
Consiglio Nazionale dei Geologi
alessandro pasuto
Jesi, 10th June 2016
Landslide Monitoring: basic concepts and case studies in the Eastern Alps

MONITORING: BASIC CONCEPTS

Monitoring is the process-like method of **checking**, **observing** and **tracking** processes with the purpose of evaluating system threshold values

Monitoring systems consist of a complex combination of **sensors**, **software**, **hardware** and data processing procedures

Monitoring systems produce **information** which is useful to assess **hazard** and **risk** scenarios as well as to establish where, how and when a specific process will take place

The information produces by a monitoring systems can be used for **study** or **alarm** purposes. In both cases a deep knowledge of the investigated process, in terms of **geology, geomorphology, tectonic, etc.**, is needed

Each instrument on a project should be selected and placed to assist in **answering** a specific **questions**: if there are no questions, there should be no instrumentation (Dunnicliff, 1988)

MONITORING: BASIC CONCEPTS

OBJECTS	to investigate
PARAMETERS	to measure
INSTRUMENTS	to use
SCENARIOS	to define
COUNTERMEASURES	to adopt

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MONITORING: OBJECTS

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MONITORING: MAIN PURPOSES

- **Zoning** unstable areas
- Define the **geometry** and depth of the slip surface
- Estimate the **volume** of the moving mass
- Assess the **rate of movements** either on the surface or in depth
- Record **GWL variations** possibly with respect to climatic trend of the area
- Define the **style of activity** of the study landslide (acceleration, stabilization , etc.)
- Provide a temporal and spatial **forecasting** of landslide behavior
- Provide further knowledge aimed at the designing of possible **mitigation measures**
- Provide a strong support in **spatial and urban planning**
- Provide an adequate **alarm system** in case of impending danger for public safety
- Increase the **public awareness** and the risk perception
- Verify the **effectiveness** of mitigation measures

MONITORING: MAIN ACTIONS

Collect all the available information on the investigated landslide and formulate possible hypothesis on its mechanisms

Establish the **parameters to monitor**, assess their range of variability and frequency of data acquisition

Select the most suitable **instrumentations**

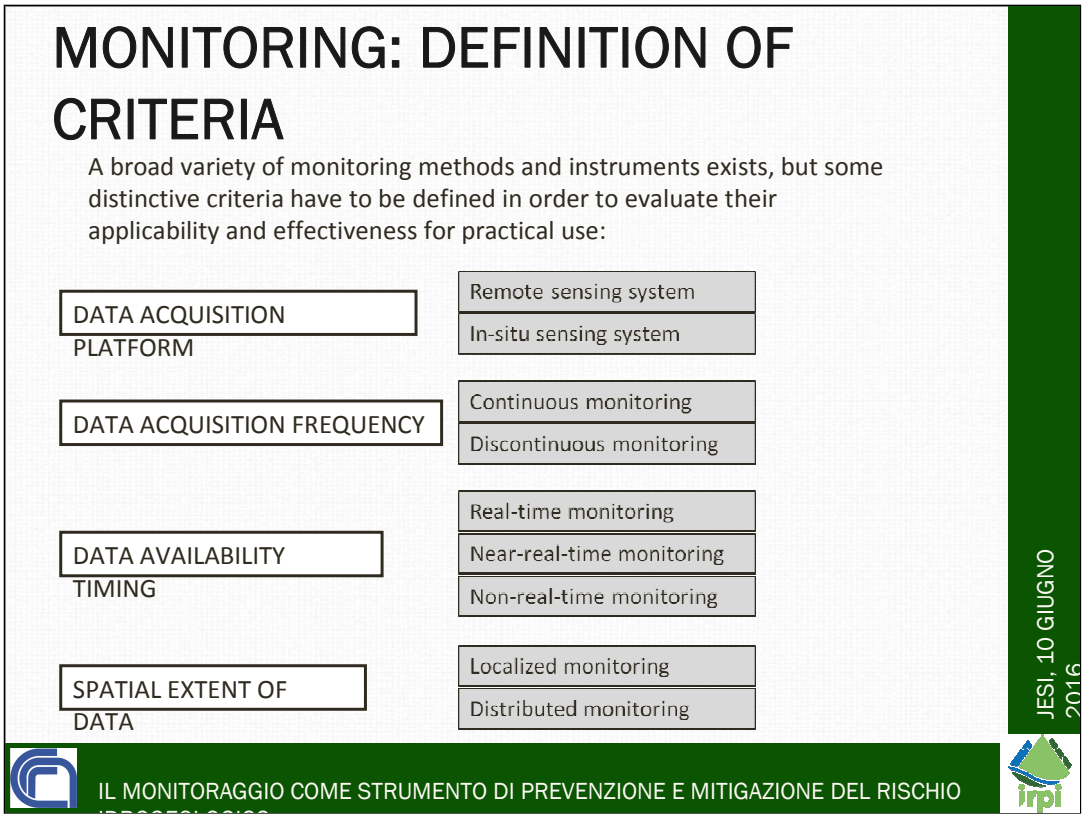
Establish the **best location** for the monitoring instrumentation

Plan instrument **maintenance** and management

Plan **data collection**, storage and management as well as their interpretation

Monitor parameters that could **influence the accuracy** of measurements (air pressure, wind speed and direction …..)

Review the system and **adapt** where necessary


MONITORING: DEFINITION OF CRITERIA
A broad variety of monitoring methods and instruments exists, but some distinctive criteria have to be defined in order to evaluate their applicability and effectiveness for practical use:
DATA ACQUISITION PLATFORM
Remote sensing system
In-situ sensing system
DATA ACQUISITION FREQUENCY
Continuous monitoring
Discontinuous monitoring
DATA AVAILABILITY TIMING
Real-time monitoring
Near-real-time monitoring
Non-real-time monitoring
SPATIAL EXTENT OF DATA
Localized monitoring
Distributed monitoring
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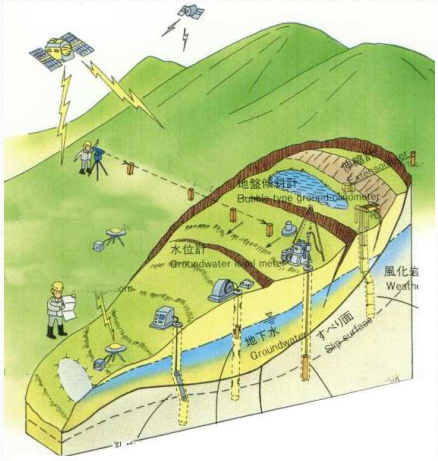
MONITORING: PARAMETERS TO MEASURE

ACCURACY of a measurement system is the **degree of closeness** of measurements of a quantity to the true value.

PRECISION of a measurement system, also called **reproducibility** or **repeatability** is the degree to which repeated measurements under unchanged conditions show the same results



IN SITU MONITORING: SURFICIAL DISPLACEMENTS

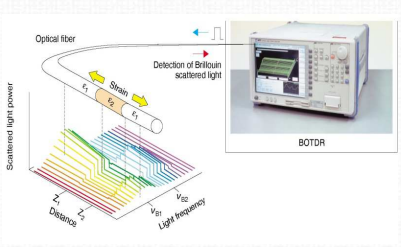
Topography

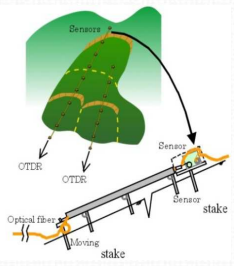
GPS

Exstensometers

Crackmeters

FOS - Optical Fiber Sensors





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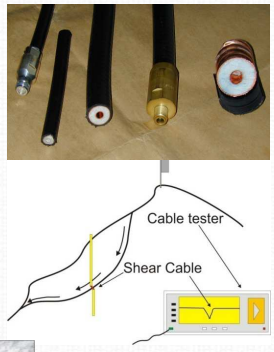
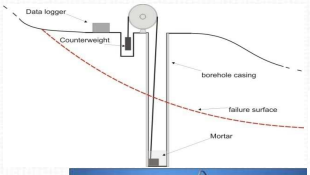
IN SITU MONITORING: DEEP DISPLACEMENTS

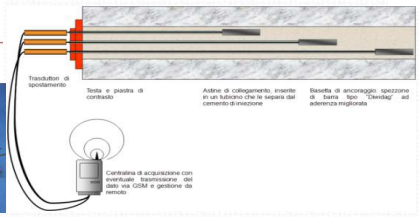
Inclinometer

TDR Cables



Extensometers





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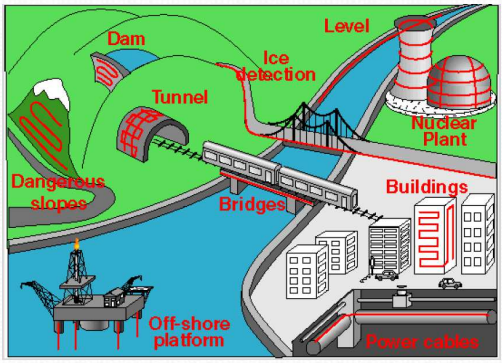
FOS: FIBER OPTIC SENSORS

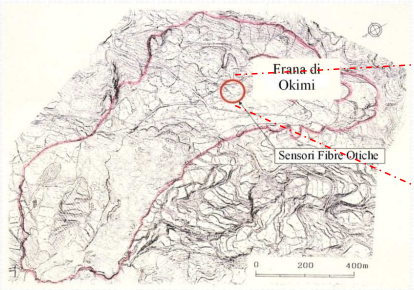
The fiber (or fiber-based device) acts as a transducer whose optical characteristics are changed by the surrounding environment. In the field of landslides monitoring, typical fiber sensors are based on the analysis of the micro-bending loss induced by the movements, or on the analysis of Brillouin or Raman backscattered fields

Main advantages

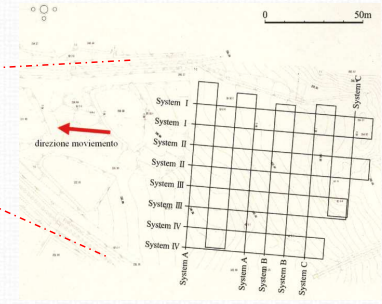
- easiness of installation
- possibility of measuring strain, temperature, GWL
- Intrinsic robustness to electromagnetic interferences and lightning
- remote operability
- distributed and on spot sensing ability (up to 30 km)
- high accuracy and precision
- real time monitoring

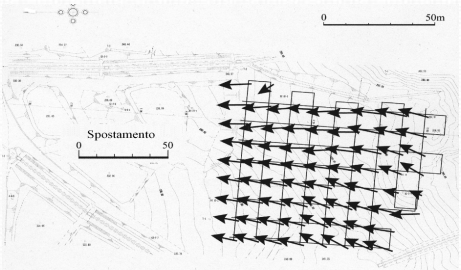


Okimi Landslide Japan

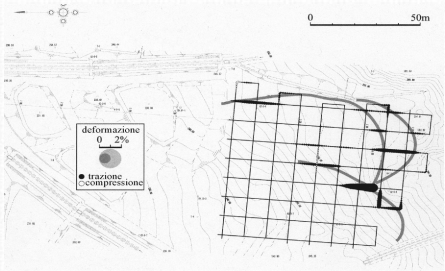


Optical fiber scheme





One year displacement vectors



Geomorphological interpretation

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Highway n. 222 in Kyushu




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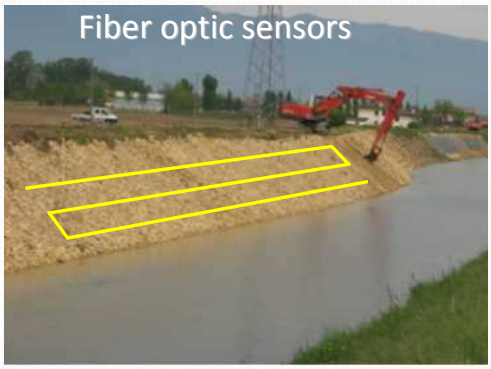
Highway crossing Kobe City, Hyogo Prefecture

Monitoring River Embankments



Tens/hundreds of measurement points
Complex installation
High maintenance and calibration costs

One single fiber
Easy to install
Low maintenance and calibration costs
High reliability

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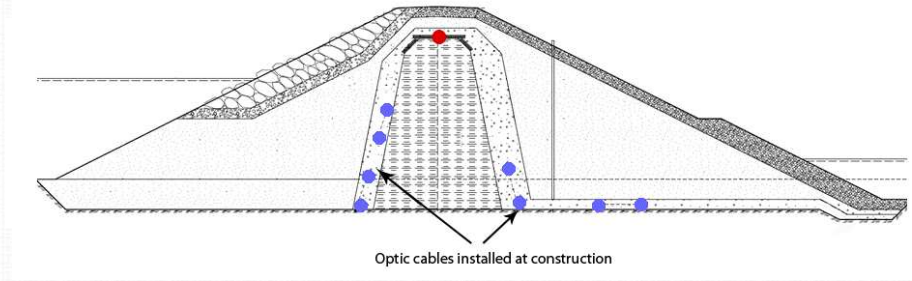

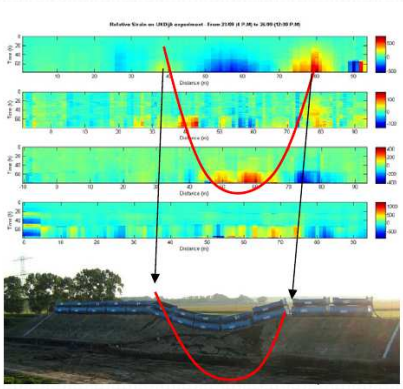

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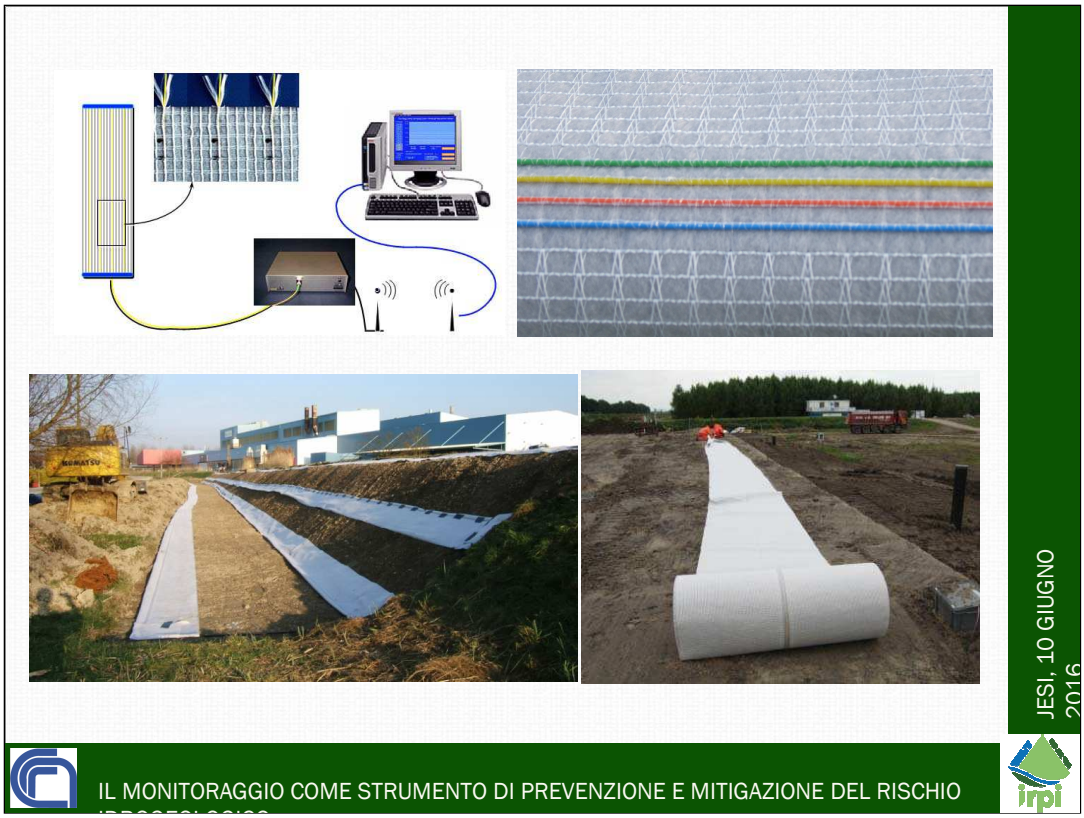
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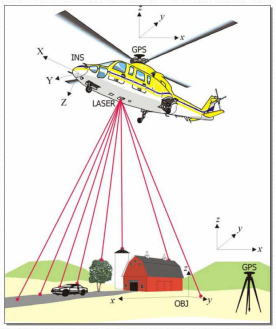
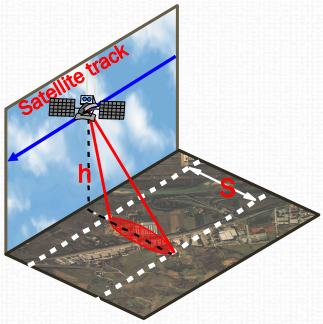
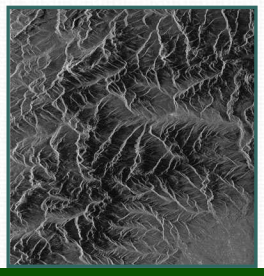
REMOTE SENSING MONITORING TECHNIQUES

LIDAR

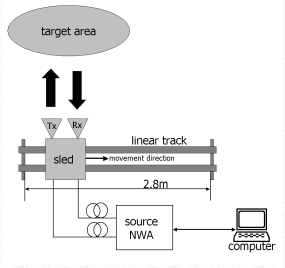


Satellite InSar





Ground-based Sar



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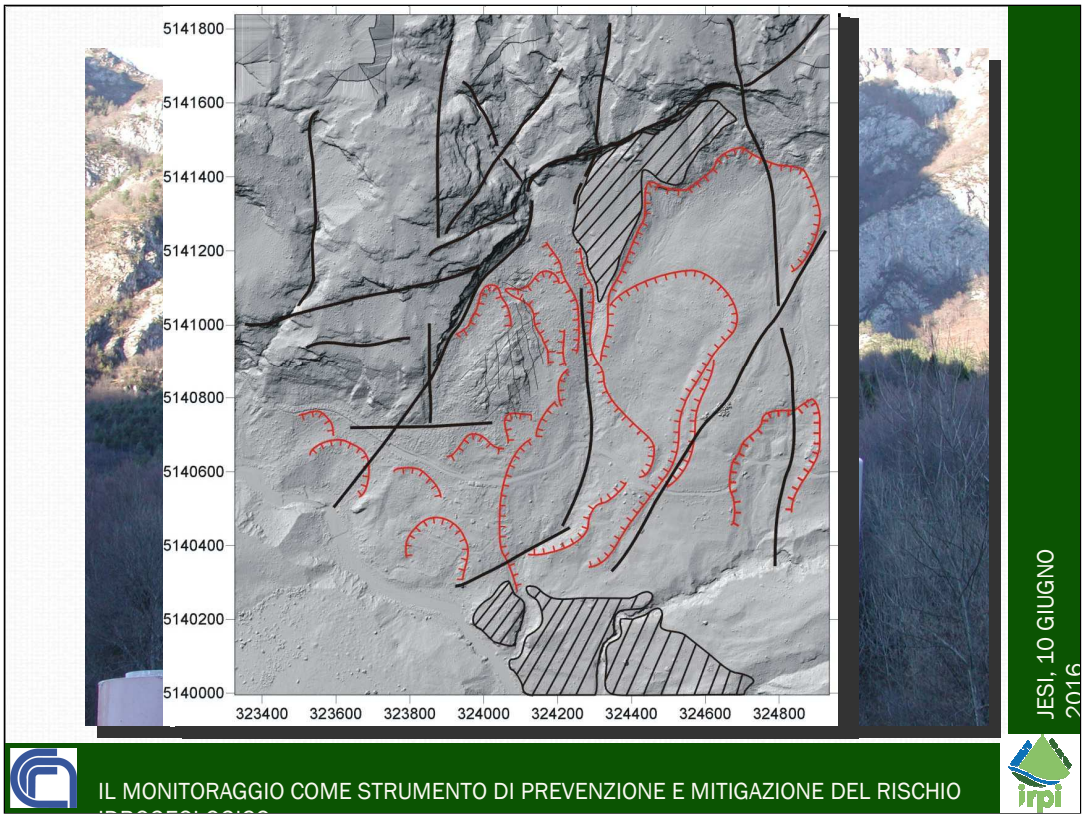
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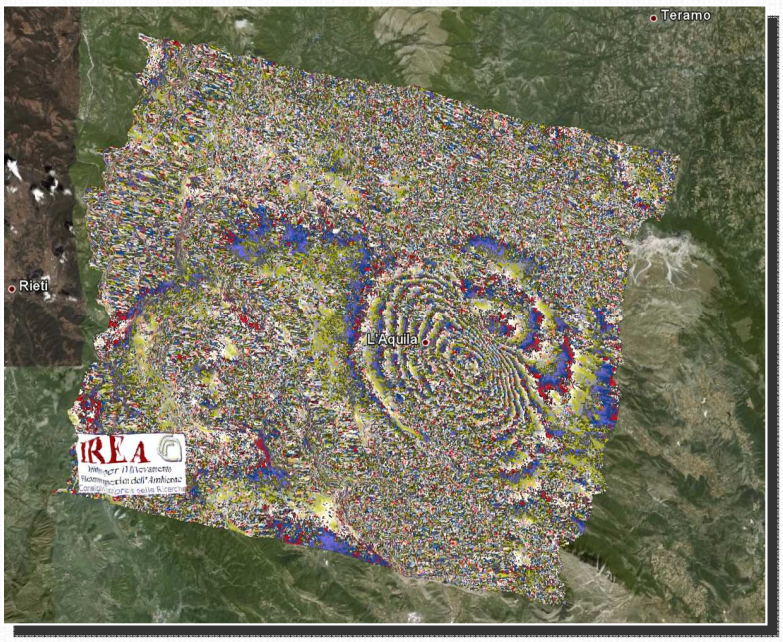

Ground deformation caused by the L'Aquila earthquake in 2009

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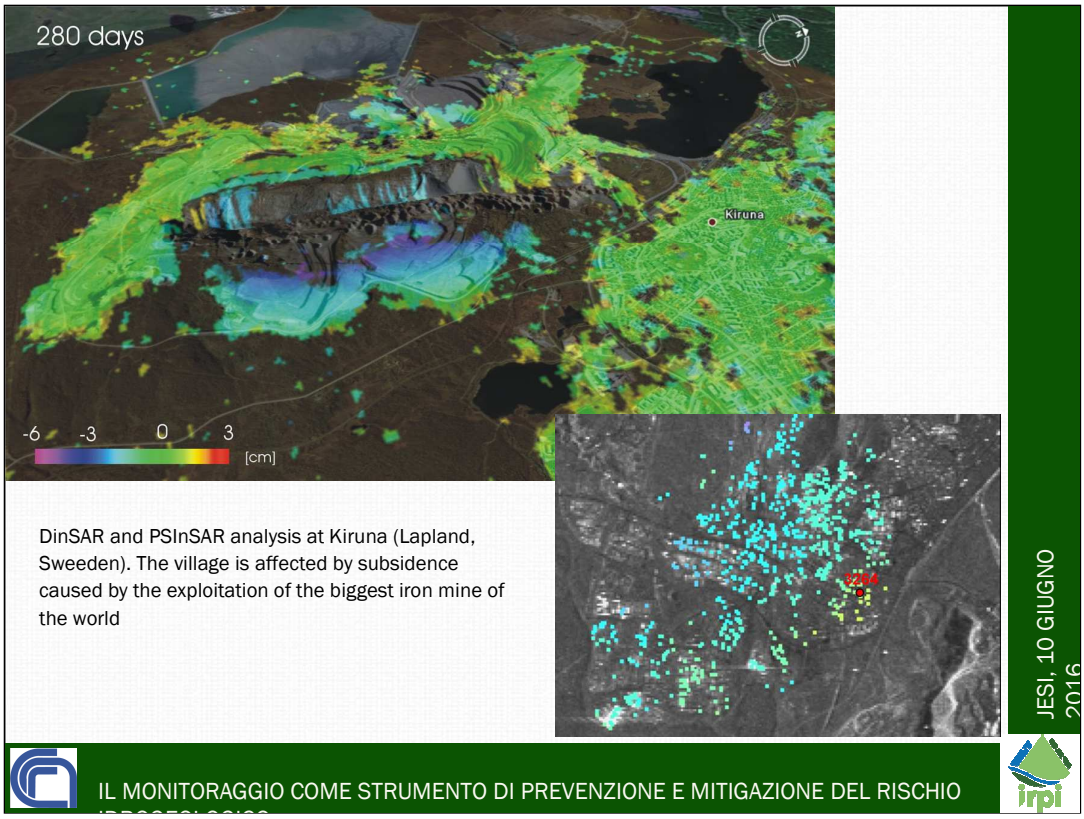
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DinSAR and PSInSAR analysis at Kiruna (Lapland, Sweeden). The village is affected by subsidence caused by the exploitation of the biggest iron mine of the world
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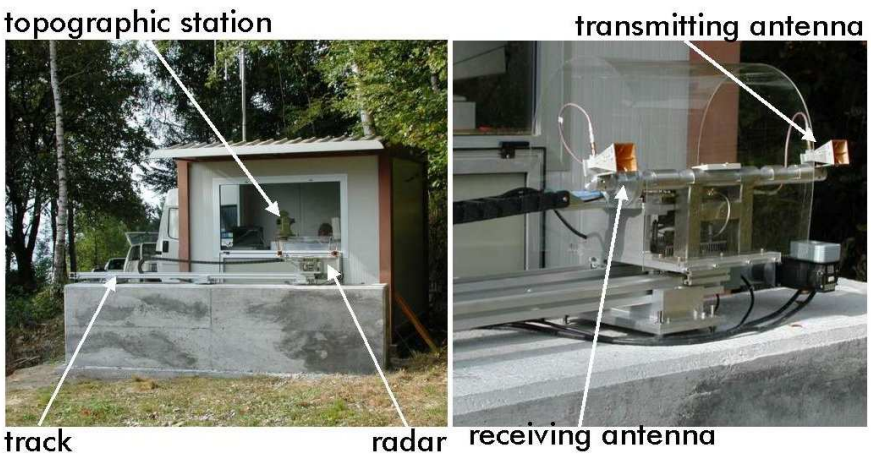
GROUND-BASED RADAR INTERFEROMETRY



Tessina Landslide (Chies d'Alpago, Belluno, Italy)

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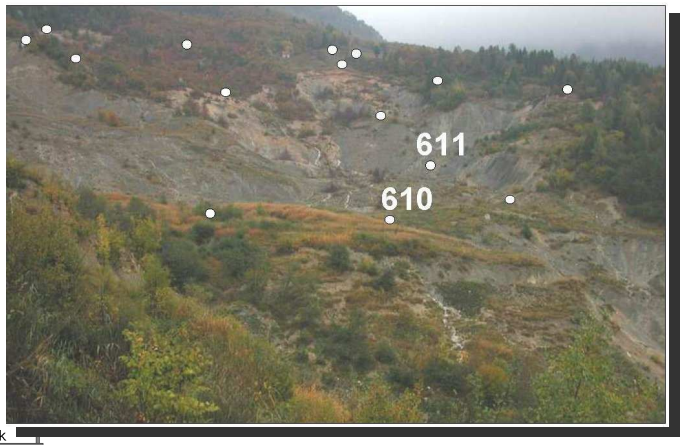
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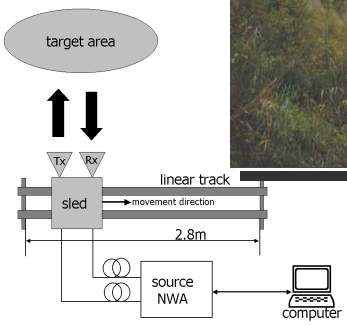
target area
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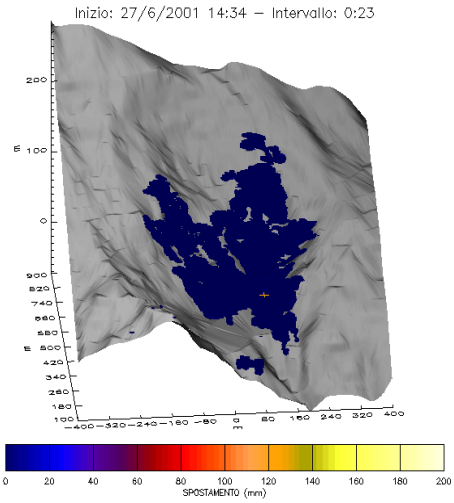
computer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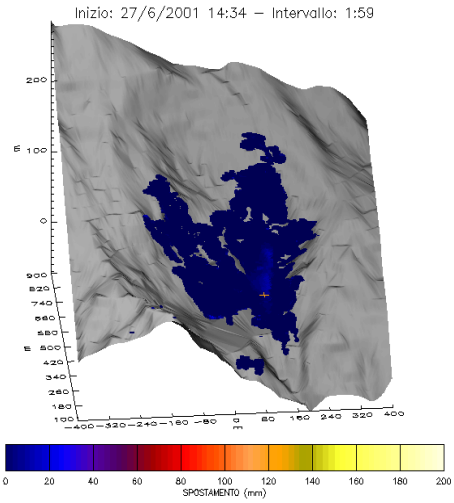
SPOSTAMENTO (mm)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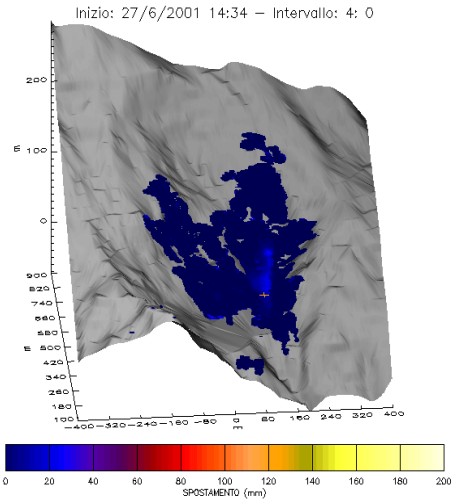
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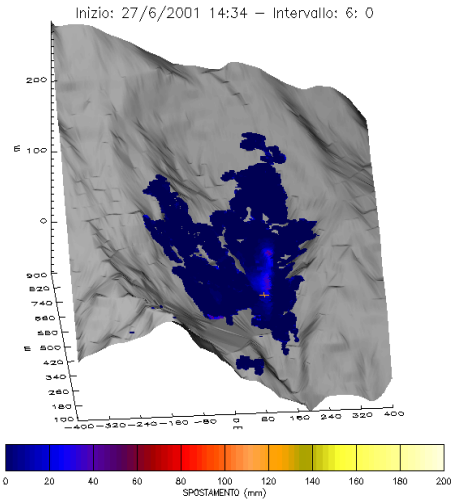
SPOSTAMENTO (mm)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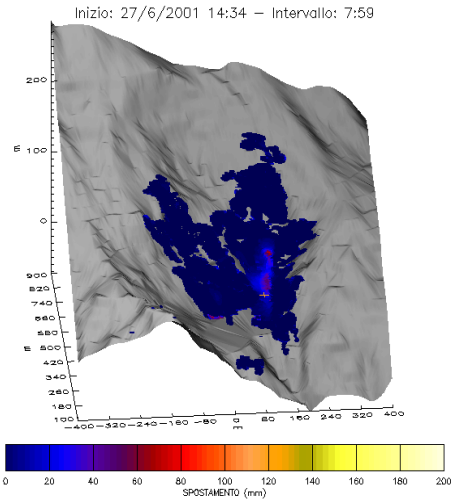
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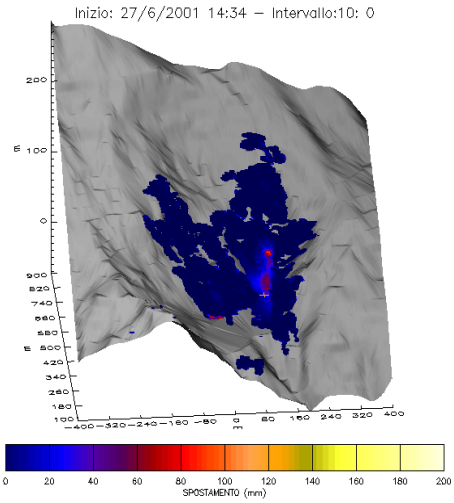
SPOSTAMENTO (mm)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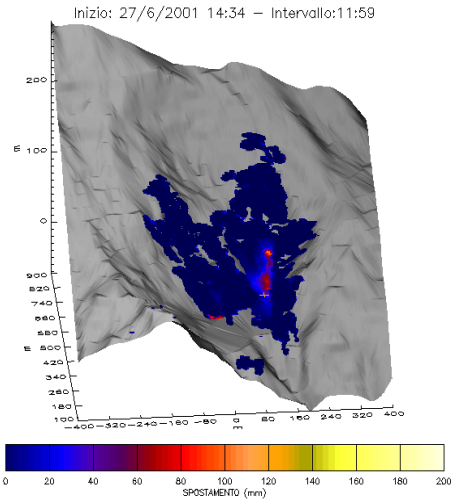
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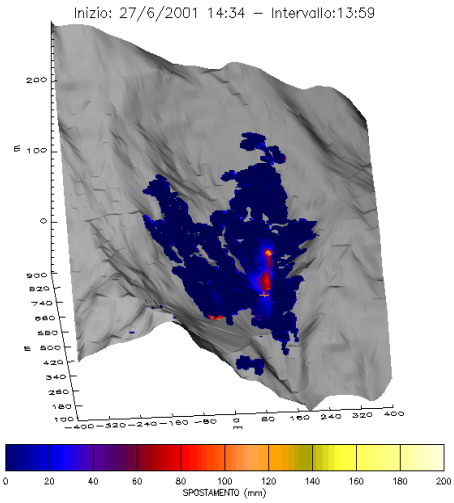
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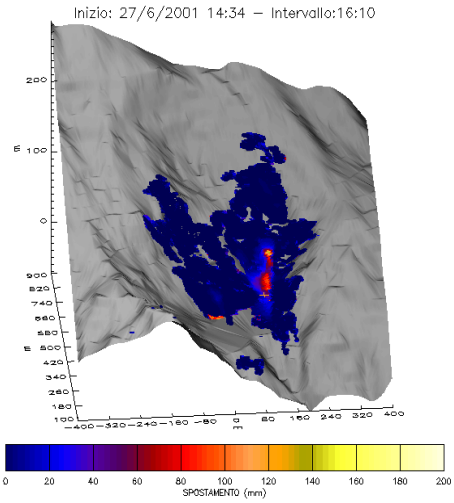
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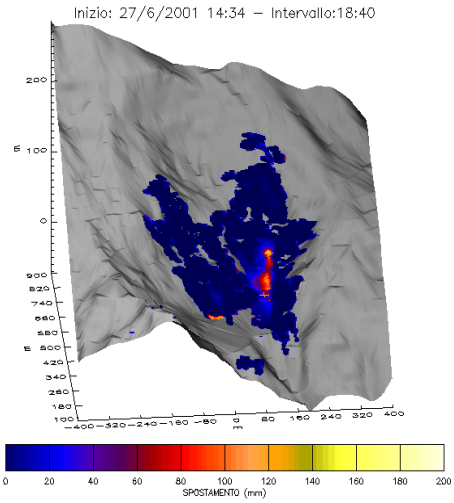
SPOSTAMENTO (mm)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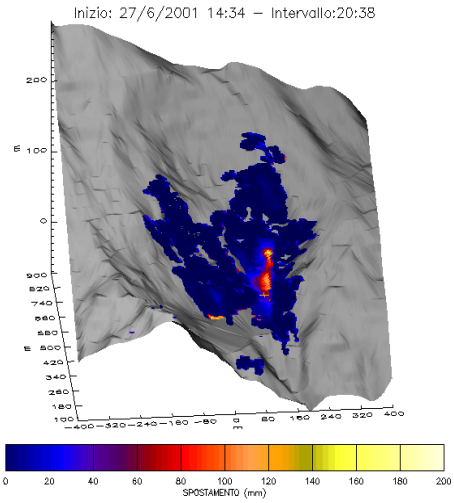
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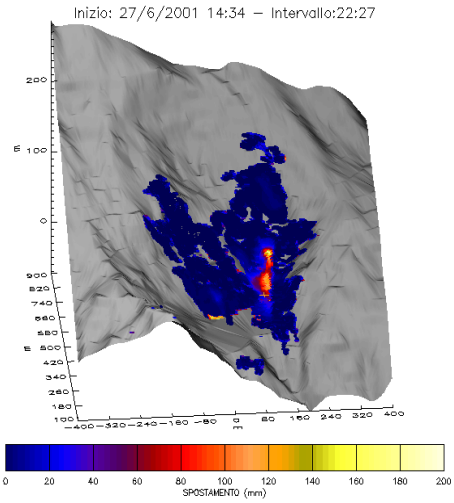
SPOSTAMENTO (mm)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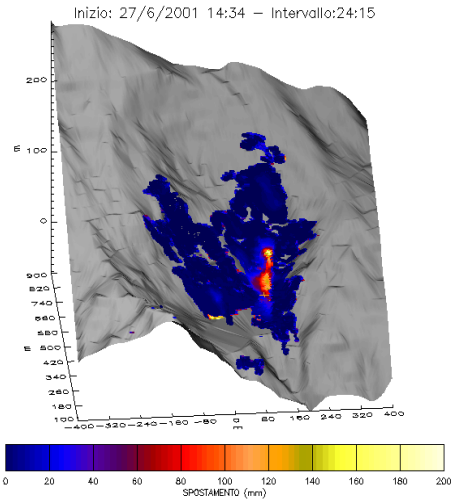
SPOSTAMENTO (mm)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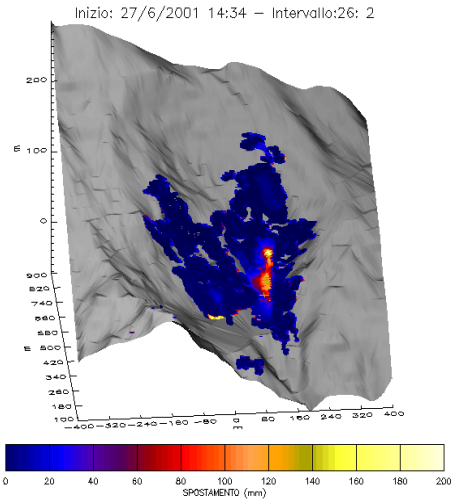
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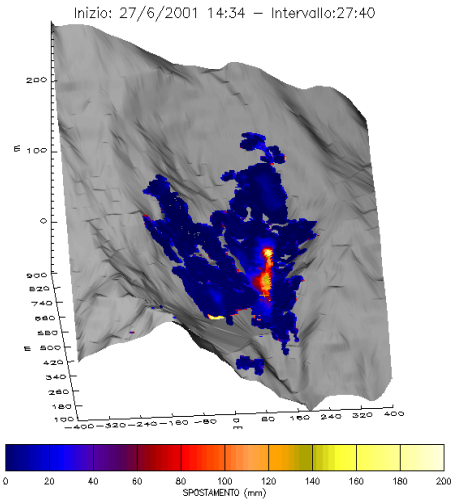
SPOSTAMENTO (mm)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-400 -320 -240 -160 -80 0 80 160 240 320 400
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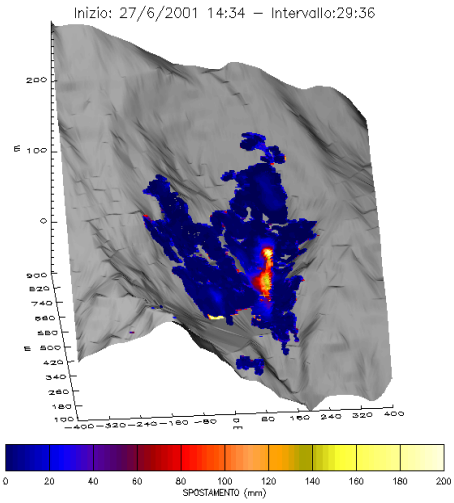
SPOSTAMENTO (mm)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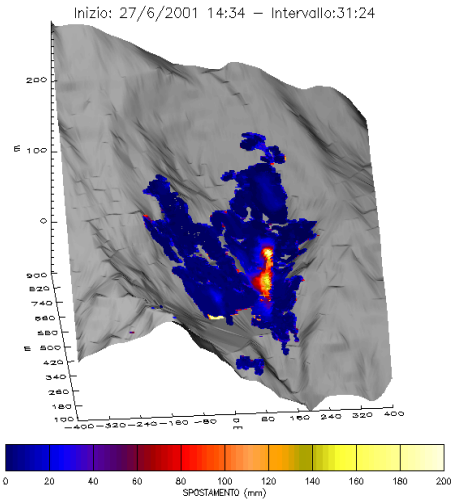
SPOSTAMENTO (mm)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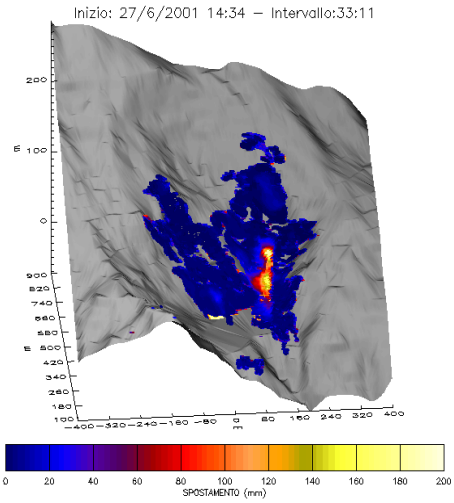
SPOSTAMENTO (mm)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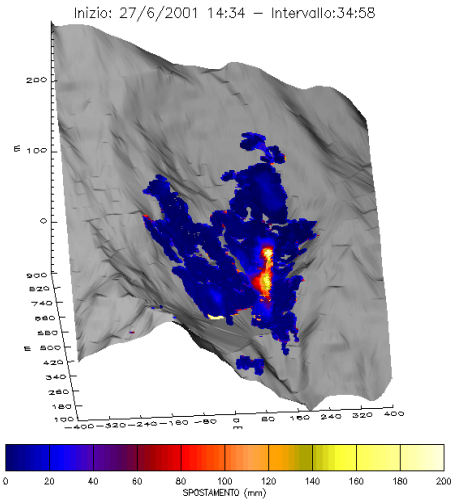
SPOSTAMENTO (mm)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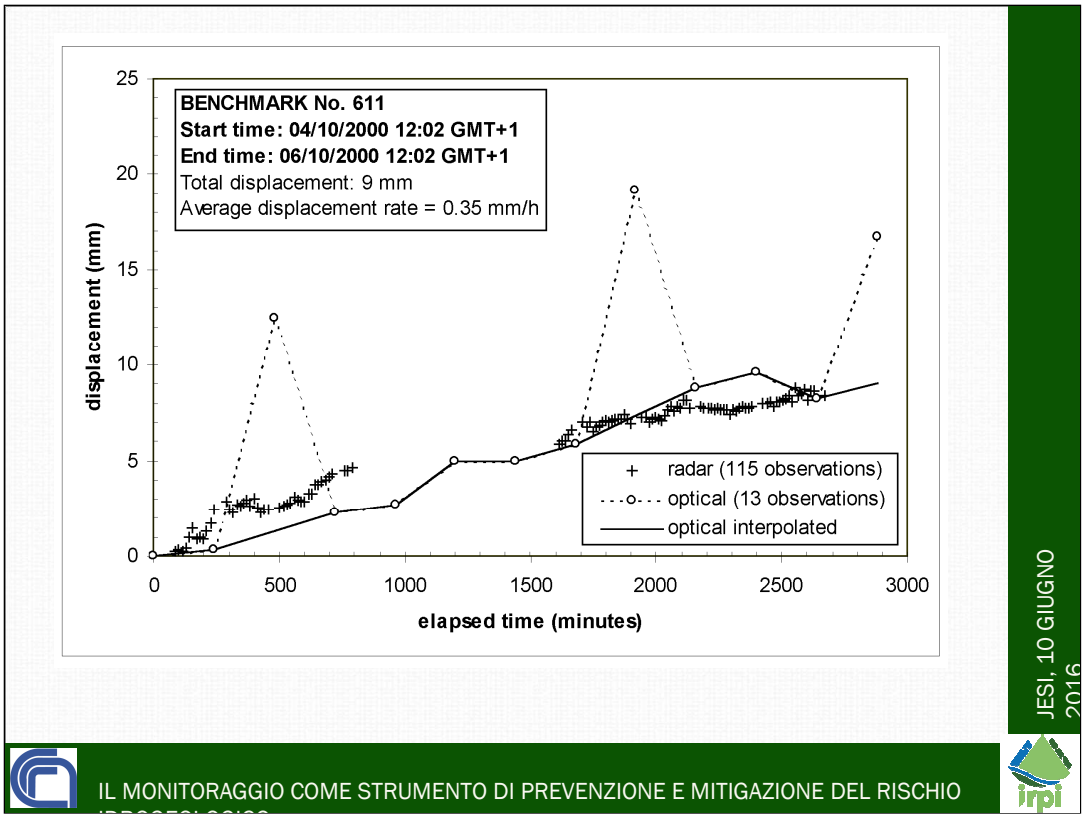
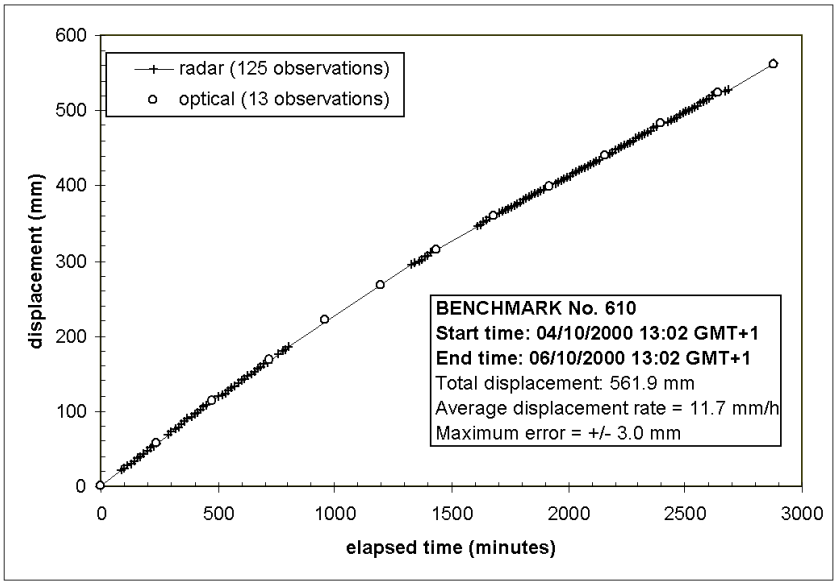
SPOSTAMENTO (mm)


BENCHMARK No. 611
Start time: 04/10/2000 12:02 GMT+1
End time: 06/10/2000 12:02 GMT+1
Total displacement: 9 mm
Average displacement rate = 0.35 mm/h
displacement (mm)
elapsed time (minutes)
radar (115 observations)
optical (13 observations)
optical interpolated
JESI, 10 GIUGNO 2016
IL MONITORAGGIO COME STRUMENTO DI PREVENZIONE E MITIGAZIONE DEL RISCHIO



JESI, 10 GIUGNO 2016

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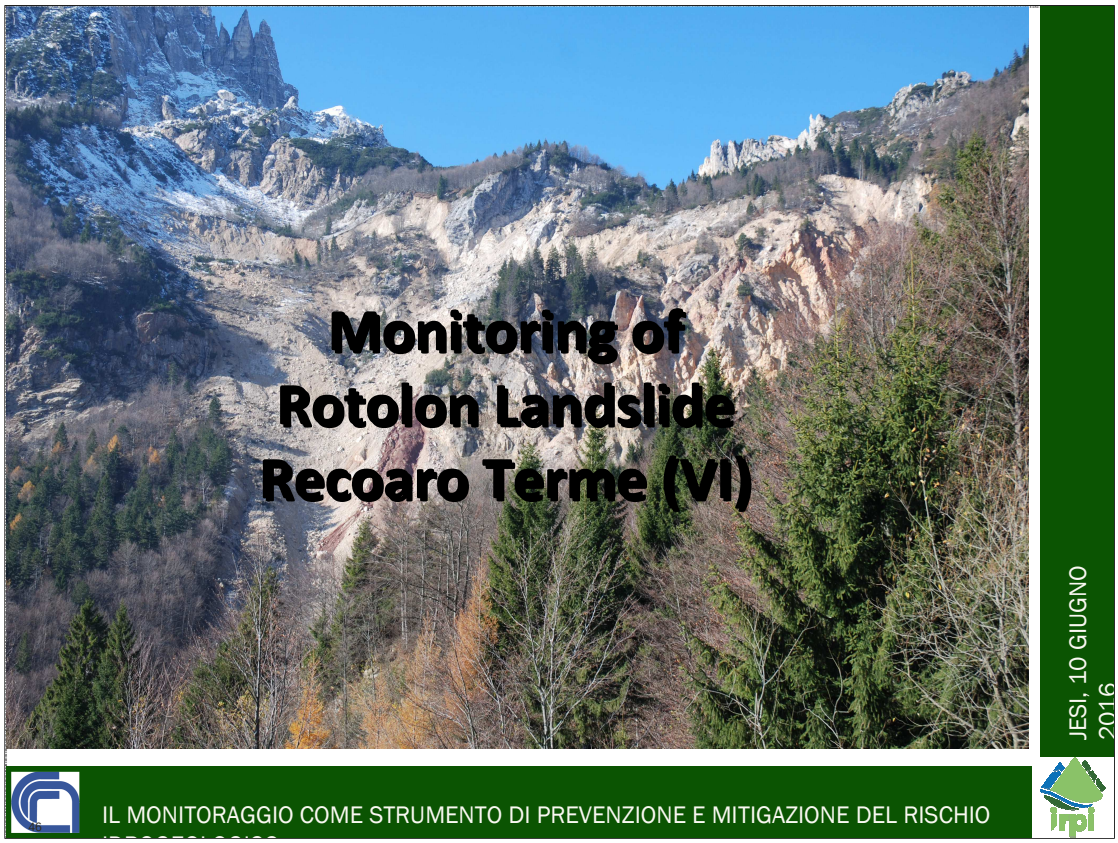

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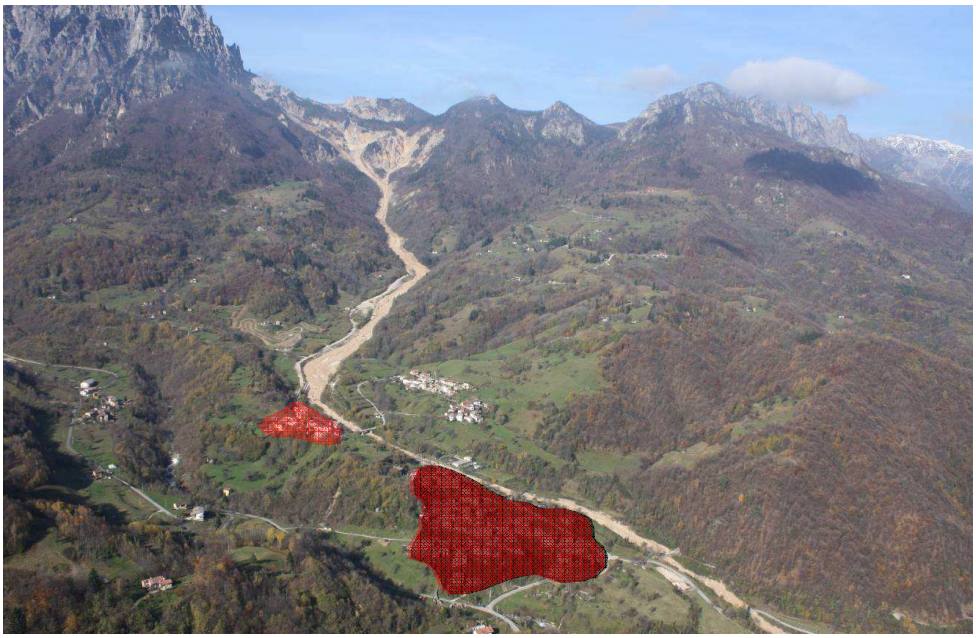

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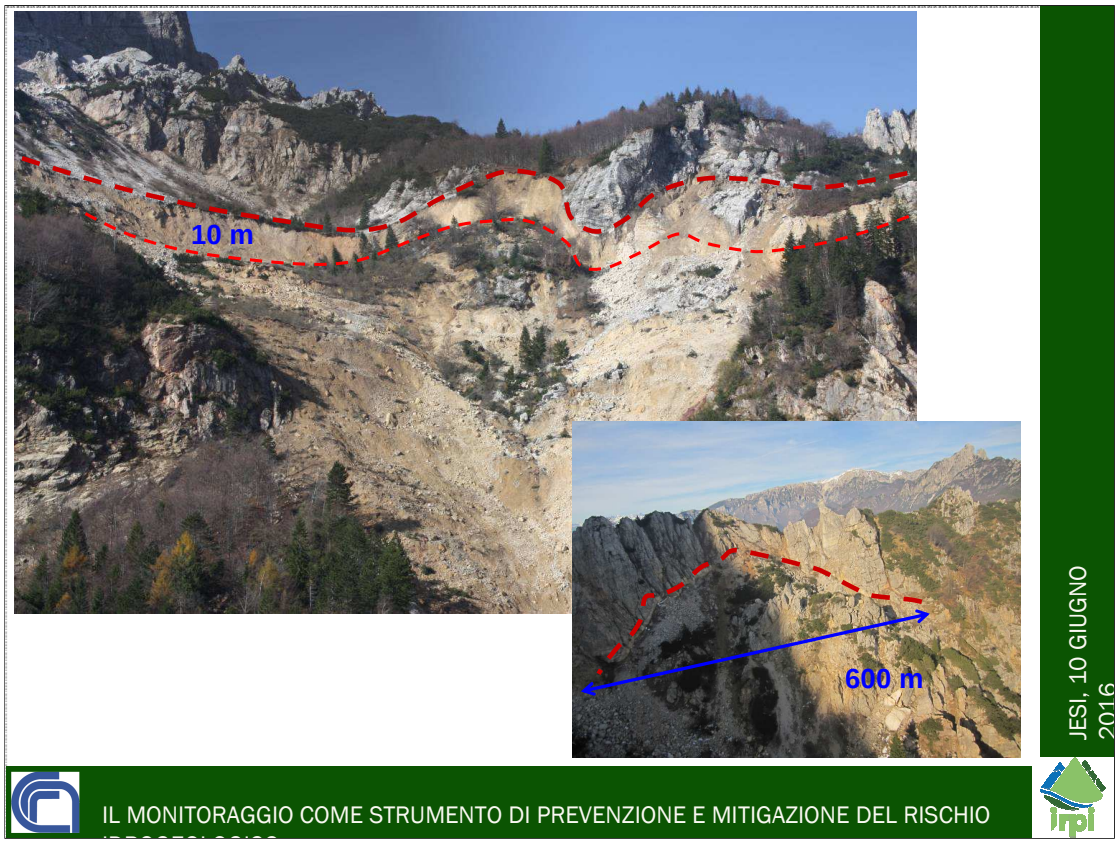

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- 2 rain gauges
- 1 video camera
- 6 wire extensometers
- Automated Total Station (ATS) with 42 benchmarks
- 3 pendulum section
- 1 trip wire
- Sirens system and thresholds
- Master Station
- Modem ADSL and WiFi
- Radio link

JESI, 10 GIUGNO 2016

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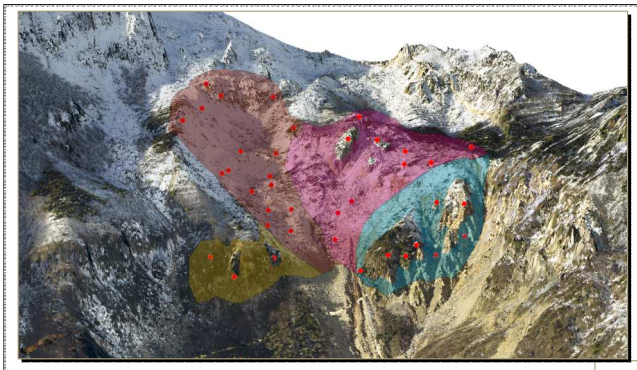

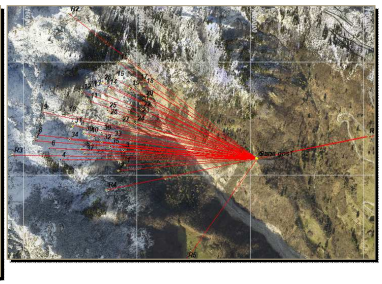

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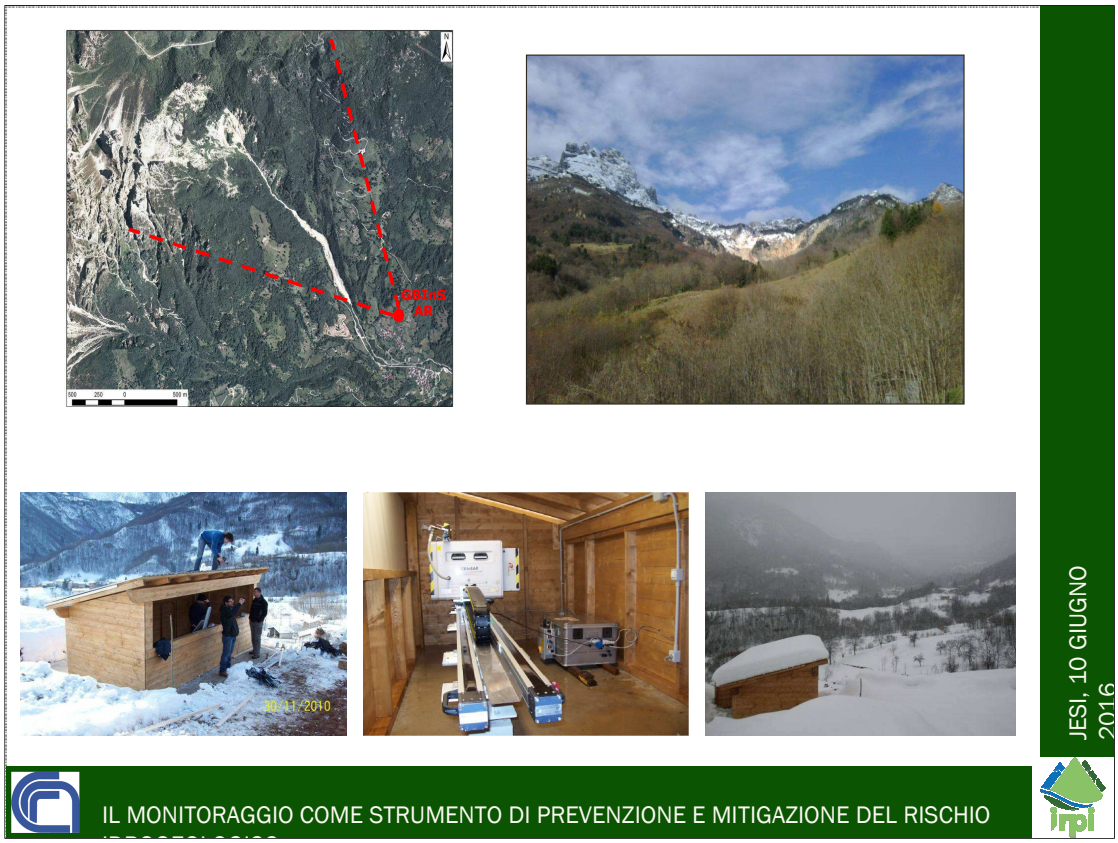

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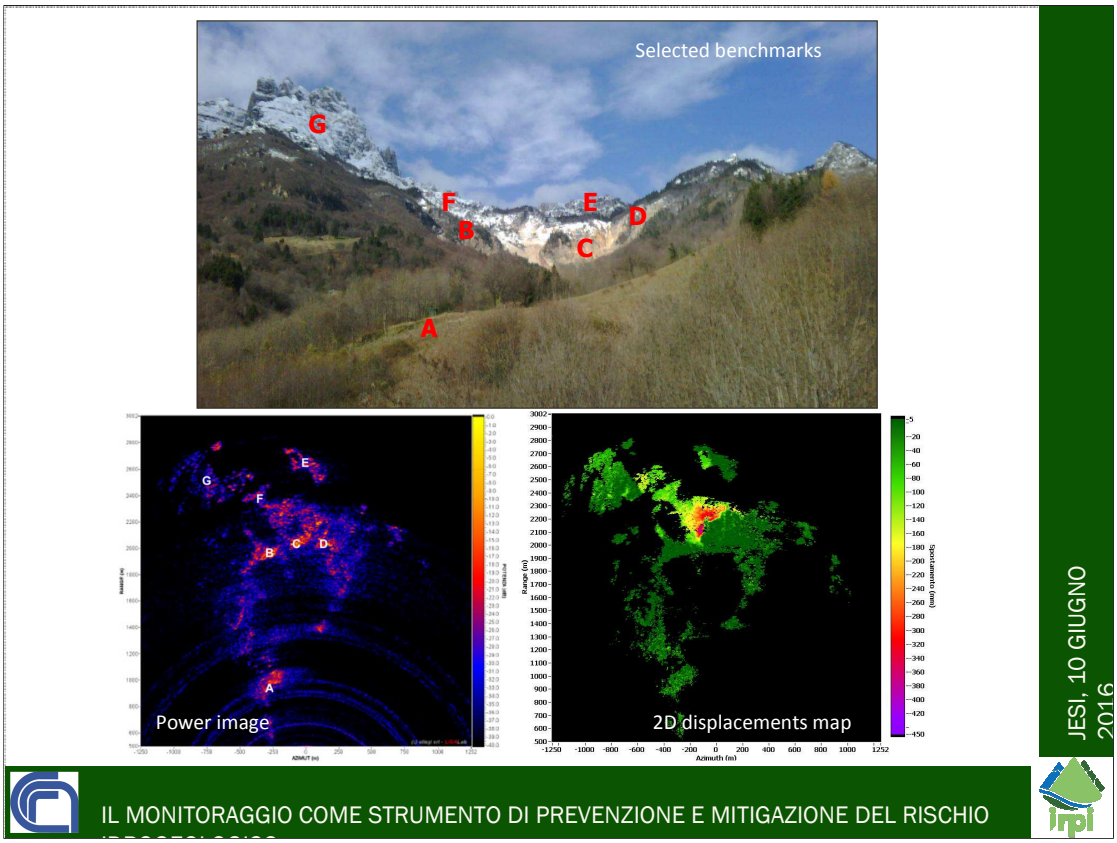

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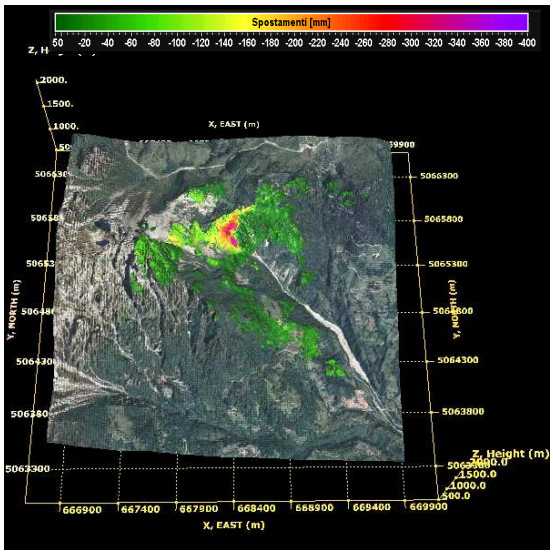
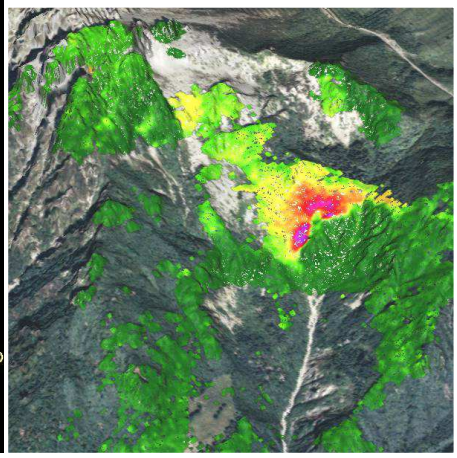
Total landslide view



Zoom on landslide area



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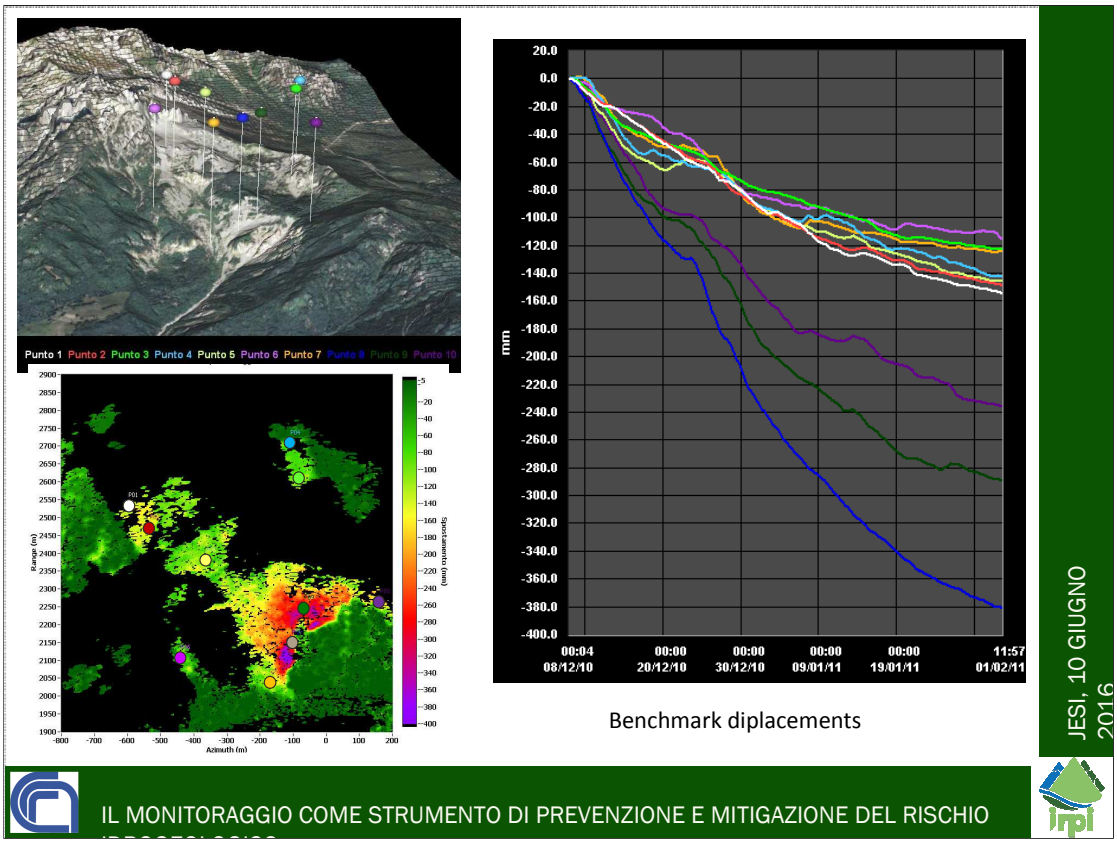

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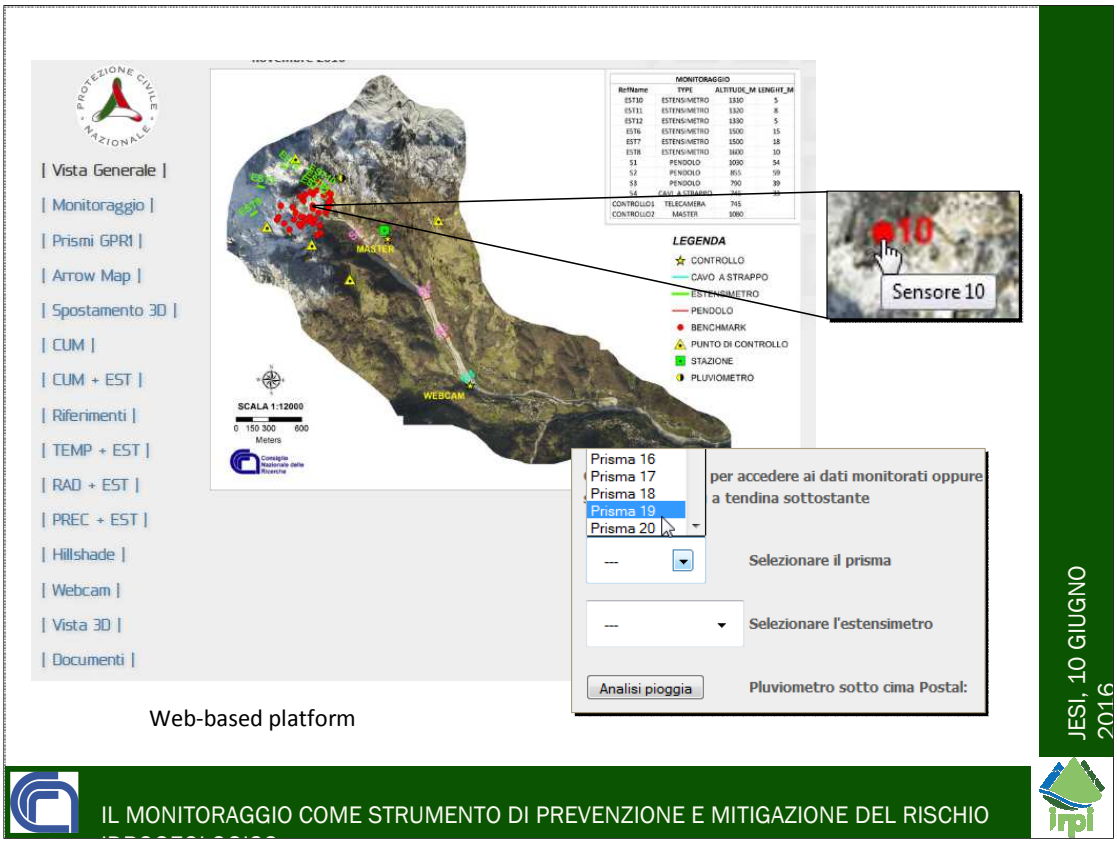

Web-based platform

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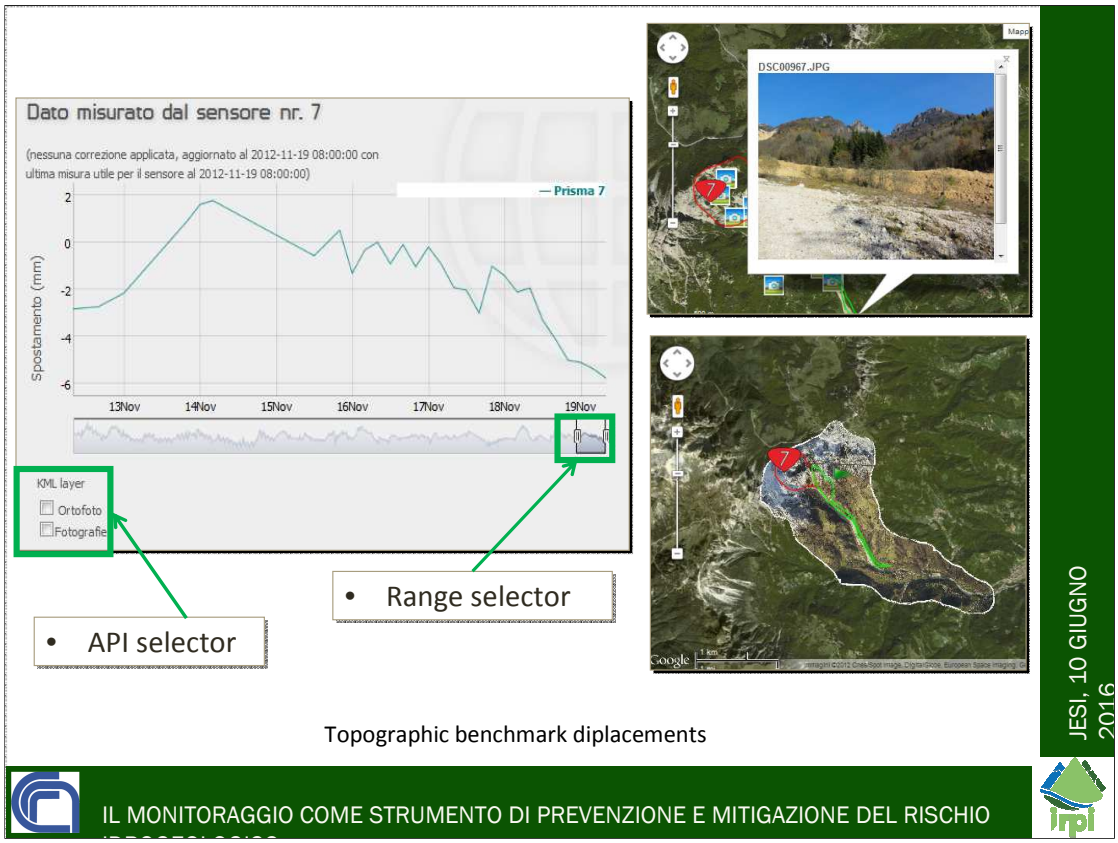

Topographic benchmark diplacements

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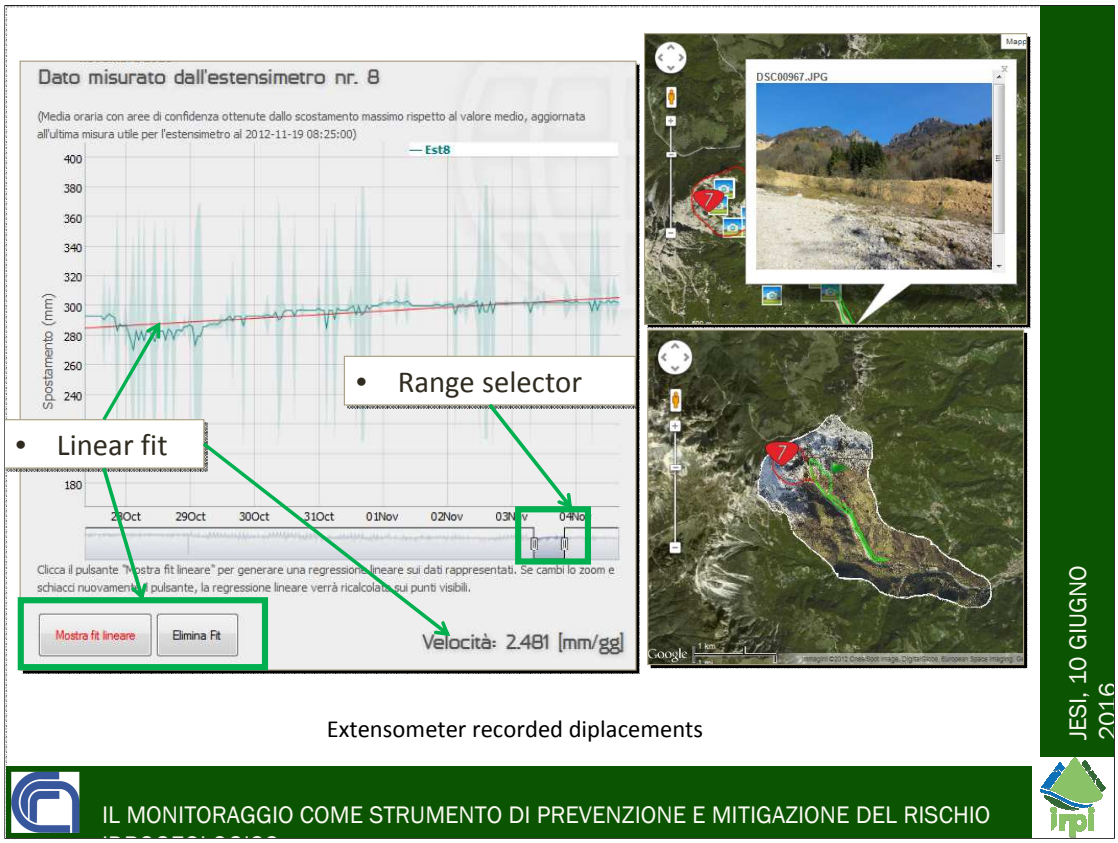

Extensometer recorded diplacements

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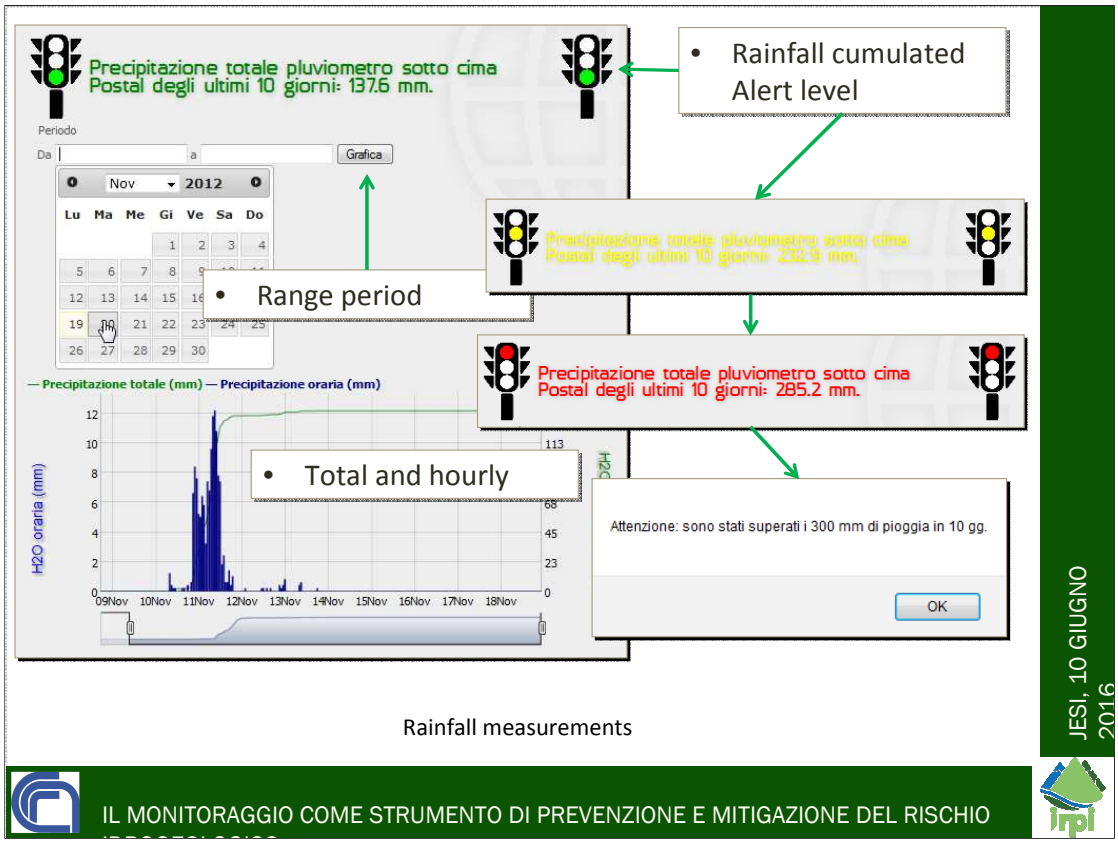

Rainfall measurements

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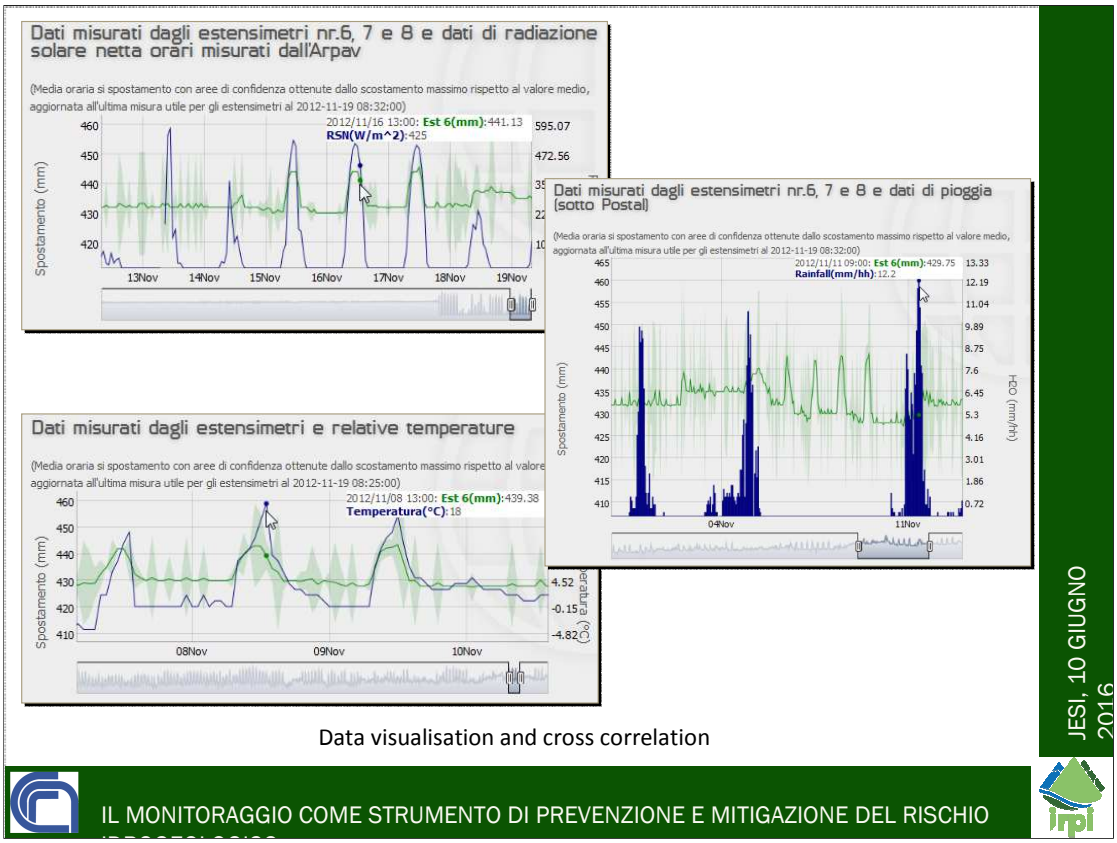

Data visualisation and cross correlation

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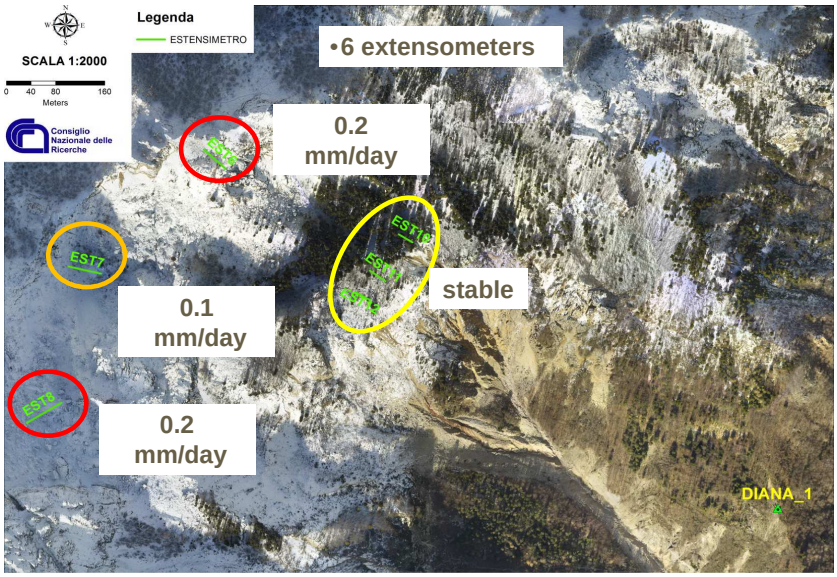

Landslide style of activity

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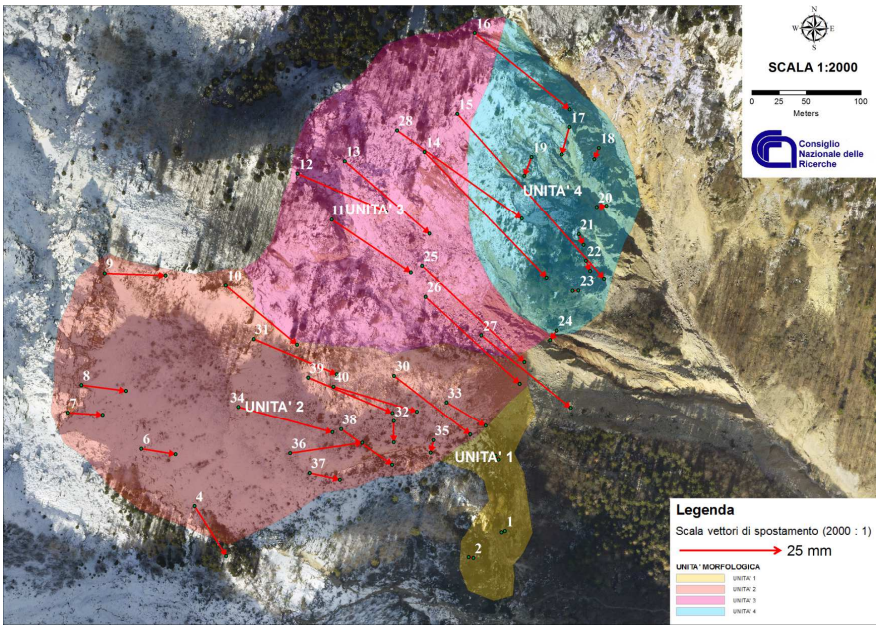

Data interpretation

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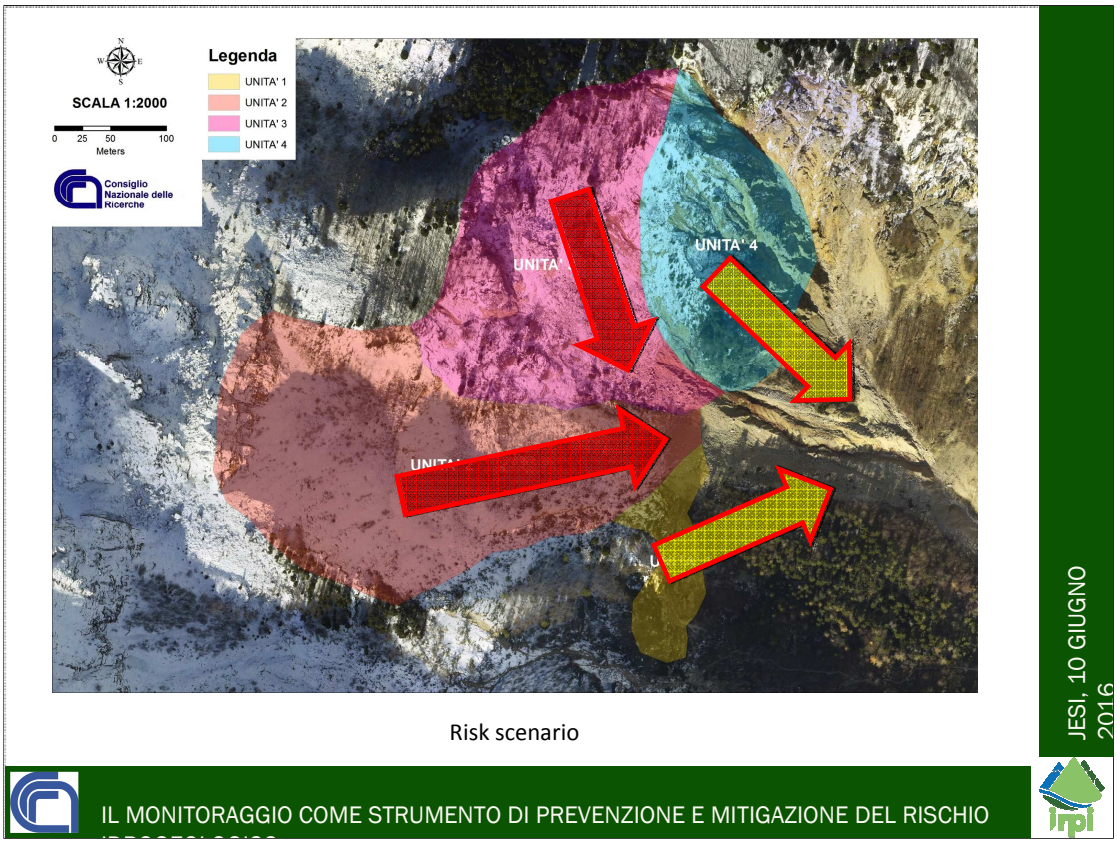

Risk scenario

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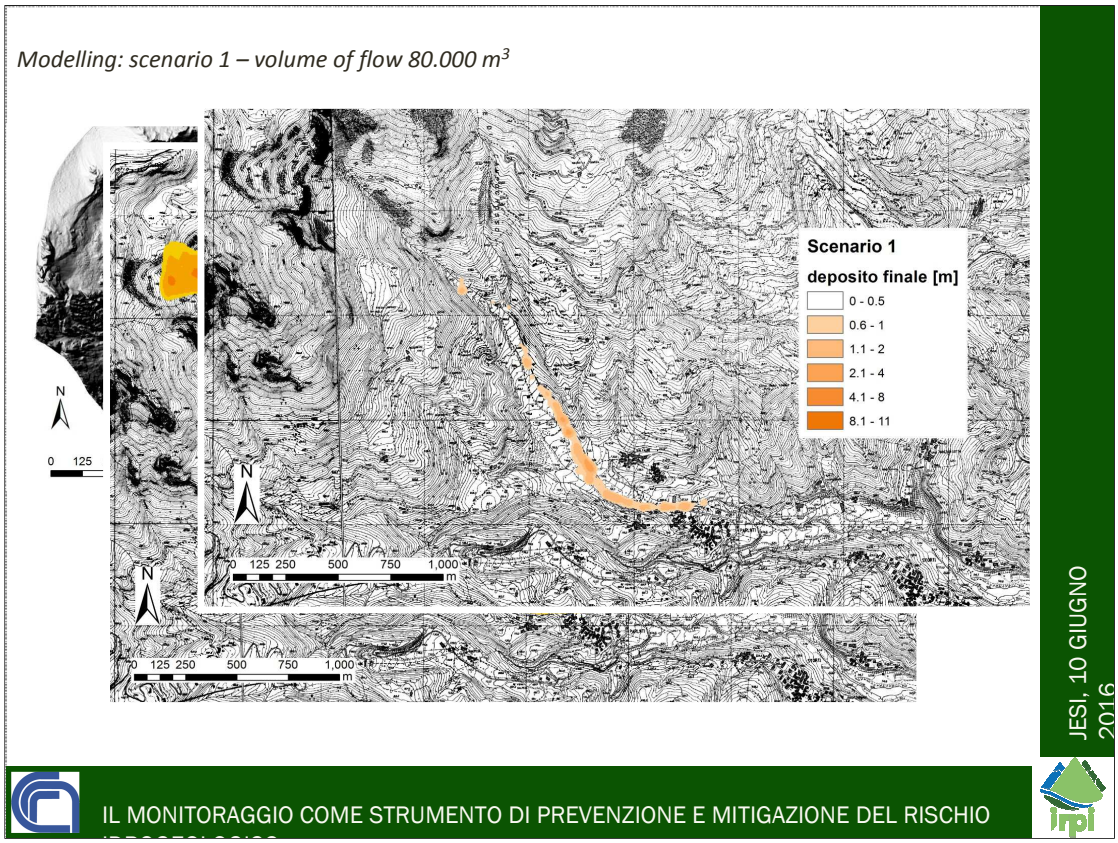

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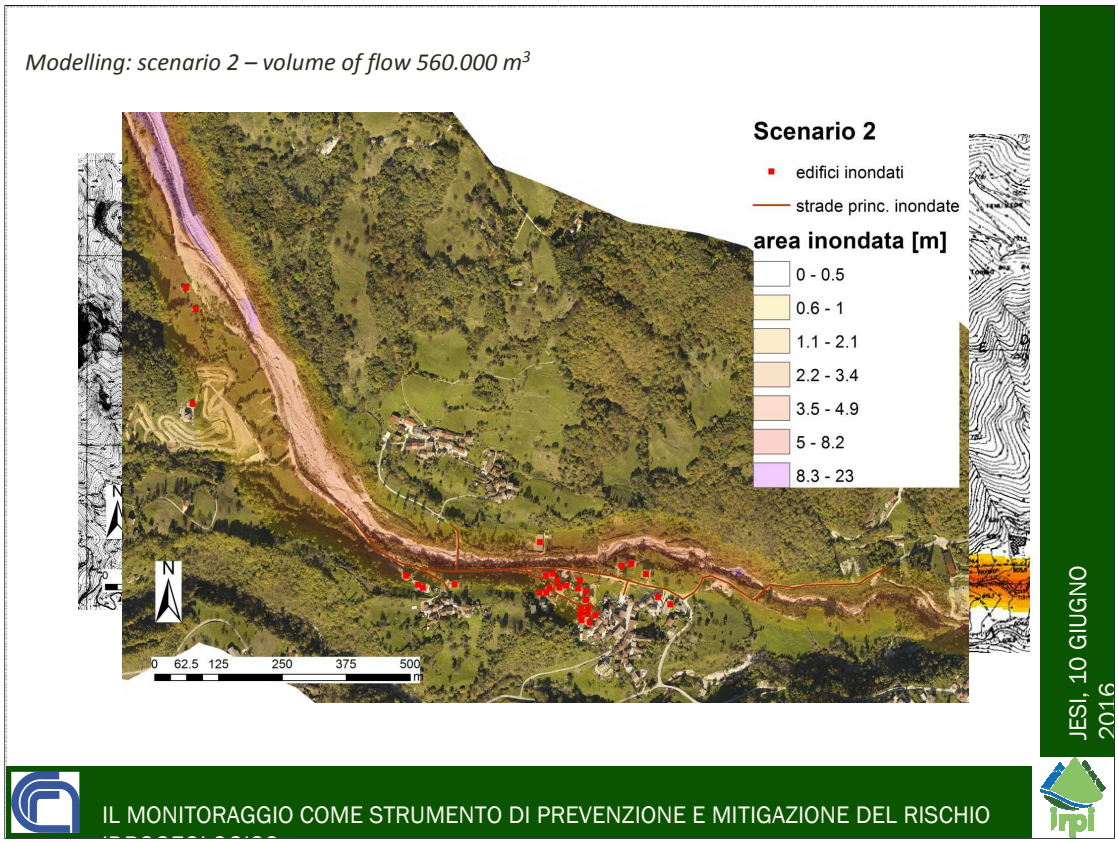

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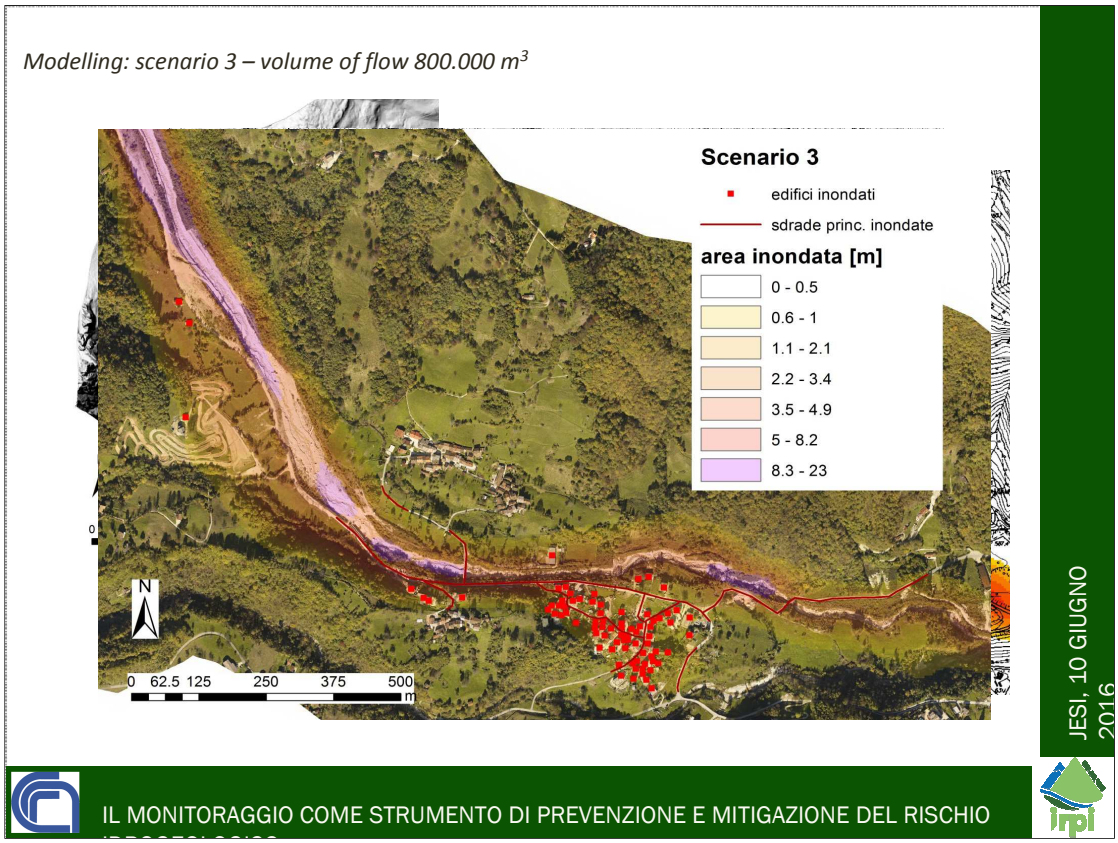

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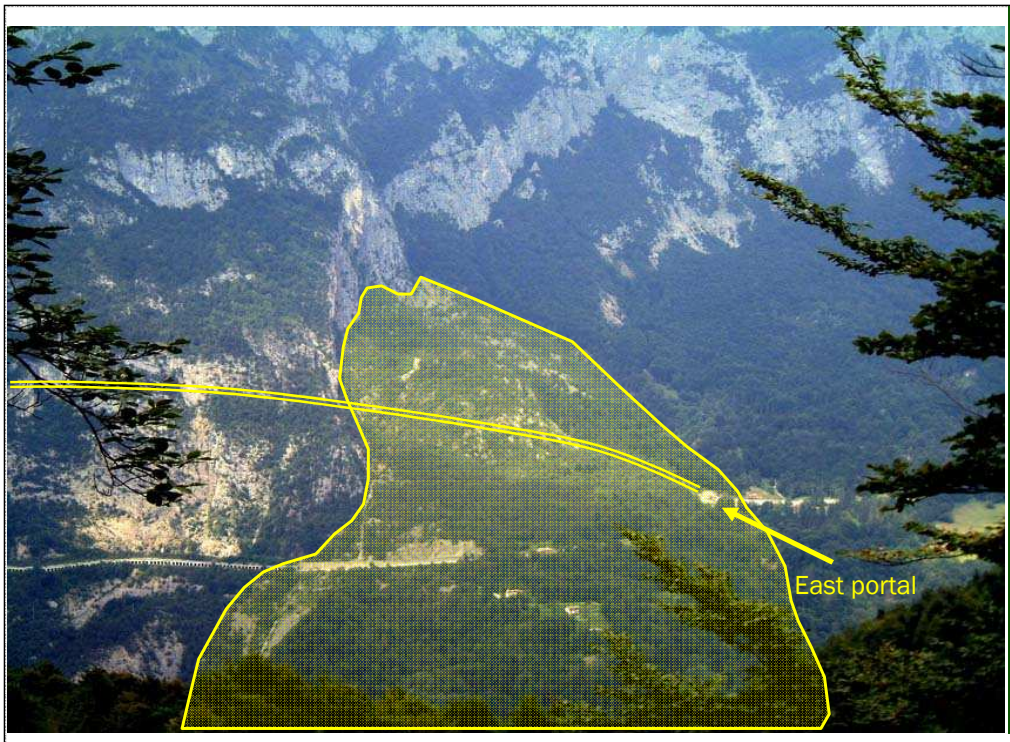
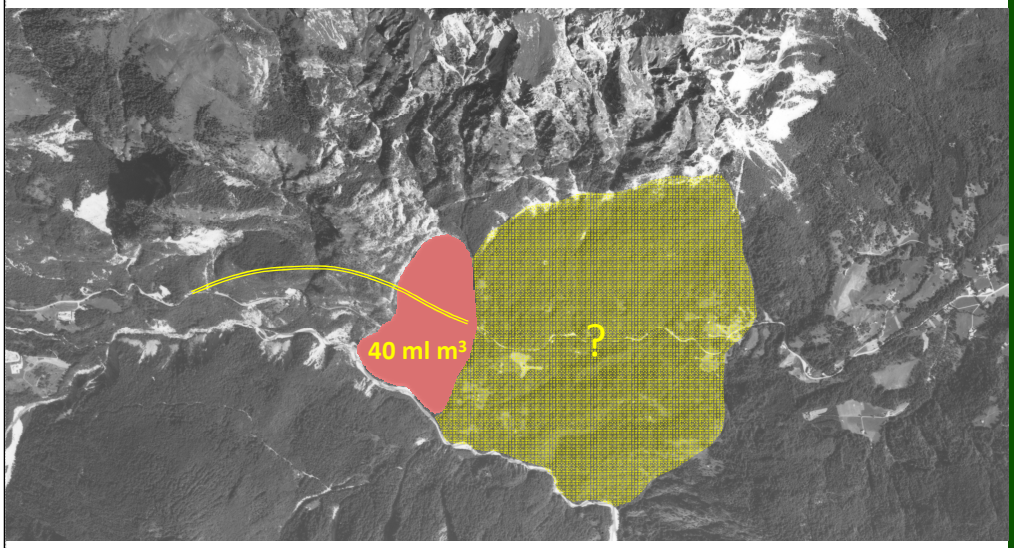
Monitoring activity at Passo della Morte landslide and road tunnel (Eastern Italian Alps)

JESI, 10 GIUGNO 2016


East portal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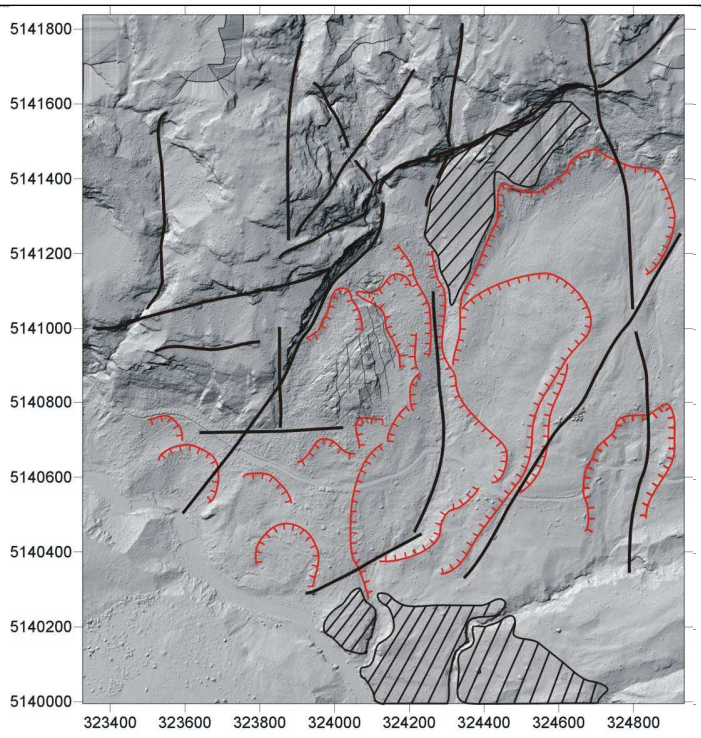
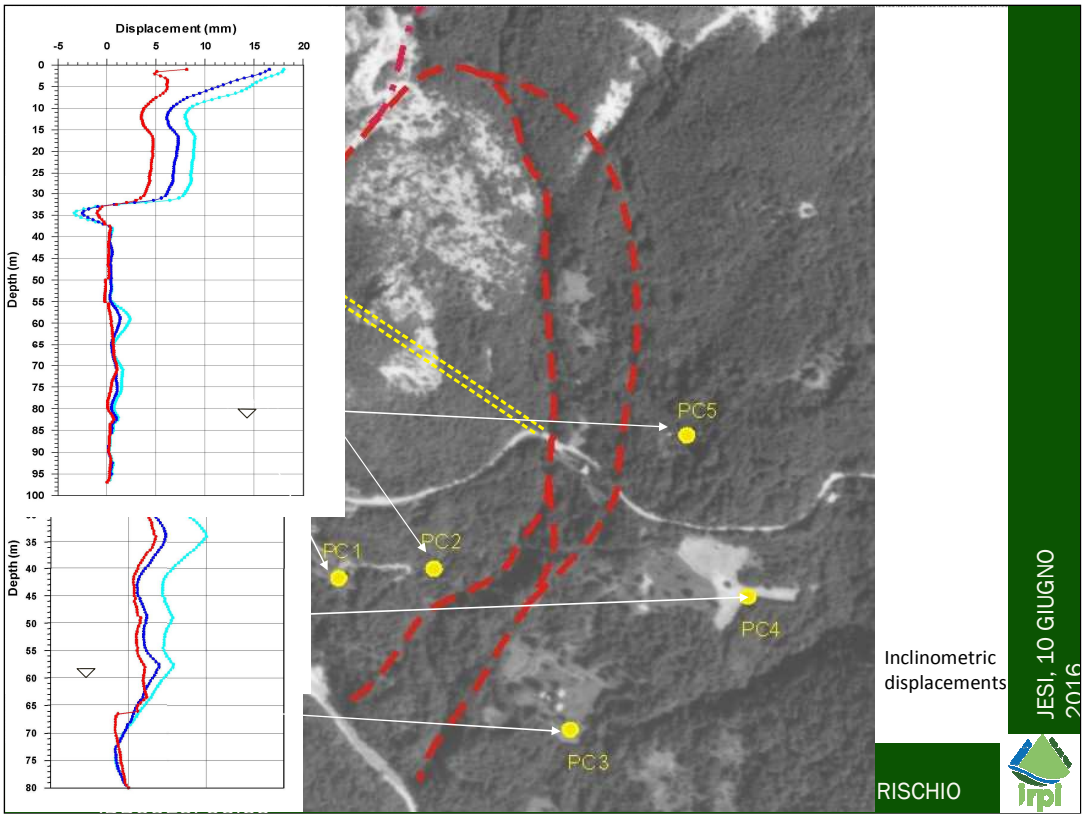
JESI, 10 GIUGNO 2016

IL MONITORAGGIO COME STRUMENTO DI PREVENZIONE E MITIGAZIONE DEL RISCHIO



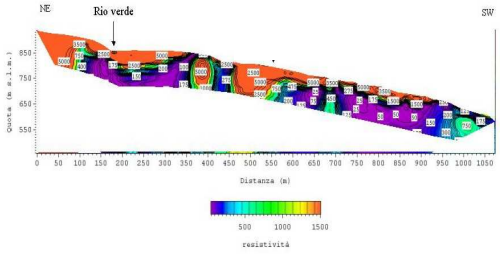
LIDAR Investigations



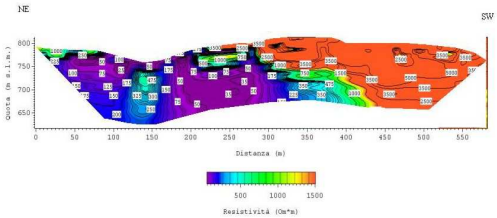
Inclinometric displacements

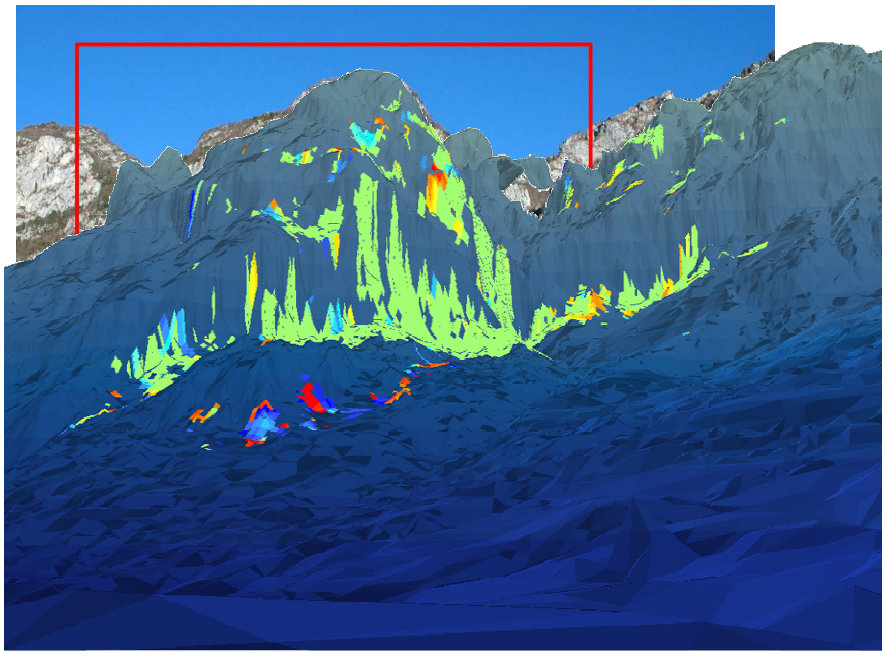
JESI, 10 GIUGNO 2016

RISCHIO



Geophysical Investigations

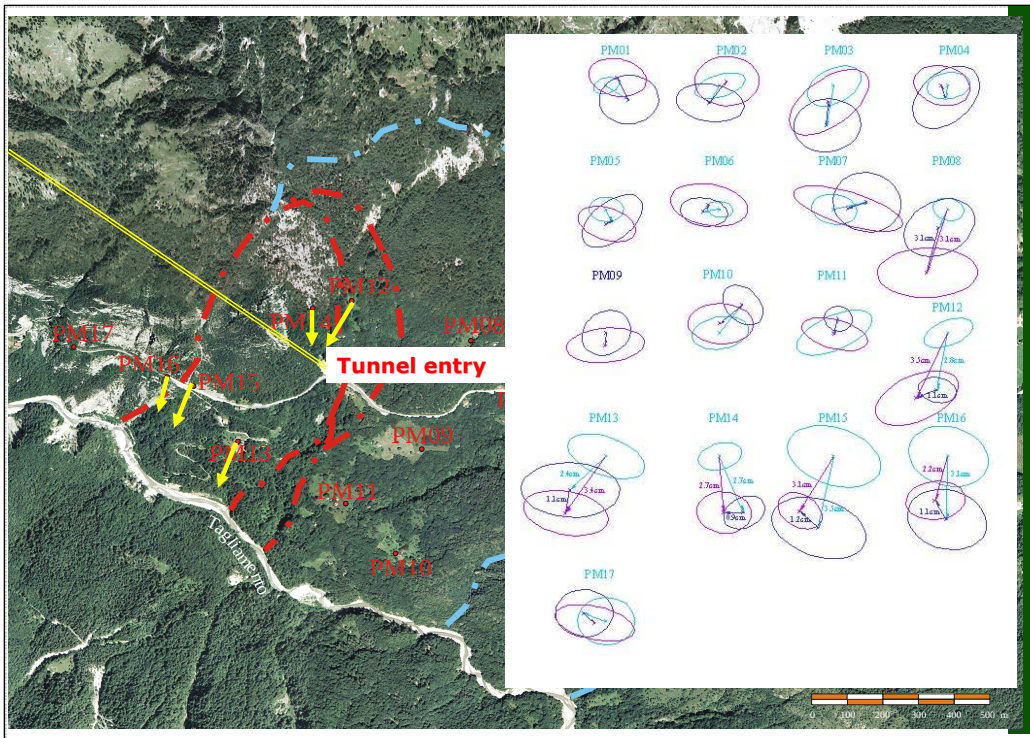


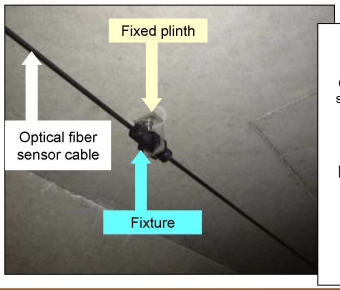


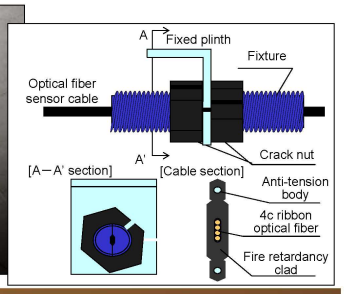
-12.5 Spostamento (mm) 12.5

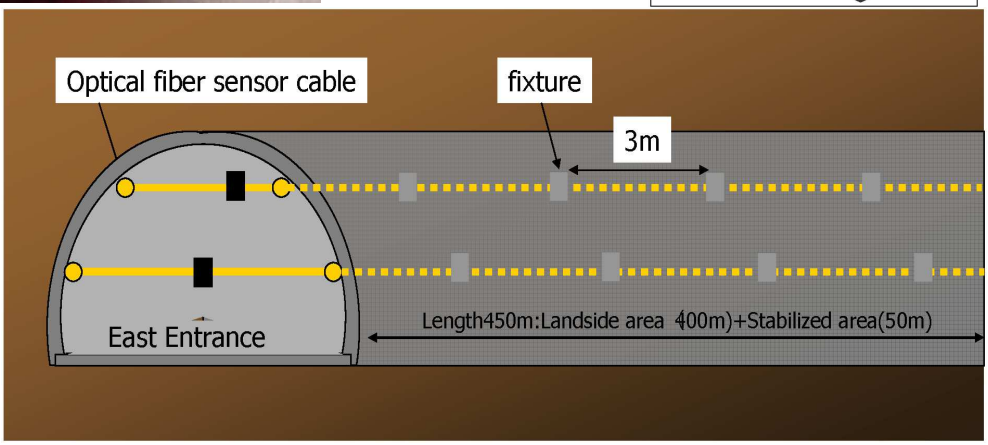
GBInSar Surveys

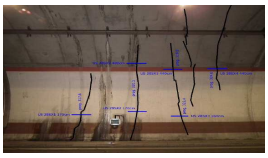
JESI, 10 GIUGNO 2016

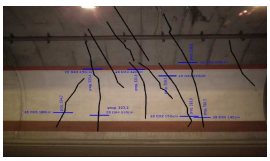

PM12
PM14
PM08
PM17
PM16
PM15
Tunnel entry
PM09
PM13
PM11
Tagliamento
PM10
PM01
PM02
PM03
PM04
PM05
PM06
PM07
PM08
PM09
PM10
PM11
PM12
PM13
PM14
PM15
PM16
PM17
0 100 200 300 400 500 m

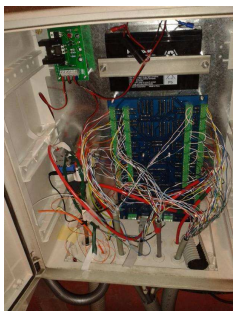

Fixed plinth
Optical fiber sensor cable
Fixture

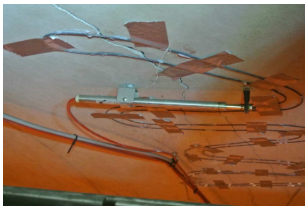

A
Fixed plinth
Fixture
Optical fiber sensor cable
A'
[A—A' section]
[Cable section]
Crack nut
Anti-tension body
4c ribbon optical fiber
Fire retardancy clad

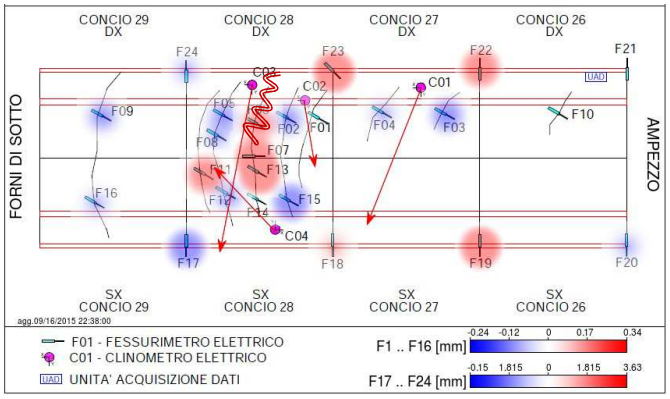

Optical fiber sensor cable
fixture
3m
East Entrance
Length450m:Landside area 400m)+Stabilized area(50m)

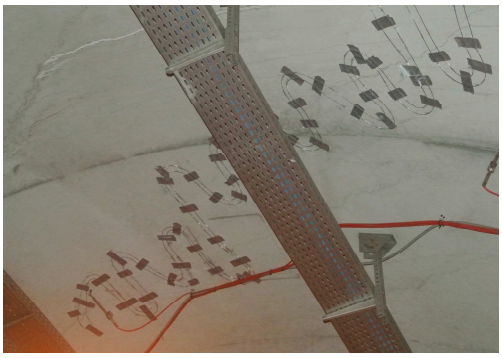






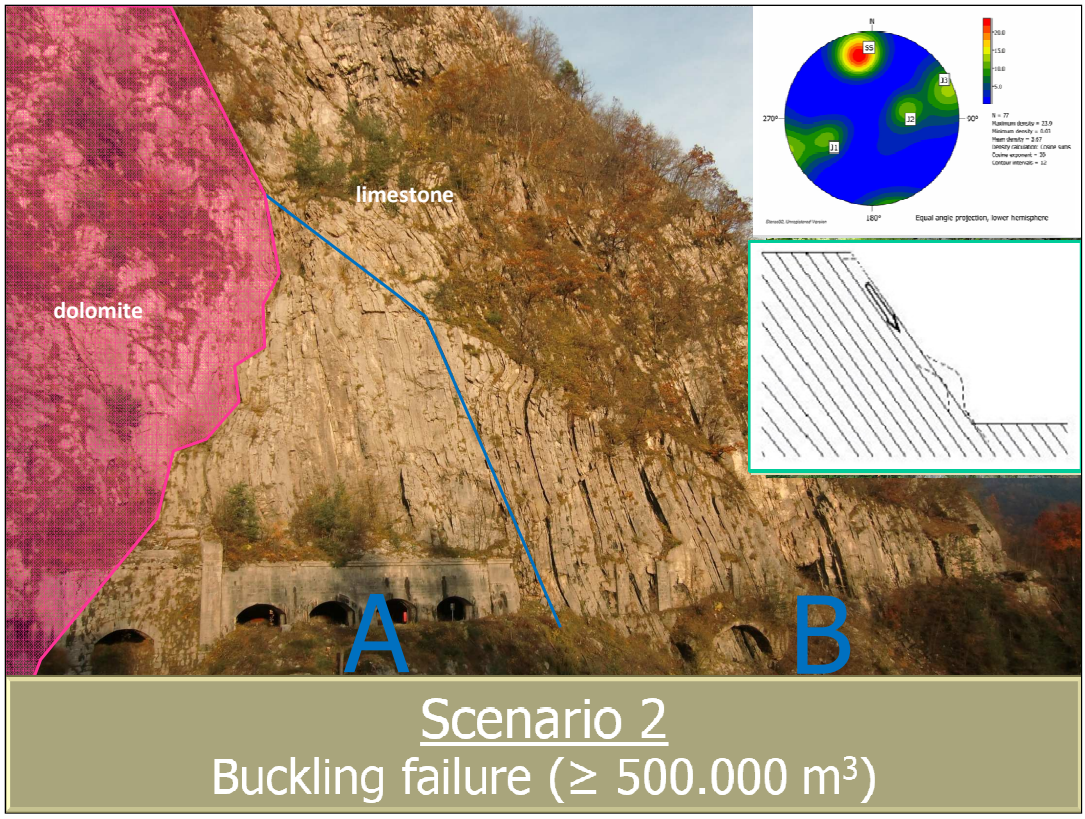



CONCIO 29 DX
CONCIO 28 DX
CONCIO 27 DX
CONCIO 26 DX
F24
F23
F22
F21
C03
C02
C01
UAD
F09
F05
F02
F01
F04
F03
F10
F08
F07
F11
F13
F16
F12
F14
F15
C04
F17
F18
F19
F20
FORNI DI SOTTO
AMPEZZO
SX CONCIO 29
SX CONCIO 28
SX CONCIO 27
SX CONCIO 26
agg.09/16/2015 22:38:00
F01 - FESSURIMETRO ELETTRICO
C01 - CLINOMETRO ELETTRICO
UAD UNITA' ACQUISIZIONE DATI
F1 .. F16 [mm]
-0.24 -0.12 0 0.17 0.34
F17 .. F24 [mm]
-0.15 1.815 0 1.815 3.63



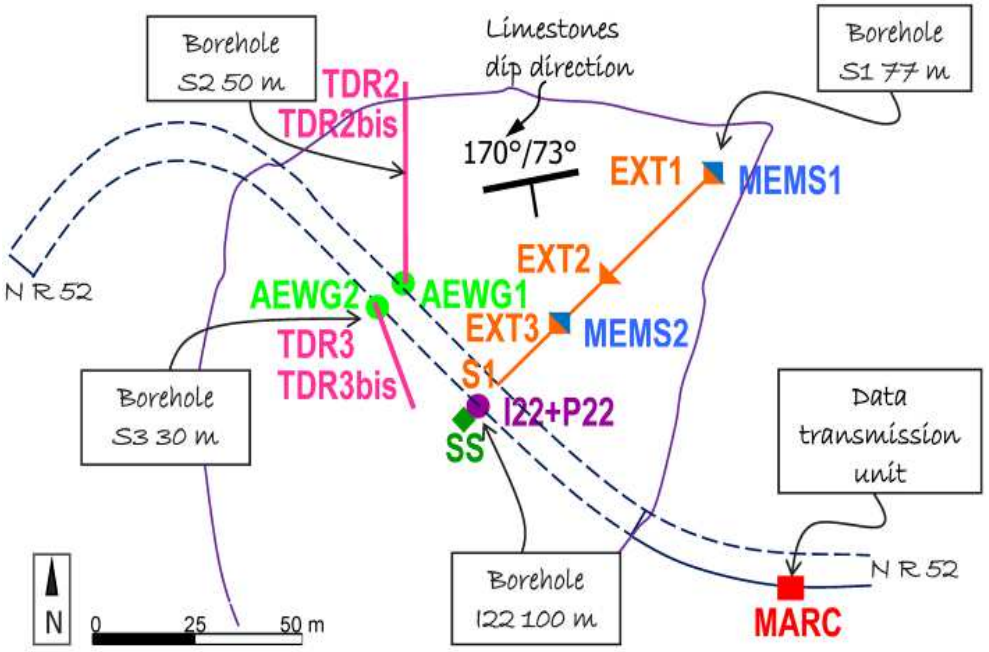

AVAGO

Collateral movements

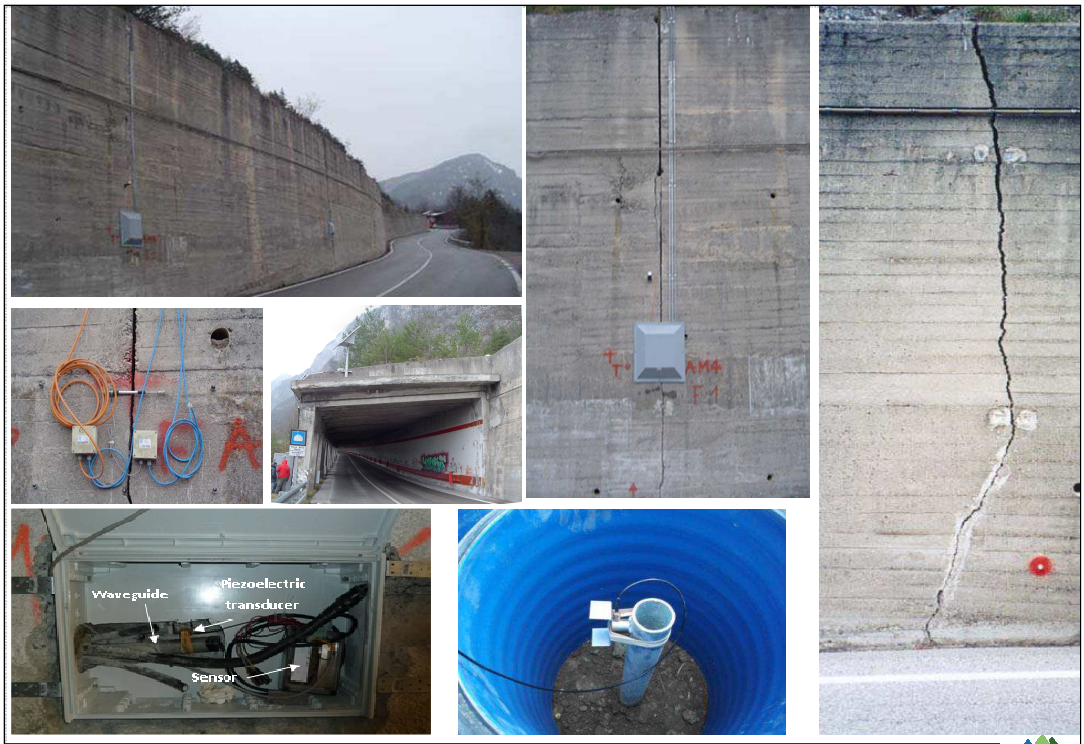


Scenario 2

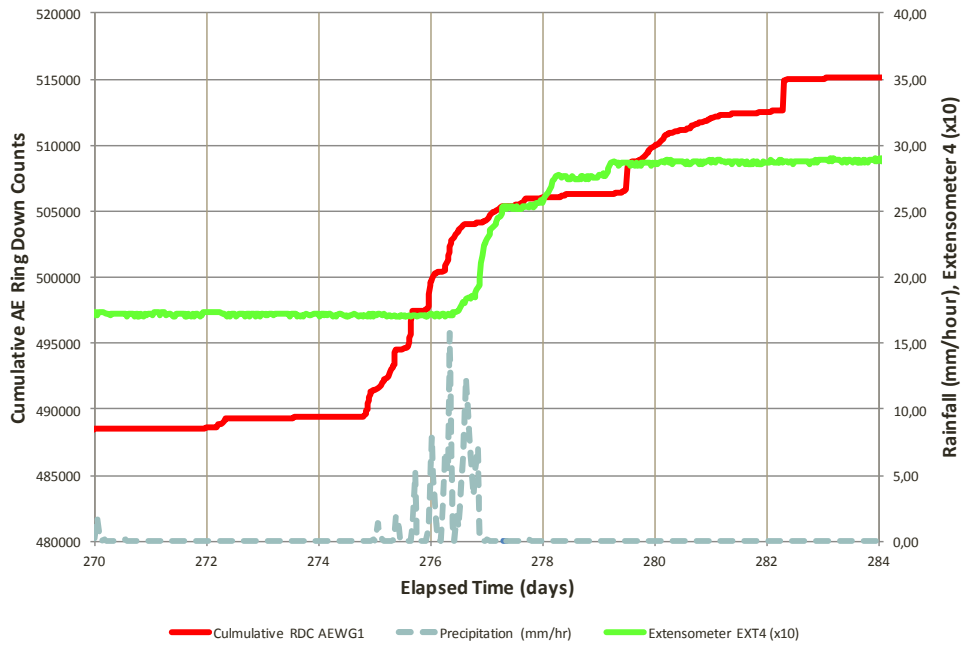
Buckling failure (≥ 500.000 m³)



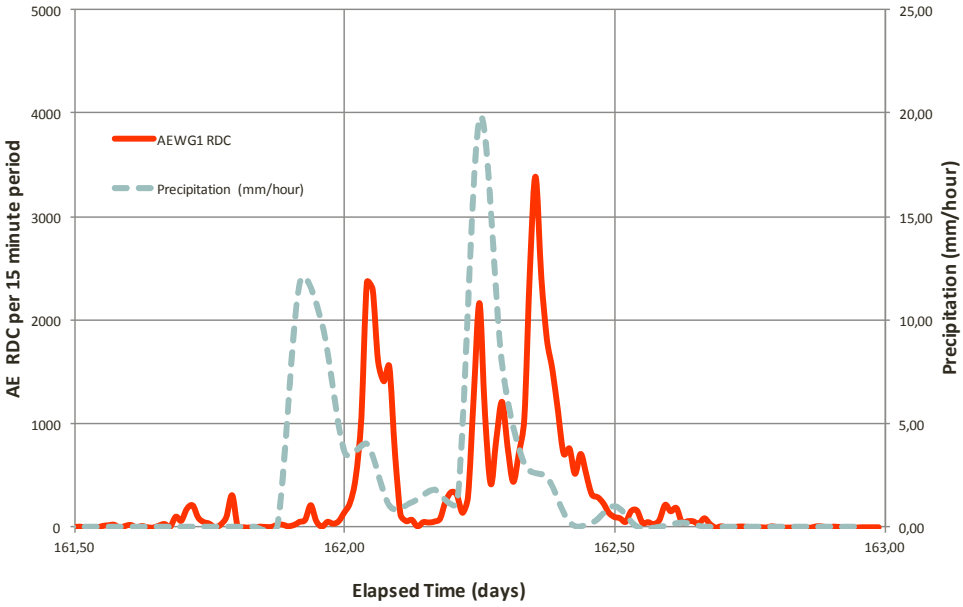
Layout of the monitoring system



IL MONITORAGGIO COME STRUMENTO DI PREVENZIONE E MITIGAZIONE DEL RISCHIO



Extensometer and AE response



AE response to rainfall input

FINAL REMARKS

Geotechnical instrumentation is a **powerful tool** for landslide hazard assessment, prevention and mitigation

The data provide by monitoring systems can be useful to formulate possible **landslide evolutionary scenarios**

Almost all the technologies used in slope monitoring can by fruitful used in **buildings and infrastructures monitoring** and vice versa

The **integration** of different type of actions as well as different type of instrumentation is of paramount importance in building a reliable protection system and a resilience society

They can be used also as **input data for hydrological and slope stability models** and therefore their quality strongly affects the results of such models

The data gathered from monitoring and modeling must be included in a **Decision Support System** (DSS) to support the end-users in risk management

Thank you very much for your attention

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JESI, 10 GIUGNO 2016

IL MONITORAGGIO COME STRUMENTO DI PREVENZIONE E MITIGAZIONE DEL RISCHIO