achieved in the Palermo test area, the Italian MoE extended the application of this methodology to many critical areas spread throughout Italian territory, in agreement with local competent authorities (administrative unities called Regions and Autonomous Provinces). First objective of PST-A-3 has been to increase and update the previous database, through the implementation of new

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