Istituto di Ricerca per la Protezione Idrogeologica

Consiglio Nazionale delle Ricerche

THE USE OF MONITORING SYSTEMS FOR LANDSLIDES RISK ASSESSMENT IN MOUNTAIN AREAS

Daniele Giordan

CNR IRPI - Geohazard Monitoring Group

GEOHAZARD MONITORING GROUP

Istituto di Ricerca per la Protezione Idrogeologica (IRPI)

Competence center of the National Civil Protection Agency for landslides

Research, Risk analysis and Monitoring

Ordinary activities: Identification, analysis and monitoring of hydrogeological hazards

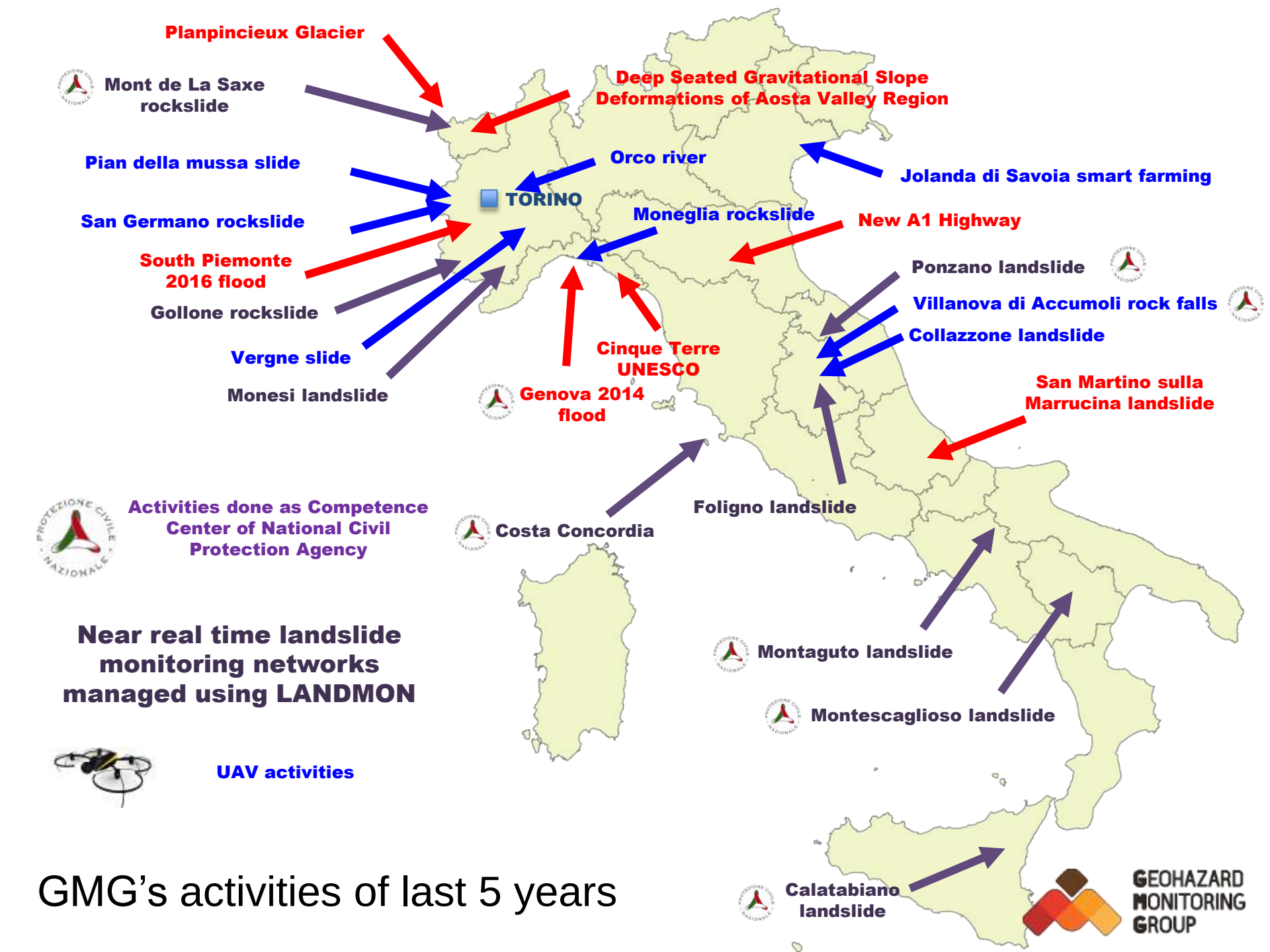
Extra-ordinary: Technical and scientific support during and after emergencies (floods, earthquakes, landslides, etc.)

The Geohazard Monitoring Group (GMG)

- Advanced research on hydrogeological hazards and development of innovative monitoring methods

- Ideation and realization of new monitoring instruments and software (3 recently patented)

- Technical and scientific support to private and public Institutions for the monitoring and the analysis of hydrogeological hazards



GMG's activities of last 5 years

GMG activities in emergency scenarios

5 Terre (UNESCO) Flood

Costa Concordia

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PROTEZIONE CIVILE NAZIONALE

Mt de La Saxe rockslide (12 M m^3)

Montaguto earthflow (6 M m^3)

Introduction

This presentation is focused on the use of monitoring systems for the definition of landslide evolution and hazard assessment

Landslides are a geo-hydrological process very frequent in Italy that every year causes a large amount of damage and victims

Landslide monitoring can be divided in four steps

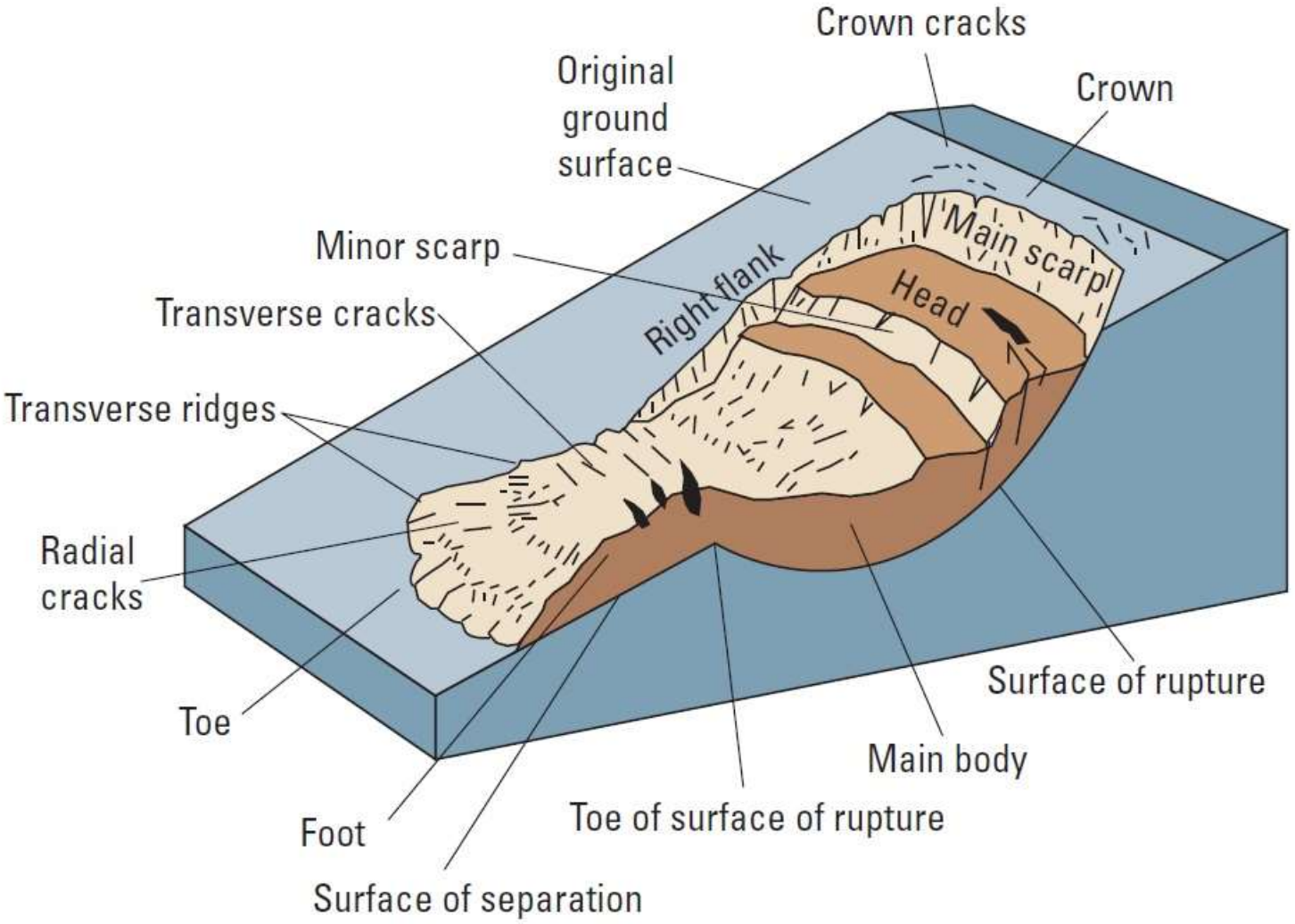
A) Landslides identification and mapping

B) In situ physical parameters acquisition

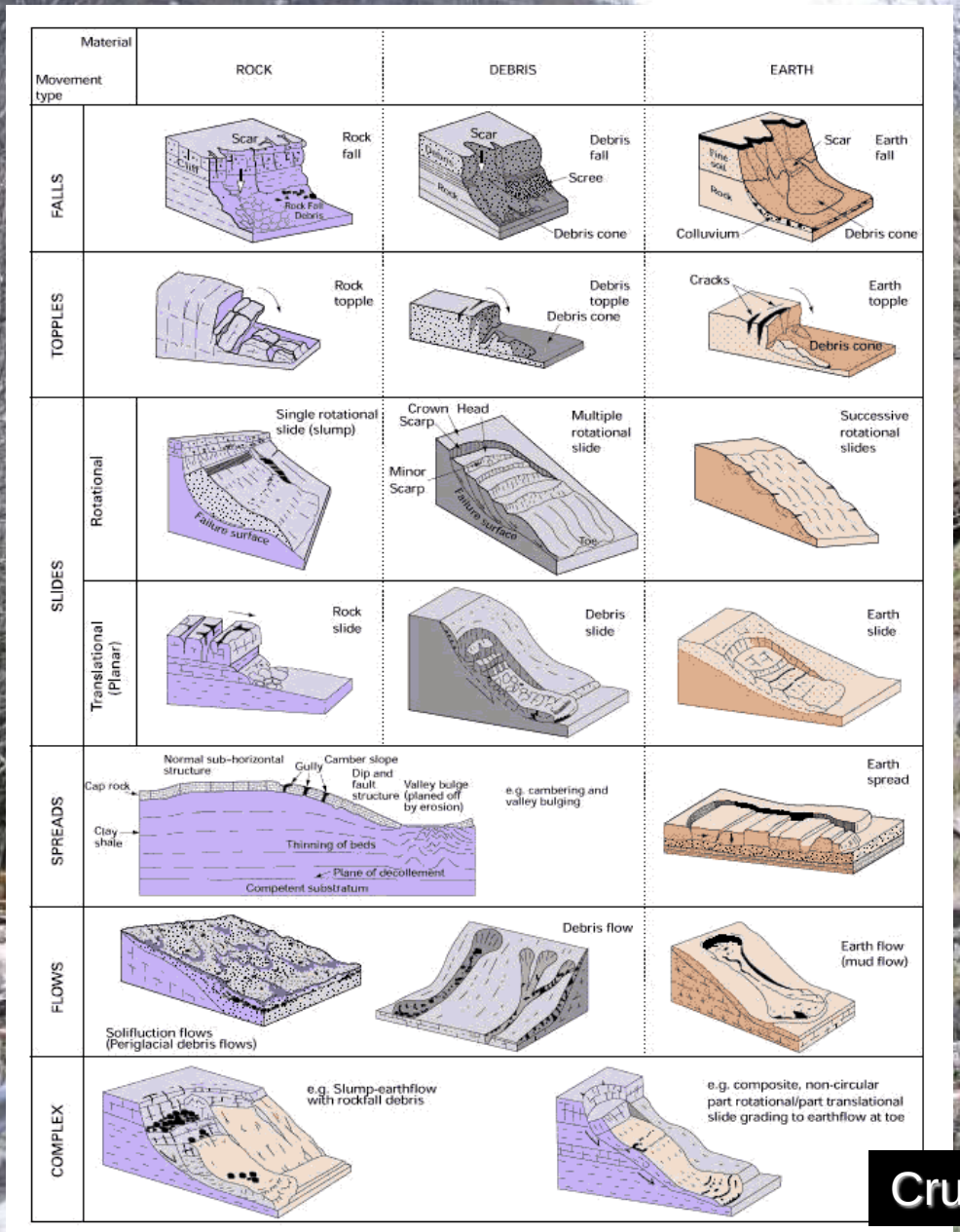
C) Data processing

D) Results dissemination

Just a short refresh….

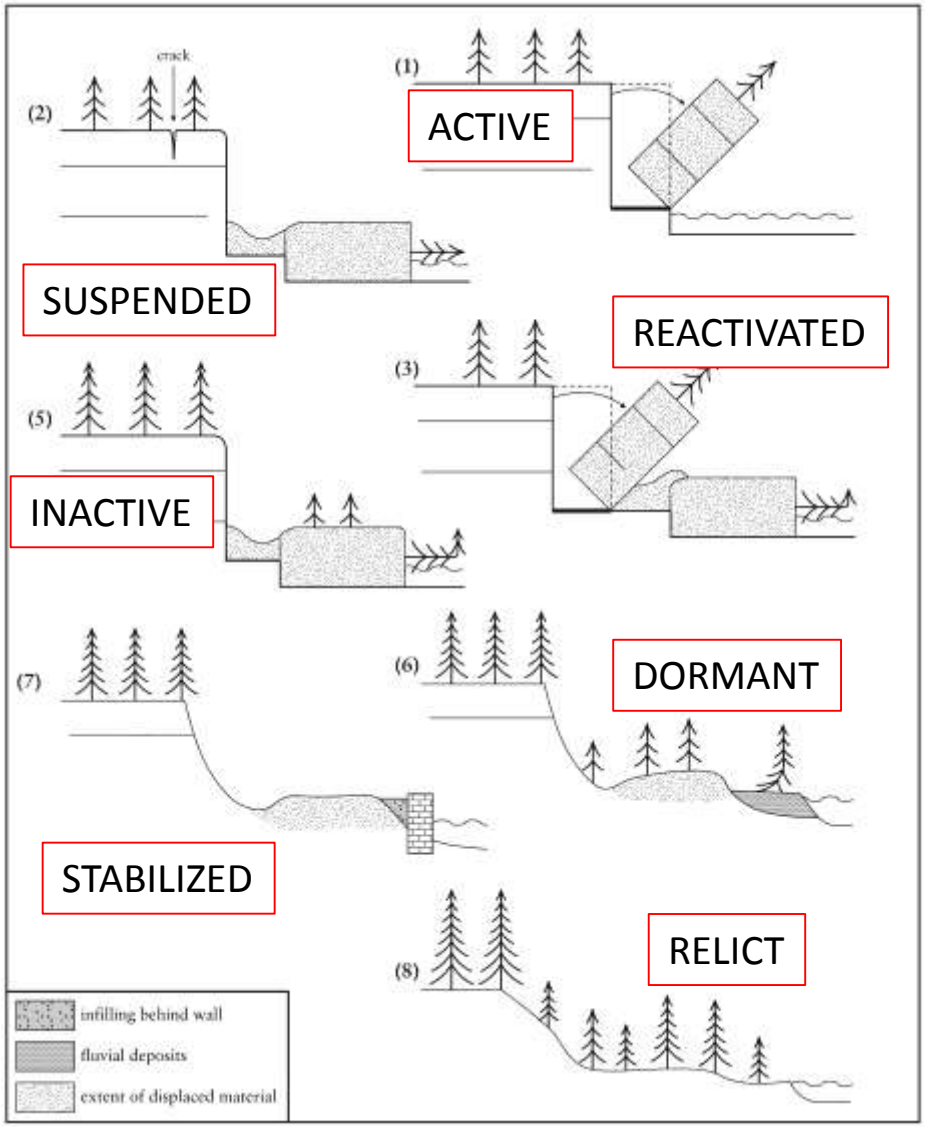


Just a short refresh….



Cruden & Varnes 1996

Just a short refresh….



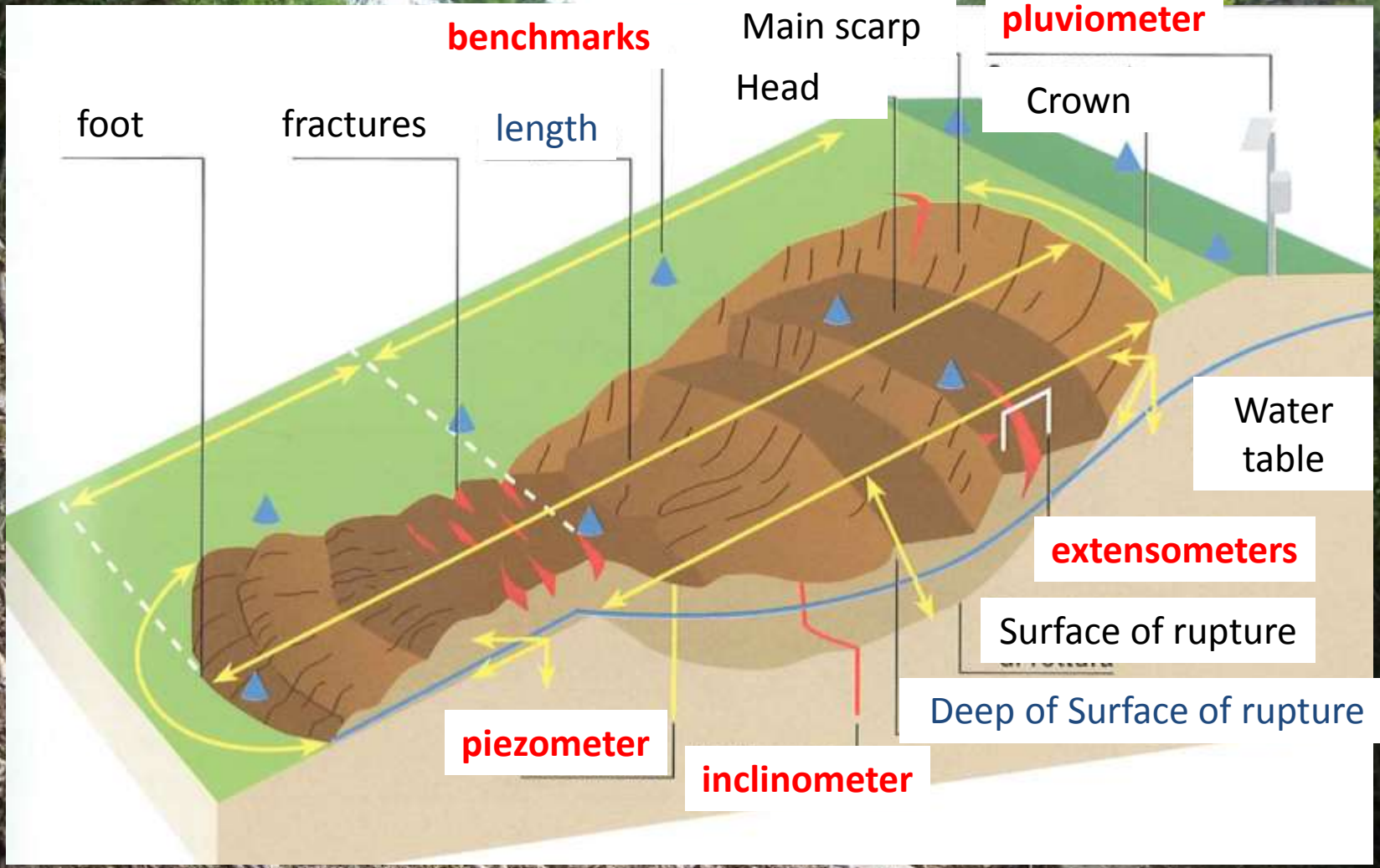
Active: An active landslide is currently moving. In the example shown erosion at the toe causes a block to topple.
Suspended: A suspended landslide has moved within the last 12 months, but is not active at present. In the example shown local cracking can be seen in the crown of the topple.
Reactivated: A reactivated landslide is an active landslide which has been inactive. In the example shown another block topples and disturbs the previously displaced material.
Inactive: An inactive landslide has not moved within the last 12 months and can be divided into 4 states: Dormant, Abandoned, Stabilised and Relict.
Dormant: A dormant landslide is an inactive landslide which can be reactivated by its original causes or other causes. In the example shown the displaced mass begins to regain its tree cover and scarps are modified by weathering.
Abandoned: An abandoned landslide is an inactive landslide which is no longer affected by its original causes. In the example shown the fluvial deposition has protected the toe of the slope, the scarp begins to regain its tree cover.
Stabilised: A stabilised landslide is an inactive landslide which has been protected from its original causes by remedial measures. In the example shown a retaining wall protects the toe of the slope.
Relict: A relict landslide is an inactive landslide which developed under climatic or geomorphological conditions considerably different from those at present. In the example shown uniform tree cover has been established.

Image Source: Cooper, R.G. (2007) Mass Movements in Great Britain, Geological Conservation Review Series, No. 33, Joint Nature Conservation Committee, Peterborough, 348 pp

Just a short refresh….

Velocity Class	Description	Velocity (mm/sec)	Typical Velocity	Probable Destructive Significance
7	Extremely Rapid	5×10^{3}	5 m/sec	Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely
6	Very Rapid	5×10^{1}	3 m/min	Some lives lost; velocity too great to permit all persons to escape
5	Rapid	5×10^{-1}	1.8 m/hr	Escape evacuation possible; structures; possessions, and equipment destroyed
4	Moderate	5×10^{-3}	13 m/month	Some temporary and insensitive structures can be temporarily maintained
3	Slow	5×10^{-5}	1.6 m/year	Remedial construction can be undertaken during movement; insensitive structures can be maintained with frequent maintenance work if total movement is not large during a particular acceleration phase
2	Very Slow	5×10^{-7}	15 mm/year	Some permanent structures undamaged by movement
	Extremely **SLOW**			Imperceptible without instruments; construction **POSSIBLE WITH PRECAUTIONS**

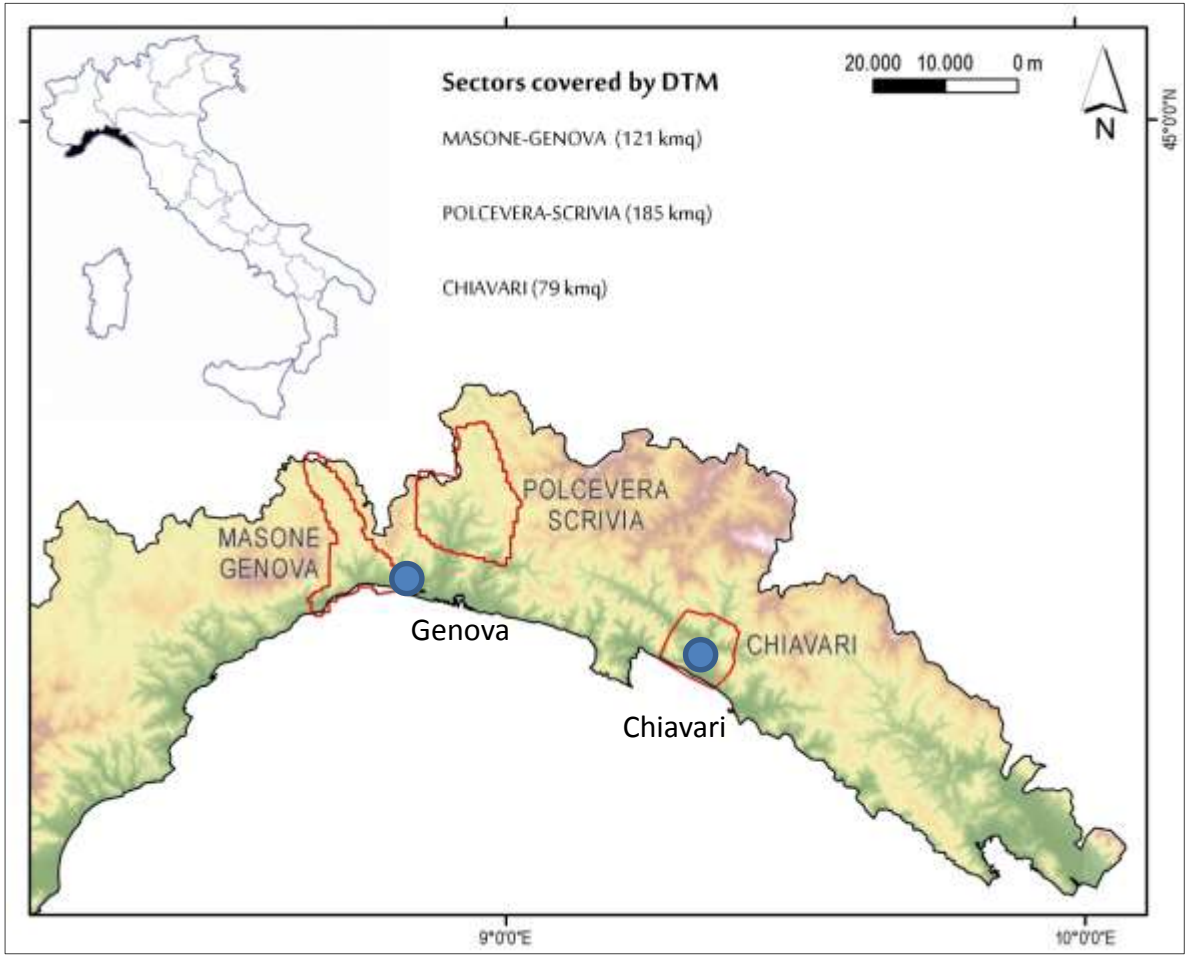
What and how



From Mannucci & Notarpietro, 2005

Landslide identification and mapping

Liguria Region - November 2014 Flash flood events



Sequence of flash floods struck Genova and Chiavari and caused three victims and a large amount of damages

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CNR IRPI ACTIVITIES

A) Lidar survey of most involved areas (390 km^2):

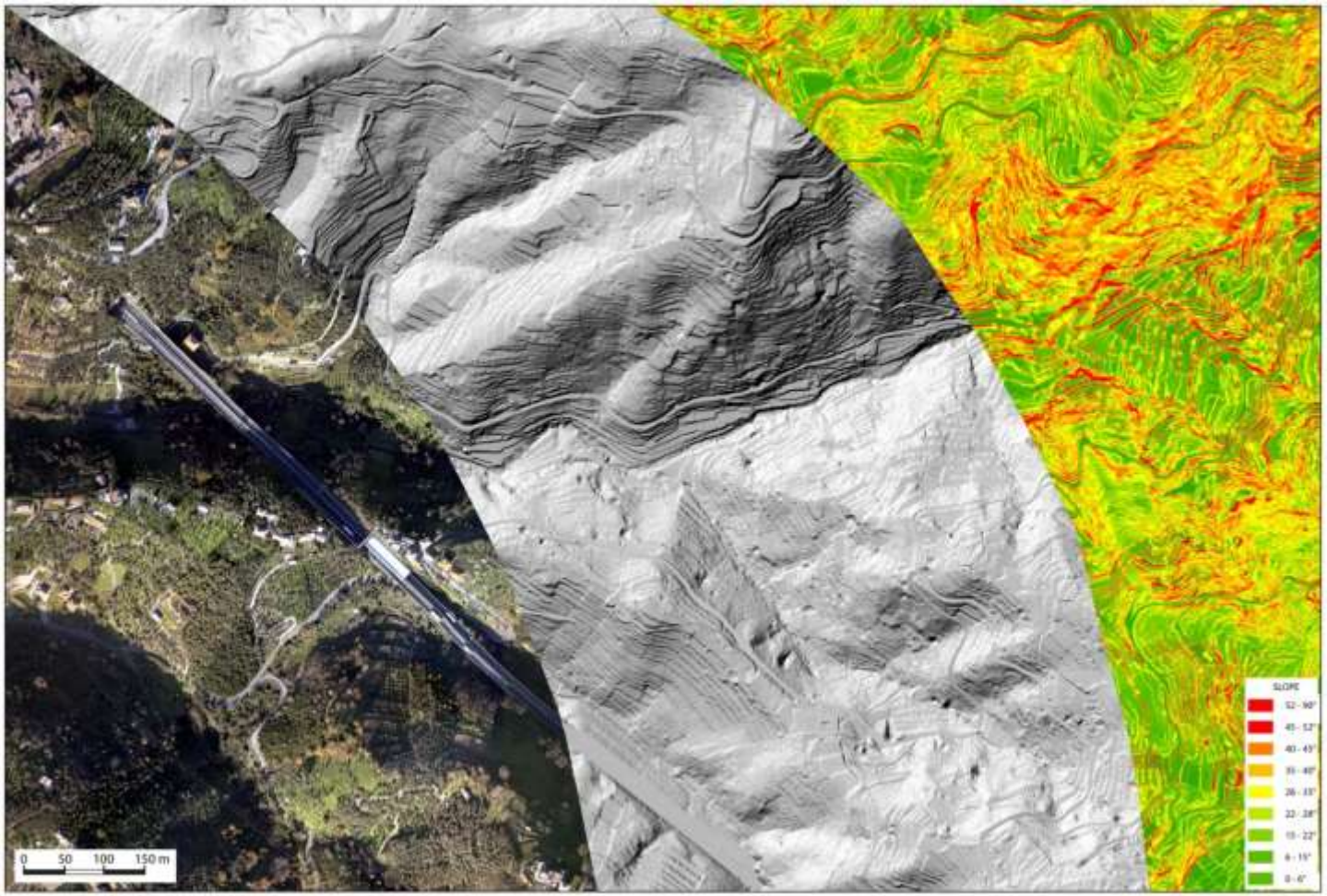
1. Digital Elevation Model (5/11 RAW point for meter square)
2. Orthophoto (25 cm/pixel)

B) Geomorphological map with the main geo-hydrological processes affecting slopes (soilslip, debris flow, rotational slide, etc.) and water courses (bank erosion, local deposition, flooding, etc.)

C) Analysis of the results focused on the landslides distribution

D) Study of the relationship between landslides distribution and man made conditioning of the landscape

DTM, orthophoto and other products



The integrated use of DTM, **orthophoto**, **shaded relief** and **slope** maps has been very useful both for landslide mapping and terraced areas identification

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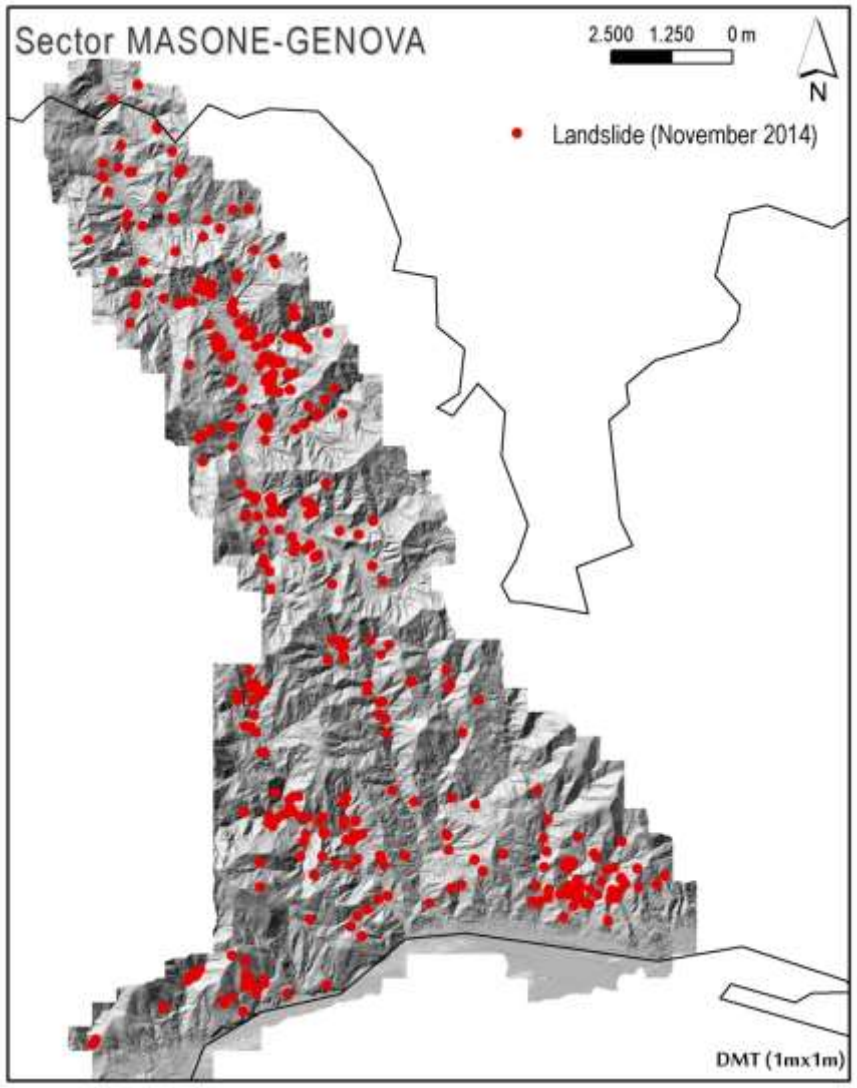
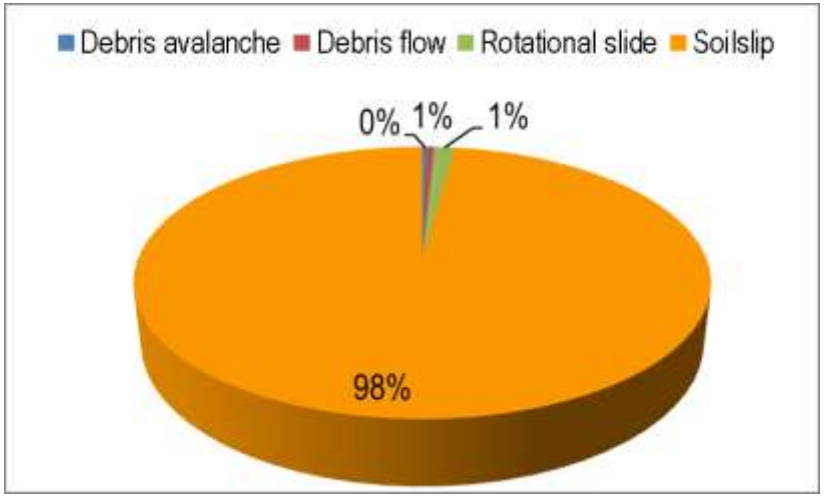
Geomorphological mapping results



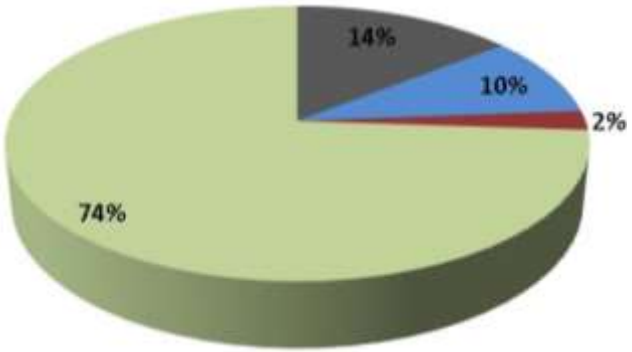
Over **1600** landslides were triggered by the considered flood events

Area of interest	Number of landslides inventoried
CHIAVARI	307
MASONE-GENOVA	493
POLCEVERA-SCRIVIA	841

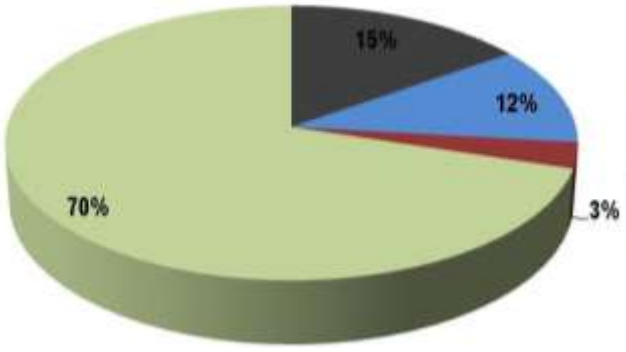


Landslides inventory analysis

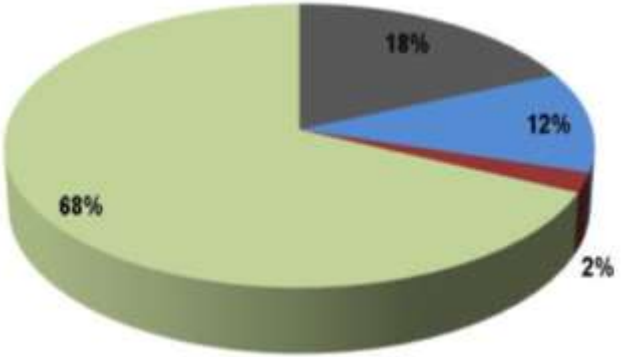
CHIAVARI



MASONE-GENOVA



POLCEVERA-SCRIVIA



ROAD STREAM ROAD/STREAM NONE

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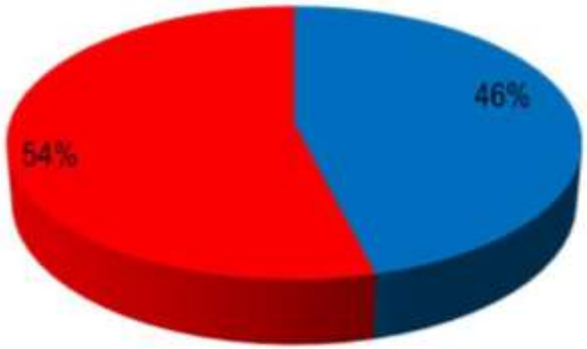
Identification of terraced areas

LANDSLIDES OCCURRED IN TERRACED AREA: 45%

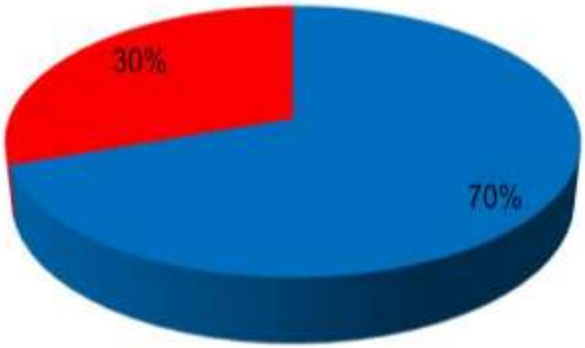
MASONE-GENOVA



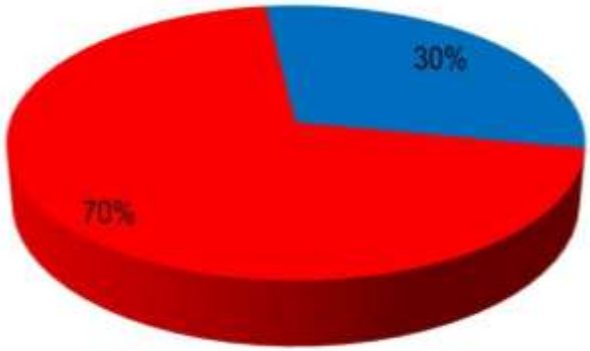
NOT TERRACED

TERRACED

POLCEVERA-SCRIVIA



CHIAVARI



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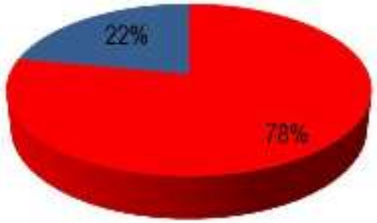
Results

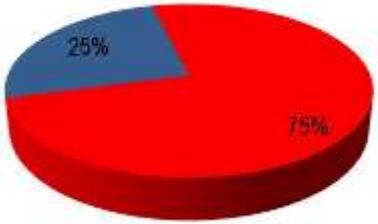
Landslide classification based on the Land use

Chiavari sector:

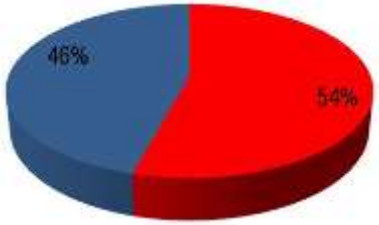
Class 0-100 mq



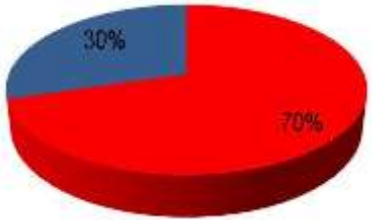
Class 100-500 mq

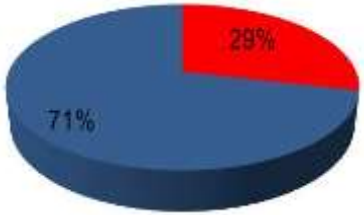


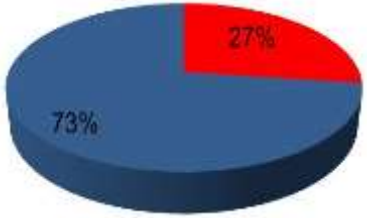
Class > 500 mq



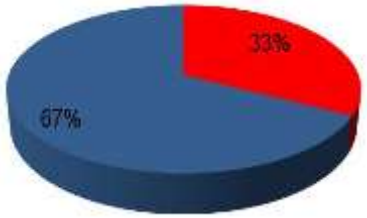
Masone-Genova sector:

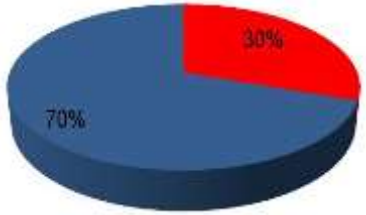


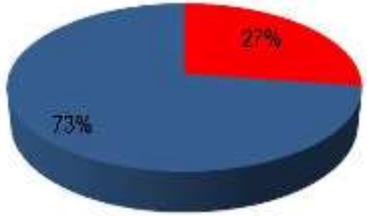




Polcevera-Scrivia sector







TERRACED

NOT TERRACED

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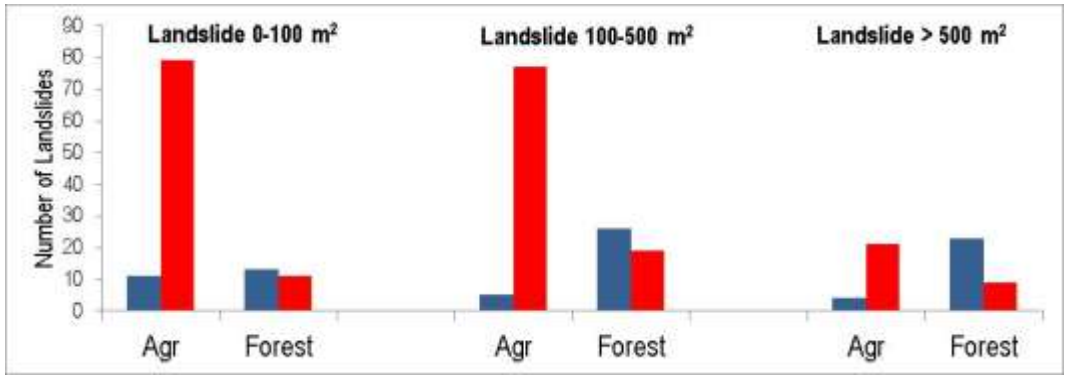
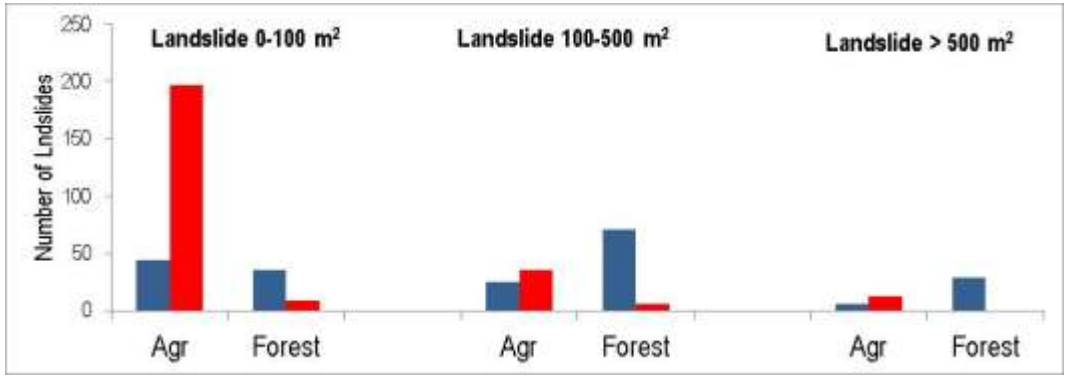
Results

Chiavari



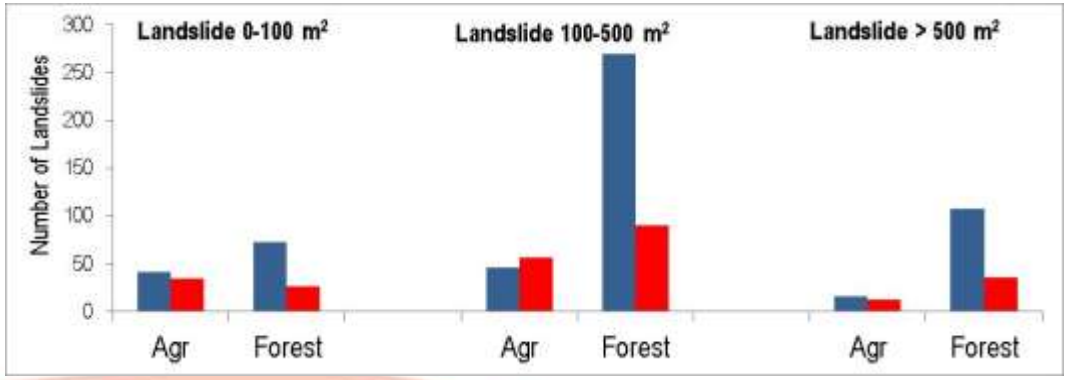
Masone-Genova



TERRACED

NOT TERRACED

Polcevera-Scrivia



Land Use (2012)
AGR = Agricultural areas, with **medium to high maintenance**

FOREST = Forest and seminatural areas, with **low to no maintenance**

Predominance of small slides in terraced and maintained areas and a higher number of larger phenomena that affected the not terraced and not maintained areas

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Landslide monitoring

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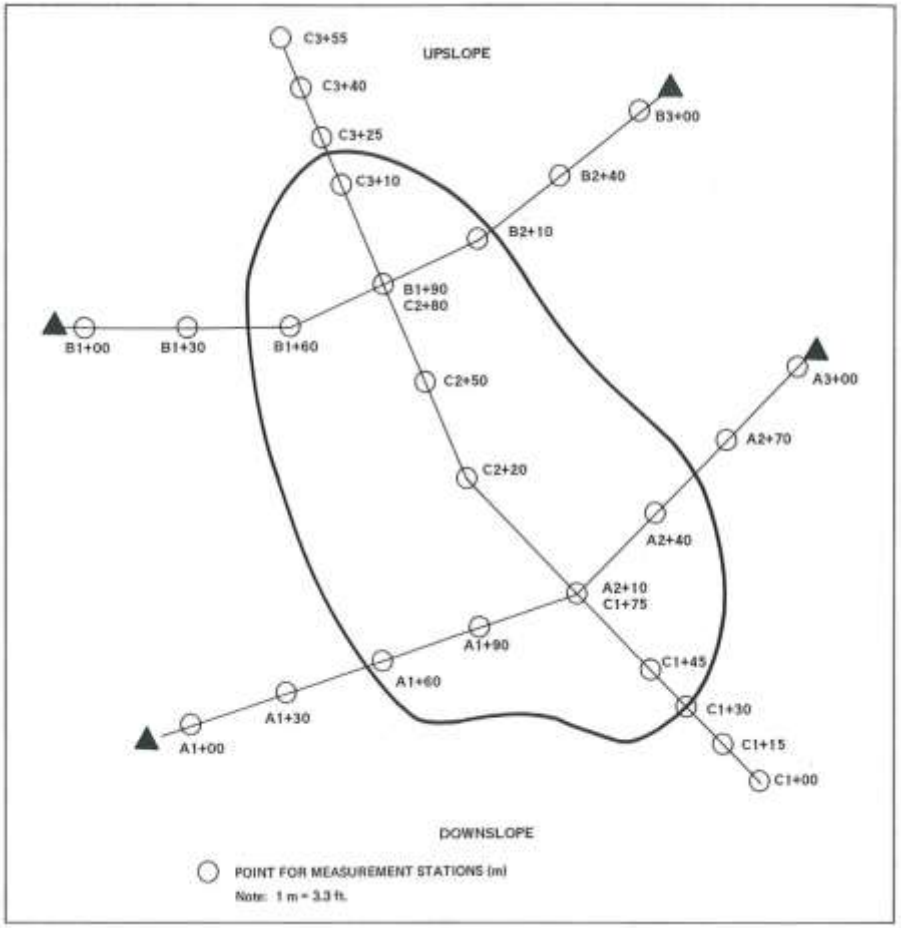
Periodical monitoring



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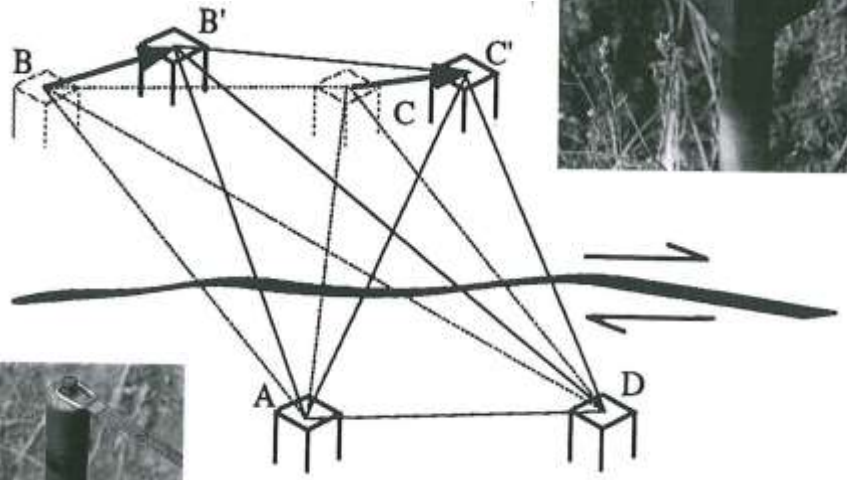
Periodical monitoring



RADICOFANI LANDSLIDE

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PLANAR SLIDE affecting the Pelithic Units of Monte Paglia;

The landslide locally evolves as a flow, especially on the toe due to a progressive erosion of the deposits

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RADICOFANI LANDSLIDE

DUE TO THE HIGH PELITHIC CONTENT OF THE DEPOSITS, IT WAS IMPOSSIBLE TO INSTALL ANYTHING ON THE LANSDLIDE

IT WAS NECESSARY TO USE AN «EXTERNAL» MONITORING METHOD (terrestrial LiDAR)

2006

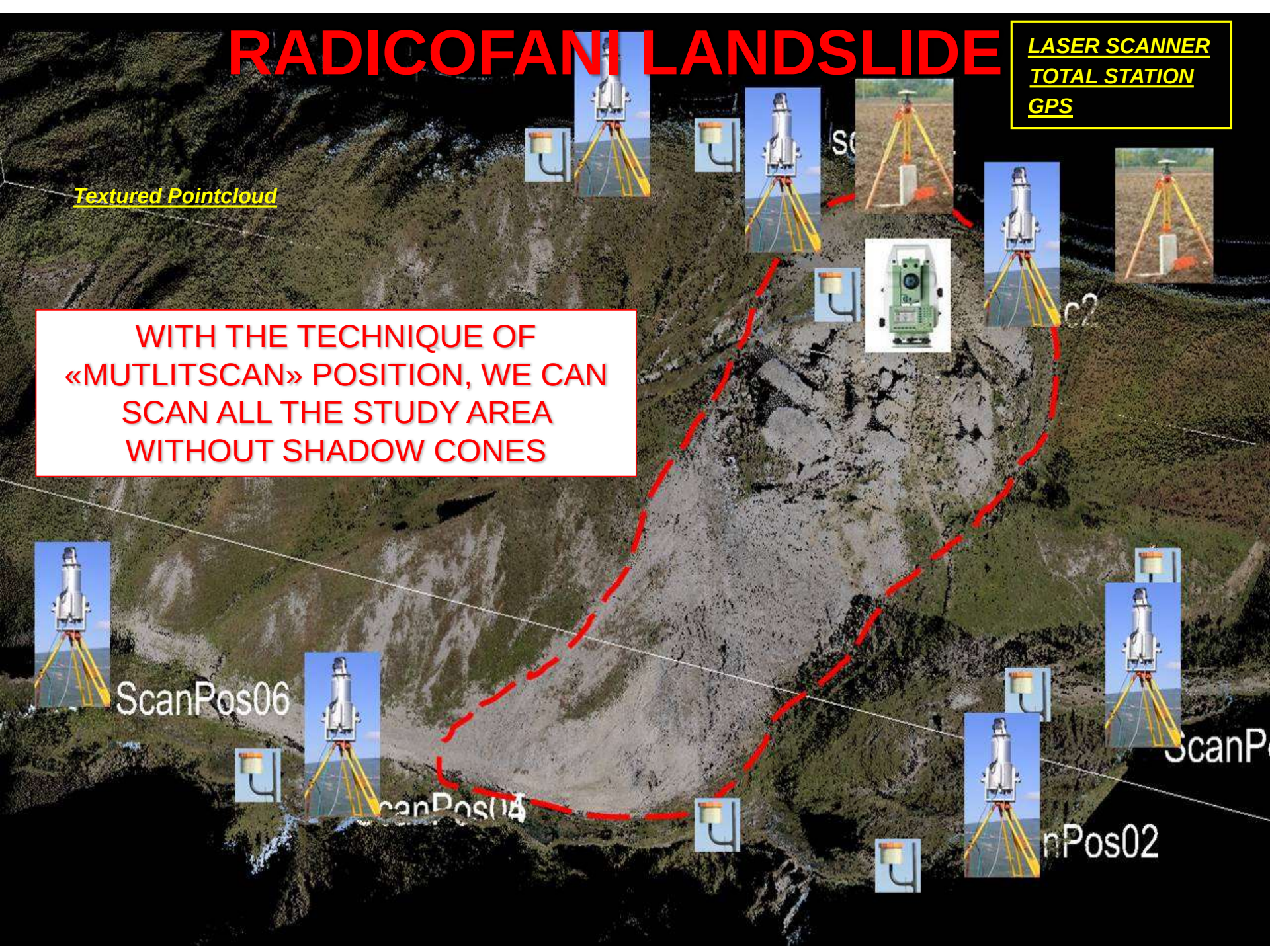
2007

RADICOFANI LANDSLIDE

LASER SCANNER
TOTAL STATION
GPS

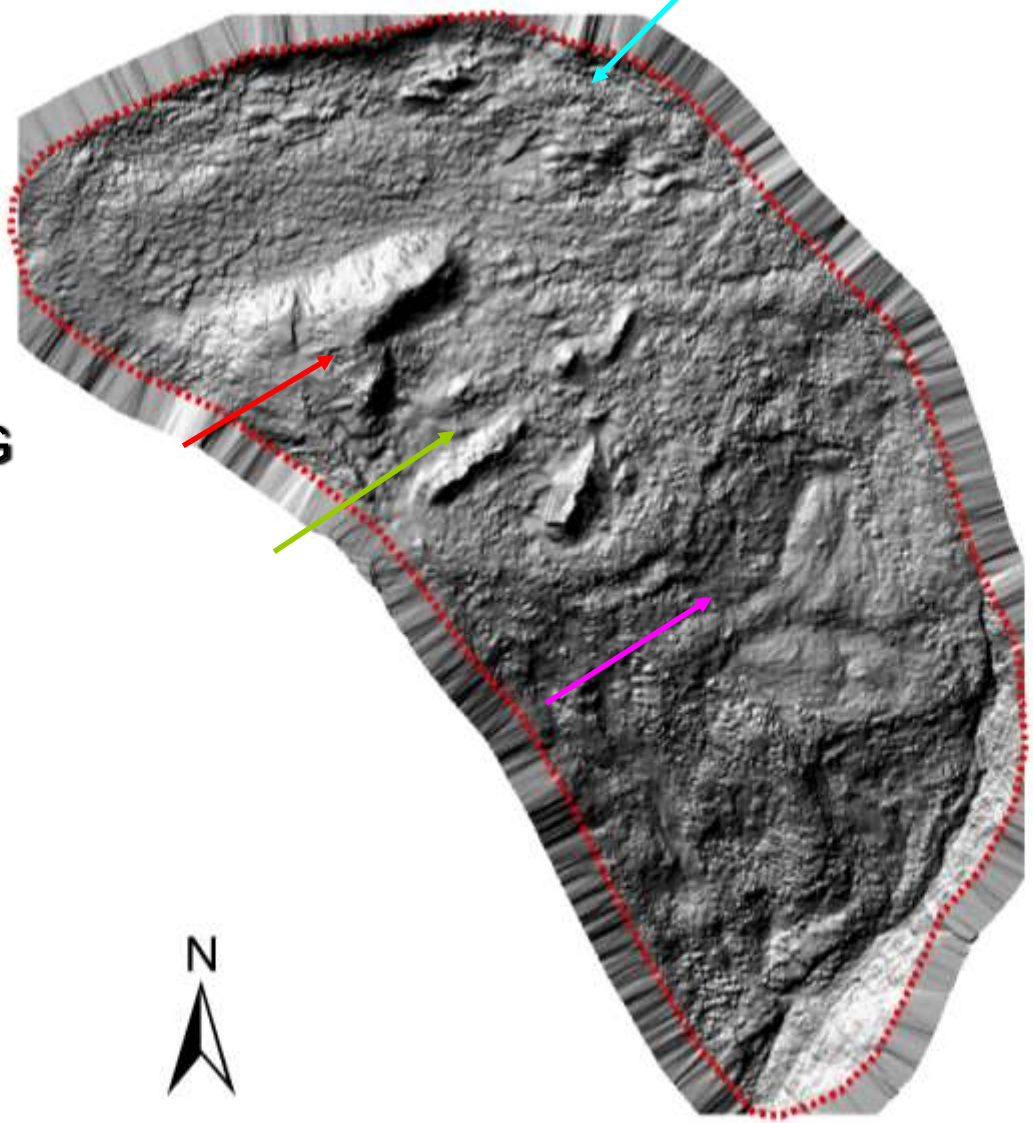
Textured Pointcloud

WITH THE TECHNIQUE OF «MUTLITSCAN» POSITION, WE CAN SCAN ALL THE STUDY AREA WITHOUT SHADOW CONES



RADICOFANI LANDSLIDE

HILL-SHADING SURFACE



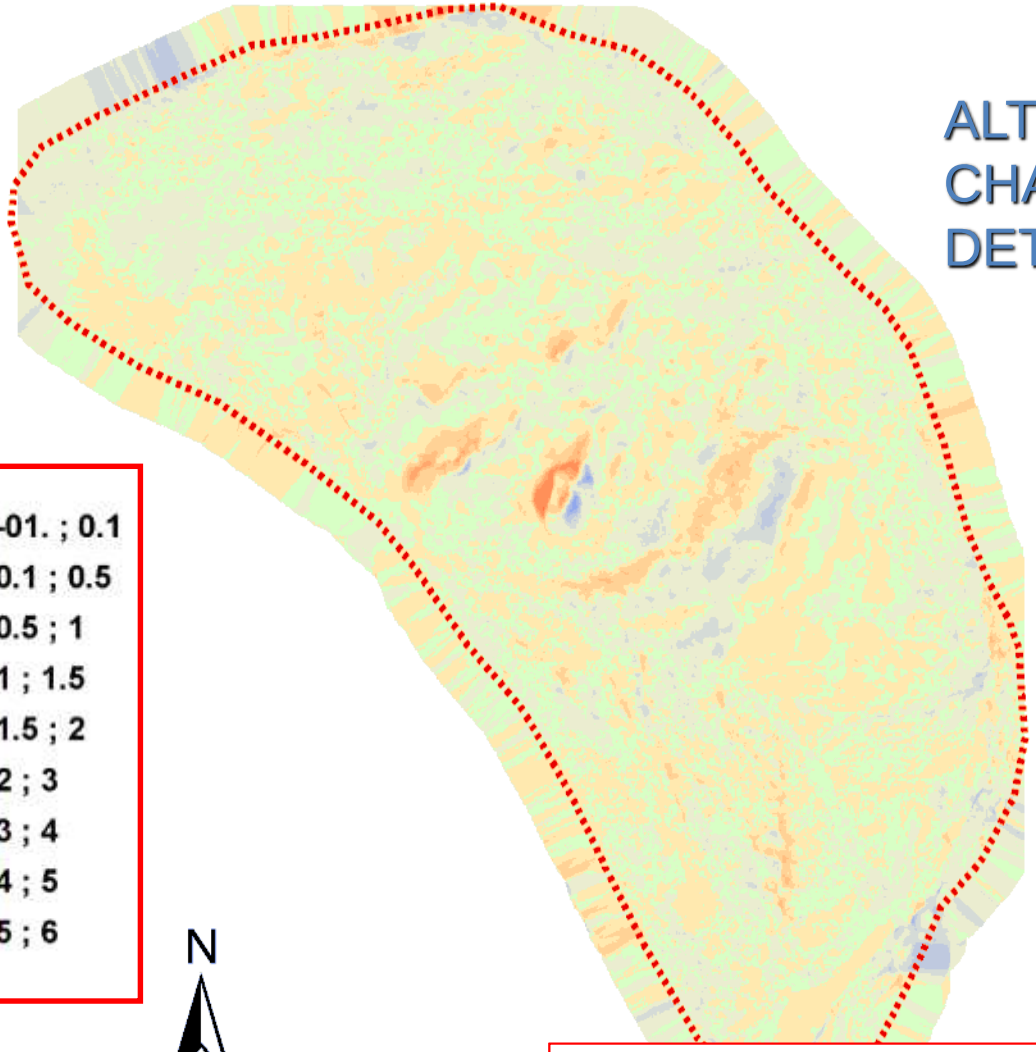
2004

2005

2006

2007

RADICOFANI LANDSLIDE



ALTIMETRIC CHANGE DETECTION

-7 ; -6	-01. ; 0.1
-6 ; -5	0.1 ; 0.5
-5 ; -4	0.5 ; 1
-4 ; -3	1 ; 1.5
-3 ; -2	1.5 ; 2
-2 ; -1.5	2 ; 3
-1.5 ; -1	3 ; 4
-1 ; -0.5	4 ; 5
-0.5 ; -0.1	5 ; 6

N

0 12.5 25 50 75

Total volumetric change registered in the period 2006-2007 → 471 m^3

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NEAR REAL TIME MONITORING NETWOK

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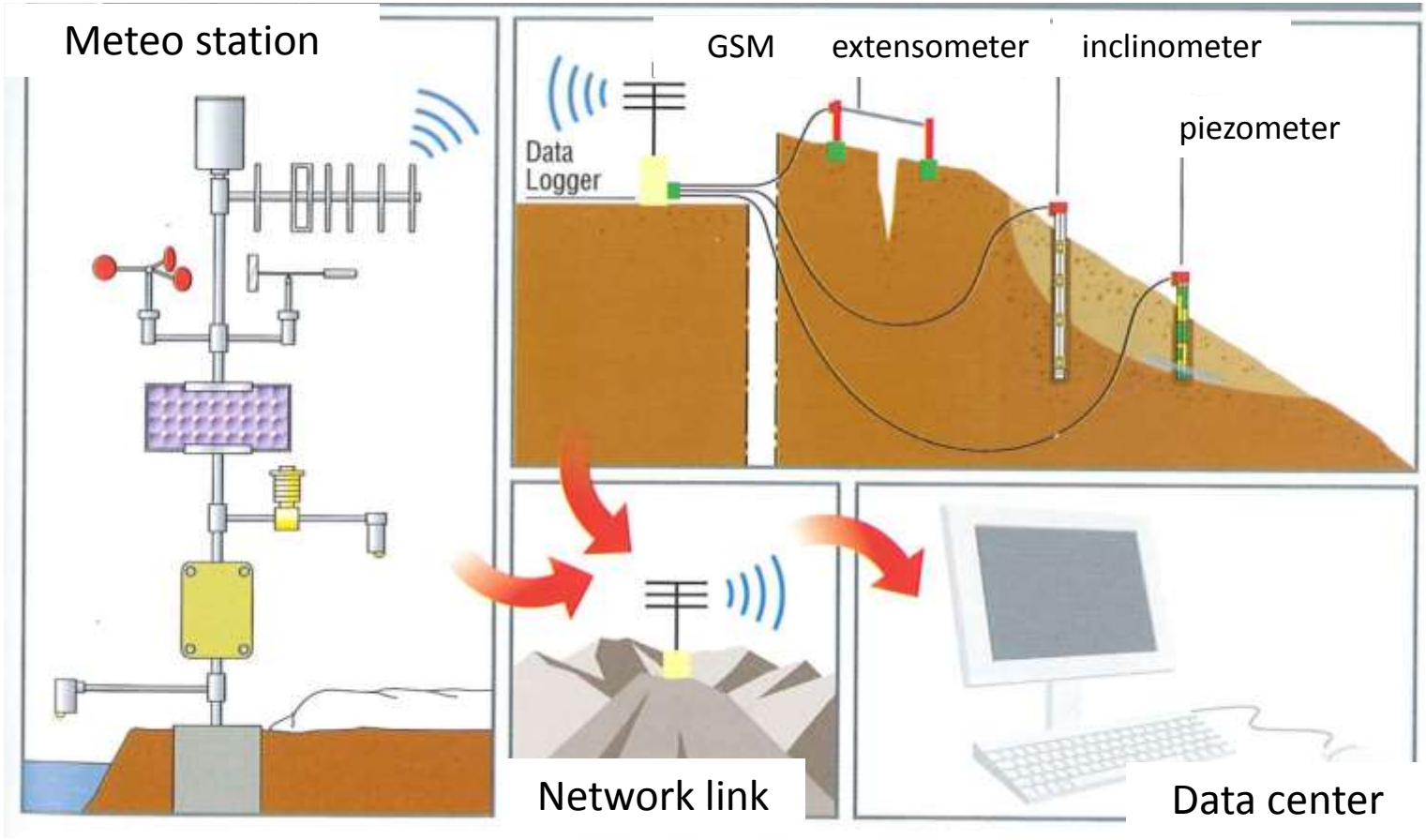
Near real time monitoring



From Mannucci & Notarpietro, 2005

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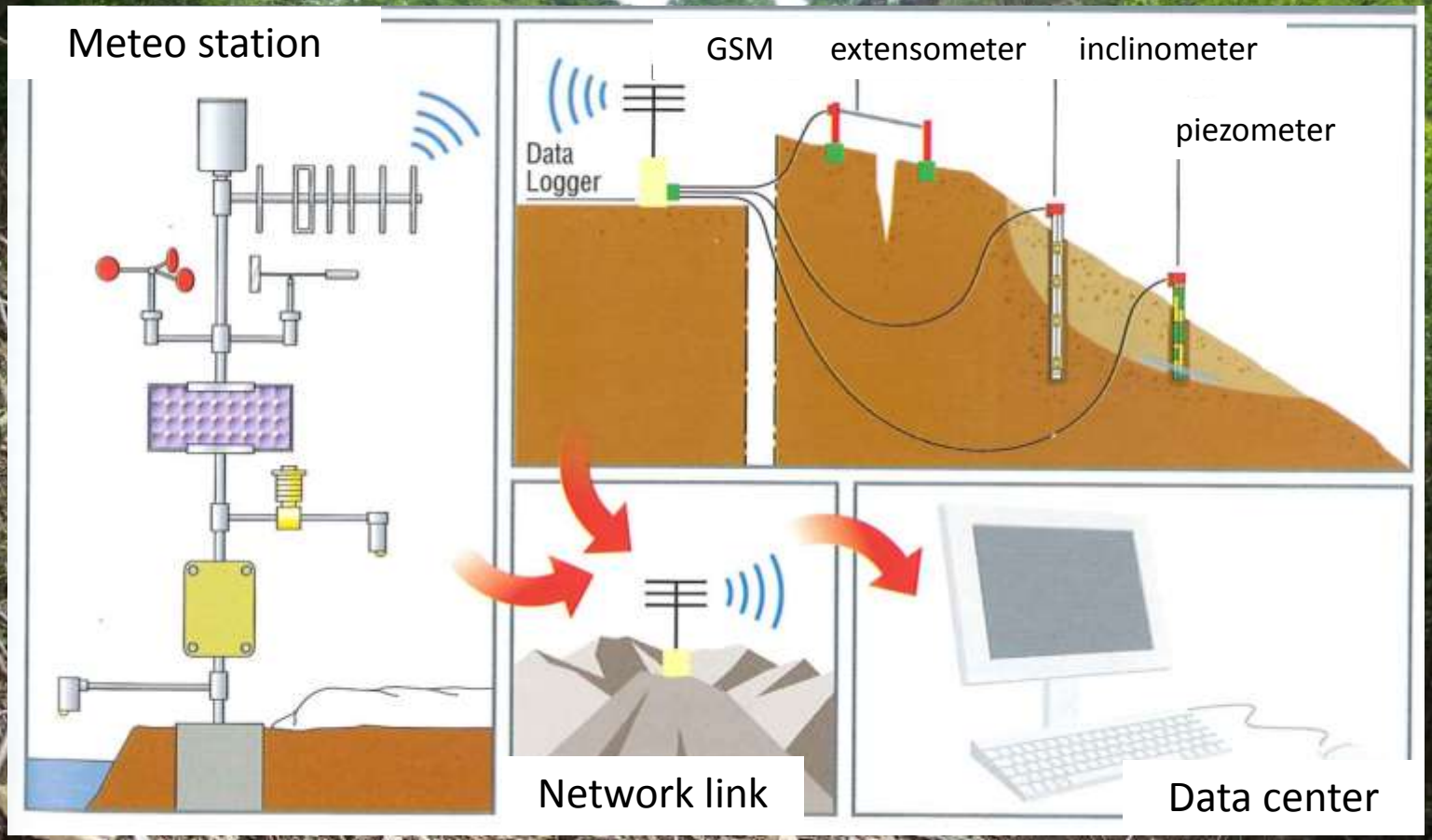
Near real time monitoring



From Mannucci & Notarpietro, 2005

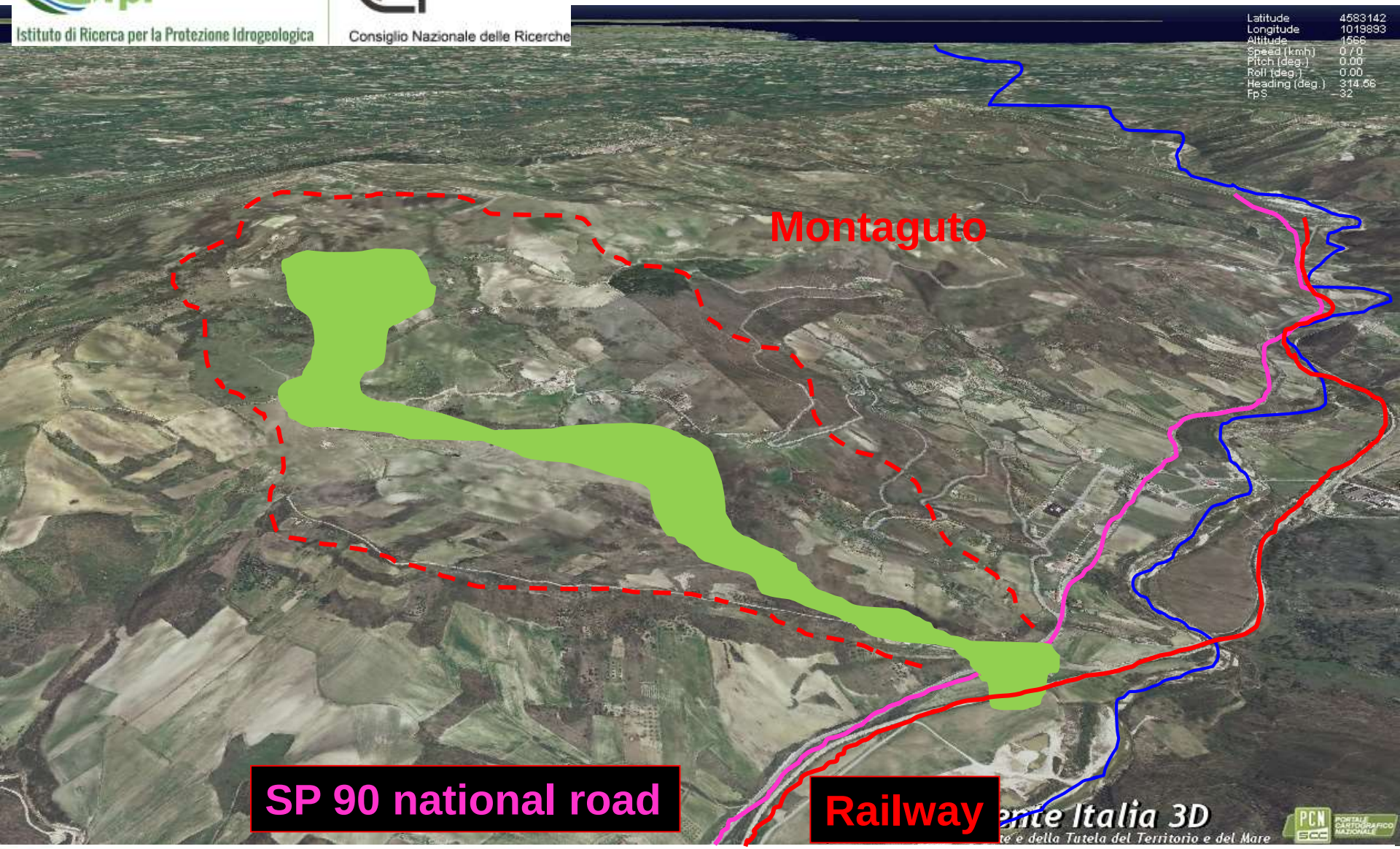
Montaguto earthflow

One of the largest active earthflow in Italy (6M m^3)

Giordan D., Allasia P., Manconi A., Baldo M., Santangelo M., Cardinali M., Corazza A., Albanese V., Lollino G., Guzzetti F., 2013. Morphological and kinematic evolution of a large earthflow: The Montaguto landslide, southern Italy, Geomorphology, 187, 61-79. DOI: 10.1016/j.geomorph.2012.12.035

Lollino P., Giordan D., Allasia P. 2014. The Montaguto earthflow: A back-analysis of the process of landslide propagation. Engineering Geology, 170, 66–79; DOI:10.1016/j.enggeo.2013.12.011

MONTAGUTO LANDLSIDE



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THE MONTAGUTO EMERGENCY TEAM

National Civil Defence

Italian Army

CNR IRPI
(as National Civil Defence "Centro di Competenza" for landslides)

University of Florence - Earth Department
(as National Civil Defence "Centro di Competenza" for terrestrial SAR)

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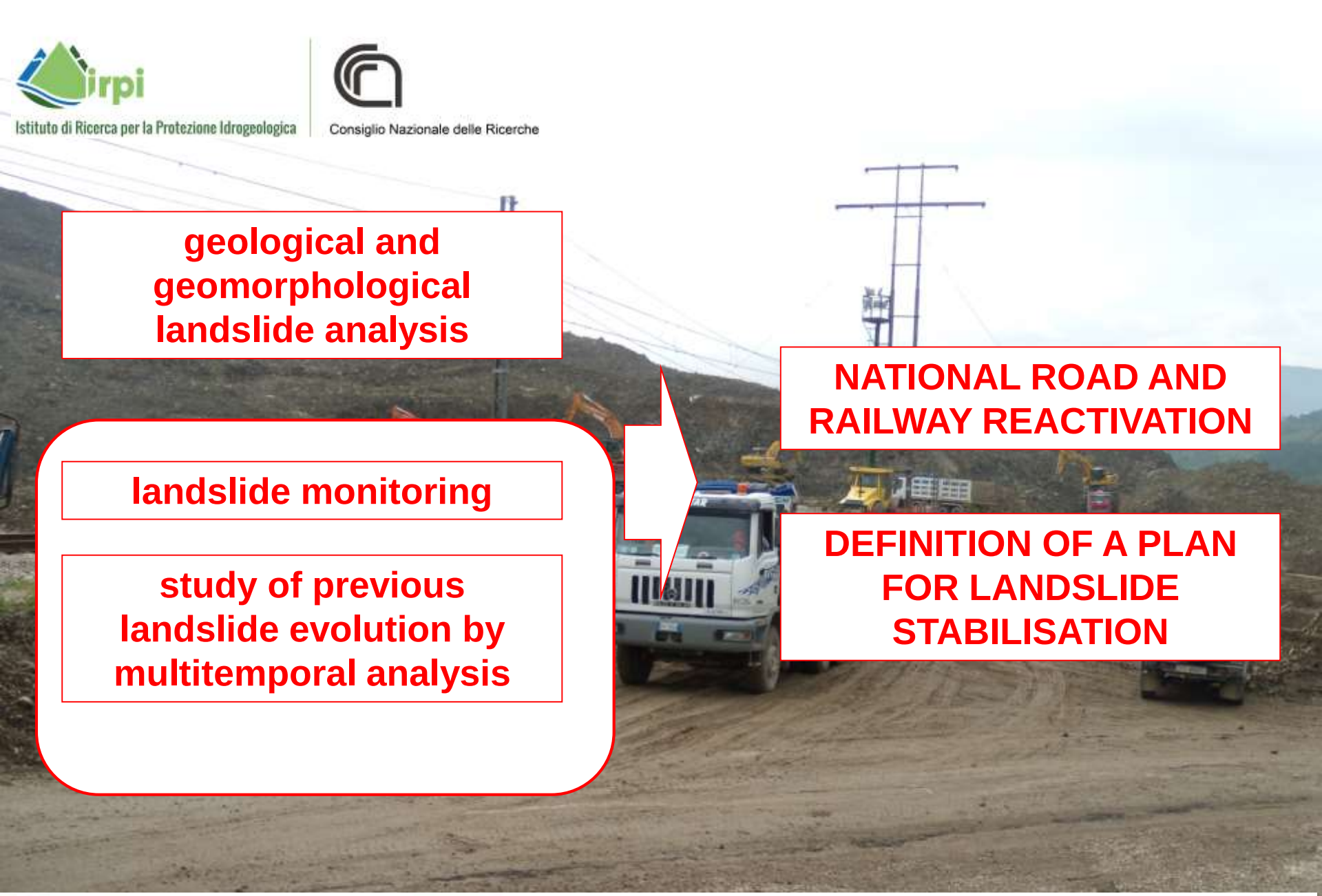

geological and geomorphological landslide analysis

landslide monitoring

study of previous landslide evolution by multitemporal analysis

NATIONAL ROAD AND RAILWAY REACTIVATION

DEFINITION OF A PLAN FOR LANDSLIDE STABILISATION

LANDSLIDE OVERVIEW

BEDROCK

- **Flysh of Faeto (Burdig. Inf. –sup.): clay, sandstone and marl**

- **Villamaina Unit (Messin. inf.): silt, sandstone and clay**

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LANDSLIDE OVERVIEW

Landslide head zone

The main scarp is subjected to the activation of slides and/or soil slips alog the unstable bedrock outcrops

High retrogressive trend

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LANDSLIDE OVERVIEW

Landslide channel

The presence of springs increase the water content and the landslide body velocity

The seasonally activation of this landslide area is connected to waterfall

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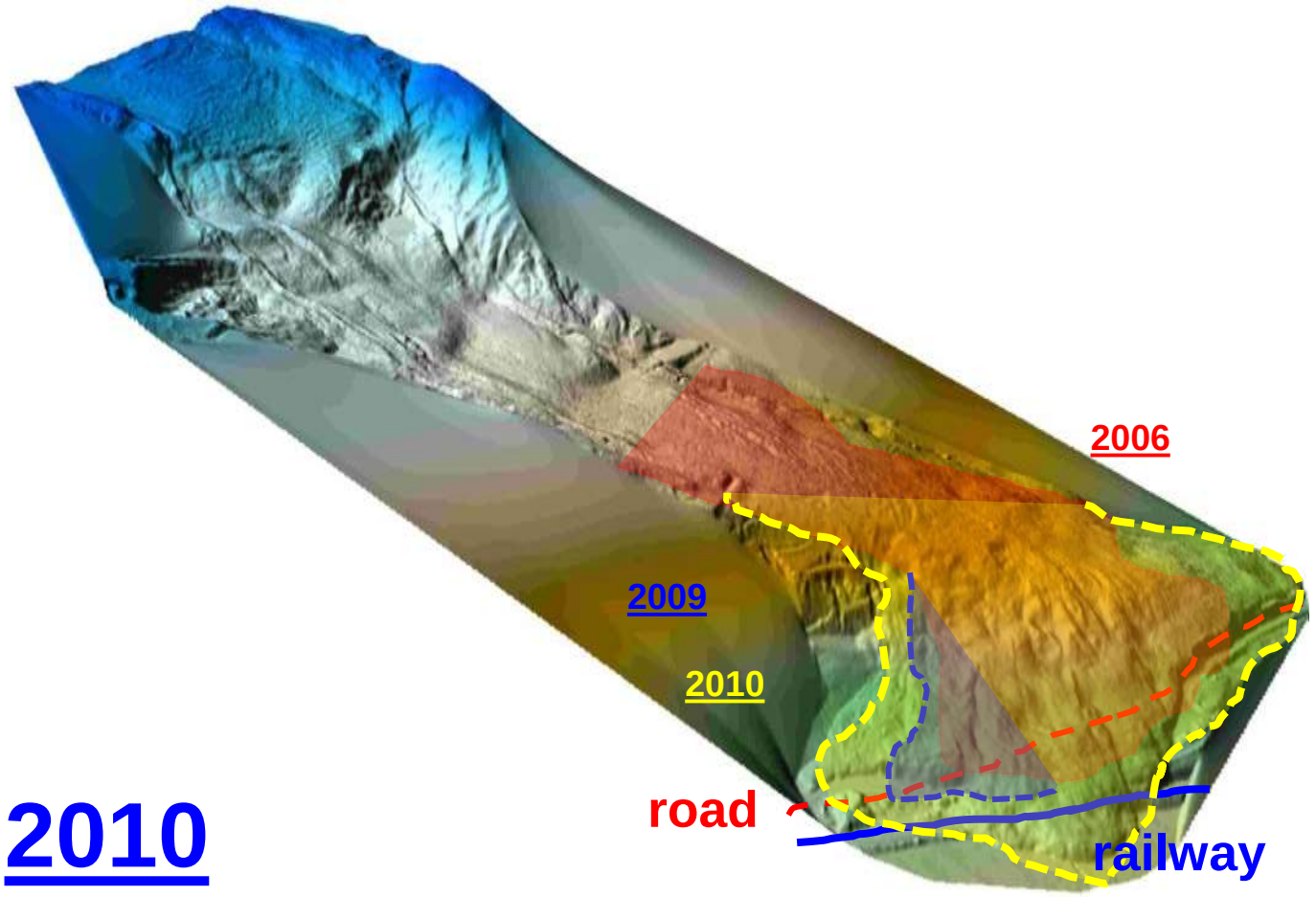
LANDSLIDE OVERVIEW

2006-2010 landslide tip evolution

The landslide body flow along the original stream valley up to the Biferno valley plain, where it made different lobes



2010

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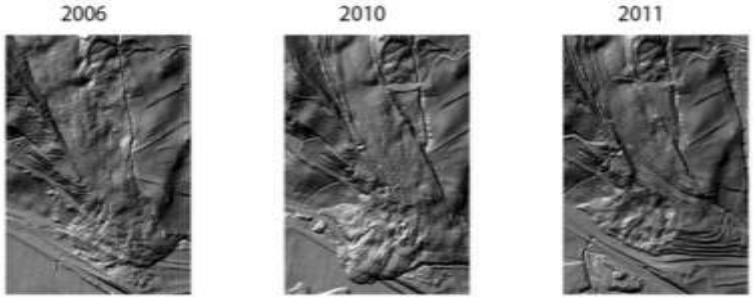
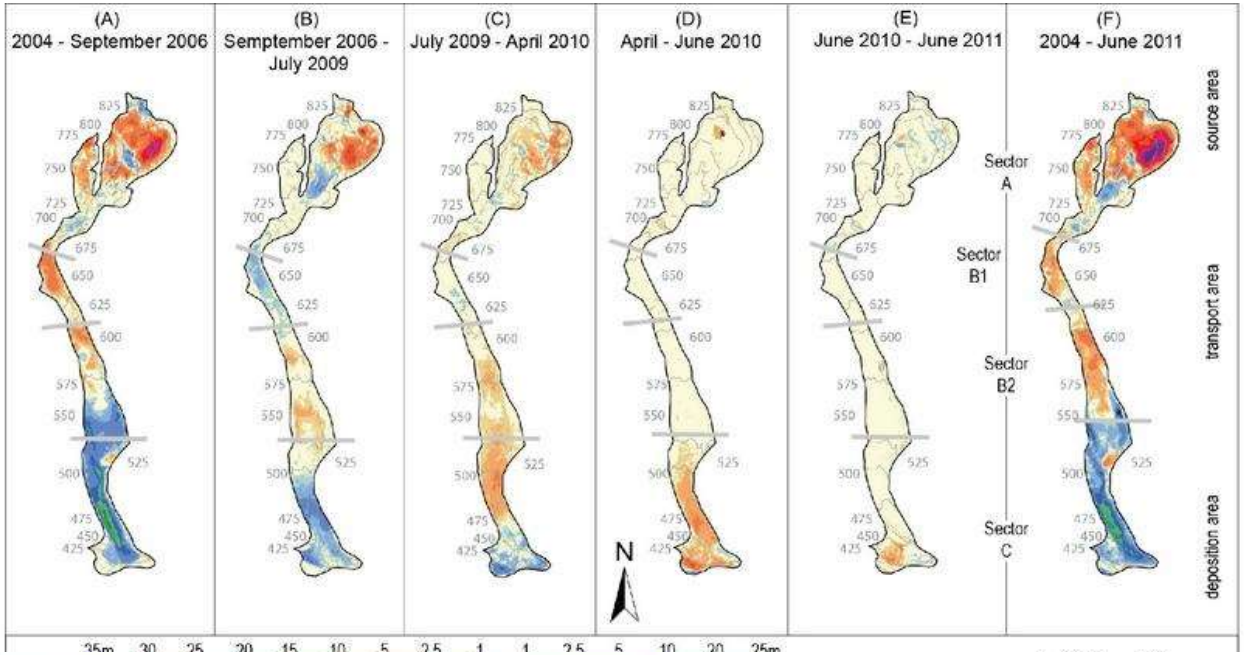
Remote sensing: Airborne LiDAR to measure surface changes due to the earthflow





Main advantage:

spatial coverage, remote measurement of topographic (and volume) changes caused by the landslide

Main disadvantage:

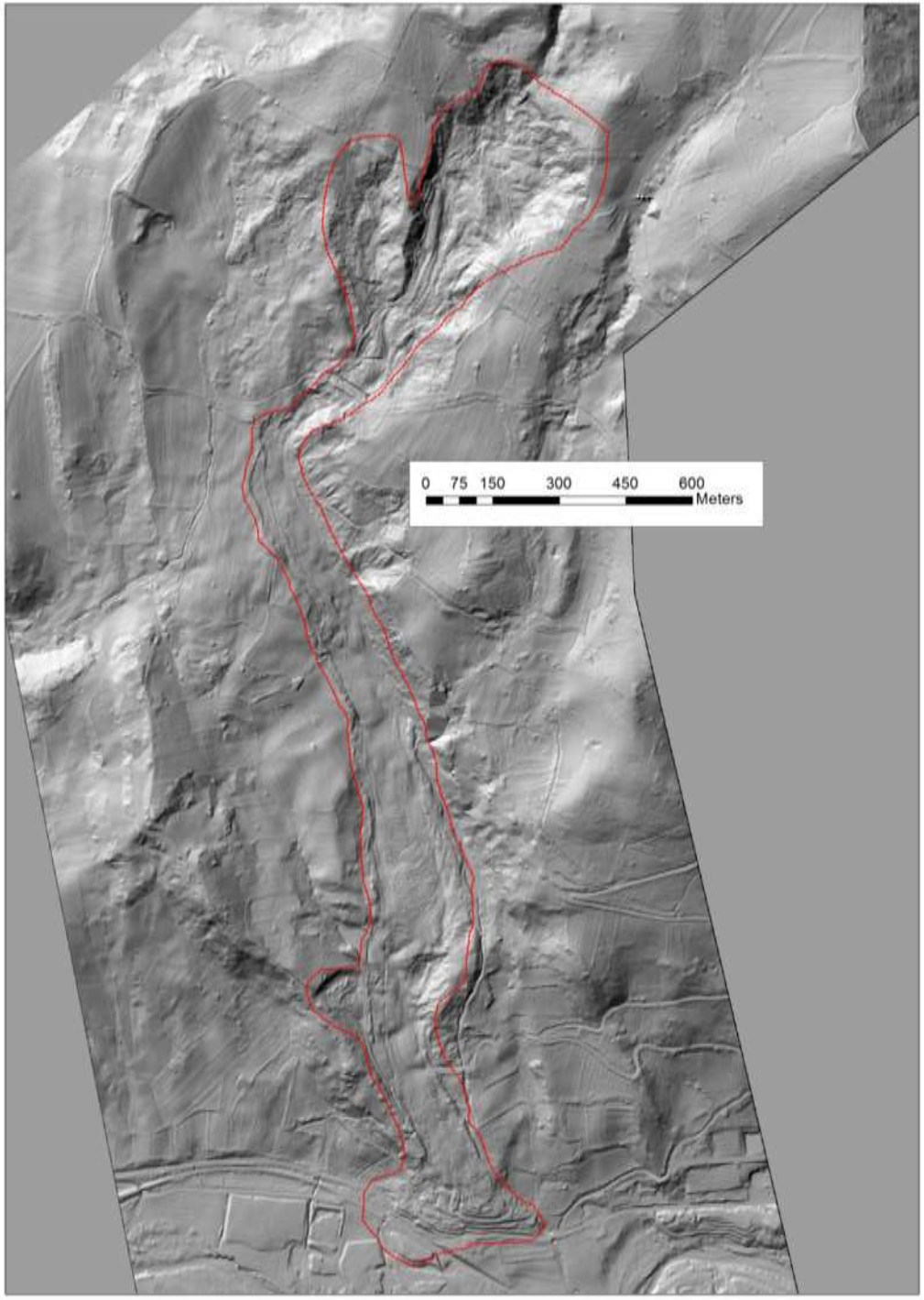
Revisit time is not suitable for near-real time monitoring, thus cannot be used for early warning purposes

GEOHAZARD MONITORING GROUP

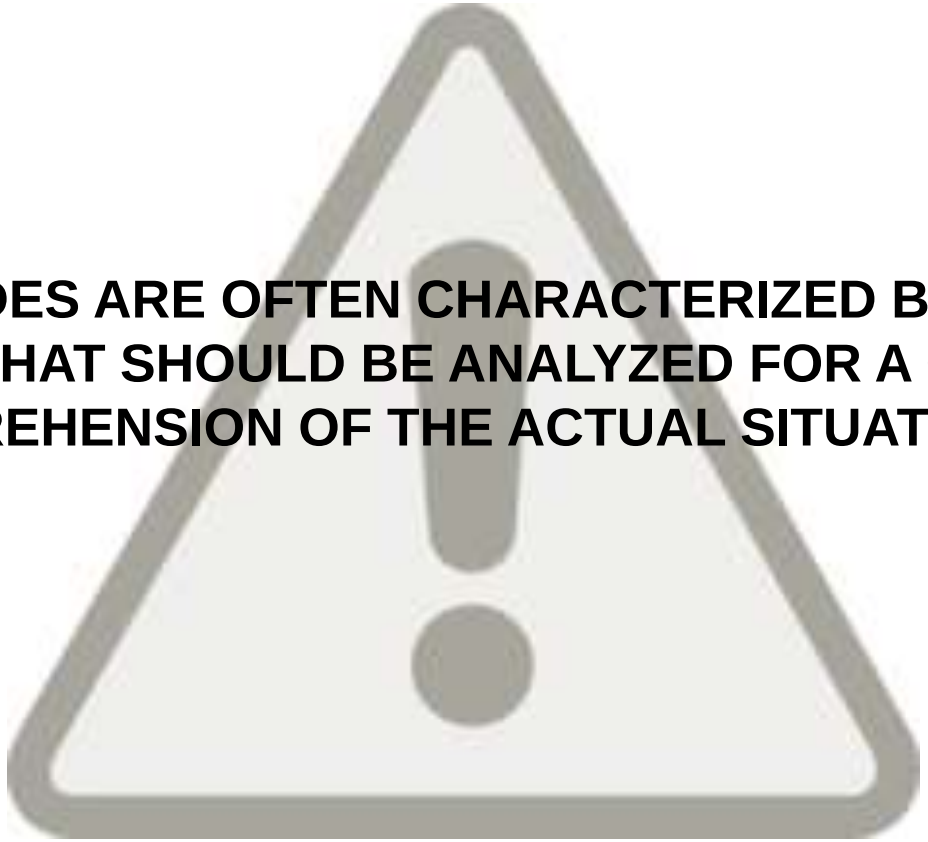
2004-2010 LANDSLIDE EVOLUTION

Available surveys:

- **2004 DTM (vector topography)**
- **2006 DTM (LIDAR)**
- **2009 DTM (LIDAR)**
- **2010 (april) DTM (LIDAR)**
- **2010 (july) DTM (LIDAR)**



LESSON LEARNED



LARGE LANDSLIDES ARE OFTEN CHARACTERIZED BY A COMPLEX EVOLUTION THAT SHOULD BE ANALYZED FOR A CORRECT COMPREHENSION OF THE ACTUAL SITUATION

Istituto di Ricerca per la Protezione Idrogeologica

Consiglio Nazionale delle Ricerche

Near-Real-Time Displacement monitoring via Robotized Total Station

→ 3 Robotized Total Stations, remotely controlled, working H24 with revisit time ranging from 30 minutes to 2 hours

→ 1 Meteo Station, H24 10 minutes sampling rate

→ The data is sent to a remote server for post-processing

→ Daily report to the authorities

GEOHAZARD MONITORING GROUP

Istituto di Ricerca per la Protezione Idrogeologica

Consiglio Nazionale delle Ricerche

CNR IRPI MONITORING SYSTEMS

All the systems are automatized and work h 24

The robotized total station made the measurement sessions

A GSM/UMTS connection transfer all the raw data to the Geo-monitoring Group CNR IRPI (Turin) server

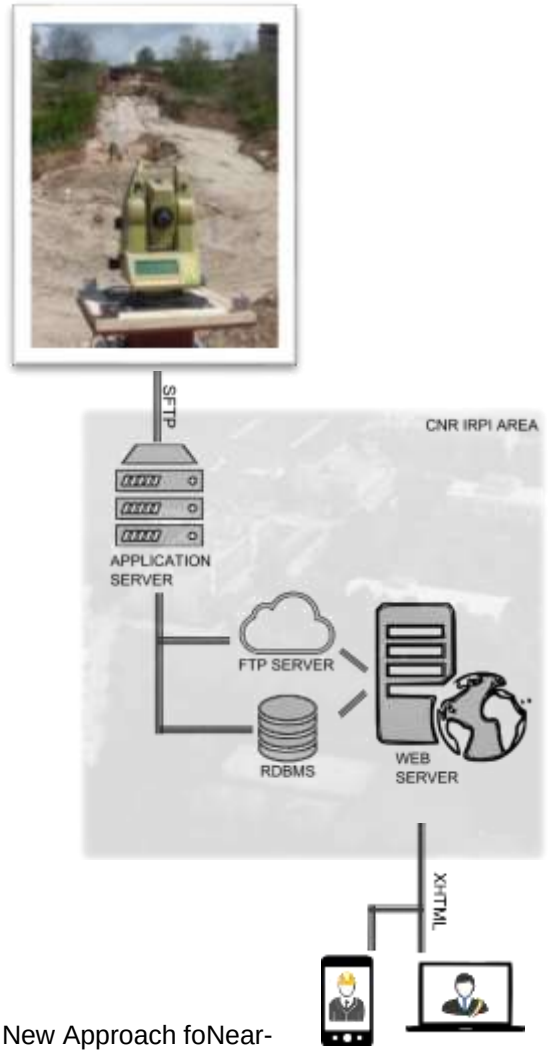
A CNR IRPI software suite collects all the data and transforms the raw measures in excel graphics in few minutes

A daily report is sent to the National Civil Defence

GEOHAZARD MONITORING GROUP

LANDMON

The Geohazard Monitoring Group developed **LANDMON (LANDslides MOnitorng Network)**, a system able to manage landslide monitoring networks in near real time



MAIN FEATURES:

Acquisition, management and merging of different instrumentation datasets

On line publication of monitoring results

Management of thresholds for early warning applications

Further information: Allasia P., Manconi A., Giordan D., Baldo M., Lollino G. 2013. ADVICE: A New Approach foNear-Real-Time Monitoring of Surface Displacements in Landslide Hazard Scenarios. Sensors, 13(7), 8285-8302;

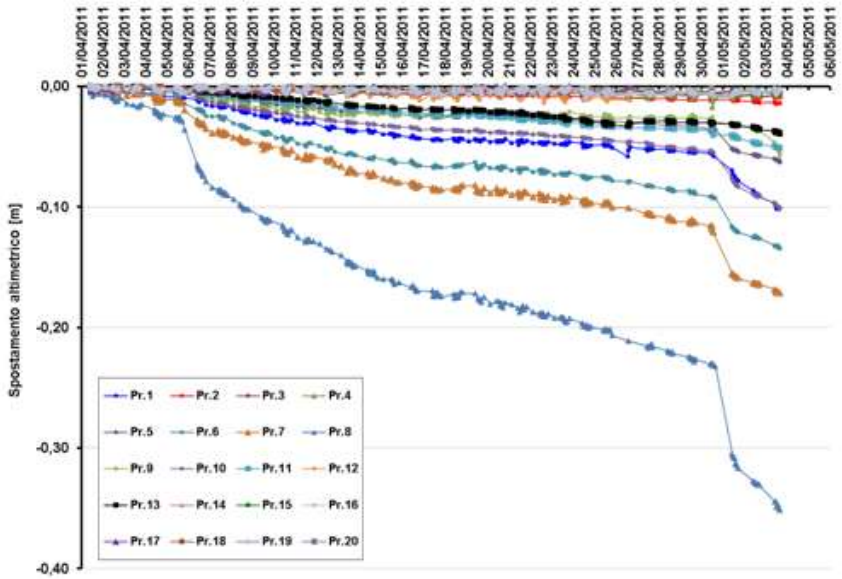
GEOHAZARD MONITORING GROUP

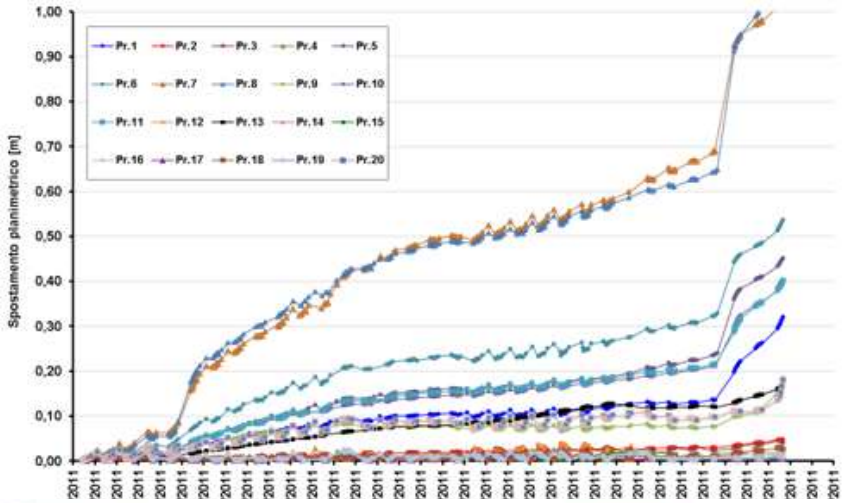
LESSON LEARNED

Landslides near real time monitoring network are a complex technological challenge

We have to consider not only the in situ acquisition but also the remote transfer of acquired data and their management

Displacement monitoring via Robotized Total Station (RTS)



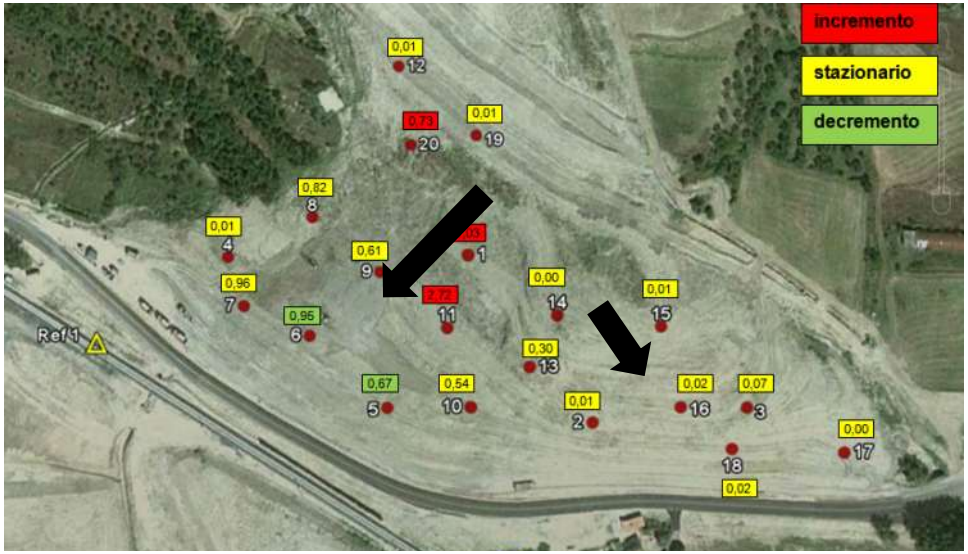


Example of the landslide toe:

→20 targets monitored via RTS

→Dispacement behavior changes spatially in terms of amplitude…

→ …and direction



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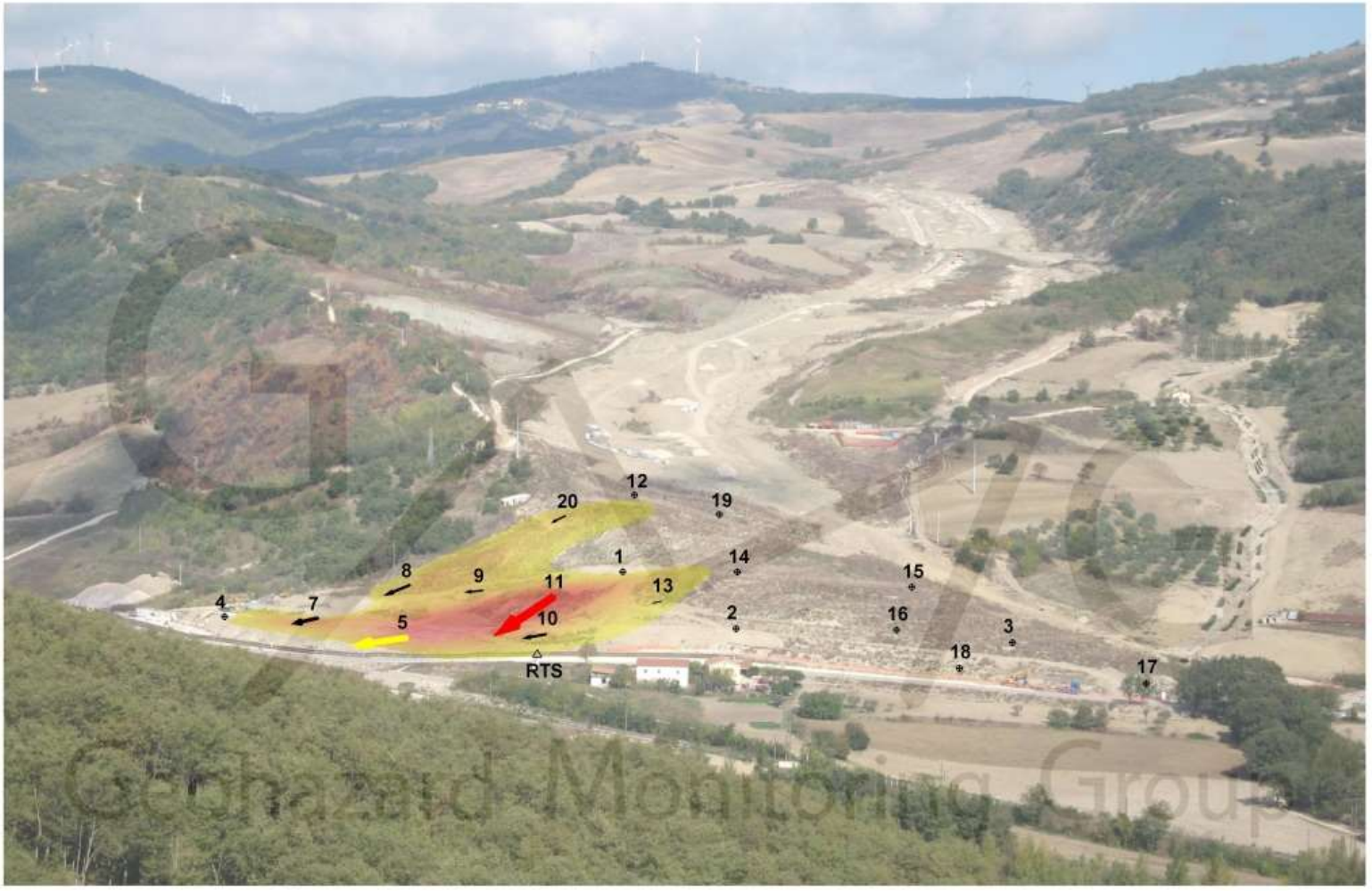
©3DA – Three-dimensional Displacement Analysis for early warning (GMG copyright)



3DA
Three-Dimensional Displacement Analysis

Frana di Montaguto (AV)

E: 518533 m*
N: 4565133 m*
Z: 424 m (s.l.m.)

*Sistema di riferimento UTM-WGS84
Le coordinate sono riferite alla posizione della stazione di misura

Foto del 19/10/2011

AGGIORNAMENTO

Data misura: 01/03/2011
Ora: 12:00:00
Target misurati 20 / 20
Target in movimento** 8 / 20

**Per movimento si considera come soglia il valore di 0.1 m/mese

SIMBOLOGIA

- Target misurato
- Target non misurato
- Target in movimento < 1 m/mese
- Warning, movimento > 1 m/mese
- Alarm, movimento > 2 m/mese
- RTS: Stazione totale

Vettori spostamento

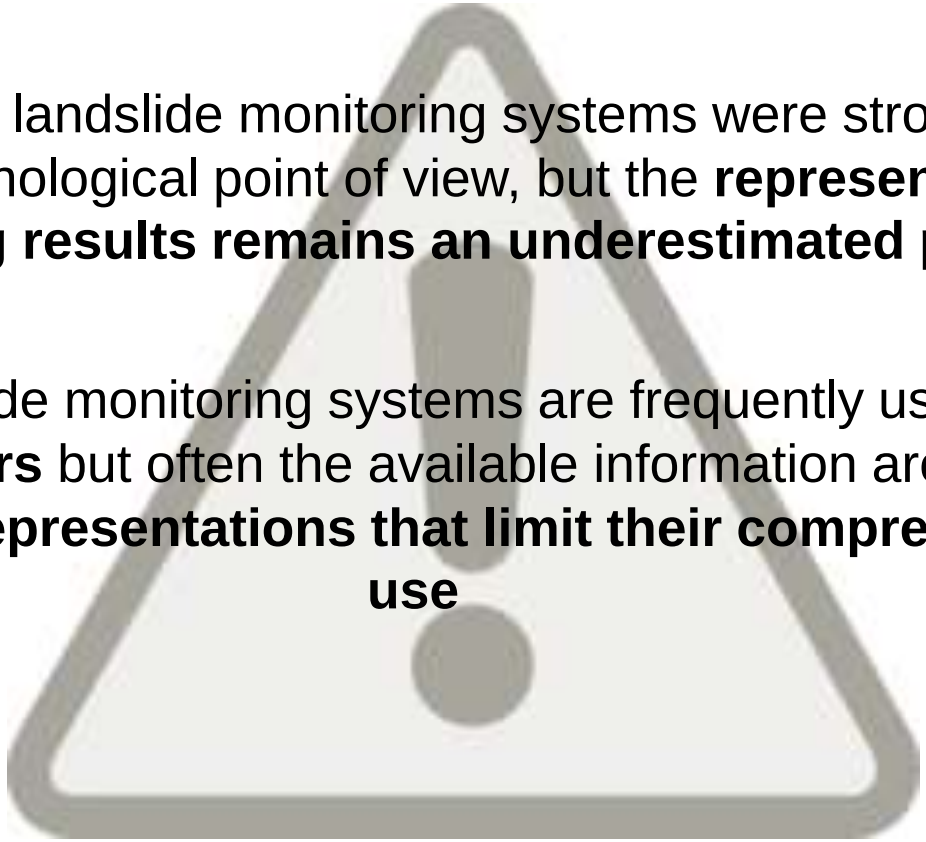
2.2 m/mese

Mappa delle deformazioni (dXYZ)

m/mese

0.1 0.31 0.52 0.73 0.94 1.145 1.36 1.57 1.78 1.99 2.2

LESSON LEARNED



In the last decade, landslide monitoring systems were strongly improved from the technological point of view, but the **representation of monitoring results remains an underestimated prolem**

Nowadays, landslide monitoring systems are frequently used to **support decision makers** but often the available information are presented using **complex representations that limit their comprehension and use**

Mt. de la Saxe rockslide

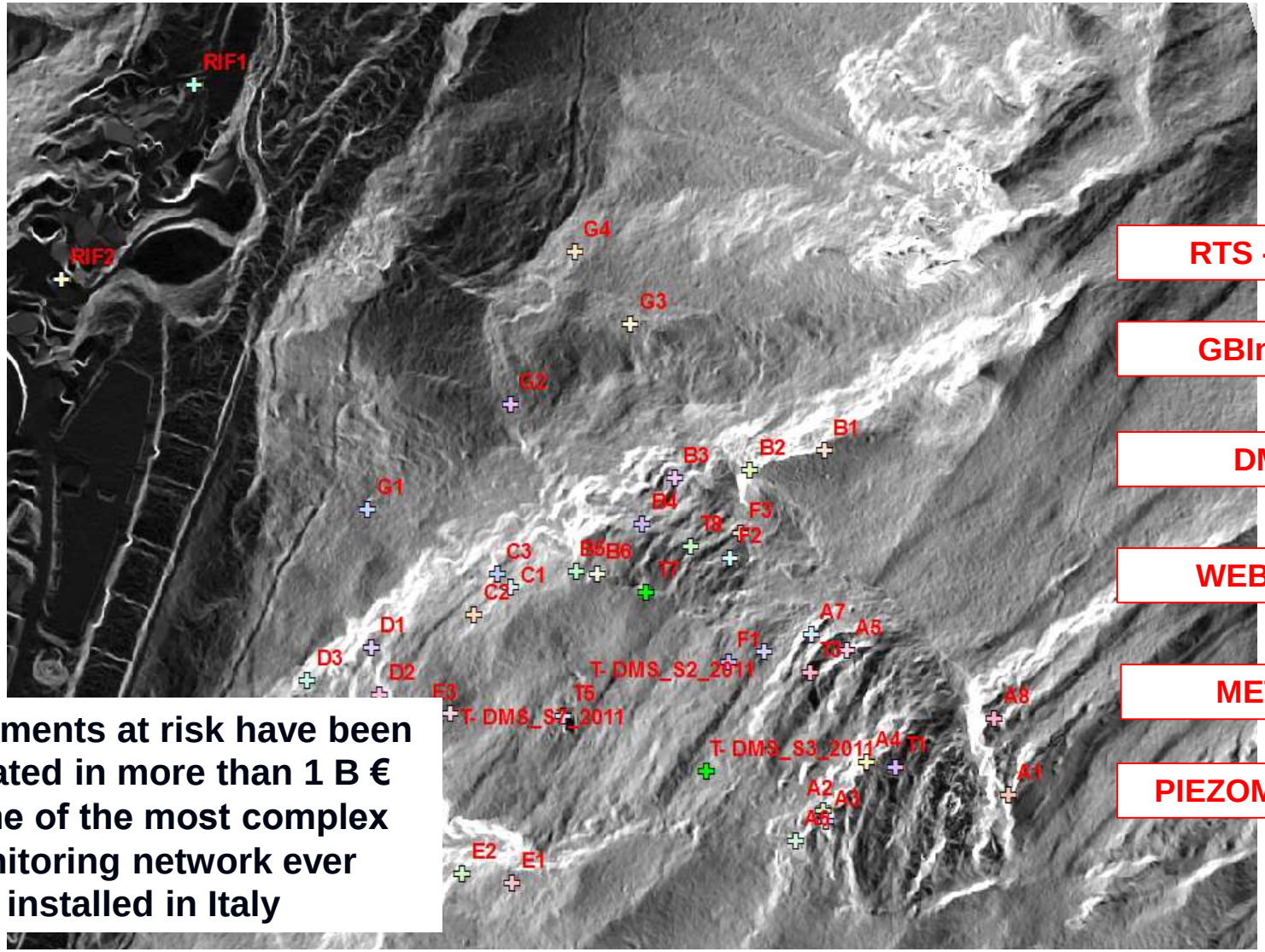
One of the largest active rockslide in Italy (12M m^3)

Manconi A., Giordan D. 2016. Landslide failure forecast in near-real-time. Geomatics, Natural Hazards and Risk, 7 (2), 639, 648. DOI: 10.1080/19475705.2014.942388

Crosta G.B., Lollino G., Frattini P., Giordan D., Tamburini A., Rivolta C., Bertolo D. 2015 Rockslide Monitoring Through Multi-temporal LiDAR DEM and TLS Data Analysis. In: Lollino G., et al. (eds.) Engineering Geology for Society and Territory – Volume 2, Springer International Publishing Switzerland, 613-617

Manconi A., Giordan D. 2015. Landslide early warning based on failure forecast models: the example of the Mt. de La Saxe rockslide, northern Italy. Nat. Hazards Earth Syst. Sci., 15, 1639–1644.

Mt. de la Saxe rockslide



RTS - GPS

GBInSAR

DMS

WEBCAM

METEO

PIEZOMETERS

The elements at risk have been evaluated in more than 1 B € It's one of the most complex monitoring network ever installed in Italy

GEOHAZARD MONITORING GROUP

LESSON LEARNED

According to our experience, one of the most critical element in landslides management (in particular during emergencies) is the **lack of a correct dissemination of available information**

THIS IS MAINLY DUE TO:

1) Poor communication strategies dedicated to the information of population

2) Problems in the management of the available dataset in particular when the study of the phenomenon started many years ago

Mt. de la Saxe rockslide

The landslide management team is composed by an heterogeneous group of people with different background and duties

Prefect/mayor/ alderman, or other politician that often don't have a specific technical background on landslide (GROUP 1)

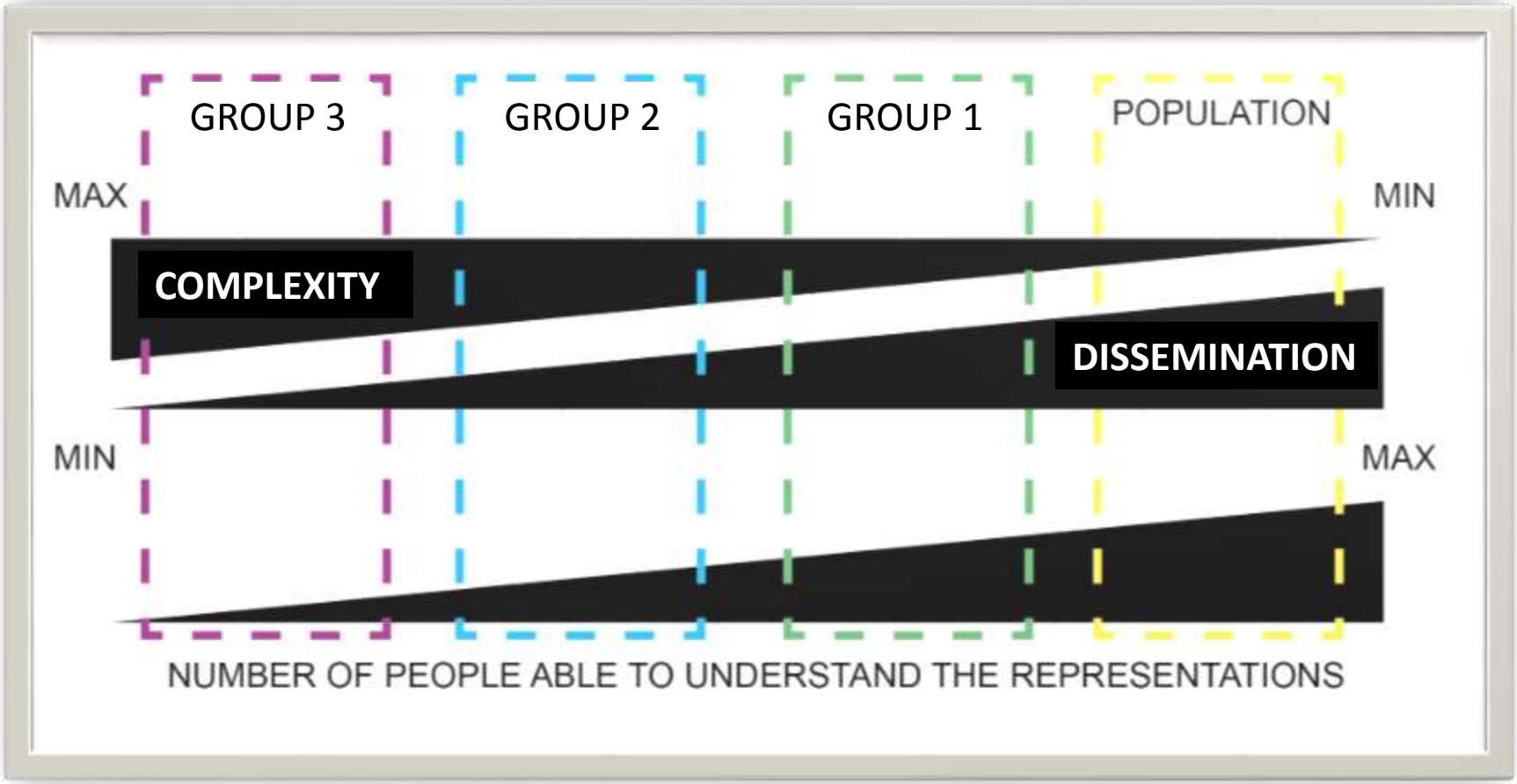
Engineers, geologists, and others technicians that have good preparation on landslides but not always have a specific knowledge about monitoring systems (GROUP 2)

Engineers, geologists, and others technicians that have a specific preparation on landslides monitoring systems (GROUP 3)

All these groups contribute to the emergency management and need a system able to support thier decisions and to illustrate the landslide evolution

Giordan D., Manconi A., Allasia P., Bertolo D. 2015. Brief Communication: On the rapid and efficient monitoring results dissemination in landslide emergency scenarios: the Mont de La Saxe case study. Nat. Hazards Earth Syst. Sci., 15, 2009–2017

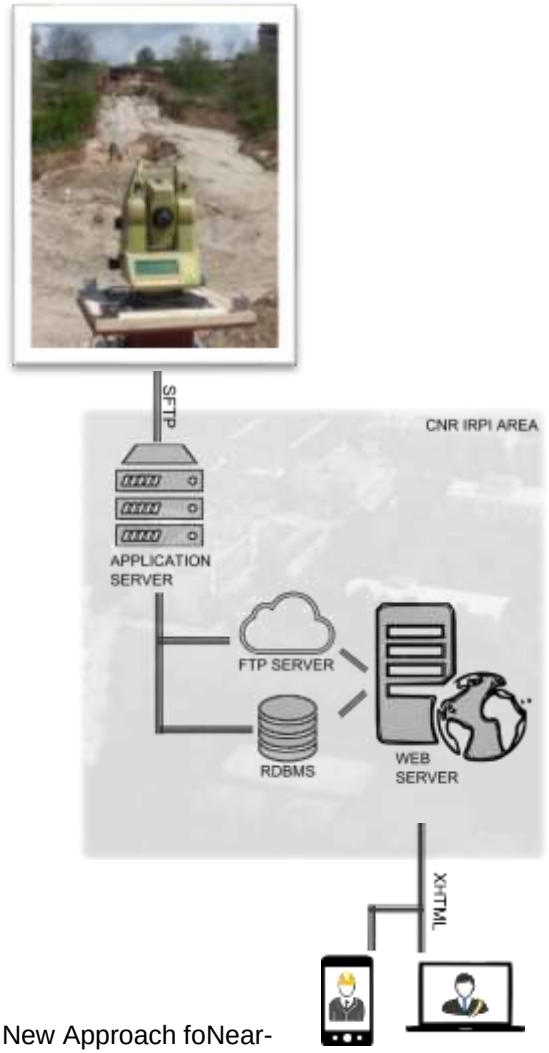
Mt. de la Saxe rockslide



The same dataset should be represented in different ways according to the communication target

LANDMON – main features

The Geohazard Monitoring Group developed **LANDMON (LANDslides MOnitorng Network)**, a system able to manage landslide monitoring networks in near real time



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LANDMON – main features

LANDMON is also a communication system that supplies different monitoring results representations according to the stakeholders' background

ASSUMPTION

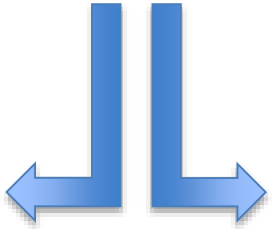
The use of monitoring systems is correct only if ALL INVOLVED PEOPLE are ABLE TO UNDERSTAND their results

GEOHAZARD MONITORING GROUP

LANDMON – main features

LANDMON communication strategy

Near real time website application for the publication of monitoring results



Periodically bulletins with the description of the landslide evolution

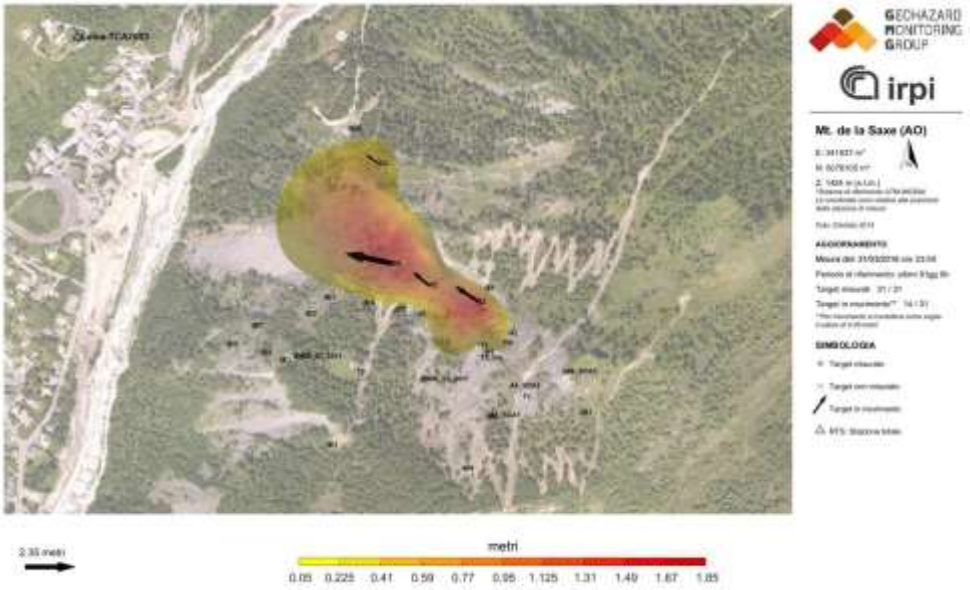
Description of recent landslide evolution - **Support to decision makers** that need a fast and effective system for the management and visualization of the available dataset

The use of bulletins is important for a correct **analysis of landslide evolution**

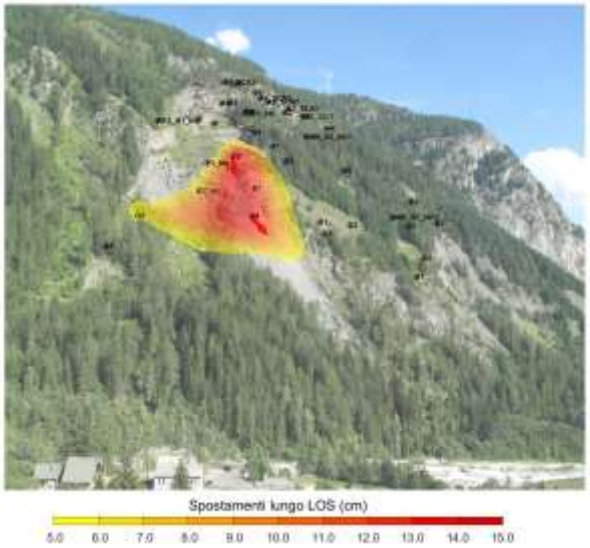
GEOHAZARD MONITORING GROUP

Mt. de la Saxe rockslide

NEAR REAL TIME WEBSITE APPLICATION
2D / 3D INFOGRAPHICS



Ortho-photo/photo from Google Maps



Frontal view

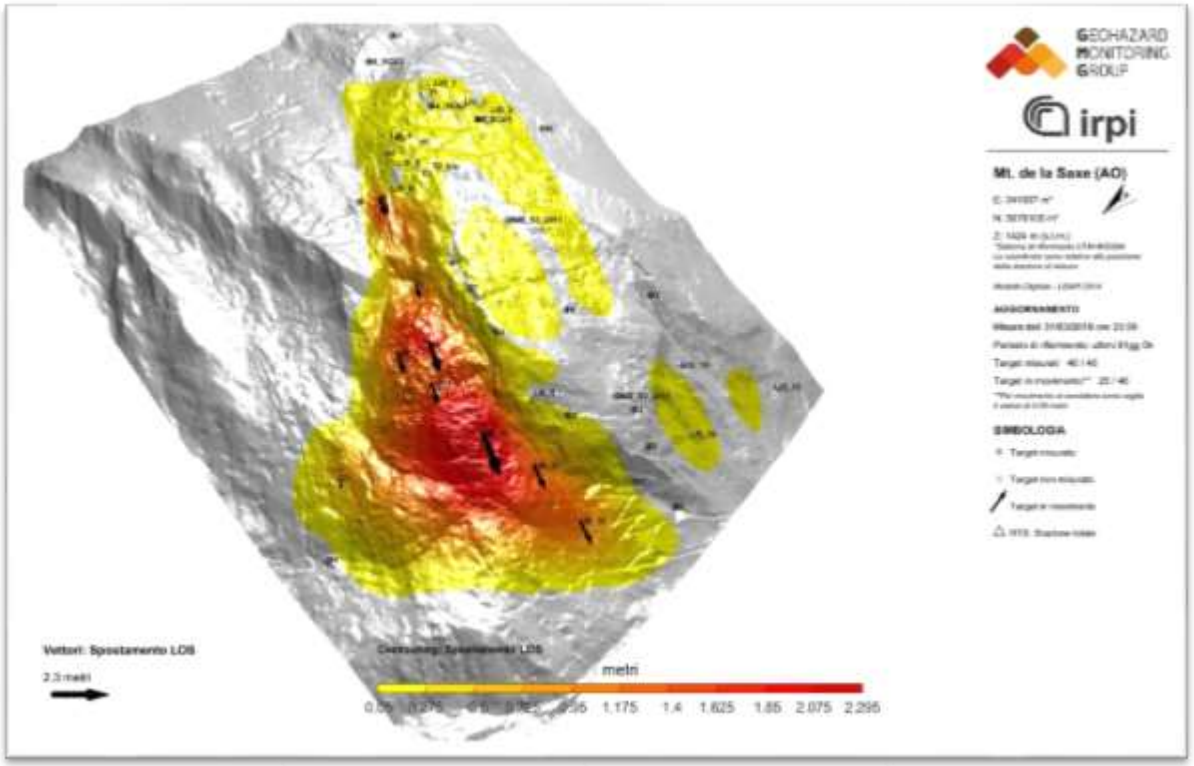
GROUP 1

GEOHAZARD MONITORING GROUP

Mt. de la Saxe rockslide

NEAR REAL TIME WEBSITE APPLICATION
MULTI INSTRUMENTAL 3D REPRESENTATIONS

GbinSAR and Robotised total station datasets merged in the same representation

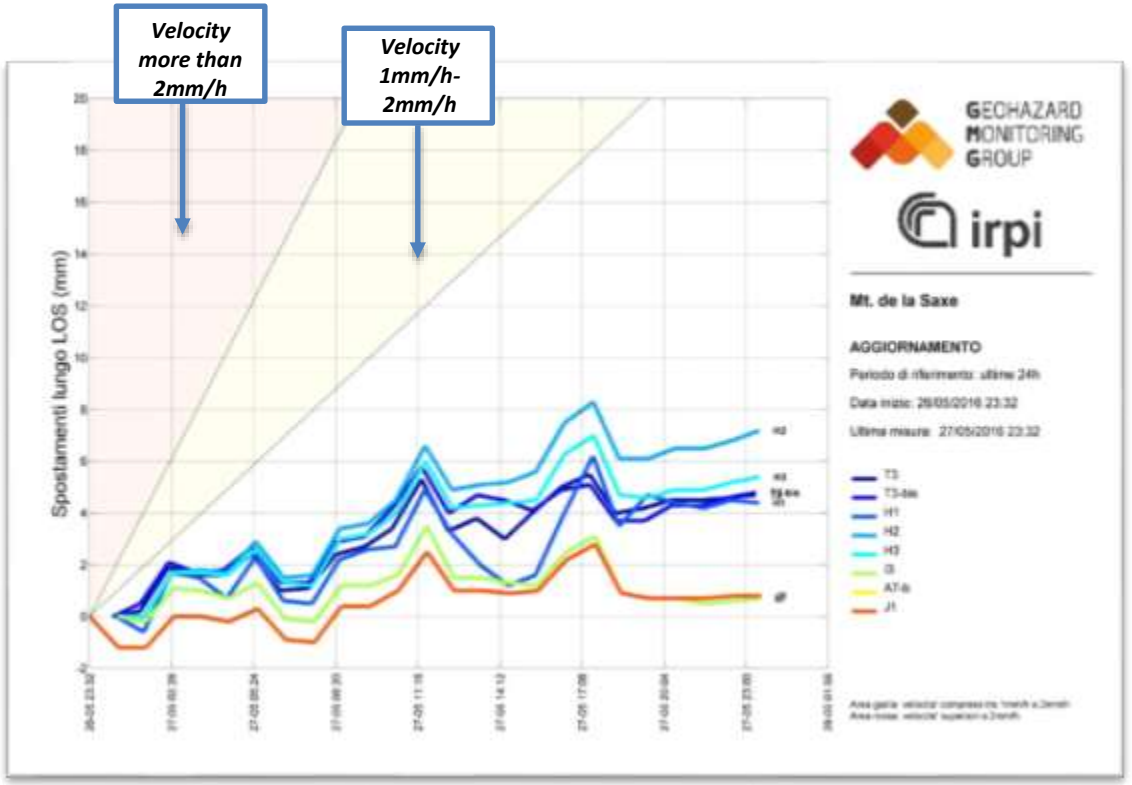


GROUP 2

GEOHAZARD MONITORING GROUP

Mt. de la Saxe rockslide

NEAR REAL TIME WEBSITE APPLICATION
PLOTS FOR EARLY WARNING

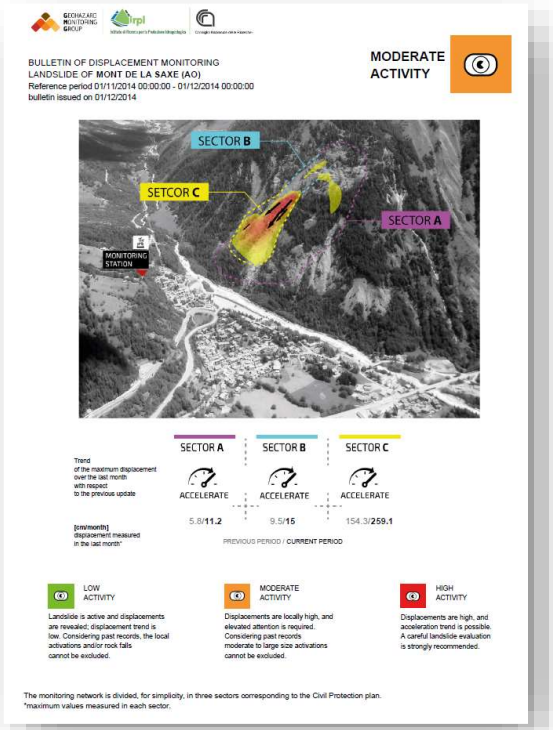


GROUP 3

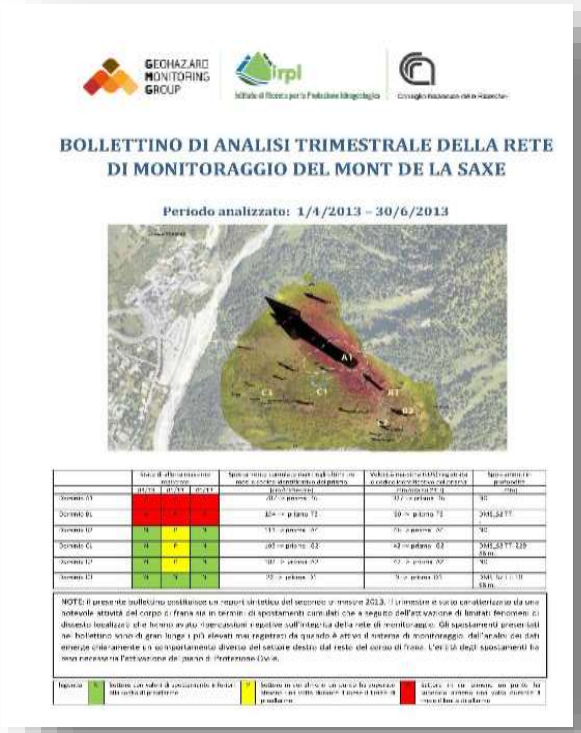
Mt. de la Saxe rockslide

PERIODICALLY BULLETINS

Single page bulletin
For a rapid information



25 pages bulletin
For a deep analysis



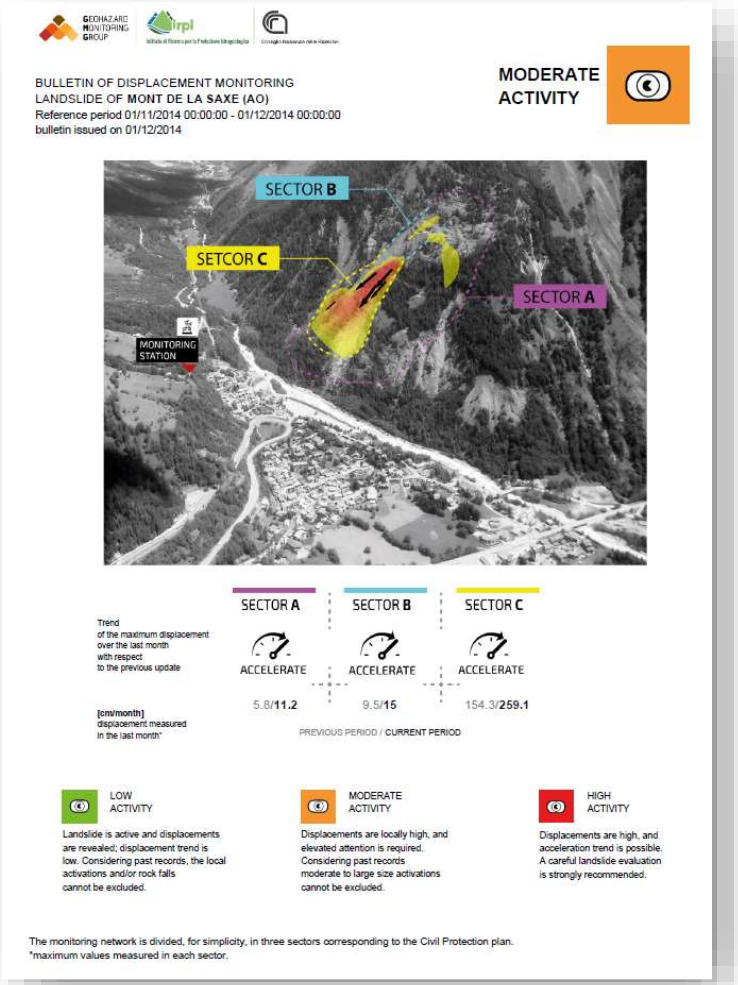
Monography
Synthesis of all collected data

Not in near real time but important for a more detailed analysis of landslide evolution

GEOHAZARD MONITORING GROUP

Mt. de la Saxe rockslide

SINGLE PAGE BULLETIN



BULLETIN OF DISPLACEMENT MONITORING
LANDSLIDE OF **MONT DE LA SAXE (AO)**
Reference period 01/11/2014 00:00:00 - 01/12/2014 00:00:00
bulletin issued on 01/12/2014

MODERATE ACTIVITY

SECTOR B
SETCOR C
SECTOR A
MONITORING STATION

	SECTOR A	SECTOR B	SECTOR C
Trend of the maximum displacement over the last month with respect to the previous update	ACCELERATE	ACCELERATE	ACCELERATE
[cm/month] displacement measured in the last month*	5.8/**11.2**	9.5/**15**	154.3/**259.1**

PREVIOUS PERIOD / **CURRENT PERIOD**

LOW ACTIVITY
Landslide is active and displacements are revealed; displacement trend is low. Considering past records, the local activations and/or rock falls cannot be excluded.

MODERATE ACTIVITY
Displacements are locally high, and elevated attention is required. Considering past records moderate to large size activations cannot be excluded.

HIGH ACTIVITY
Displacements are high, and acceleration trend is possible. A careful landslide evaluation is strongly recommended.

The monitoring network is divided, for simplicity, in three sectors corresponding to the Civil Protection plan.
*maximum values measured in each sector.

Automatic publication system

User friendly representation of the landslide evolution

Covered time interval: from 12 hours to1 month

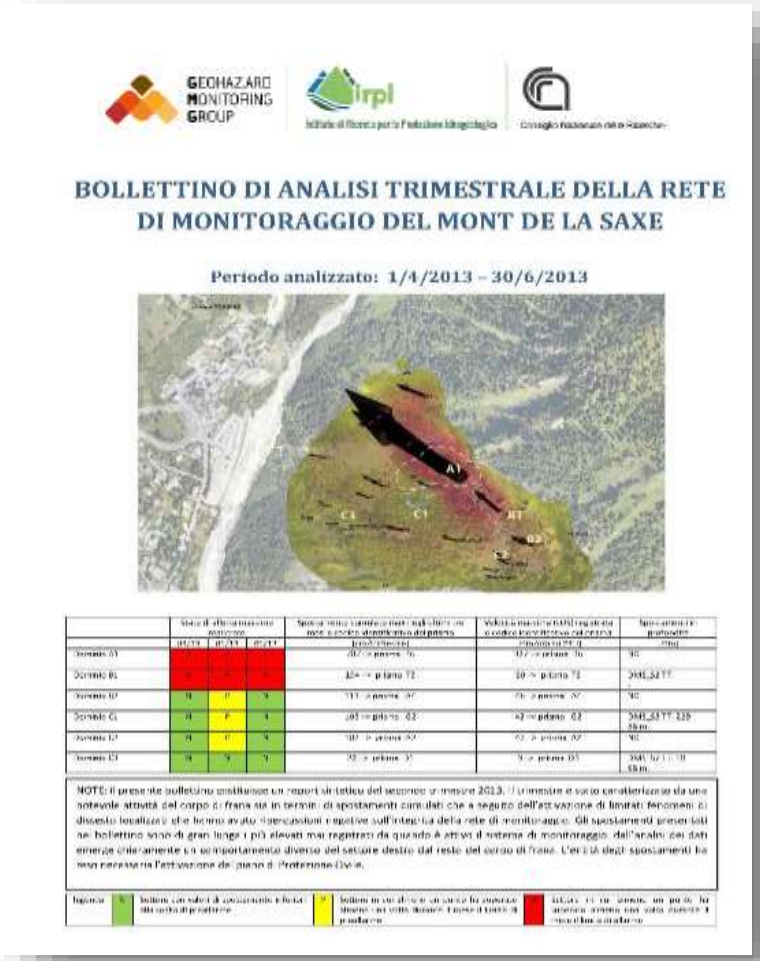
Use of infographics for an easy representation of monitoring results

Developed for a correct information of population during emergencies

Giordan D., Manconi A., Allasia P., Bertolo D. 2015. Brief Communication: On the rapid and efficient monitoring results dissemination in landslide emergency scenarios: the Mont de La Saxe case study. Nat. Hazards Earth Syst. Sci., 15, 2009–2017

Mt. de la Saxe rockslide

25 PAGE BULLETIN



GEOHAZARD MONITORING GROUP

BOLLETTINO DI ANALISI TRIMESTRALE DELLA RETE DI MONITORAGGIO DEL MONT DE LA SAXE

Periodo analizzato: 1/4/2013 – 30/6/2013

Manually redacted by GMG

Detailed analysis of recent landslide evolution

Covered time interval: three months

Not only infographics but also commented plots

Dedicated to the landslide monitoring team

Mt. de la Saxe rockslide

MONOGRAPHY

Manually redacted by GMG

Operative document with a synthesis of all the available information

Not only monitoring data but also geological, geotechnical……

Updated every year

Dedicated to the landslide monitoring team

CONCLUSION

Monitoring systems in the past probably were used in particular to improve the knowledge of studied phenomenon, but now the most important application (in particular during emergencies) is to support decision makers

Our experience, in particular with the management of landslide emergencies as scientific advisor of National Civil Protection Agency, evidenced the need for a more effective communication strategy of monitoring results

This presentation is focused on the development of LANDMON, a system aimed to manage landslides monitoring network datasets and share results

This system tries to answer to a recent problem: the development of monitoring systems has been concentrated on their improvement from technological point of view, but few attention has been dedicated to the post processing and data results management

CONCLUSION

The future development of monitoring systems will be dedicated to the creation of user friendly applications that will able to collect data, but also to publish understandable results

LADMON can be considered an example of this new generation of systems, where the technical features are coupled with a communication strategy aimed to support the decision makers in their job, in particular during emergencies

We live in the era of internet and social network, and that means that also data from geo-hydrological hazards monitoring network should be distributed to the population but using a correct strategy of dissemination to guarantee the transmission of a correct message

The dissemination of the correct message it mandatory for the information of the population about the real level of risk and to ask them their cooperation that is fundamental for a correct management of an emergency

daniele.giordan@irpi.cnr.it