Geological Survey of Austria

Robert SUPPER and Ivo BAROŇ (Eds.)

Landslide Monitoring Technologies & Early Warning Systems

Current Research and Perspectives for the Future

Book of extended abstracts
Open Workshop within the frame of the EU FP7 "SafeLand" Project
February 24th, 2010, Vienna

Berichte der Geologischen Bundesanstalt, 82

SEVENTH FRAMEWORK PROGRAMME

SafeLand

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Cover:
Airborne photograph of the Gschliefgraben area (Upper Austria), view towards the East (R. SUPPER, 2009).

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Preface

Gravitational mass movements represent a major hazard in Austria, causing high numbers of damages and fatalities each year. Since its foundation in 1849, the Geological Survey of Austria (GBA) is putting high efforts in the research of gravitational mass movements and other hazardous processes.

The sound basis for this research is provided by GBA's continuous geo-scientific mapping program of Austria, within which the investigation of different types of mass movements and predispositional factors plays an important role. Furthermore research activities include the development and application of methods (e.g. neural networks, airborne geophysics and others) to delineate potentially susceptible areas. Concerning deep seated mass movements additional emphasize is laid on the development of mitigation measures like early warning systems.

In this respect it is important to point out the excellent cooperation between GBA, the Austrian Service for Torrent and Avalanche Control and the Federal State Governments of Austria, which is helping to progress the development of new methodologies in the area of natural hazard mitigation to the benefit of the Austrian society.

Governments across Europe are aware of the importance of research in the field of natural hazard and risk assessment and the need to develop and plan mitigation measures like continuous monitoring of endangered areas respectively. As a result leading scientific research institutions are combining their efforts and are creating multinational research groups exchanging their experience regarding this very important issue within the European project SafeLand.

We were glad to host the Workshop on "**Monitoring Technologies and Early Warning Systems – Current Research and Perspectives for the Future**" at our survey in Vienna and happy to have offered a platform to the group of international experts presenting leading edge technology and concepts in this field.

Dr. Peter Seifert
Director
Geological Survey of Austria

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Introductory Foreword

The Austrian Geological Survey, as the leader of the work package 4.3 of the SafeLand project, hosted the Workshop on **"Monitoring Technologies and Early Warning Systems – Current Research and Perspectives for the Future"** in Vienna. The workshop took place during the first day of the "Area 4" meeting of the project SafeLand on February 24th to 26th, 2010.

Landslides are one of the major natural threats to human lives, settlements and infrastructure, causing enormous human suffering and property losses. As summarized by the SafeLand (http://www.safeland-fp7.eu), Europe experienced the second highest number of fatalities and the highest economic losses caused by landslides compared to other continents during the 20th century: 16,000 people lost their lives because of landslides and the material losses amounted to over USD 1.7 billion. Furthermore, the number of people affected by landslides is much larger than reported.

The best way to limit the number of casualties and avoid destruction is effective land-use planning, based especially on a good knowledge of the landslide susceptibility, hazards and risks within specific areas as a part of mitigation. However, this ideal approach is impossible in many places, due to several historical or political reasons e.g., many human settlements and infrastructure have already existed in landslide-prone areas or on dormant landslides decades before the availability of detailed hazard zone maps. Consequently in most cases it is not possible to resettle people living in such areas.

The relevance of these topics for Austria was recently highlighted in the aftermaths of the landslide event at Gschliefgraben. In late 2007, during a hazardous landslide event, 55 buildings had to be evacuated. Within the following months, more than € 10 million had to be invested for mitigation measures under the responsibility of the Torrent and Avalanche Control Survey (WLV). Today people live in their houses again and one of the most sophisticated monitoring and early warning systems of Europe is currently set up to safeguard the daily life of people concerned.

A good knowledge about structure, dynamics, triggers, history and possible magnitude of such high-risk landslides is an important prerequisite to be able to evaluate actual hazard and, eventually, to alert people before a catastrophic event takes place. This knowledge is obtainable only through a complex approach consisting of investigations coming from several different interdisciplinary methods and techniques, long-term continuous monitoring of deformation and triggering factors and by establishing early warning systems/centres. This is exactly how the project SafeLand wants to contribute.

SafeLand will develop and implement an integrated and comprehensive approach to help to guide decision-making. It will develop generic quantitative risk assessment and management tools and strategies for managing landslide risk at local, regional, European and societal scales. In addition, it will establish the baseline for the risk associated with landslides in Europe, improve our ability to forecast landslide hazards and detect hazard and risk zones.

All these issues got addressed during the workshop on **"Monitoring Technologies and Early Warning Systems – Current Research and Perspectives for the Future"** in Vienna. Seventeen scientific contributions of the project partners presented the results of the work carried out within the first year of the SafeLand project in the framework of "Area 4". They highlighted the need of innovation and technological progress in the area of landslide monitoring and early warning on an international level and presented how SafeLand will contribute to meet these needs. The session was open to the public, end-users and the scientific community.

This book contains the collection of extended abstracts summarizing the content of the talks held during this workshop.

The Safeland Project – General Overview and Monitoring Technology Development

The SafeLand Consortium [a], N. CASAGLI [b] & R. SUPPER [c]

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[b] Earth Sciences Department, University of Firenze, UNIFI.
[c] Geological Survey of Austria, Neulinggasse 38, A 1030 Vienna, Austria.

SafeLand is a large-scale integrating collaborative research project (for further information see http://www.safeland-fp7.eu/Introduction.html) funded by the Seventh Framework Program for research and technological development (FP7) of the European Commission. Thematically the project belongs to Cooperation Theme 6 Environment (including climate change), Sub-Activity 6.1.3 Natural Hazards.

SafeLand will develop generic quantitative risk assessment and management tools and strategies for landslides at local, regional, European and societal scales. It will establish the baseline for the risk associated with landslides in Europe, to improve our ability to forecast landslide hazard and detect hazard and risk zones. The scientific work packages in SafeLand are organized in five Areas:

- Area 1 focuses on improving the knowledge on triggering mechanisms, processes and thresholds, including climate-related and anthropogenic triggers, and on run-out models in landslide hazard assessment;
- Area 2 harmonises quantitative risk assessment methodologies for different spatial scales, looking into uncertainties, vulnerability, landslide susceptibility, landslide frequency, and identifying hotspots in Europe with higher landslide hazard and risk;
- Area 3 focuses on future climate change scenarios and changes in demography and infrastructure, resulting in the evolution of hazard and risk in Europe at selected hotspots;
- Area 4 addresses the technical and practical issues related to monitoring and early warning for landslides, and identifies the best technologies available in both the context of hazard assessment and design of early warning systems;
- Area 5 provides a toolbox of risk mitigation strategies and guidelines for choosing the most appropriate risk management strategy.

Maintaining the database of case studies, dissemination of the project results, as well as project management and coordination are defined in work packages 6, 7 and 8.

Objectives of the Project

SafeLand has the objectives to (1) provide policy-makers, public administrators, researchers, scientists, educators and other stakeholders with an improved **harmonized framework and methodology for the assessment and quantification of landslide risk in Europe's regions;** (2) **evaluate the changes in risk pattern caused by climate change, human activity and policy changes**; and (3) provide **guidelines for choosing the most appropriate risk management strategies**, including risk mitigation and prevention measures.

To be able to produce results at the European scale, SafeLand needs to link hazards and risks at the local scale, i.e. individual slopes and slides to the hazards and risks at the European scale. The smallest scale of interest in this proposal refers to the local slope scale (less than 3 km^2) where most of the research will be done on the triggering factors. The regional studies, including the "hotspots" evaluations, form the intermediary scale: from 10 to 200 km^2, depending on the site. The largest scale will be the "country" and European scale.

To develop the required methodologies, SafeLand will improve and adapt existing knowledge on landslide hazard and risk to link the slope-scale results to methodologies required for the assessment of landslide hazard and risk at regional and European scales. The present day knowledge on landslide hazard and risk is still under development. Even if basic mechanisms are well known, quantitative relationships between triggers and hazard are still not well enough established. For instance, the relationship between slope stability and rainfall, not only in magnitude but also in frequency of different ground instabilities, is not well known. Climate change, through the modulation in amplitude, frequency as well as duration of precipitation events, will dramatically influence ground stability. Hence, SafeLand will dedicate resources and research on technical issues (models and monitoring tools), integrate climate change and human activity scenarios into quantitative risk assessment (QRA) and develop society-oriented risk management methodologies for landslide risk mitigation and prevention.

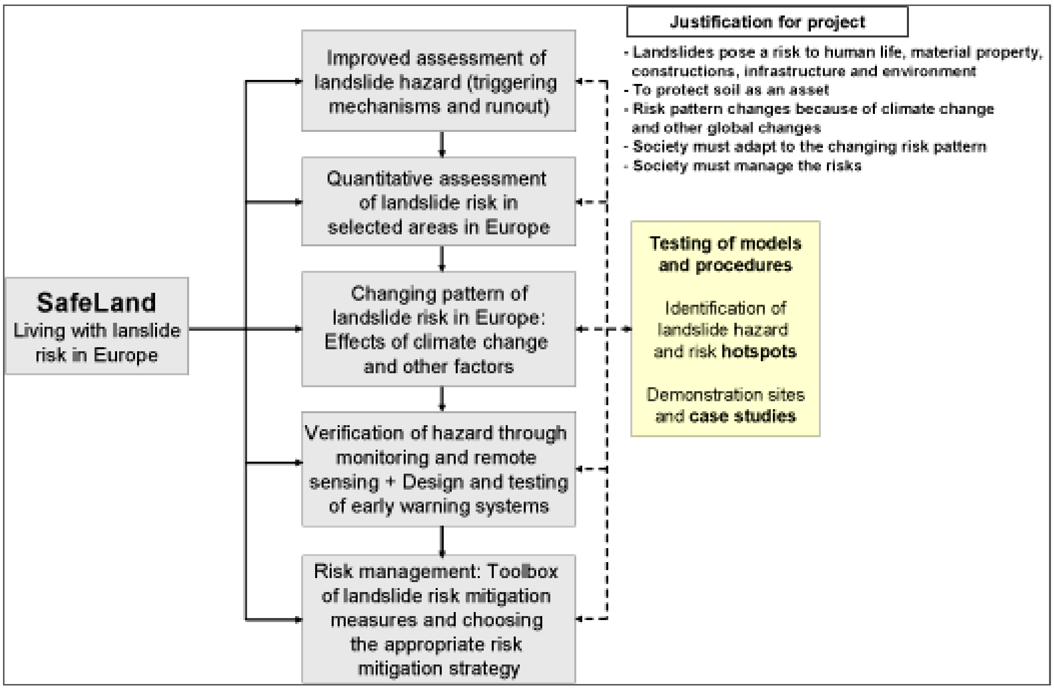

Fig. 1: Working Areas of SafeLand.

SafeLand stresses the necessity to integrate the technology and social aspects to ensure that the risk assessment and management strategies are realistic and representative of the forces at play in an actual situation. Global changes, due to both climate and human activity, will provide insight on future risk patterns. The landslide risk assessment and management strategies developed in the SafeLand project will be implemented to forecast future risk.

When the research is completed, SafeLand will provide Member States with the means to contribute to the Soil Framework Directive, using well understood and commonly adopted risk assessment and management terminology, methodology, harmonized approaches and tools, and will have insight on the potential effects of global change (climatic and anthropogenic) scenarios.

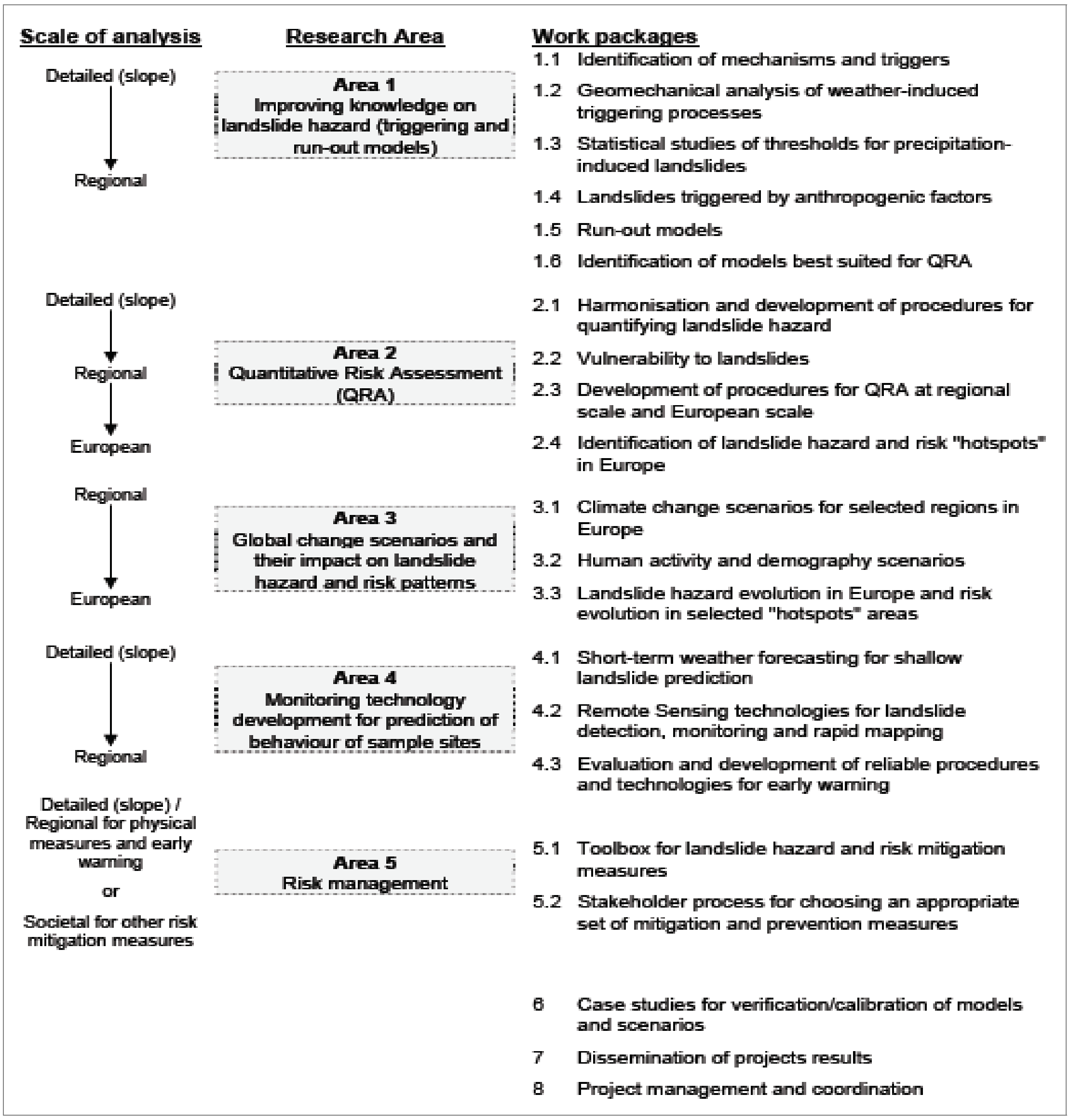

Fig. 2: Overview of the general work package structure of SafeLand.

The Consortium

The project team composed of 25 institutions from 13 European countries is coordinated by the Norwegian Geotechnical Institute (NGI). An overview is given in Landslide "hotspot" areas in Europe and SafeLand test sites

SafeLand will develop and implement an integrated and comprehensive approach to help guide decision-making. The methodologies developed will be tested in selected hazard and risk "hotspots" in Europe, in turn improving knowledge, methodologies and integration strategies for the management of landslide risk. The work will be performed in close cooperation with the local stakeholders.

The harmonised methodologies and technical developments, combined with the social, economic and environmental dimensions will play a significant role in the detection, prediction and forecasting of landslides and landslide risk posed to individuals, society, the environment in general and for the locally concerned test sites (Figure 4).

Table 1: The SafeLand consortium.

Number	Partner name	Shortname	Country
1 (Coordinator)	International Centre for Geohazards / Norwegian Geotechnical Institute	ICG	Norway
2	Universitat Politecnica de Catalunya	UPC	Spain
3	A.M.R.A. s.c.a.r.l.	AMRA	Italy
4	Bureau de recherches géologiques et minières	BRGM	France
5	Università degli Studi di Firenze	UNIFI	Italy
6	International Institute for Applied Systems Analysis	IIASA	Austria
7	Joint Research Centre	JRC	Italy
8	Fundación Agustín de Betancourt	FUNAB	Spain
9	Aristotle University of Thessaloniki	AUTh	Greece
10	Universita' degli Studi di Milano - Bicocca	UNIMIB	Italy
11	Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.	MPG	Germany
12	Centro Euro-Mediterraneo per i Cambiamenti Climatici s.c.a.r.l.	CMCC	Italy
13	Studio Geotecnico Italiano S.r.l.	SGI-MI	Italy
14	University of Salerno	UNISA	Italy
15	International Institute for Geo-information Science and Earth Observation – United Nations University	ITC	Nertherlands
16	Eidgenössische Technische Hochschule Zurich	ETHZ	Switzerland
17	Université de Lausanne	UNIL	Switzerland
18	C.S.G. S.r.l. Centro Servizi di Geoingegneria	CSG	Italy
19	Centre National de la Recherche Scientifique	CNRS	France
20	King's College London	KCL	United Kingdom
21	Geologische Bundesanstalt (Geological Survey of Austria)	GSA	Austria
22	Ecole Polytechnique Fédérale de Lausanne	EPFL	Switzerland
23	TRL Limited	TRL	UK
24	Geological Institute of Romanian	GIR	Romania
25	Geological Survey of Slovenia	GeoZS	Slovenia

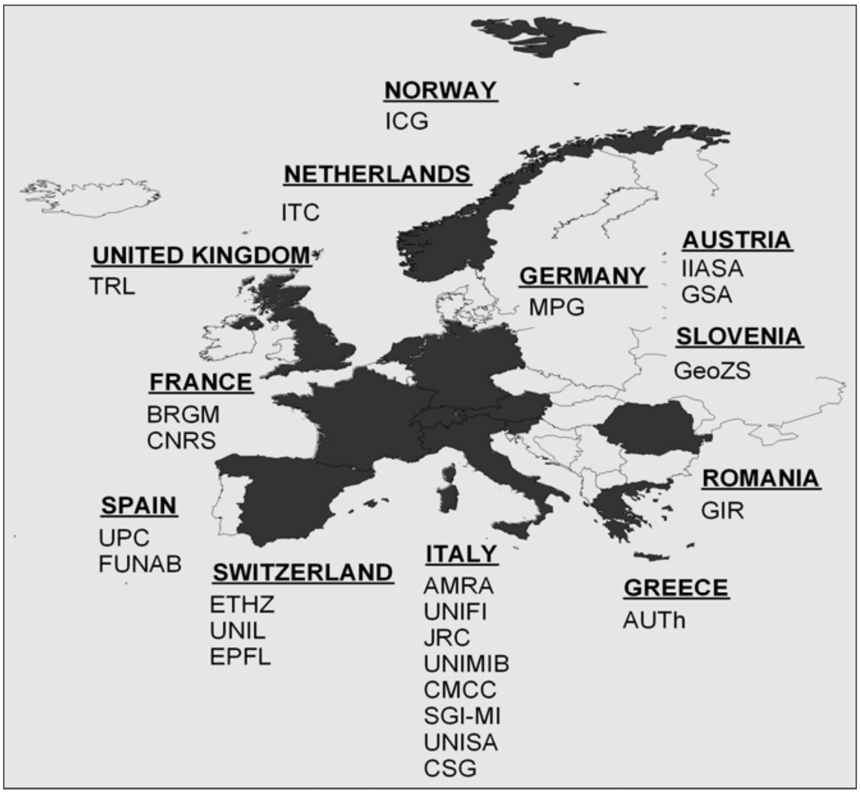

Fig. 3: Overview showing the composition of the SafeLand consortium.

Fig. 4: Overview on the location of SafeLand test sites within Europe.

Area 4: Development of Monitoring Technology, Especially Early Warning Systems and Remote Sensing Techniques, and Applications.

Research Area 4 (leader Nicola CASAGLI, UNIFI) involves considerable technological developments on hazard and risk mitigation measures that are required for the risk assessment and, more importantly, for the development of the toolbox of mitigation measures and risk management process in Research Area 5. The research focuses on monitoring technology and the development of systems (remote sensing and early warning) for the prediction of the behaviour of sample sites.

SafeLand's major contributions to monitoring and early warning are:

1. Short-term weather forecasts for shallow landslide predictions
2. Remote sensing detection and monitoring of slow-moving landslides
3. Advanced air-borne and in situ techniques for site monitoring and early warning
4. Verification with case studies
5. Improved knowledge and technology for the web-based toolbox developed in Research Area 5.

In particular predictions of shallow landslide, based on short-term weather forecasts, will be carried out with a new integrated model able to produce a warning regional map for landslides forced by meteorological events. The model output consists of threshold hazard maps of different European areas. This warning map represents an innovative approach to shallow landslides risk prevention as it integrates multidisciplinary instruments such as meteorology, hydrology, geologic modelling, remote sensing and GIS.

A common methodology for detection, rapid mapping, characterization and monitoring of landslides at regional/catchment scale using advanced remote sensing techniques will be defined, as well as a common methodology for the rapid creation and updating of landslide inventories and hazard maps at regional/catchment scale. Three classes of techniques will be exploited and integrated: space borne radars, airborne and VHR space borne optical sensors, and airborne geophysics. The main expected outcome is the integration of these advanced remote sensing techniques within a QRA framework for a global integrated risk management process.

User-oriented guidelines for incorporation of advanced remote sensing technologies within integrated risk management processes and best practices will be realized. A toolbox of remote sensing applications will be proposed as part of an integrated risk management process including procedures for data acquisition and updating, recommended processing methods, road maps for data integration in QRA and risk mitigation measures.

The development and evaluation of advanced and adaptive methodologies for real-time monitoring and early-warning systems for specific landslide sites will focus on landslides that are most affected by climate triggering factors. In order to achieve the high quality necessary for early-warning systems, SafeLand will address the following aspects: investigation stage, design of monitoring systems, infrastructure (i.e. power supply, data transfer etc), definition of key processes leading towards triggering, operational handling of the monitoring and communication with responsible authorities (early-warning centres).

This work package is separated into 3 sub-work-packages:

- **Short-term weather forecasting** for shallow landslide prediction (WP 4.1; leader Pasquale SCHIANO, CMCC)
- Development of **remote sensing technologies** for the detection, monitoring and rapid mapping of landslides (WP 4.2; leader Nicola CASAGLI; UNIFI)
- Evaluation and development of reliable procedures and technologies for **monitoring and early warning** (WP 4.3; leader Robert SUPPER; GSA)

In the following chapter a short overview on the content of each of the sub-work-packages is given.

WP 4.1 Short-Term Weather Forecasting for Shallow Landslide Prediction

Objectives
Design and implementation of an integrated model able to produce warning maps for shallow landslides triggered by meteorological events.

Description of work
Landslides triggered by rainfall can be predicted with a limited area model for numerical weather prediction that operates in the short time range: from 0 to 3 days before landslide occurrence. Enhanced prediction closer to the event can be achieved by defining algorithms based on meteo radar and satellite data in the nowcasting range: from 0 to 6 hours before the triggering event. A near-real-time warning system for shallow landslides based on forecasted meteorological variables, such as cumulated and maxima/minima values of precipitation (rain and snow), will be developed at multiple scales. The research of this WP will benefit from related ongoing international studies such as the activities under development at NASA with the TRMM model. Work performed here will be carried out in close cooperation with WPs 1.1 and 1.2.

WP 4.1 – Tasks

- **Task 1:** Refinement of meteorological forecasting of extreme events in the short time and nowcasting range (CMCC)
- **Task 2:** Development of post-processing methods (e.g. dynamic and statistical downscaling) for improved coupling of meteorological and landslide models (CMCC)
- **Task 3:** Development and testing of models for infiltration and stability in shallow slope (UNIFI)
- **Task 4:** Delivery of a prototype early warning system (CMCC/UNIFI)

WP 4.1 – Deliverables

Deliverable D4.1: Short-term weather forecasting for prediction of triggering of shallow landslides – Methodology, evaluation of technology and validation at selected test sites.

WP 4.2 Remote Sensing Technologies for Landslide Detection, Monitoring and Rapid Mapping

Description of work

Remote sensing imagery is a powerful tool for the rapid assessment of surface motions over large areas and for the fast characterization of slope instability factors. Three classes of techniques will be exploited and integrated in this WP: Spaceborne radars, airborne and VHR spaceborne optical sensors and airborne geophysics.

WP 4.2 – Tasks

- **Task 1:** Define and validate a methodology for detection, rapid mapping, characterization and monitoring of landslides.
- **Task 2:** Define a methodology for updating landslide inventory maps and landslide hazard maps.
- **Task 3:** Prepare user-oriented guidelines for the incorporation of remote sensing technologies within landslide risk management processes and best practices.

WP 4.2 – Deliverables

- **D4.1**: Review of monitoring and remote sensing methodologies for landslide detection, fast characterization, rapid mapping and long-term monitoring (delivery date: 12 months) (Responsible: UNIL)
- **D4.3**: Creation and updating of landslide inventory maps, landslide deformation maps and hazard maps as input for QRA using remote sensing technology (delivery date: 24 months) (Responsible: CNRS)
- **D4.4**: Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides (delivery date: 24 months) (Responsible: ITC)
- **D4.5**: Evaluation report on innovative monitoring and remote sensing methods and future technology (together with WP4.3) (delivery date: 24 months) (Responsible: UNIFI)

WP 4.2 – Techniques

- Optical VHR satellite data (Object-oriented analysis, Ontology): **ITC, JRC, CNRS**
- InSAR / A-DInSAR: **UNIFI, UPC, UNIL, GeoZS, ICG, UNISA, AMRA**
- Airborne Geophysics: **GSA**
- Airborne Optical Sensors / LiDAR: **UNIL, ICG**

WP 4.3 Evaluation and Development of Reliable Procedures and Technologies for Early Warning

Objectives

Development and evaluation of advanced and adaptive methodologies for real-time monitoring and early-warning for selected landslide sites.

Description of work

The work will merge the experience of scientists from leading European research centres, each covering certain unique aspects of site monitoring and contributing with its complementary skills in monitoring technology, finally synthesized in a concerted evaluation of methodologies. The efforts will concentrate on a selected number of well-instrumented and monitored landslide sites. It will include landslides from extremely slow to very rapid mass movements and from shallow to deep-seated. The monitoring methods will cover all kinds of technologies, ranging from the application of traditional monitoring methods to the improvement of new and advanced technologies, including geoelectrical, self-potential monitoring, acoustic noise measurements, DMS, optical fibres, acoustic emissions etc. … The work will be carried out in cooperation with WP 4.2.

WP 4.3 – Tasks

- **Task 1**: Assessment of current state-of-art in monitoring and early warning (technology).
- **Task 2**: Exploring the role of "geo-indicators" as early warning parameters (processes and related parameters).
- **Task 3**: Method evaluation and implementation of guidelines for monitoring and early warning.

WP 4.3 – Deliverables

- **D4.5**: Evaluation report on innovative monitoring and remote sensing methods and future technology (together with WP 4.2) (delivery date: 24 months)
- **D4.6**: Report on geo-indicator evaluation (delivery date: 32 months)
- **D4.7**: Report on the development of software for early-warning based on real-time data (delivery date: 32 months)
- **D4.8**: Guidelines for monitoring and early warning systems in Europe – Design and required technology (delivery date: 32 months)

WP 4.3 – Techniques

- Traditional monitoring methods (inclinometers, extensometers, piezometers etc.)
- New and advanced technologies (GB-InSAR, geoelectrical, DMS, optical fibres etc.)
  - Geodetic / geotechnical: **ETHZ, CSG, UNIMIB, AMRA, CNRS, GeoZS**
  - GB-InSAR: **UNIFI, IGC, UNIMIB, ATB, UPC**
  - Terrestrial Laser Scanner: **UNIL, UNIFI, UNIMIB**
  - Geoelectrical: **ETHZ, GSA**
  - Acoustic emissions: **ETHZ, UNIMIB**
  - Self-potential: **GSA**
  - DMS: **CSG, ETHZ, UNIMIB, ATB**
  - Optical fibres: **AMRA**
  - Suction measurement / tensiometers: **ETHZ, AMRA**
  - Sensor networks**: ICG**

State-of-the-Art of Landslide Site Monitoring in Europe: Preliminary Results of the SafeLand Questionnaire

I. BAROŇ & R. SUPPER

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Inventory, complex investigation and monitoring of high-risk slope failures are essential tasks for any effective early warning and risk management worldwide. Different approaches are being applied for different sites regarding the affected mass parameters, behaviour, activity state and national tradition as well. However, a summarizing study to compare approaches throughout Europe is still missing. Therefore we prepared a **Questionnaire on National State of Landslide Site Investigation and Monitoring**, which was disseminated among European institutes and representatives within the frame of the SafeLand project.

The principal goals and expected output of the questionnaire study were:

- Assessing **general state** of the slope-instability investigation and monitoring in different (all) European countries
- Assessing **effectiveness / reliability** of each method for slope-instability investigation and monitoring
- **Applicability** of the monitoring techniques **for early warning**.

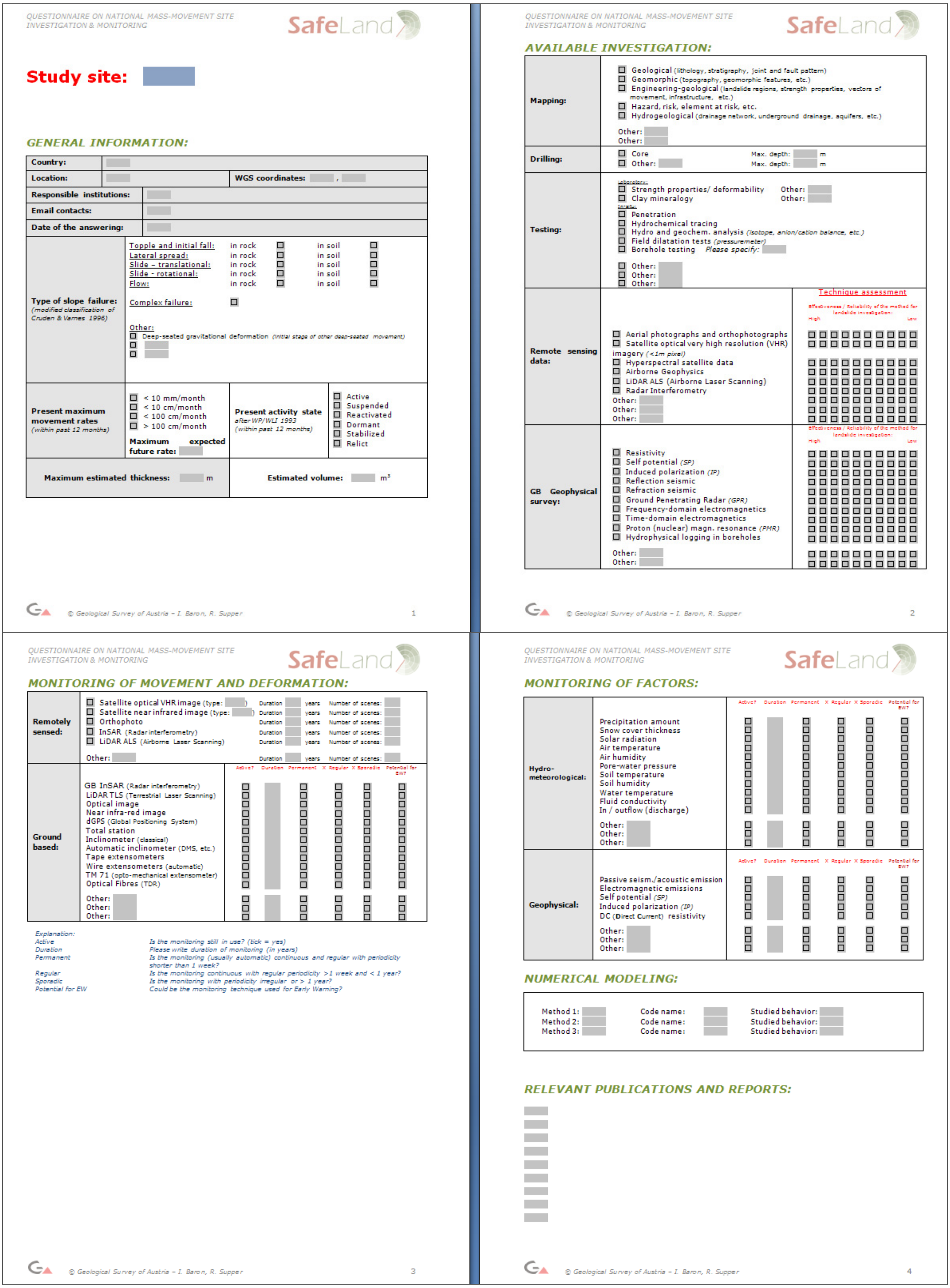
This was done through tick-answering and was an input for the statistical assessment.

The **general information on monitored mass movement** (slope failure typology, activity state and recent movement rates) was expressed relative to the total number of phenomena. The **investigation methods** (testing, mapping, ground-based geophysical surveys and remote-sensing data) were assessed by relative occurrence (%) per total number of case sites and their relative reliability (%), evaluated by authors of the answers. **Methods of landslide monitoring** (monitoring of displacement and deformation, hydrometeorological factors, and geophysical factors) were assessed by their relative occurrence (%) per total number of case sites. Another parameter, the index of early warning potential of each method, was given by positive answers on the possibility to use the method for EW relative to occurrence of the method, divided by total number of sites. General outlines and graphical outputs of the study are presented in Table 1 and Figures 2–11.

The most abundant slope failures that have been monitored were active translational and rotational slides with recent movement rates less than 10 mm/month. The most frequently applied **investigation methods** were geological, geomorphic and engineering-geological mapping and core drilling, testing of strength properties / deformability and clay mineralogy, studying of aerial photographs, LiDAR airborne laser scans (ALS), radar interferometry, resistivity measurements and refraction seismic.

Aerial photographs, satellite optical very high resolution (VHR) imagery, LiDAR ALS, radar interferometry and measuring of resistivity, reflection and refraction seismic, time-domain electromagnetic, passive acoustic emissions, geophysical logging were **the most reliable investigation methods**.

Monitoring of movement and deformation was most frequently done by repeated orthophotos, radar interferometry, differential LiDAR ALS, webcam, dGPS, total station, inclinometer (classical) and wire extensometers. Most frequently **monitored hydro-meteorological factors** were precipitation amount, pore-water pressure and air temperature; the most frequently monitored **geophysical parameters** were passive seismic/acoustic emissions, electromagnetic emissions and direct current resistivity. However, distinct differences in application of individual methods, especially in the case of remote-sensing data and new technologies, were observed between the countries of the former eastern and western block. Also, different slope failures need different investigation and monitoring approaches. The study will be finalized in the near future, after evaluating more answers from other countries.



QUESTIONNAIRE ON NATIONAL MASS-MOVEMENT SITE
INVESTIGATION & MONITORING

SafeLand

Study site:

GENERAL INFORMATION:

Country:			
Location:		**WGS coordinates:** ,	
Responsible institutions:			
Email contacts:			
Date of the answering:			

Type of slope failure: *(modified classification of Cruden & Varnes 1996)*	Topple and initial fall:	in rock ☐	in soil ☐	
	Lateral spread:	in rock ☐	in soil ☐	
	Slide – translational:	in rock ☐	in soil ☐	
	Slide - rotational:	in rock ☐	in soil ☐	
	Flow:	in rock ☐	in soil ☐	
	Complex failure:	☐		
	Other: ☐ Deep-seated gravitational deformation *(Initial stage of other deep-seated movement)* ☐ ☐			
Present maximum movement rates *(within past 12 months)*	☐ < 10 mm/month ☐ < 10 cm/month ☐ < 100 cm/month ☐ > 100 cm/month **Maximum expected future rate:**	**Present activity state** *after WP/WLI 1993 (within past 12 months)*	☐ Active ☐ Suspended ☐ Reactivated ☐ Dormant ☐ Stabilized ☐ Relict	
Maximum estimated thickness: m		**Estimated volume:** m³		

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QUESTIONNAIRE ON NATIONAL MASS-MOVEMENT SITE
INVESTIGATION & MONITORING

SafeLand

AVAILABLE INVESTIGATION:

Mapping:	☐ Geological (lithology, stratigraphy, joint and fault pattern) ☐ Geomorphic (topography, geomorphic features, etc.) ☐ Engineering-geological (landslide regions, strength properties, vectors of movement, infrastructure, etc.) ☐ Hazard, risk, element at risk, etc. ☐ Hydrogeological (drainage network, underground drainage, aquifers, etc.) Other: Other:
Drilling:	☐ Core Max. depth: m ☐ Other: Max. depth: m
Testing:	Laboratory: ☐ Strength properties/ deformability Other: ☐ Clay mineralogy Other: In-situ: ☐ Penetration ☐ Hydrochemical tracing ☐ Hydro and geochem. analysis *(isotope, anion/cation balance, etc.)* ☐ Field dilatation tests *(pressuremeter)* ☐ Borehole testing *Please specify:* ☐ Other: ☐ Other: ☐ Other:

Technique assessment

		Effectiveness / Reliability of the method for landslide investigation: High … Low
Remote sensing data:	☐ Aerial photographs and orthophotographs	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Satellite optical very high resolution (VHR) imagery *(<1m pixel)*	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Hyperspectral satellite data	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Airborne Geophysics	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ LiDAR ALS (Airborne Laser Scanning)	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Radar Interferometry	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	Other:	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	Other:	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	Other:	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

		Effectiveness / Reliability of the method for landslide investigation: High … Low
GB Geophysical survey:	☐ Resistivity	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Self potential *(SP)*	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Induced polarization *(IP)*	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Reflection seismic	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Refraction seismic	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Ground Penetrating Radar *(GPR)*	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Frequency-domain electromagnetics	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Time-domain electromagnetics	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Proton (nuclear) magn. resonance *(PMR)*	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	☐ Hydrophysical logging in boreholes	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	Other:	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
	Other:	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

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QUESTIONNAIRE ON NATIONAL MASS-MOVEMENT SITE
INVESTIGATION & MONITORING

SafeLand

MONITORING OF MOVEMENT AND DEFORMATION:

Remotely sensed:	☐ Satellite optical VHR image (type:)	Duration	years	Number of scenes:
	☐ Satellite near infrared image (type:)	Duration	years	Number of scenes:
	☐ Orthophoto	Duration	years	Number of scenes:
	☐ InSAR (Radar interferometry)	Duration	years	Number of scenes:
	☐ LiDAR ALS (Airborne Laser Scanning)	Duration	years	Number of scenes:
	Other:	Duration	years	Number of scenes:

		Active?	Duration	Permanent	X Regular	X Sporadic	Potential for EW?
Ground based:	GB InSAR (Radar interferometry)	☐		☐	☐	☐	☐
	LiDAR TLS (Terrestrial Laser Scanning)	☐		☐	☐	☐	☐
	Optical image	☐		☐	☐	☐	☐
	Near infra-red image	☐		☐	☐	☐	☐
	dGPS (Global Positioning System)	☐		☐	☐	☐	☐
	Total station	☐		☐	☐	☐	☐
	Inclinometer (classical)	☐		☐	☐	☐	☐
	Automatic inclinometer (DMS, etc.)	☐		☐	☐	☐	☐
	Tape extensometers	☐		☐	☐	☐	☐
	Wire extensometers (automatic)	☐		☐	☐	☐	☐
	TM 71 (opto-mechanical extensometer)	☐		☐	☐	☐	☐
	Optical Fibres (TDR)	☐		☐	☐	☐	☐
	Other:	☐		☐	☐	☐	☐
	Other:	☐		☐	☐	☐	☐
	Other:	☐		☐	☐	☐	☐

Explanation:	
Active	*Is the monitoring still in use? (tick = yes)*
Duration	*Please write duration of monitoring (in years)*
Permanent	*Is the monitoring (usually automatic) continuous and regular with periodicity shorter than 1 week?*
Regular	*Is the monitoring continuous with regular periodicity >1 week and < 1 year?*
Sporadic	*Is the monitoring with periodicity irregular or > 1 year?*
Potential for EW	*Could be the monitoring technique used for Early Warning?*

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QUESTIONNAIRE ON NATIONAL MASS-MOVEMENT SITE
INVESTIGATION & MONITORING

SafeLand

MONITORING OF FACTORS:

		Active?	Duration	Permanent	X Regular	X Sporadic	Potential for EW?
Hydro-meteorological:	Precipitation amount	☐		☐	☐	☐	☐
	Snow cover thickness	☐		☐	☐	☐	☐
	Solar radiation	☐		☐	☐	☐	☐
	Air temperature	☐		☐	☐	☐	☐
	Air humidity	☐		☐	☐	☐	☐
	Pore-water pressure	☐		☐	☐	☐	☐
	Soil temperature	☐		☐	☐	☐	☐
	Soil humidity	☐		☐	☐	☐	☐
	Water temperature	☐		☐	☐	☐	☐
	Fluid conductivity	☐		☐	☐	☐	☐
	In / outflow (discharge)	☐		☐	☐	☐	☐
	Other:	☐		☐	☐	☐	☐
	Other:	☐		☐	☐	☐	☐
	Other:	☐		☐	☐	☐	☐

		Active?	Duration	Permanent	X Regular	X Sporadic	Potential for EW?
Geophysical:	Passive seism./acoustic emission	☐		☐	☐	☐	☐
	Electromagnetic emissions	☐		☐	☐	☐	☐
	Self potential *(SP)*	☐		☐	☐	☐	☐
	Induced polarization *(IP)*	☐		☐	☐	☐	☐
	DC (Direct Current) resistivity	☐		☐	☐	☐	☐
	Other:	☐		☐	☐	☐	☐
	Other:	☐		☐	☐	☐	☐
	Other:	☐		☐	☐	☐	☐

NUMERICAL MODELING:

Method 1:	Code name:	Studied behavior:
Method 2:	Code name:	Studied behavior:
Method 3:	Code name:	Studied behavior:

RELEVANT PUBLICATIONS AND REPORTS:

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Fig. 1: General appearance of the Questionnaire on National State of Landslide Site Investigation and Monitoring.

Table 1: Review of the number of sites and countries included in the study.

No.	Country Code	Country	Number of Sites
1	AD	Andorra	1
2	AT	Austria	7
3	CH	Switzerland	3
4	CZ	Czech Republic	11
5	ES	Spain	1
6	FR	France	5
7	GB	Great Britain	1
8	IT	Italy	22
9	KG	Kyrgyzstan	8
10	NO	Norway	3
11	RU	Russia	1
12	SI	Slovenia	3
13	SK	Slovakia	16

Fig. 2: Reviewing map of countries included in the study (source of map: GoogleEarth).

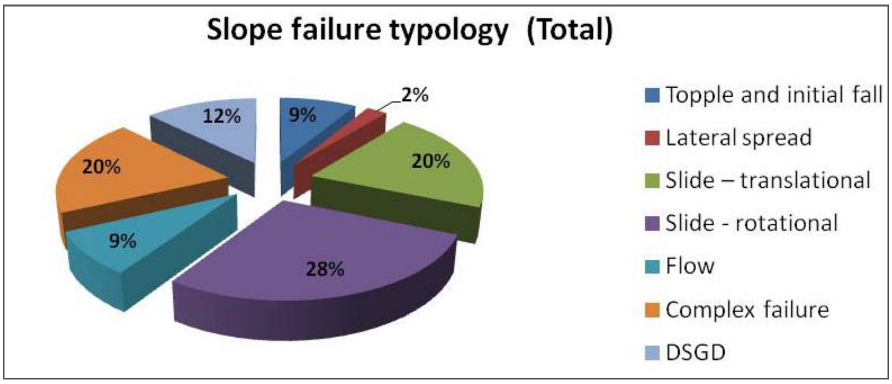

Fig. 3: Review of monitored slope failures included in the study (modified classification of CRUDEN & VARNES, 1996).

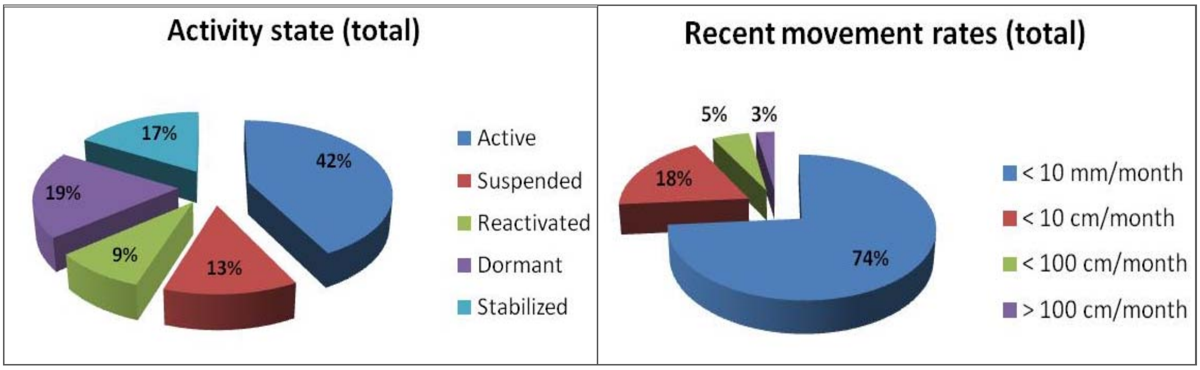

Fig. 4: Review of slope failures included in the study by their activity state (after WP / WLI, 1993) and actual movement rates.

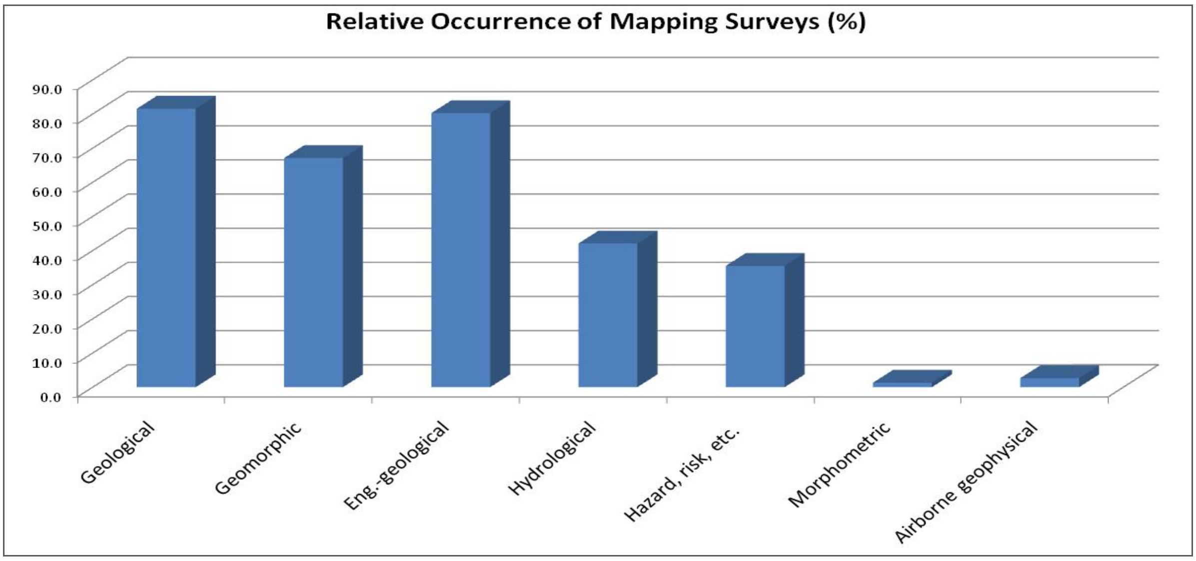

Fig. 5: Review of relative occurrence of different mapping approaches (per number of sites) applied in the case sites.

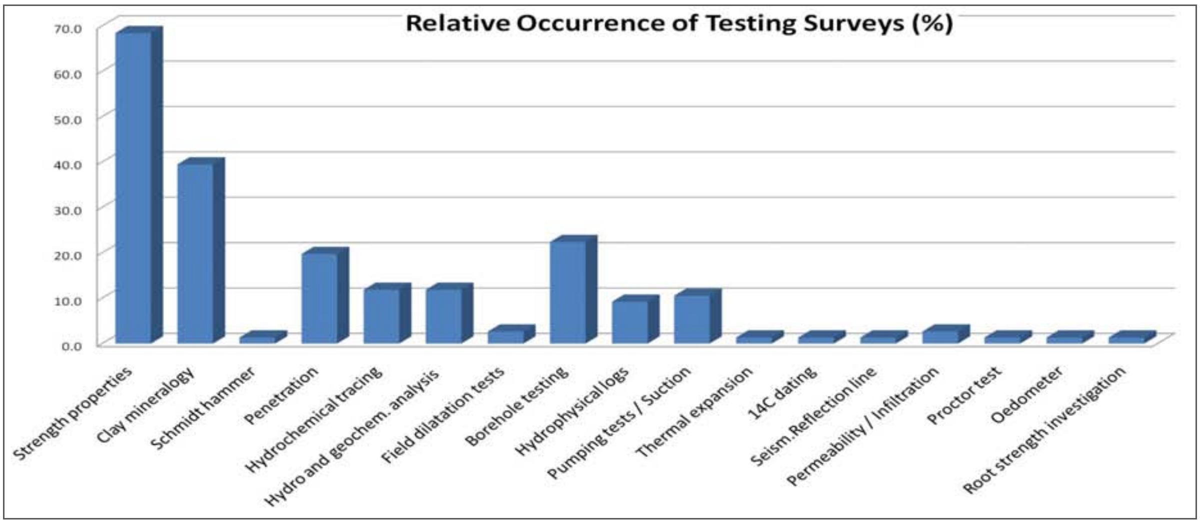

Fig. 6: Review of relative occurrence of different testing approaches applied in the case sites.

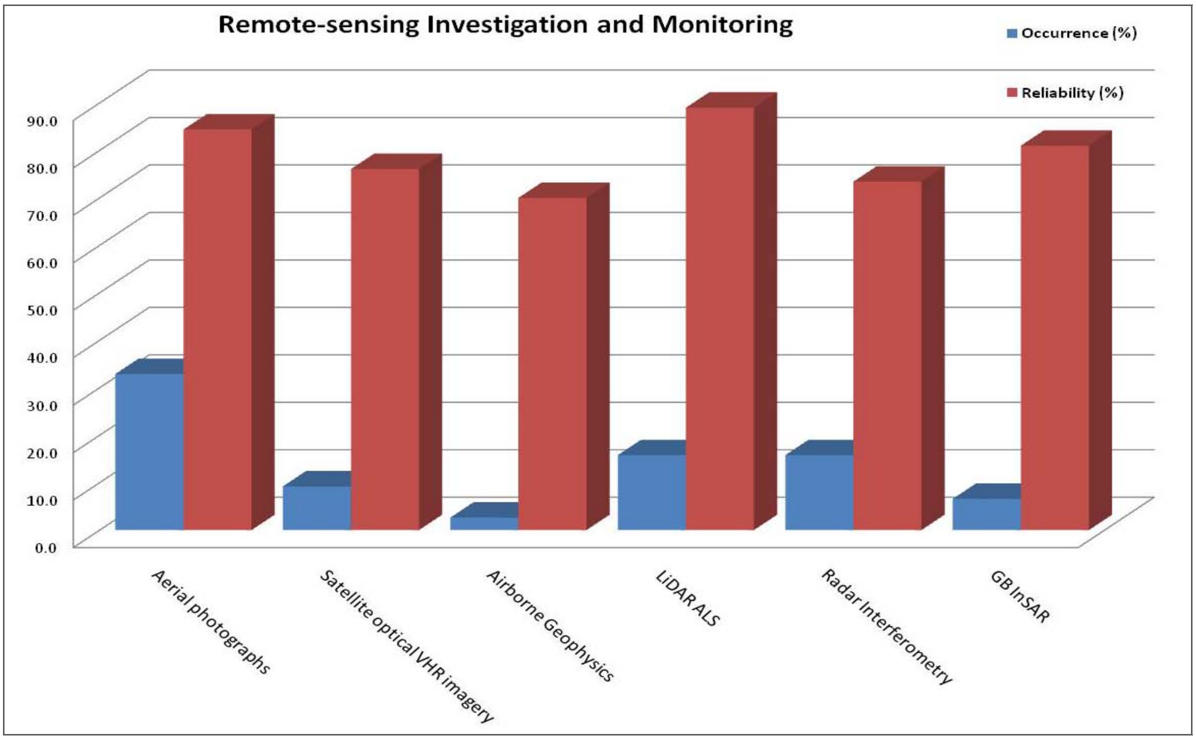

Fig. 7: Review of relative occurrence (blue) and relative reliability (red) of different remote-sensing data applied for investigating or monitoring of the case sites.

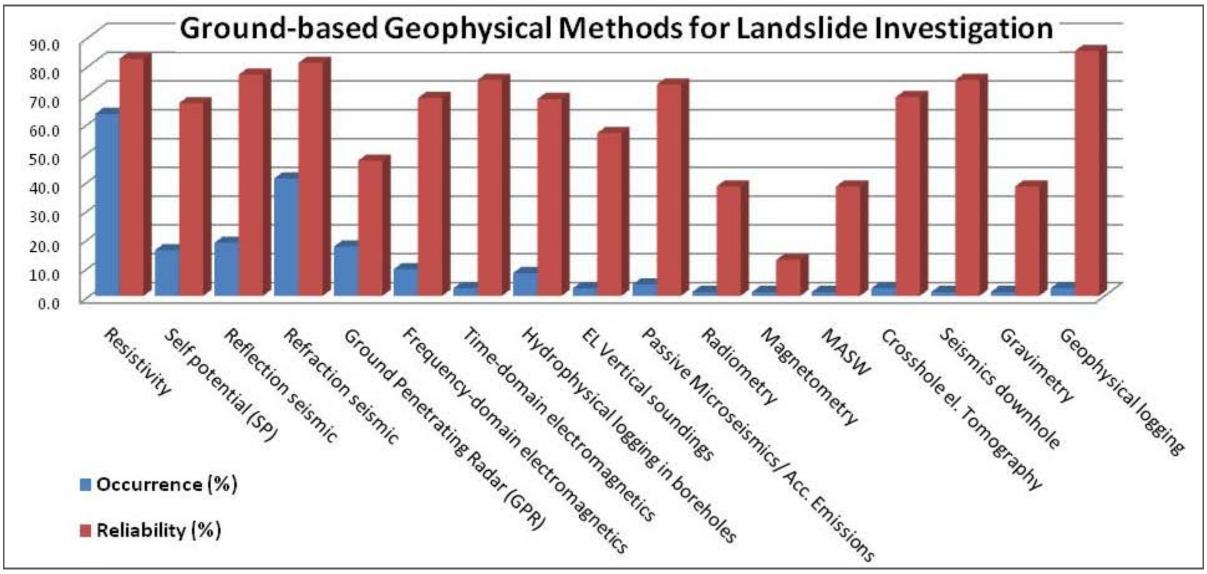

Fig. 8: Review of relative occurrence and reliability of different geophysical methods applied for investigation of the case sites.

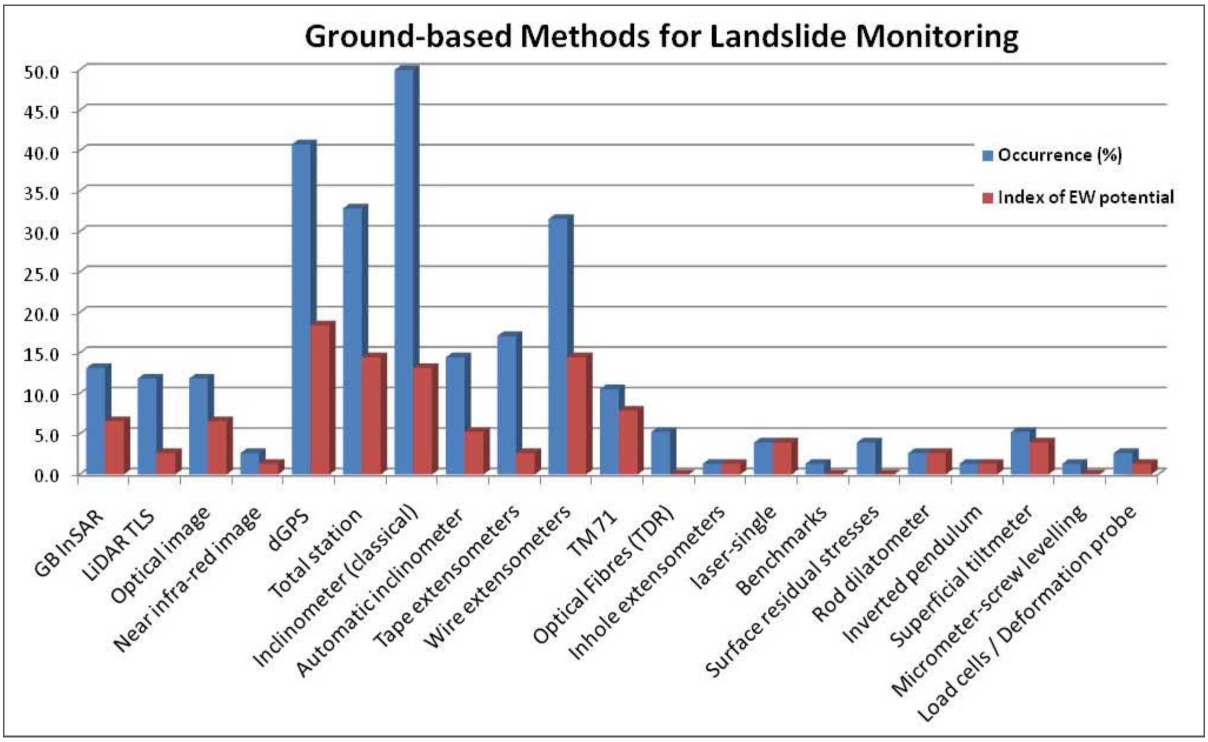

Fig. 9: Review of relative occurrence and index of early-warning potential of ground-based techniques applied for displacement and deformation monitoring of the case sites.

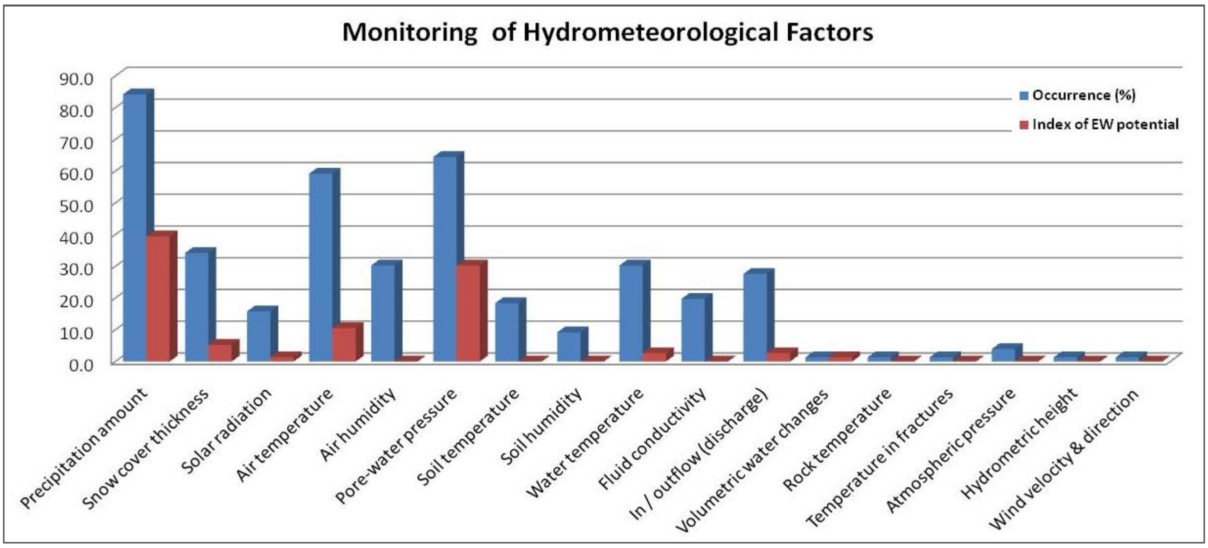

Fig. 10: Review of monitoring of hydrometeorological factors at the case sites, and their index of early-warning potential.

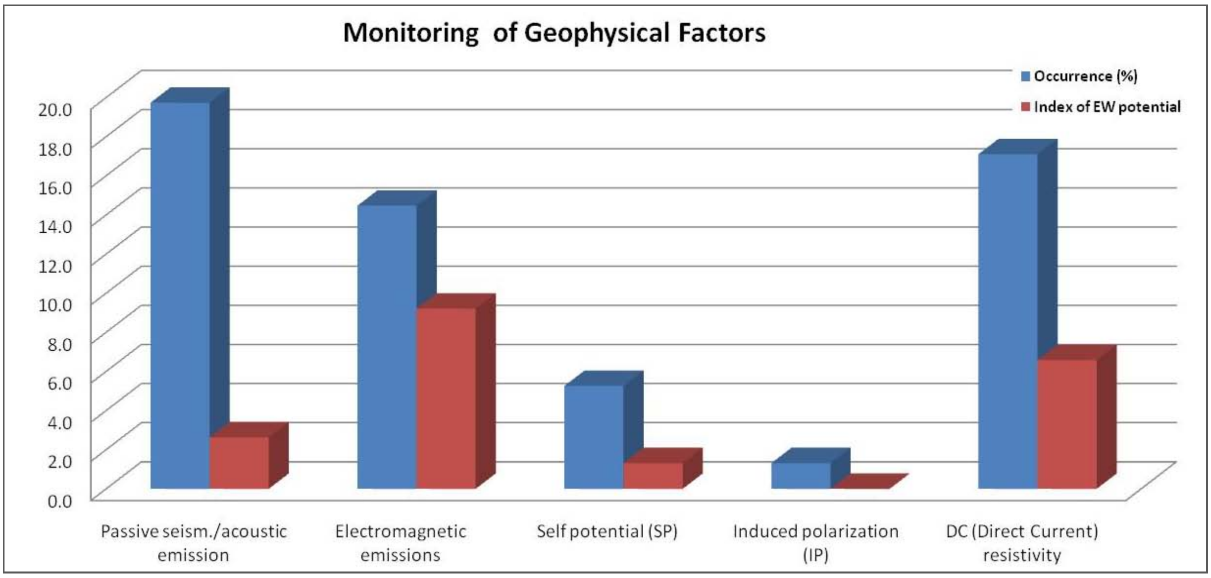

Fig. 11: Review of monitoring of geophysical factors at the case sites, and their index of early-warning potential.

Acknowledgement

The authors would like to **acknowledge everyone who helped through discussions to improve the form** to be as comprehensive and "user-friendly" as possible. Special thanks go to all the local national coordinators who helped to disseminate the questionnaire effectively and to obtain as many answers as possible; and, of course all specialist and responsible persons, who filled in the form, must be thanked, i.e.: **M. Bil, P. Blaha, J. Blanc, L.H. Blikra, M. Broccolato, S. Cardellini, M. Carman N. Casagli, J. Corominas, C. Foster, S. Garambois, W. Gasperl, V. Hanzl, F. Hartvich, A. Helmstetter, Ch. Ihrenberger, M.M. Ilyin, D. Jongmans, V. Kaufmann, J. Klimes, S. Kumelj, M. Lovisolo, J.-F. Malet, S. Novosad, A. Passuto, L. Picarelli, J. Rybar, S. Springman, I. Torgoev, G. Truffelli, G. Urciuoli, Z. Varilova, P. Wagner, and M. Wöhrer-Alge.**

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Meteorological and Climate Forecasting for Landslide Prediction

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Introduction and Motivation of Work

The aim of the presentation is to show the results obtained during the first two years of research activity of the work group 2 "Impacts on territory monitoring activity and hydrological risk prevention" of the Division "Impact on soil and coast" (I.S.C) in the framework of the project Euro-Mediterranean Centre for the Climate Change (C.M.C.C.).

The CMCC is a structure of scientific research with the aims to deepen knowledge on the climate variability, its causes and its consequences, this is done by providing models, simulations, middleware, application software and high quality personnel training, both in the specific field of climate dynamics and computer technology. The CMCC uses these simulations directly to effect studies of climate change impact on the economy, on agriculture, on sea and earth ecosystems, on coastal zones and health. All these research activities are developed by its six divisions, each one devoted to specific issues relating to the themes of climate change.

The work group 2 of the I.S.C. division has as its main goal the study and the development of models, algorithms and software for the analysis of landslides related to extreme meteorological events. Interest in these events occurs, especially in recent years, for a gradual increase in hydrogeological phenomena of failure. As shown in several studies, the causes of such disasters must be sought both in the changing climate and in an increasingly intensive exploitation of the territory (spreading urbanisation, funnel of rivers, intensive agriculture and so on).

The hydrogeological phenomena of interest are generally described (basin and/or slope scale) and so the tools for prediction and prevention require not only the development and the optimization of ad hoc numerical codes (accurate, robust, efficient), but also to couple the meteorological model with models evaluating impact of such phenomena on the soil (i.e. hydrological models), both at high resolution. The main result expected in this framework is a numerical simulation instrument to permit an early warning for hydrological instability phenomena (landslide, flood) connected to meteorological events. An innovative aspect of this activity is that the research work is developed by a multidisciplinary team; this permits to face the issues from different points of view and to introduce, through the integration and comparison between different skills, new methodologies producing optimums for simulating phenomena of a different nature (thunderstorm, landslide or floods).

This result has been obtained by realizing the "hydrometeorological simulation chain"; the numerical tool defined for the prediction and prevention of some type of hydrological disasters. All the tools defined in the chain are optimized to produce scenarios in less than half a day. In the future, then, this research tools will be available to the end users (civil protection and so on) to warn the people.

The Hydrometeorological Simulation Chain

Different components contribute to the definition of chain; a brief description of them follows.

The first simulation model of the "chain" is represented by the Numerical Weather Prediction (NWP); the code choice is essential for the weather forecasting quality and then for the evaluation of the hydrological calamities. The NWP model selected for this application is the COSMO-LM model [1] [2], this is the regional numerical model operatively used in Italy, and in many other European countries, to forecast mesoscale-phenomena; different numerical schemes and physical parameterization are available in the model and, depending on the application, different configurations can be defined. Two versions of the model are available: one with 7 km of horizontal resolution and forecast range up to 72 hours, running operatively all over the country, and a second one, pre-operative, with 2.8 km of horizontal resolution and up to 18 hours of forecast time range with a smaller spatial domain. Preliminary work has been done to find the optimal configuration to specialize the two COSMO-LM versions (7 km and 2.8 km) for the simulations of extreme meteorological events on the Mediterranean area. This last topic requires, in particular, a detailed study of precipitation, soil-atmosphere interaction and soil infiltration, runoff, and transpiration/evaporation. Different NWP models are used in the "chain": a limited area version model with a horizontal resolution of 2.8 km is nested on the one covering a bigger area with 7 km of horizontal resolution. This last one is nested on a global model, in our application this last one is represented by the IFS model running at ECMWF [3] [4], performing weather forecast all over the globe. This two-step nesting is necessary to guarantee the best quality of the forecast produced (in fact, a resolution of 2.8 km is more able to take into account the effect produced by a complex orography) but also to permit a smaller resolution jump among the NWP model and the others cascade simulation models; nevertheless this requires very long computational time; for this reason very efficient and powerful super computers are available to CMCC permitting to produce the scenarios for the different risks in less than half a day.

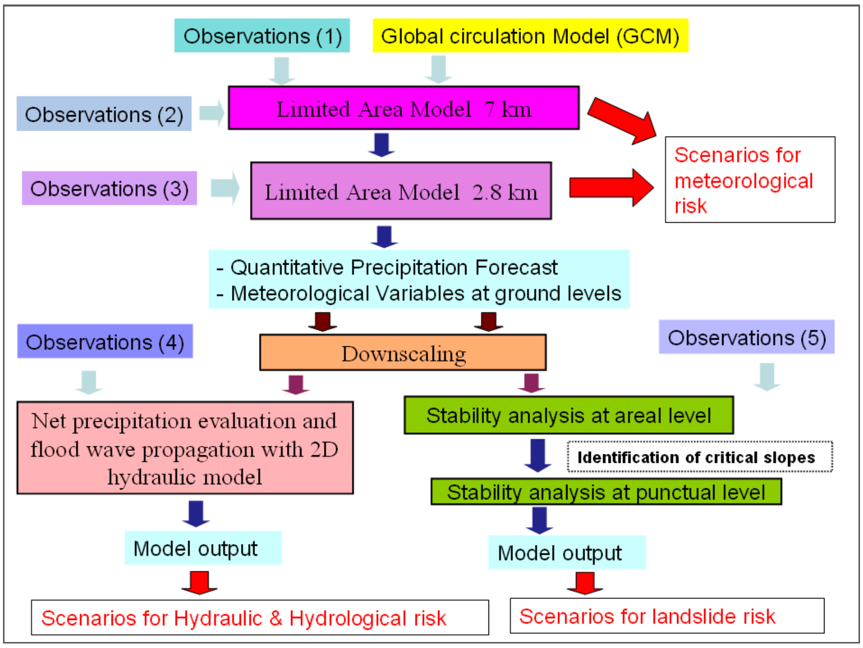

Fig. 1: Flow chart of the hydrometeorological simulation chain.

Taking into account the very high resolution required for the landslide simulation models and the impossibility to use higher resolution than 2.8 km for the limited NWP models, the opportunity has also been investigated to use statistical downscaling techniques to interface the models; this permit to have a smaller discontinuity and then more coherence in the results. It is important to emphasize that the coupling among the models is obtained through the precipitation fields and other soil properties; in particular, the precipitation is a discontinuous variable, depending strongly on orography and soil properties, then the downscaling algorithms also have to consider all these factors. About the landslide models, in order to produce risk scenarios on slopes, it has been decided that it is more useful to use a one-step nesting technique; this means that precipitation information are used to initialize a stability simulation model working on area level; this first step permits a preliminary individuation of the critical slopes, then, this information is used to perform a more precise investigation only on these last slopes through a more complex simulation model for the stability analysis at punctual level. The outputs of this study are scenarios for the landslide risks on areas affected by intense rainfall.

The Performed Test Cases

The hydrometeorological simulation chain has been tested on three test cases found in the Campania region, located in southern Italy. This area is frequently subject to landslides, some initialized by precipitation (this special type of landslide will be investigated). The first two test cases happened at the Camaldoli site, located near Naples. The first one occurred on 18th of September, 2005, after a thunderstorm in which 70 mm of rain was observed in 30 minutes; the second one occurred on 13th of October, 2004, after about 47.6 mm of rain in 24 hours. The third event occurred at Nocera site, located about 30 km south of Naples, on 4th of March, 2005, in which about 200 mm of rain was measured in less than 1 day.

Conclusions

This work describes the results obtained by applying the hydrometeorological simulation chain, defined by a multidisciplinary team working in the CMCC, on some test cases, located in southern Italy, in which the landslides were initialized by intense precipitation. The test cases permit to compare the results (risks scenarios) predicted by the numerical simulations and those that were observed during the events. This activity is necessary to assess the predictive power of the defined simulation chain and to understand its limits and then make some improvements.

The same approach is under development applied to climate change. In this case a coupling between climate regional models together with landslide models will allow the evaluation of how it will change the landslide risk according to the increase of precipitation events foreseen in some specific areas according to the new climate scenario.

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[3] http://www.ecmwf.int/research/ifsdocs/CY28r1/index.html.

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A Review of Remote Sensing and Ground-Based Techniques for Landslides Detection, Fast Characterization, Rapid Mapping and Long-Term Monitoring

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European countries are exposed to numerous geohazards, such as landslides and rockfalls, which endanger inhabitants and infrastructures. The European project FP7 "SafeLand" wants to develop innovative mapping and monitoring methods in order to improve regional assessments and early warning systems (SafeLand European project, 2009). More specifically, Area 4 addresses the technical and practical issues related to monitoring and early warning for landslides. During the last decade, different monitoring and remote sensing techniques underwent rapid development. In order to summarize these scientific and technical advances, the University of Lausanne, in close collaboration with 12 European institutions, is leading the deliverable 4.1: *"Review of Remote Sensing and Ground Based Techniques for Landslide Detection, Fast Characterization, Rapid Mapping and Long-Term Monitoring"*.

The core of this review consists of two main chapters. Chapter 3 summarizes the different techniques and methods (e.g. Ground-Based and Space-Borne optical images, Aerial and Terrestrial Laser Scanning, Radar Interferometry, Ground Based and Airborne Geophysical investigations, Geotechnical Ground-Based monitoring systems and Global Positioning System) from a theoretical point of view. The structure of this chapter is illustrated in Figure 1. Each technique described in the deliverable has benefited of the expertise of specialized research groups. Chapter 4 shows the main applications of these techniques to landslides, through the synthesis of different case studies. To this end, each partner provided different examples which summarize the state-of-the-art of a given technique for different hazards in several situations. As an example, Figure 2 shows a combination of Aerial and Terrestrial Laser Scanning for rockfall characterization.

This review seeks to represent a common reference for the different deliverables of Area 4 of the SafeLand European project, specifically for the D 4.3, D 4.4 and D 4.8 (*"Creation and updating of landslide inventory maps, landslide deformation maps and hazards maps as input for QRA using remote sensing technologies"*, *"Guidelines for the selection of appropriate remote sensing technologies for monitoring different types of landslides"*, *"Guidelines for monitoring and early-warning systems in Europe – Design and required technology"*).

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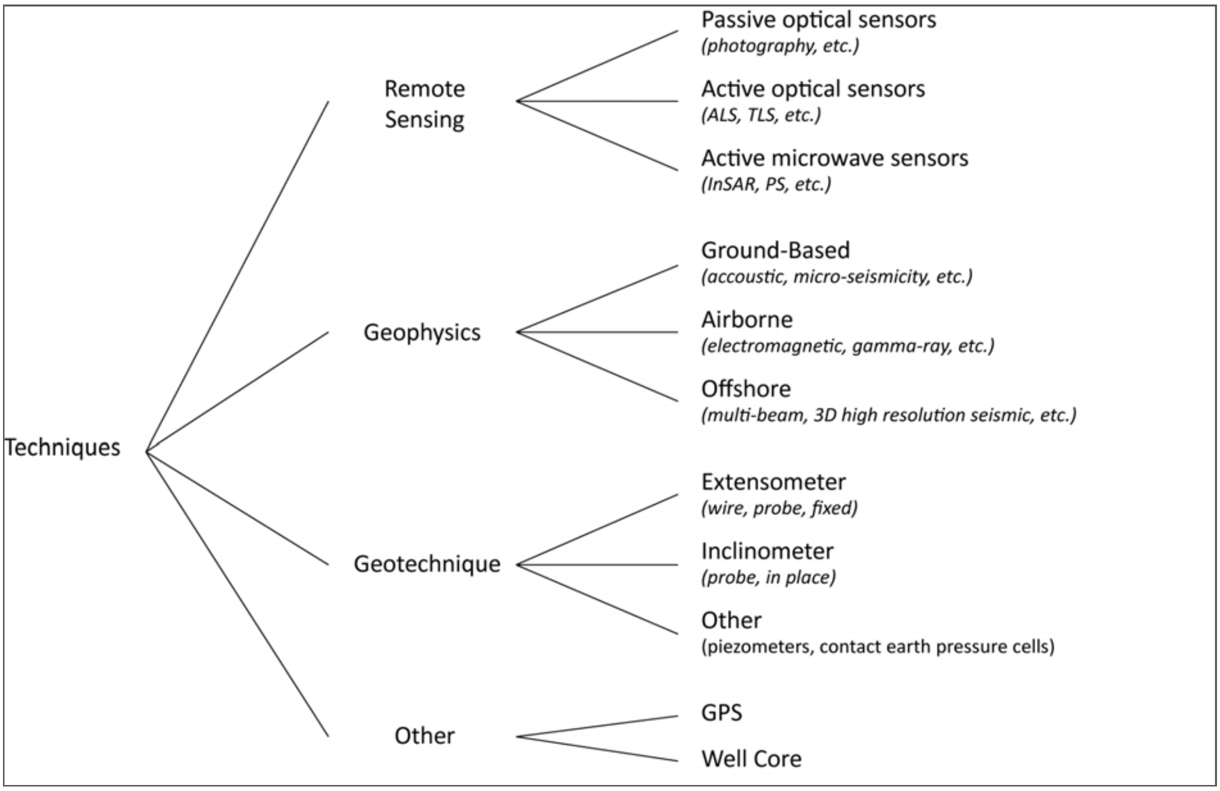

Fig. 1: Structure of the major chapter of the deliverable exploring the state-of-the-art and the theory of remote sensing and ground based techniques applied to landslides detection, fast characterization, rapid mapping and long-term monitoring.

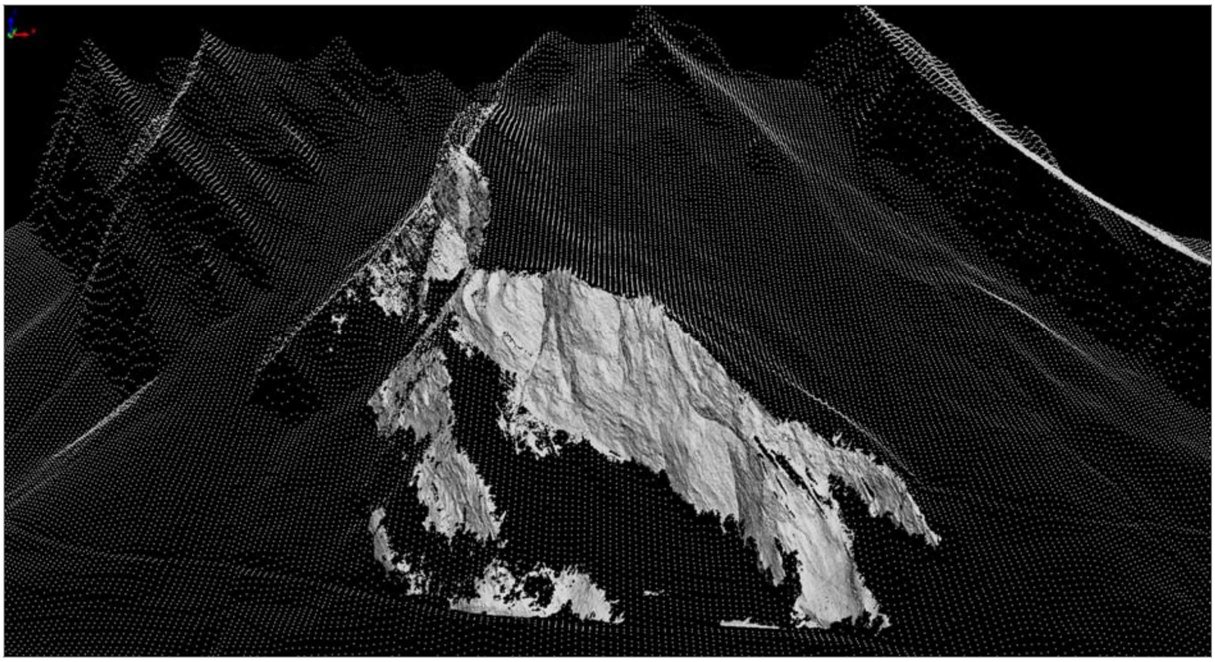

Fig. 2: Example of a remote sensing method applied to structural characterizations and rockfall assessment: frontal view of the suspected unstable cliff with a 10 cm resolution point cloud acquired by Terrestrial Laser Scanning (© IGAR UNIL) wrapped on a pre-existing 2 m resolution DEM from Aerial Laser Scanning (MNT-MO © GEO VS).

A Multi-Temporal Image Correlation Method to Characterize Landslide Displacements

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Objectives

This work presents a method to characterize the displacement pattern of slow moving landslides from multitemporal optical, very high resolution images by using Digitial Image Correlation (DIC) (DELACOURT et al., 2007). The method is applied on the Super-Sauze mudslide (South French Alps) (Figure 1), which exhibits velocities from 0.01 to 0.4 m.d^{-1} (MALET et al., 2002). The performance of the method is discussed by analyzing the displacement pattern during an important acceleration in the period May–July 2008.

Image Acquisition

The monitoring system consists of a low-cost Nikon D80 camera (1000 USD) installed on a concrete pillar located on a stable crest in front of the mudslide (Figure 1). The camera is controlled by a datalogger (CR10) and the power is provided by a 40 W solar panel. Every four days, 4 photographs are registered at 11:00 a.m., 12:00 p.m., 13:00 p.m. and 14:00 p.m.. Each photograph (6 Mb) is stored in a native file format without any loss of information.

DIC: Digital Image Correlation Technique

The DIC method determines the maximum of cross correlation between small zones extracted from the images. The maximum corresponds to the displacement (translation) vector of the considered zone. By changing the zone of interest, it is then possible to determine displacements at various positions inside the photographs (CHAMBON et al., 2003).

The use of a multi-resolution correlation algorithm is motivated by the necessity:

- to avoid incoherent results due to changes in landslide surface aspect (soil moisture changes, soil surface weathering) and changes in illumination
- to identify and characterize heterogeneous distributed displacement fields.

The correlation technique is based on:

- successive degradations of image resolution for changing the physical size of the interest zone. The correlator starts at the lowest resolution image for determining global displacements, then the location of the maximum cross correlation is used as a start point for the next correlation with a higher resolution to determine local displacements.
- correlation of gradient values by using an edge detection algorithm (Sobel or Prewitt operators), applied on the images to identify object texture (through an estimation of the gradient image intensity function).

Conversion of Pixel Displacement to Ground Surface Displacement

Because stereoscopic view of the mudslide is not possible, a method using projective transformation is used to associate the pixel coordinates of the image plane (in 2D) to ground coordinates (E, N, Z) of the local coordinate system (in 3D) using DEMs interpolated from airborne LiDAR datasets (Figure 2) (HEEGER, 1998). In the conversion, the global morphology of the mudslide is assumed nearly invariant in time.

Results

Displacements in the Image Plane

The accuracy in pixel displacements is estimated on stable areas outside the landslide (Figure 3, red square); in this area, the residual pixel shift is less than 1 pixel after correction of slight rigid movements of the camera.

The amplitude and direction of pixel displacements point out distributed displacement (Figure 3). During the acceleration period, the kinematics of the upper part of the landslide is more important than the lower part in terms of pixel velocity, assuming that a pixel in the upper part covers a larger ground surface (about 5.10^{-2} m^2) than a pixel in the lower part (2.10^{-3} m^2). The maximum velocity is observed at the beginning of June 2008.

Displacements in the Ground System

The close to null displacements observed in the stable area allow to estimate an average accuracy of 0.10 m in the ground surface coordinate system. The displacement fields are coherent with the topography and previous knowledge on landslide kinematics (MALET et al., 2002) (Figure 4A, B, C, D, E). The displacements vary temporally and spatially. The difference in horizontal displacements between the upper part (10.5 m in 4 days) and the lower part (1.1 m in 4 days) is clearly noticeable (Figure 4A). The displacement maps show that the kinematics is mainly controlled by the buried topography.

Conclusion

Digital Image Correlation (DIC) of terrestrial optical imagery is a powerful and low-cost tool to monitor the displacement pattern of slow-moving landslides. After conversion of pixel coordinates into metric coordinates, the displacement pattern is coherent with the topography and previous knowledge. Acquisition of accurate DEMs is important to improve the accuracy of the computed displacement field in the ground local reference system. Comparisons of displacements with control points measured with DGPS will be used to further validate the methodology. Inversion of the displacement field will be developed to characterize the macroscopic geomechanical properties of the landslide material.

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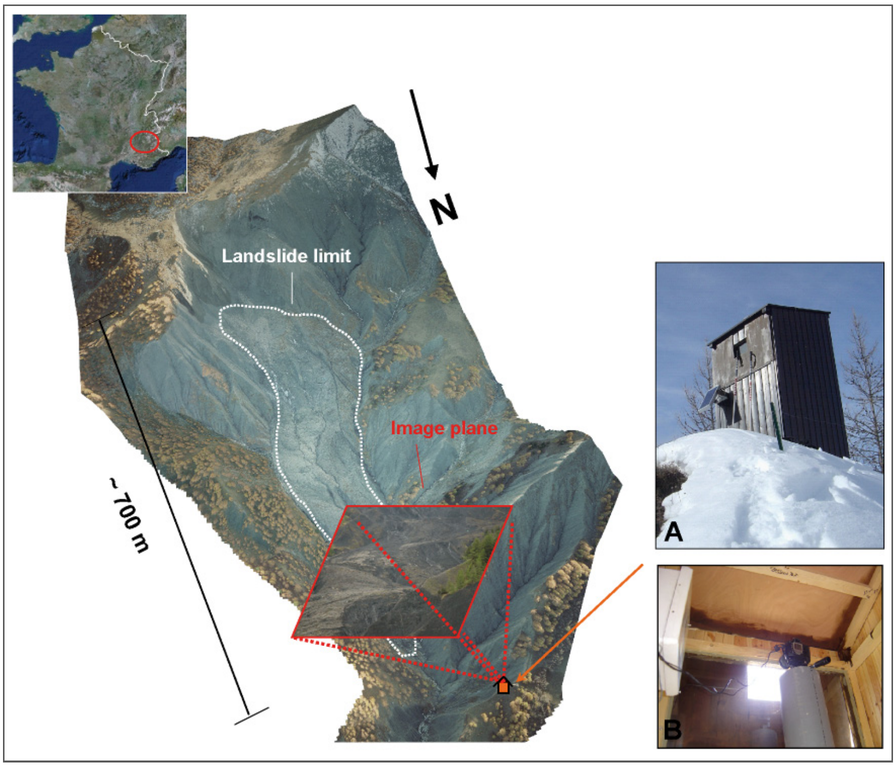

Fig. 1: View of the Super-Sauze landslide towards the South. The orange square represents the location of the camera (in a hut, A) where a high resolution camera is installed (B). The red square represents the image plan of a photograph taken by the camera.

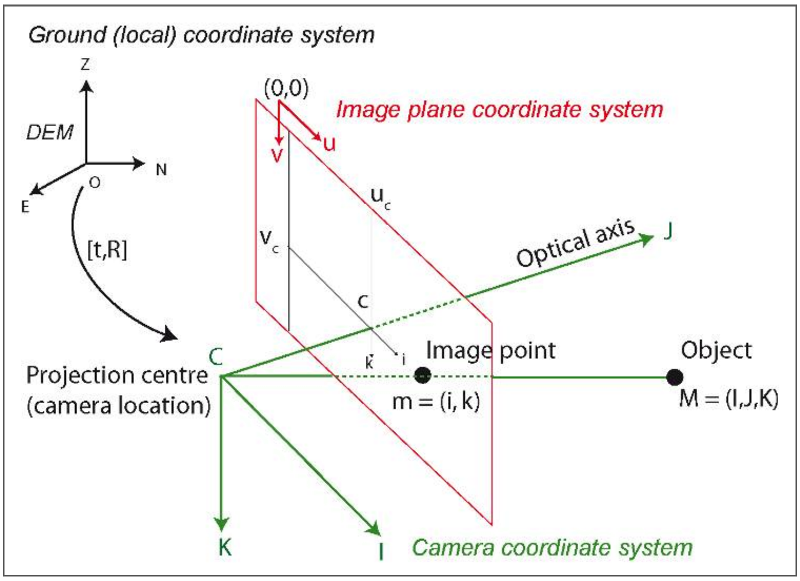

Fig. 2: Coordinate systems used in the conversion procedure.

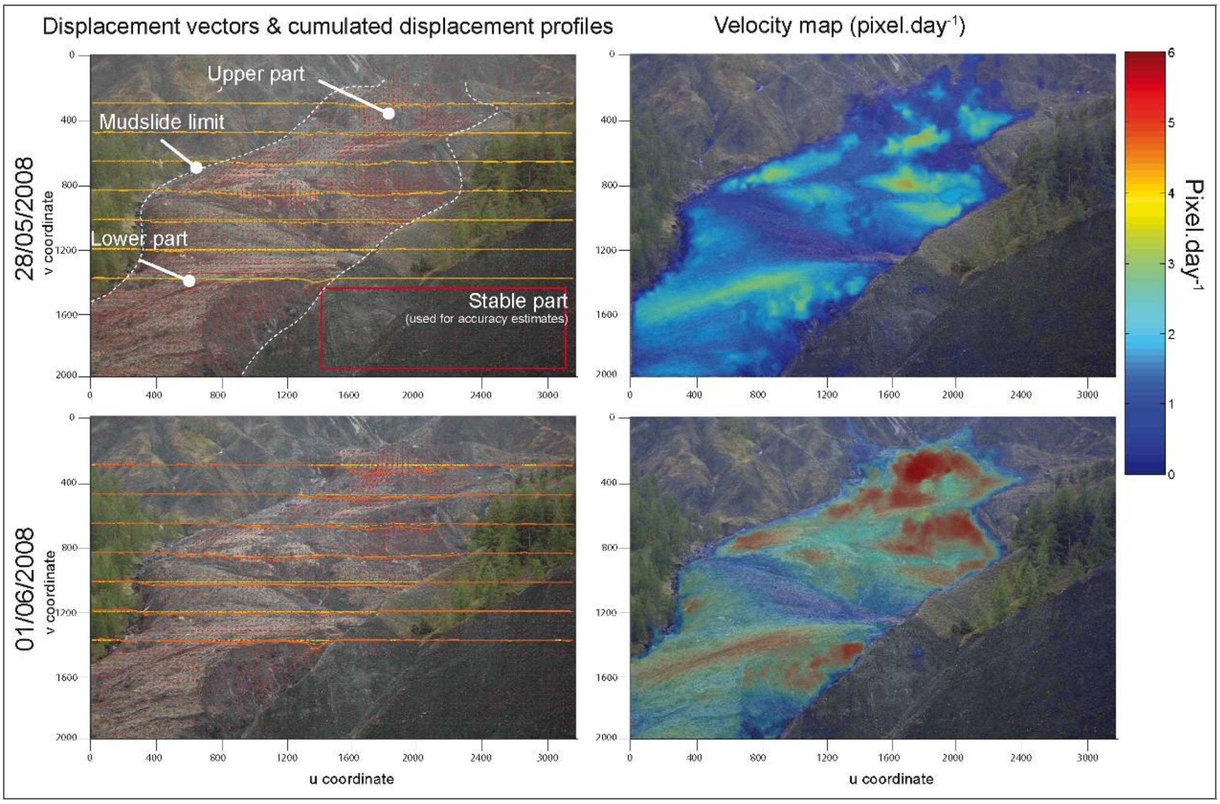

Fig. 3: Displacement vectors, cumulated displacements and velocity maps in the image plane coordinate system. Period: 28th May 2008 – 6th June 2008.

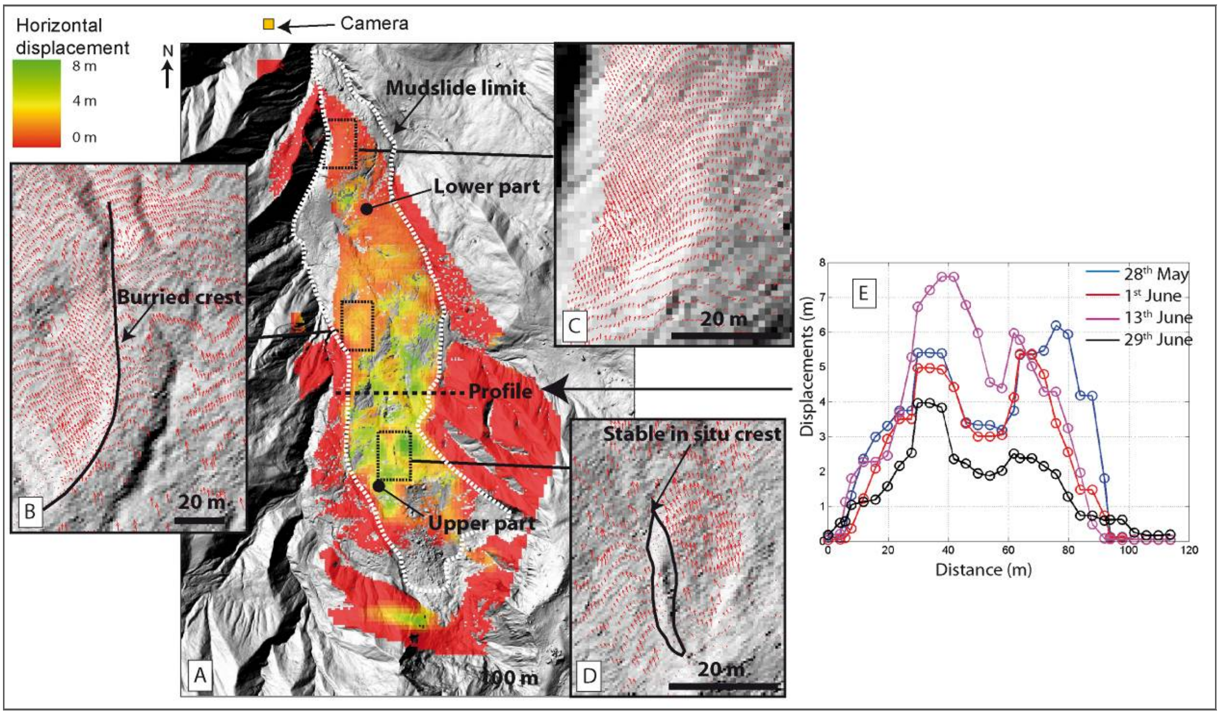

Fig. 4: A) Horizontal displacements in the period 28th May – 1st June 2008, B) Amplitude and direction of displacement vectors nearby a buried crest, C) Displacement vectors in the lower part, D) Displacement vectors nearby an in-situ crest. E) Profiles of cumulated displacements over 4 successive periods of 4 days.

Object-Oriented and Cognitive Methods for Multi-Data Event-Based Landslide Detection and Monitoring[1]

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Landslides are a major hazard, in 2008 alone leading to more than 400 fatal disasters worldwide which killed over 32,000 people. Understanding the hazard, and subsequently the risk, requires accurate inventories of past slides, including their location, extent, type and triggering mechanism. Those inventories are difficult to obtain through field mapping, mainly due to access challenges and rapidly vanishing traces. Geoinformatics tools have proved to be of great value in disaster risk management, such as through remote sensing that allows accurate and timely acquisition of information on hazard processes, elements at risk or consequences of a hazardous event, which can be analysed or integrated with auxiliary information in GIS programmes or models. Landslides are one of those phenomena where geoinformatics developments have opened up new ways to build inventories of previous mass movements, but also to monitor potential or ongoing slides.

In the past, image-based mapping was primarily done by visual analysis of aerial photos or, increasingly, satellite imagery, and a number of automatic methods have been devel-oped. However, until recently only pixel-based methods, primarily employing different classi-fication or change detection techniques, were used. Those are beginning to be replaced by approaches based on objects or segments (BARLOW et al., 2003; MOINE et al., 2009). Object-oriented analysis (OOA) is inherently more suitable, as it can address the phenomena studied, landslides in this case, as what they really are – objects, not pixels – that have spectral, spatial and contextual characteristics (Figure 1). They thus allow limitations of pixel-based methods to be overcome, which are largely restricted to using spectral and texture information. Past landslide characterisations have identified a number of different landslide types and defined them, for example in terms of source material type, run-out length, failure plane curvature or crown shape. These characteristics also form the basis of cognitive, expert knowledge-driven visual landslide mapping. However, potentially any of these characteristics can also be employed in OOA, provided suitable data needed to calculate those parameters are available. The results can then be a (semi-)automatic and robust procedure that can identify landslides and determine their type, making use of the same expert knowledge that drives visual image analysis.

This was demonstrated in recent work that used multispectral 5.8 m IRS P6 LISS-IV imagery of parts of the High Himalayas in India, together with elevation information extracted from 2.5 m stereo-Cartosat1 data (MARTHA et al., 2010). These data were used for automatic mapping and discrimination of debris slides and flows, as well as translational or rotational rockslides. The approach developed is able to eliminate false positives that have proved difficult in previously reported research, such as clear-cuts, roads or riverbeds, and allows an effective integration of process knowledge, for example, the spatial relation of landslides with causative factors such as slope or road construction. Landslides mapped in an independent watershed of 53 km^2, using a process developed for a smaller area, were detected and correctly classified with accuracies of 76.4 % and 69.1 %, respectively, the smallest one meas-uring less than 800 m^2. This suggests that object-based automatic methods can well be used to substitute visual interpretation or field mapping, particularly when large areas need to be covered.

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[1] Based in part on material by Tapas MARTHA (ITC [the Netherlands] and NRSC [India]).

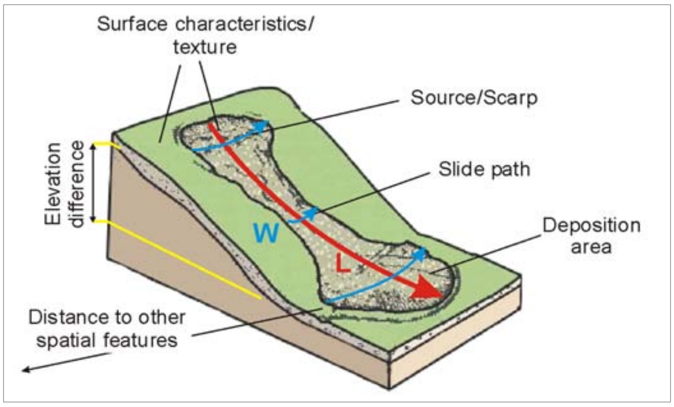

Fig. 1: Anatomical and contextual parameters that determine the type of landslide, and that can be used in OOA.

Using OOA efficiently also raises several problems. The actual analysis is reliant on proper image segmentation (Figure 2), the subjectivity and trial-and-error nature which has been the subject of years of research. Hence, research now focuses on how image statistics and intelligent object merging, rather than visual fine-tuning, can be used for an objective segmentation. Further work is also needed to develop OOA-based methods that include the mapping of other parameters needed in risk assessment, such as elements at risk. Segmentation-based analysis can also be applied to other data types often collected in landslide areas, such as laser scanning or airborne geophysical data, or to track changing features in slow-moving landslides. In the context of the SAFELAND project those, too, are explored.

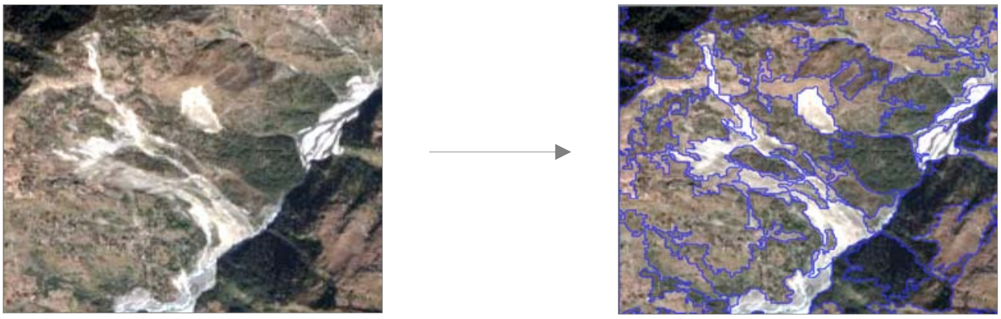

Fig. 2: The success of OOA relies heavily on proper delineation of the features of interest, hence on appropriate segmentation. Only then it is possible to make use of contextual parameters, such as length/width ratios of slides, or adjacency to specific source areas that supports landslide type determination.

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Weather Forecasting and Radar Technologies for Landslide Prediction and Mapping: Some Examples in Italy

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UNIFI (Earth Sciences Department, University of firenze) has gathered expertise in different fields of landslide study for many years. In particular, in the framework of the SafeLand project, it is currently working on short-term weather forecasting for shallow landslide prediction and on the development of remote sensing technologies for the detection, monitoring and rapid mapping of landslides and evaluation and development of reliable procedures and technologies for early warning.

Concerning the temporal prediction of hazard assessment, UNIFI is active in the study of methods for the real-time and quasi real-time forecast of rainfall induced landslides. Since the beginning, this has been developed along two, partly independent, research lines: the statistical methods based on rainfall thresholds and the development of advanced probabilistic approaches relying on deterministic schemes. The state of development of probabilistic real-time prediction methods is also very promising and can be summarized in its preliminary outcomes by the European Commission funded project PREVIEW (SEGONI et al., in press), in which a complex operative chain has been devised and set up based on radar rainfall measurements, a soil saturation hydrological model and a simple infinite-slope stability code, and, in its following further advancement, by the introduction of a more sophisticated two-stage geotechnical model coupling an explicit saturation scheme and a slope stability model with cohesion terms and variable depth of detachment surface (CATANI et al., in press). One of the key elements which make the use of such sophisticated models possible is the definition of a distributed computational scheme for the prediction of soil depth at the basin scale, a fundamental parameter in shallow-landsliding initiation (Figure 1). Such model has been recently developed by the UNIFI and it is based on geo-morphometric and geological parameters easily measurable in the field or through remote sensing. Currently under development is the attempt at perfecting the deterministic model with the add-on of a probabilistic definition of the parameters with high spatial variability (see e.g. geomechanical parameters) and porting all the computational code on a parallel processing structure on multi-processor supercomputers.

Nowadays, rapid advances of Earth Observation (EO) are effective tools for landslide mapping, monitoring, management and mitigation. Applications are originating from nearly all the types of sensors available today; the very high spatial resolution obtained by optical systems, which are now in the order of tens of centimeters, the launching of SAR (Synthetic Aperture Radar) sensors purposely built for interferometric applications and with lower revisiting times are all leading to rapid developments that make the field extremely promising. During the last years UNIFI has contributed to research activities regarding the use of interferometric applications, both DInSAR and A-DInSAR, for landslide studies.

UNIFI has largely worked on the applications of Synthetic Aperture Radar interferometry (InSAR) to typical geomorphological problems (CATANI et al., 2005). The application of InSAR to the quantification of landform attributes such as the slope and to the estimation of landform variations has been investigated.

ThePS-InSAR technique has been applied at a regional scale as support for landslide inventory mapping and at the local scale for the monitoring of a single well-known slope movements (FARINA et al., 2006; FERRETTI et al., 2005; CANUTI et al., 2007; CASAGLI et al., 2008; PANCIOLI et al., 2008; HERRERA et al., 2009; CASAGLI et al., 2009). At the regional scale, PS-analysis allowed to update the boundary and the state of activity of the existing landslides and to map new movements. At the local scale, PS-InSAR technique has provided an accurate analysis of the temporal and spatial displacement fields, for the creation of activity maps, and combined with other information, for interpreting the movement geometry (Figure 2).

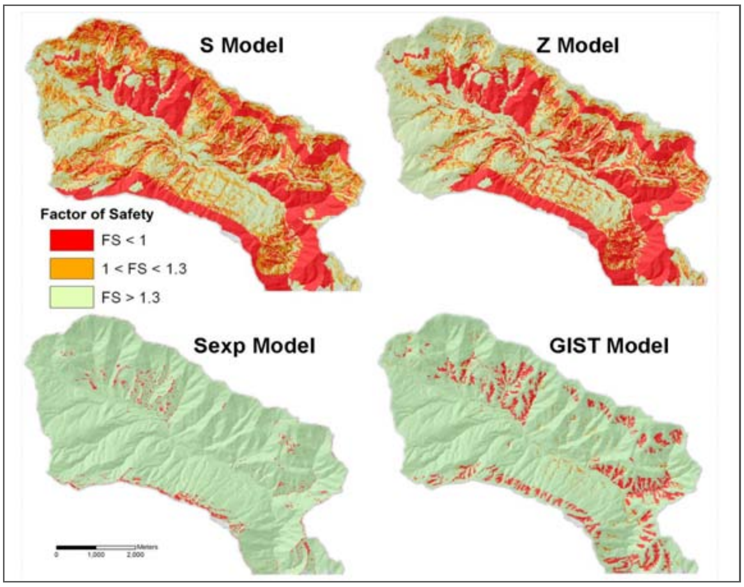

Fig. 1: Factor of safety maps obtained in the Armea basin (Liguria, NW Italy) using four different soil thickness patterns: S Model is based on a linear correlation between soil thickness and slope gradient, Z Model is based on a linear correlation between soil thickness and elevation, Sexp Model is based on an exponential correlation between soil thickness and slope gradient, GIST model (CATANI et al., in press) is based on geomorphometric and geological parameters.

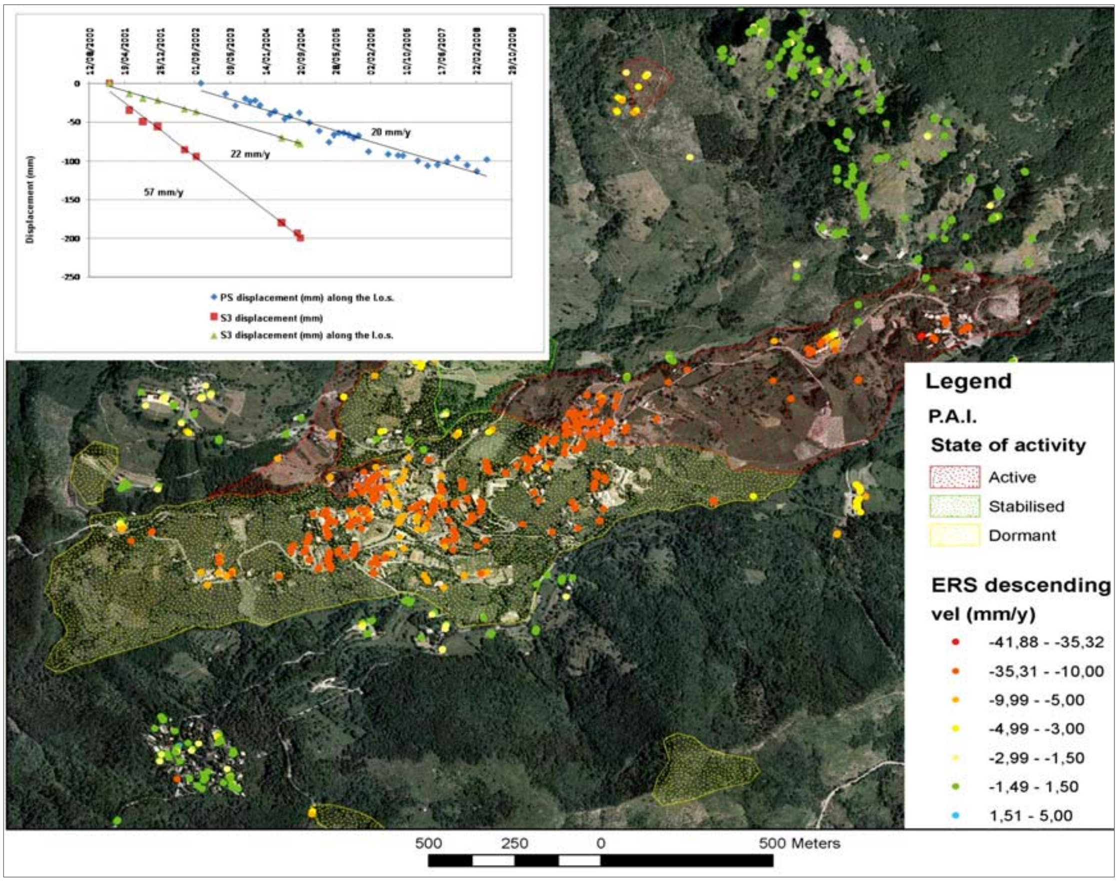

Fig. 2: Landslide monitoring by means of PS-InSAR technique and comparison with in-situ instrumentations.

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Testing Different Techniques for Detection, Rapid Mapping and Monitoring of Landslides in the Barcelonnette Region Using Satellite and Airborne Optical Imagery

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Within SafeLand the Joint Research Centre (JRC) of the European Commission is involved in three research areas, i.e. Area 2 on "Quantitative risk assessment", Area 3 on "Quantifying global change scenarios (climatic and anthropogenic) and their impact on land-slide hazard and risk in the future" and Area 4 on "Development of monitoring technology, especially early warning systems and remote sensing techniques, and applications". This abstract focuses on the activities within Area 4. A short overview will be provided of the research planned by JRC. For more elaborate information on the techniques presented, reference is made to some clarifying research articles.

With the increasing spatial resolution of e.g. IKONOS (1999), QuickBird (2001), OrbView-3 (2003), now phased out, Worldview (2007; 0.44 m pan) or GeoEye (2008; 0.41 m pan) sensors, application fields which had previously been the domain of airborne remote sensing (ARS) could be tackled by satellite remote sensing (SRS [BLASCHKE, 2010]). Indeed, two of the three methods that will be tested and eventually improved by JRC within Area 4 have been originally designed with ARS images. JRC will test two techniques for detection and rapid mapping of landslides and one technique for long-term change detection of landslides. The techniques are planned to be applied to very high resolution (VHR) spaceborne optical sensors and airborne LiDAR. For this, the Barcelonnette test site (200 km²; Alpes-de-Haute-Provence, France) was selected, but probably also data from other SafeLand test sites will be used.

With regard to landslide detection and mapping, the first technique to be tested and eventually improved is a semi-automatic texture classification technique developed by HERVÁS & ROSIN (1996), HERVÁS et al. (1996) and HERVÁS & ROSIN (2001). These authors obtained good results with a discrimination method for landslide mapping in a semi-arid, sedimentary area in SE Spain from high resolution Daedalus ATM (3 m), IRS-1C Pan (5 m) and SPOT Pan (10 m) images. The second landslide identification technique will use LiDAR data in combination with optical images for Object Oriented Analysis (OOA; e.g. MARTHA et al., 2010). The possibilities of the Definiens Developer software for segmentation and classification of landslides are illustrated with results obtained from the exploration of the software.

For long-term detection of landslide activity, a method entailing automatic change detection of suitably pre-processed multitemporal images, followed by thresholding of pixel intensities into landslide-related change pixels was developed by HERVÁS et al. (2003). The method was previously applied to VHR (1 m) orthoimages of the Tessina landslide (Italy) and provided representative results on the pixel intensity changes related to the reactivation of the landslide in 1992 (Figure 1).

In agreement with SafeLand's objective to secure data exchange with other Areas, the results obtained from this study will be used as input data in Areas 2 and 3.

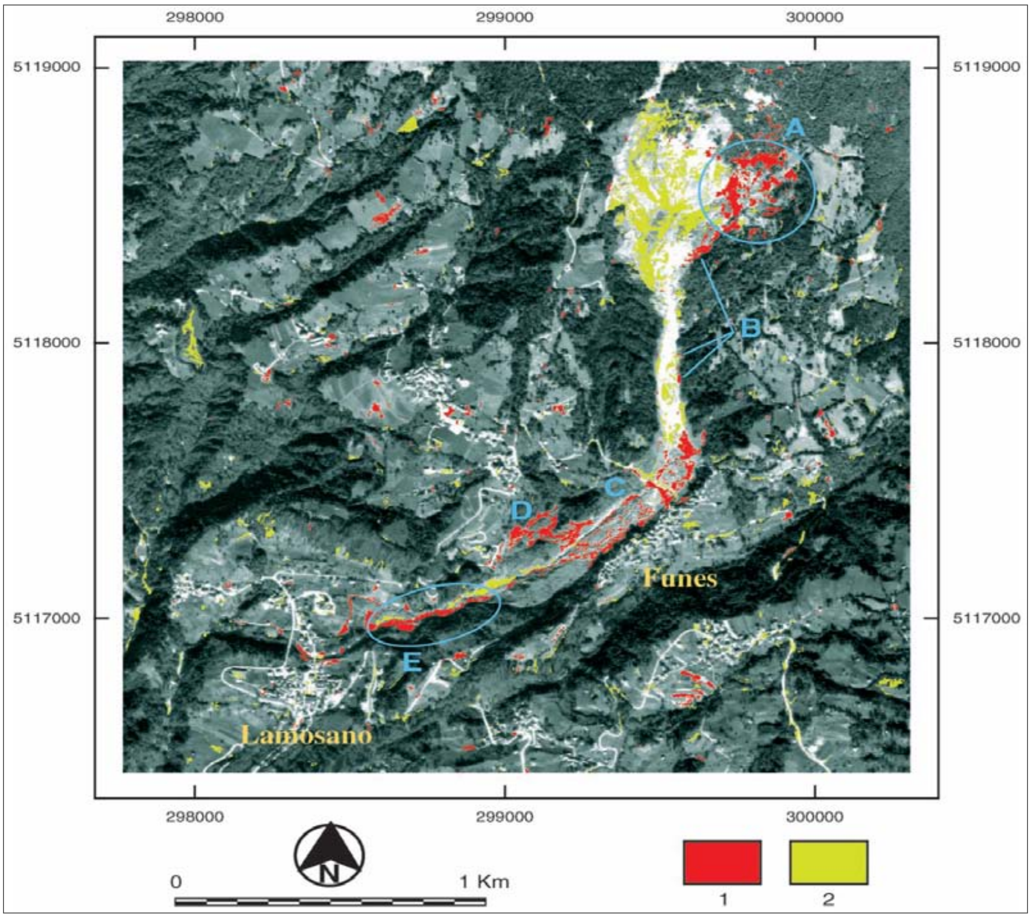

Fig. 1: Surface changes in the Tessina landslide between 1988 and 1994, illustrated on the 1994 orthophotograph. (1) within the landslide body, positive pixel intensity changes represent new soil outcrops and remobilised soil as a result of landslide reactivation; (2) negative pixel intensity changes are due to vegetation growth or soil moisture increase. Most changes outside the landslide correspond to land use change. Coordinates in UTM (HERVÁS et al., 2003).

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Advanced Criteria and Techniques for Landslide Monitoring

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AMRA is developing two main tasks about landslide monitoring, which respectively concern advanced criteria (geoindicators) to be used within early warning systems of rainfall-induced flowslides (WP 4.3) and remote sensing techniques (WP 4.2).

Geoindicators

The interest for early warning takes its origin from the high rainfall-induced landslide hazard which affects extensive areas in Campania, Southern Italy, where debris flows can take place along steep slopes covered by shallow unsaturated deposits of loose granular pyroclastic soils. The great extent of zones susceptible to debris flow makes the adoption everywhere of structural works for slope stabilization practically impossible. So, the development of innovative procedures for timely landslide alerting is an emerging idea. This requires, as a first step, the understanding of the hydro-mechanical processes which lead to slope failure, and, as a second step, the study of the precursors and of the indicators of impending failure to be monitored and evaluated in real time.

Such a study is being carried out through physical modelling and monitoring of instrumented slopes. The physical model consists of a heavy instrumented flume, purposely designed and built to reproduce precipitation-induced slope failure in unsaturated soils, by imposing an artificial rainfall. Several sensors allow the observation of the soil behaviour, i.e.:
i) miniaturized tensiometers, to monitor matric suction; ii) minitransducers located at the bottom of the slope, to measure positive pore pressures; iii) laser sensors to record settlements of the soil surface; iv) video-cameras to investigate the displacement field prior and after slope failure.

The experiments show that slope failure in loose soils is announced by large volumetric strain and by the formation of large cracks in the source area. Also, if the slope angle is close to the friction angle of soil, failure occurs only when a condition of full saturation is reached. Thus, both soil deformation and water content changes can be used as indicators of impending failure. Starting from these considerations, a new experimental program is going on in order to test optical fibres and TDR sensors to be used in situ as geoindicators. Optical fibres are stimulated by two counterpropagating light-waves, whose interaction causes a power transfer which, in turn, depends on fibre temperature and strain. Although Time Domain Reflectometry technique for the measurement of the average soil moisture is well known, we are actually adopting an inverse procedure to retrieve the moisture profile along the entire probe. Such a technique seems promising since the thickness of the covers subjected to debris flows in source areas is generally quite thin, ranging between some decimetres and almost a few metres, and so the water content along the entire thickness of the soil can be estimated by a single probe.

We are testing both devices in the flume. The geometry of the slope and position of the adopted devices are illustrated in Figure 1: two strands of optical fibres, running the length of the slope, are buried in the soil. The two strands are separated by a fiber spoil of some tens of meters, placed outside the soil and not subjected to strain. The TDR is placed normal to the ground surface and can capture the entire profile of the water content within the layer.

TDR robes have been installed in an instrumented slope just aside the Cervinara landslide (1999) and in another slope (Monteforte Irpino) along the highway linking Naples and Avellino. The availability of rainfall data, which is monitored by a rain gauge and of suction, which is measured by a number of tensiometers will allow to assess the usefulness of the proposed approach in real cases.

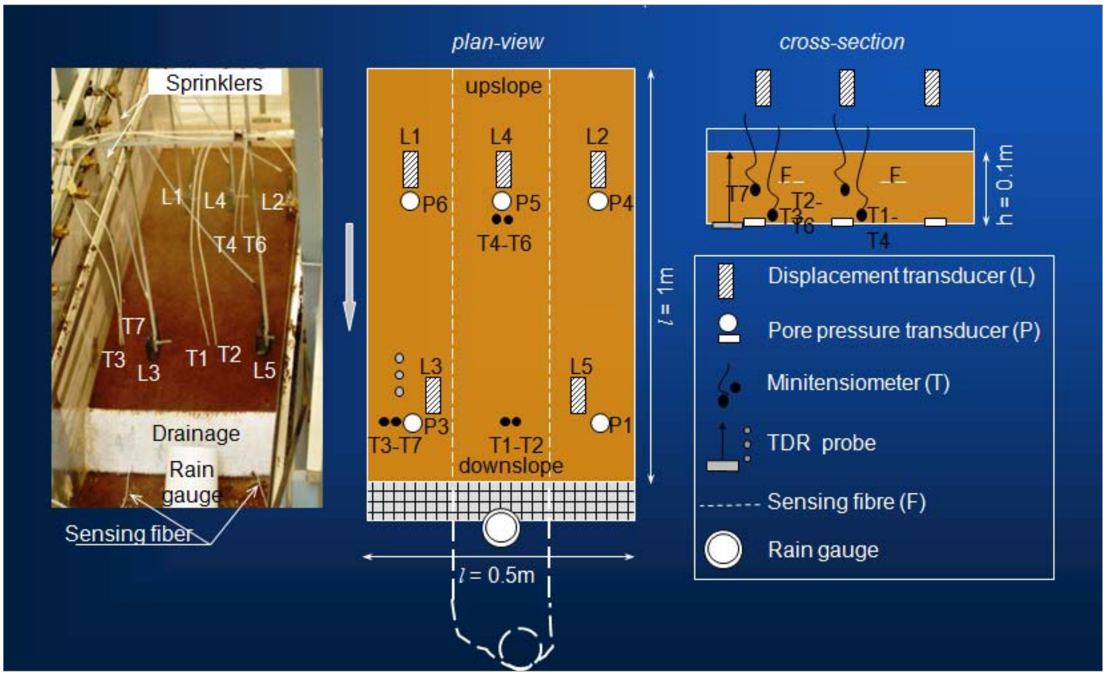

Fig. 1: Assessment of new devices for early warning of rainfall-induced flowslides.

Remote Sensing

The second part of the presentation in Vienna has dealt with remote sensing techniques for landslide monitoring. AMRA has first of all provided a contribution to the review of the so-called Advanced-DInSAR (A-DInSAR) techniques, i.e. the techniques that, allow monitoring of ground deformations by using multiple passes of the satellite SAR sensors. Such techniques are grouped in two classes: the Interferogram Stacking Techniques and the Persistent Scatterer Interferometry (PSI). The AMRA review activity has concerned the Interferogram Stacking Techniques, which have been originally designed for monitoring at a low resolution scale of scenes characterized by a distributed scattering. These techniques are complementary to the Persistent Scattering Interferometry techniques, which model the ground scattering and carry out only a highest scale analysis. Nonetheless, additional modules, such as the high resolution Small BAseline Subset (SBAS) and the Tomographic analysis, use the low resolution products for the calibration of the data and for the generation of DinSAR products at the highest resolution. An example of full resolution tomographic analysis is given in Figure 2a, which shows the radar points overlaid on the Google image in the area of Viale Giustiniano Imperatore in Rome: serious building damages were reported in the past and the deformation area associated with the red pixels is located on a recent alluvial deposit area due to the Tevere River. Figure 2b, on the other hand, shows an example of low resolution analysis performed on an area in Nevada of 60,000 km^2. Another contribution provided by AMRA in cooperation with the University of Salerno has regarded the analysis of already available DInSAR results relevant to the ERS-1 and ERS-2 satellite descending passes over the test site "Liri Garigliano Volturno Basin in Central Italy" (test site 33). In particular, we have investigated the issue of radar visibility of areas affected by landslides, which may be impaired by the presence of slopes. Typically, landslides are visible only on one of the pass classes: ascending (i.e. the radar line of sight toward east) and descending (i.e. the radar line of sight toward west). A-priori visibility maps allow to investigate, the visibility of the areas on the ground, thus providing useful indications for the choice of the dataset. Radar interferometry only allows measuring a scalar component of the displacement: i.e. the component of the displacement along the radar line of sight. We have also analyzed the possibility to integrate radar measurements and displacement models to allow improving the interpretation of DInSAR results (for instance evaluating the translational displacement).

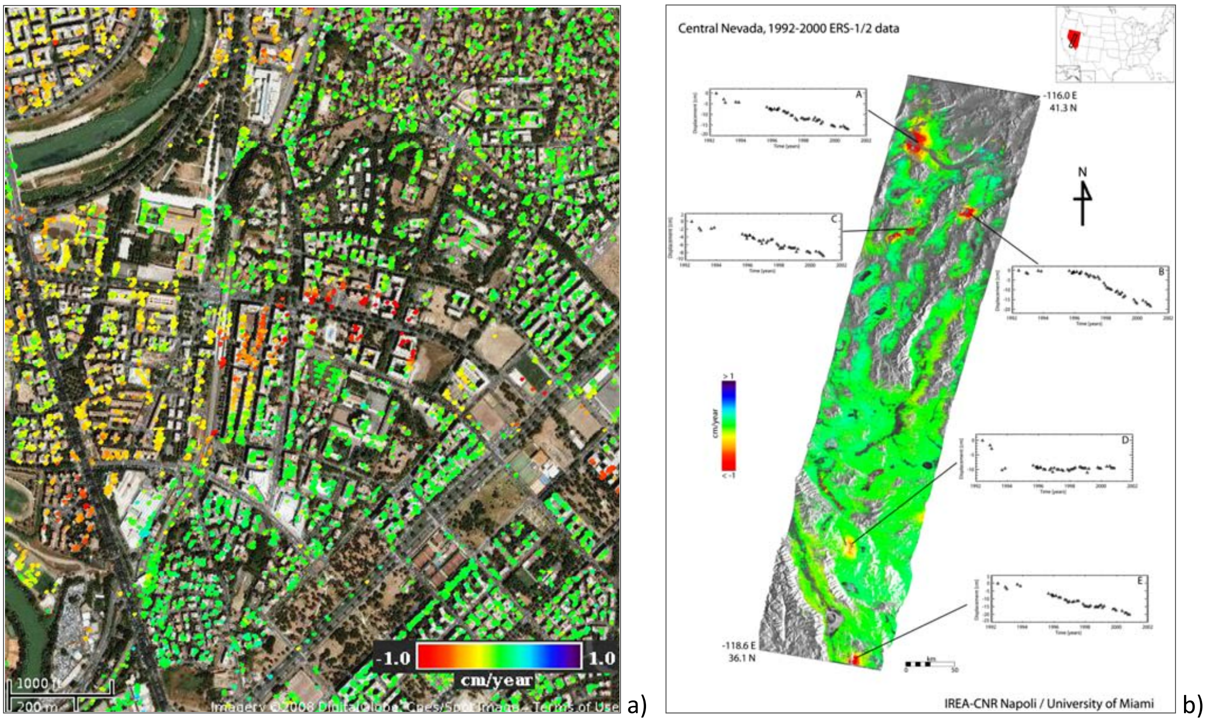

Fig. 2: Examples of tomographic analyses: a) full resolution; b) low resolution (IEEE Copyright).

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A New Approach to the Use of DInSAR Data in Landslide Studies at Different Scales: the Case Study of National Basin Authority of Liri-Garigliano and Volturno Rivers (Italy)

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In the last decade, remote sensing techniques have proven to be helpful in detecting large areas and in analyzing both the state of activity and the kinematical characteristics of the instability phenomena. In particular, the contribution of the integrated use of remote sensing techniques such as Differential SAR Interferometry has already been dealt with in the scientific literature via a number of case studies. However, standardized procedures for the interpretation and the confident use of DInSAR data, according to landslide zoning developments, have not been fully investigated and validated, although algorithms for image processing have become more and more sophisticated.

Starting from current limits to the applicability to landslide studies, this research introduces innovative procedures for the generation of advanced DInSAR landslide velocity maps (CASCINI et al., 2010) based on the joint use of DInSAR data at both full- and low-resolution (FORNARO et al., 2009a and b), simple geomorphological models and geometric considerations. To this aim, ERS image datasets are processed inside a well documented area, of 489 m^2 within the National Basin Authority of "Liri-Garigliano and Volturno" Rivers (Central-Southern Italy), for which both base and thematic maps are available.

The first step is the generation of the a-priori DInSAR landslide visibility map (described in detail in CASCINI et al., 2009) which allows zoning the areas where remote-sensed data can be available. Then, the use of advanced low-resolution DInSAR landslide velocity maps suggests perspectives of increasingly reliable applications to check/update landslide inventory maps at a scale of 1:25,000 over large areas (CASCINI et al., 2009, 2010). As for the full-resolution DInSAR data, the analyses carried out at a scale of 1:5,000 allow: i) the investigation of likely relationships among evidence of movement/no movement derived from DInSAR data; ii) the updating of the evolution model of the slope affected by landsliding, as well as an insight into the damage survey to buildings located within the unstable areas (CASCINI et al., 2010).

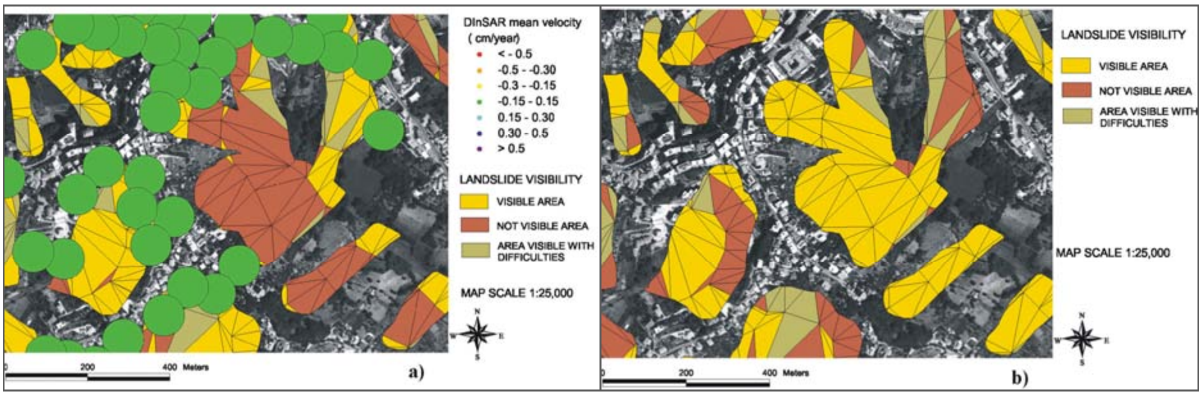

Fig. 1: The "a priori DInSAR landslide visibility map": a) on descending orbits with low-resolution DInSAR coherent pixel distribution; b) on ascending orbits (CASCINI et al., 2009).

The results obtained seem particularly appealing considering the enhanced capabilities of the newest sensor (e.g. TerraSAR_X, COSMO/SKYMED, etc.) which will offer high resolution DEMs also allowing improved spatial resolution, three times higher data acquisition frequency and an increase in the sensitivity to temporal decorrelation via the reduction of the wavelength.

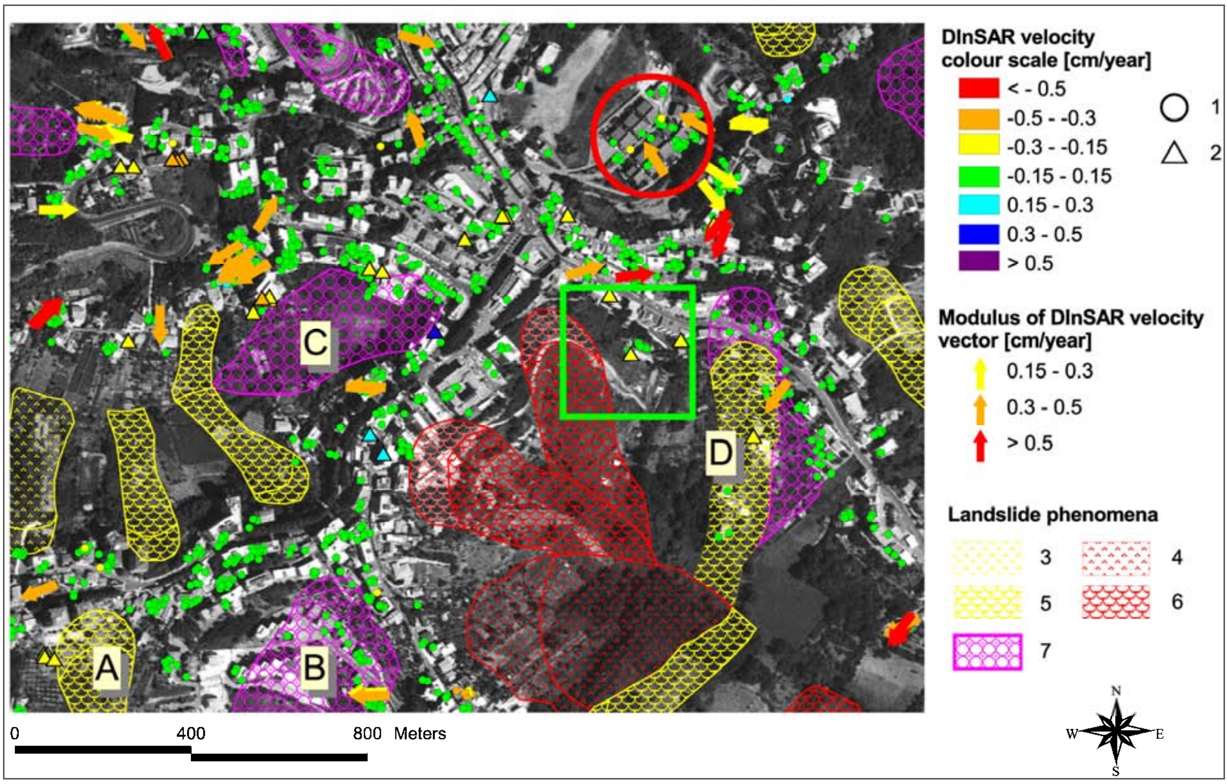

Fig. 2: Example of advanced full-resolution DInSAR landslide velocity map.
1) Not moving DInSAR coherent pixel or on flat areas; 2) not projected translational displacement owing to high condition number; 3) dormant rotational slide; 4) active rotational slide; 5) dormant earth flow; 6) active earth flow; 7) creep phenomenon (CASCINI et al., 2010).

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GeoZS – Landslide Issues in Slovenia and Contribution to the SafeLand Project Stože Landslide

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Slovenia is positioned on the complex Adria – Dinaridic – Pannonian structural junction and its general geological structure is well known. As a consequence of an extraordinarily heterogeneous geological setting, Slovenia is very much exposed to slope mass movement processes. Figure 1 shows that almost one quarter of Slovenian territory is subjected to processes of slope mass movements, and based on rough estimations, around 18 % of the population is under threat (KOMAC, 2005).

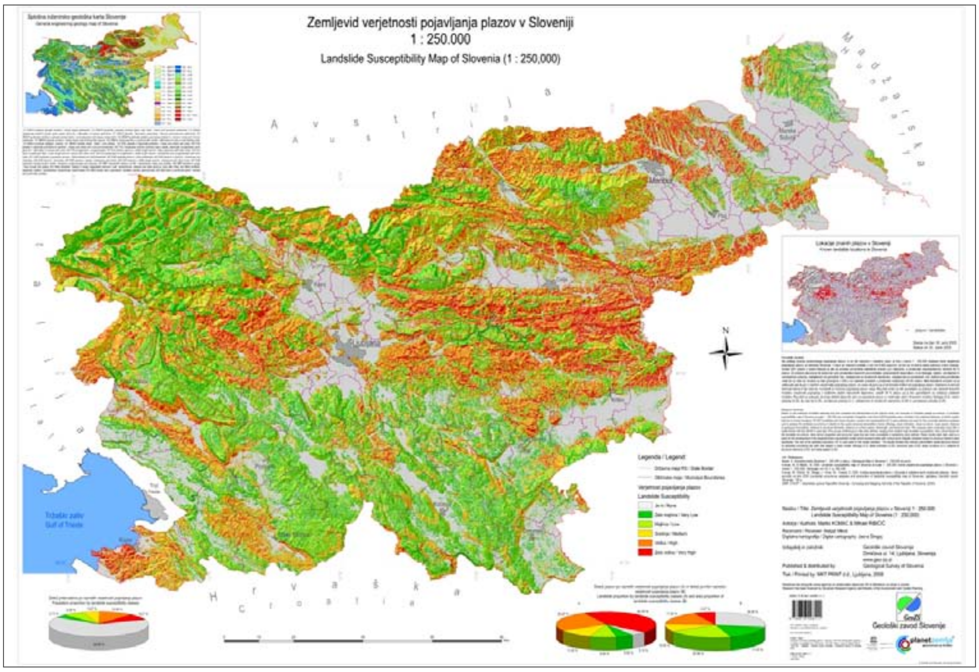

Fig. 1: Landslide susceptibility map of Slovenia (1:250,000) (KOMAC, 2005).

Legislation, planning and prevention measures are not satisfying in the field of landslides in Slovenia and the primary activities are still focused on the remediation instead of the prevention measures. The updated spatial law from 2007 governing natural disasters also discuss problems with mass movements, but a common methodology and procedures to prevent geology-related natural disasters does not yet exist. Local communities, which are currently preparing new planning acts of the municipalities, are committed to include a part on protection from natural hazards. Most important is to ensure the production of good evidence, which will clearly identify risk areas. Unfortunately, there is no statutory methodology for hazard mapping, so it is expected that local communities will have different quality bases.

Effective prevention is based on two equally important components: (1) Capturing and storing data on landslides (GIS_UJME – a national landslide database containing 6602 landslides, but has not been updated since 2005) and monitoring changes in the existing (active) landslides and (2) Production of risk assessment maps (geo-risk maps for municipalities and probability maps), indicating the threat of certain areas to possible landslide occurrence.

Our contribution to the SafeLand project in the Area 4 will be performed on the Stože landslide, which occurred in November 2000 in the NW of Slovenia, in the Bovec municipality, under the Stože mountain (Figure 2). In the lower part of the slope, at the bottom of a small valley, runs a torrent named Mangartski potok. The first landslide movement (which was triggered by very intense rainfall) dammed up the torrent, resulting in a huge debris flow which flooded the village of Log pod Mangartom 4 km downstream. By its size, this was one of the largest events in Slovene history (materials from an area of over 25 hectares were displaced and deposited over more than 15 hectares). The consequences were catastrophic, with 7 casualties and huge material damage (MAJES, 2001).

A part of the slope debris above the landslide (approx. 1 million m^3) remained in place, but its stability was reduced to the limit state of equilibrium and continues to pose a threat. That is why we want to apply new techniques and to evaluate and compare the results with already performed researches: geological, engineering geology and hydrogeology mapping, drilling (piezometers, inclinometers – which were destroyed later), ground seismometry and ground radar. Our work will comprehend (1) microtremor measurements (TROMINO portable seismographs for microtremor monitoring on landslides with HVSR – Horizontal to Vertical Spectral Ratio) to determine the depth of landslide thickness and landslide activity stage in time of measurement) and (2) airborne geophysical mapping (will be performed by GSA) to help detect areas susceptible to a high sliding risk.

Fig. 2: Left – municipality Bovec, where landslide Stože is located.
Right – slope, where landslide Stože was "triggered" (Photo: M. ČARMAN, 2009).

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DInSAR vs. Wire Extensometer Calibration, and GBSAR First Survey at the Vallcebre Landslide (Spain)

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The Technical University of Catalonia (UPC) group collaborates in the Area 4 of the SAFELAND project. It is composed of researchers from the Geotechnical Engineering and Geosciences Dpt., the Signal Theory and Communications Dpt. and the Institute of Geomatics. The leaders of this group for SAFELAND are Prof. J. COROMINAS and Prof. E. ALONSO.

The work carried out by the UPC in Area 4 up to now has been presented by J.A. GILI on behalf of the group. We have some expertise in general DInSAR (Differential Radar Interferometry) monitoring with ENVISAT images that is currently extended to TerraSAR-X images. The Institute of Geomatics owns a GBSAR (Ground Based Synthetic Aperture Radar) system (IBIS-L model from Ingegneria Dei Sistemi – IDS; working in the Ku band, 17.1 GHz), and the Signal Theory and the Communications Dpt. have developed a R&D GBSAR prototype system that can work in the K, X and C bands, with polarimetric capabilities (PIPIA et al., 2009). We are in the initial steps for the application of both the DInSAR and the GBSAR techniques to landslide monitoring. As field sites for the SAFELAND project, we are considering the Vallcebre landslide (NE of Spain) and the Canillo landslide (Andorra).

DInSAR vs. Wire Extensometer Calibration

When possible, it is desirable to compare the modern and the classical techniques in order to calibrate their results and to validate the new methodologies as well. We have carried out a DInSAR versus wire extensometer calibration in the Vallcebre Landslide (Figure 1).

Fig. 1: The Vallcebre landslide (Eastern Pyrenees, Spain).

The Vallcebre landslide is a translational one where a 5–30 m layer of clayey limes and silts slide over a limestone rockbed. Its behaviour is closely related with the rain and the water presence and pressure inside the slope, registering velocities between 0.2 and 1.5 m per year. Since 1985, we have installed and used several monitoring systems there (surveying, piezometers, inclinometers, rain gauges, GPS, wire extensometers...). In November 2006, we installed seven corner reflectors to enhance the performance of DInSAR techniques (Figure 2). The cross-checking of the DInSAR results versus the displacements derived from the wire extensometers has been carried out in 2007 and 2008, and some preliminary results have been obtained (GILI et al., 2009).

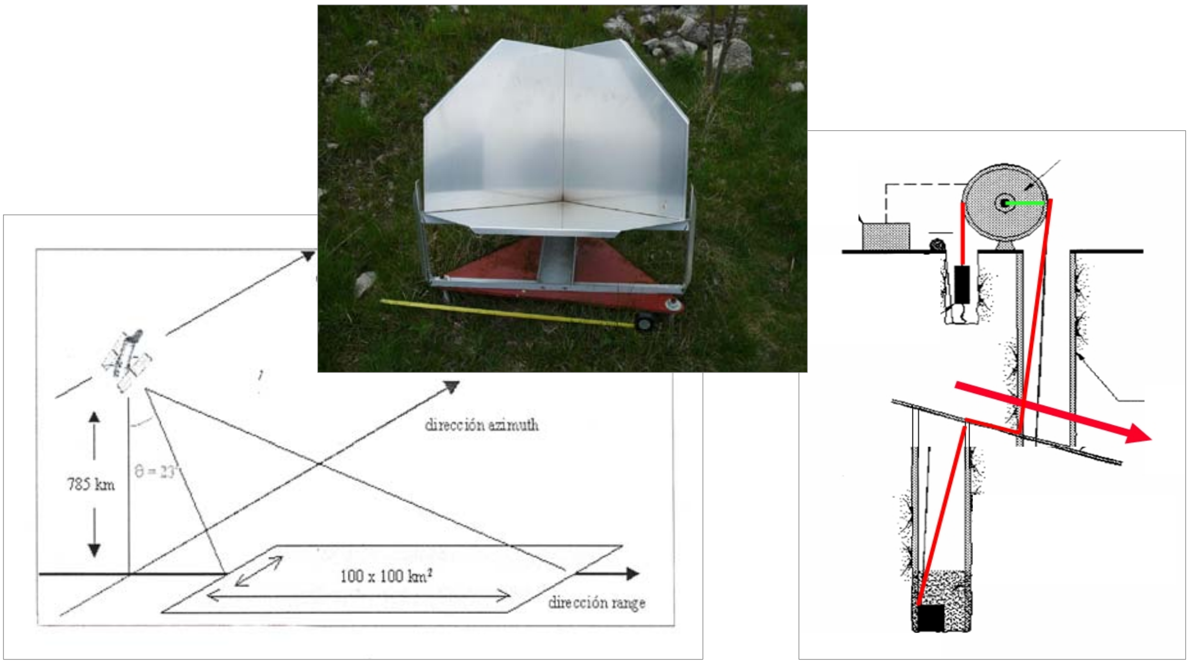

Fig. 2: The DInSAR technique (left, CROSETTO et al., 2009) has been calibrated in several corner reflectors (center) versus the wire extensometer displacement (right, COROMINAS et al., 2000).

GBSAR First Surveys

This winter has been quite harsh, which complicated the field works in the Pyrenees range. However, several preliminary GBSAR campaigns have been carried out in Canillo and Vallcebre (Figure 3) in order to prepare the real start of the GBSAR monitoring. This will help the SAFELAND project to assess the advantages and drawbacks of this technique as landslide monitoring and early warning system.

Fig. 3: The IBIS-L–IDS GBSAR system installed in front of the Vallcebre landslide by the Institute of Geomatics for the first tests. A number of mini-corners (right) were deployed in the scene.

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Forecasting the Failure of Large Landslides for Early Warning: Issues and Directions

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Complex, deep-seated landslides (e.g. rockslides, debris slides) pose a significant threat to human lives and infrastructures in alpine valleys. These landslides usually show peculiar structural and kinematic features, generally related to their scale. They reach up to several tens of million cubic metres and affect steep slopes up to 1000 m high. This results in a significant interplay of rock slope instabilities with large-scale geological features, acting as constraints on the rockslide geometry and kinematics (AGLIARDI et al., 2009). The long-term evolution, scale and geometrical/geomechanical complexity of large rockslides result in complex onset, deformation and failure mechanisms. These take place over a timescale of 10^2–10^3 yrs in changing geomorphological systems under the action of multiple triggers, including: post-glacial debuttressing and rock mass strength degradation, toe erosion, rainfall/snowmelt and related groundwater changes, reservoir level fluctuation, and progressive failure processes. Forecasting the failure of these landslides is difficult, due to non-linear displacement trends and the superposition of seasonal effects. Large rockslides can show creep-type deformation patterns (CROSTA & AGLIARDI, 2003), possibly characterized by continuous acceleration until catastrophic failure. The temporal pattern of displacements (slow vs. catastrophic, continuous vs. episodic) will depend on the evolutionary stage, reference time interval, seasonal effects, and whether the landslides actually reach a critical acceleration stage (BROADBENT & ZAVODNI, 1982). In any case, a sound prediction of the landslide evolution to failure require a time-dependent description of landslide behaviour in terms of some kinematic of dynamic quantity, to be calibrated using time series of measurements. Several models based on the "slope creep" theory (i.e. micro-mechanical, rheological, empirical) have been proposed in the last fifty years to provide such description. Among them, empirical/phenomenological approaches (SAITO & UEZAWA, 1961; FUKUZONO, 1985; VOIGHT, 1988) proved to be suitable to describe time series of monitoring. Different approaches have been proposed to estimate the time of failure of landslides showing accelerating creep, mainly based on the use of "inverse velocity" (FUKUZONO) and "log a – log v" plots. These methods proved to perform well in simple cases, showing continuous acceleration. Nevertheless, they fail to provide reliable failure time estimates for landslides showing complex response to external actions (e.g. seasonal pattern of displacements controlled by rainfall/snowmelt) or complex deformation-failure mechanisms (e.g. progressive failure, landslide sub-units with different scale and kinematics). These factors can result in very different temporal patterns of displacements (Figure 1), which need to be carefully evaluated when attempting to model landslide evolution. Other modelling issues include the preliminary evaluation of the type of data (i.e. surface vs. deep instrumentation, local vs. distributed measures, accuracy) and the definition of required measurement frequency and time windows. The latter affects the ability to catch progressive trends and understand landslide response.

Taking into account the issues and difficulties mentioned above, innovative approaches were proposed to establish alert displacement / velocity thresholds to be used as Early Warning tools for complex landslides showing significant seasonality. CROSTA & AGLIARDI (2003) obtained alert velocity thresholds through non-linear estimation techniques. Although physically-meaningful, the Early Warning tools provided by this approach are affected by significant uncertainty and need continuous update to be representative of the landslide evolution to failure. Thus, the approach will be implemented in the SafeLand project framework by integration of surface and deep-monitoring data (e.g. inclinometer, DMS), spatially distributed displacement measurements (e.g. GB-InSAR), and deterministic modelling of triggering processes (e.g. rainfall, groundwater changes) for selected large rock-slides and debris slides.

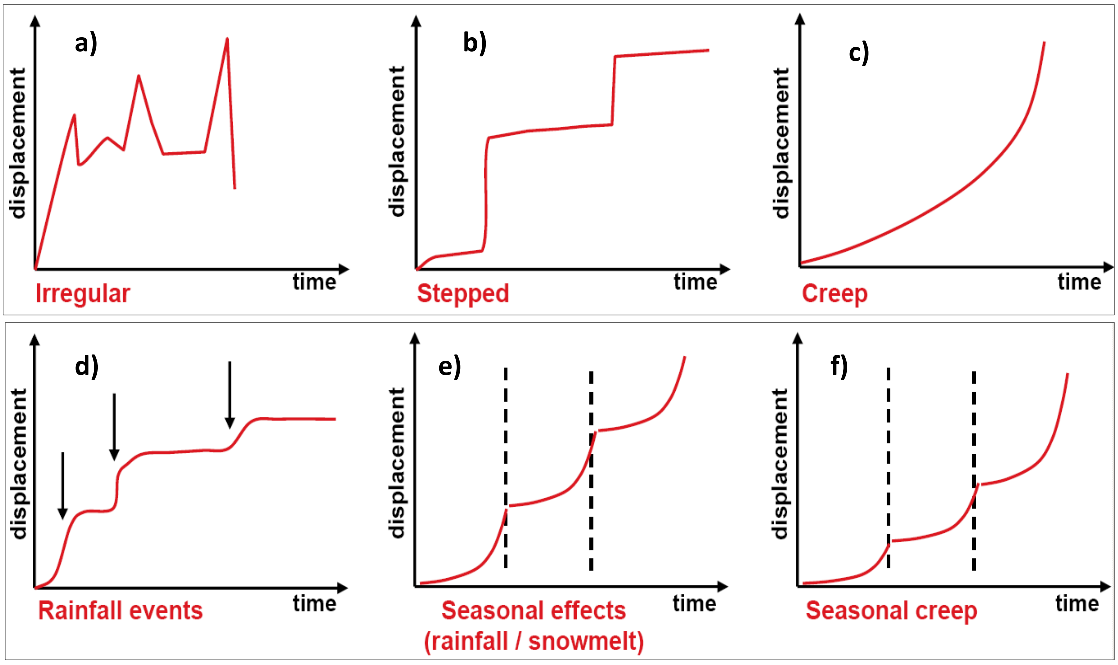

Fig. 1: Temporal pattern of displacements for large landslides, commonly derived by time series of monitoring data. Different patterns can be observed depending on the landslide failure mechanism and kinematics at different scale (a, b, c), and on the response to external actions (d, e, f).

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Airborne Geophysics and Geoelectric and Inclinometric Monitoring at the Gschliefgraben Landslide

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Airborne geophysics has recently emerged as an innovative methodology for landslide investigation (SUPPER et al., 2007). By the end of September 2009, a complex airborne geophysical survey was performed in a large complex of geologically controlled landslides and earth flows in the Gschliefgraben valley in Upper Austria (municipality Gmunden) east of the lake Traunsee. Simultaneously, the GEOMON^{4D} and DMS automated monitoring systems were installed to obtain the information on ground resistivity temporal change, displacement and ground water level changes.

The area of Gschliefgraben is a 2.85 km long and 0.85 km wide valley along the foot of the Northern Calcareous Alps. The front of the Northern Calcareous Alps forms a steep cuesta there with the summit at Mt. Traunstein (1691 m a.s.l.; Figure 1). The catchment is divided into small subparallel channels and subsequent catchments; its topography is strongly controlled by the mass wasting that has developed since the end of the last glacial period. In late November 2007, probably triggered by a rock fall in April 2006, an earth flow of about 3.8 million m^3 of colluvial mass was reactivated. Displacement velocity was up to 4.7 m/day at the beginning (MARSCHALLINGER et al., 2009). The main mass wasting processes are represented by sliding and flowing in the central part (Figure 2), which is built mostly of Ultrahelvetic marls and shale. These incompetent, soft rocks are intensively fragmented with relatively high content of swelling clay minerals. They emerge here in the form of a tectonic window below the Rhenodanubian Flysch and the overlying Northern Calcareous Alps. On the other hand falling, toppling, and spreading are the most characteristic types of movement in the eastern and southern marginal areas of the Gschliefgraben where mostly hard rock occurs (Northern Calcareous Alps, Pleistocene talus breccias).

Fig. 1: Airborne photograph of the Gschliefgraben area from the West (Photo by R. SUPPER, 2009).

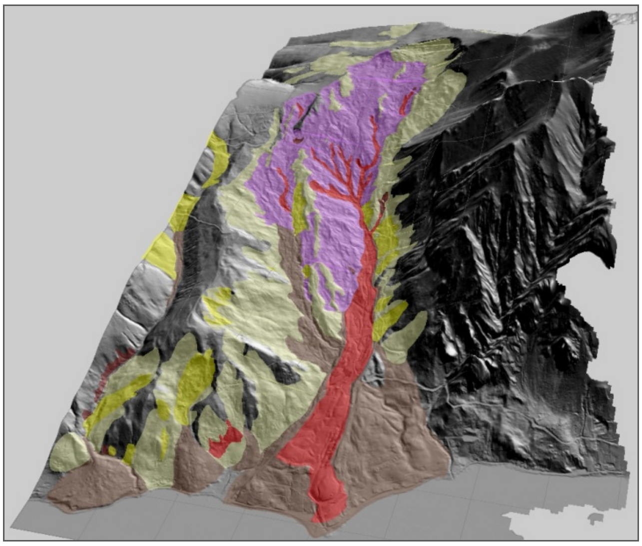


Fig. 2: 3D visualization of the slope-failure inventory map of the Gschliefgraben area: red – active landslides and earthflows, purple – area of active and suspended small scale shallow landslides and earthflows, brown – inactive earthflow accumulations, yellow – suspended landslides, light yellow – dormant and relict landslides.

Airborne Geophysics

Airborne geophysics is now a promising method for landslide investigation. Therefore, it was tested in the well-documented and investigated site of Gschliefgraben. One of the big advantages of this approach is surveying of large areas within relatively short time, while the internal structure can be derived. The airborne geophysical survey consisted of the frequency domain electromagnetic, gamma-ray spectroscopy, and magnetic and passive microwave survey.

The frequency domain electromagnetic method is intended to determine the distribution of the specific ground electrical resistivity, giving information mainly on porosity, water saturation, conductivity of the pore fluid and clay content. Variable frequencies and different geometric arrangements of the coils were used in order to allow depth-specific sounding of the subsurface. The lowest frequency determines the total penetration depth of the method, i.e. approximately 120 m below the ground surface. The registered lowest resistivity is related generally to areas most susceptible to mass wasting (Figs. 3 and 4).

Another approach (gamma-ray spectroscopy) determines the natural and artificial radioactivity, which depends on the content of radioactive minerals within the first decimeters of the subsurface. Natural gamma radiation is essentially derived from three sources: the radioactive elements thorium (energy peak: 2.62 MeV), uranium (energy peak: 1.76 MeV) and potassium (energy peak: 1.46 MeV). These elements occur in different rocks and soils at various concentration levels. The content of those radioactive elements was explicitly related to the original geological structure: the highest content was registered in areas of shale, claystone and sandstone, while the lowest content along limestone and breccias (Figure 5). The relation of the radioactive contents to landslide bodies will be a task for further research.

The airborne magnetic survey defines the total intensity of the earth’s magnetic field. Deviations from a reference earth magnetic field are considered as anomalies and assist e.g. in the discovery of differently magnetized bodies (i.e. ore bodies, young volcanic rocks, metallic contents of waste repositories) or fracture zones. The relation of the magnetic field anomalies and mass wasting also remains a task for further research.

The last tested parameter, the passive microwave, is used for estimating soil moisture (in water content percentage) within the first centimetres of the subsurface by a passive L-band antenna (1400 to 1427 MHz). The intensity of this radiation correlates to the water content in the soil and is influenced by the surface temperature, surface roughness as well as vegetation; the "penetration" depth of this method is 5–10 cm. The highest soil water content was registered within the zone of the active earthflow and along a shore line of Traunsee (Figure 6). The soil moisture surveying seems to be a promising indicator of active mass movements.

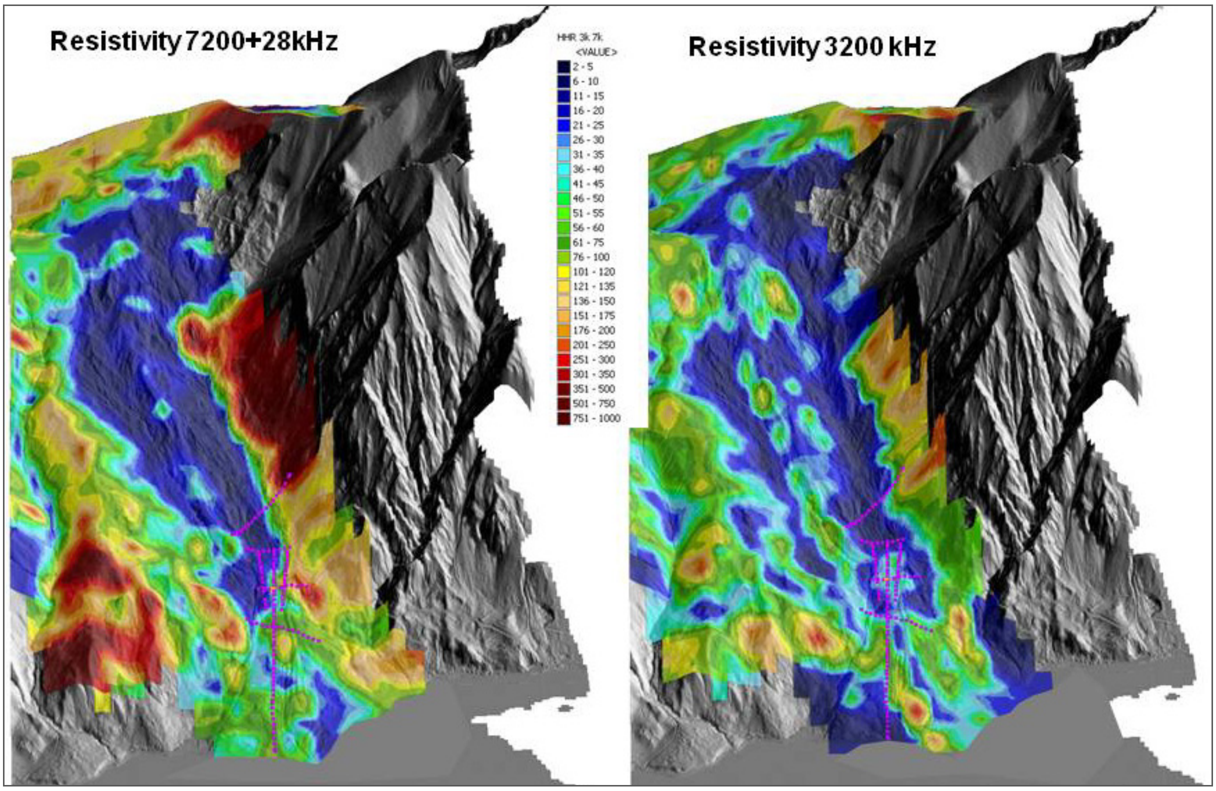


Fig. 3: 3D visualization of the airborne electromagnetic survey of the Gschliefgraben area.

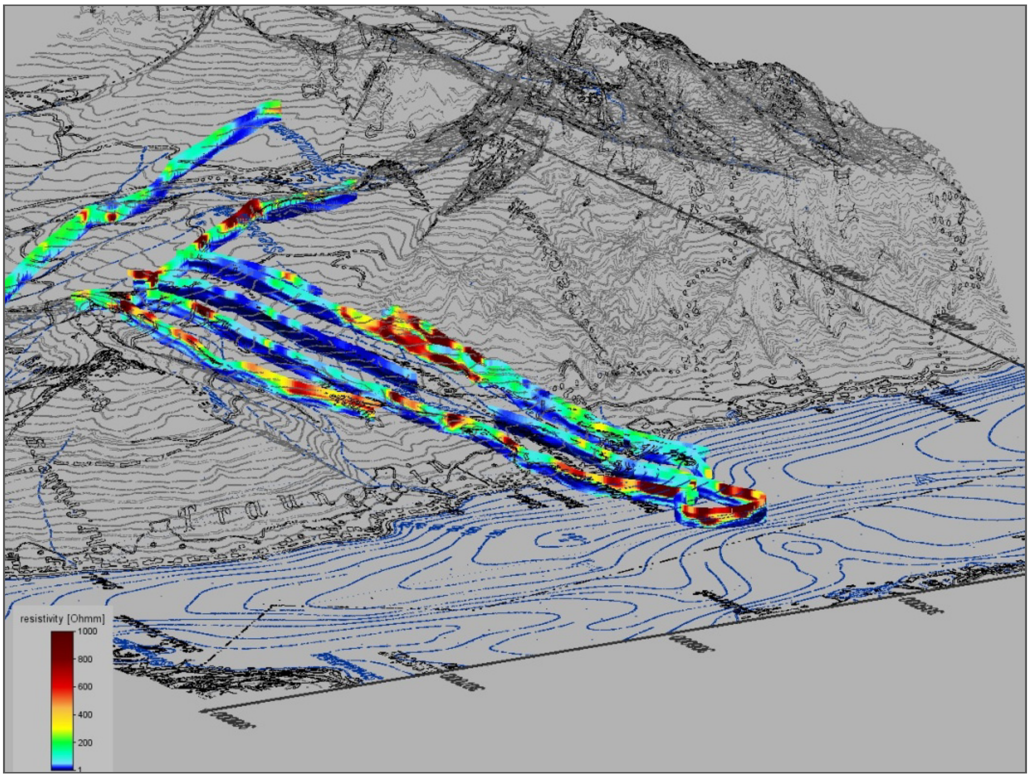
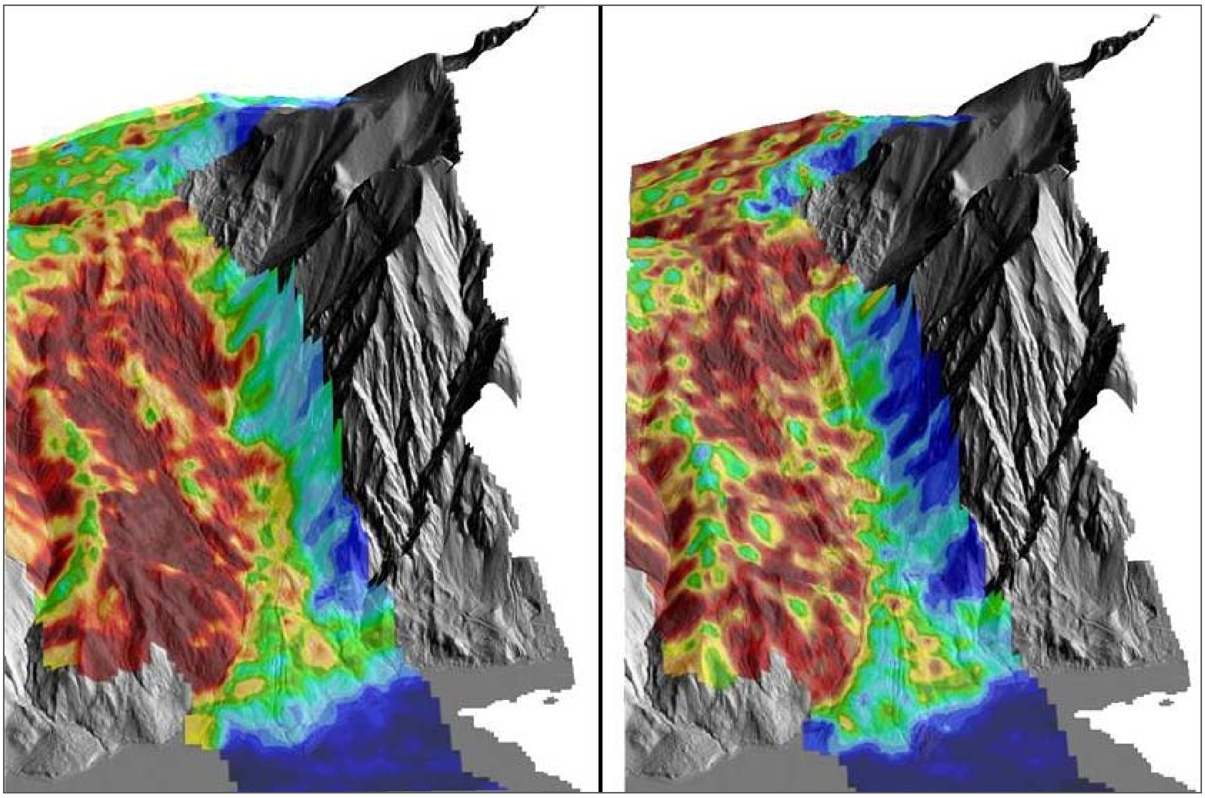


Fig. 4: 3D visualization of the airborne electromagnetic survey of the Gschliefgraben area: ground resistivity profiles are 120 m deep and follow the path of the helicopter.



A)

B)

Fig. 5: 3D visualization of the airborne gamma-ray survey of the Gschliefgraben area for: A) Potassium and B) Thorium (high content in red colors, the lowest content is in deep blue).

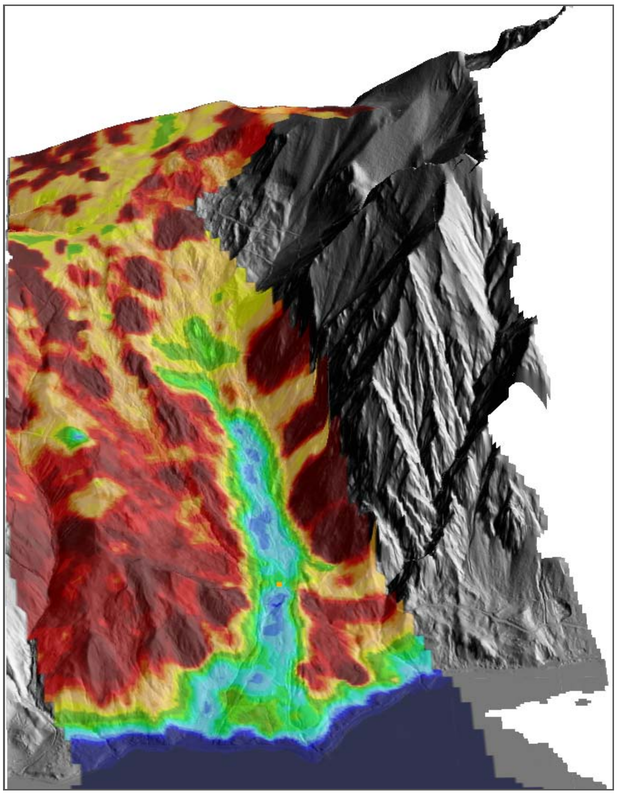


Fig. 6: 3D visualization of soil moisture of the Gschliefgraben area by the airborne survey.

Mass Movement Monitoring

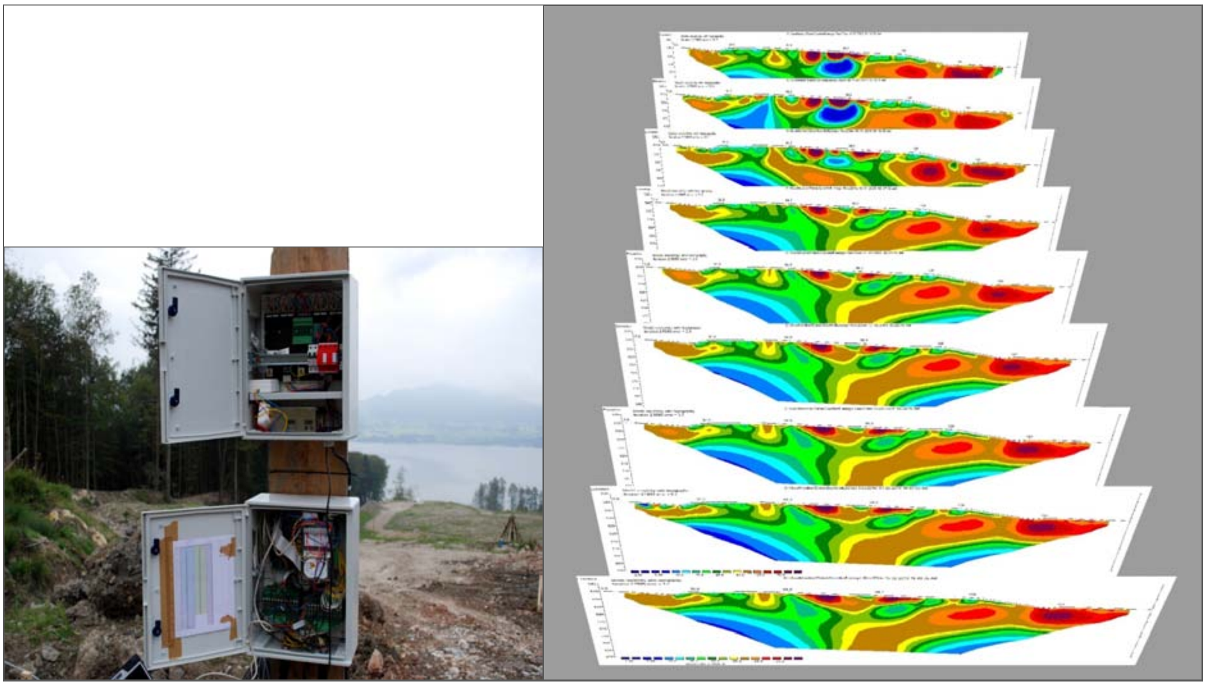
The other aim of our activities at the Gschliefgraben test site was to introduce new techniques for mass movement monitoring and early warning. For this purpose, the GEOMON^{4D} and D.M.S. automated monitoring systems were installed in the lower central part of Gschliefgraben valley.

The GEOMON^{4D} is a new tool for high speed ground resistivity and self-potential measurement. Data acquisition of about 3000 measurements/hour in single channel mode and usually 1000 samples per single configuration (including recording of the full signal) enable effective noise analysis and filtering. Moreover, a completely open architecture allows installation of any number of current or potential electrodes by adding parallel or serial cards. The GPRS (General Packet Radio Service) data transfer allows the maintenance to be performed fully remote-controlled. Data, such as measurement results, test sequences and log files, containing information about system and GPRS connection status are sent automatically via email to the data processing centre at GSA. Consequently, immediate availability of information for local stakeholders could be guaranteed.

In the centre of the landslide of Gschliefgraben, two monitoring profiles were installed. The central control unit and preliminary results from one profile are presented in Figure 7.

To define correlation between geoelectric anomalies and the triggering of movements, an innovative multiparametric monitoring system of stability D.M.S. (**D**ifferential **M**onitoring of **S**tability; Centro Servizi di Geoingegneria, Italy) was implemented in the crossing of the GEOMON^{4D} profiles. The D.M.S. tool measures high accuracy displacements in 2 or 3 directions (both horizontal and vertical at all the prefixed depths), piezometric ground-water level and soil temperature up to depths of 26 m below the ground-surface. Thus it allows the complex analysis of the dynamics of mass movement, e.g. deformation analysis, displacement, velocity, acceleration, and depth of failure or piezometric variations (FOGLINO et al., 2006).

As the preliminary results show, the monitored earthflow at Gschliefgraben undergoes continuous movement since the installation of D.M.S. (24th September, 2009) with a few smooth acceleration phases only (Fig. 8). The correlation of displacement and precipitation is not very clear. The correlation of the ground resistivity and the mass movement is a task for further research.



A) B)

Fig. 7: Geomon^{4D}: a tool for continuous, automatic and remotely-managed monitoring of ground resistivity changes. A) a photo of the central part of the Geomon^{4D}, B) set of result images of the longitudinal profile registered between September 2009 and February 2010 with a 14-day separation.

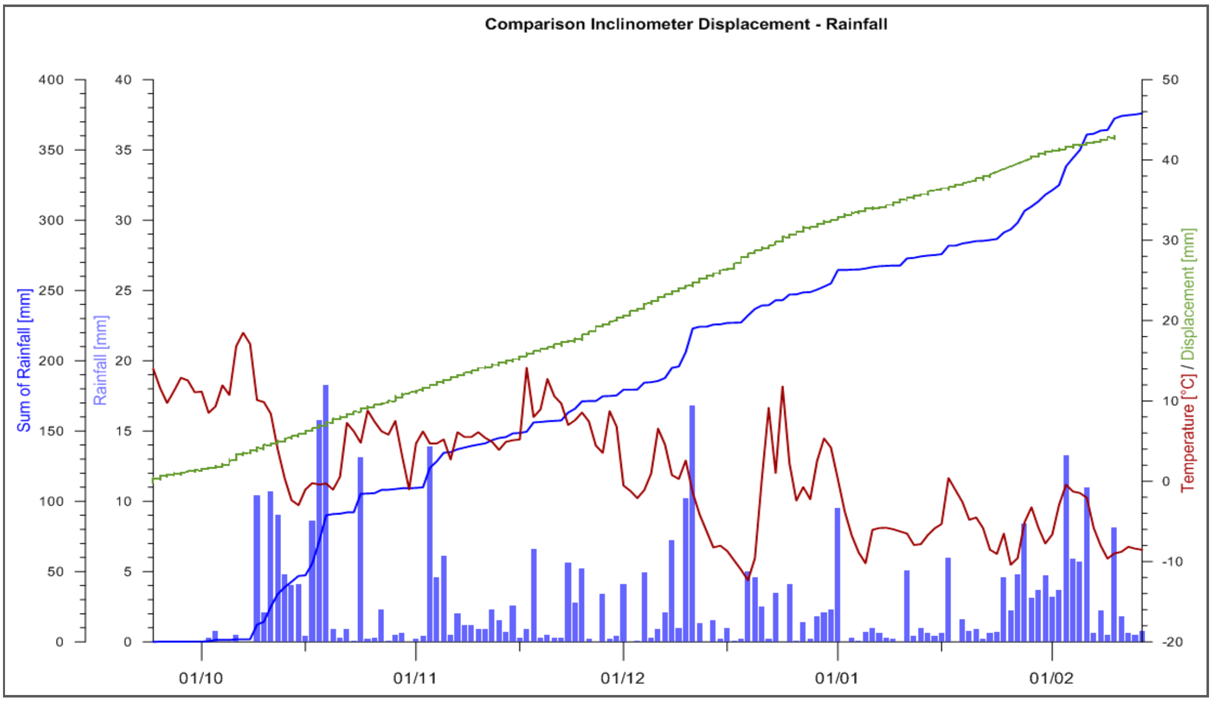


Fig. 8: Results of DMS monitoring of cumulative displacement correlated with air temperature, ground water level and mean day precipitation registered between September 2009 and February 2010 in the central part of Gschliefgraben.

Acknowledgement

The authors would like to acknowledge the excellent close cooperation with **Torrent and Avalanche Control (WLV), Section Upper Austria, Centro Servizi di Geoingegneria, Ricaldone (Italy), and ZT Büro Moser/Jaritz, Gmunden (Austria).** The study was supported by the 7th FP project "SafeLand – Living with the landslide risk in Europe".

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Bagnaschino Landslide: From Early Warning to Site-Specific Kinematic Analysis

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During the flood event in 1994, the highway no. 194 was seriously damaged by a composite landslide activated in Bagnaschino (Torre Mondovì, Cuneo). In proximity of km 1400 the landslide invaded the carriage way. The estimated area and volume involved are 150,000 m^2 and 1.2 million m^3, respectively.

In order to continuously monitor the stability conditions, the Province of Cuneo (Civil Protection Office) established a slope monitoring plan in 2008 with a DMS column 60 m long. The instrumentation was installed for a monitoring stage in a borehole (28th October 2008 – 13th July 2009) connected to a local control unit and equipped with solar cell power supply and GSM data transmission.

DMS is a multiparametric system for the stability monitoring of slopes, excavation fronts, engineering works; the column is like a spiral cord composed of a sequence of hard tubular modules connected to each other by special flexible 2D-3D junctions that mimic any deformation, working continuously for Early Warning functions.

Fig 1, 2: DMS column installation (28th October 2008) and removal (13th July 2009) – Bagnaschino site.

Correlation between DMS column and weather data allowed to identify critical events that have reactivated the landslide on the sliding surface at 7 m blg, with direction 30° NE. During the observation period, it was possible to continuously monitor different kinematics and different weather conditions. The DMS column allowed investigating 5 triggering events and their relative period of stasis, with a clear delay time after rain events or snow melting.

The following describes the characteristics of each event:

- ***First event:*** 28th November, 2008, saw the first snowfall (one of the most intense of the last century in the area) that was followed by some rainy days and finally by another snowfall on 13–19th December. At the same time, there was a temperature rise that caused the partial snow melting and subsequently the first movement read by DMS column.
- ***Second event:*** on 1st March, 2009, there was light rainfall followed by a strong temperature rise (thermal zero at 1500 m asl) that caused the second landslide activation on 2nd March, 2009, at 20:03, 37 hours after the rainfall began.
- ***Third event:*** on 31st March, 2009, at 06:00 a strong rainfall began and lasted for some days. After 30 hours, the landslide moved.
- ***Fourth event:*** this event is linked to more rainfalls, which occurred in the days 16th–22nd April, 2009, and is different from the previous events because of a lower movement velocity (displacement about 10 mm).
- ***Fifth event:*** on 26th April, 2009, the strongest spring rainfall started and after about 29 hours (27th April, 08:00) the landslide moved. This heavy rainfall lasted for some days: the cumulative displacement was 299.7 mm in only two days. The roll axis on the involved DMS module reached its saturation angle (tilt >20°): the further displacement is calculated with the interpolation of its pitch axis, still active.

In the following diagram and table each triggering event has been described in detail considering also rain, cumulative rain, snow events and temperature.

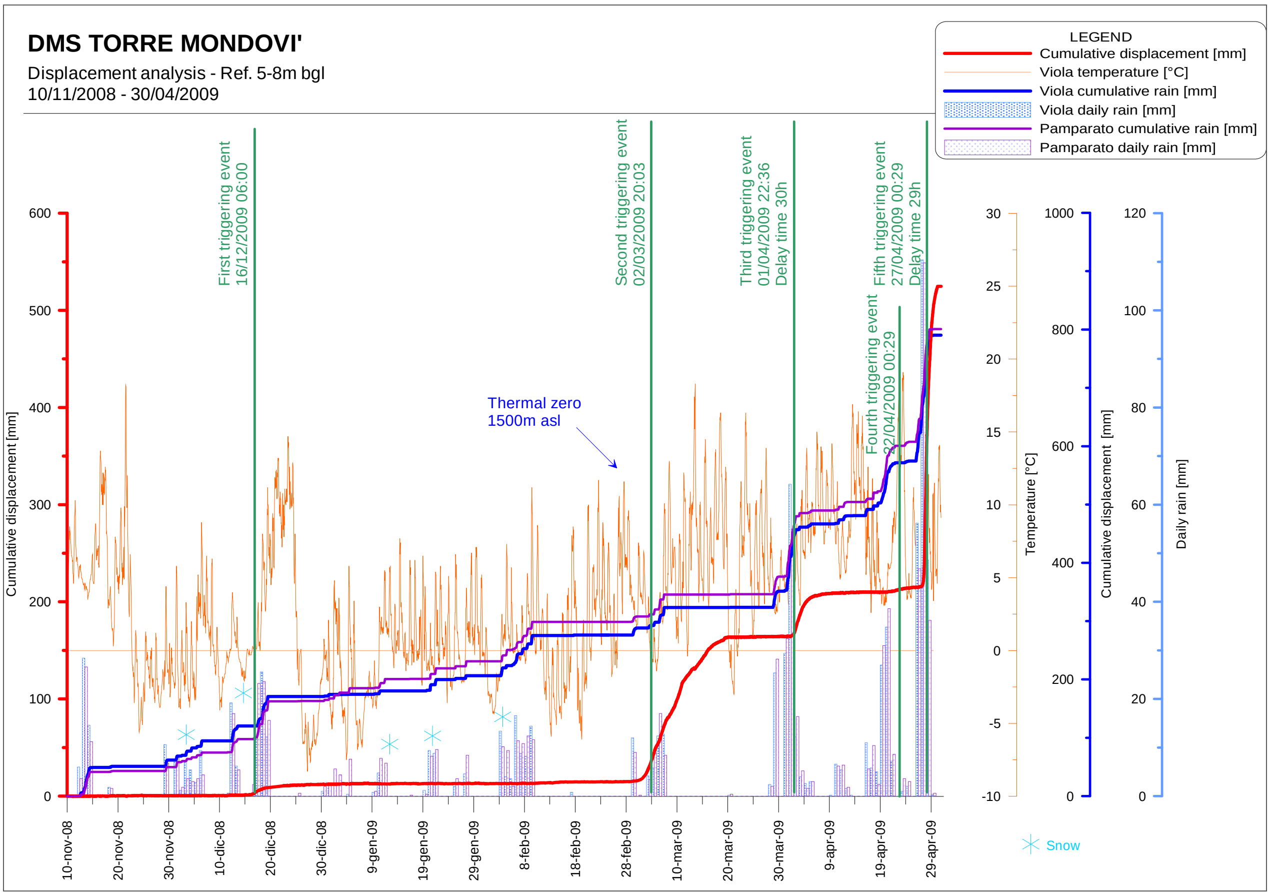

Fig. 3: Triggering events.

Table 1: Triggering events.

	1st EVENT	2nd EVENT	3rd EVENT	4th EVENT	5th EVENT
Rainfall start	12/12/2008 0.00	01/03/2009 6.00	31/03/2009 6.00	16/04/2009 6.00	26/04/2009 3.00
Displacement start	16/12/2008 6.00	02/03/2009 20.00	01/04/2009 12.00	22/04/2009 0.00	27/04/2009 8.00
Rainfall type	Snow	Rain/snow	Rain	Rain	Rain
Snow at ground	Yes	Yes	Yes	No	No
Temperature rise	Yes	Yes	No	No	No
Concomitant factors	Snow melting 90 mm	Snow melting 120 mm	–	–	–
Rainfall [mm]	70	44	63	160	77.6
Rainfall duration [h]	84	96	30	138	29
Critical intensity [mm/h]	1.786	1.708	2.100	1.159	2.676
Total cumulative rainfall [mm]	190	354	480	590	800
Cumulative rainfall event [mm]	150	164	180	110	220
Total cumulative displacement [mm]	11.5	160.6	209.0	225.0	524.7
Cumulative displacement event [mm]	11.5	149.1	48.4	10.0	299.7

For each event a particular value was calculated, the *critical intensity*, that corresponds to the ratio between precipitation quantity (calculated in mm) that caused triggering movement and its duration (calculated in hours).

The interpolated line in the bi-logarithmic plot can be considered a site specific deterministic approach to the limit equilibrium threshold that separates the stability and instability field.

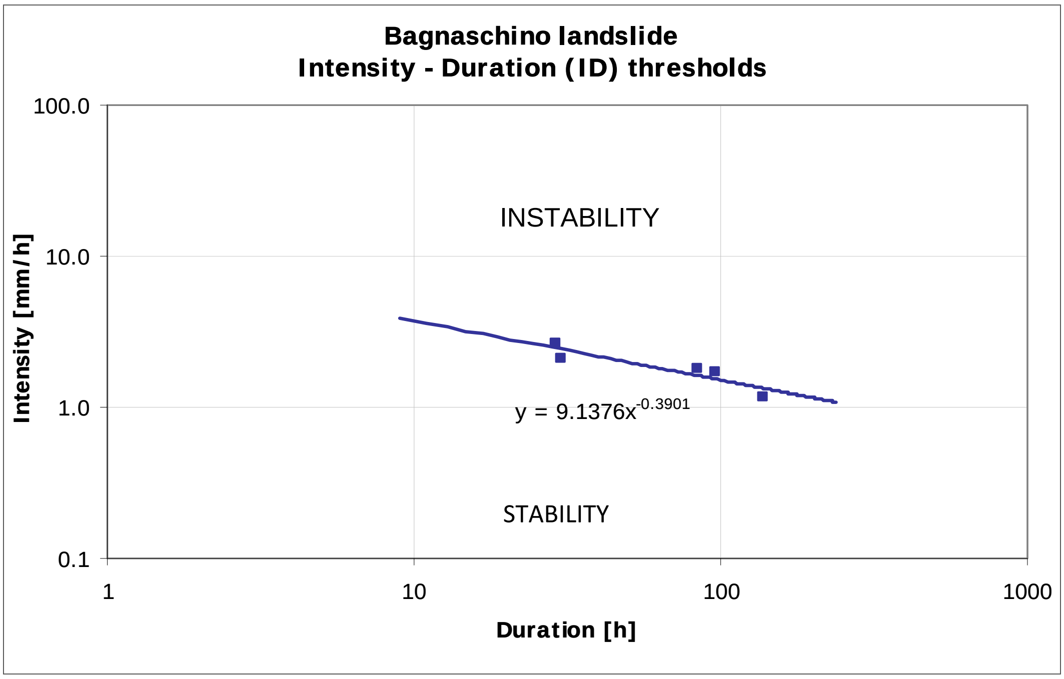

Fig 4: Rain Intensity – duration, Bagnaschino site.

On 13th July, 2009, the DMS column was removed (Figure 2). The DMS column allowed to obtain with continuity the kinematics of the landslide in action, not only limited to the initial stages of triggering, but also during the evolution up to achievement of stasis conditions.

The integrity of the DMS column is preserved in spite of the displacement of 60 cm; the excavation realized subsequently to release the column confirmed depth, direction and extent of the displacement, allowing the complete recovery of the instrumentation and the repair of the inclinometric pipe that is replaced and protected by another pipe with a large diameter.

Continuous monitoring of the landslide allowed to notice weak deep creep in the interval 30–44 m blg in addition to considerable shallow movements. The activation of deep movements is delayed in respect to shallow movements, with well defined behaviour.

A new DMS system will be installed in spring 2010 for Early Warning function by means of 2 columns (DMS 1-60 and DMS 2-10 active in the intervals depths 20–60 m and 0–10 m). The Bagnaschino landslide is a test site within the EU SafeLand project 2009–2012.

Living with Landslides: the Ancona Case History and Early Warning System

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On 13th December, 1982, Ancona city, an historical and capital region of Le Marche – Italy, located on the East coast of the Adriatic sea, was involved in a large and deep landslide.

An intense landslide affected the northern area of the city, the "Montagnolo" hill started to slide towards the sea. The event involved about 180 m³ during the movement.

Fig. 1: 1982 event.

It damaged structures and infrastructure and some important public and strategic buildings, among them the Faculty of Medicine, the Oncological Hospital, the Geriatric Hospital and the Tambroni retirement home. All the older people and the patients were moved to the nearest Hospitals for first aid.

The National Railway MI-LE (Adriatica) and regional Highway Flaminia slid down 10 meters towards the sea. The movements started from the lower border of the landslide and came up the slope. At the end of the event the movements surveyed were: on the base, max. 8 metres in horizontal and 3 meters in height, while on the top, 5 meters in horizontal and 2.5 meters downwards.

In the morning of 13th December, after a night of uninterrupted movements and noises due to the opening fractures of buildings, the residential districts named "Posatora" and "Borghetto", were evacuated (Figure 2).

Fig. 2: The National Railway MI-LE (Adriatica) and regional Highway Flaminia.

The landslide damaged private houses and infrastructures and about 3000 people were evacuated. 1562 people were moved to hotels and other residences by Municipality and they remained in that situation for a long time. Gas and water supplies were interrupted too and the city remained for some days without the necessary services.

The more significant damages can be resumed as follows:

- 220 hectares extension (affecting 11 % urban area of Ancona)
- 3661 people evacuated (1071 families)
- 1562 people moved to hotels and other residences by Municipality
- 280 buildings destroyed or damaged (a total of 865 residences)
- Faculty of Medicine, Oncological Hospital, Geriatric Hospital, Tambroni retirement home, were irreparably damaged
- 31 farms damaged
- 101 SME
- 3 industries
- 42 shops
- 500 people lost their jobs
- National Railway MI-LE (Adriatica) and regional Highway Flaminia blocked
- Gas and water supplies interrupted
- Luckily, no people died during the event!

The dynamic of the landslide of Ancona can be explained in two steps:

A gravity slide happened at great depth, probably induced by some dislocations activated during the 1972 earthquake, then re-activated by the intense rain infiltration (some days before the event, it rained for almost 6 days without interruption).

After the first step, we had an activation of superficial and medium landslides. These started to move after about 10 minutes, with consequent damages to buildings and infrastructures (this second step continued for some hours).

The superficial geomorphology of the Ancona landslide is influenced by many and complex movements. The colluvial soils, in some places of the landside, where their thickness is about 10 m, have flown down as a mudslide. This dynamic was helped by the high rate of saturation.

Taking into account all the researches and investigations over the last 25 years spent in the site and in laboratory, we can conclude that the Great Landslide of Ancona city is a Deep-seated landslide (complex, composite according to CRUDEN & VARNES, 1996), reactivated after a long period of precipitation; new fractures were opened by a long period of earthquakes 10 yrs before (6 months duration) (Figure 3).

The landslide involves clay and silty clay layers (Pliocene–Pleistocene), fractured with different OCR parameters, alternated with thin sand levels.

Overlapped sliding zones are active (maximum depth: 100–120 m, maximum depth 1982 event is 75 m bgl).

Across the entire body of the landslide, in horizontal direction, parallel to the coast, there are two natural trenches that cross the slope. These trenches are upstream of old landslides slid down and now they are filled with heterogenic and plastic soils. These soils involve clay and silty clay, mud and thin sand levels with some fragments of calcarenitic layers.

These trenches together with a complex structural system of fracture and discontinuity, influenced the system of underground water.

All the geological and geotechnical analyses of the landslide mechanisms aimed at the consolidation preliminary design in 2000; but this plan concluded that a consolidation was impossible, both due to very large expenses and to a very strong environmental impact, which would have totally changed the site appearance with a severe socio-economical impact.

Ancona Administration decided then to live with the landslide, nevertheless, reducing the risk for the people living there.

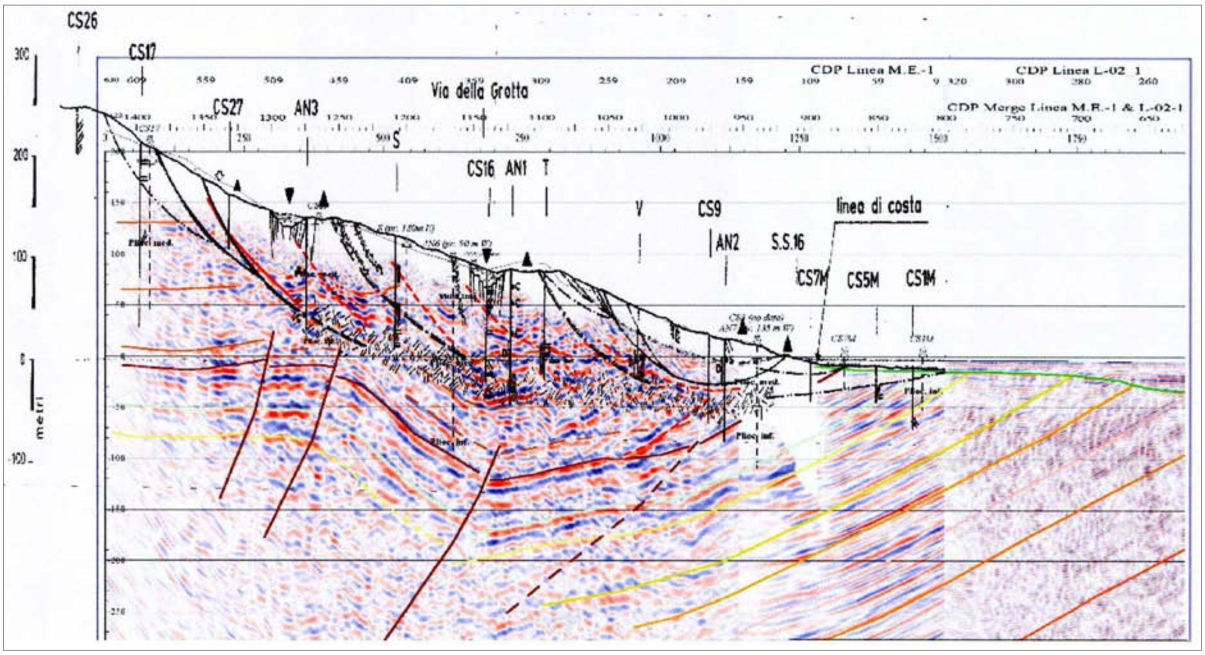

Fig. 3: Geomorphological and seismic section.

During the last years, some partial interventions of the total preliminary design for the consolidation stroke have been made. Two drainage systems were put in place, a deep one based on trenches and wells, and a more superficial one with canals. Reinforced bulkheads were built and in some part of the area reforestations were made.

Ancona Administration decided to continue both drainage systems both superficial and deep.

In 2002, the Regione Marche passed a law for the people that still today live inside the landslide area, giving Ancona Administration the responsibility of creating an Early Warning System and an Emergency Plan for people. The whole project has the aim to issue the population a certification to live safely in their homes and to check the landslide movements.

The projected Early Warning System consists of the integration of continuous surface and borehole active monitoring.

The first phase of the monitoring system, concerning the control of the surface, has been working since 2008. The Geotechnical in Place Continuous monitoring system (II phase) has been activated also.

Surface Monitoring

The surface monitoring system is based on 7 Automatic Robotic Stations, 230 reflector points (installed partly on the 64 inhabited houses and on the structures and infrastructures), 26 geodetic GPS, 8 geodetic GPS (dual frequency), 7 high precision clinometric sensors for the stability control of the main stations of the I and II level of the net. The combination of the different instruments: GPS, Automatic Robotic Stations and the clinometric sensors allows us to monitor a great number of points previously identified, to keep them under supervision with different measuring techniques and from different control positions in the three coordinates (3D, X, Y, Z). The adoption of the geodetic GPS at dual frequency assures a high quality of the GPS measures, and a greater versatility of the whole system.

Geotechnical Monitoring (DMS)

Recently, the Geotechnical Monitoring Systems DMS (patents and trade mark CSG-Italy) have been installed inside n°3 boreholes (100 metres depth).

Each DMS column is formed by n°85 Biaxial Inclinometric modules (range ±20°, resolution 0.01°), n° 2 Piezometric Sensors (range 100 psi, resolution 0.01 m), n°85 Temperature Sensors (range 0–70°C, resolution 0,1°C) for a total active vertical of 85 metres controlled. Digital compasses are on board, accuracy 1° azimuth.

DMS has been preassembled in the factory and installed in place by a DMS reeler, forming an instrumented column, like a spiral cord, connecting the required number of modules, each containing one or more geotechnical-geophysical sensor and the electronic boards for data collection and transmission.

Fig. 4: Surface and geotechnical DMS-systems (Via delle Grotte site).

This monitoring system is studied to try to determine every surface movement both in the area and in the inhabited houses and to produce some alarms managed by a Control Centre H24 placed in the Town Hall, where a staff of technicians have to estimate the alarms. Only whenever the situation requires the Coordinator does the Civil Protection Plan come into action.

The measuring cycle is set up on 30 minutes, but in emergencies or after a long rainy period, the system can operate on every point of the dual frequency GPS net also in Real Time RTK, and with the 7 Automatic Robotic Stations.

The modules are linked by special 2D/3D flexible joints that allow strong, continuous adaptability to bends and twists of the borehole, whilst maintaining rigorously the orientation with respect to a reference system defined during installation.

Fig. 5: DMS installation stroke.

The data from the DMS instrumentation column are sent through RS485 protocol to the control unit, which compares them with threshold values (set by the user) and stores them in a circular buffer.

In case of movements larger than threshold values, the control unit sends a warning SMS/direct call to the staff on duty of the Ancona Monitoring Centre.

The same is the case of rapid change of water-table levels. Warning levels are counted from 1 to 4, in a order of hazard.

In the monitoring centre, the GeoMaster and Guardian software take care of downloading the data stored in the control unit memory buffer.

The DMS Early Warning is the software that visualizes the subsurface data at the monitoring centre and wherever an Internet or GSM connection is possible. The software in a compact check panel allows the contextual control of displacement (E–W, N–S, Module diagrams, on Polar and Azimuthal plots), as well as the variations of the level of the water table and temperature; time history of each multiparametric module, and displacement-velocity are also displayed at selected intervals.

Transmission System

The transmitted data coming from the different sensors, are collected according to the two following procedures:

a. I and II Level Net: data transmission in real-time through a WiFi Standard HyperLan to the Town Monitoring Centre. The system is based on a main radio line (spot to spot) between the Automatic Robotic Stations and the Ancona Municipality Monitoring Centre. Data transmission in real-time works through some free frequencies radio links of 5.4 GHz (HyperLan). It realizes a strong transmission and a low environmental impact thanks to their noise control system.

b. III Level Net: data transmission through periodic GSM with data acquisition/6 h.

Preliminary Data

After some months of observation and data analysis of the surface monitoring system, apart from any ordinary variations connected to the days and seasons, some small movements have been located inside the landslide. Some geodetic GPS at single frequency L1 installed on 26 inhabited houses inside the landslide area (third network) have monitored displacements 0.5–1.5 cm towards N. This area is located where the landslide shows the maximum depth (100–120 m), trenches are also mapped, filled by soft clays.

But the movements examined are not worrying, because they happen in a restricted area and during seasons changes (summer – winter), when the clay soils lose their humidity and reduce their volume.

These data have permitted the verification of the monitoring system sensibility also for what concerns the smallest movements in the colluvial soils.

In this way, the Ancona administration has chosen to "LIVE WITH THE LANDSLIDE": this new concept implies that the safety of the population is achieved through a high-quality and comprehensive early-warning system. This – in contrast with the more static concept of standard engineering remediation – works which is clearly impracticable so far, in our case.

This project is the result of the best conjunction between human resources and a more reliable technology in the Early Warning monitoring field, put in use for a best safety and peacefulness for the people living on the Ancona landslide.

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Seismic Monitoring of the Unstable Rock Slope at Åknes, Norway

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A sudden failure of the unstable rock slope at Åknes, Norway, has the potential to generate a local tsunami in the inner Storfjord system. The slope is monitored continuously by a multitude of systems, amongst them a microseismic network and a newly installed seismic broadband station. The seismic systems are considered complementary to the direct measurement equipment (extensometers, crack-meters, DMS-columns, laser ranging, optical total station, etc) installed at the site. They record seismic events associated directly with the movement of the slope, as well as secondary events such as small-scale slides and rock falls. Our expectation is that an acceleration of the slope will be accompanied by a change/increase of the microseismic activity.

The seismic network consists of 8 3-component geophones installed on an area of about 250 x 150 m at the upper part of the slope. It has been operational since October 2005, with only very few and brief outages. Data are transferred over radio link in real-time to NORSAR where an automatic event detection is performed. These results are immediately (about 10 min delay) made available in terms of simple daily and monthly overviews, event lists and waveform plots on the project webpage http://www.norsar.no/pc-47-48-Latest-Data.aspx and forwarded to the early warning centre http://www.aknes.no/. We observe increased microseismic activity during snow melt and heavy/persistent rainfalls. During these periods, also acceleration phases of the slope occurred.

In November 2009, we expanded the seismic monitoring with a high-sensitive broadband station (Guralp ESPC 60 s-100 Hz). The station AKN provides continuous real-time data and it is fully integrated into the NORSAR station network, the Norwegian National Seismic Network and ORFEUS. Data are stored permanently at these institutes and are open to the public. The purpose of the station is to get a better constraint on the location of the microseismic events and to get an overview on local, regional (and teleseismic) events. Real-time displays of the data are made available in terms of short and long-period helicorder plots at http://www.norsardata. no/NDC/heliplots.

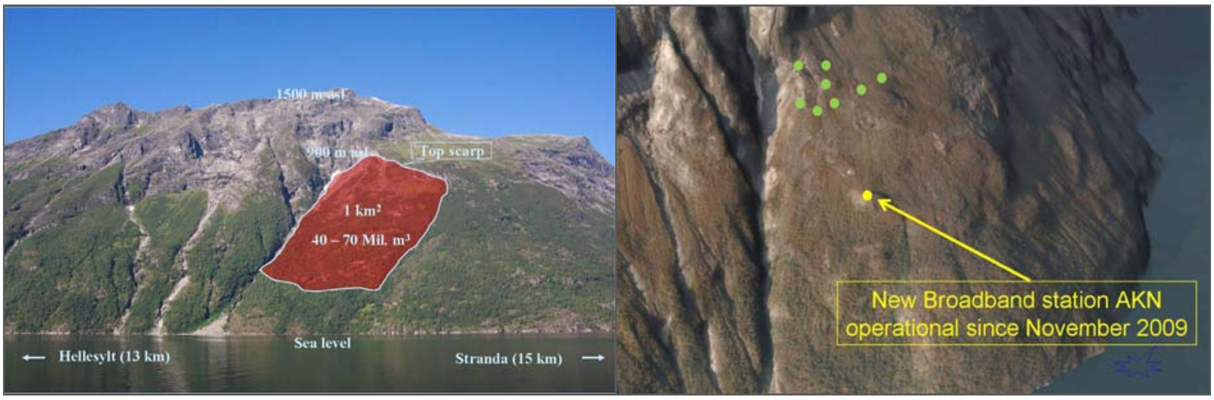

Fig. 1: Left: The unstable Åknes rock-slope in the county of Møre og Romsdal, Norway.
Right: Location of the geophone network (green dots) and the new broadband station AKN (yellow dot).

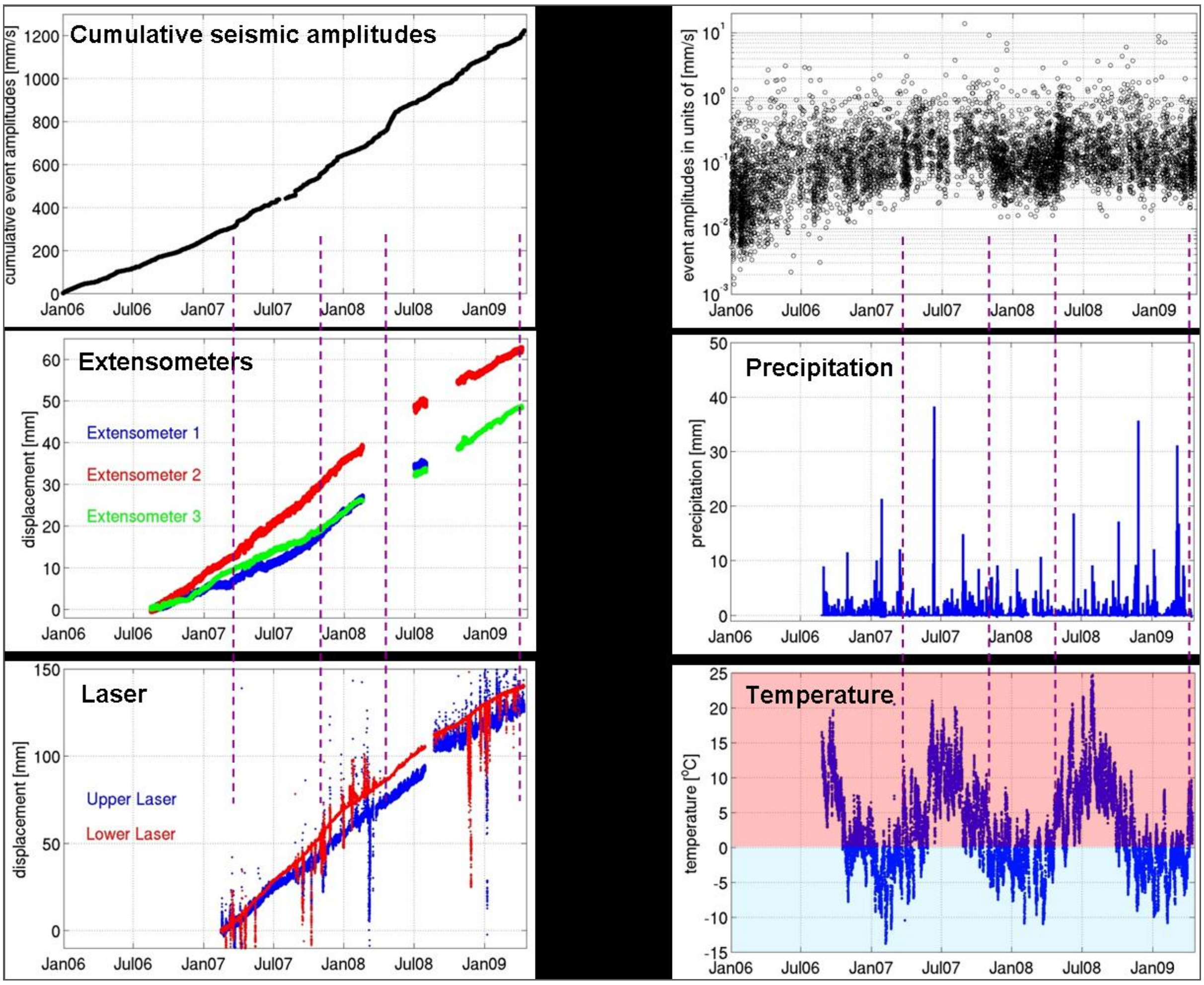

Fig. 2: Overview on cumulative seismic amplitudes, seismic amplitudes, extensometer, laser, precipitation and temperature measurements for the time period January 2006 to March 2009.

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