Istituto di Ricerca per la Protezione Idrogeologica
Consiglio Nazionale delle Ricerche
GEOHAZARD MONITORING GROUP

Identification and management of geo-hydrological instabilities for a better landscape governance

Daniele Giordan, Danilo Godone

CNR IRPI - 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



overview

1: Landslides classification

2: Landslide mapping, susceptibility, hazard and risk zoning

3 Landslides characterization and monitoring

4 Landslide data management and dissemination

LANDSLIDES CLASSIFICATION

irpi
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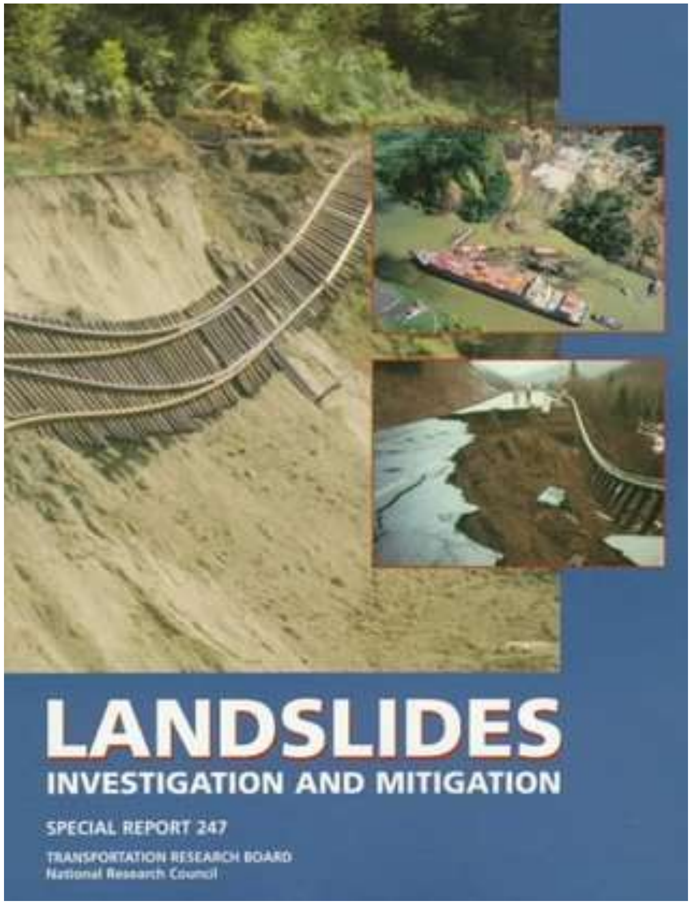
LANDSLIDES CLASSIFICATION

The term "**landslide**" describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these.

This is the definition reported in the "Special *Report 29, Landslides and Engineering Practice".*
Special Report 29, which was written by the Highway Research Board Committee on Landslide Investigations and published in 1958

LANDSLIDES CLASSIFICATION



Landslides: Investigation and Mitigation (National Research Council (U.S.) Transportation Research Board Special Report)

by Robert L. Schuster, A. Keith Turner (1996)

This Special Report is a greatly expanded edition of a previous report on landslides (Special Report 176, Landslides: Analysis and Control) published in 1978. The new report, which has been designed with an even broader international scope, contains comprehensive, practical discussions of field investigations, laboratory testing, and stability analysis procedures and technologies; comprehensive references to the literature; and discussions of case studies, state-of-the-art techniques, and research directions. The report is presented in five sections: (1) Principles, Definitions, and Assessment; (2) Investigation; (3) Strength and Stability Analysis; (4) Mitigation; and (5) Special Cases and Materials.

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LANDSLIDES CLASSIFICATION

- Failure surfaces (shape, roughness, defects)
- Surface topography
- Extension of the involved area
- Depositional area
- Type of movement
- Rate of movement
- Size and properties of material (structure, strength, friction angle)
- Age of failure
- Subsurface water level, pore pressure
- Trigger mechanisms

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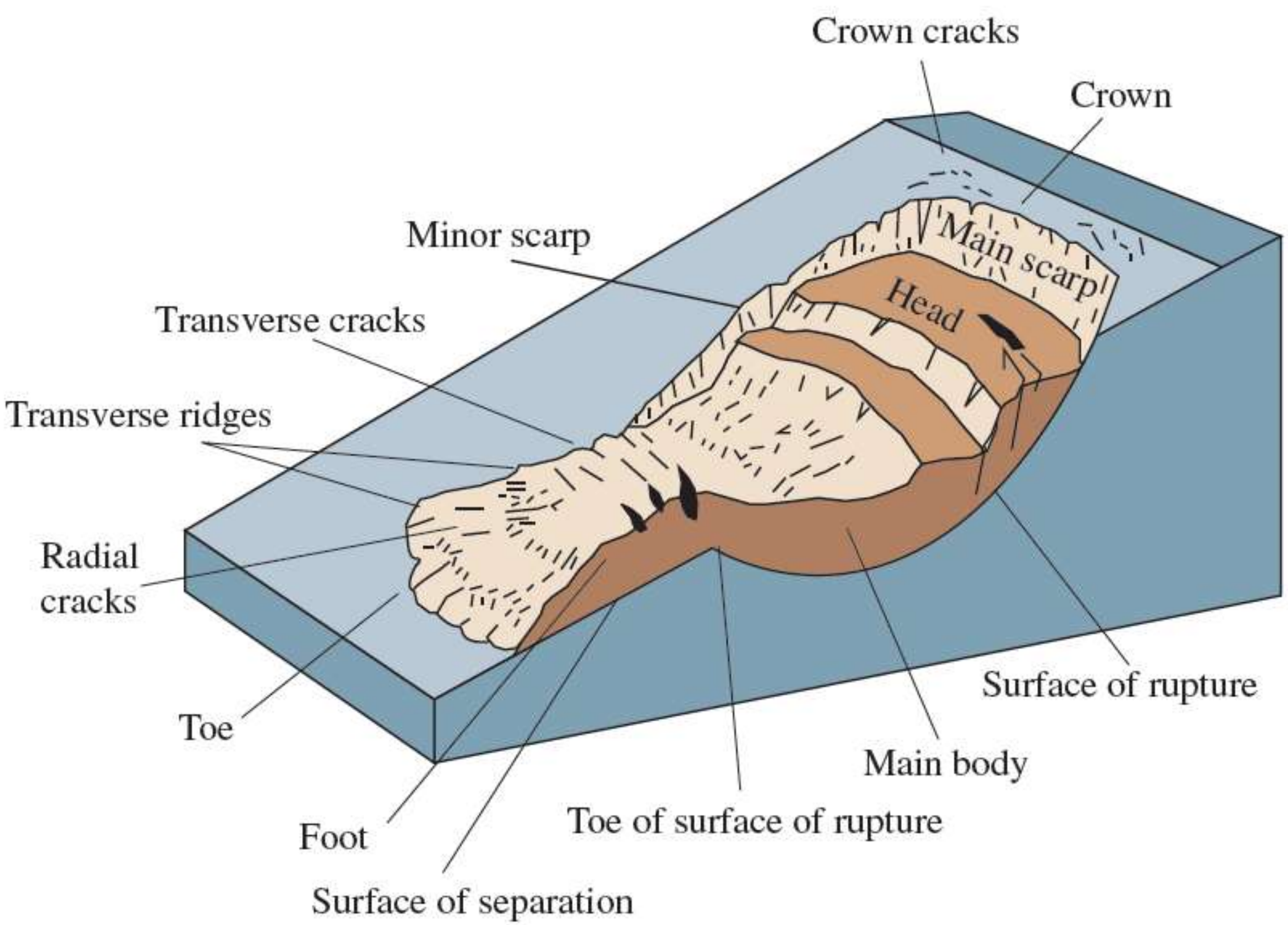
LANDSLIDES CLASSIFICATION



https://pubs.usgs.gov/fs/2004/3072/pdf/fs2004-3072.pdf

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LANDSLIDES CLASSIFICATION

<table>
<tr><th colspan="2" rowspan="3">TYPE OF MOVEMENT</th><th colspan="3">TYPE OF MATERIAL</th></tr>
<tr><th rowspan="2">BEDROCK</th><th colspan="2">ENGINEERING SOILS</th></tr>
<tr><th>Predominantly coarse</th><th>Predominantly fine</th></tr>
<tr><td colspan="2">FALLS</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="2">TOPPLES</td><td>Rock topple</td><td>Debris topple</td><td>Earth topple</td></tr>
<tr><td rowspan="2">SLIDES</td><td>ROTATIONAL</td><td rowspan="2">Rock slide</td><td rowspan="2">Debris slide</td><td rowspan="2">Earth slide</td></tr>
<tr><td>TRANSLATIONAL</td></tr>
<tr><td colspan="2">LATERAL SPREADS</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="2" rowspan="2">FLOWS</td><td>Rock flow</td><td>Debris flow</td><td>Earth flow</td></tr>
<tr><td>(deep creep)</td><td colspan="2">(soil creep)</td></tr>
<tr><td colspan="2">COMPLEX</td><td colspan="3">Combination of two or more principal types of movement</td></tr>
</table>

Varnes 1978

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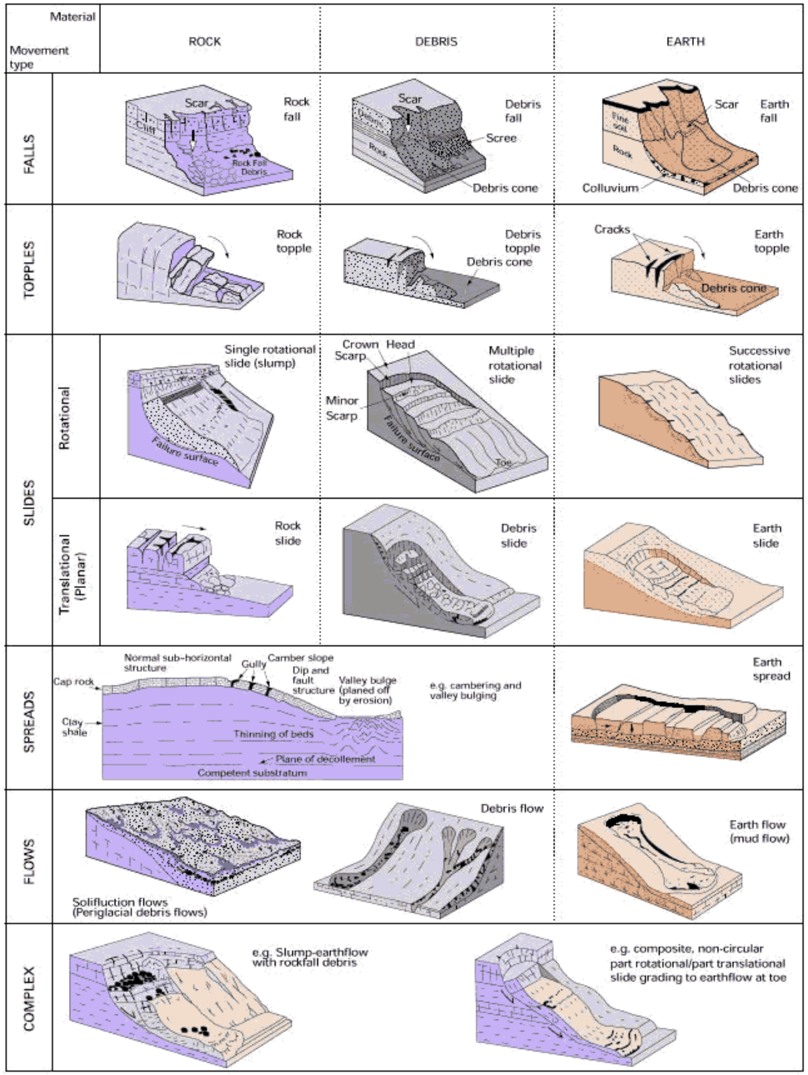
LANDSLIDES CLASSIFICATION



Rock: is “a hard or firm mass that was intact and in its natural place before the initiation of movement”.
Debris: “contains a significant proportion of coarse material; 20% to 80% of the particles are larger than 2mm, and the remainder are less than 2mm”.
Earth: “describes material in which 80% or more of the particles are smaller
than 2mm, the upper limit of sand sized particles”.

Cruden & Varnes 1996

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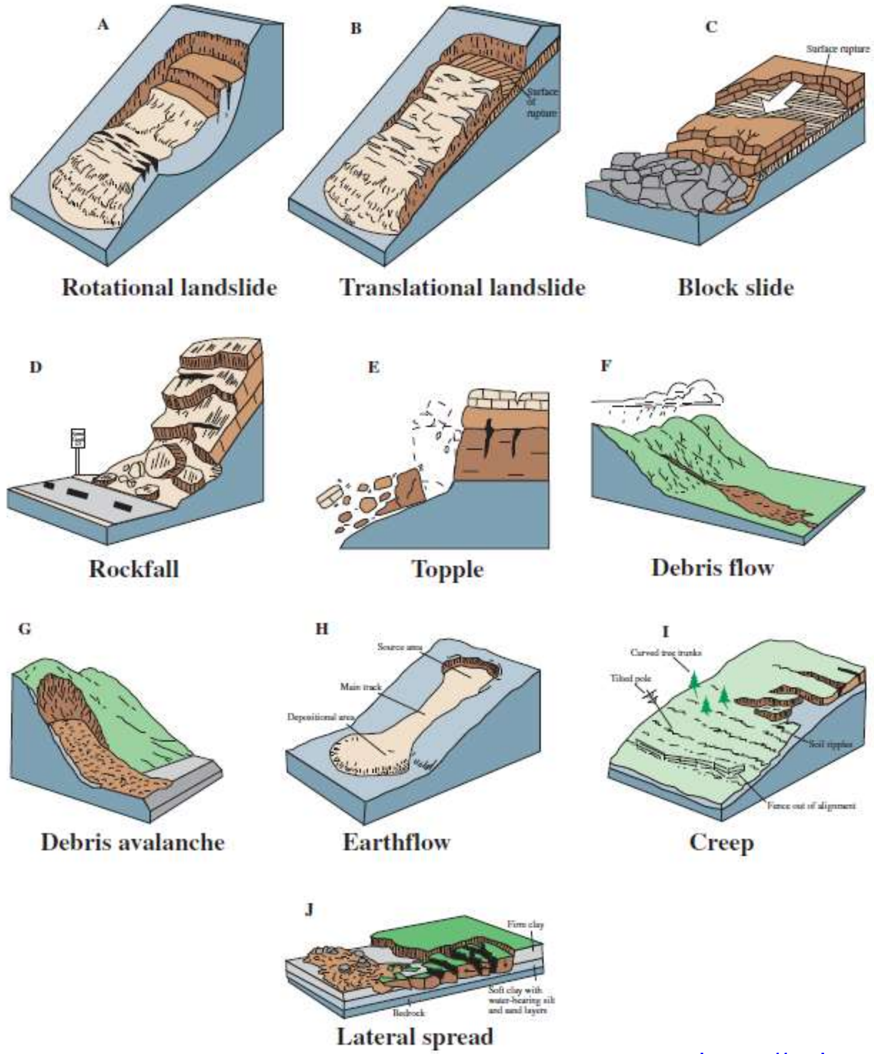

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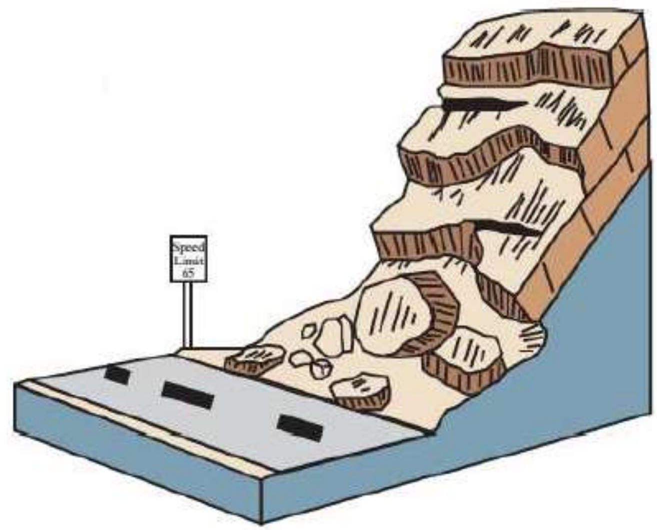
LANDSLIDES CLASSIFICATION

Falls are abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs.
Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water.

Figure 4. A rockfall/slide that occurred in Clear Creek Canyon, Colorado, USA, in 2005, closing the canyon to traffic for a number of weeks. The photograph also shows an example of a rock curtain, a barrier commonly applied over hazardous rock faces (right center of photograph). (Photograph by Colorado Geological Survey.)



(https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html)

FALLS

Occurrence and relative size/range

Common worldwide on steep or vertical slopes—also in coastal areas, and along rocky banks of rivers and streams. The volume of material in a fall can vary substantially, from individual rocks or clumps of soil to massive blocks thousands of cubic meters in size.

Velocity of travel

Very rapid to extremely rapid, free-fall; bouncing and rolling of detached soil, rock, and boulders. The rolling velocity depends on slope steepness.

Triggering mechanism

Undercutting of slope by natural processes such as streams and rivers or differential weathering (such as the freeze/thaw cycle), human activities such as excavation during road building and (or) maintenance, and earthquake shaking or other intense vibration.

Effects (direct/indirect)

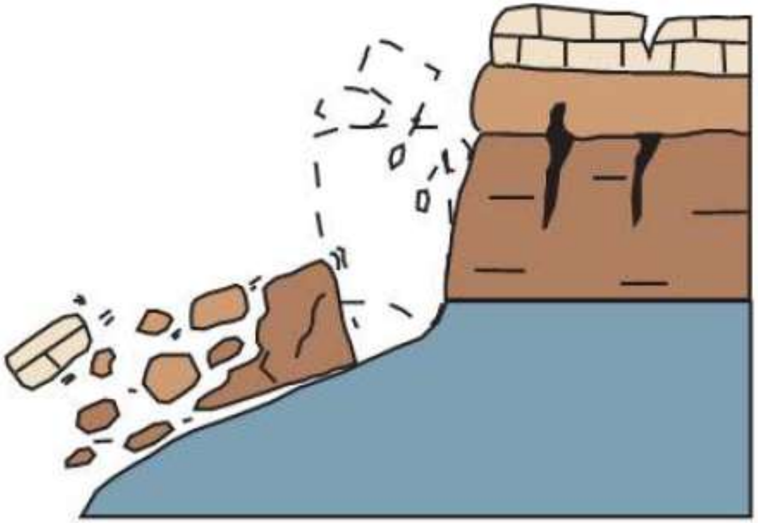
Falling material can be life-threatening. Falls can damage property beneath the fall-line of large rocks. Boulders can bounce or roll great distances and damage structures or kill people. Damage to roads and railroads is particularly high: rockfalls can cause deaths in vehicles hit by rocks and can block highways and railroads.

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

LANDSLIDES CLASSIFICATION

Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks.

Figure 6. Photograph of block toppling at Fort St. John, British Columbia, Canada. (Photograph by G. Bianchi Fasani.)



(https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html)

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LANDSLIDES CLASSIFICATION

TOPPLES

Occurrence

Known to occur globally, often prevalent in columnar-jointed volcanic terrain, as well as along stream and river courses where the banks are steep.

Velocity of travel

Extremely slow to extremely rapid, sometimes accelerating throughout the movement depending on distance of travel.

Triggering mechanism

Sometimes driven by gravity exerted by material located upslope from the displaced mass and sometimes by water or ice occurring in cracks within the mass; also, vibration, undercutting, differential weathering, excavation, or stream erosion.

Effects (direct/indirect)

Can be extremely destructive, especially when failure is sudden and (or) the velocity is rapid.

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

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LANDSLIDES CLASSIFICATION

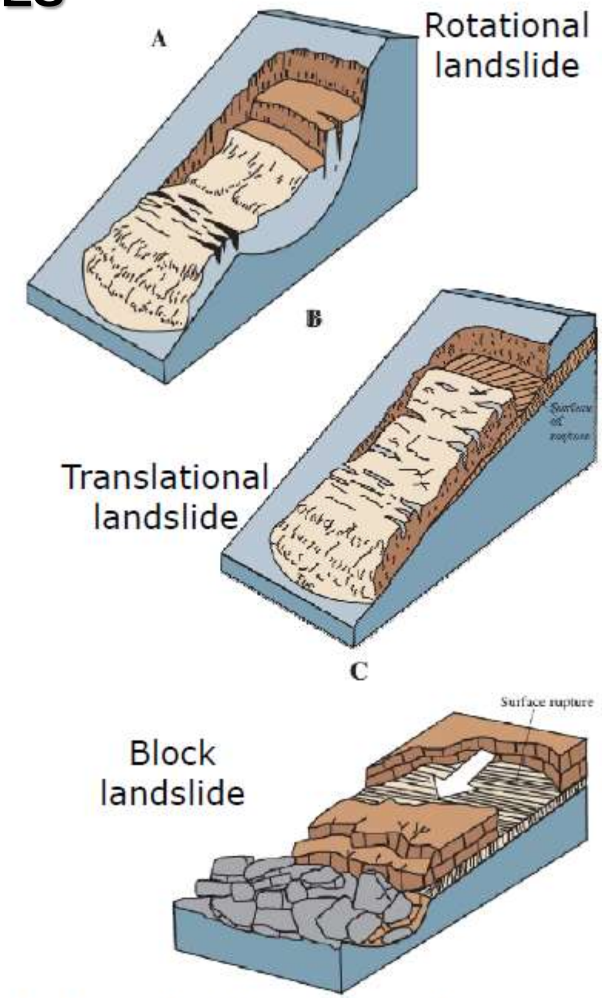
ROTATIONAL SLIDES

Slide is a mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides are rotational slides and translational slides.

Rotational slide: This is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground surface and transverse across the slide (A).

Translational slide: In this type of slide, the landslide mass moves along a roughly planar surface with little rotation or backward tilting (B).

Block slide is a translational slide in which the moving mass consists of a single unit or a few closely related units that move downslope as a relatively coherent mass (C).



(https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html)

LANDSLIDES CLASSIFICATION

Courtesy of BGS Coastal Landslide Observatory

ROTATIONAL SLIDES

Occurrence

Because rotational slides occur most frequently in homogeneous materials, they are the most common landslide occurring in “fill” materials.

Relative size/range

Associated with slopes ranging from about 20 to 40 degrees. In soils, the surface of rupture generally has a depth-to-length ratio between 0.3 to 0.1.

Velocity of travel (rate of movement)

Extremely slow (less than 0.3 meter or 1 foot every 5 years) to moderately fast (1.5 meters or 5 feet per month) to rapid.

Triggering mechanism

Intense and (or) sustained rainfall or rapid snowmelt can lead to the saturation of slopes and increased groundwater levels within the mass; rapid drops in river level following floods, ground-water levels rising as a result of filling reservoirs, or the rise in level of streams, lakes, and rivers, which cause erosion at the base of slopes. These types of slides can also be earthquake-induced.

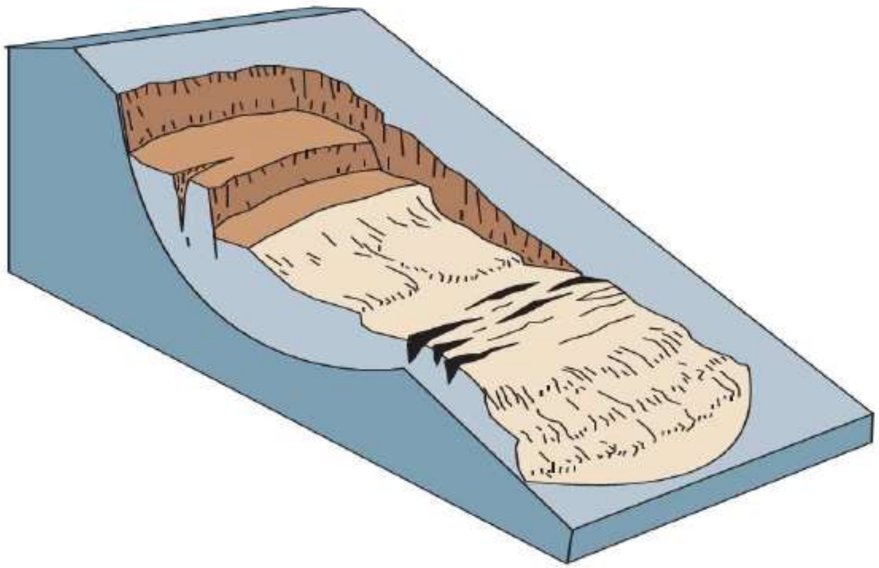
(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

LANDSLIDES CLASSIFICATION

ROTATIONAL SLIDES

Effects (direct/indirect)

Can be extremely damaging to structures, roads, and lifelines but are not usually life-threatening if movement is slow. Structures situated on the moving mass also can be severely damaged as the mass tilts and deforms. The large volume of material that is displaced is difficult to permanently stabilize. Such failures can dam rivers, causing flooding.



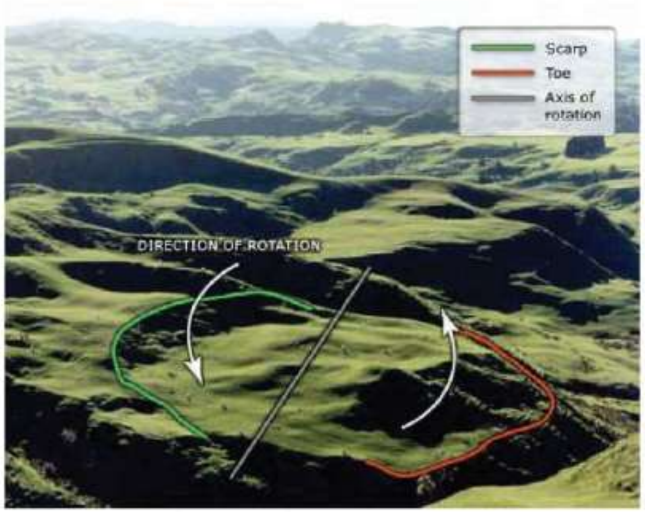


Figure 8. Photograph of a rotational landslide which occurred in New Zealand. The green curve at center left is the scarp (the area where the ground has failed). The hummocky ground at bottom right (in shadow) is the toe of the landslide (red line). This is called a rotational landslide as the earth has moved from left to right on a curved sliding surface. The direction and axis of rotation are also depicted. (Photograph by Michael J. Crozier, Encyclopedia of New Zealand, updated September 21, 2007.)

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

LANDSLIDES CLASSIFICATION

TRASLATIONAL SLIDES

https://www.regione.piemonte.it/web/temi/protezione-civile-difesa-suolo-opere-pubbliche/prevenzione-rischio-geologico/frane-monitoraggio/frane-piemonte

LANDSLIDES CLASSIFICATION

TRASLATIONAL SLIDES

Occurrence

One of the most common types of landslides, worldwide. They are found globally in all types of environments and conditions.

Relative size/range

Generally shallower than rotational slides. The surface of rupture has a distance-to-length ratio of less than 0.1 and can range from small (residential lot size) failures to very large, regional landslides that are kilometers wide.

Velocity of travel

Movement may initially be slow (5 feet per month or 1.5 meters per month) but many are moderate in velocity (5 feet per day or 1.5 meters per day) to extremely rapid. With increased velocity, the landslide mass of translational failures may disintegrate and develop into a debris flow.

Triggering mechanism

Primarily intense rainfall, rise in ground water within the slide due to rainfall, snowmelt, flooding, or other inundation of water resulting from irrigation, or leakage from pipes or human-related disturbances such as undercutting. These types of landslides can be earthquake-induced.

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

TRASLATIONAL SLIDES

Effects (direct/indirect)

Translational slides may initially be slow, damaging property and (or) lifelines; in some cases they can gain speed and become life-threatening. They also can dam rivers, causing flooding.

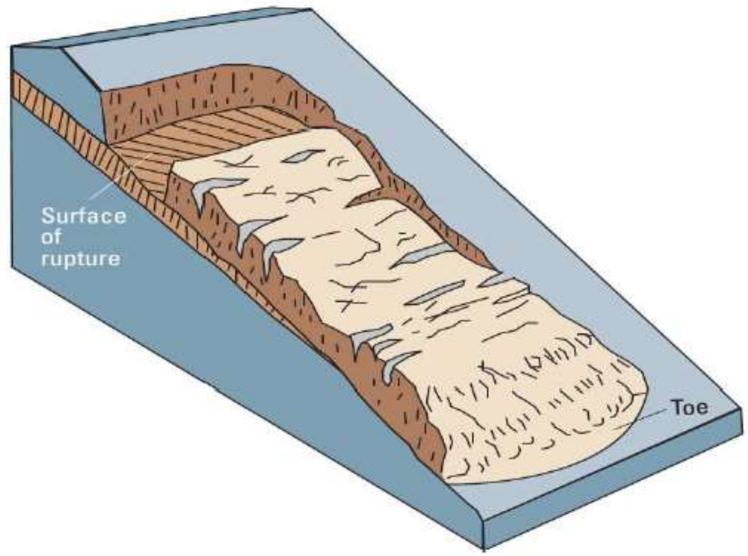
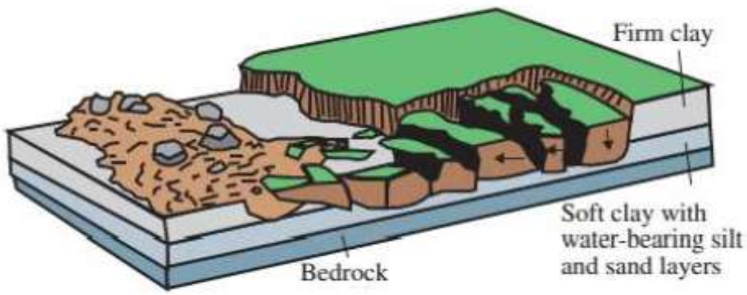


Figure 10. A translational landslide that occurred in 2001 in the Beatton River Valley, British Columbia, Canada. (Photograph by Réjean Couture, Canada Geological Survey.)

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

LANDSLIDES CLASSIFICATION

Lateral spreads are distinctive because they usually occur on very gentle slopes or flat terrain. The dominant mode of movement is lateral extension accompanied by shear or tensile fractures.
The failure is caused by liquefaction, the process whereby saturated, loose, cohesionless sediments (usually sands and silts) are transformed from a solid into a liquefied state.
Failure is usually triggered by rapid ground motion, such as that experienced during an earthquake, but can also be artificially induced.



When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and may then subside, translate, rotate, disintegrate, or liquefy and flow.
Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Often the initial failure is a slump, but in some materials movement occurs for no apparent reason.

(https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html)

LANDSLIDES CLASSIFICATION

LATERAL SPREAD

Champlong landslide

http://www.italiantouristoffice.se/sv/docs/1675.pdf

https://issuu.com/comunicambiente/docs/pannelli_web

LATERAL SPREAD

Occurrence

Worldwide and known to occur where there are liquefiable soils. Common, but not restricted, to areas of seismic activity.

Relative size/range

The area affected may start small in size and have a few cracks that may spread quickly, affecting areas of hundreds of meters in width.

Velocity of travel

May be slow to moderate and sometimes rapid after certain triggering mechanisms, such as an earthquake. Ground may then slowly spread over time from a few millimeters per day to tens of square meters per day.

Triggering mechanism

Triggers that destabilize the weak layer include:

- Liquefaction of lower weak layer by earthquake shaking
- Natural or anthropogenic overloading of the ground above an unstable slope
- Saturation of underlying weaker layer due to precipitation, snowmelt, and (or) ground-water changes
- Liquefaction of underlying sensitive marine clay following an erosional disturbance at base of a riverbank/slope
- Plastic deformation of unstable material at depth (for example, salt)

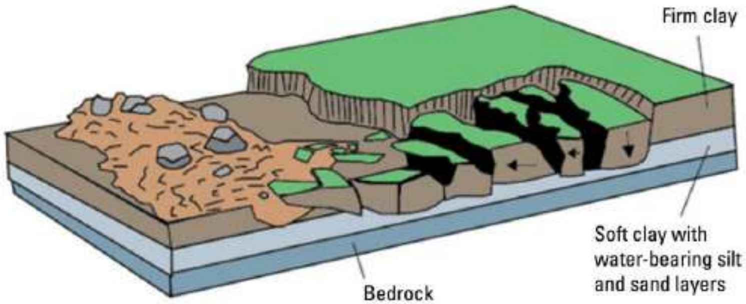
(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

LATERAL SPREAD

Effects (direct/indirect)

Can cause extensive property damage to buildings, roads, railroads, and lifelines. Can spread slowly or quickly, depending on the extent of water saturation of the various soil layers. Lateral spreads may be a precursor to earthflows.

Figure 12. Photograph of lateral spread damage to a roadway as a result of the 1989 Loma Prieta, California, USA, earthquake. (Photograph by Steve Ellen, U.S. Geological Survey.)

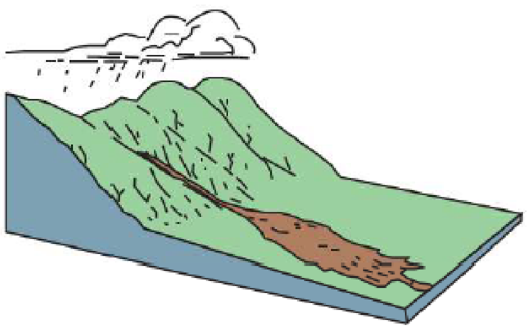


(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

LANDSLIDES CLASSIFICATION

Flow is a spatially continuous movement in which surfaces of shear are short-lived, closely spaced and not usually preserved. The distribution of velocities in the displacing mass resembles that in a viscous liquid.

F



There are five basic categories of flows that differ from one another in fundamental ways.

***Debris flow**:* A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope (F). Debris flows include <50% fines. Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt, that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. Debris-flow source areas are often associated with steep gullies, and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies. Fires that denude slopes of vegetation intensify the susceptibility of slopes to debris flows.

(https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html)

Debris Flows

Occurrence

Debris flows occur around the world and are prevalent in steep gullies and canyons; they can be intensified when occurring on slopes or in gullies that have been denuded of vegetation due to wildfires or forest logging. They are common in volcanic areas with weak soil.

Relative size/range

These types of flows can be thin and watery or thick with sediment and debris and are usually confined to the dimensions of the steep gullies that facilitate their downward movement. Generally the movement is relatively shallow and the run out is both long and narrow, sometimes extending for kilometers in steep terrain. The debris and mud usually terminate at the base of the slopes and create fanlike, triangular deposits called debris fans, which may also be unstable.

Velocity of travel

Can be rapid to extremely rapid (35 miles per hour or 56 km per hour) depending on consistency and slope angle.

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

LANDSLIDES CLASSIFICATION

Debris Flows

Triggering mechanisms

Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt, that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material.

Effects (direct/indirect)

Debris flows can be lethal because of their rapid onset, high speed of movement, and the fact that they can incorporate large boulders and other pieces of debris. They can move objects as large as houses in their downslope flow or can fill structures with a rapid accumulation of sediment and organic matter. They can affect the quality of water by depositing large amounts of silt and debris.

Figure 14. Debris-flow damage to the city of Caraballeda, located at the base of the Cordillera de la Costan, on the north coast of Venezuela. In December 1999, this area was hit by Venezuela's worst natural disaster of the 20th century; several days of torrential rain triggered flows of mud, boulders, water, and trees that killed as many as 30,000 people. (Photograph by L.M. Smith, Waterways Experiment Station, U.S. Army Corps of Engineers.)

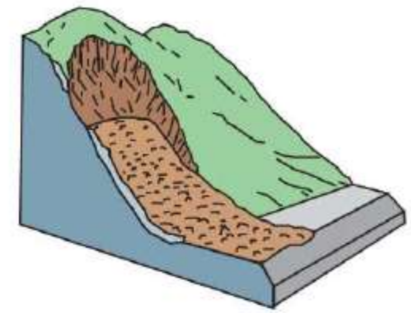
(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

LANDSLIDES CLASSIFICATION

Flows

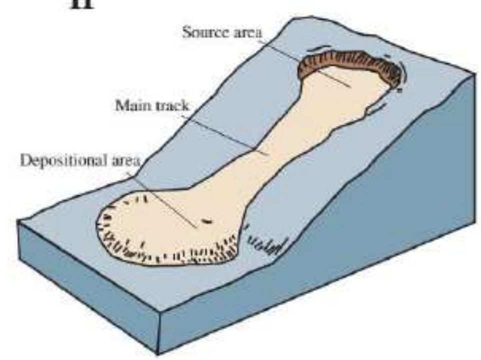
Debris avalanche*:* Debris avalanches are essentially large, extremely rapid, often open-slope flows formed when an unstable slope collapses and the resulting fragmented debris is rapidly transported away from the slope. In some cases, snow and ice will contribute to the movement if sufficient water is present, and the flow may become a debris flow and (or) a lahar (G).

G



Earthflows*:* have a characteristic "hourglass" shape (H). The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.

H



(https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html)

Debris avalanche

Occurrence

Occur worldwide in steep terrain environments. Also common on very steep volcanoes where they may follow drainage courses.

Relative size/range

Some large avalanches have been known to transport material blocks as large as 3 kilometers in size, several kilometers from their source.

Velocity of travel

Rapid to extremely rapid; such debris avalanches can travel close to 100 m/s.

Triggering mechanism

In general, the two types of debris avalanches are those that are “cold” and those that are “hot.” A cold debris avalanche usually results from a slope becoming unstable, such as during collapse of weathered slopes in steep terrain or through the disintegration of bedrock during a slide-type landslide as it moves downslope at high velocity. At that point, the mass can then transform into a debris avalanche. A hot debris avalanche is one that results from volcanic activity including volcanic earthquakes or the injection of magma, which causes slope instability.

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

Debris avalanche

Effects (direct/indirect)

Debris avalanches may travel several kilometers before stopping, or they may transform into more water-rich lahars or debris flows that travel many tens of kilometers farther downstream. Such failures may inundate towns and villages and impair stream quality. They move very fast and thus may prove deadly because there is little chance for warning and response.

Figure 18. A debris avalanche that buried the village of Guinsaugon, Southern Leyte, Philippines, in February 2006. (Photograph by University of Tokyo Geotechnical Team.)

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

Earthflow

Occurrence

Earthflows occur worldwide in regions underlain by fine-grained soil or very weathered bedrock. Catastrophic rapid earthflows are common in the susceptible marine clays of the St. Lawrence Lowlands of North America, coastal Alaska and British Columbia, and in Scandinavia.

Relative (size/range)

Flows can range from small events of 100 square meters in size to large events encompassing several square kilometers in area. Earthflows in susceptible marine clays may runout for several kilometers. Depth of the failure ranges from shallow to many tens of meters.

Velocity of travel

Slow to very rapid.

Triggering mechanisms

Triggers include saturation of soil due to prolonged or intense rainfall or snowmelt, sudden lowering of adjacent water surfaces causing rapid drawdown of the ground-water table, stream erosion at the bottom of a slope, excavation and construction activities, excessive loading on a slope, earthquakes, or human-induced vibration.

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

LANDSLIDES CLASSIFICATION

Earthflow

Effects (direct/indirect)

Rapid, retrogressive earthflows in susceptible marine clay may devastate large areas of flat land lying above the slope and also may runout for considerable distances, potentially resulting in human fatalities, destruction of buildings and linear infrastructure, and damming of rivers with resultant flooding upstream and water siltation problems downstream. Slower earthflows may damage properties and sever linear infrastructure.

Figure 20. The 1993 Lemieux landslide—a rapid earthflow in sensitive marine clay near Ottawa, Canada. The headscarp retrogressed 680 meters into level ground above the riverbank. About 2.8 million tons of clay and silt liquefied and flowed into the South Nation River valley, damming the river. (Photograph by G.R. Brooks, Geological Survey of Canada.)

(The Landslide Handbook—A Guide to Understanding Landslides, 2008)

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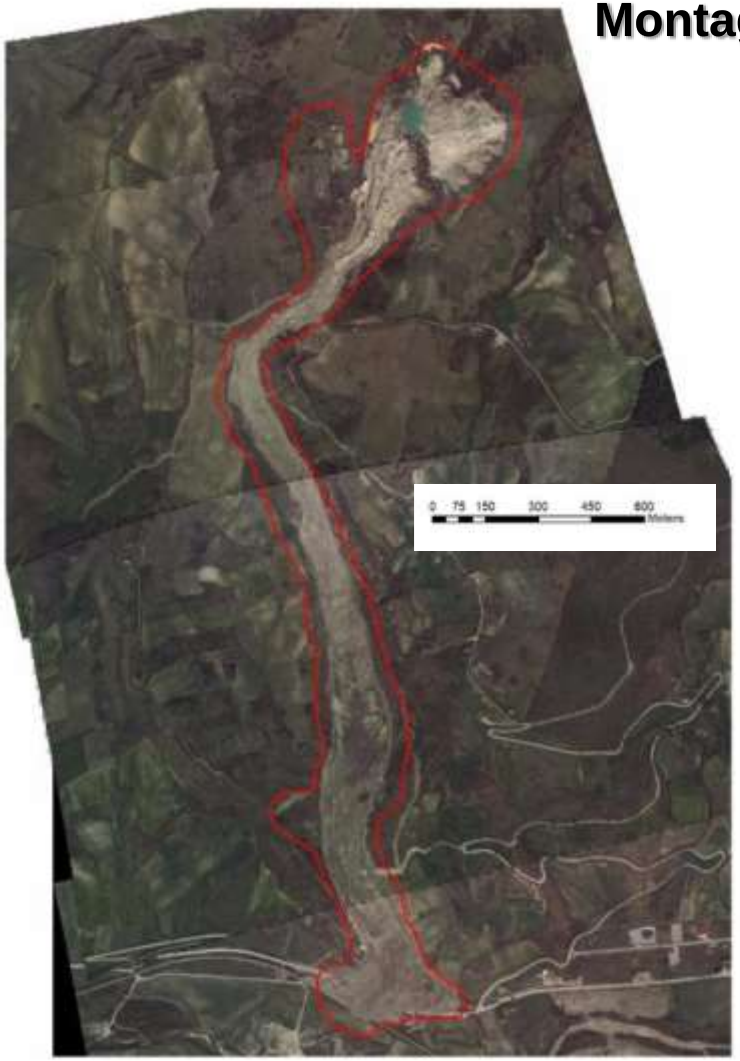
LANDSLIDES CLASSIFICATION

Montaguto Earthflows



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.

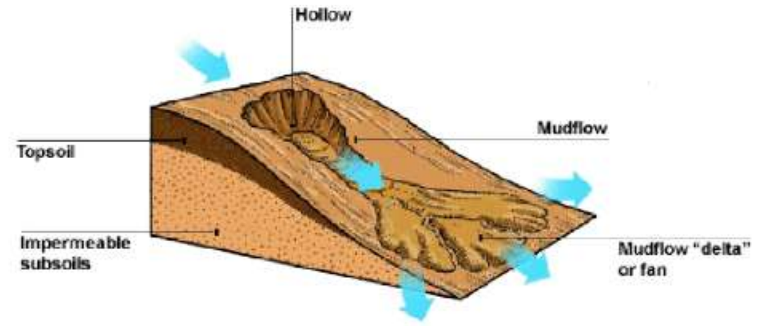
Lollino P., Giordan D., Allasia P. 2014. The Montaguto earthflow: A back-analysis of the process of landslide propagation. Engineering Geology, 170, 66–79;

P. Lollino, D. Giordan, P. Allasia. Assessment of the behavior of an active earth-slide by means of calibration between numerical analysis and field monitoring. Bulletin of Engineering Geology and the Environment. 2017 76(2), 421-435

GEOHAZARD MONITORING GROUP

mudflows

Mudflow: mudflow is an earthflow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles. In some instances, for example in many newspaper reports, mudflows and debris flows are commonly referred to as "mudslides."

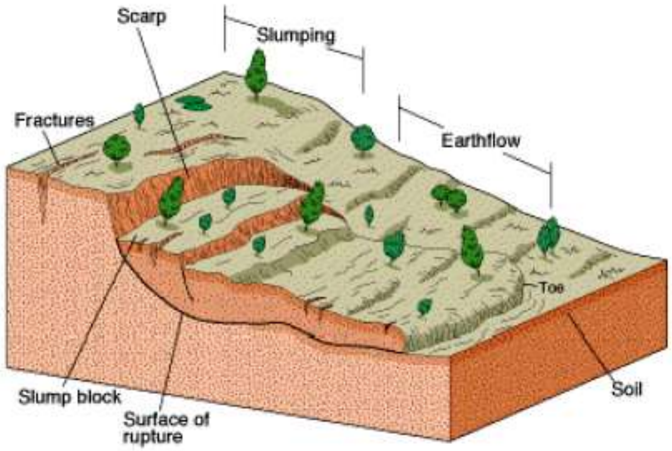


(https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html)
(https://watchoutnaturaldisasters.weebly.com/mudflows.html)

LANDSLIDES CLASSIFICATION

Complex

Combination of two or more of the above types is known as a **complex landslide**.



sliding

flow

Complex


Maierato
Retrait of 20 February
Scotrapiti T.
A
D
E
B
Corvoli T.
D
E
C
Corvoli T.

LANDSLIDE CAUSES

"One of the most common and most obvious causes of landslides consists in the undercutting of the foot of the slope or deposition of earth or other materials along the upper edge of the slope, both operations produce an increase in the shearing stresses in the ground beneath the slope. If and as soon as the average shearing stress on the potential surface of sliding becomes equal to average shearing resistance, a landslide occur".

Karl Terzaghi

LANDSLIDES CLASSIFICATION

LANDSLIDE CAUSES

1. Geological causes

a. Weak or sensitive materials
b. Weathered materials
c. Sheared, jointed, or fissured materials
d. Adversely oriented discontinuity (bedding, schistosity, fault, unconformity, contact, and so forth)
e. Contrast in permeability and/or stiffness of materials

2. Morphological causes

a. Tectonic or volcanic uplift
b. Glacial rebound
c. Fluvial, wave, or glacial erosion of slope toe or lateral margins
d. Subterranean erosion (solution, piping)
e. Deposition loading slope or its crest
f. Vegetation removal (by fire, drought)
g. Thawing
h. Freeze-and-thaw weathering
i. Shrink-and-swell weathering

3. Human causes

a. Excavation of slope or its toe
b. Loading of slope or its crest
c. Drawdown (of reservoirs)
d. Deforestation
e. Irrigation
f. Mining
g. Artificial vibration
h. Water leakage from utilities

https://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

LANDSLIDE VELOCITY

Velocity Class	Description	Velocity (mm/sec)	Typical Velocity	Probable Destructive Significance
7	Extremely Rapid			Catastrophe of major violence; buildings destroyed by impact of displaced material; many deaths; escape unlikely
		5×10^{3}	5 m/sec	
6	Very Rapid			Some lives lost; velocity too great to permit all persons to escape
		5×10^{1}	3 m/min	
5	Rapid			Escape evacuation possible; structures; possessions, and equipment destroyed
		5×10^{-1}	1.8 m/hr	
4	Moderate			Some temporary and insensitive structures can be temporarily maintained
		5×10^{-3}	13 m/month	
3	Slow			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
		5×10^{-5}	1.6 m/year	
2	Very Slow			Some permanent structures undamaged by movement
		5×10^{-7}	15 mm/year	
	Extremely SLOW			Imperceptible without instruments; construction POSSIBLE WITH PRECAUTIONS

Cruden & Varnes 1996

LANDSLIDES CLASSIFICATION

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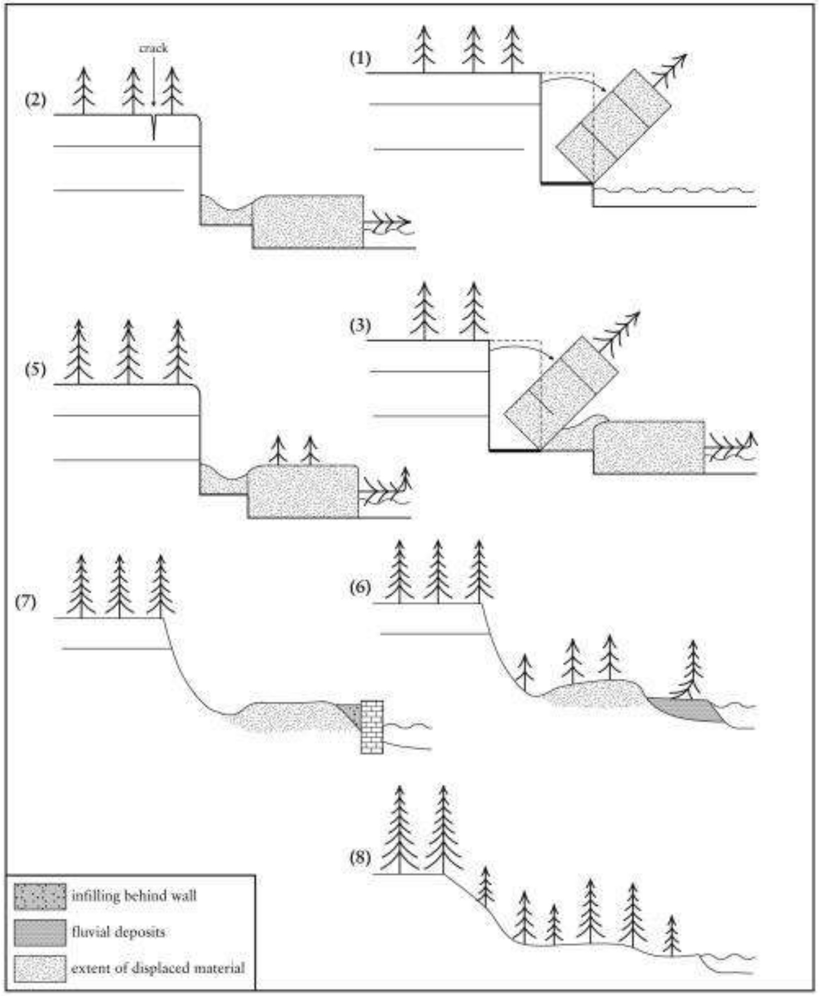
Consiglio Nazionale delle Ricerche

LANDSLIDE STATE OF ACTIVITY



Cruden & Varnes 1996

1 Active: An active landslide is currently moving. In the example shown erosion at the toe causes a block to topple.
2 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.
3 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.
5 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.
6 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.
7 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.
8 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.

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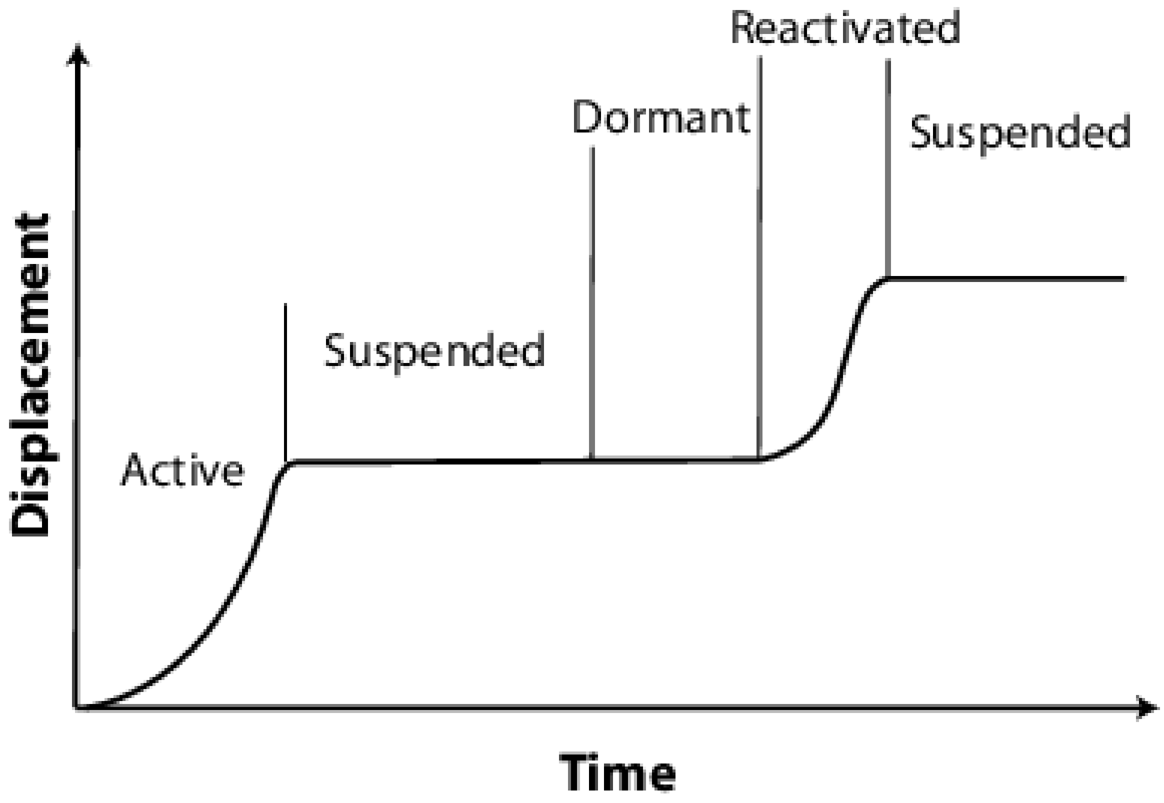
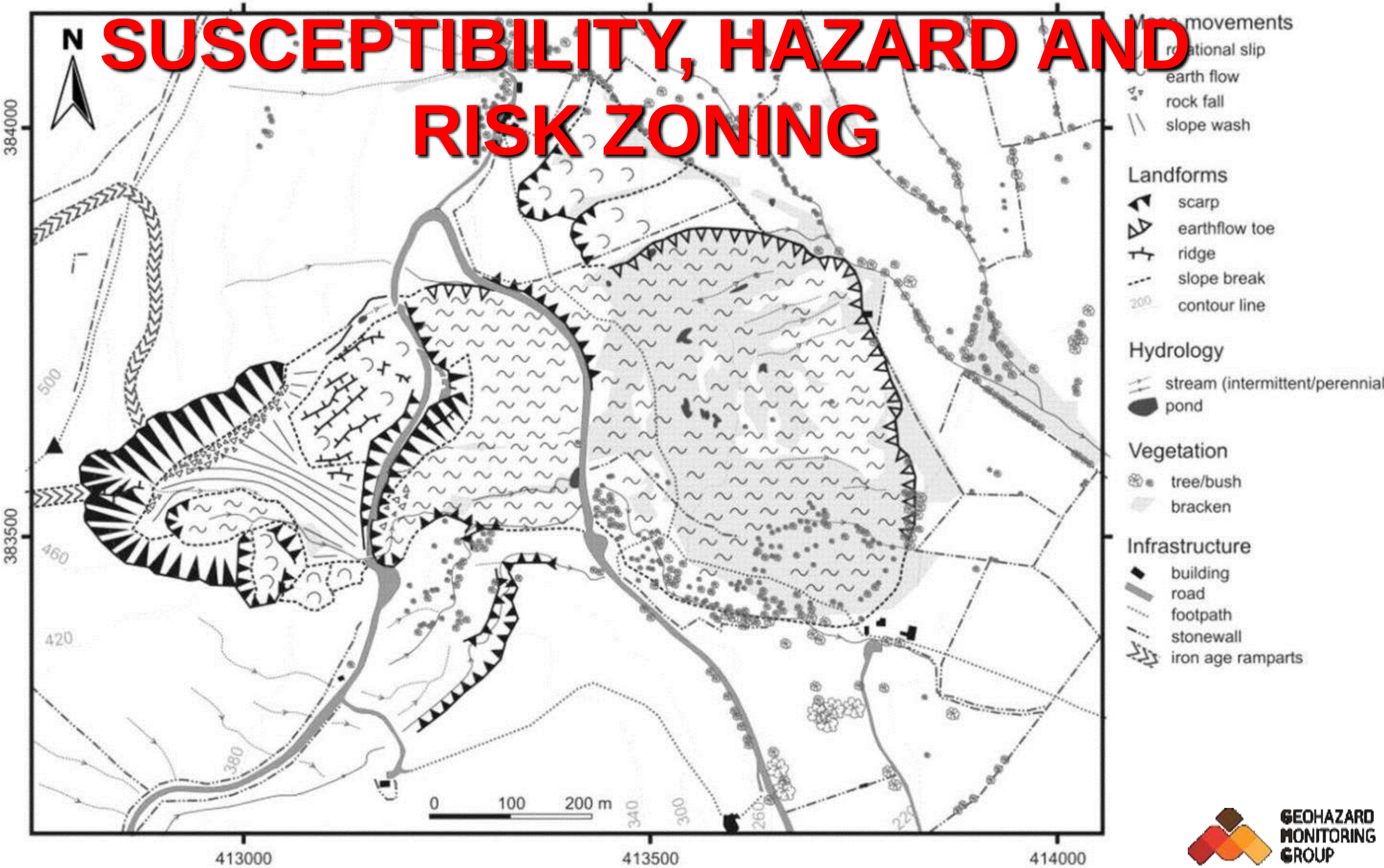
LANDSLIDES CLASSIFICATION



Cruden & Varnes 1996

LANDSLIDE MAPPING, SUSCEPTIBILITY, HAZARD AND RISK ZONING



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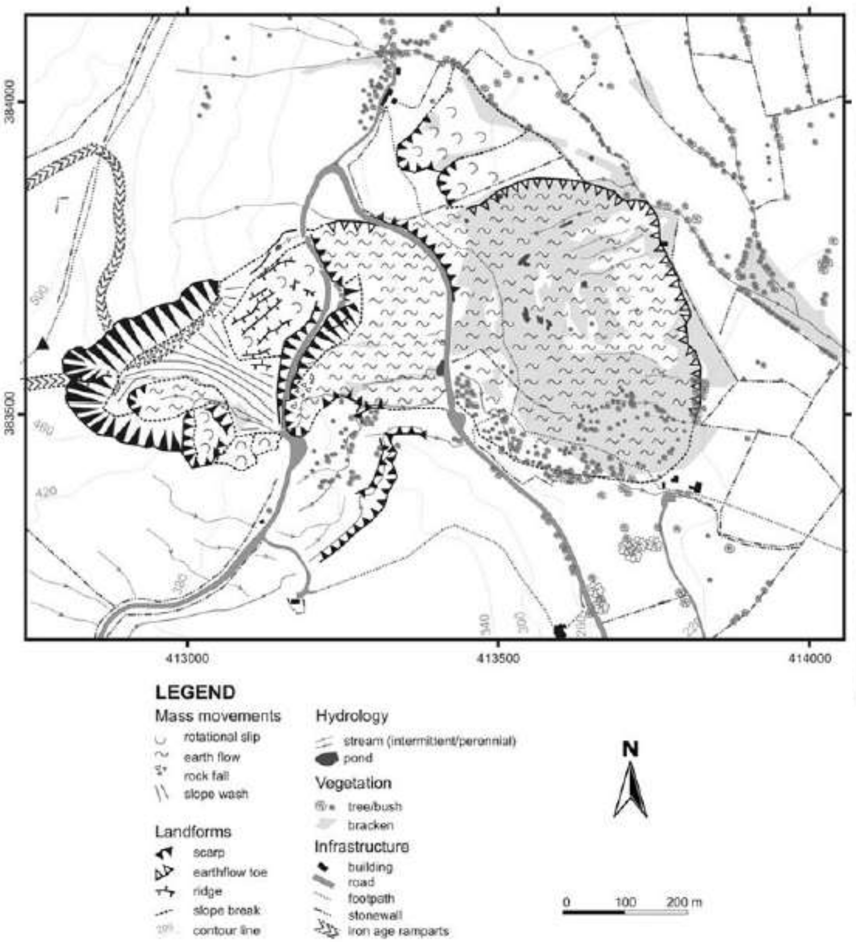
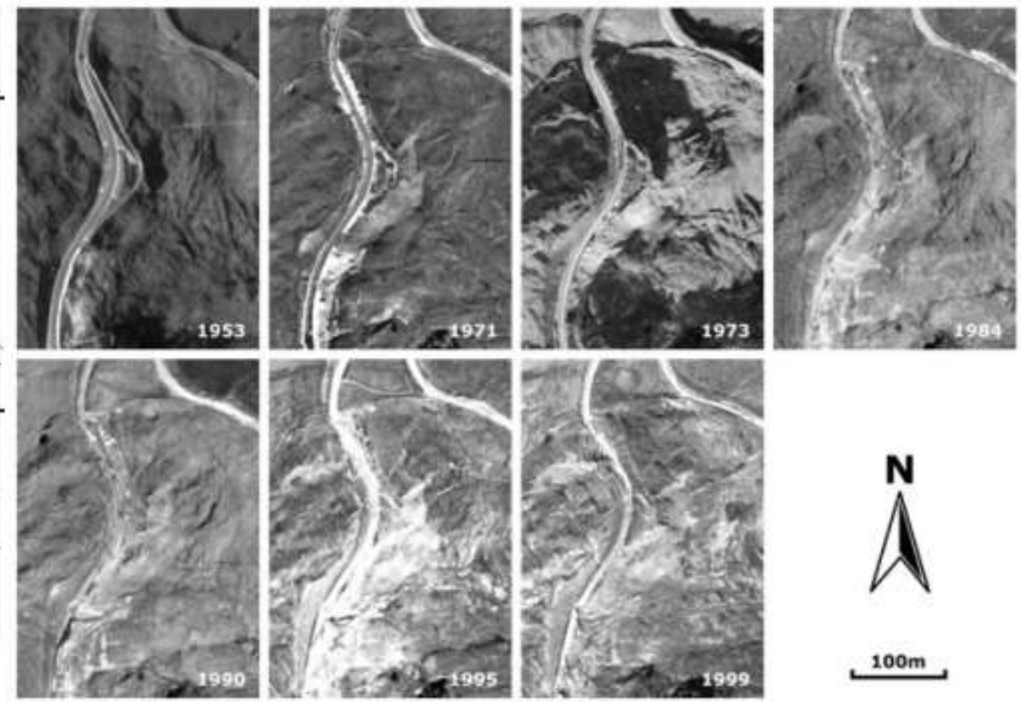
LANDSLIDE MAP AND INVENTORY

Single slide inventory





J. Walstra, N. Dixon, J.H. Chandler. 2007 Historical aerial photographs for landslide assessment: two case histories. Quarterly Journal of Engineering Geology and Hydrogeology, 40, 315-332

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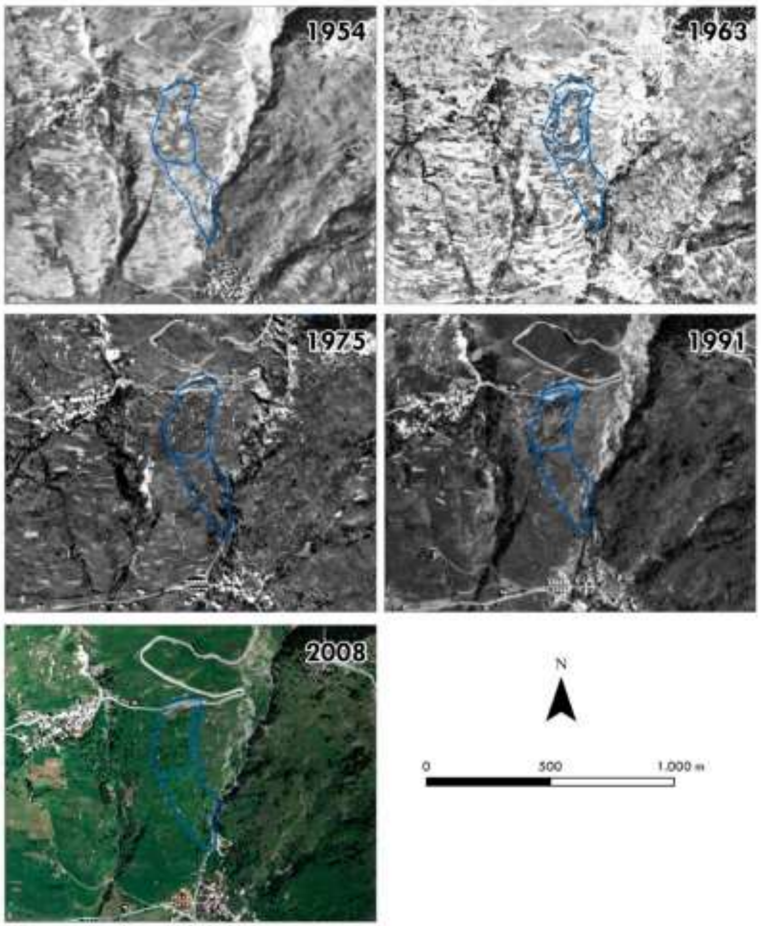
LANDSLIDE MAP AND INVENTORY

Champlas du Col case study



Cignetti M., Godone D., Wrzesniak A., Giordan D. 2019 Structure from Motion Multisource Application for Landslide Characterization and Monitoring: The Champlas du Col Case Study, Sestriere, North-Western Italy. Sensors, 19, 2364

GEOHAZARD MONITORING GROUP

LANDSLIDE MAP AND INVENTORY

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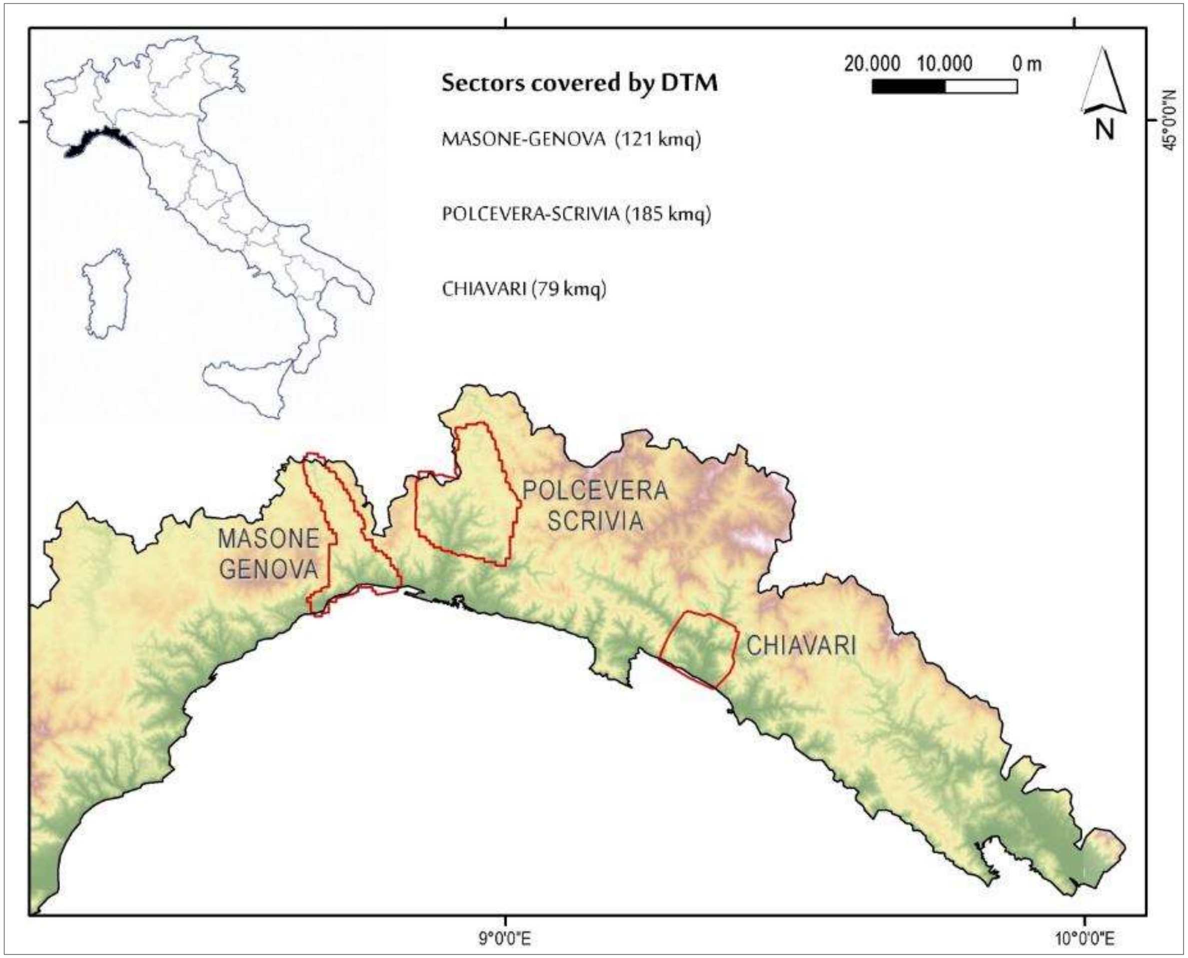
Geomorphological event map



In October/November 2014, a sequence of flash floods struck different sectors of Liguria region causing three victims and a large amount of damages

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LANDSLIDE MAP AND INVENTORY

Geomorphological event map

A) Lidar survey of most involved areas (390 km^2):
Digital Elevation Model (5/11 RAW point for meter square)
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.)

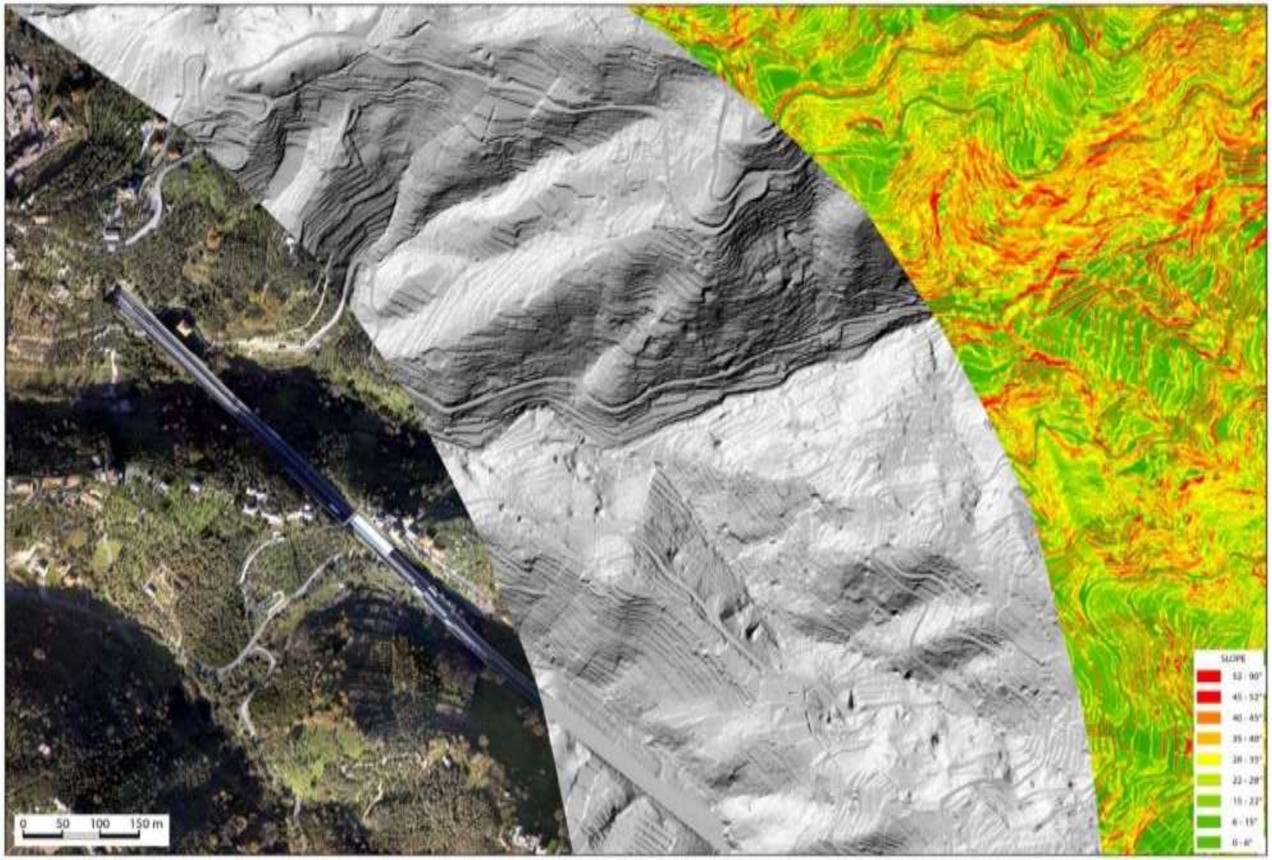
C) Analysis of the results focused on the landslides distribution

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

GEOHAZARD MONITORING GROUP

LANDSLIDE MAP AND INVENTORY

Geomorphological event map



The use of LiDAR was useful for the acquisition of DTM and orthophoto

Regional / national inventory

IFFI Project – Italian landslide inventory

The IFFI Project aims at
•identifying and mapping landslides over the whole Italian territory, based on standardized criteria;
•building up a National Landslide Geographic Information System;
•providing a tool for hazard and risk assessment and land use planning.

528.903 Landslides,
covering an area of almost **22.176 km²**,
which is equivalent to **7,3% of Italy.**

(Inventario dei Fenomeni Franosi in Italia - Progetto IFFI, Report 2015)

Remote sensing systems for landslides mapping

Landslide Recognition			
Method		**RS Tool**	**Authors**
Visual interpretation & geomorphic features extraction	Manual	*Aerial photogrammetry and HR/VHR satellite images*	Marcelino *et al.* 2009 [26]; Tsai *et al.* 2010 [24]; Gao & Maroa, 2010 [27]; Fiorucci *et al.* 2011 [25]; Ghosh *et al.* 2012 [34]; Murillo-García *et al.* 2014 [28]; Dagdelender *et al.* 2014 [51]; Othman & Gloaguen, 2013 [46]
		Laser scanning	Agliardi *et al.* 2009 [103]; Corsini *et al.* 2009 [104]; Oppikofer *et al.* 2009 [105]
	Automated/ Semi-automated	*Aerial photogrammetry*	Eisenbeiss, 2008 [128]; Rau *et al.* 2011 [48]; Wiegand *et al.* 2013 [33]
		HR/VHR satellite images	Cheng *et al.* 2004 [32]; Barlow *et al.* 2006 [23]; Moine *et al.* 2009 [42]; Blaschke, 2010 [40]; Lu *et al.* 2011 [41]; Mondini *et al.* 2011 [47]; Lacroix *et al.* 2013 [38]
		Airborne laser scanning	Chigira *et al.* 2004 [116]; Glenn *et al.* 2006 [107]; Ardizzone *et al.* 2007 [108]; Borlat *et al.* 2007 [109]; Sato *et al.* 2007 [110]; Van Asselen & Seijmonsbergen, 2007 [111]; Booth *et al.* 2009 [114]; Kasai *et al.* 2009 [113]; Bull *et al.* 2010 [115]; Huat *et al.* 2012 [118]; Rau *et al.* 2012 [117]; Tarolli *et al.* 2012 [112]

(Scaioni et al, 2014)

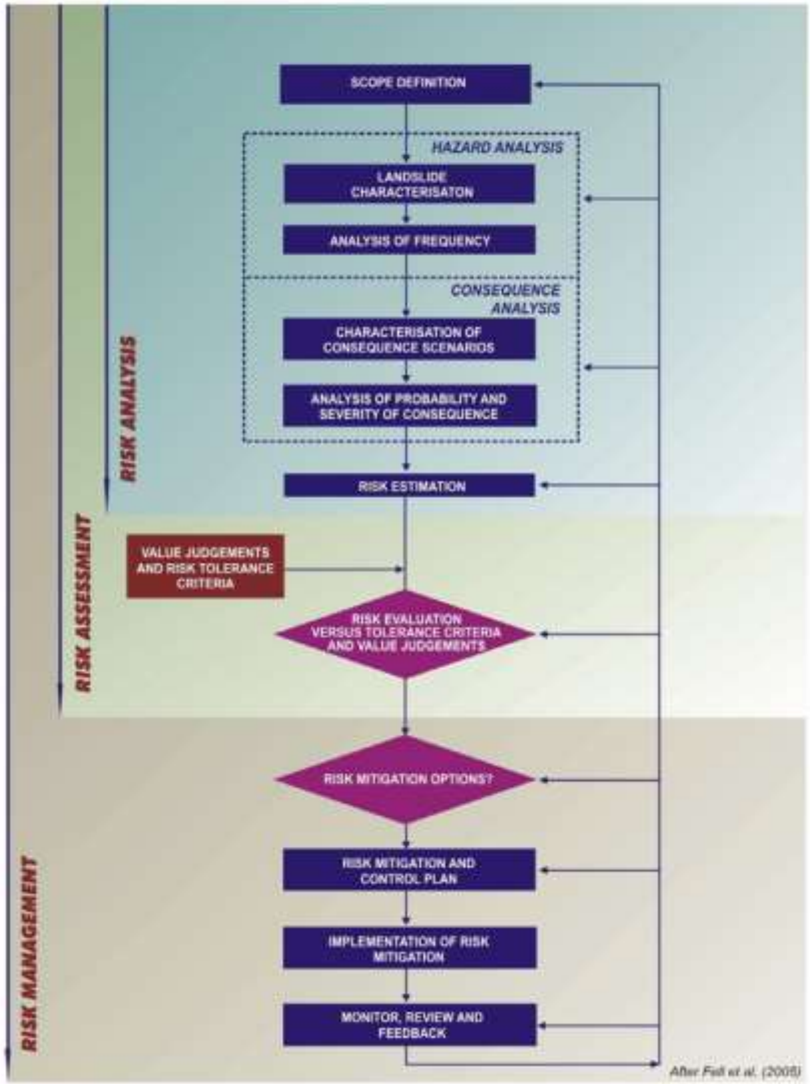
LANDSLIDE MAP AND INVENTORY

Remote sensing systems for landslides mapping

Landslide Recognition			
Method		**RS Tool**	**Authors**
Visual interpretation & geomorphic features extraction	Automated/ Semi-automated	*Terrestrial laser scanning*	Rosser *et al.* 2005 [120]; Lim *et al.* 2005 [121]; Squarzoni *et al.* 2008 [75]; Oppikofer *et al.* 2009 [105,123]; Abellán *et al.* 2010 [122]; Stock *et al.* 2011 [129]; Jaboyedoff *et al.* 2012 [95]; Longoni *et al.* 2012 [119]; Viero *et al.* 2012 [125]; Pesci *et al.* 2012 [126]
Stereovision		*HR/VHR satellite images*	Haeberlin *et al.* 2004 [54]; Bajracharya & Bajracharya, 2008 [55]; Alkevli & Ercanoglu, 2011 [56]
SAR Interferometry		*Spaceborne InSAR*	Ferretti *et al.* 2001 [80]; Farina *et al.* 2006 [87]; Reidel & Walter, 2008 [88]; Guzzetti *et al.* 2009 [89]; Lauknes *et al.* 2010 [92]; Yonezawa *et al.* 2012 [78]; Hölbling *et al.* 2012 [90]; Lu *et al.* 2012 [91]; Righini *et al.* 2012 [86]; Lu *et al.* 2014 [93]

(Scaioni et al, 2014)

LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING



• **Landslide Susceptibility.** A quantitative or qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding.

• **Hazard.** A condition with the potential for causing an undesirable consequence. The description of landslide hazard should include the location, volume (or area), classification and velocity of the potential landslides and any resultant detached material and the probability of their occurrence within a given period of time. Landslide hazard includes landslides which have their source in the area or may have their source outside the area but may travel on to or regress into the area.

• **Risk**. A measure of the probability and severity of an adverse effect to health, property or the environment. Risk is often estimated by the product of probability and consequences. However, a more general interpretation of risk involves a comparison of the probability and consequences in a non-product form.

(a) *For life loss*, the annual probability that the person most at risk will lose his or her life taking account of the landslide hazard and the temporal spatial probability and vulnerability of the person.

(b) *For property loss*, the annual probability of the consequence or the annualised loss taking account of the elements at risk, their temporal spatial probability and vulnerability.

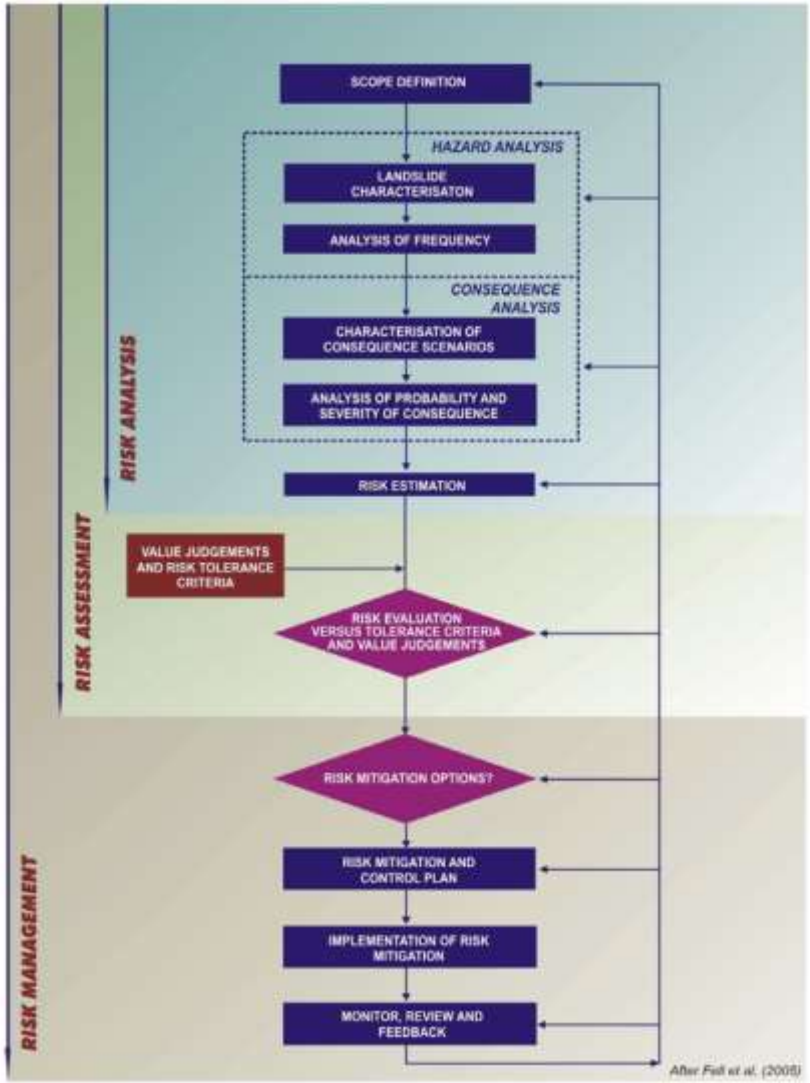
• **Elements at Risk.** The population, buildings and engineering works, economic activities, public services utilities, infrastructure and environmental features in the area potentially affected by the landslide hazard.

• **Vulnerability.** The degree of loss to a given element or set of elements within the area affected by the landslide hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss). For property, the loss will be the value of the damage relative to the value of the property; for persons, it will be the probability that a particular life (the element at risk) will be lost, given the person(s) is (are) affected by the landslide.

• **Zoning.** The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide Susceptibility, hazard or risk.

Journal and News of the Australian Geomechanics Society
Volume 42 No 1 March 2007

LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING



Landslide Susceptibility Zoning involves the classification, volume (or area) and spatial distribution of existing and potential landslides in the study area. It may also include a description of the travel distance, velocity and intensity of the existing or potential landsliding. Landslide susceptibility zoning usually involves developing an inventory of landslides which have occurred in the past together with an assessment of the areas with a potential to experience landsliding in the future, but with no assessment of the frequency (annual probability) of the occurrence of landslides. In some situations susceptibility zoning will need to be extended outside the study area being zoned for hazard and risk to cover areas from which landslides may travel on to or regress into the area being zoned. It will generally be necessary to prepare separate susceptibility zoning maps to show landslide sources and areas onto which landslides from the source landslides may travel or regress.

Landslide Hazard Zoning takes the outcomes of landslide susceptibility mapping, and assigns an estimated frequency (annual probability) to the potential landslides. It should consider all landsliding which can affect the study area including landslides which are above the study area but may travel onto it and landslides below the study area which may retrogressively fail up-slope into it. The hazard may be expressed as the frequency of a particular type of landslide of a certain volume or landslides of a particular type, volume and velocity (which may vary with distance from the landslide source) or, in some cases, as the frequency of landslides with a particular intensity where intensity may be measures in kinetic energy terms. Intensity measures are most useful for rock falls.

Landslide Risk Zoning takes the outcomes of hazard mapping and assesses the potential damage to persons (annual probability the person most at risk loses his or her life) and to property (annual value of property loss) for the elements at risk, accounting for temporal and spatial probability and vulnerability.

Journal and News of the Australian Geomechanics Society
Volume 42 No 1 March 2007

Landslide zoning mapping scales and their application

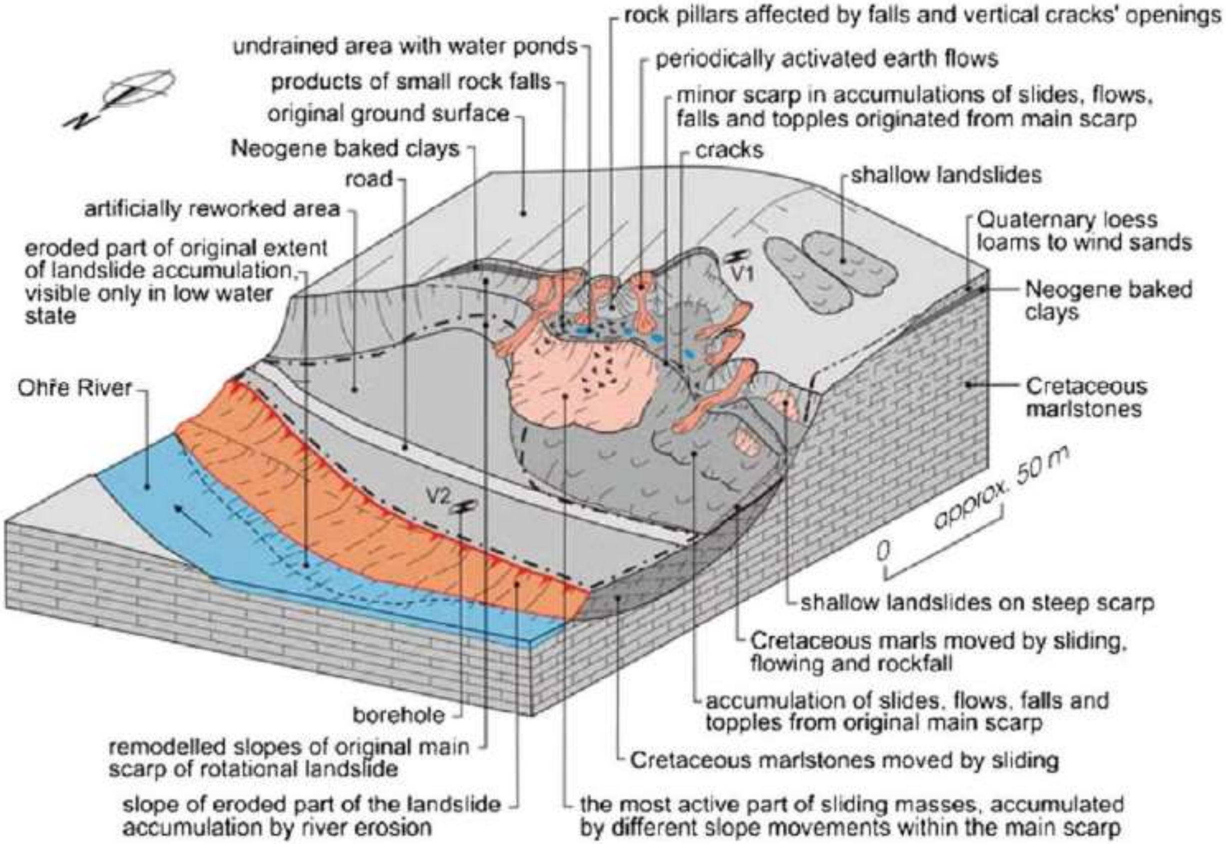
Scale Description	Indicative Range of Scales	Examples of Zoning Application	Typical Area of Zoning
Small	< 1:100,000	Landslide inventory and susceptibility to inform policy makers and the general public	>10,000 square kilometres
Medium	1:100,000 to 1:25,000	Landslide inventory and susceptibility zoning for regional and local development or very large scale engineering projects. Preliminary level hazard mapping for local areas	1000 – 10,000 square kilometres
Large	1:25,000 to 1:5,000	Landslide inventory, susceptibility and hazard zoning for local areas Preliminary level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways	10-1000 square kilometres
Detailed	> 5,000	Intermediate and advanced level hazard and risk zoning for local and site specific areas and for the design phase of large engineering structures, roads and railways	Several hectares to tens of square kilometres

For further information: GUIDELINE FOR LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING (https://landsliderisk.org/resources/guidelines/)

Journal and News of the Australian Geomechanics Society Volume 42 No 1 March 2007

LANDSLIDE SUSCEPTIBILITY, HAZARD AND RISK ZONING

CONCEPTUAL ENGINEERING GEOLOGICAL MODEL



Observational model of the Březno landslide in Cretaceous marlstones

(Jan Novotný, 2014)

Combining geological, geomorphological, hydrological, and geotechnical data we can obtain an engineering geological model

LANDSLIDE CHARACTERIZATION AND MONITORING

LANDSLIDE CHARACTERIZATION AND MONITORING

Two main approaches to landslides monitoring:

(1) the qualitative assessment of the general conditions of a landslide-prone slope along time;

(2) the quantitative measurement of ground deformation and surface point displacements (also addressed as deformation measurement), variation of geotechnical or geophysical parameters, measurement of water table level…

Angeli, M.; Pasuto, A.; Silvano, S. A critical review of landslide monitoring experiences. Eng. Geol. 2000, 55, 133–147

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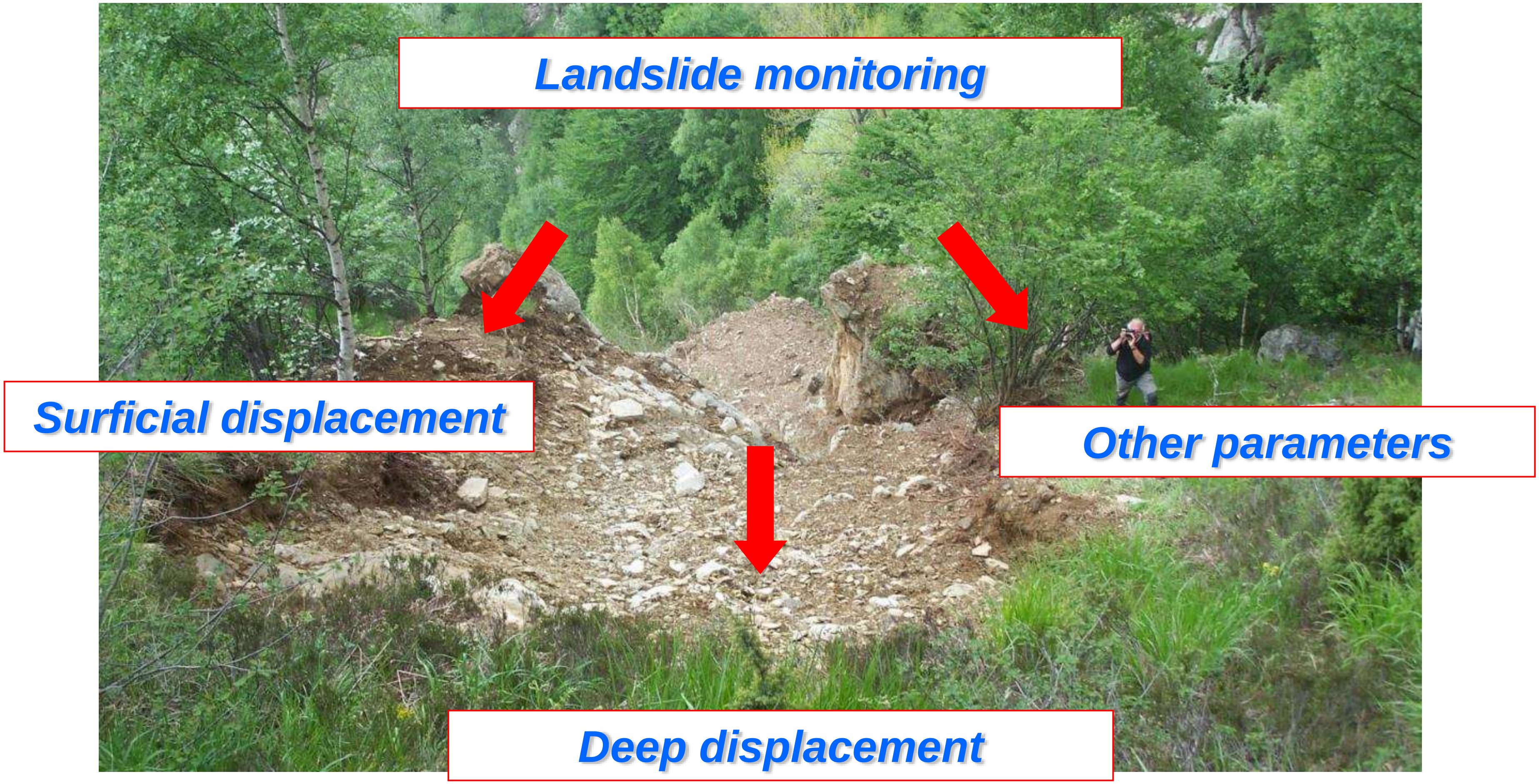
LANDSLIDE CHARACTERIZATION AND MONITORING



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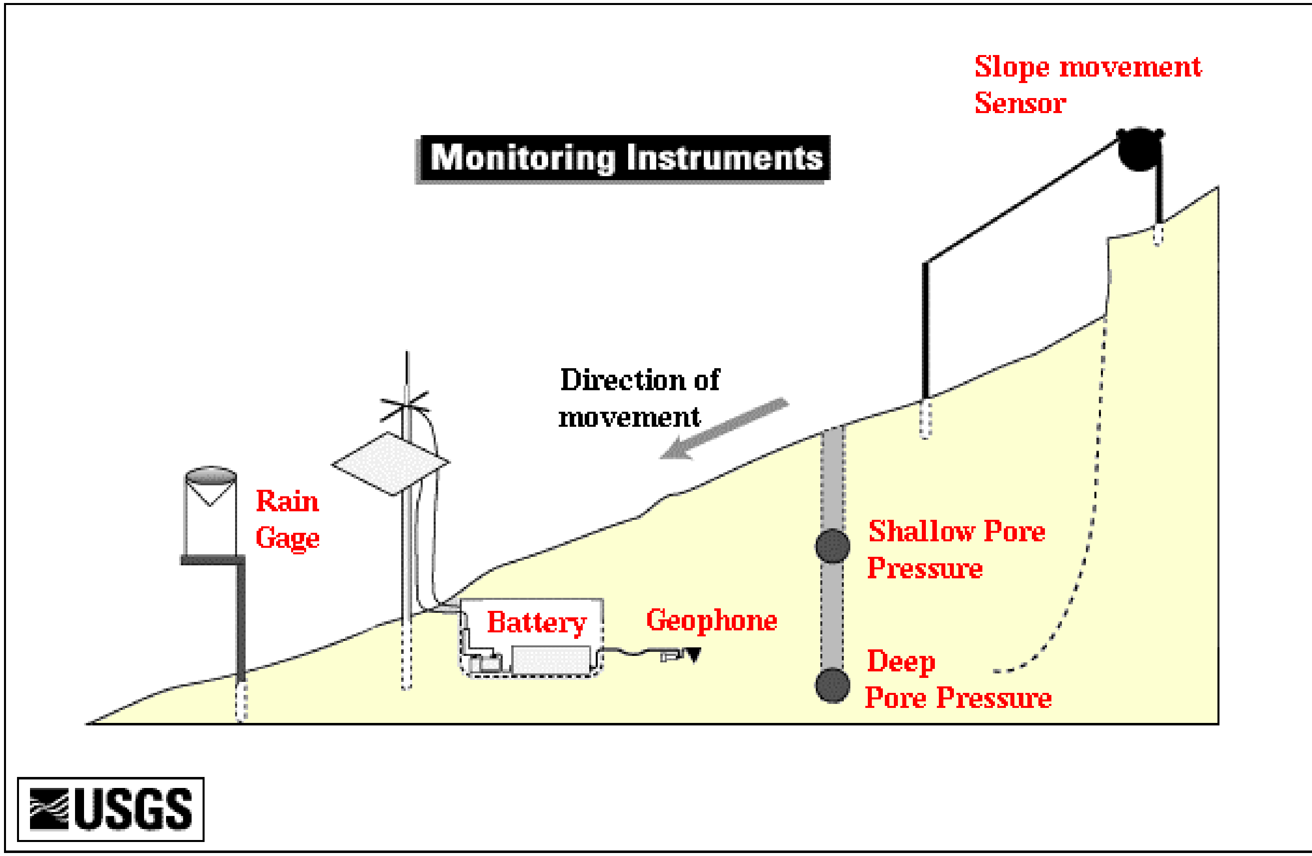
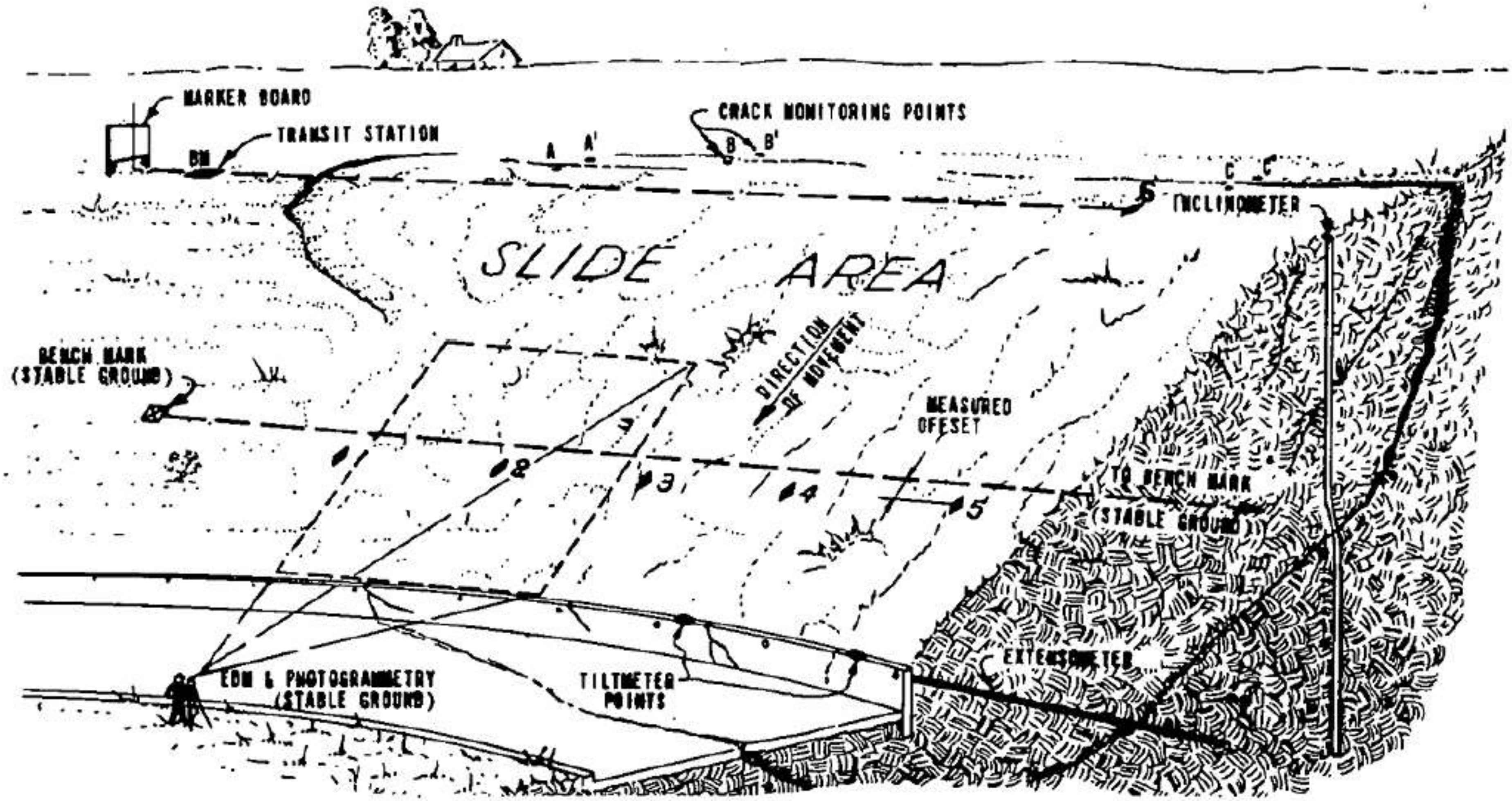
"Every instrument on a project should be selected and placed to assist with answering a specific <u>question</u>:
if there is no question, there should be no instrumentation"

John Duncliff

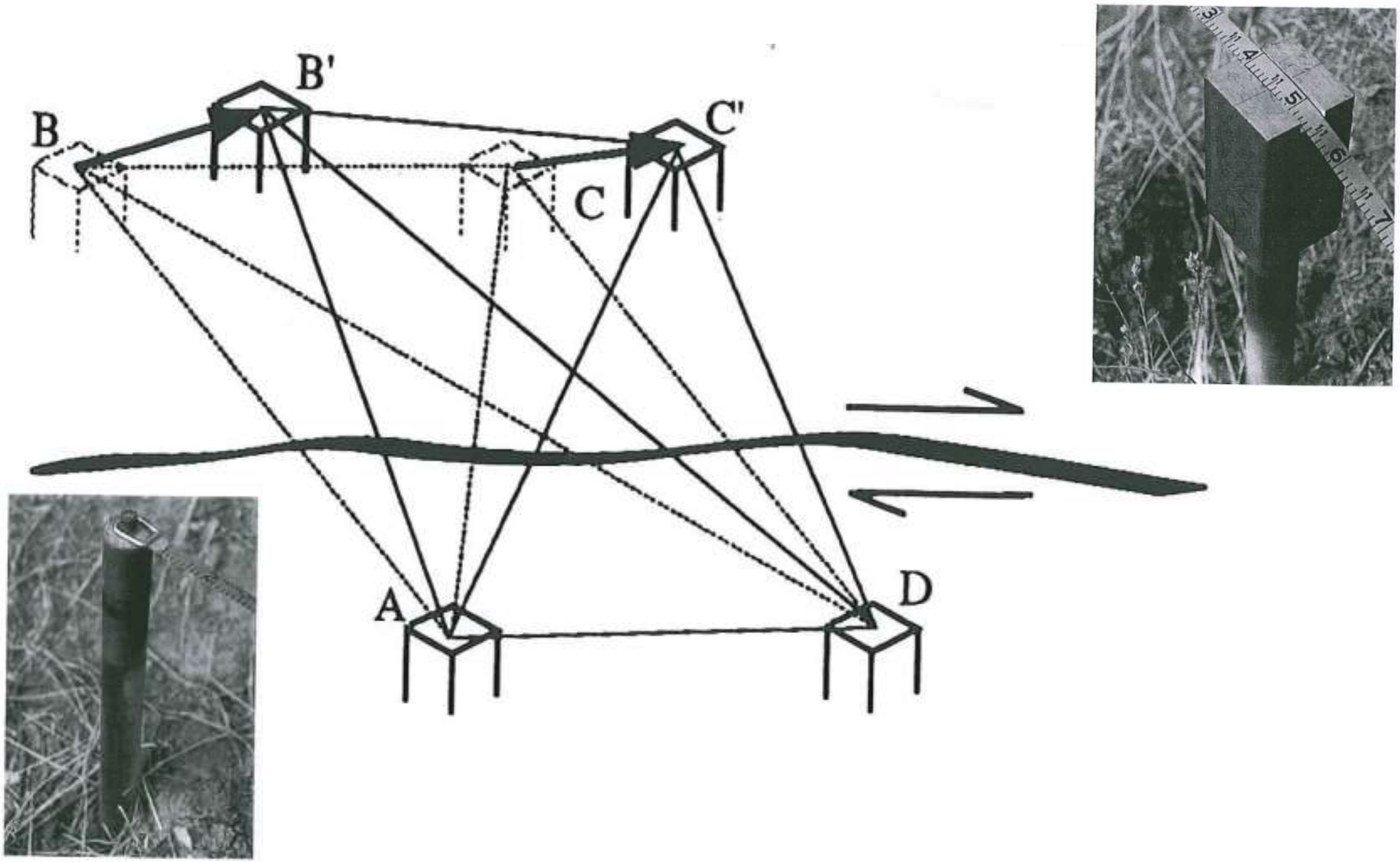
LANDSLIDE MONITORING



LANDSLIDE CHARACTERIZATION AND MONITORING



LANDSLIDE CHARACTERIZATION AND MONITORING



Unmanned Aerial Vehicles

Remotely Piloted Aerial Systems

Drones

D. Giordan, Y. Hayakawa, F. Nex, F. Remondino, P. Tarolli. 2018 Review article: the use of remotely piloted aircraft systems (RPASs) for natural hazards monitoring and management. Nat. Hazards Earth Syst. Sci., 18, 1079–1096

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LANDSLIDE CHARACTERIZATION AND MONITORING

GMG UAV

DJI
PHANTOM 4

DJI
PHANTOM 4 PRO

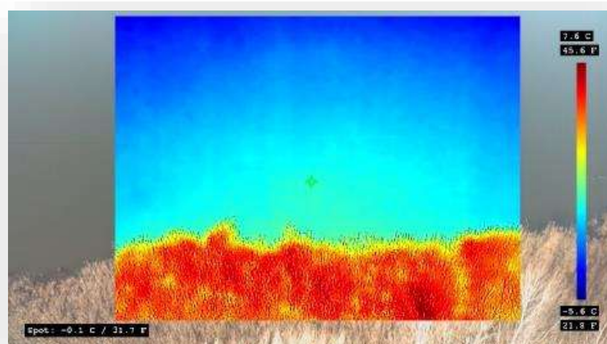
SENSEFLY
ALBRIS

CNR - T

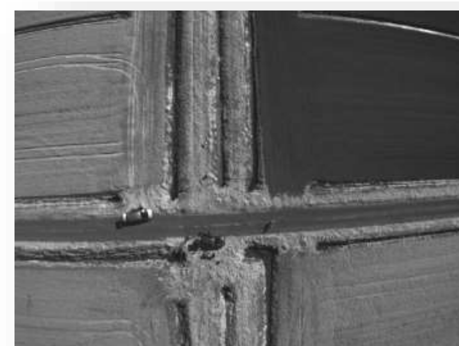
CNR - M

Used sensors

optical



thermal



Multi-spectral

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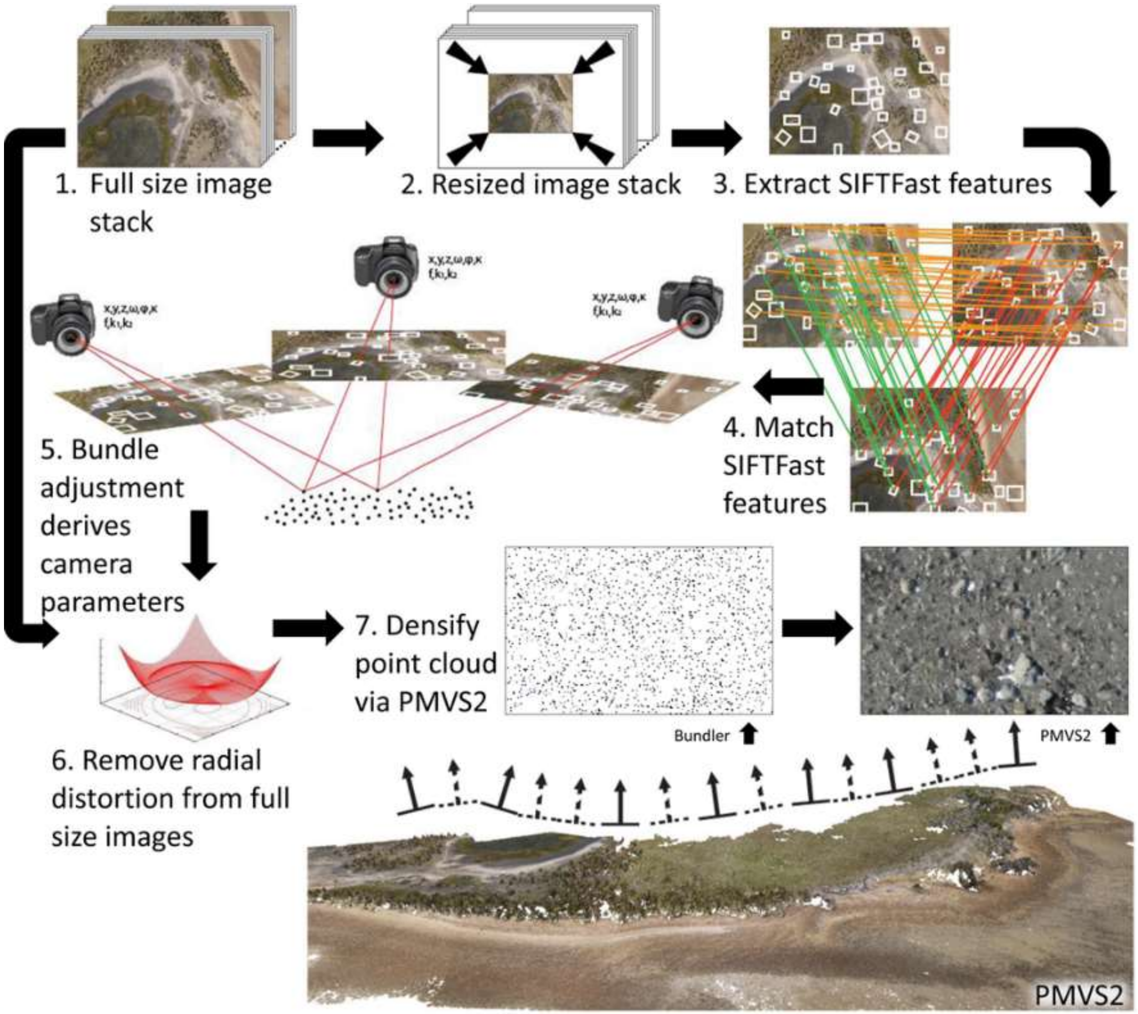
LANDSLIDE CHARACTERIZATION AND MONITORING

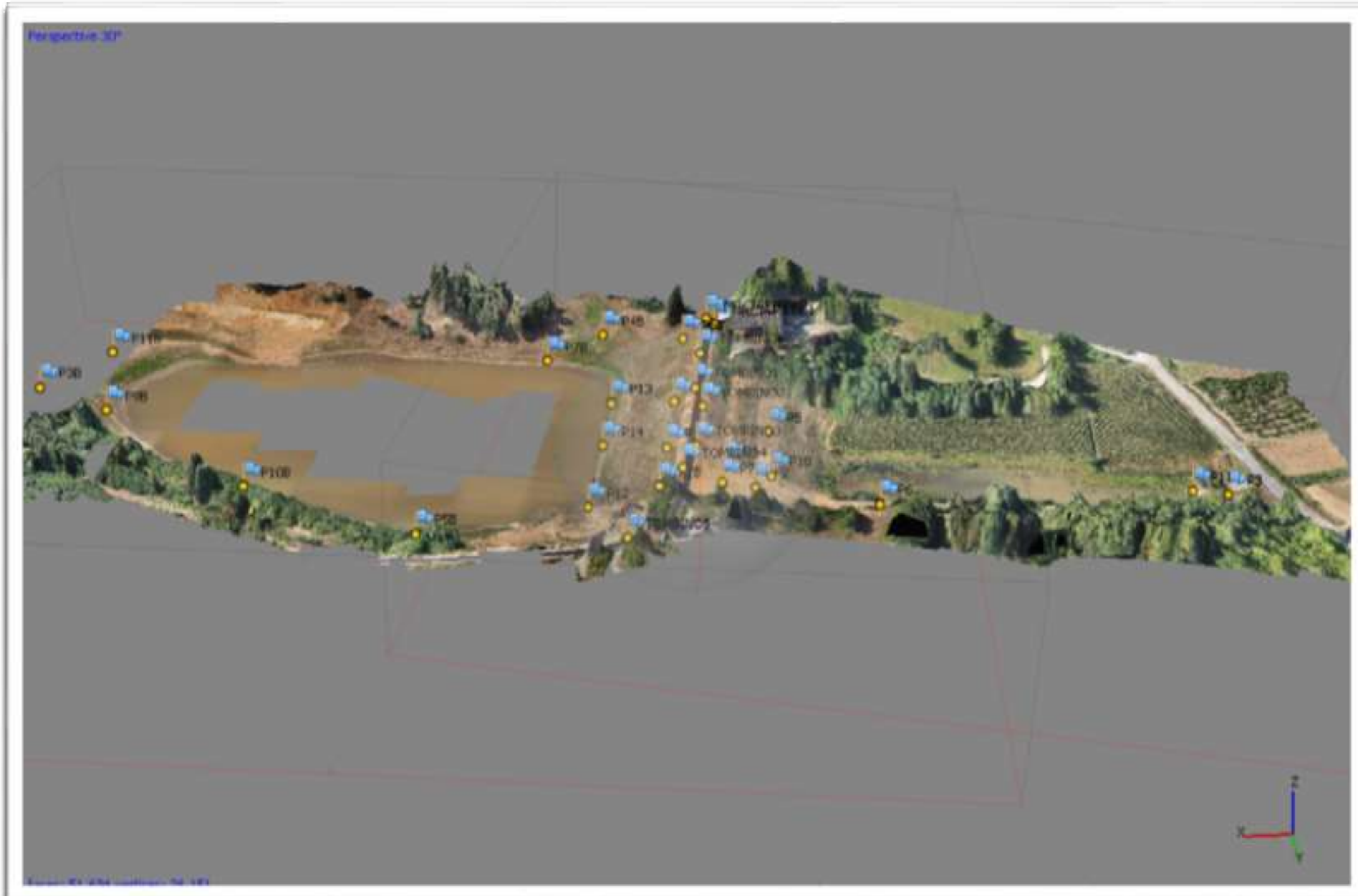
UAV and STRUCTURE FROM MOTION



Steve Harwin * and Arko Lucieer
Assessing the Accuracy of Georeferenced Point Clouds Produced via Multi-View Stereopsis from Unmanned Aerial Vehicle (UAV) Imagery. *Remote Sensing* 2012, *4*(6), 1573-1599

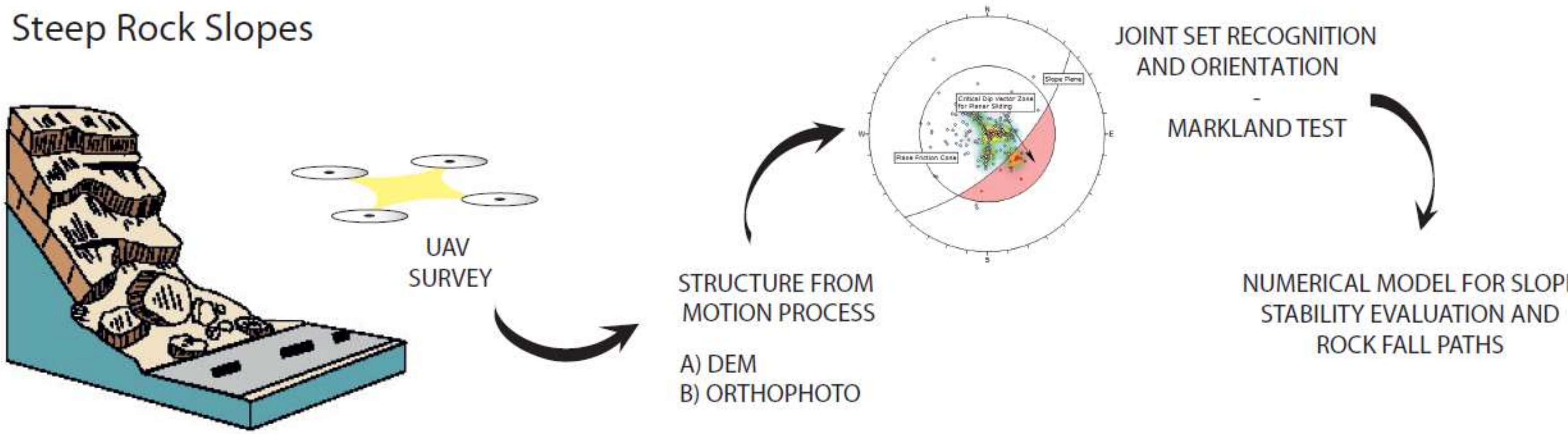
LANDSLIDE CHARACTERIZATION AND MONITORING

UAV and STRUCTURE FROM MOTION

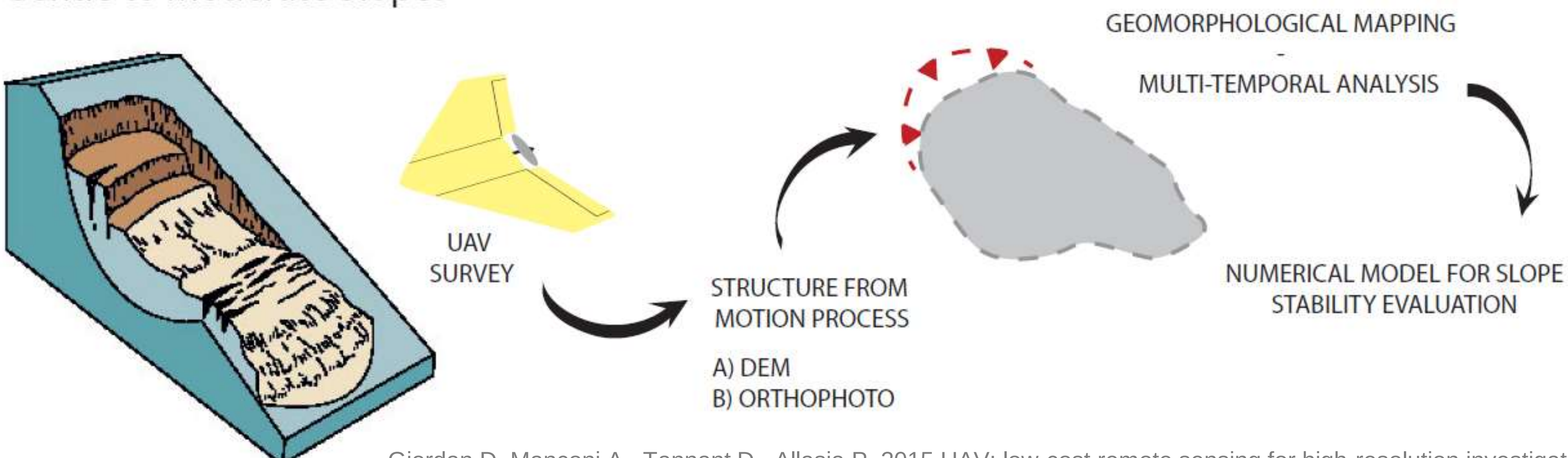


LANDSLIDES INVESTIGATION WORKFLOW

Steep Rock Slopes



Gentle to Moderate Slopes



Giordan D. Manconi A., Tannant D., Allasia P. 2015 UAV: low-cost remote sensing for high-resolution investigation of landslides. Geoscience and Remote Sensing Symposium (IGARSS), 2015 IEEE International, 5344-5347.

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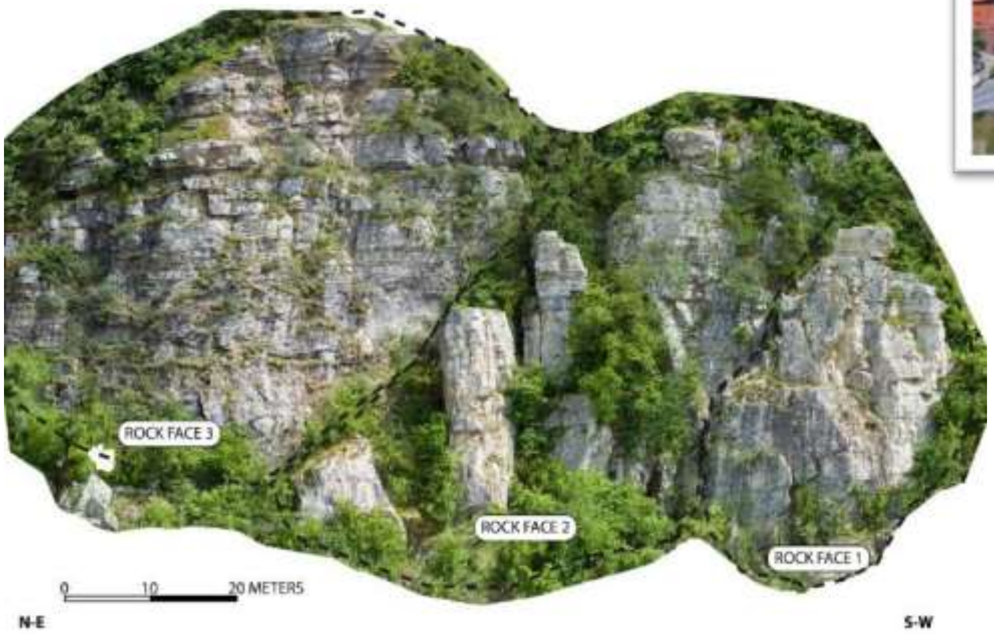
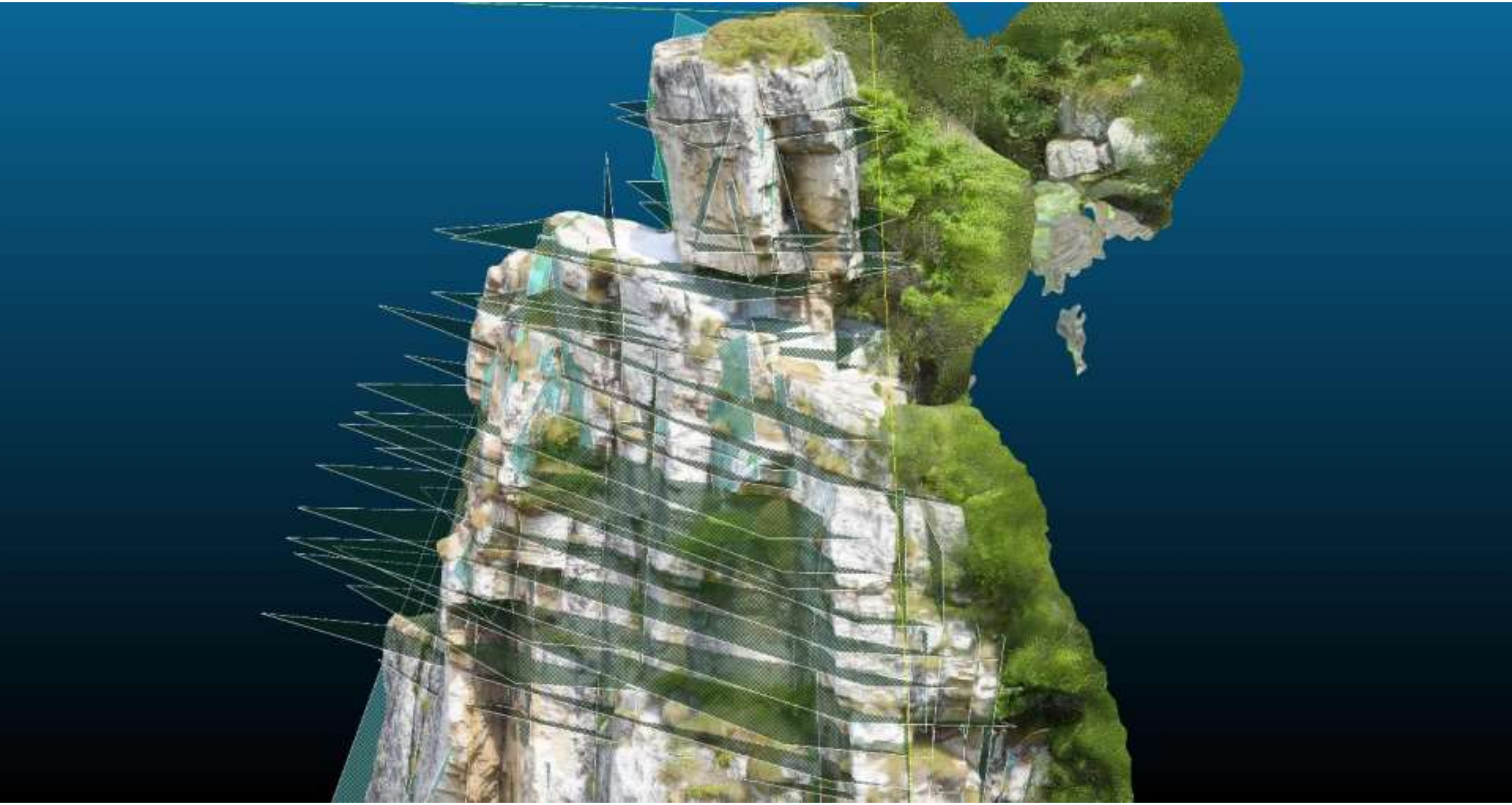
Ormea rock falls prone area



Menegoni N., Giordan D., Perotti C., Tannant D. 2019. Detection and geometric characterization of rock mass discontinuities using a 3D high-resolution digital outcrop model generated from RPAS imagery – Ormea rock slope, Italy. Engineering Geology, 252, 145-163

Ormea rock fall prone area



ROCK FACE 1: **Width: 30 m**
Height: 60 m

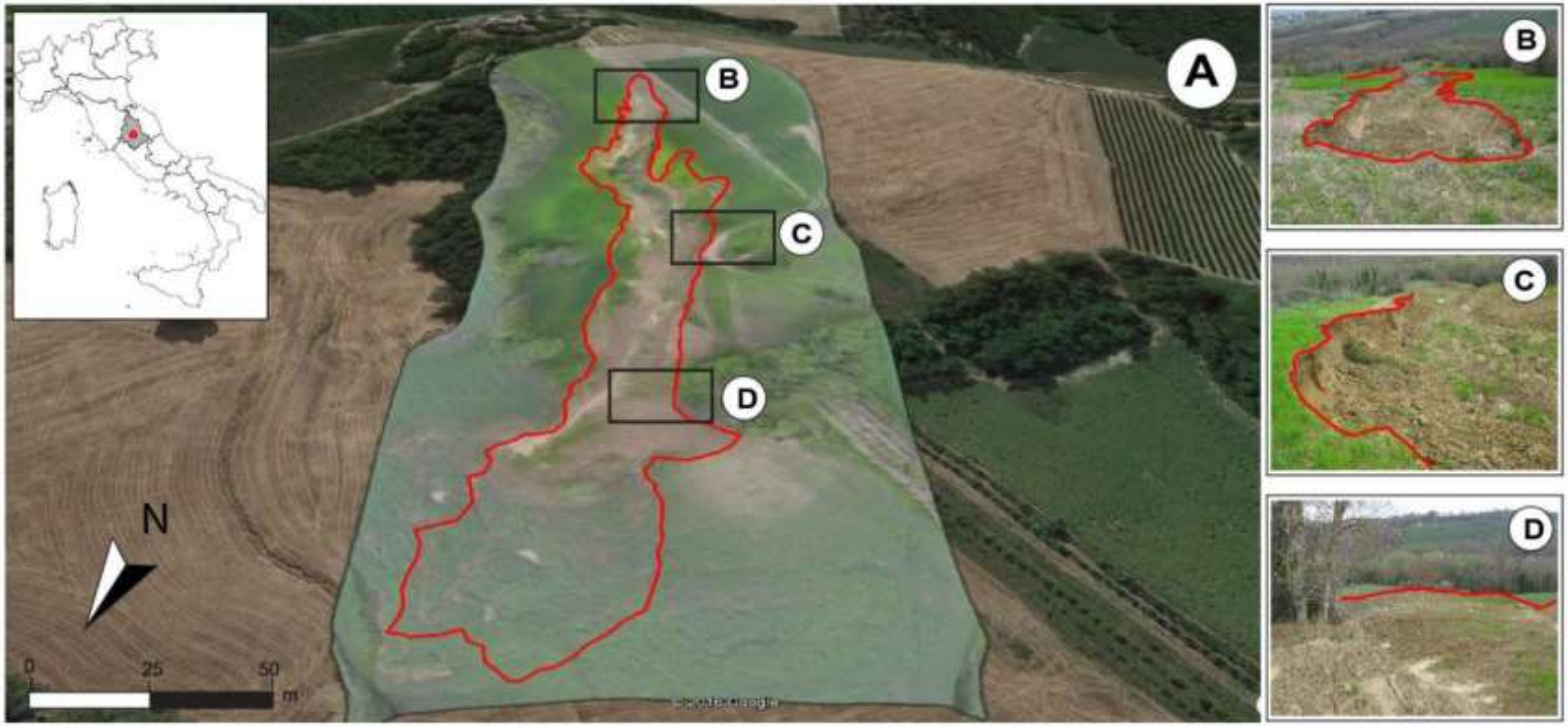
192 discontinuities + bedding measures

Collazzone slide-earthflow case study

A 'typical' slide-earthflow of central Italian Appenine activated during the flood of March 2014

F. Fiorucci, D. Giordan, M. Santangelo, F. Dutto, M. Rossi, F. Guzzetti. 2018. Criteria for the optimal selection of remote sensing optical images to map event landslides. Nat. Hazards Earth Syst. Sci., 18, 405-417

Collazzone slide-earthflow case study



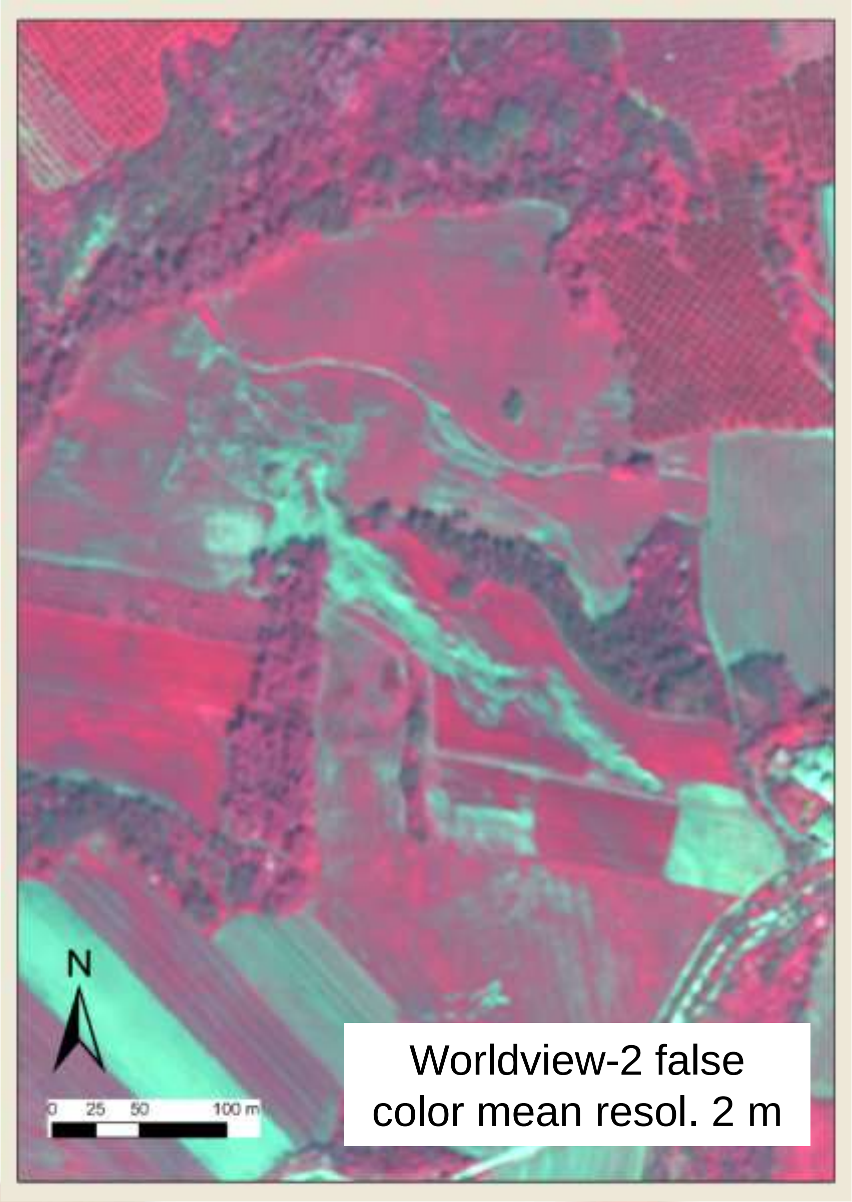
We chose this landslide to test the best solution for the earthflow mapping:

i) UAV
ii) Satellite image (Worldview II)
iii) Field geomorphological mapping
iv) GPS RTK
v) (LiDAR)

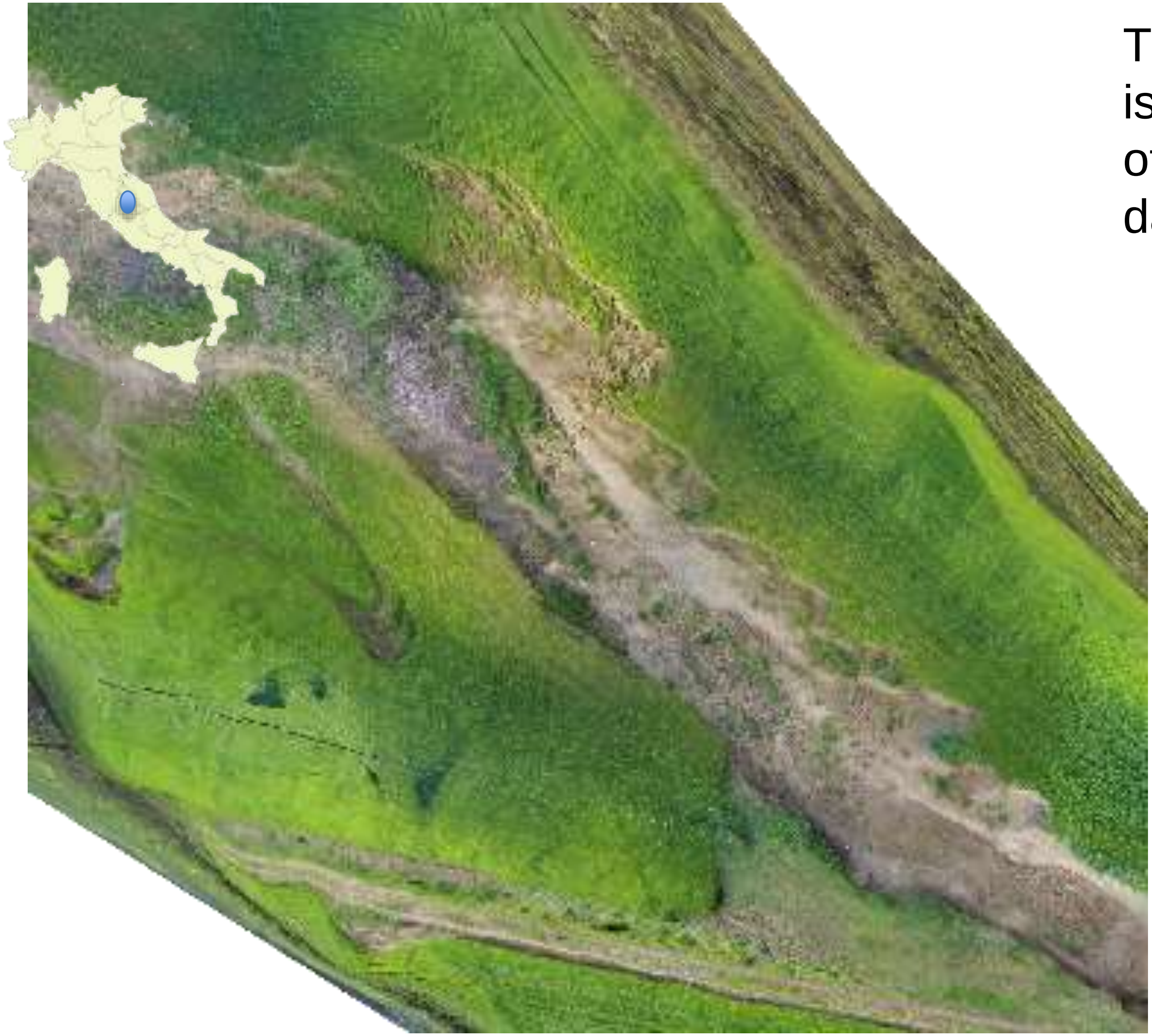
Collazzone slide-earthflow case study

GPS RTK survey of the Collazzone landslide is considered the benchmark

Collazzone slide-earthflow case study



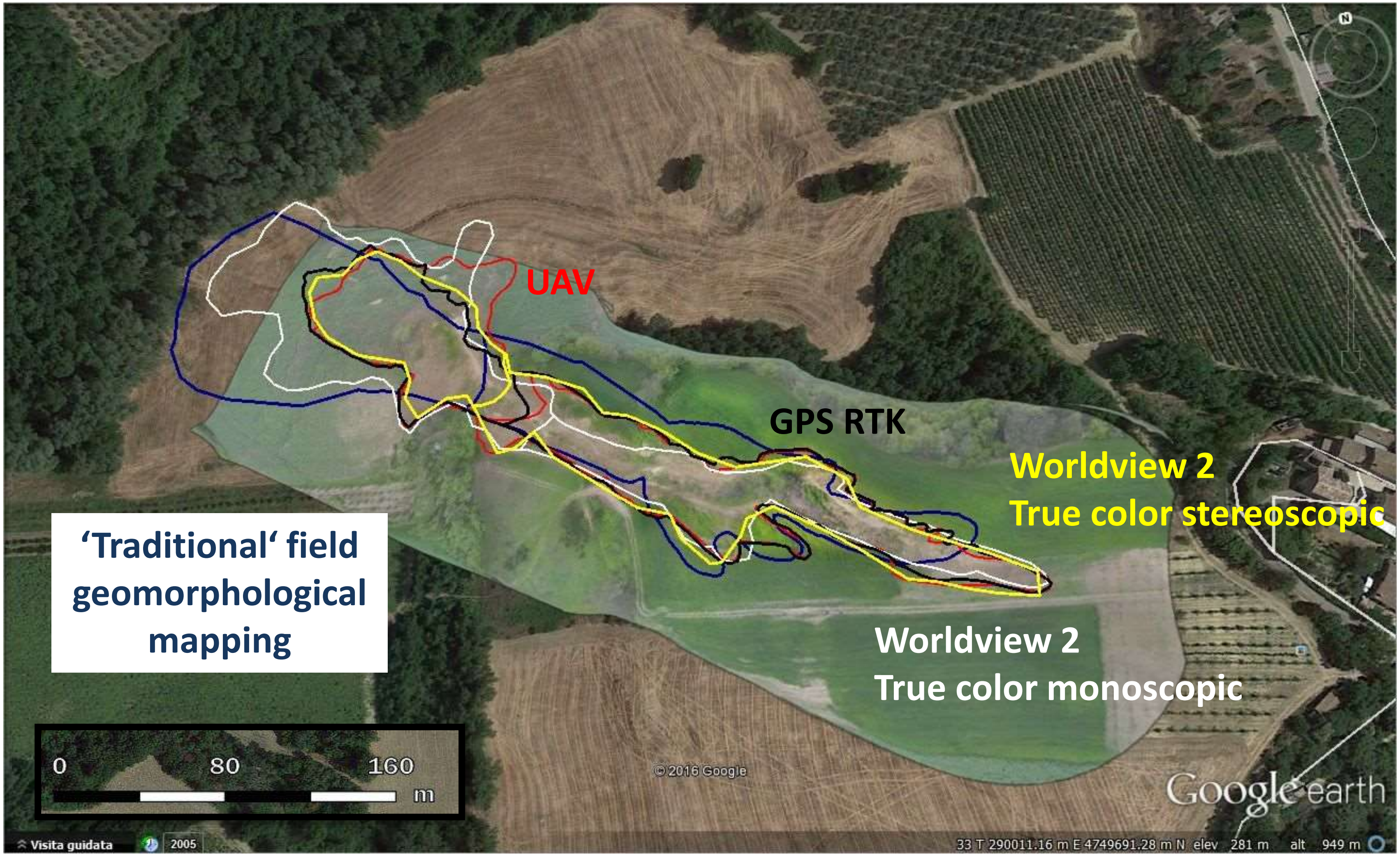
Collazzone slide-earthflow case study



The resolution of UAV is higher than the other available datasets (3 cm/pixel)

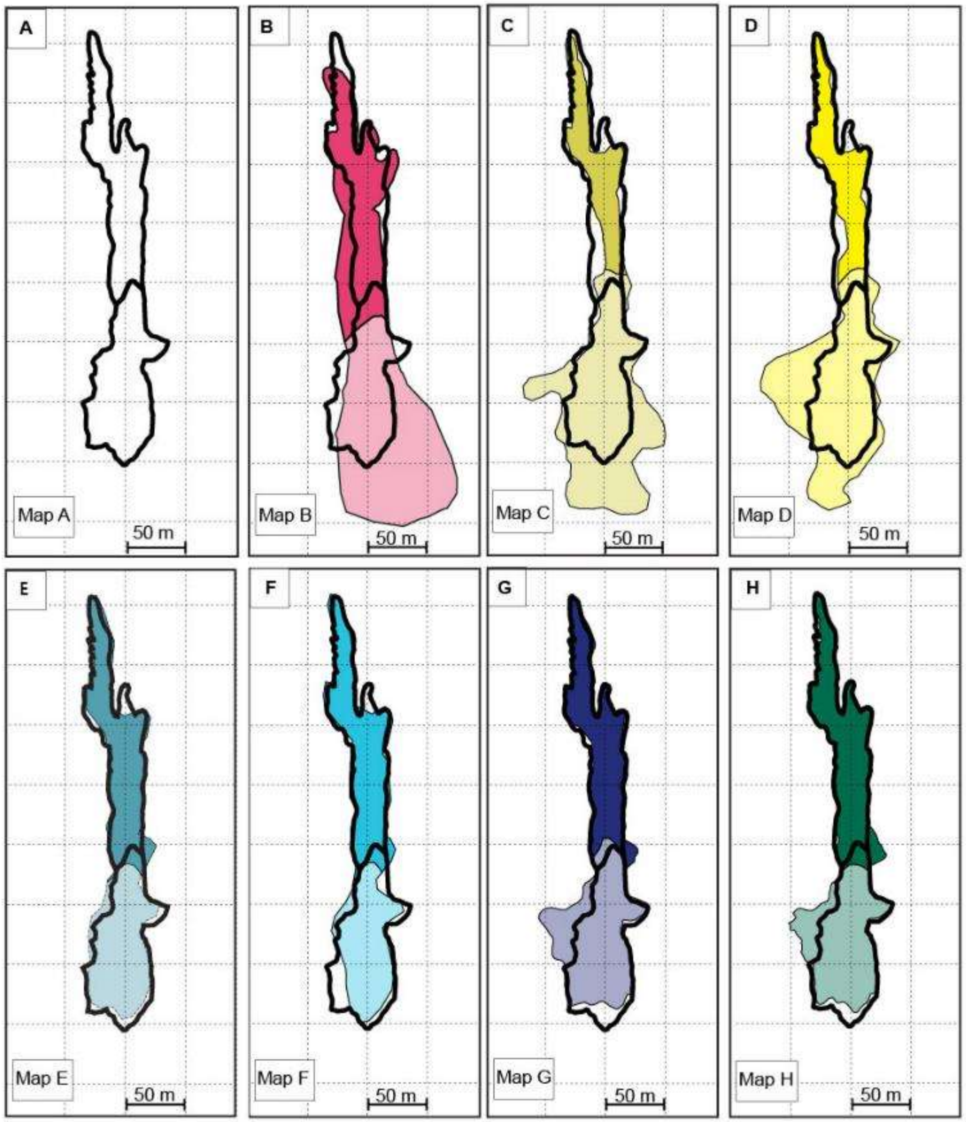
UAV image is the only one that could be used for the identification of landslide's morphological features

Collazzone slide-earthflow case study



GEOHAZARD MONITORING GROUP

Collazzone slide-earthflow case study



A - GPS RTK – benchmark
B - Field survey
C - True-colour WordView-2 Monoscopic view
D - False-5 colour-composite WordView-2 Monoscopic view
E - True-colour WordView-2 Stereoscopic view
F - False-5 colour-composite WordView-2 Stereoscopic view
G - UAV ultra-high resolution Monoscopic
H - UAV ultra-high resolution Speudo stereoscopic

Collazzone slide-earthflow case study

				Map A	Map B	Map C	Map D	Map E	Map F	Map G	Map H
Field mapping		RTK	Map A		0.55	0.45	0.40	0.18	0.20	0.19	0.19
		VIS	Map B			0.45	0.57	0.57	0.57	0.59	0.59
Expert visual interpretation	WolrdView 2D	TC	Map C				0.29	0.48	0.50	0.46	0.47
		FCC	Map D					0.42	0.44	0.35	0.37
	WolrdView 3D	TC	Map E						0.15	0.21	0.20
		FCC	Map F							0.26	0.25
	UAV 2D	TC	Map G								0.08
	UAV 2.5D	TC	Map H								

Entire landslide

A - GPS RTK – benchmark
B - Field survey
C - True-colour WordView-2 Monoscopic view
D - False-5 colour-composite WordView-2 Monoscopic view
E - True-colour WordView-2 Stereoscopic view
F - False-5 colour-composite WordView-2 Stereoscopic view
G - UAV ultra-high resolution Monoscopic
H - UAV ultra-high resolution Speudo stereoscopic

Best performance

$$E = \frac{(A_{L1} \cup A_{L2}) - (A_{L1} \cap A_{L2})}{(A_{L1} \cup A_{L2})}\,;\ 0 \leq E \leq 1,$$

Error indexing (Carrara et alii., 1992)

1- True-colour WordView-2 Stereoscopic view

2 - UAV ultra-high resolution

San Germano rock-slide case study

The history of a real emergency application

Giordan D., Manconi A., Facello A., Baldo M., Dell'Anese F., Allasia P., Dutto F. 2015 Brief Communication: The use of an unmanned aerial vehicle in a rockfall emergency scenario. Nat. Hazards Earth Syst. Sci., 15, 163–169.

San Germano rock-slide case study

The history of a real emergency application

San Germano rock-slide case study

Before the rock-slide: videos and images were used to support local authorities decisions to close the road and isolate the Pramollo municipality

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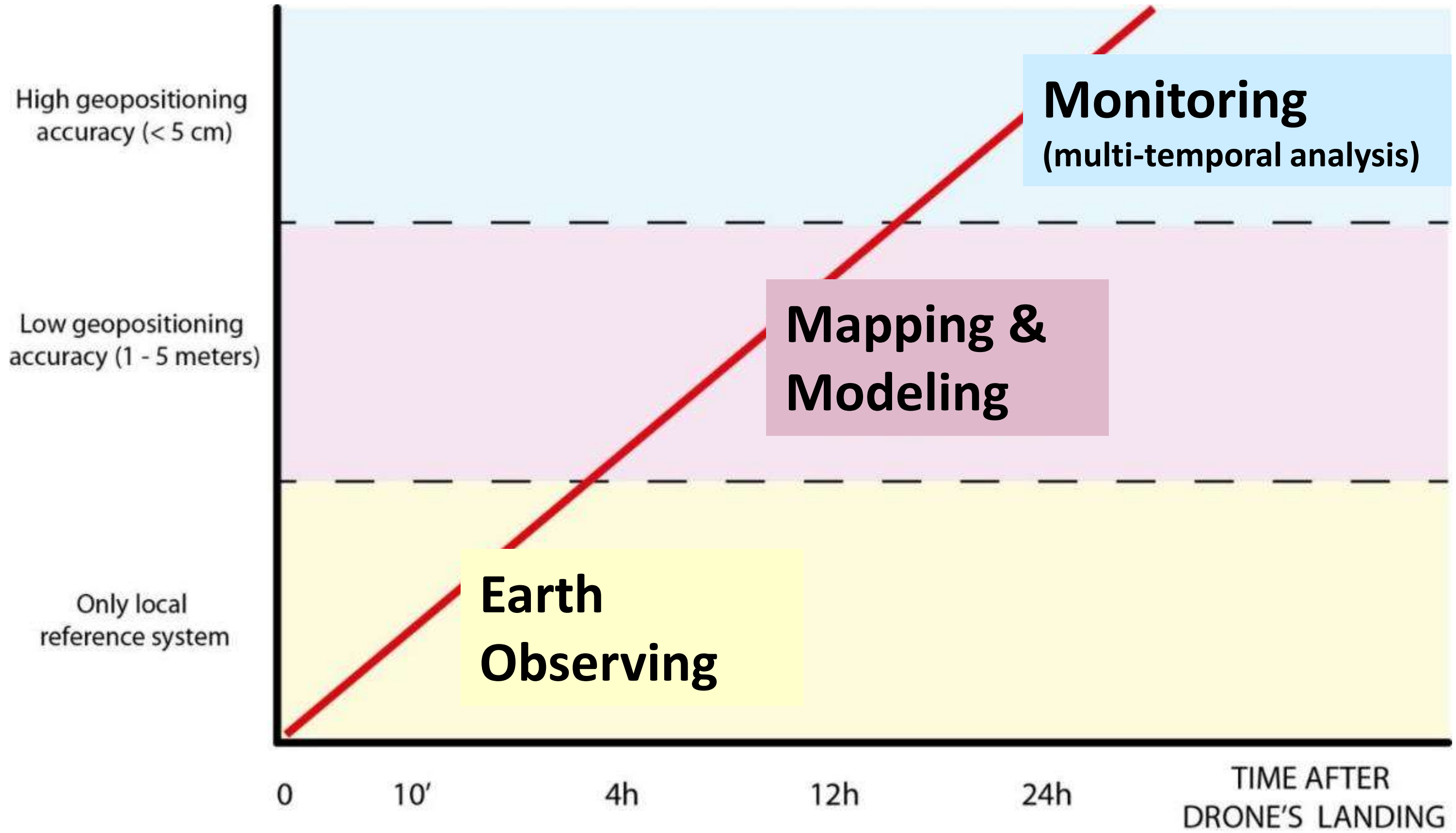
San Germano rock-slide case study

San Germano rock-slide case study

After the rock-slide: images used for a first damages evaluation and to support remedial works

LANDSLIDE CHARACTERIZATION AND MONITORING

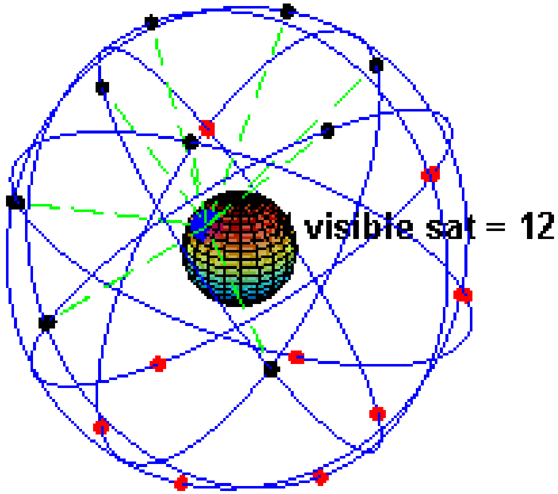
For the use of UAV (in particular during emergencies) it is important to consider not only RESULTS but also the TIME



D. Giordan, A. Manconi, A. Facello, M. Baldo, F. dell'Anese, P. Allasia, and F. Dutto. Brief Communication "The use of UAV in rock fall emergency scenario" Nat. Hazards Earth Syst. Sci. Discuss., 15, 1639-1644, 2015

GNSS – global navigation satellite system

The **global navigation satellite system** (**GNSS**), is a global navigation satellite system that provides geolocation and time information to a GNSS receiver anywhere on or near the Earth where there is an unobstructed line of sight to four or more GNSS satellites. The GNSS concept is based on time and the known position of GNSS specialized satellites. The satellites carry very stable atomic clocks that are synchronized with one another and with the ground clocks. In the same manner, the satellite locations are known with great precision. GNSS satellites continuously transmit data about their current time and position. A GNSS receiver monitors multiple satellites and solves equations to determine the precise position of the receiver and its deviation from true time.

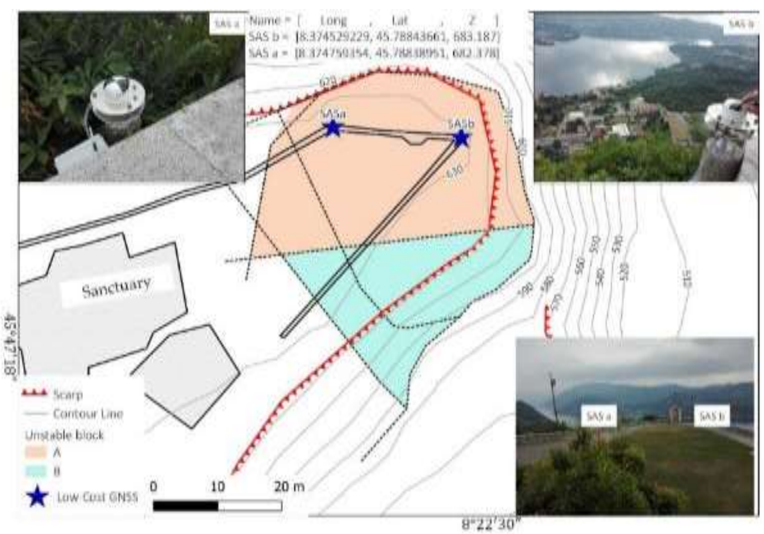


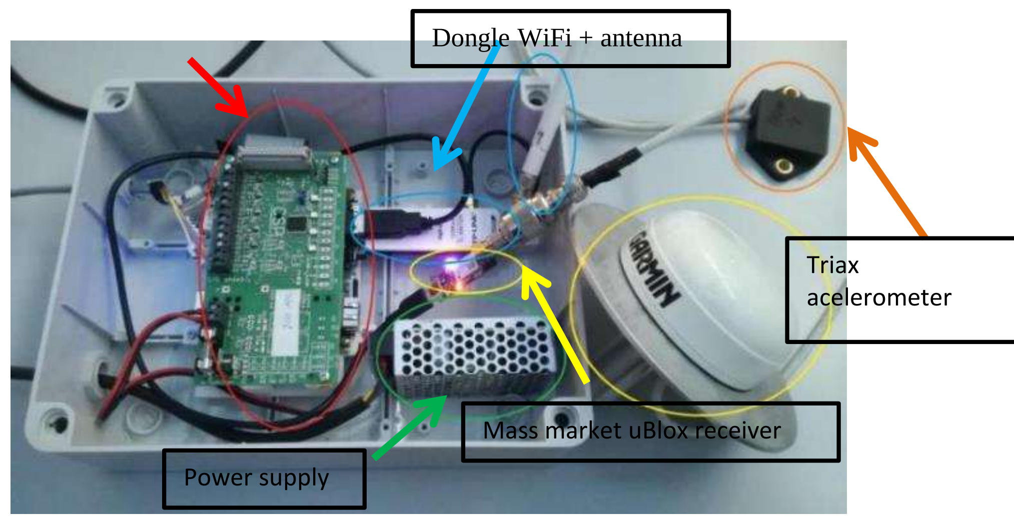
wikipedia

LANDSLIDE CHARACTERIZATION AND MONITORING

Madonna del Sasso Sanctuary
GNSS low cost monitoring solution

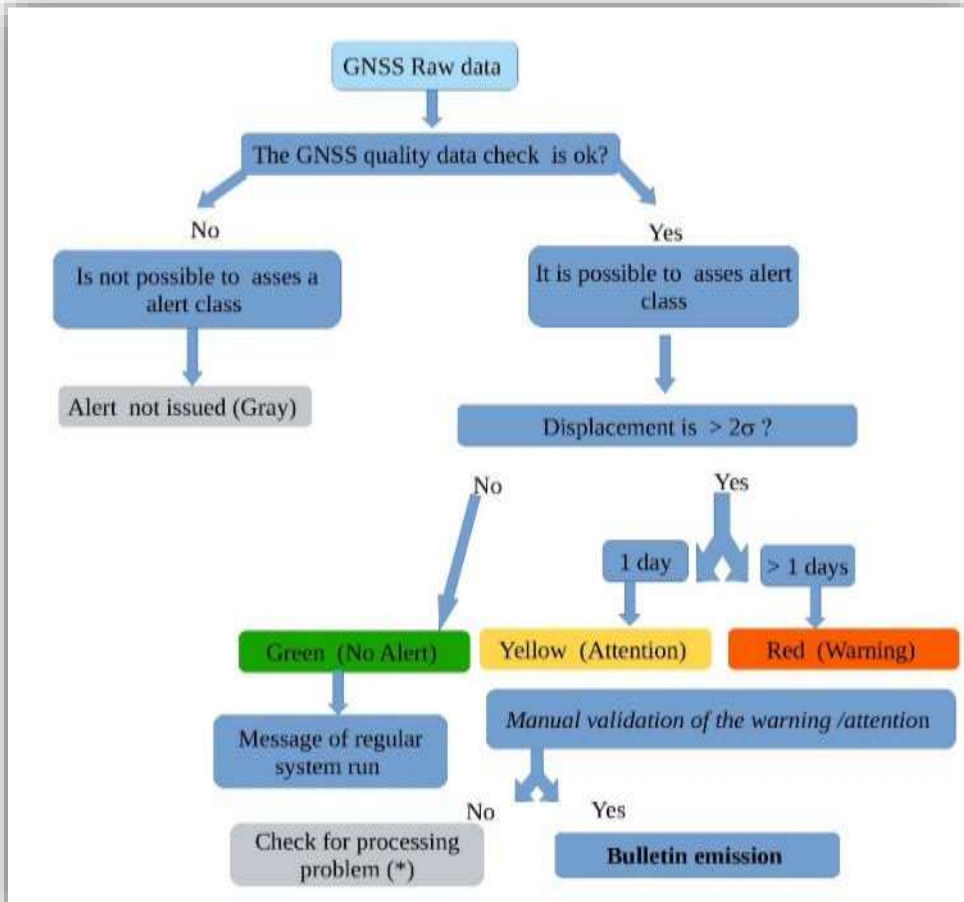
Instrument	Unit Cost
GNSS uBlox L1	70 €
Garmin antenna	50 €
Tri-axial accelerometer + temperature sensor	150 €
Micro PC mainboard, plastic box and dongle Wi-Fi	200 €
batch procedure RTKlib per RT e PP from NRTK SPIN	free

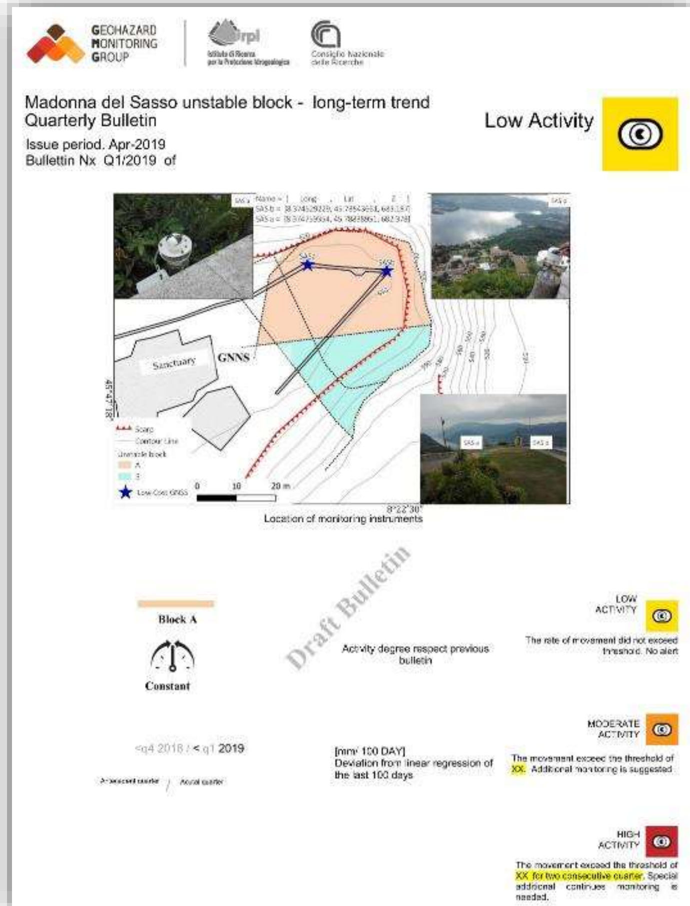




LANDSLIDE CHARACTERIZATION AND MONITORING

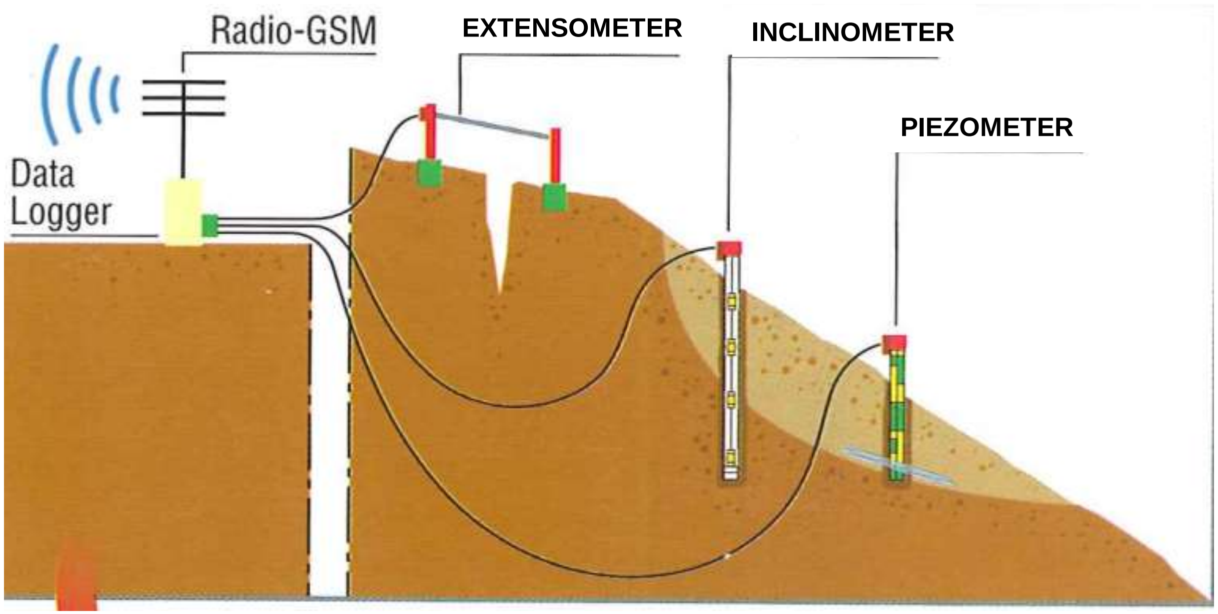
Madonna del Sasso Sanctuary
GNSS low cost monitoring solution





LANDSLIDE CHARACTERIZATION AND MONITORING

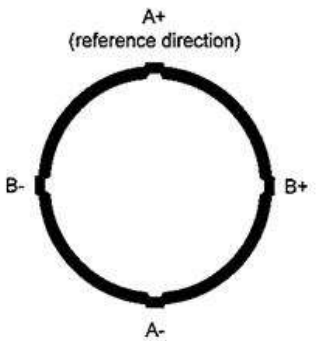
Deep displacement monitoring



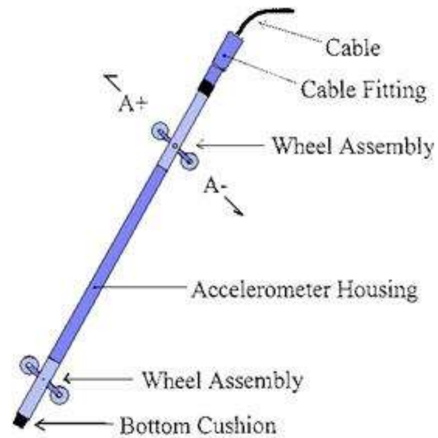
LANDSLIDE CHARACTERIZATION AND MONITORING

Manual inclinometer

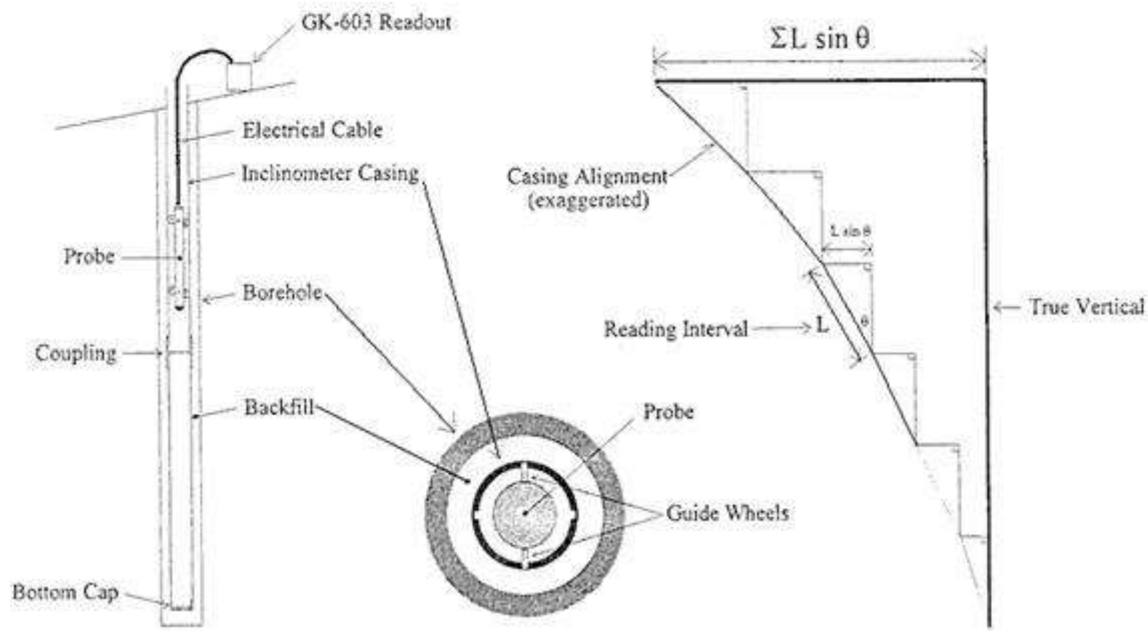
LANDSLIDE CHARACTERIZATION AND MONITORING



Inclinometer grooves, A+A- is the primary direction, B+B- is the secondary direction



Inclinometer probe



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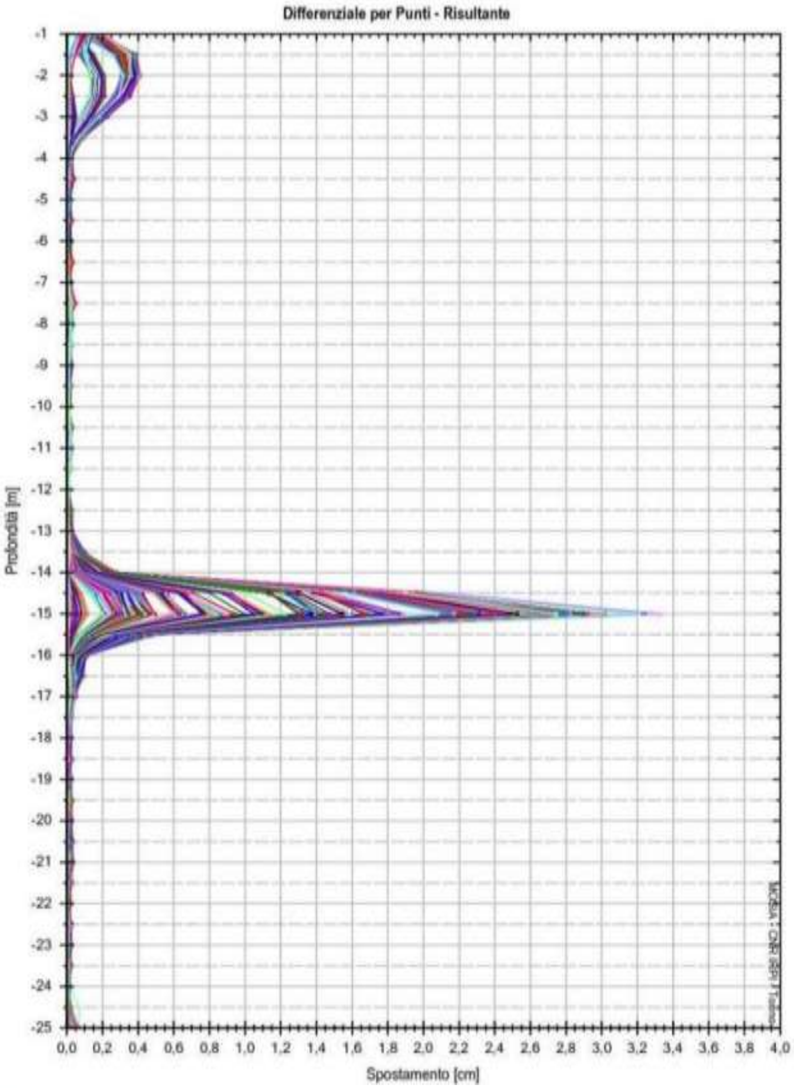
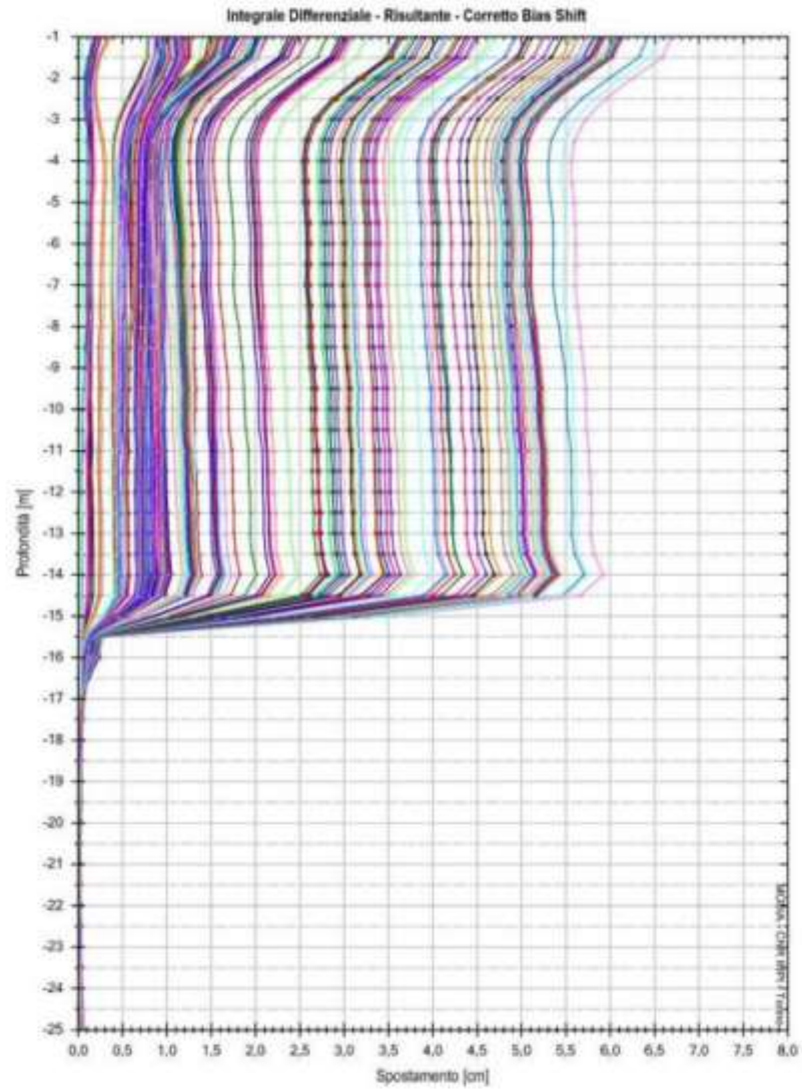
Consiglio Nazionale delle Ricerche

LANDSLIDE CHARACTERIZATION AND MONITORING





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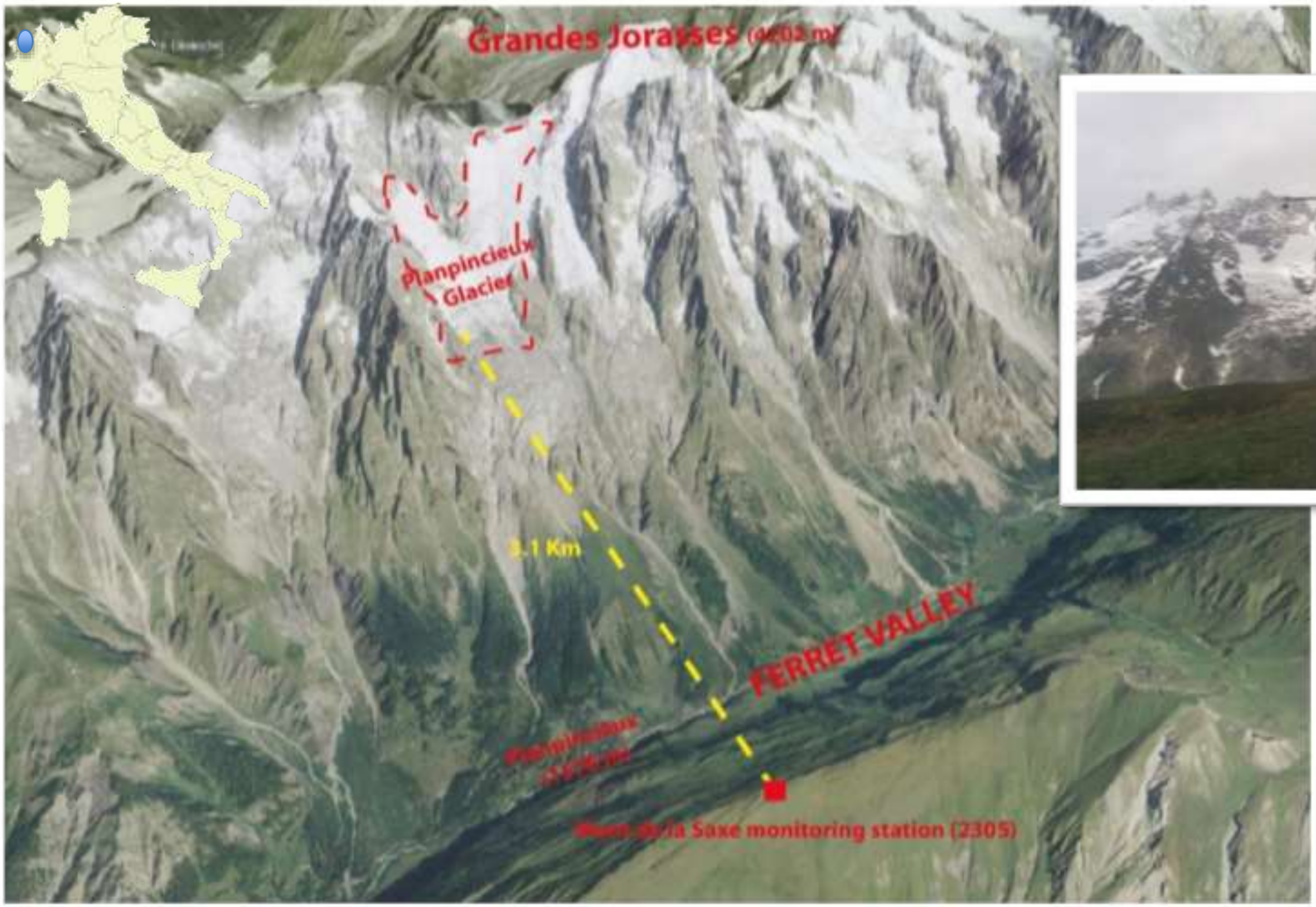
LANDSLIDE CHARACTERIZATION AND MONITORING

Optical based monitoring system



Giordan et al.; A low-cost optical remote sensing application for glacier deformation monitoring in an Alpine environment; *Sensors*, 16, 1750; 2016.

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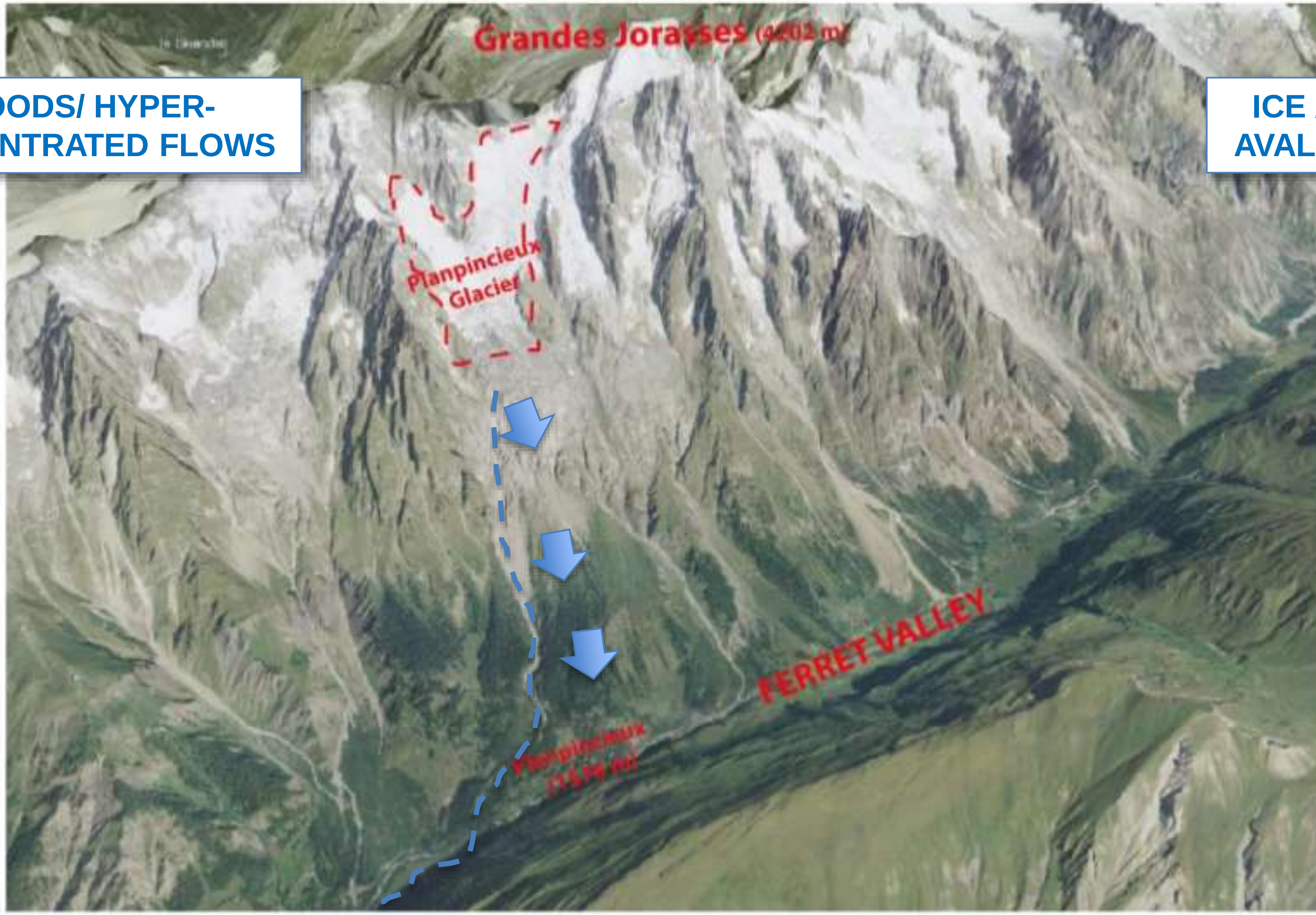
Consiglio Nazionale delle Ricerche

Planpicieux glacier

FONDAZIONE MONTAGNA SICURA MONTAGNE SÛRE

FLOODS/ HYPER-CONCENTRATED FLOWS

- 1929
- 1984
- 1985
- 1986
- 1987
- 1996
- 1998
- 2008



ICE / SNOW AVALANCHES

- 1952
- 1982
- 2005

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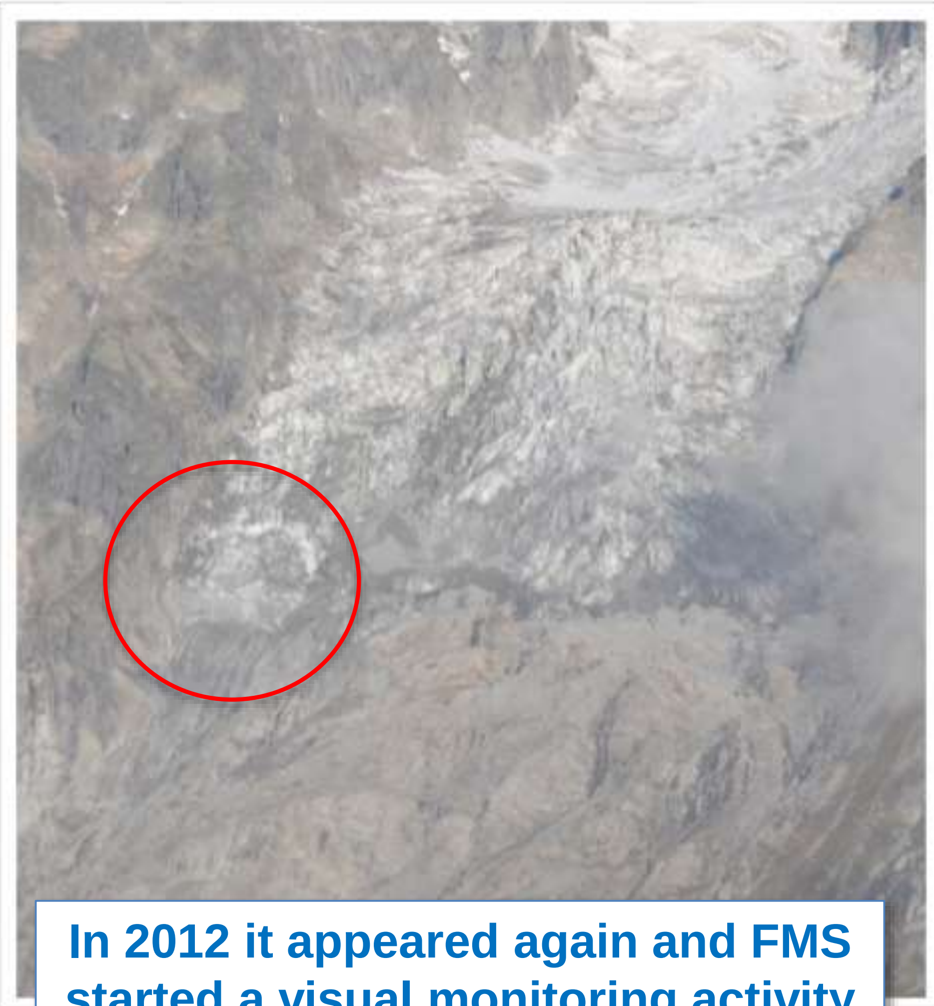
Planpicieux glacier

FONDAZIONE MONTAGNA SICURA MONTAGNE SÛRE



In 2012 it appeared again and FMS started a visual monitoring activity of the galcier evolution

OCTOBER 2011
A large anomalous crevasse opening was observed in the most active part of the glacier tongue

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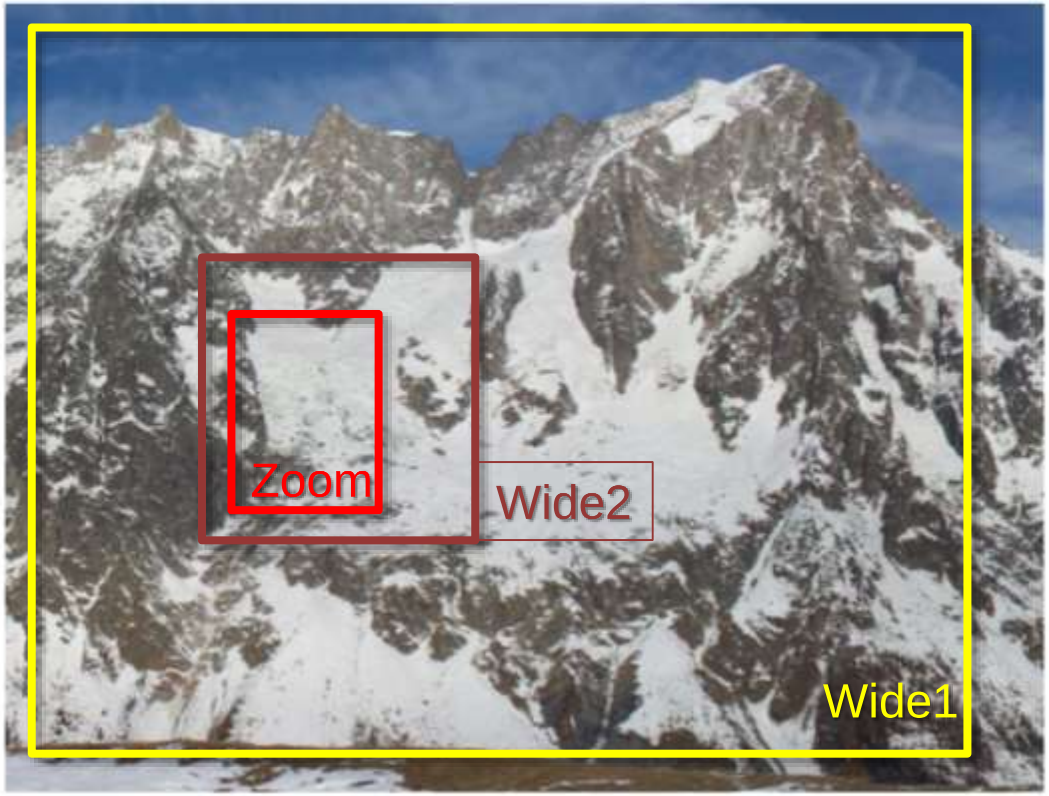
Planpicieux glacier



Monitoring module	Camera	Sensor/resolution	Aperture lens	Camera lens	Auto focus	ISO (maximum)
ZOOM	Canon EOS 600D	CMOS 18 MPixel	f/8	100-400mm (settled at 297 mm)	manual	200 (6400)
WIDE1	Canon powershot	CMOS 8 MPixel	Auto f/2,6-5,5	20 110 mm	Auto 9 points	100 (3200)
WIDE 2	Canon EOS 600D	CMOS 18 MPixel	f/8	100-400mm (settled at 297 mm)	manual	200 (6400)

irpi

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Consiglio Nazionale delle Ricerche

Planpicieux glacier

FONDAZIONE
MONTAGNA SICURA
MONTAGNE SÛRE

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MONITORING
GROUP

Planpicieux glacier

Monitoring station management workflow

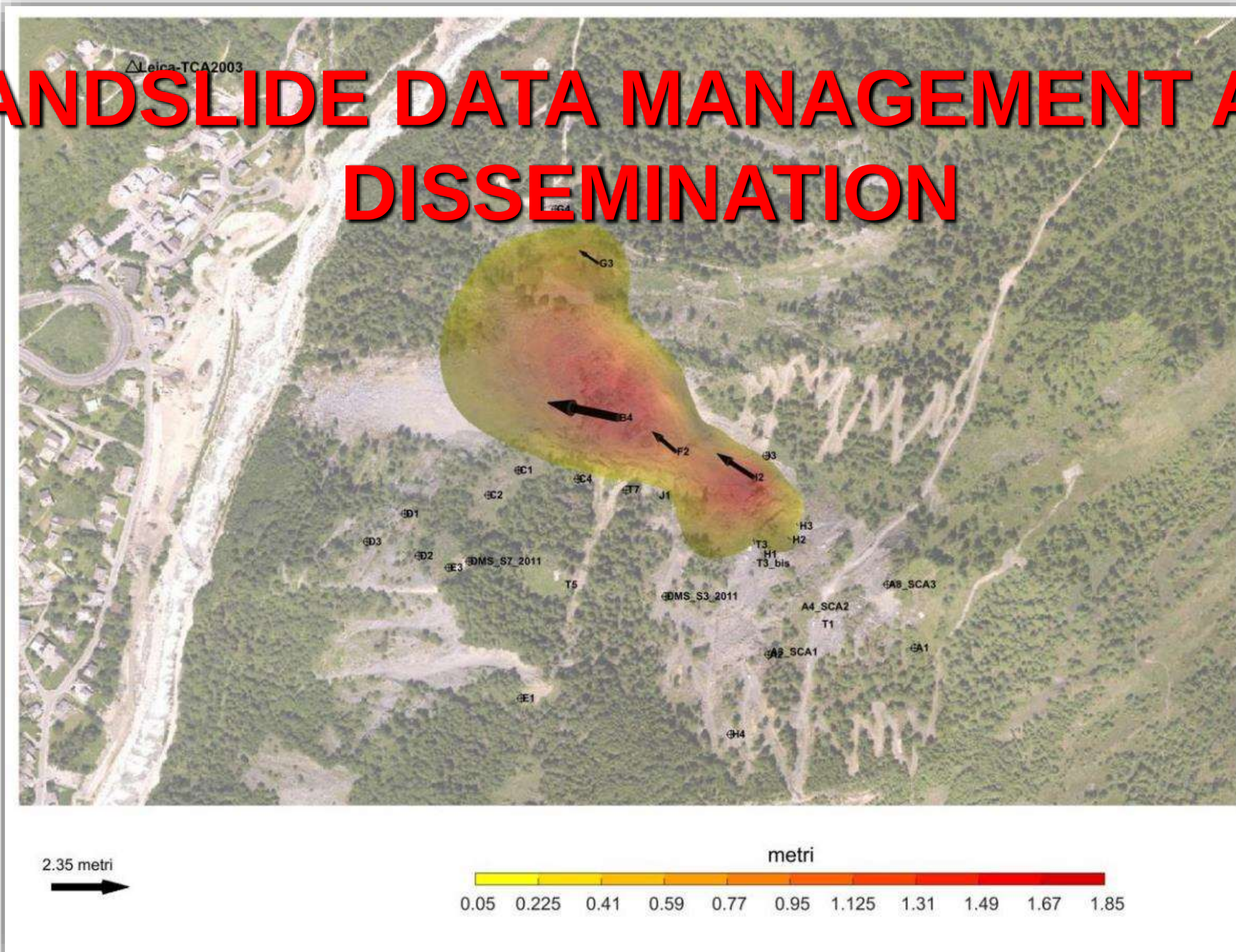
IMAGE ACQUISITION AND TRANSFER
Automatic acquisition at Mont de la Saxe monitoring station and transfer to CNR Ftp Server in Torino

IMAGE CO-REGISTRATION
Automatic proccessing, dataset organization and filtering

VISUAL INTERPRETATION AND IMAGE SELECTION
Qualitative analisys of images for main processes effects recognition and selection of top quality images

PIXEL OFFSET ALGORITHM APPLICATION
Surface displacement maps and time series

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION



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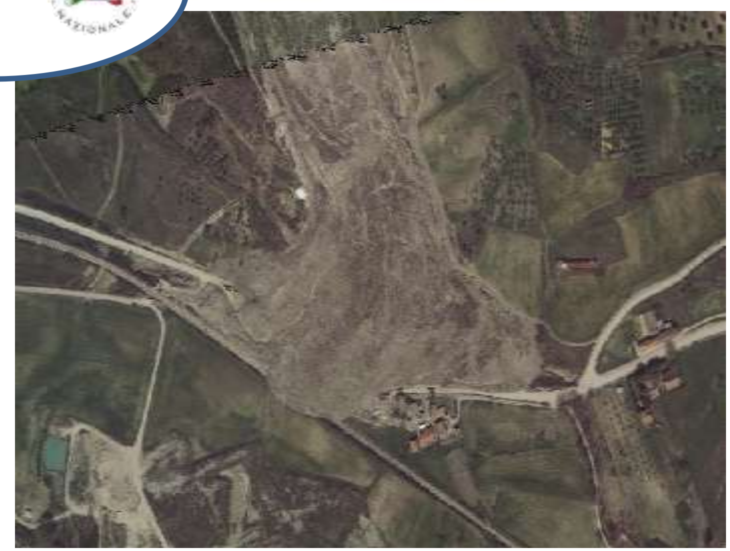
LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

5 Terre (UNESCO) Flood

Costa Concordia

Mt de La Saxe rockslide (10 M m^3)



Montaguto earthflow (6 M m^3)

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LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

The use of monitoring systems can be considered a good solution for the acquisition of a dataset that can be very useful for the study of the evolution of the slope instability

Acquired data can be also important during emergency, when decision makers have to activate (often in critical conditions) measures to assure the safety of population

The question is:

ARE DECISION MAKERS AND/OR POPULATION ABLE TO UNDERSTAND MONITOIRNG DATA RESULTS?

Giordan D., Wrzesniak A., Allasia P. 2019. The importance of a dedicated monitoring solution and communication strategy for an effective management of complex active landslides in urbanized areas. Sustainability, 11(4), 946

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 case study

One of the largest active rockslide in Italy ($8M\ m^3$)

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.

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Consiglio Nazionale delle Ricerche
Région Autonome Vallée d'Aoste
Regione Autonoma Valle d'Aosta
GEOHAZARD MONITORING GROUP

Mt. de la Saxe rockslide

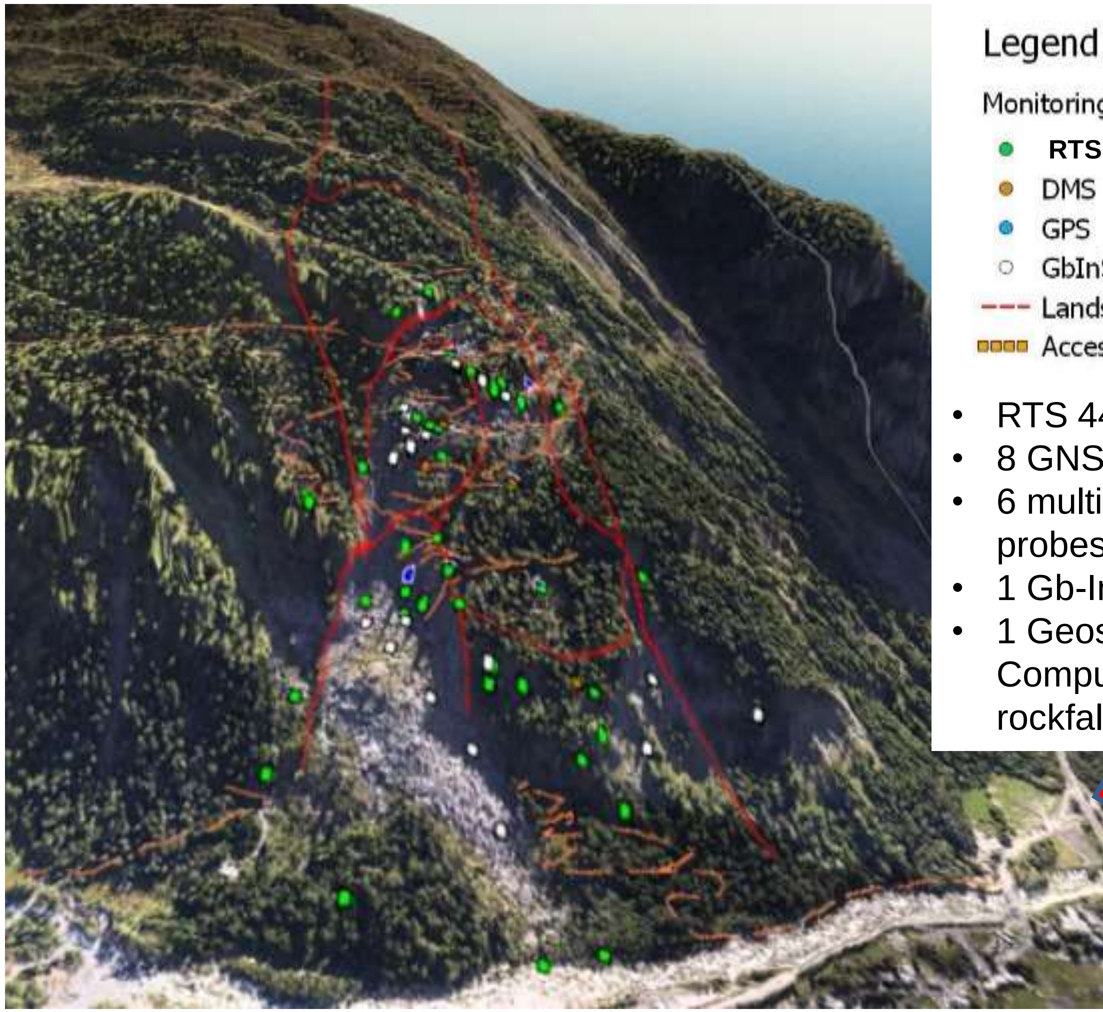
HIGH VALUE TARGETS AT STAKE - A COMPLEX MONITORING SYSTEM

Elements at risk evaluated in more than 1 B €

One of the most complex monitoring network ever installed in Italy

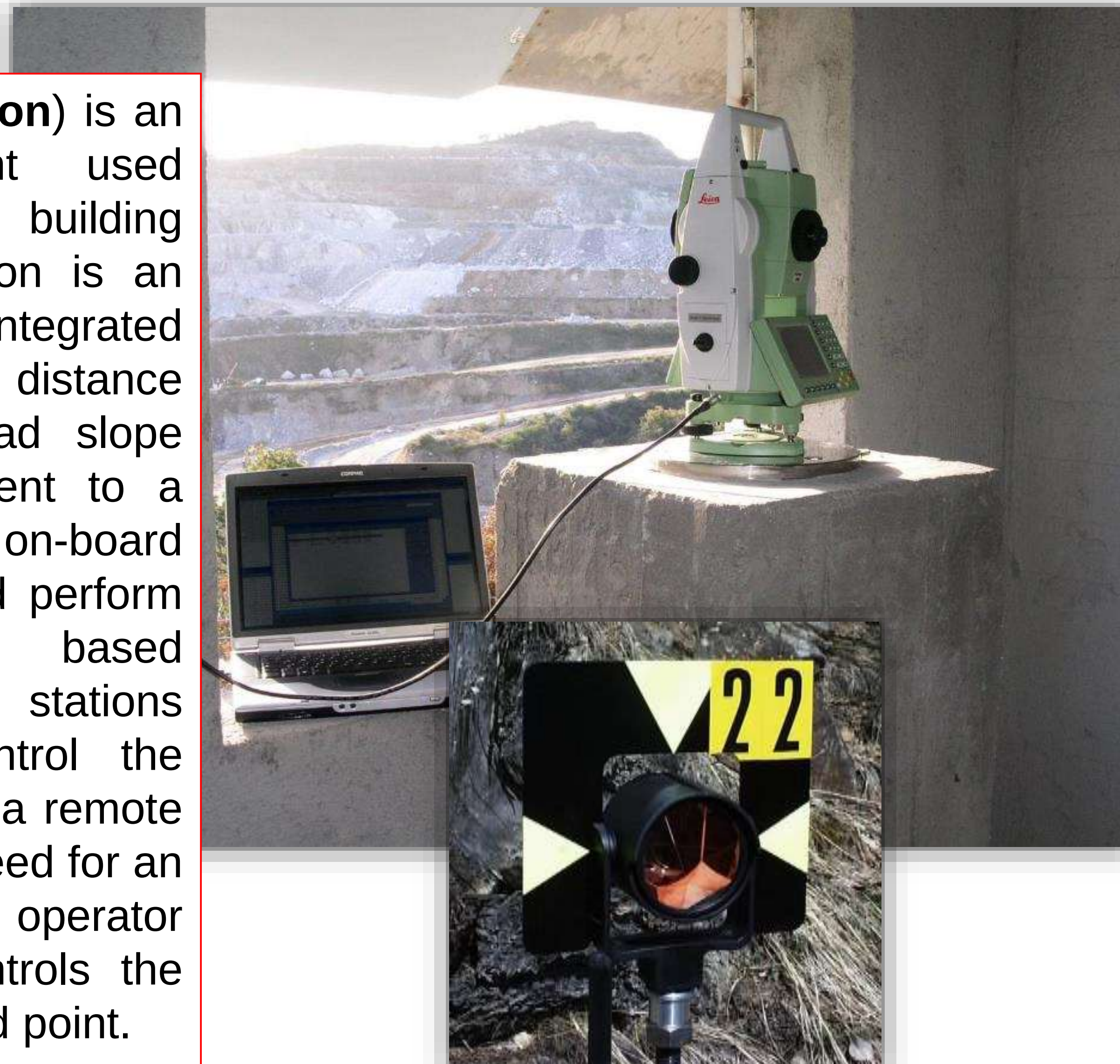
Near real time network installed in 2009

Cost of monitoring network 2 M €

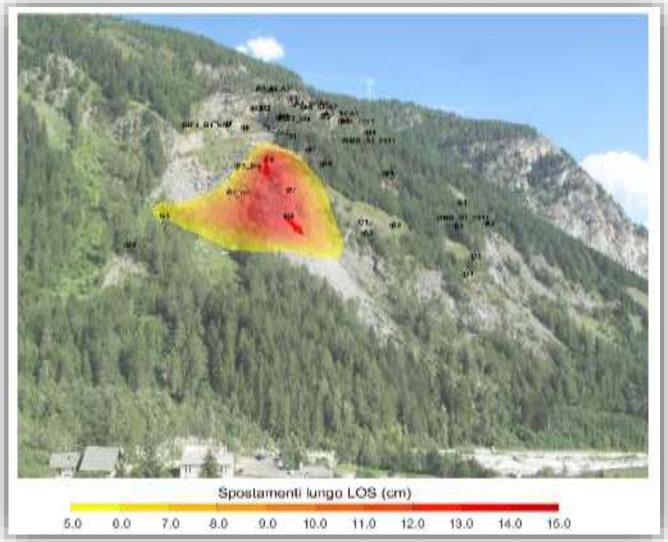


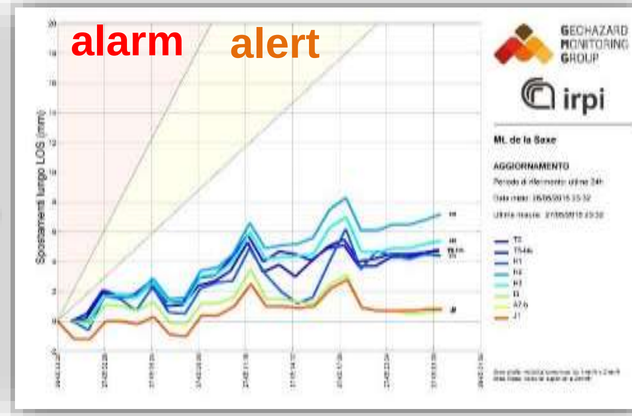
- RTS 44 targets
- 8 GNSS receivers
- 6 multiparametric DMS probes, down to 110 m
- 1 Gb-InSAR
- 1 Geosurveyor Hi-RES Computer Vision System for rockfall detection

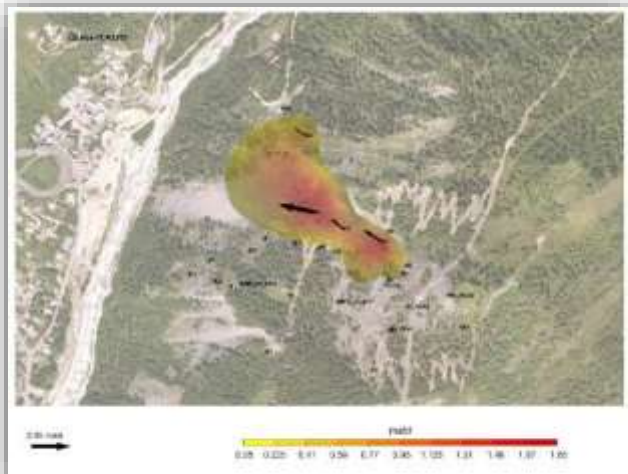
A **RST** (**robotized total station**) is an electronic/optical instrument used for surveying and building construction. The total station is an electronic theodolite (transit) integrated with an electronic distance measurement (EDM) to read slope distances from the instrument to a particular point, and an on-board computer to collect data and perform advanced coordinate based calculations. Robotic total stations allow the operator to control the instrument from a distance via remote control. This eliminates the need for an assistant staff member as the operator holds the reflector and controls the total station from the observed point.



LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

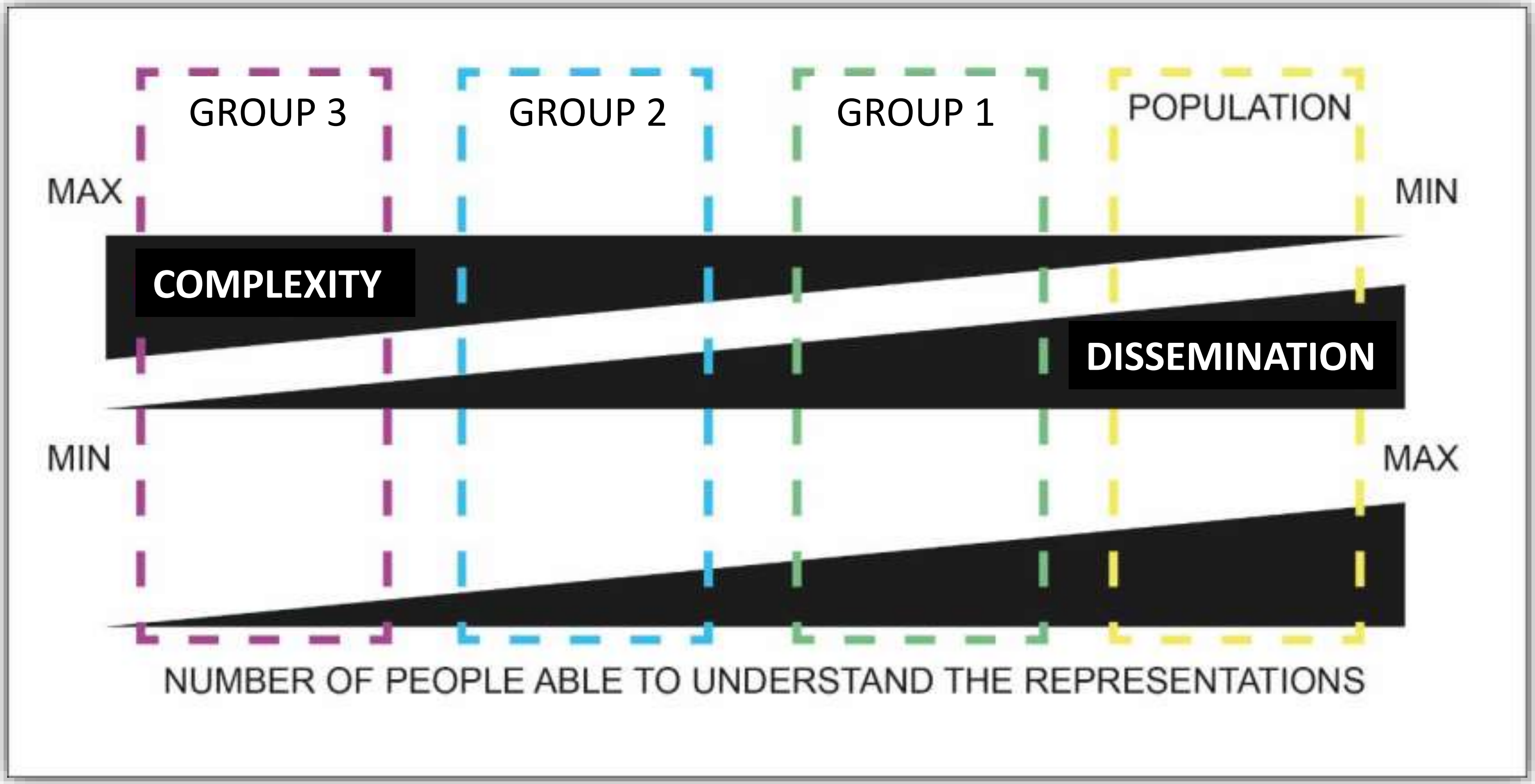






Data dissemination examples from the same dataset

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION



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

Giordan D., Wrzesniak A., Allasia P. 2019. The importance of a dedicated monitoring solution and communication strategy for an effective management of complex active landslides in urbanized areas. Sustainability, 11(4), 946

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

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**

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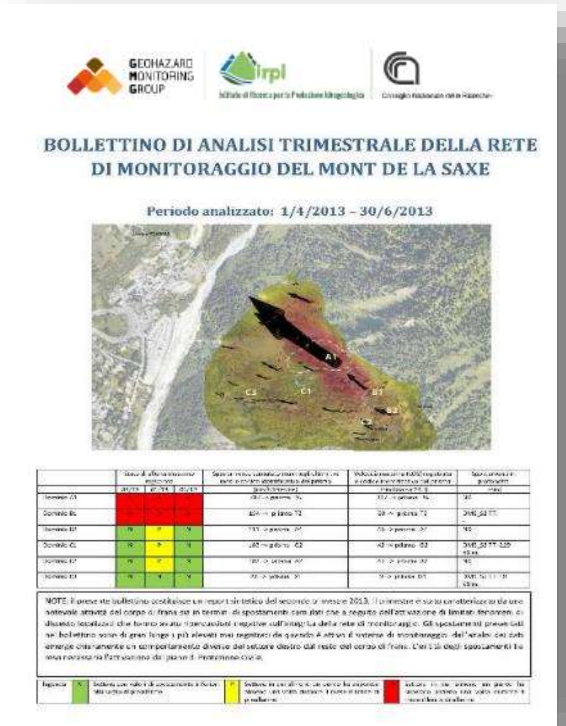
Consiglio Nazionale delle Ricerche

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

PERIODICALLY BULLETINS

Single page bulletin For a rapid information	Extended bulletin For a detailed analysis	Operative Monography Synthesis of all collected data



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

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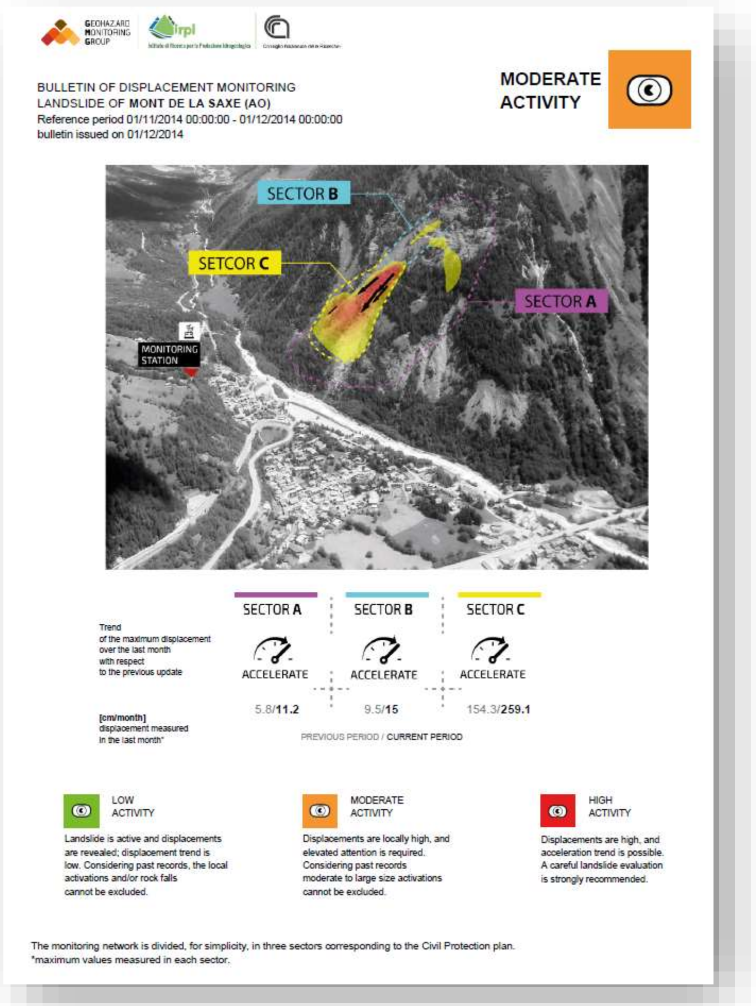
LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

SINGLE PAGE BULLETIN



Automatic publication system

User friendly representation of the landslide evolution

Covered time interval: from 12 hours to1 month

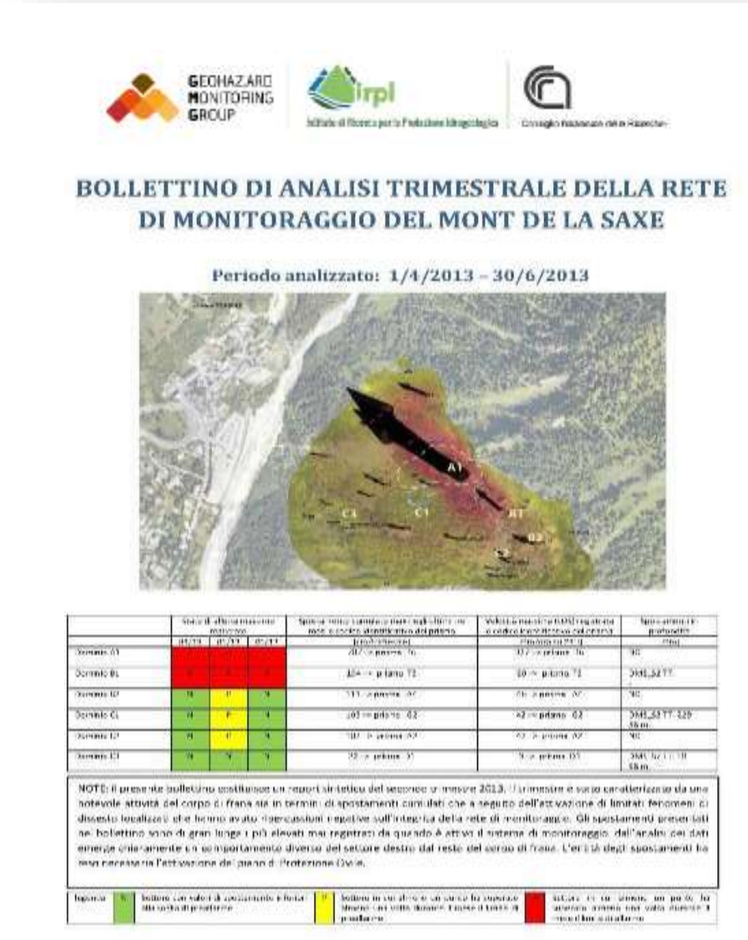
Use of infographics for an easy representation of monitoring results

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

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

EXTENDED BULLETIN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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

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

OPERATIVE MONOGRAPHY


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ANALISI dei FENOMENI FRANOSI ATTUALMENTE INSERITI nella RETE di MONITORAGGIO della REGIONE AUTONOMA VALLE d'AOSTA

Frana del Mont de La Saxe

DATA PUBBLICAZIONE
NOVEMBRE 2016

irpi Consiglio Nazionale delle Ricerche
Istituto di Ricerca per la Protezione Idrogeologica

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 in particular to the Geological Survey and to the landslide monitoring team

Giordan D., Cignetti M., Wrzesniak A., Allasia P., Bertolo D. 2018 The Operative Monographies: development of a new tool for an effective management of landslide risks. Geosciences, 8, 455

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

OPERATIVE MONOGRAPHY

Starting from ICAO (International Civil Aviation Organization) procedure for the redaction of Aviation Company manual of operations, we defined a standard for the organization and publication of available data of a studied landslide.
The Operative Monography is a standardized document that has always the same organization, even if some chapter can be empty.

The main chapters are:

- Geological-Geomorphological survey (GeoGeomS);
- Geological map (GeoM);
- Geomorphological map (GeomM);
- Structural Survey (StrM);
- Geological Profile (GeoP);
- Hydrological/Hydrogeological (Hyd/Hydg);
- Risk scenarios and Spatial prediction model (Rsk/Sc);
- Monitoring Network report (MonNet).

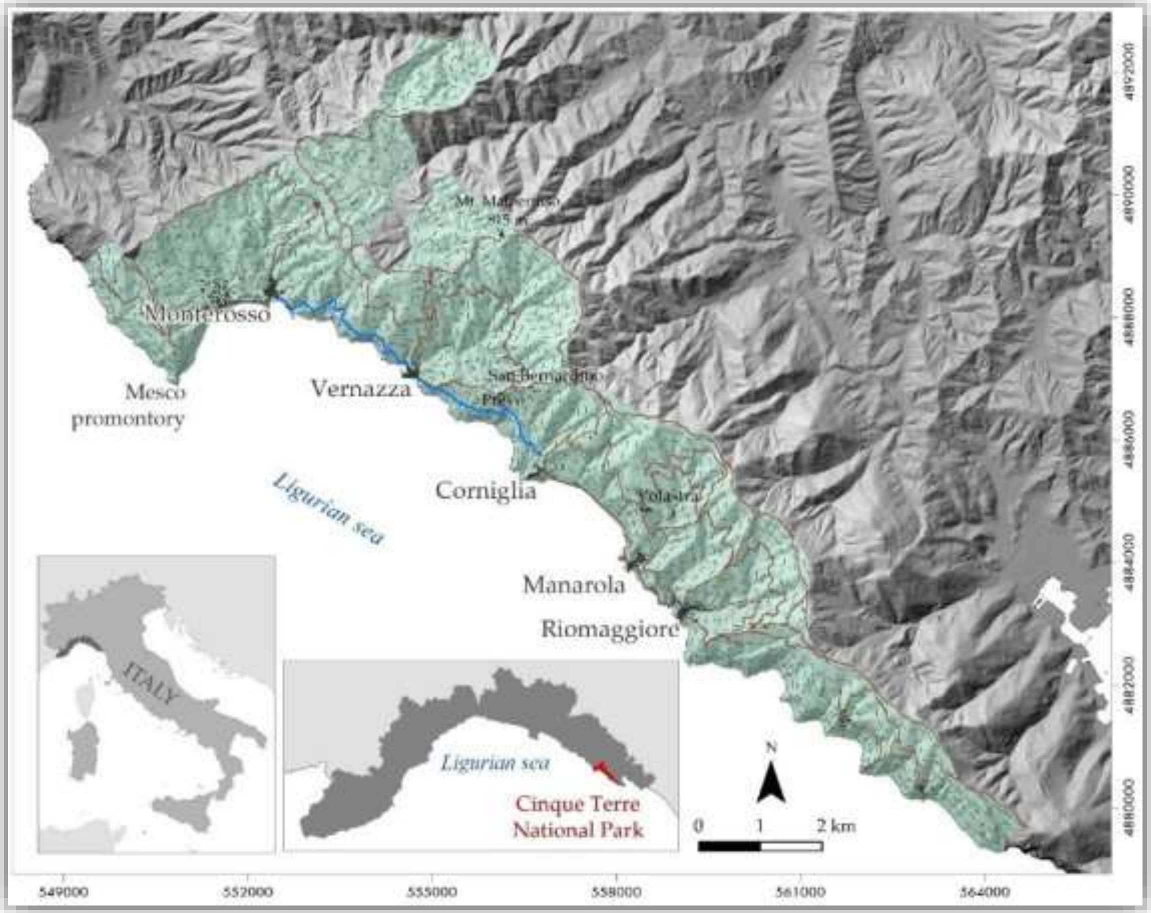
Giordan D., Cignetti M., Wrzesniak A., Allasia P., Bertolo D. 2018 The Operative Monographies: development of a new tool for an effective management of landslide risks. Geosciences, 8, 455

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

OPERATIVE MONOGRAPHY

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

Cinque Terre National Park case study



UNESCO area since 1997

One of the most famous and visited Italian National Park

The “Sentiero Azzurro” trail is one of the most visited of the Cinque Terre National Park

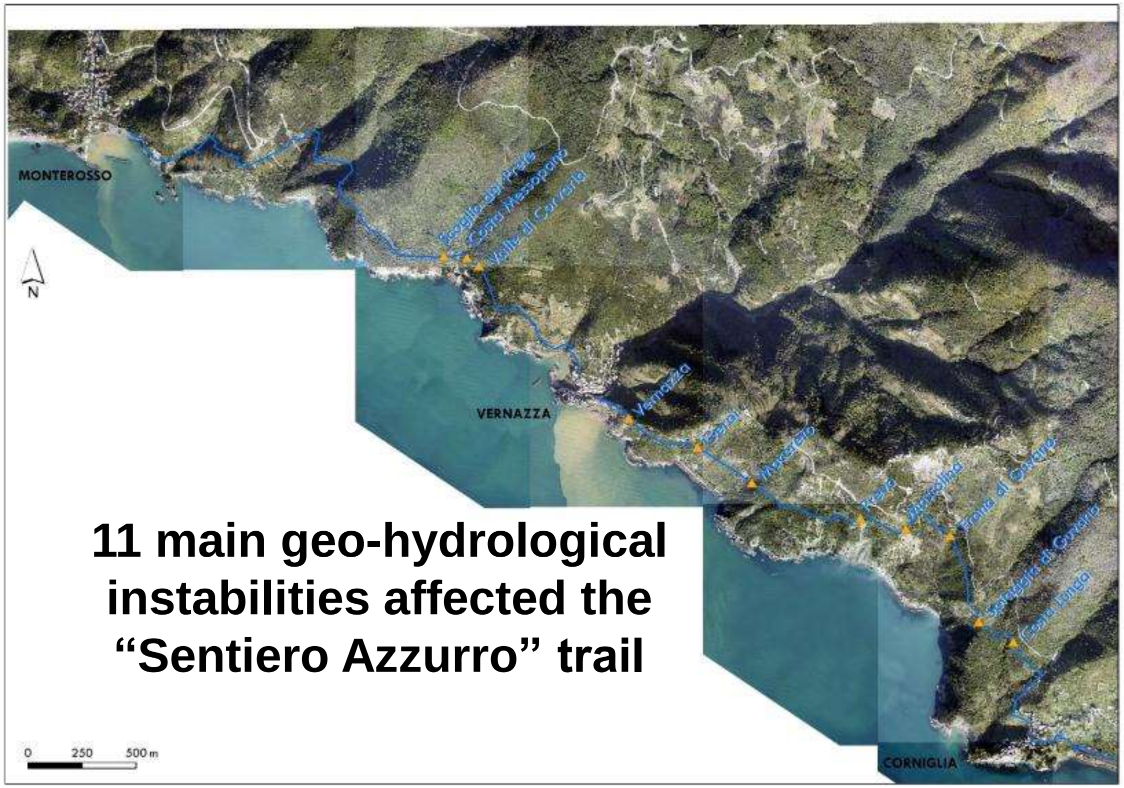
LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

Cinque Terre National Park case study

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

Istituto di Ricerca per la Protezione Idrogeologica — Consiglio Nazionale delle Ricerche — Parco Nazionale delle Cinque Terre

Cinque Terre National Park case study



11 main geo-hydrological instabilities affected the "Sentiero Azzurro" trail

We organized all available information of these instabilities in 11 Operative Monographies that describe what we know

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LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

Cinque Terre National Park case study

After the 2011 flood that seriously damaged the Cinque Terre area, all trails are automatically closed when a critic weather condition is forecasted.

The regional authority send a red meteorological alert and a civil protection procedure is immediately activated.

From normal days ... **to** **October 25, 2011**

Monterosso, Via Roma – Pastanelli creek coverage
Photo from http://www.about-cinqueterre.com

Monterosso, Via Roma – Pastanelli creek coverage 25/10/2011
Photo from www.youreporter.it

Height reached by debris during the October 25, 2011 flood

Vernazza, Via Roma – Vernazza creek old course
Photo from https://emilayusof.com, mod.

Vernazza, Via Roma – Vernazza creek old course 26/10/2011 Photo from www.youreporter.it

Courtesy of Prof. Andrea Cevasco

LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

Cinque Terre National Park case study

With the Study Center for Geological Risks of Cinque Terre National Park has been implemented a procedure for the management of trails that can affected by activation/reactivation of slope instabilities

ACTIONS	RESULTS
1. Historical Data Collection 2. Field Survey 3. Operative Monographies Application	Operative Monographies
4. Analysis of Survey Activities Results Collected after Previous Rainfall Events	Survey Form
5. Identification of Cinque Terre National Park Needs and Development of a Dedicated Procedure	Codified Procedure for the Identification and Mapping of Effects of heavy rainfall events

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LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

Cinque Terre National Park case study

SURVEY FORM for the ASSESSMENT of the PRACTICABILITY STATE OF THE TRAIL NETWORK
CINQUE TERRE NATIONAL PARK

Date: **Form n.:**

Operator

GEOGRAPHIC INFORMATION

Municipality/Locality/Path:

GPS Geographical coordinates (datum WGS84)
latitude: **longitude:** **altitude m a.s.l.:**

Photos and/or geo-referenced photographic reference (annexes):

Cartographic and geological setting of the site (annexes):

GEO-HYDROLOGICAL PHENOMENA and/or OTHER EVIDENCES DETECTED

1) – **Hydraulic** issues or otherwise evidences due to water flow and runoff issues ☐
Description:

Timing of the occurred event (if know) Date: Hour:

2) – **Geomorphological** issues due to slope instability or landslide exposure ☐
Description:

Timing of the occurred event (if know) Date: Hour:

3) – Practicability issues due to **vegetation** and/or to the vegetation setting (e.g. trails overrun by vegetation, presence of unstable or fallen trees) ☐
Description:

4) – Practicability issues due to the **path structure** or otherwise due to local instabilities close to the path (e.g. disconnected trails, damaged or absent stairways, rock outcropping, dry-stone walls or unstable or collapsed upstream and downstream retaining structures) ☐
Description (indicate causes and typology of the observed phenomenon, and the estimated dimensions of the involved structures for planning purposes of the remedial works):

Timing of the occurred event (if know) Date: Hour:

5) – Issues due to degradation and damage of the **retaining structures and the existing infrastructures** or due to their eventual absence (e.g. fences, stairs, bridges) ☐
Description:

6) – Issues due to degradation and damage of the **sign** or the possible absence of this ☐
Description:

7) – Other issues or notifications: ☐
Description:

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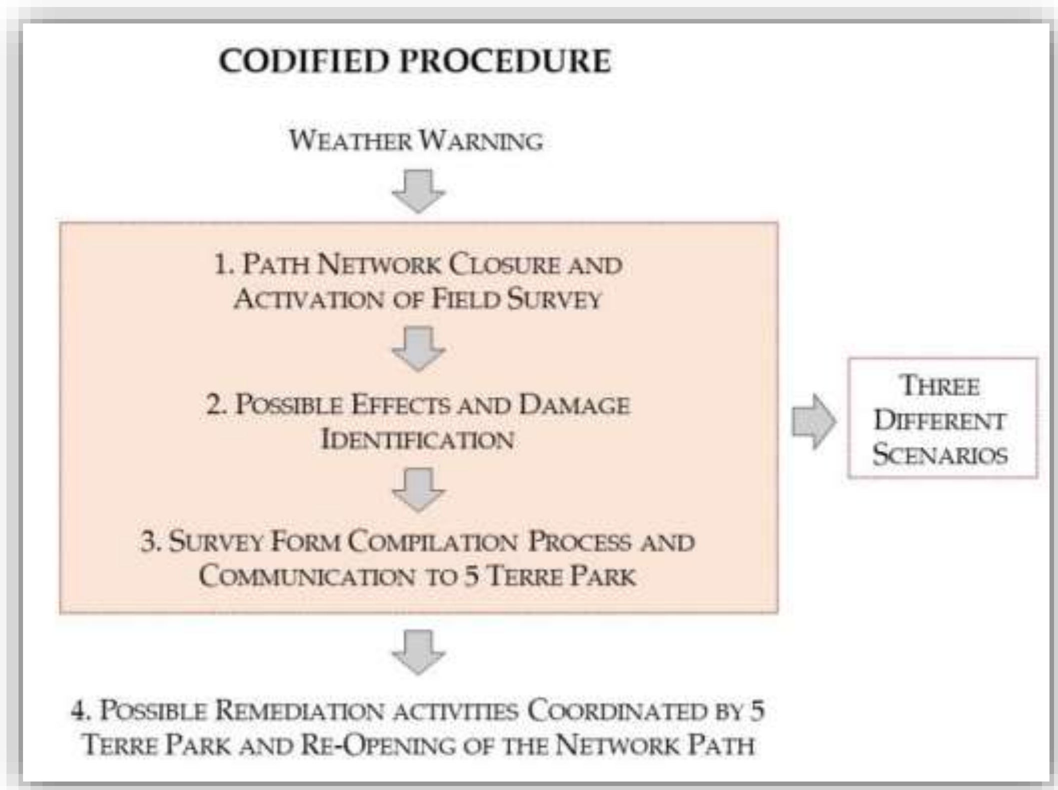
LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

Cinque Terre National Park case study

We defined a survey form that can be adopted after the meteorological event by geologists who have to check the presence of slope instabilities and other possible problem along the trail.

This codified procedure, the first in Italy, is based on the combined use of Operative Monographies (that describes what is already present on the trail) and the survey form (that can be used for the description of new problems, damages, instabilities)



LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

Cinque Terre National Park case study

Scenario 1

1. Activation of "*Presidianti*"

↓

2. Field Survey Supported by Operative Monographies for the Description of Pre-Event Condition of Main Geo-Hydrological Processes

↓

3. No Evident Effects Identified by "*Presidianti*"

↓

4. Communication by "*Presidianti*" to 5 Terre Park that the Survey Does Not Produce Any New Survey Forms

↓

5. End of "*Presidianti*" Survey

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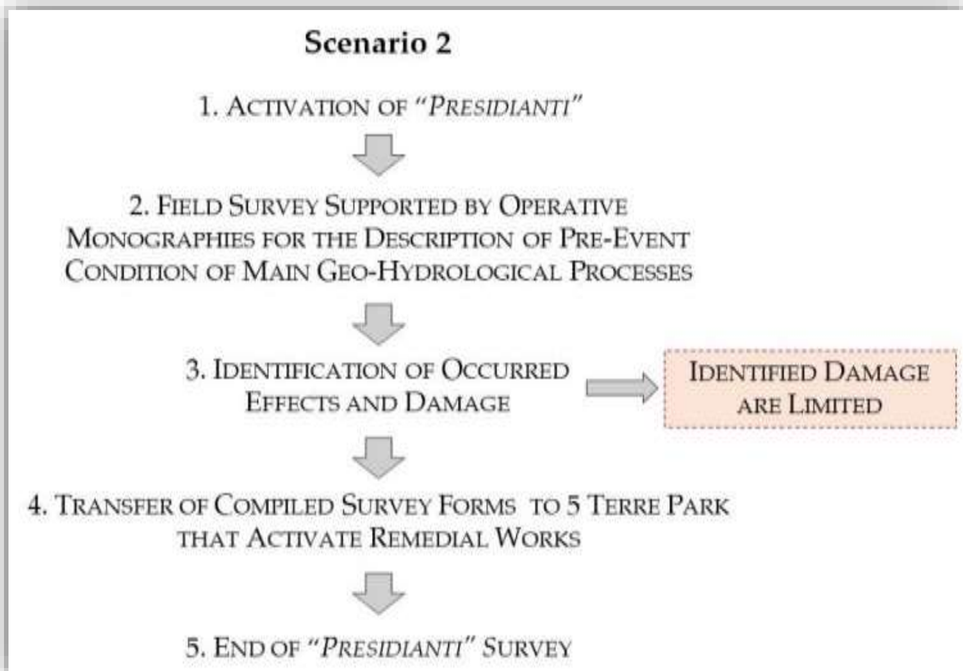
LANDSLIDE DATA MANAGEMENT AND DISSEMINATION

Cinque Terre National Park case study



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