Using GMES to map and monitor landslides and ground subsidence

by Fausto Guzzetti, Alessandro Cesare Mondini and Michele Manunta

LANDSLIDES AND SUBSIDENCE ARE WIDESPREAD AND FREQUENT IN EUROPE WHERE, EVERY YEAR, THEY CAUSE CASUALTIES AND EXTENSIVE ENVIRONMENTAL DAMAGES, WHICH OFTEN RESULT IN CONSIDERABLE COSTS. MASS MOVEMENTS ARE CAUSED BY A VARIETY OF METEOROLOGICAL, CLIMATIC AND GEOPHYSICAL TRIGGERS AND BY VARIOUS HUMAN ACTIVITIES. IMPROVED ABILITIES TO DETECT, MAP, MONITOR AND FORECAST MASS MOVEMENTS ARE IMPORTANT TO REDUCE THE CASUALTIES AND TO MITIGATE THE ECONOMIC AND ENVIRONMENTAL COSTS OF LANDSLIDES AND SUBSIDENCE.

DORIS is an advanced GMES service for the detection, mapping, monitoring and forecasting of ground deformation (primarily landslides and ground subsidence) that exploits European satellite technology already in use, and combines it with ground-based information and innovative modelling tools. Given the diversity of landslides and ground subsidence phenomena in Europe, *DORIS* is being evaluated in six study areas, with test sites in Italy, Hungary, Poland, Spain and Switzerland. The locations were selected to cover a range of physiographical and environmental settings, and represent the majority of types of ground deformations for which the service will be used. The test sites were also selected considering different societal, political and organisational conditions. This guarantees the widespread applicability of the *DORIS* service in Europe and elsewhere.

The sensors on modern Earth Observation (EO) satellites sensors can image large areas with unprecedented spatial detail, temporal revisit and potentially global coverage capability. The integration of multiple EO datasets and technologies with surface and sub-surface information provides new opportunities to advance our understanding of mass movements. Since the occurrences of these dangerous phenomena are complex and can vary widely, *DORIS* adopts a unique dual approach that combines Space-borne data and technology with ground-based data through innovative computer modelling tools. The approach is proving beneficial to the construction of a complete

Many European major cities are exposed to Geohazards. GMES data can be used before a geohazard occurs (monitoring and risk-assessment) or afterwards, notably to support the action of Civil Protections during the post-disaster management phase (Credits: Vikingenergy).

and detailed picture of the factors contributing to each ground deformation event.

"Mapping and monitoring ground movements help mitigate economic and environmental costs of ground-movements"

Mapping event landslides

DORIS exploits very high spatial resolution optical satellite images and innovative processing techniques to detect and map landslides caused by specific triggers, such as intense or prolonged rainfall events. To detect and map the landslides, the project adopts techniques based on the analysis of single images taken shortly after an event, and techniques that exploit pre- and post-event images jointly.

For example, on the October 25th, 2011, a high-intensity storm hit the Liguria coast of northern Italy with cumulated rainfall measurements exceeding 540 mm in 6 hours. The event caused numerous shallow landslides and debris flows, surface erosion, and flooding in an area exceeding 1000 km^2 The death toll was severe, with eleven casualties. Damage to agriculture and the environment was also severe. Immediately after the event, *DORIS* prepared an accurate map showing the extent of the areas affected by landslides and floods. This is important information for evaluating the amount of damage and to establish levels of residual risk. To prepare the map, on October 28th the acquisition of very high spatial resolution satellite images was commissioned for an area of 210 km^2 most affected by the rainfall event. On October 31st, the WorldView-II satellite acquired panchromatic and multispectral stereoscopic images of the area. The imagery was available on the same day. Using image classification techniques supervised by trained geomorphologists, landslides and flooded areas were detected semi-automatically on the satellite images, and an accurate map of the event was prepared. **Figure 1** shows a portion of the mapping obtained for Borghetto di Vara, a town that suffered massive inundation and widespread landsliding.

Figure 1 - Landslide and flooding map for Borghetto di Vara, Italy, where the impact of the high intensity storm of the October 25th, 2011, was most severe. The area suffered massive flooding and widespread mass movements. Mapping obtained by processing very high spatial resolution satellite images taken on October 28th, 2011.

DORIS has dealt with other events from around the globe. From the 5th to the 10th of August 2009, typhoon Morakot crossed the island of Taiwan bringing record-breaking rainfall. In some places, the accumulated amount of rainfall exceeded 2880 mm in 100 hours. The very high intensity precipitation triggered thousands of shallow landslides and debris flows, and caused inundations and massive mobilisation and deposition of sediments. The fatalities caused by landslides and inundations were at least 650 and the economic damage was severe. In the aftermath of the event,

Landslides pose serious threats to citizens living in areas prone to ground movements (Credits: Pflatsch).

DORIS prepared an event landslide inventory map showing the location and type of the landslides triggered by the typhoon. For this purpose, *DORIS* adopted an innovative image classification technique that exploits different measures of changes between pre- and post-event multispectral satellite images. **Figure 2** portrays an example of the mapping obtained processing images taken by the Formosat II satellite on July 3rd, 2007 and on November 5th, 2009 in an area where shallow landslides were particularly abundant.

"Monitoring is particularly important when the deformations affect urban areas, critical infrastructures, or the cultural heritage"

DORIS is advancing the current capabilities of detecting and mapping landslides in different physiographical and climatic environments. The results will be beneficial for civil protection and environmental authorities interested in knowing the extent of a landslide event and in assessing the impact of ground deformations shortly after an event.

Monitoring ground deformations

Where slow moving landslides are present, or where the ground is subsiding in response to human activities (e.g., mining, underground excavations, water or gas withdrawal), it is important to monitor the spatial distribution and the temporal pattern of the ground deformations. Monitoring is particularly important when the deformations affect urban areas, critical infrastructures, or the cultural heritage. Nowadays, accurate monitoring of ground deformations caused by landslides and land subsidence phenomena can be performed by effectively exploiting images captured by Synthetic Aperture Radar (SAR) sensors onboard multiple satellite platforms.

"Some of the end users are civil protection and local environment authorities"

DORIS exploits DInSAR techniques to monitor the long-term behaviour of the Ivancich landslide, in the Assisi municipality in Umbria, Italy. The Ivancich landslide is a deep-seated mass movement of the slide type that affects a residential area characterised by one- to

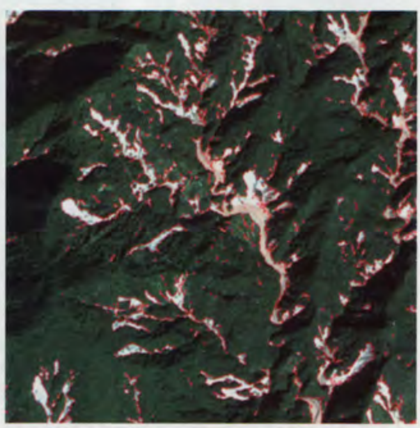

Figure 2 - Landslide map for an area in central Taiwan where landslides caused by typhoon Morakot in August 2009 were abundant. Mapping obtained processing optical satellite images taken before and after the event.

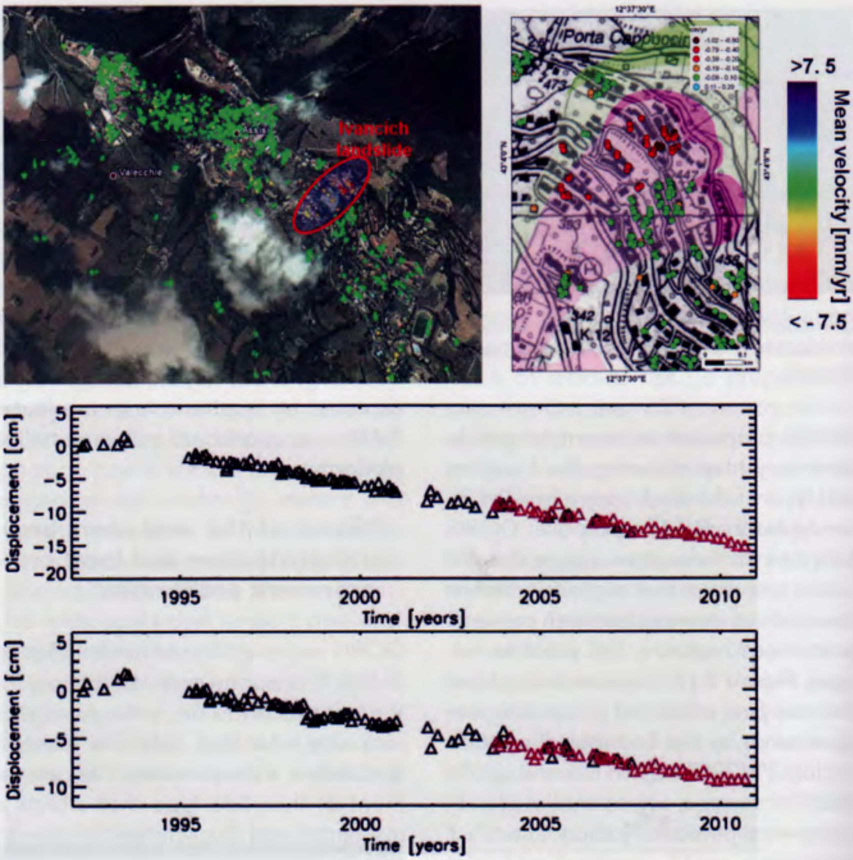

Figure 3 - Map showing the deformation velocity in a landslide area in the Ivancich area, Assisi, Italy, in the 18.5-year period from April 1992 to September 2010 and graphs reporting the temporal evolution of the ground displacements reaching a maximum value of about 15 cm during the analysed time interval. This map was obtained by processing 116 C-band images collected by the ERS-1/2 (black) and ENVISAT (red) satellites.

three-story private buildings constructed mainly between 1960 and 1970. The landslide also affects the Assisi hospital and a Franciscan convent. C-band SAR data, collected by the European Remote Sensing (ERS-1/2) satellites in the period April 1992 – July 2007, and by the ASAR sensor on board the ENVISAT satellite in the period October 2003 – September 2010, were used to obtain maps showing the total ground deformation and the average rate of deformation in the 18,5-year observation period. Processing of the satellite radar images produced a time series of deformation with an unprecedented temporal coverage for individual points ("targets") located inside and outside the landslide area i.e., in unstable and stable terrains. This information was used to single out sections of the mass movement that moved at different velocities during the investigated period. The information was also exploited to attempt a correlation between the time series of deformation and the local rainfall history recorded by a rain gauge. Results revealed the lack of an immediate effect of the rainfall on the landslide, and confirmed the existence of a complex temporal interaction between the precipitation and the mass movement. This is important information for deciding on remedial works to mitigate the risk posed by the Ivancich landslide. **Figure 3** portrays a map showing the deformation velocity in the landslide area in the 18,5-year period from April 1992 to September 2010 and graphs reporting the temporal evolution of the ground displacements reaching a maximum value of about 15 cm during the analysed time interval.

DORIS takes full advantage of the modern X-band SAR sensors on board the TerraSAR-X satellite and the Cosmo-SkyMed constellation of four satellites. The short revisiting time of the new SAR sensors and their improved ground resolution offer the unique opportunity to remotely investigate ground deformations characterised by average velocity rates of up to tens of centimetres per year. These are relatively fast-moving phenomena that cannot be monitored using C-band SAR sensors. In addition, compared to the old generation of C-band sensors, the new X-band systems significantly improve the density of "targets" on the ground where accurate deformation measurements are obtained. This facilitates the geological interpretation of the ground deformations.

For a test site located near Zermatt, Switzerland, where ground deformations caused by different geological phenomena exist, *DORIS* is collecting and analysing data captured by different SAR sensors, including images obtained by the ENVISAT and the TerraSAR-X satellites. In addition, the Gamma Portable Radar Interferometer (GPRI), an innovative ground-based radar system, is used to take repeated images of the test site. **Figure 4** shows mean deformation velocity maps performed by processing

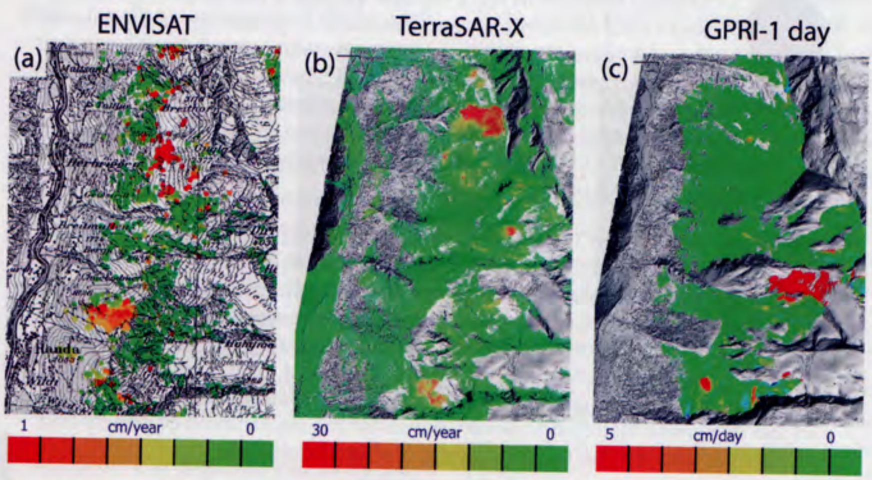

Figure 4 - Mean deformation velocity maps for an area near Zermatt, Switzerland, performed by processing data captured by (a) the ENVISAT satellite, (b) the TerraSAR-X satellite, and (c) the ground based Gamma Portable Radar Interferometer. Inspection of the maps reveals the significant increase in the number of coherent "targets" with the reduction of the sensor revisiting time (35 days for ENVISAT, 11 days for TerraSAR-X, one day for the Gamma Portable Radar Interferometer) (Credits: Tazio Strozzi, Gamma Remote Sensing AG).

data captured by different radar sensors. Inspection of the maps reveals the significant increase in the number of coherent "targets" with the reduction of the sensor revisiting time (35 days for ENVISAT, 11 days for TerraSAR-X, one day for the Gamma Portable Radar Interferometer).
DORIS exploits multi-sensor DInSAR techniques to construct very-long or high-frequency time series of ground deformations for selected test sites in Europe. This information proves to be useful to determine the kinematic behaviour of geological and geomorphological phenomena with ground deformations controlled by meteorological and climatic triggers.

Fausto GUZZETTI has a Master's degree in Geology and a PhD in Geography, and has more than 25 years of experience in landslide mapping, landslide susceptibility and hazard modelling and zonation, and landslide risk evaluation. Fausto Guzzetti was principal researcher of the ASI *MORFEO* project of the Italian Space Agency for the exploitation of remote sensing data and technology to mitigate landslide risk, and he is the principal researcher of the EU *DORIS* project for the design of a downstream service for the detection, mapping, monitoring and forecasting of ground deformations.

Michele MANUNTA has a Master's degree in Electronic Engineering and a PhD in Informatics and Electronic Engineering, and has more than 10 years of experience in high-resolution SAR interferometry data processing, geological applications, and SAR/GIS data integration. Michele Manunta has collaborated in various national and international projects for the exploitation of satellite technology, including the ASI *MORFEO* project. In *DORIS*, he is responsible for the project satellite acquisition and procurement programme.

Alessandro Cesare MONDINI has a Master's degree in Physics, is completing his PhD in Earth Sciences, and has more than 10 years of experience in remote sensing applications, including land surface temperature analysis, snow cover mapping and modelling, and landslide recognition and mapping. Alessandro Mondini has collaborated in the ASI *MORFEO* project, and he is the principal researcher of a bilateral project between the Italian National Research Council and the Taiwanese National Science Council for the exploitation of optical and SAR satellite data for the rapid mapping of event landslides.

WINDOW ON GMES

A GMES4REGIONS PUBLICATION

Discover what GMES can do for European regions and cities

FOCUS ON GMES BENEFITS FOR LOCAL GOVERNMENT AND FOR GROWTH AND JOBS

Institutional corner

Gerhard Stahl, Secretary General of the Committee of the Regions, explains why the alliance of GMES and regions is of mutual benefit

Henri Malosse, President of the European Economic and Social Committee, details his vision of GMES.

Portraits of GMES users

Thirteen users at local or regional level recount their experience of using GMES products and services.

The SME corner

Four successful entrepreneurs share their story, their experience as well as their advice on how to build a business around GMES services.

SPECIAL ISSUE

GMES4REGIONS AND LOCAL AUTHORITIES