



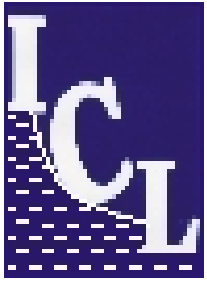
Università degli Studi di Firenze

Department of Earth Sciences
CENTRE OF COMPETENCE OF THE CIVIL PROTECTION DEPARTMENT
PRESIDENCY OF THE COUNCIL OF MINISTERS



Landslide monitoring and mapping in the frame of ICL

Sandro Moretti



ICL

<http://www.iclhq.org/index.html>

- *International Consortium on Landslides (ICL) created at the Kyoto Symposium in January 2002 is an International non-governmental and non-profit scientific organization*
- *supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Meteorological Organization (WMO), the Food and Agriculture Organization of the United Nations (FAO), the United Nations International Strategy for Disaster Reduction (UN/ISDR), and intergovernmental programmes such as the International Hydrological Programme of UNESCO; the Government of Japan;*

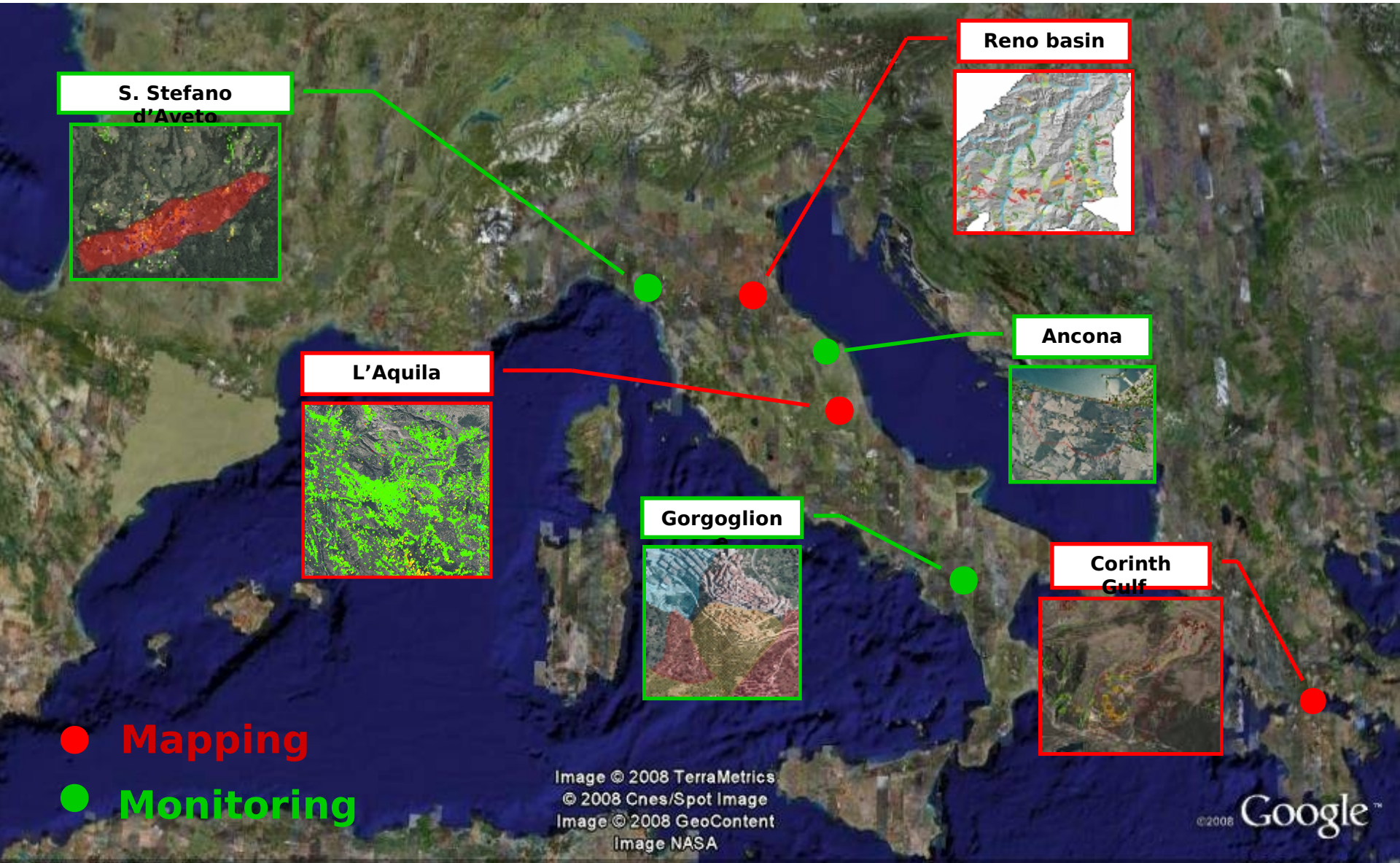
Objectives of the Consortium

- *a) promote landslide research for the benefit of society and the environment, and capacity building, including education, notably in developing countries;*
- *b) integrate geosciences and technology within the appropriate cultural and social contexts in order to evaluate landslide risk in urban, rural and developing areas including cultural and natural heritage sites, as well as contribute to the protection of the natural environment and sites of high societal value;*
- *c) combine and coordinate international expertise in landslide risk assessment and mitigation studies, thereby resulting in an effective international organization which will act as a partner in various international and national projects; and*
- *d) promote a global, multidisciplinary programme on landslides.*

ICL activities

- *The central activity is the International Programme on Landslides (IPL).*
- *Other activities planned include international co-ordination, exchange of information and dissemination of research activities and capacity building through various meetings, dispatch of experts, landslide database, and publication of “Landslides”: Journal of the International Consortium on Landslides.*

Some Examples



Objectives

- To illustrate some applications of InSAR interferometry to landslide mapping and monitoring in the framework of different projects.
- To highlight the User's role and feedback.

Sarno, 5 May 1998



Debris flows
153 victims
Hundreds of
homeless

Law n.267/1998 (Sarno Law): National landslide risk zonation

Regional landslide inventories

2 million landslides mapped at
1:10.000

Landslide risk areas

ca. 10.000 areas classified at
very high risk (R4)

Social impact

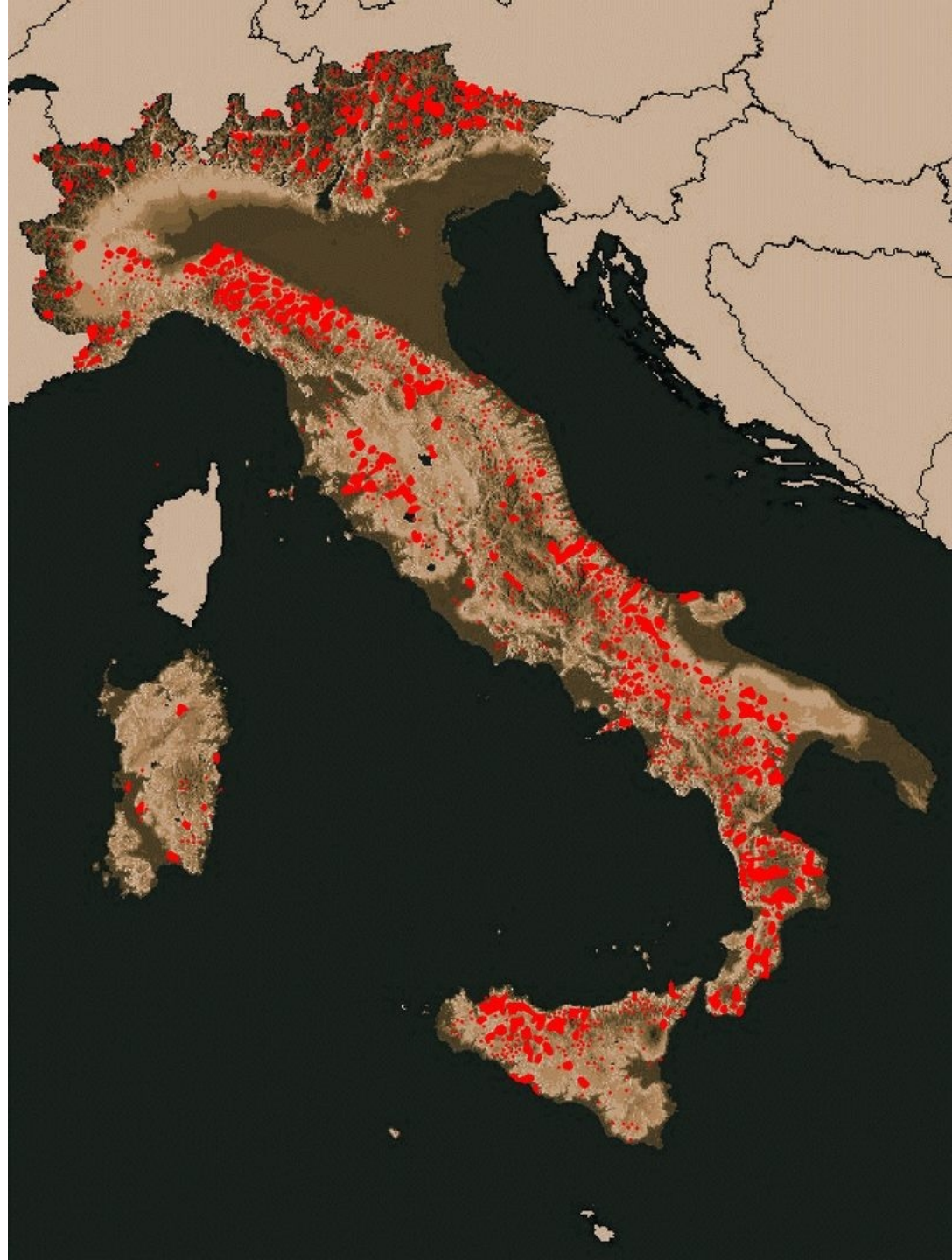
ca. 60 victims per year

Economic impact

ca. 1 - 2 billion Euro per year
(0.15% of GDP)

Unstable urban areas

1,306 to be stabilized
323 to be relocated



National risk zonation

Risk class	Level	Description	Measures
R4	Very high	Major risk for human life. Destruction of buildings and infrastructures	Reconstruction forbidden, relocation or stabilization compulsory
R3	High	Major losses for buildings and infrastructures. Possible risk for human life	Severe building restrictions. Stabilization works required.
R2	Medium	Expected damage for buildings and infrastructures. No risk for life	Medium building restrictions
R1	Low	Limited expected loss	General risk prevention measures
R0	Negligible	No expected loss	None

Photo interpretation

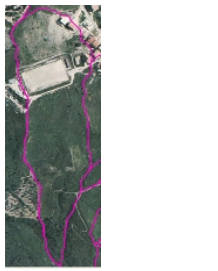
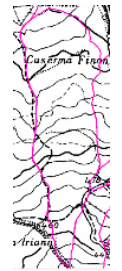
I₁: Scarps, terraces, counterslopes



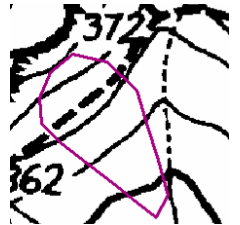
I₂: Sharp variation of curvature in the longitudinal profile



I₃: Irregular drainage system, water ponds, internal drainage depressions, stream channel deviation



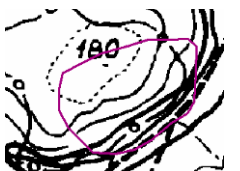
I₄: Bedrock outcrops, soil erosion, denudation



I₅: Presence of rapid-growth vegetation



I₆: Sharp difference in vegetation inside/outside the landslide



State of activity and risk zonation

1. Active (moving) - R4

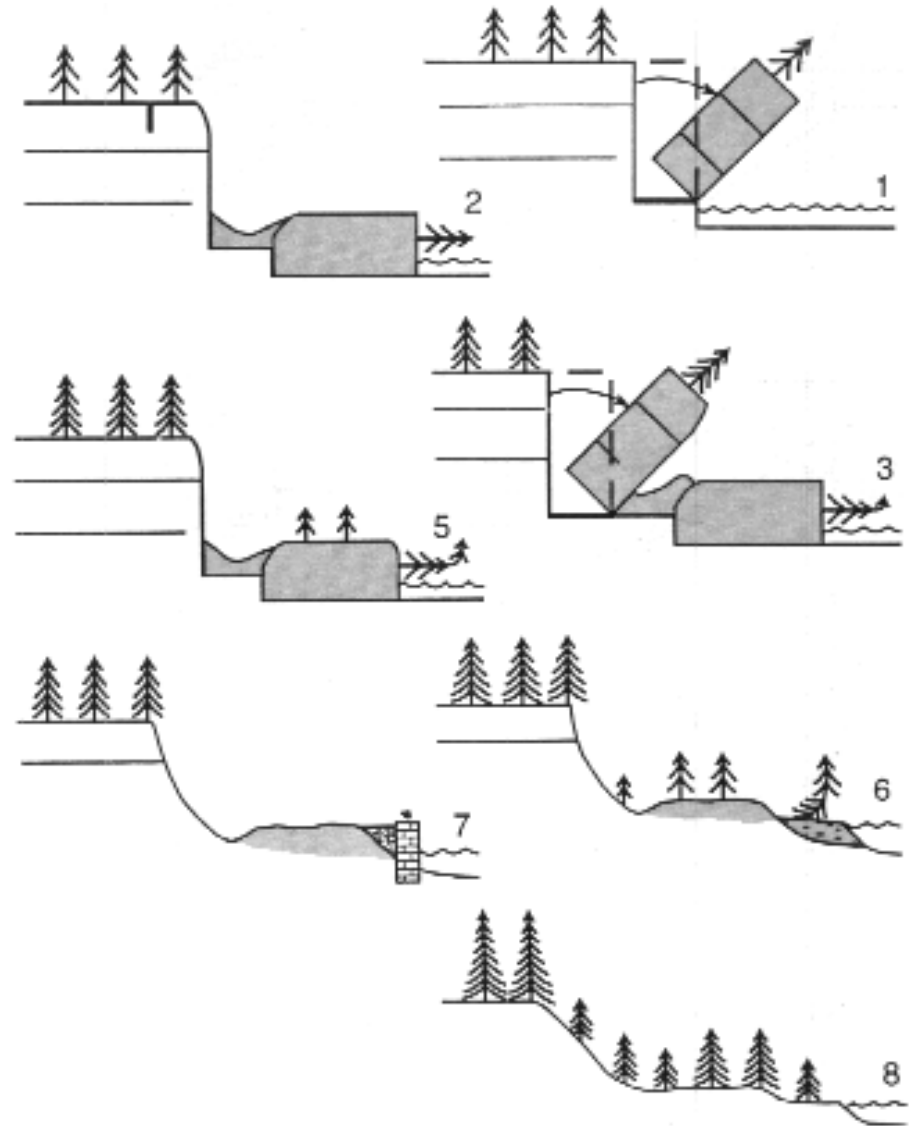
2. Suspended (seasonally) - R4

3. Dormant (recurrent) - R3

5. Naturally stabilized - R2-R1

6. Artificially stabilized - R2-R1

7. Relict - R0



Activity matrix

MATRIX OF ACTIVITY	ERS < 2mm/year (1992-2002)	ERS > 2mm/year (1992-2002)
ENVISAT/RADARSAT < 2 mm/year (2003-today)	Stable	Dormant
ENVISAT/RADARSAT > 2 mm/year (2003-today)	Active (reactivated)	Active (continuous)

Landslide analysis with PSI techniques

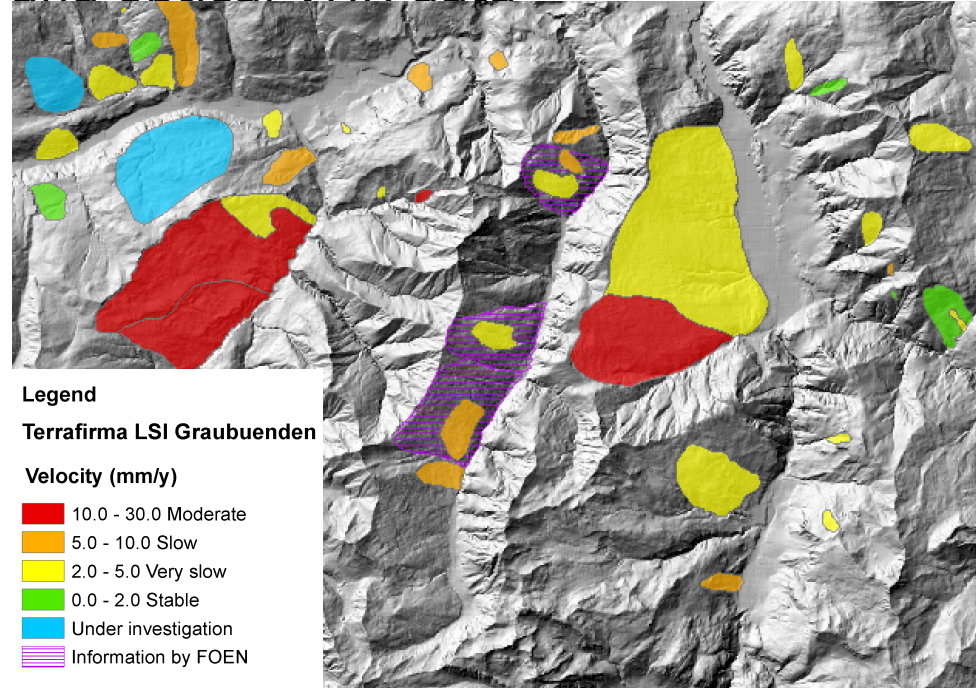
Landslide Mapping and **Landslide Monitoring** PSI analyses are made from integration of VHR optical data and thematic maps with radar data (ERS-1/2, ENVISAT, Radarsat)



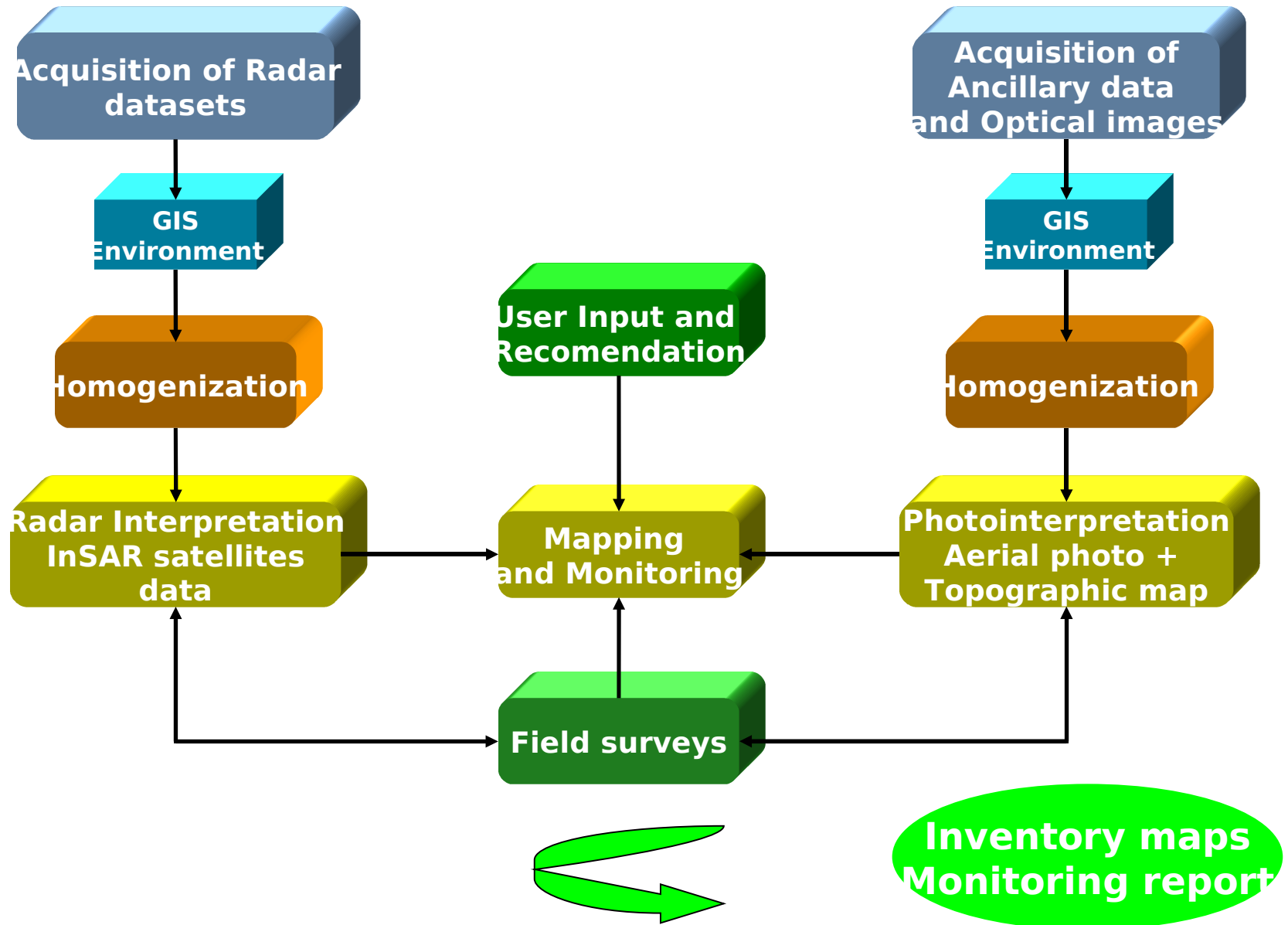
Monitoring analysis: long term PSI monitoring of ground movements induced by a specific slow-moving landslides

Mapping analysis:

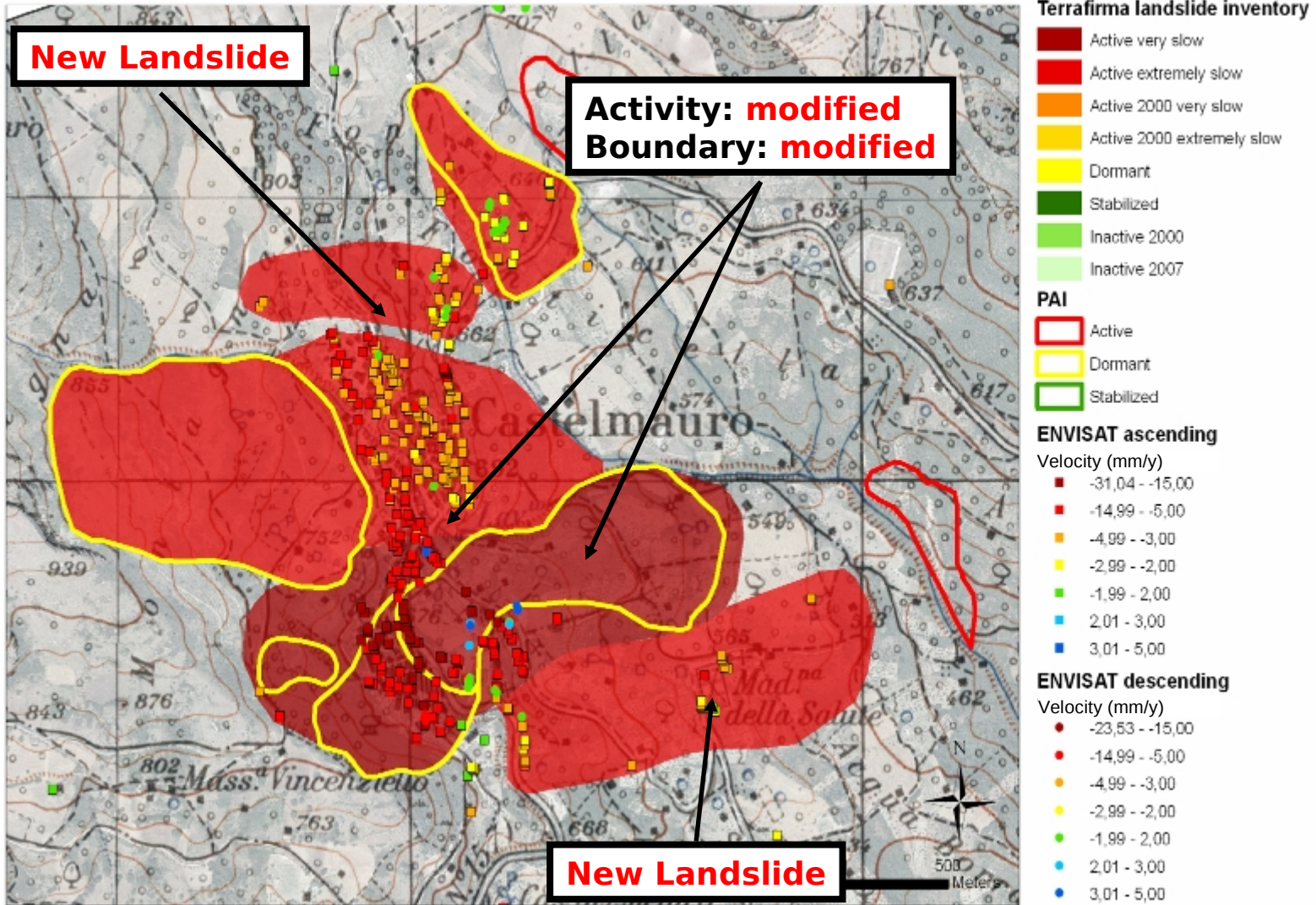
implementation and update of a landslide inventory map produced through the integration of radar data and optical VHR data



Methodology



Radar interpretation



The landslide state of activity is assessed in terms of velocity and acquisition time

USERS involved

The users of the services are Civil Protection Authorities at national and local level, regional agencies for the protection of the environment and municipalities



Italian National Civil Protection Department
Italy



**Institute of Geology
& Mineral Exploration**
Greece



REGIONE LIGURIA
Environmental Dept.
Italy



Ancona Municipality
Italy

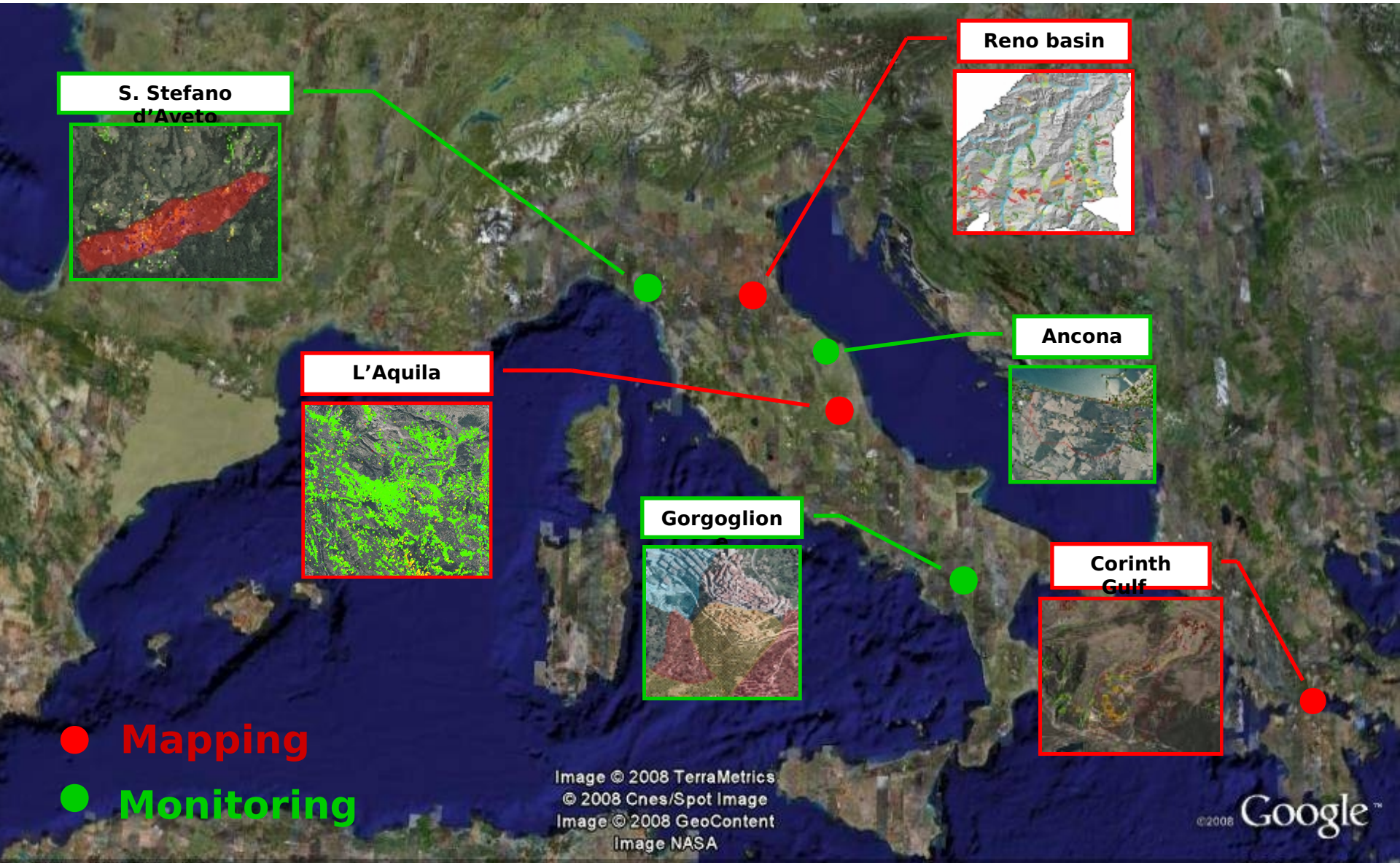


REGIONE MARCHE
Civil Protection
Italy



REGIONE EMILIA ROMAGNA
Civil Protection
Italy

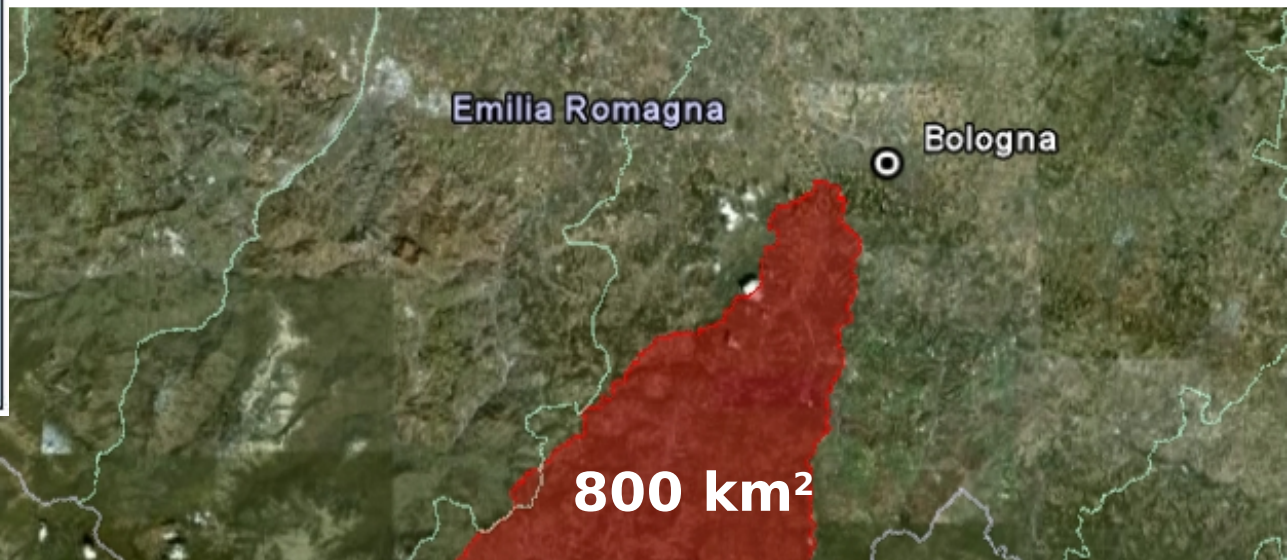
Examples of PSI analysis





Reno river basin

Landslide Mapping

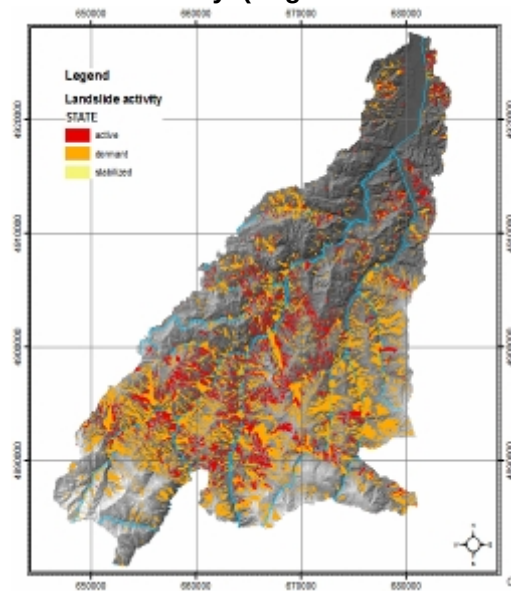


The Northern Apennines are one of the most landslide prone area of the Italian territory. Most of the landslides originated as earth-flows after the last glacial maximum and grew up during the Holocene.

The reactivation of these large landslides is one of the most important problem of the mountainous and hilly territory asset plan of the Emilia-Romagna region.

Input data

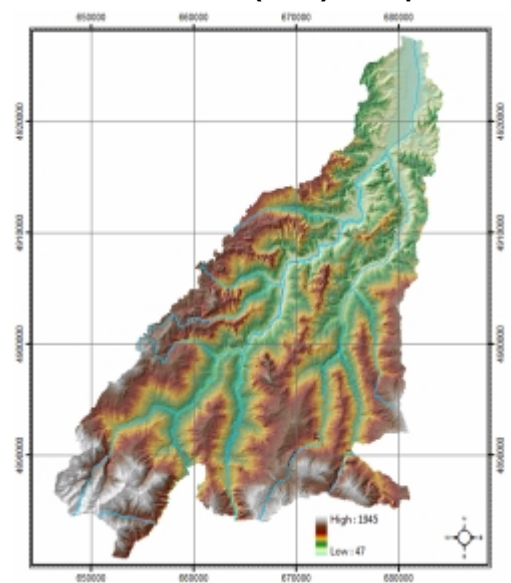
Landslide inventory (Regione Emilia-Romagna)



Digital color orthophoto - VoloITALIA 2000 (1 m ground resolution)



Digital elevation model (DEM) 20 m pixel resolution



Topographic map 1:5000



PS ERS ascending 1993 - 2000

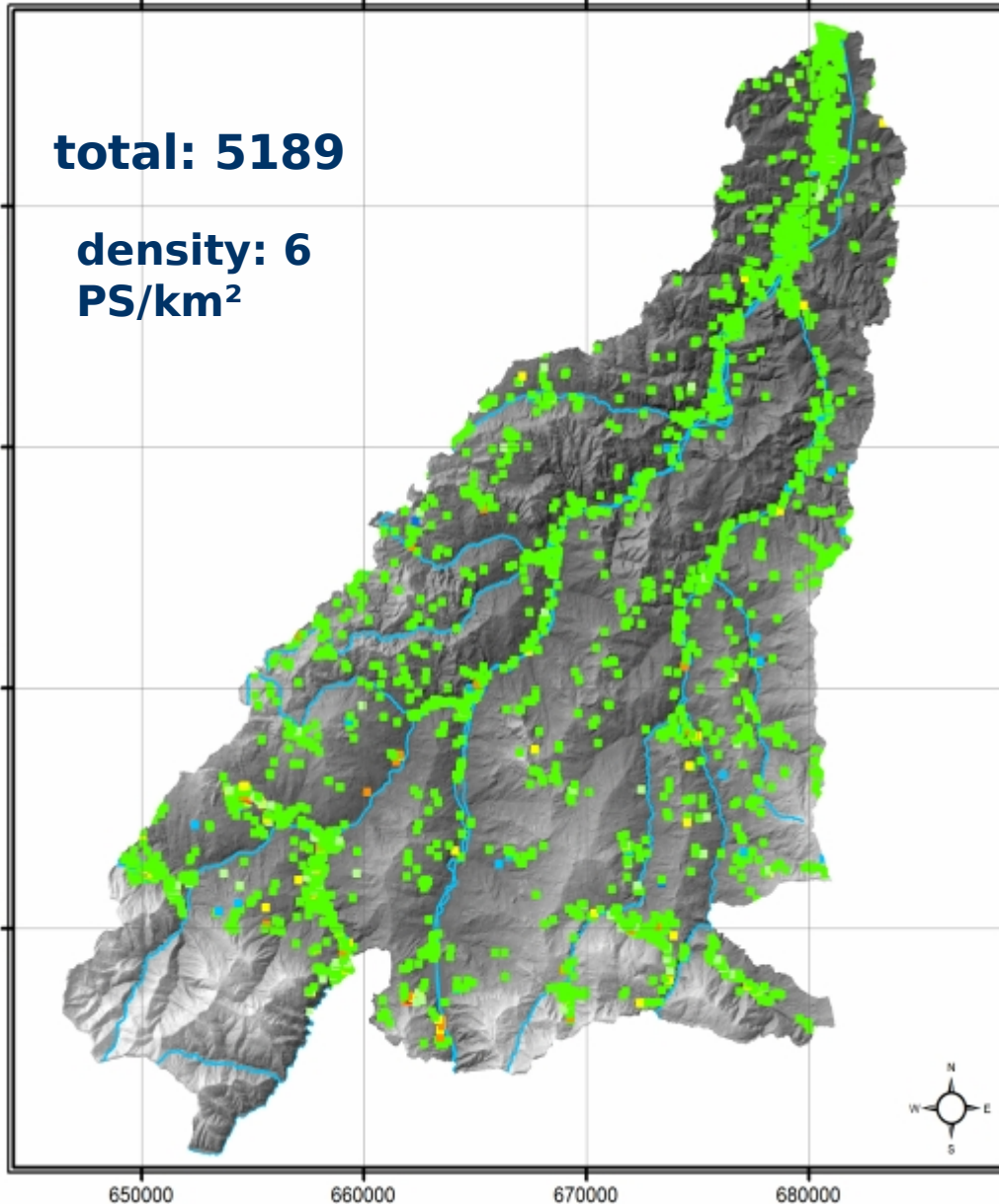


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total: 5189

density: 6
PS/km²



Regione Emilia-Romagna
Reno river basin



Permanent scatterers ERS
1993-2000

Legend

PS ERS Ascending
Velocity (mm/y)

- -14.76 - -10.00
- -9.99 - -5.00
- -4.99 - -3.00
- -2.99 - -2.00
- -1.99 - 2.00
- 2.01 - 3.00
- 3.01 - 4.45

Coordinate system UTM, datum WGS84, zone 32N



PS ERS descending 1993 - 2000

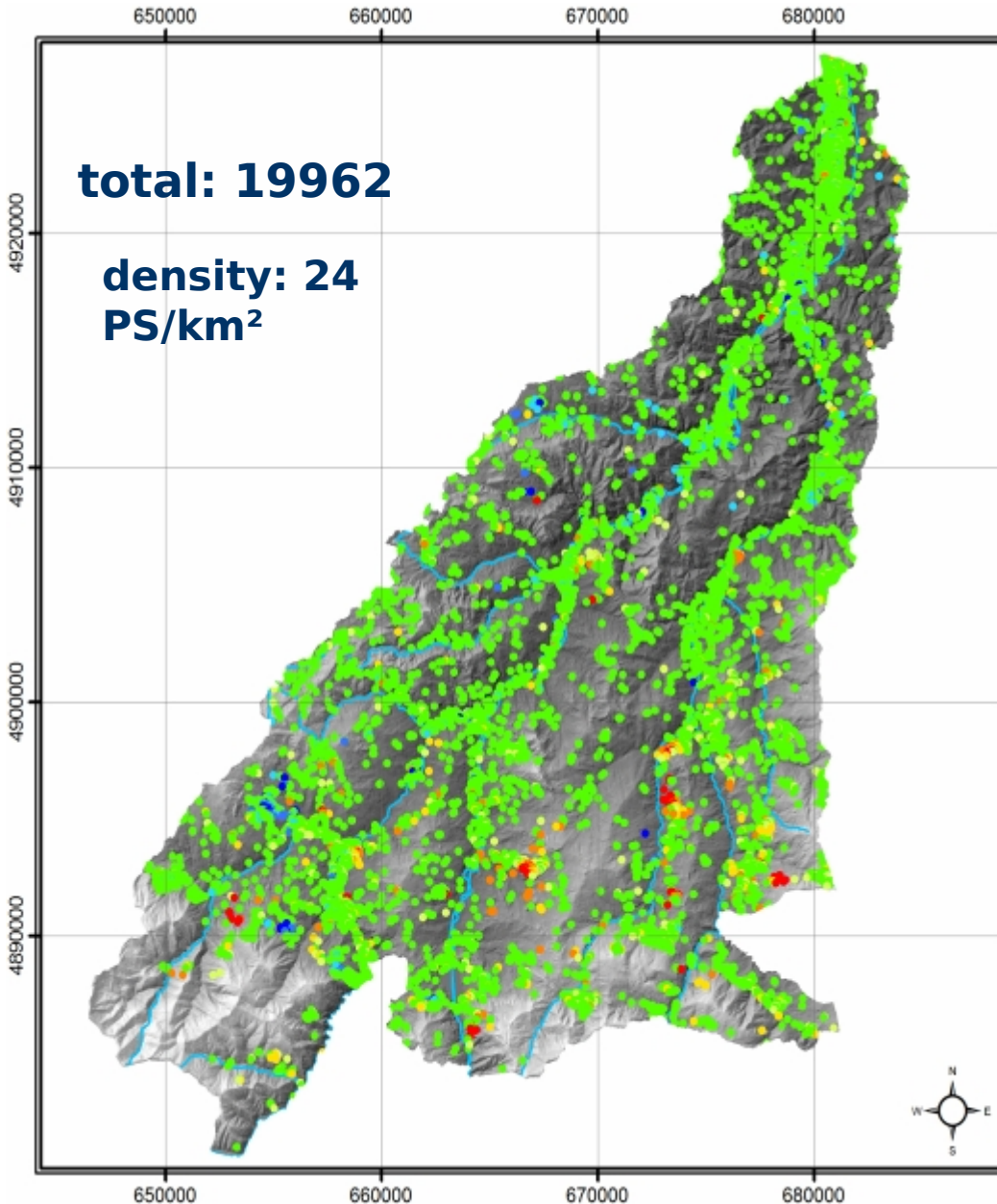


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total: 19962

density: 24
PS/km²



Regione Emilia-Romagna
Reno river basin



Legend

PS ERS Descending

Velocity (mm/y)

- -34.85 - -10.00
- -9.99 - -5.00
- -4.99 - -3.00
- -2.99 - -2.00
- -1.99 - 2.00
- 2.01 - 3.00
- 3.01 - 5.00
- 5.01 - 10.80

Permanent scatterers ERS
1993-2000

Coordinate system UTM, datum WGS84, zone 32N

PS ENVISAT ascending 2003 - 2008

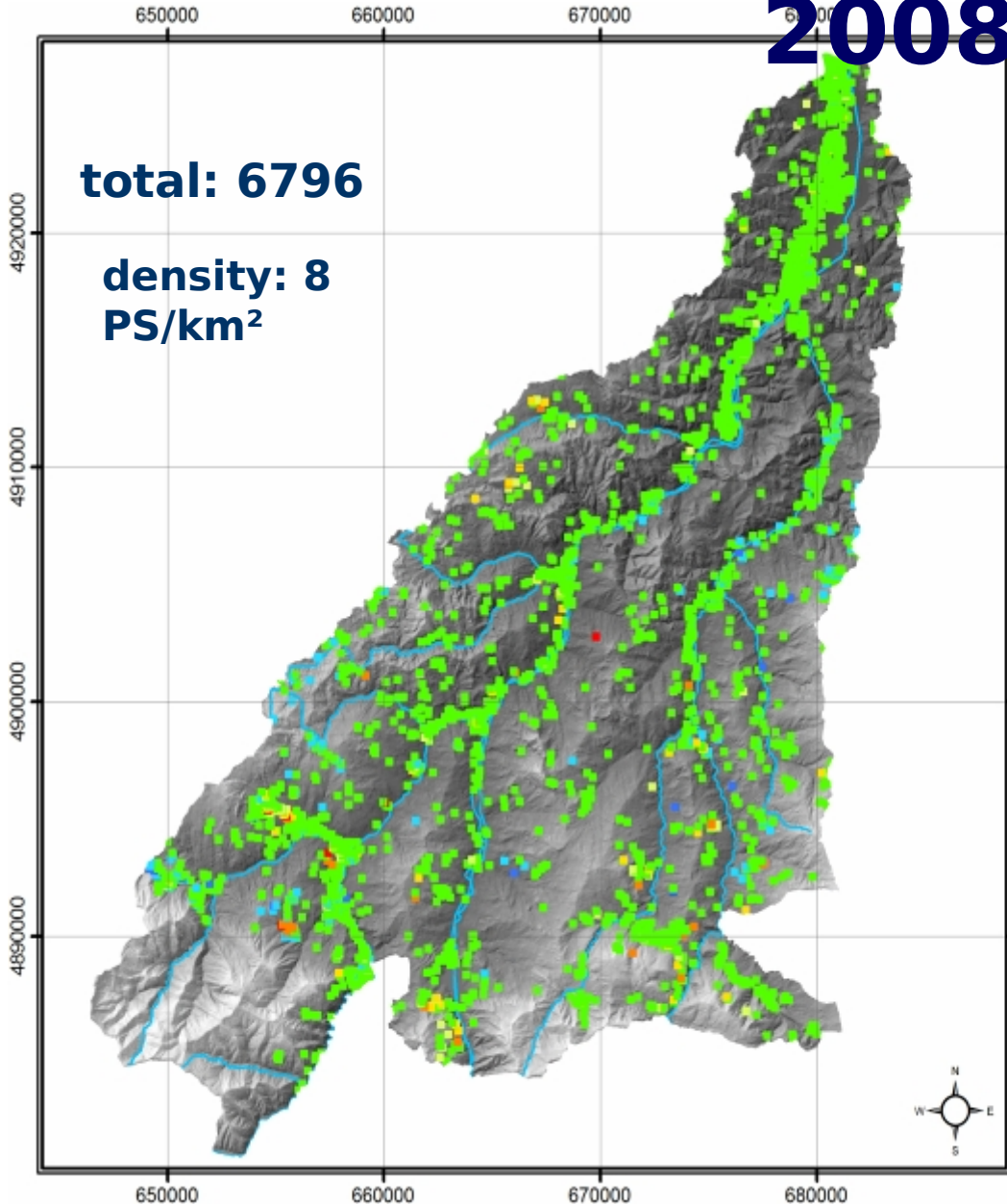


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total: 6796

density: 8
PS/km²



Regione Emilia-Romagna
Reno river basin



Legend

PS ENVISAT Ascending

Velocity (mm/y)

- -17.79 - -10.00
- -9.99 - -5.00
- -4.99 - -3.00
- -2.99 - -2.00
- -1.99 - 2.00
- 2.01 - 3.00
- 3.01 - 4.45
- 5.01 - 5.15

Permanent scatterers ENVISAT
2003-2008

Coordinate system UTM, datum WGS84, zone 32N



PS ENVISAT descending 2003 -

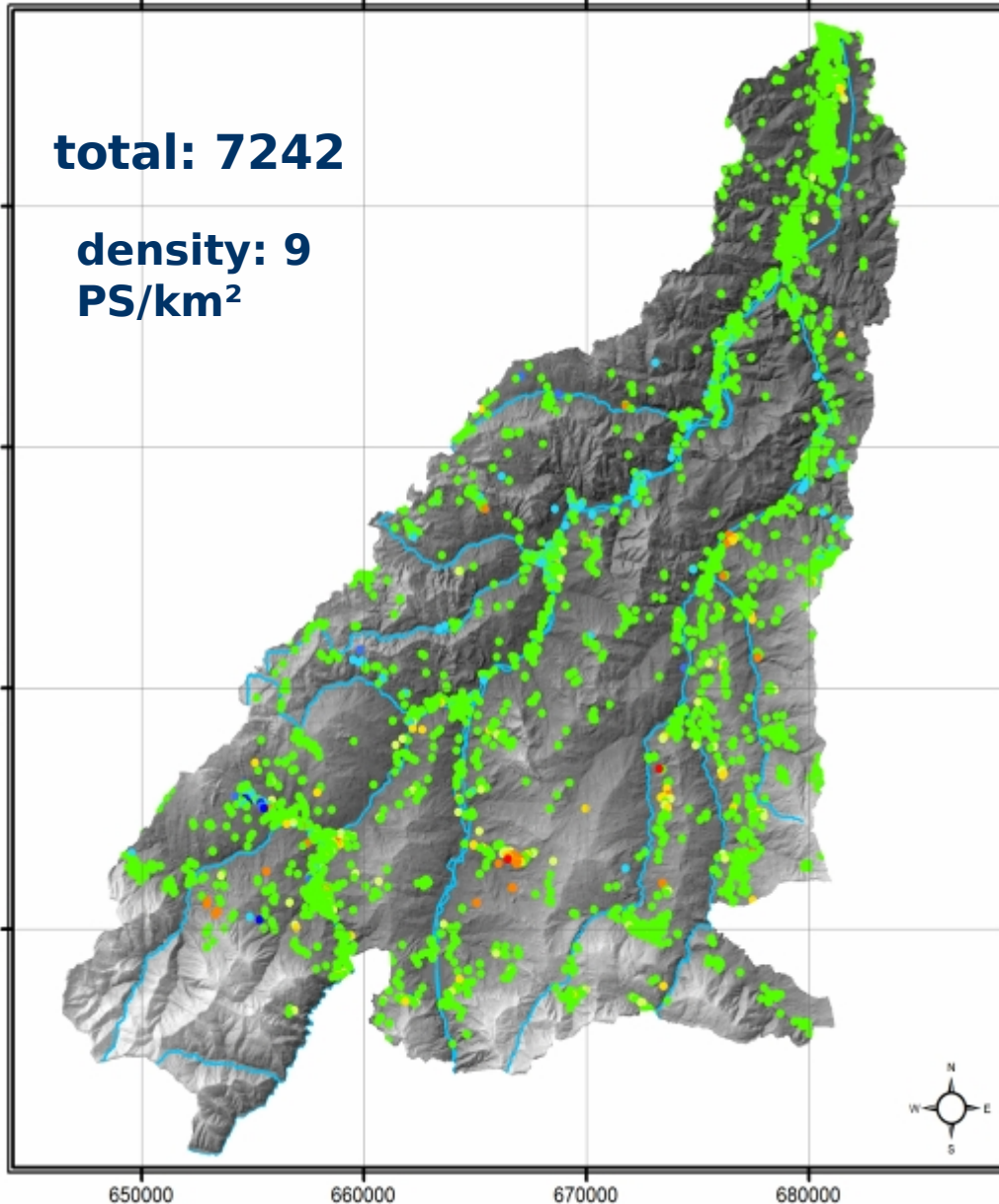


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total: 7242

density: 9
PS/km²



Regione Emilia-Romagna
Reno river basin



Legend

PS ENVISAT Descending

Velocity (mm/y)

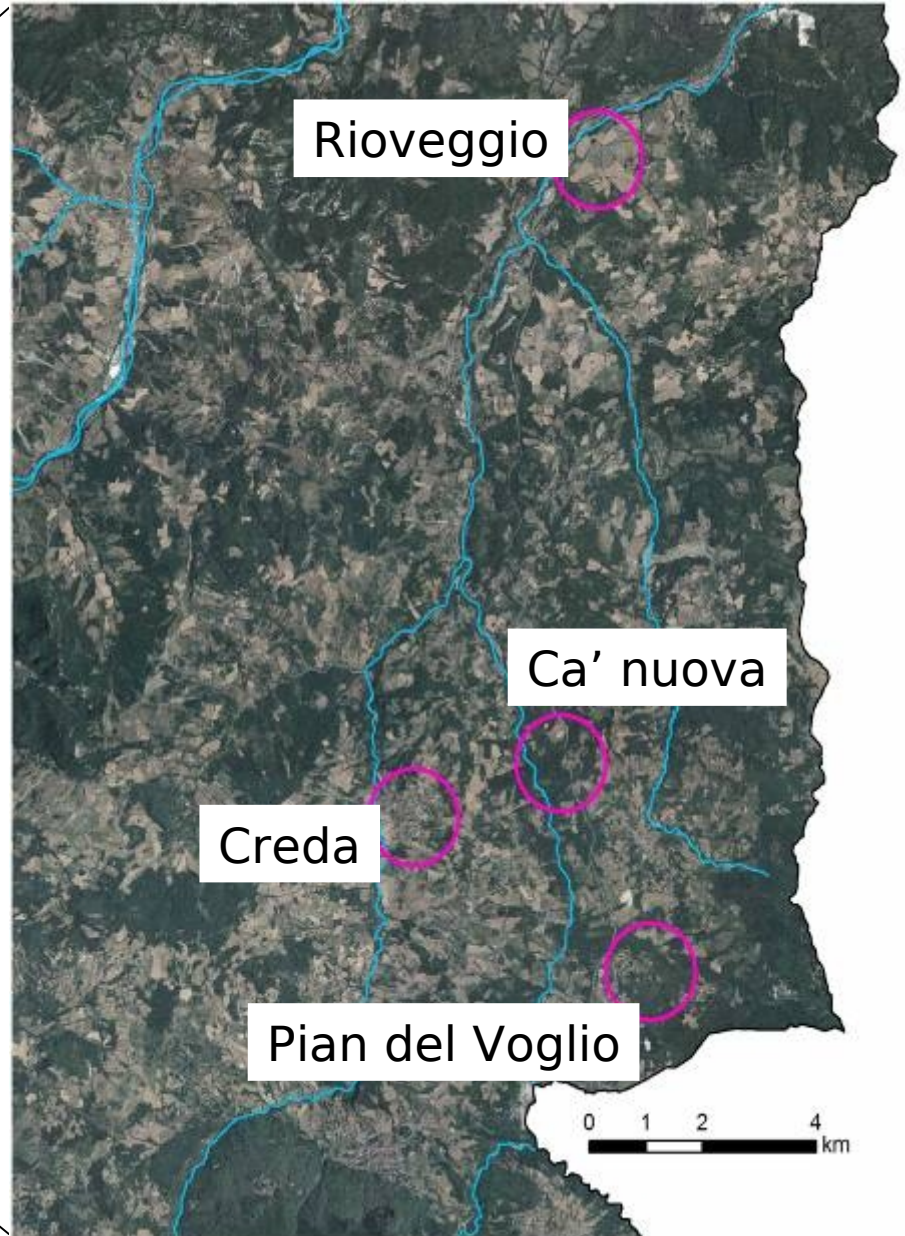
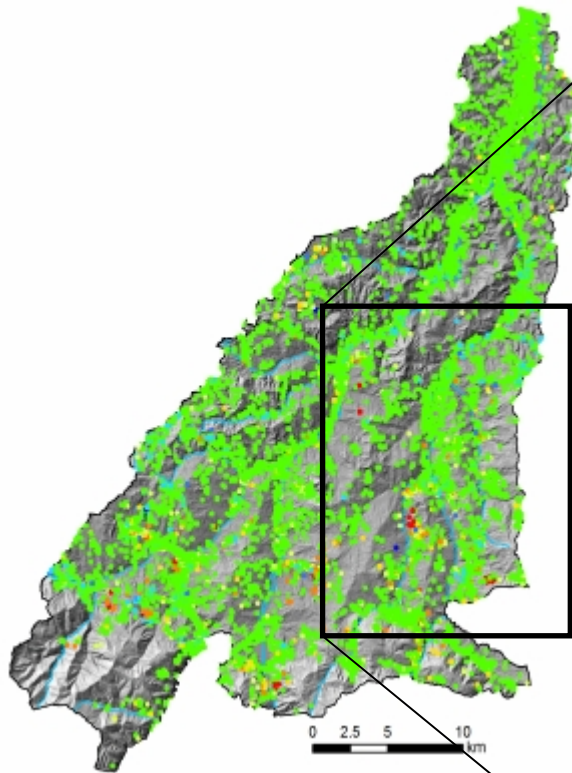
- -15.66 - -10.00
- -9.99 - -5.00
- -4.99 - -3.00
- -2.99 - -2.00
- -1.99 - 2.00
- 2.01 - 3.00
- 3.01 - 5.00
- 5.01 - 5.87

Permanent scatterers ENVISAT
2003-2008

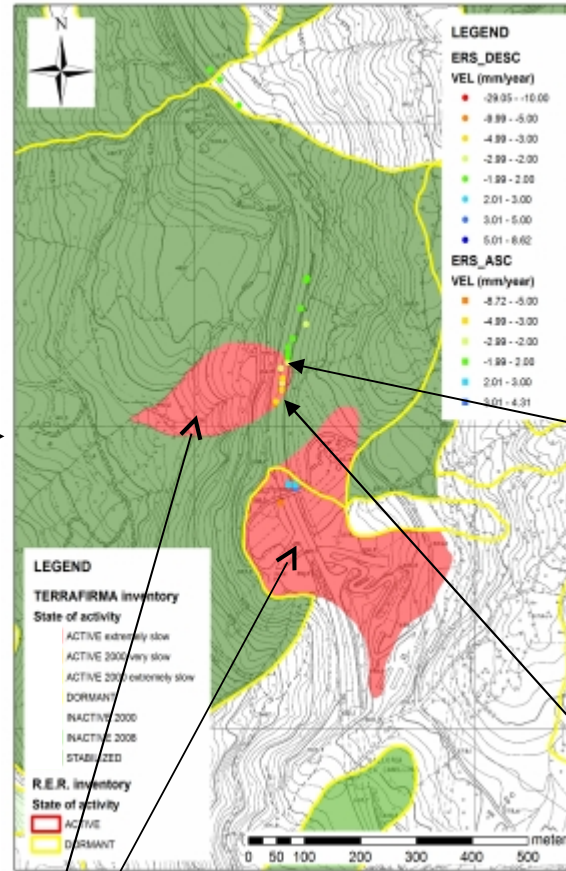
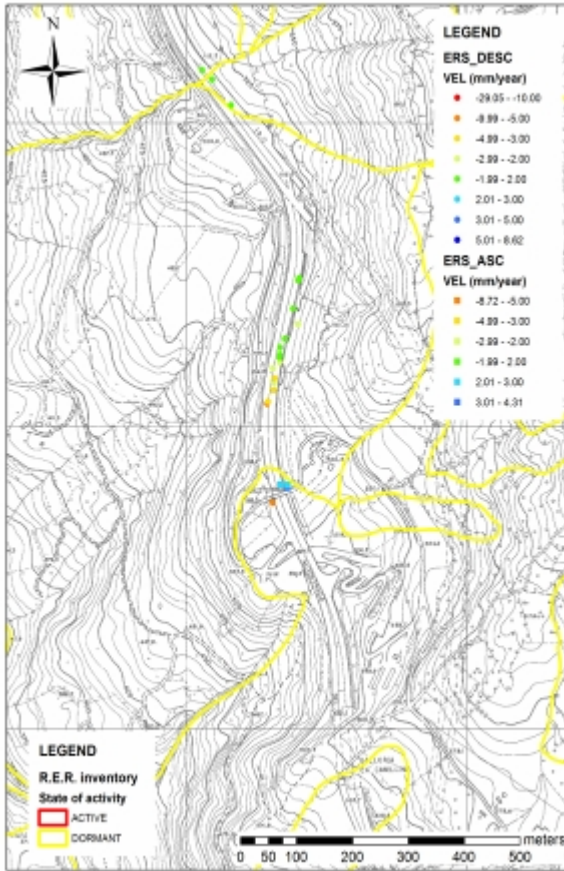
Coordinate system UTM, datum WGS84, zone 32N

Field trip

Setta subwatershed



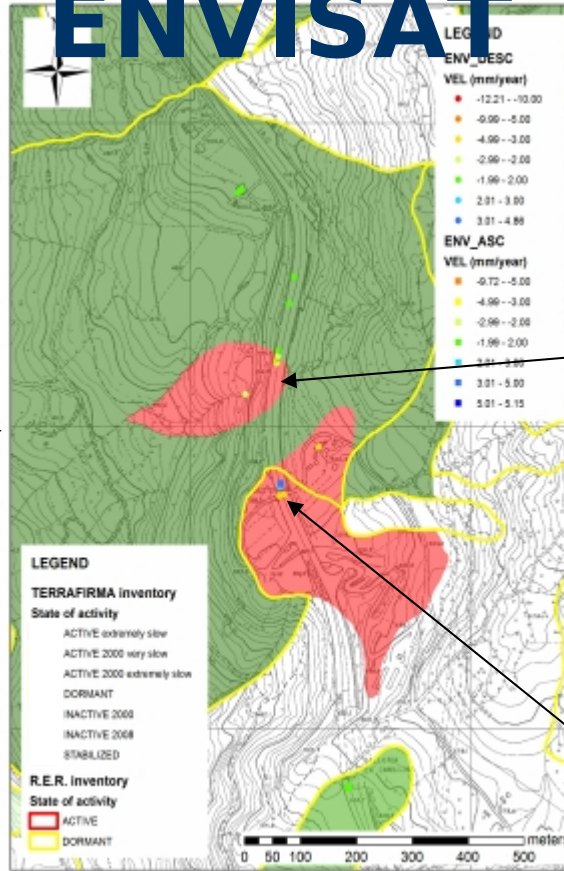
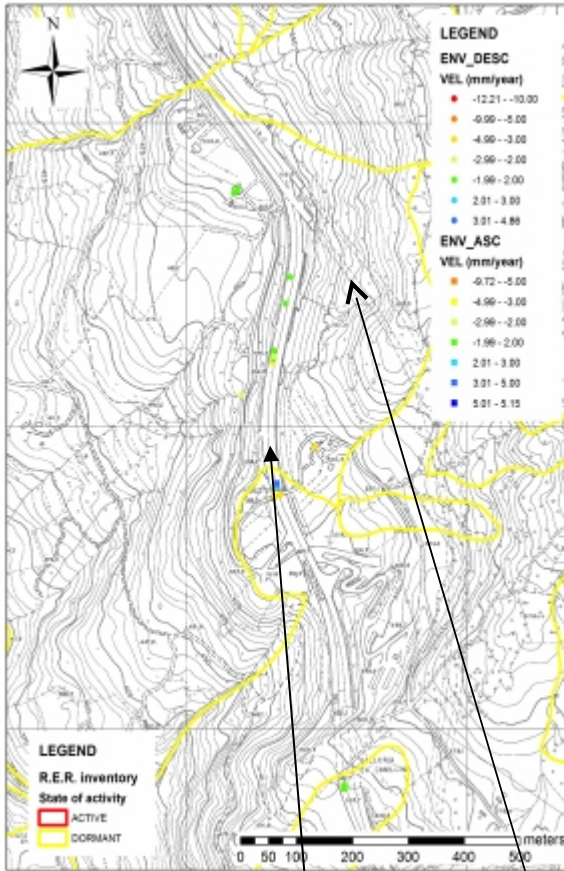
Ca' nuova (A1 highway): PS ERS



2 new active portions of a dormant landslide

Ca' nuova (A1 highway): PS

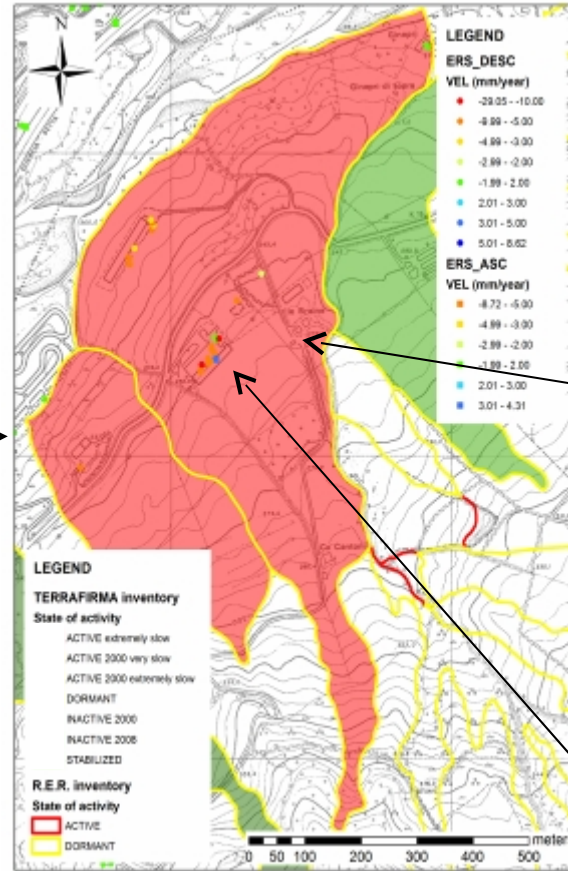
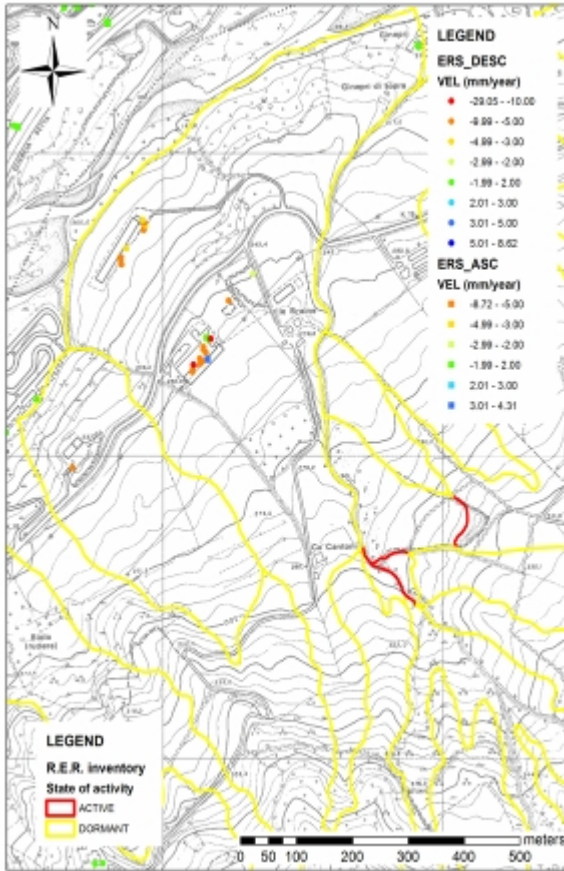
ENVISAT



New highway tunnel

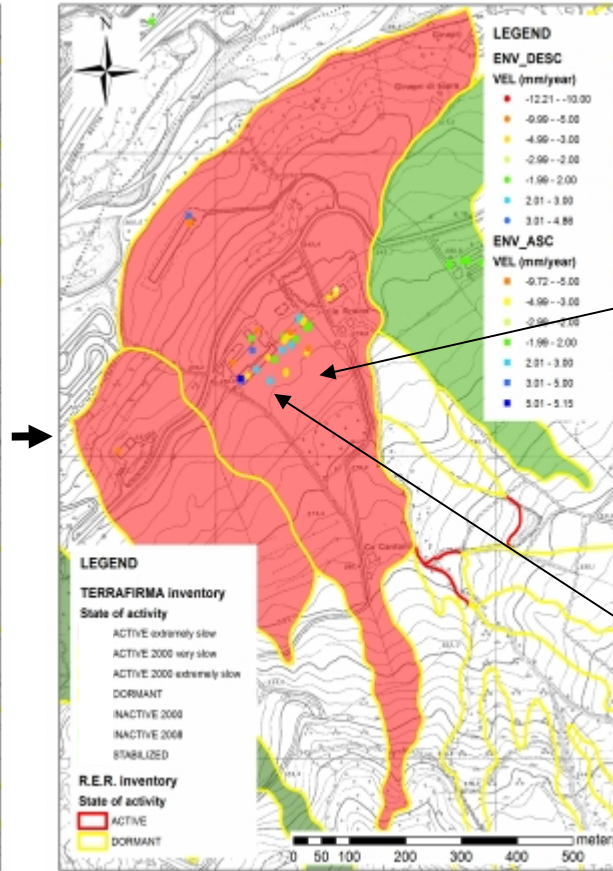
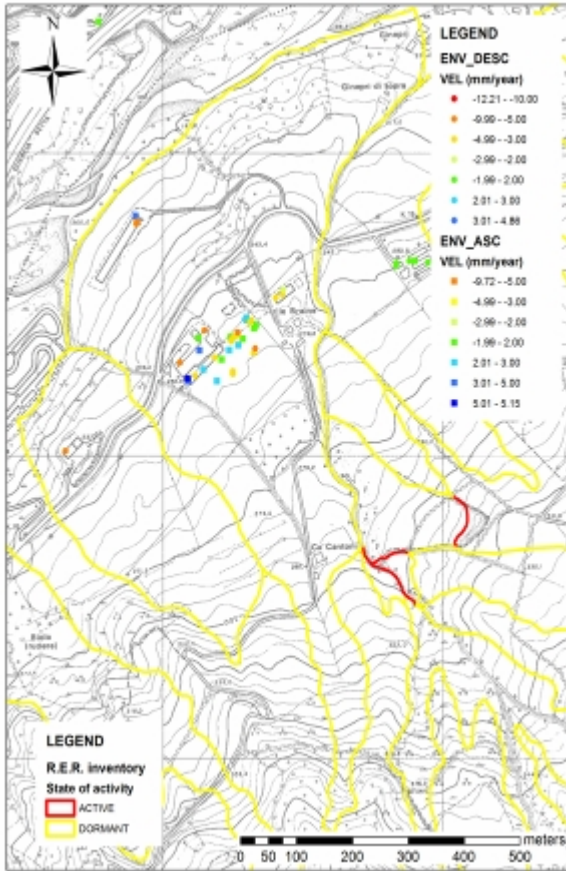
Old highway, abandoned because of structural damages

Rioveggio: PS ERS



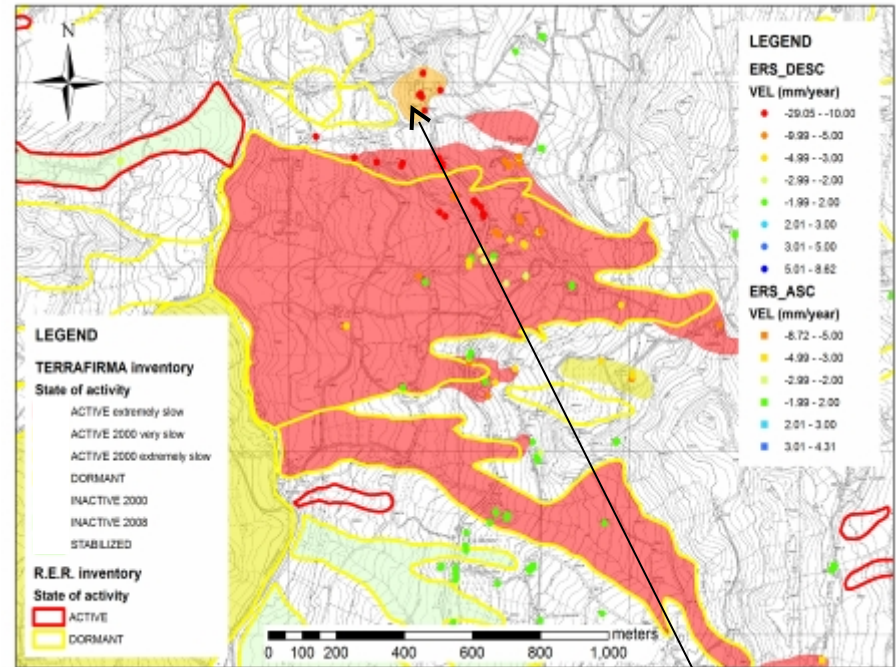
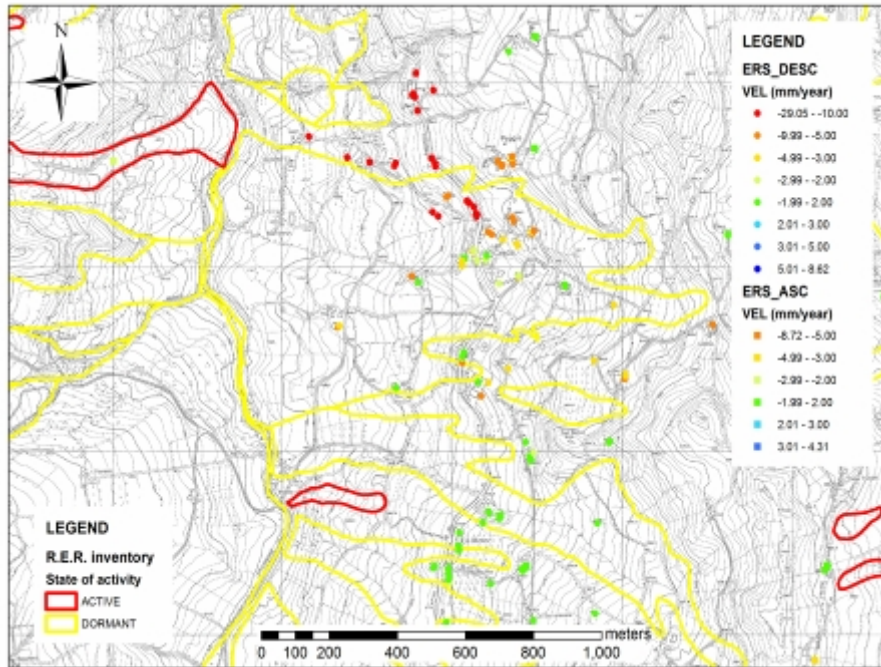
Change of activity: from *dormant* to *active*

Rioveggio: PS ENVISAT



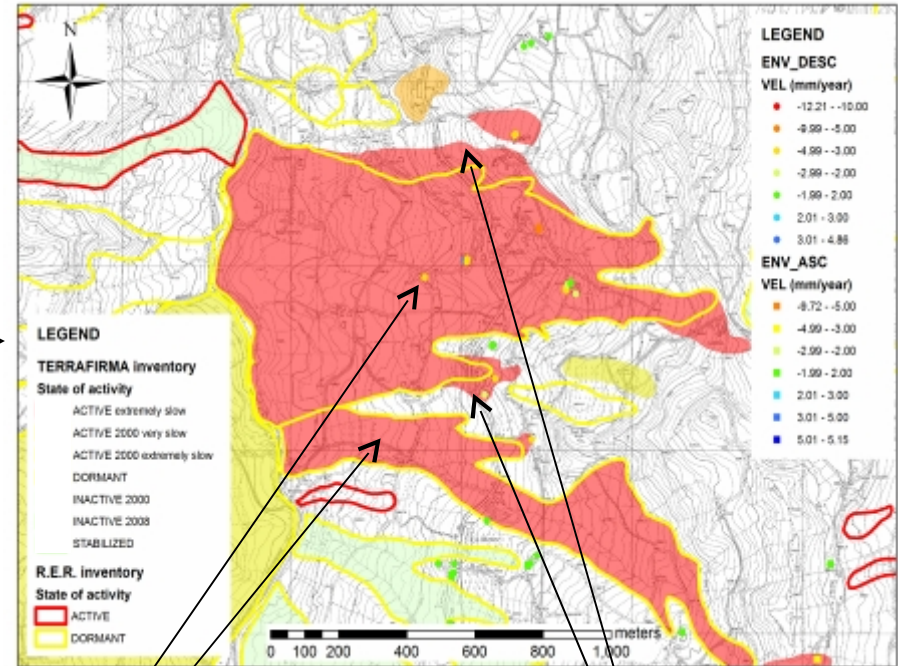
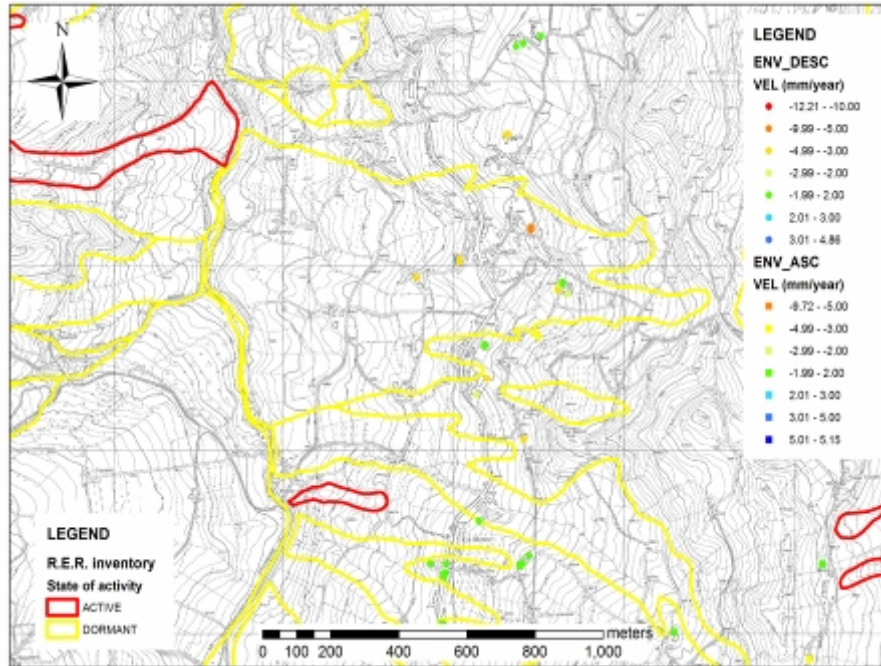
Obliterated cracks renewed by recent movements

Creda: PS ERS



A new landslide detected by means ERS PS

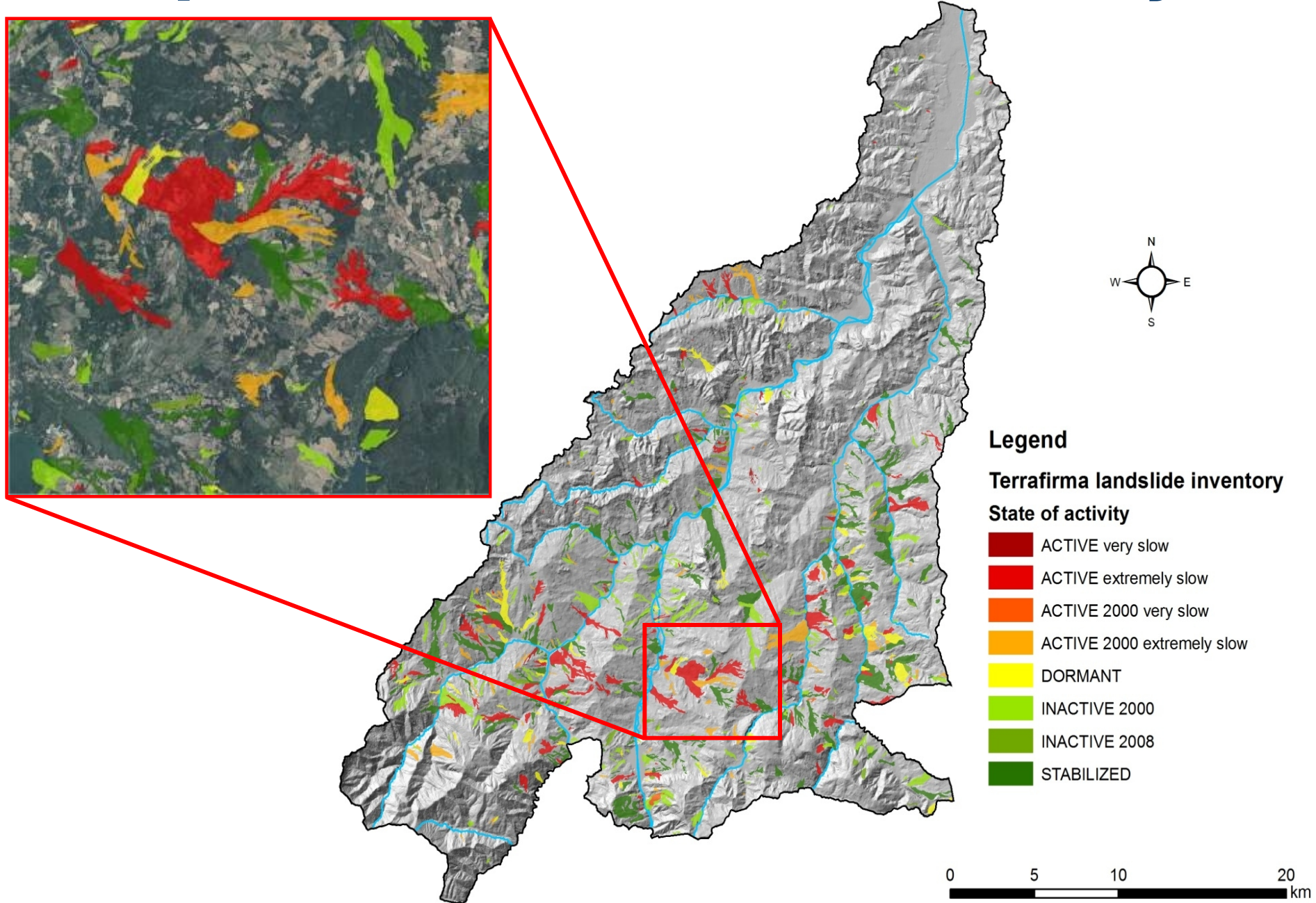
Creda: PS ENVISAT



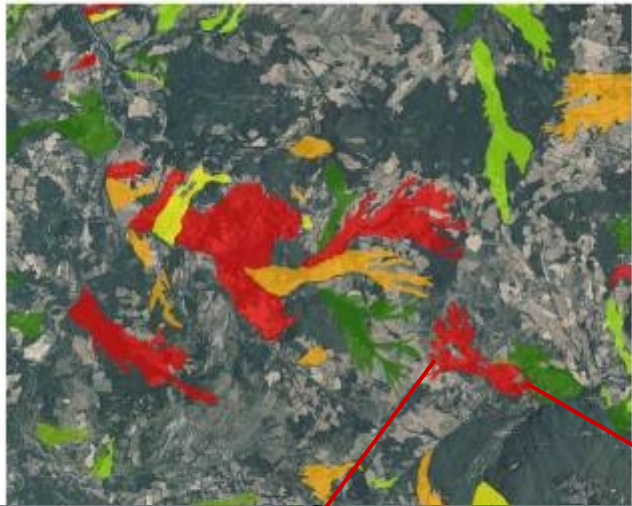
**Changes of
the state of
activity**

**Changes of
landslide
boundaries**

Updated landslide inventory



Landslide inventory database



Landslide data base:

- Geometric boundary
- Data source
- State of activity
- N° of PS ERS and ENVISAT
- Velocity statistical data

Attributes of TF Inventory frame_Reno

STATE	STATE_ILW	COMPARISON	SOURCE	N_LRS_A	VLL_LRS_A	VABS_LRS_A	MAX_LRS_A	MIN_LRS_A	N_LRS_D	VLL_LRS_D	VABS_LRS_D	MAX_LRS_D	MIN_LRS_D	N_ENV_A	VLL_ENV_A	VABS_ENV_A	MAX_ENV_A	MIN_ENV_A	N_ENV	
active	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
active	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
active	STABILIZED	mod_act	CGER+TF	0	0	0	0	0	1	0.9	0.9	0.9	0.9	0	0	0	0	0	0	0
dormant	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	INACTIVE 2008	confirmed	CGER+TF	0	0	0	0	0	0	0	0	0	0	1	0.9	0.9	0.9	0.9	0.9	0.9
dormant	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	INACTIVE 2008	confirmed	CGER+TF	0	0	0	0	0	0	0	0	0	0	1	0.1	0.1	0.1	0.1	0.1	0.1
dormant	ACTIVE extremely slow	mod_act	CGER+TF	0	0	0	0	0	0	0	0	0	0	1	-5.9	5.9	-5.9	-5.9	-5.9	-5.9
dormant	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
active	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	DORMANT	confirmed	CGER+TF	0	0	0	0	0	8	-4.8	4.8	-0.3	-8.9	2	1.3	1.3	1.8	0.8	0.8	0.8
dormant	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	STABILIZED	confirmed	CGER+TF	17	1.5	1.5	2.4	0.8	72	0.9	1.7	-3.6	8	1.5	1.5	2.3	0.8	0.8	0.8	0.8
dormant	INACTIVE 2008	confirmed	CGER+TF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
active	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
active	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
active	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
active	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	ACTIVE extremely slow	mod_act	CGER+TF	0	0	0	0	0	7	-0.3	0.8	1.5	-2.1	1	-4.3	4.3	-4.3	-4.3	-4.3	-4.3
active	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
dormant	INACTIVE 2008	confirmed	CGER+TF	0	0	0	0	0	1	-0.5	0.5	-0.5	-0.5	0	0	0	0	0	0	0
dormant	ACTIVE extremely slow	mod_bound_act	CGER+TF	1	1.9	1.9	1.9	1.9	82	-7.3	7.3	0.7	-27.5	1	3.9	3.9	3.9	3.9	3.9	3.9
dormant	N.C.	no ps	CGER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Record: 0 | Show: All Selected | Records (1 out of 5432 Selected) | Options

Updated landslide inventory

4919 PS ERS and 2852 PS ENVISAT give displacements landslide information

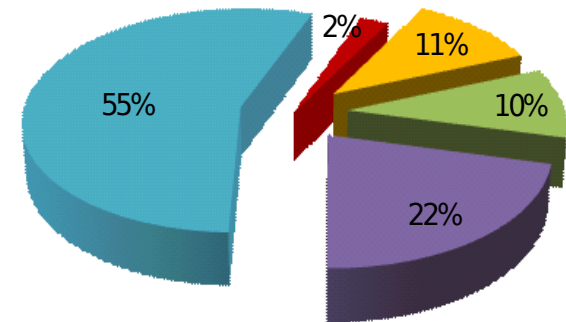
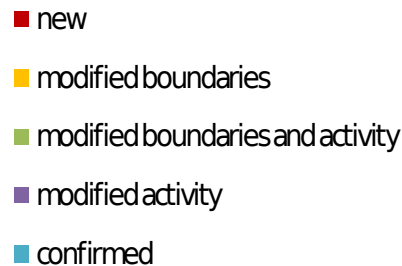
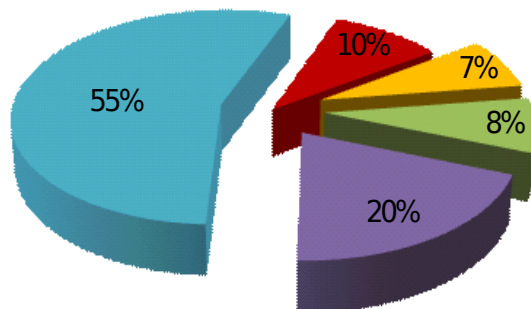
The final database consists of 5429 landslides

794 of which (15%) have PS information

357 (7%) have been modified or added by means PS information

	Number of landslides	Landslide area (km ²)
New landslides	76	2.0
Modified landslide activity	157	19.9
Modified boundaries	60	10.2
Modified boundaries and activity	64	9.3
Confirmed landslides	437	51.2

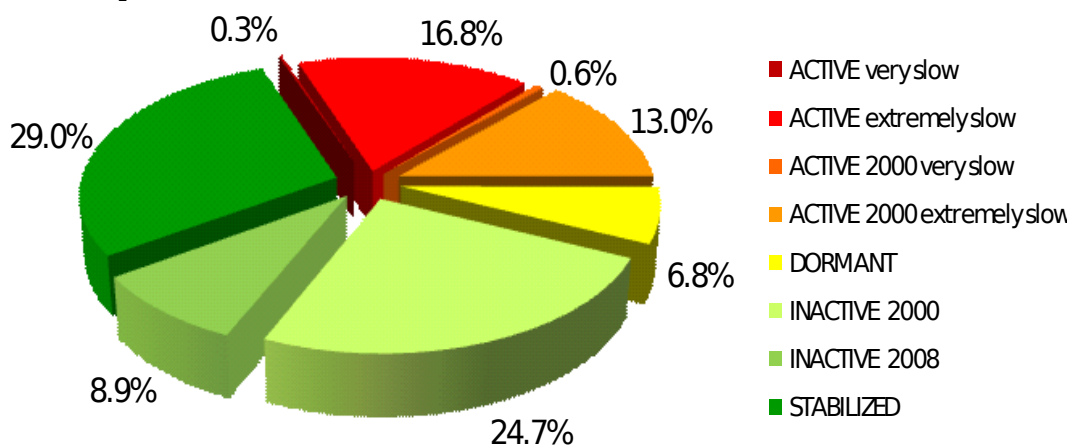
By number **By area**



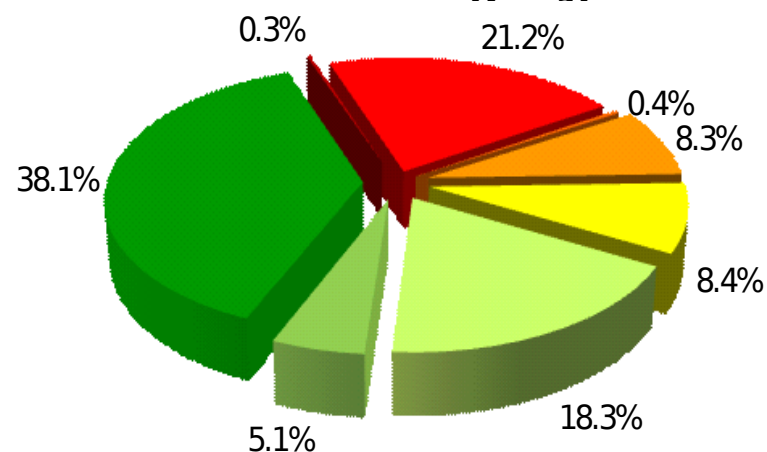
Updated state of activity

State of activity	Number of landslides	Landslide area (km ²)
Active very slow	2	0.3
Active extremely slow	133	19.6
Active 2000 very slow	5	0.4
Active 2000 extremely slow	103	7.7
Dormant	54	7.8
Inactive 2000	196	16.9
Inactive 2008	71	4.7
Stabilized	230	35.3

By



By area



Ancona

landslide monitoring

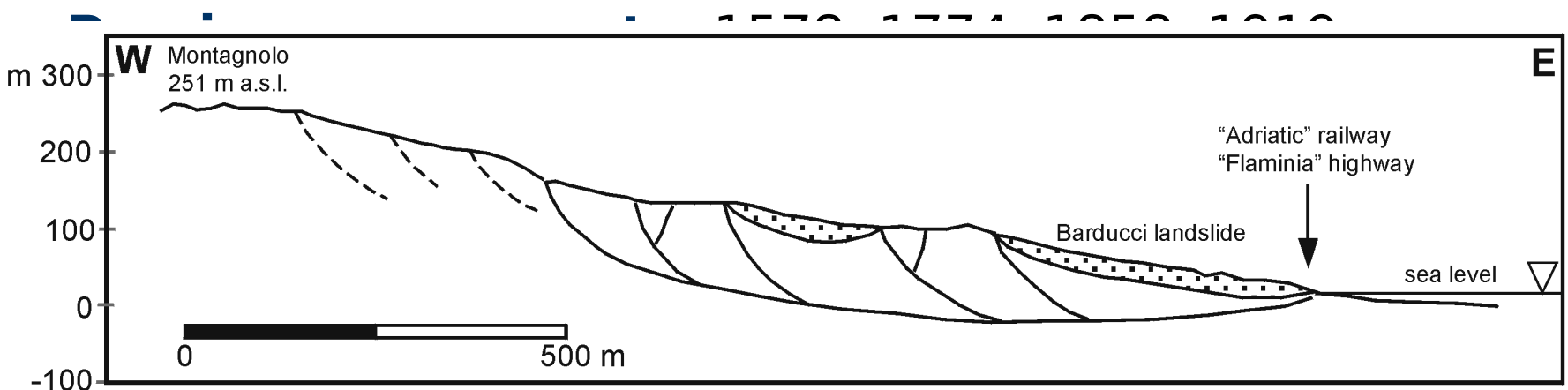


Legend

-  Landslide (PAI)
-  Studied area

Ancona landslide

- **Type:** Compound earth slide
- **Volume:** more than 200 million cubic meters (one of the largest landslide in Italy)
- **Depth:** more than 100 m
- **Re-activation:** The landslide was partially reactivated in 1982 causing widespread damages, involving more than 250 buildings and the Adriatic railway, the A-14 motorway and the SS.16 highway.



Input Data

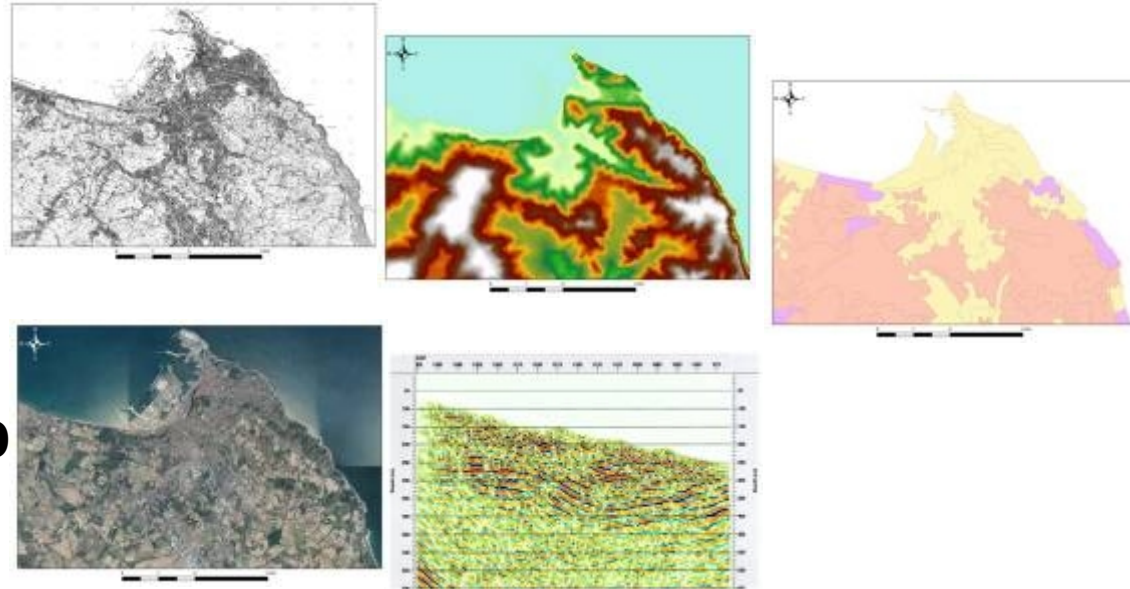
Topography 1:10.000

DEM 20mx20m

Corine Land Cover (2000)

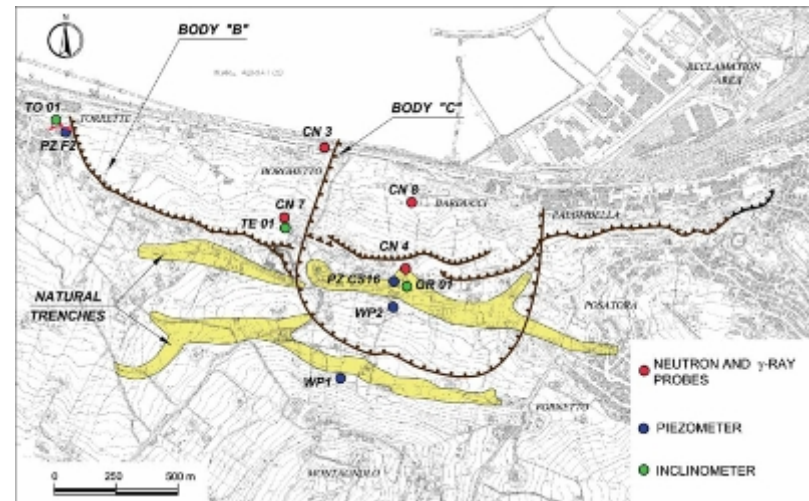
Ortophoto (VOLOITALIA 200

Seismic line



in-situ measurements:

- **Inclinometers**
- **Piezometers**
- **Estensometers**



PS ERS (1992-2000)



ERS PS number:

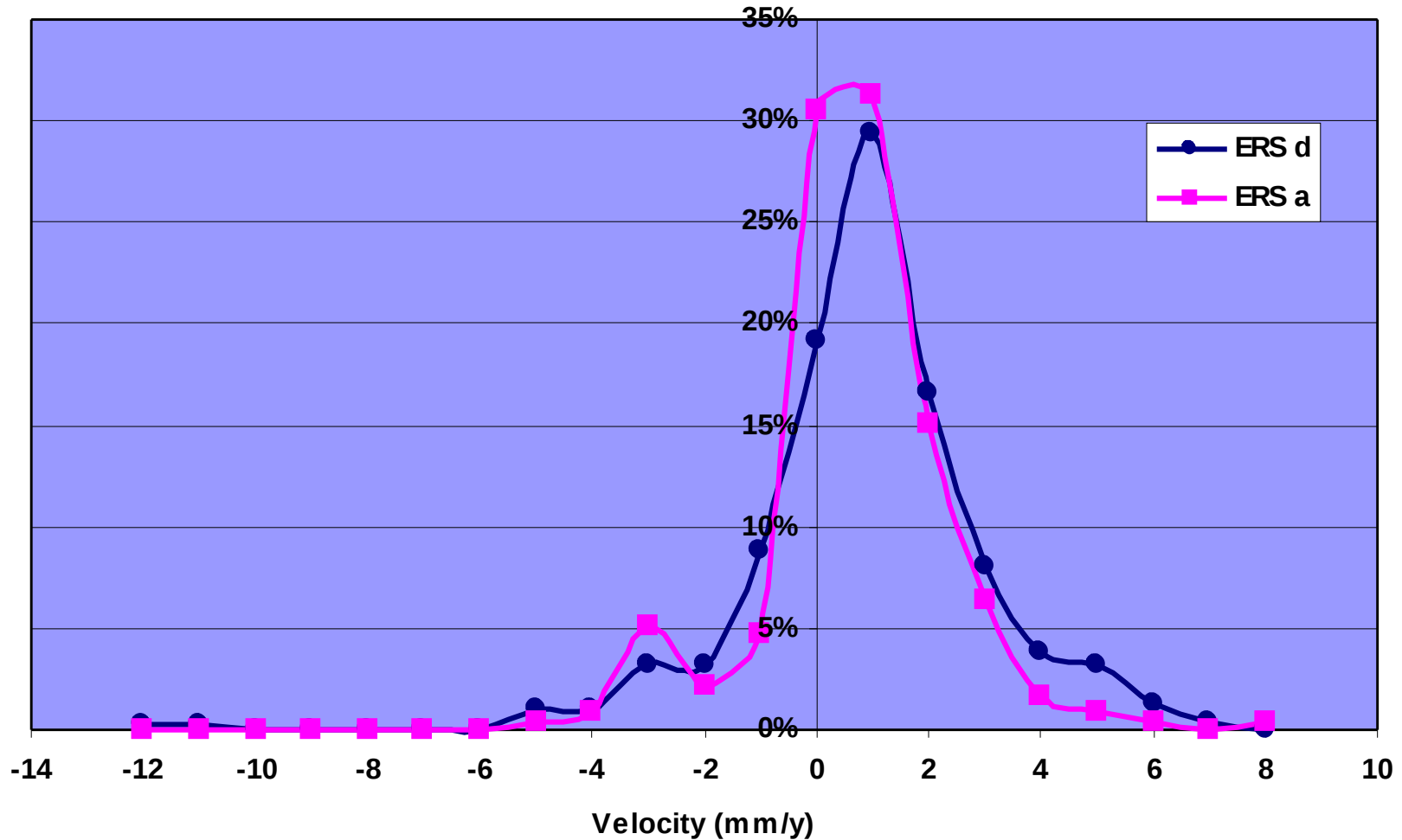
- 233 Asc
- 463 Desc

ERS PS density:

- 88,6 PS/km²
- 176 PS/km²

PS ERS (1992-2000) distribution

Frequency distribution PS ERS



PS ENVISAT (2002-2008)



Legend

ENVISAT Asc Velocity (mm/y)

- -8,46 - -5,00
- -4,99 - -3,00
- -2,99 - -2,00
- -1,99 - 2,00
- 2,01 - 5,34

ENVISAT Desc Velocity (mm/y)

- -8,46 - -5,00
- -4,99 - -3,00
- -2,99 - -2,00
- -1,99 - 2,00
- 2,01 - 5,34

□ landslide

ENVISAT PS number:

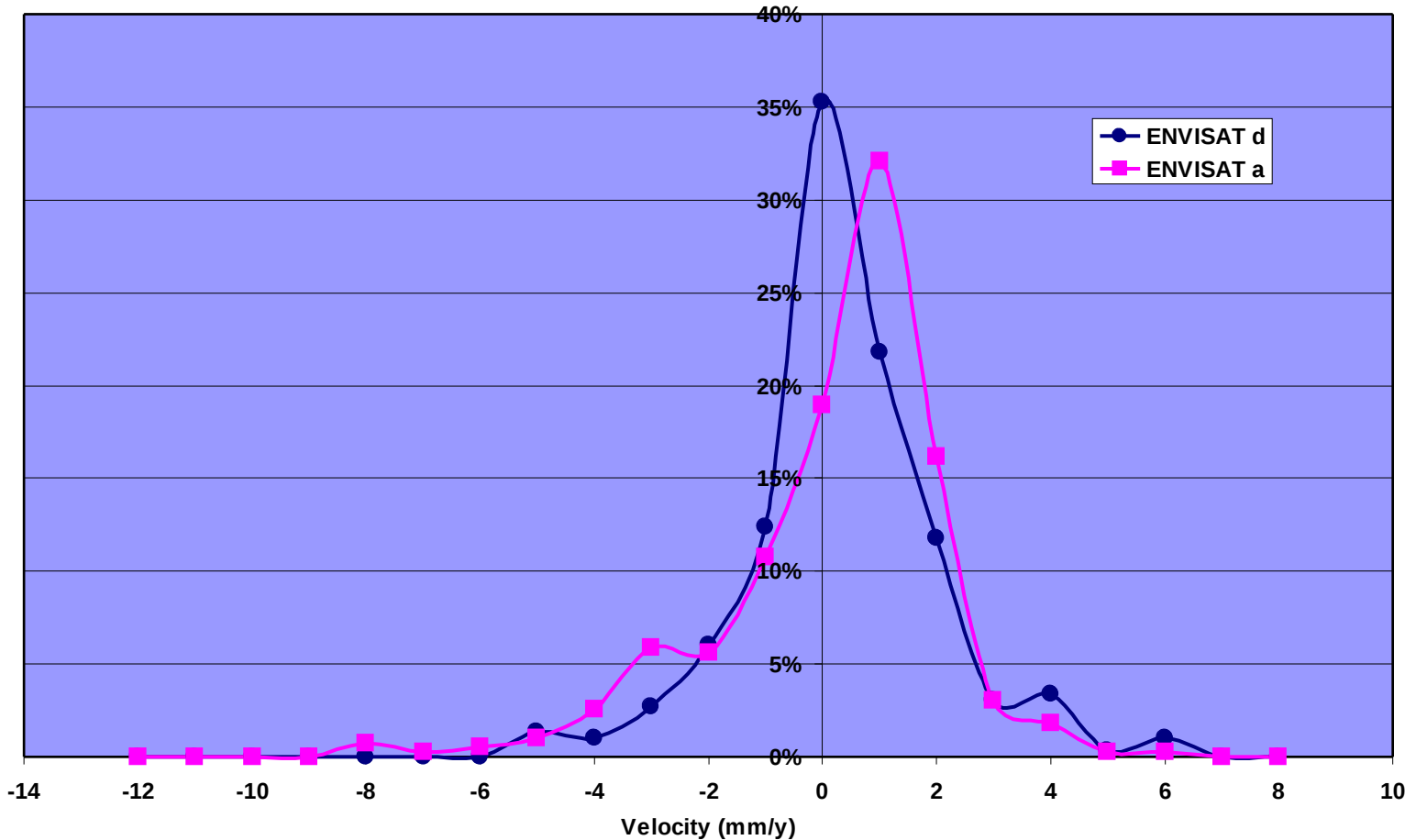
- 390 Asc
- 298 Desc

ENVISAT PS density:

- 148,3 PS/km²
- 113,3 PS/km²

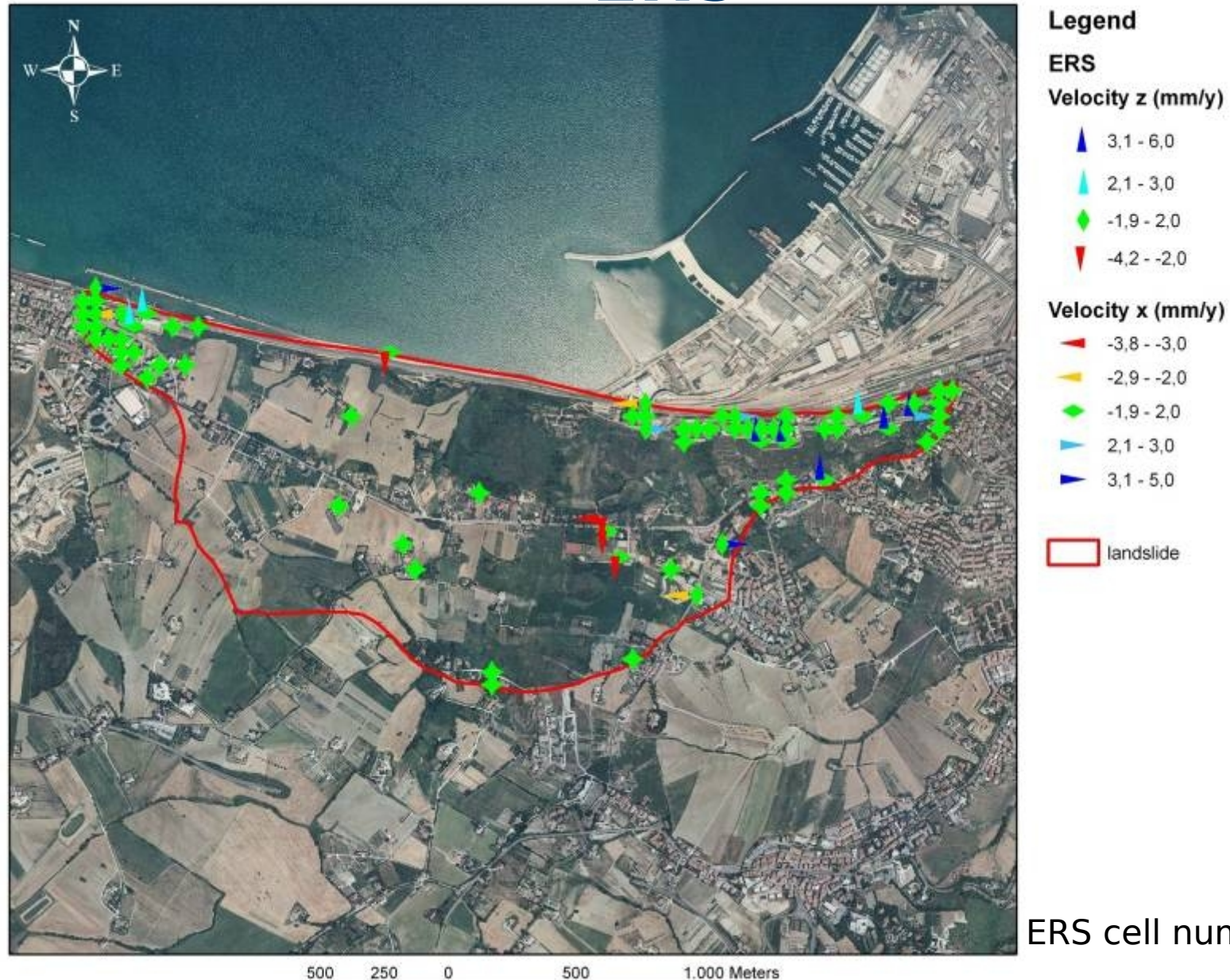
PS ENVISAT (2002-2008) distribution

Frequency distribution PS ENVISAT



The frequency distribution supported by the spatial analysis distribution, points out that the positive values and negative values for both the geometry acquisition for ERS and ENVISAT data are spatially correlated and this suggests that the measured displacements should be referred mainly to the zenith component.

Zenith (z) and E-W (x) components PS ERS



ERS cell number: 73

Zenith (z) and E-W (x) components PS ENVISAT



Legend

ENVISAT

Velocity z (mm/y)

- ▲ 2,1 - 6,0
- ◆ -1,9 - 2,0
- ▼ -2,9 - -2,0
- ▼ -5,6 - -3,0

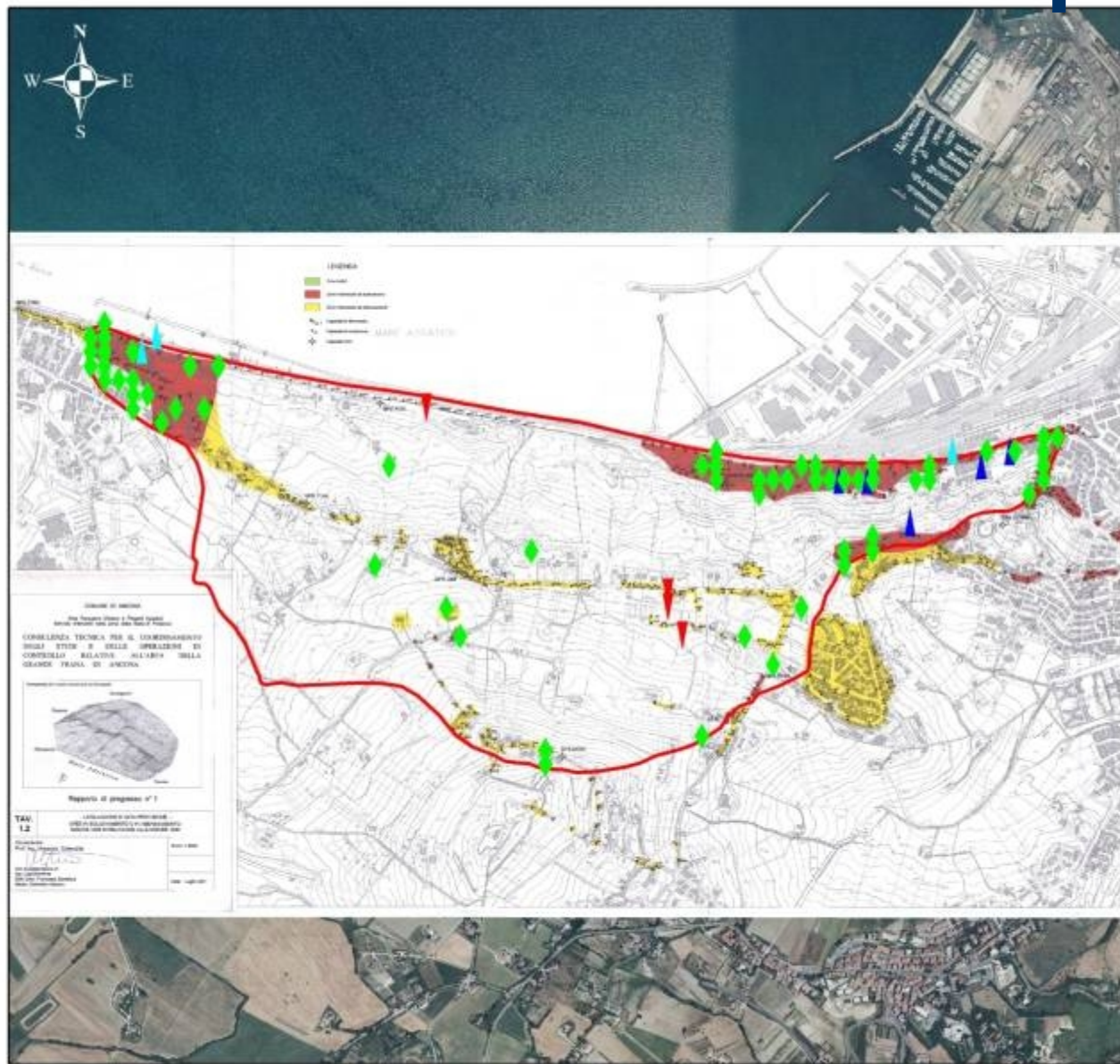
Velocity x (mm/y)

- ▶ -6,7 - -5,0
- ▶ -4,9 - -2,0
- ◆ -1,9 - 2,0
- ▶ 2,1 - 5,0
- ▶ 5,1 - 8,0

▭ landslide

ENVISAT cell number: 95

Topographic levelling 1983-1999 vs 1992-2000 ERS z-component



Legend

ERS

Velocity z (mm/y)

▲ 3,1 - 6,0

▲ 2,1 - 3,0

◆ -1,9 - 2,0

▼ -4,2 - -2,0

▭ landslide

▭ Stable areas

▭ Areas in uplift

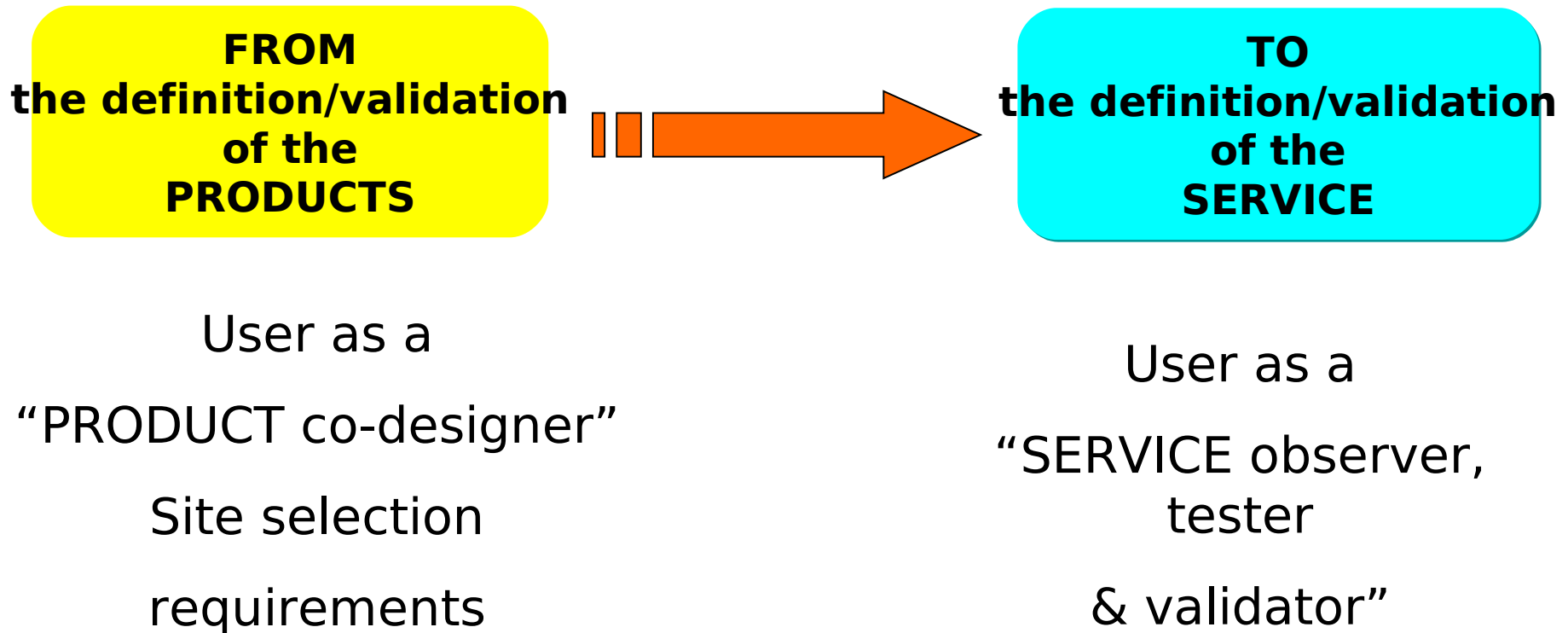
▭ Areas in subsidence

500 250 0 500 1.000 Meters

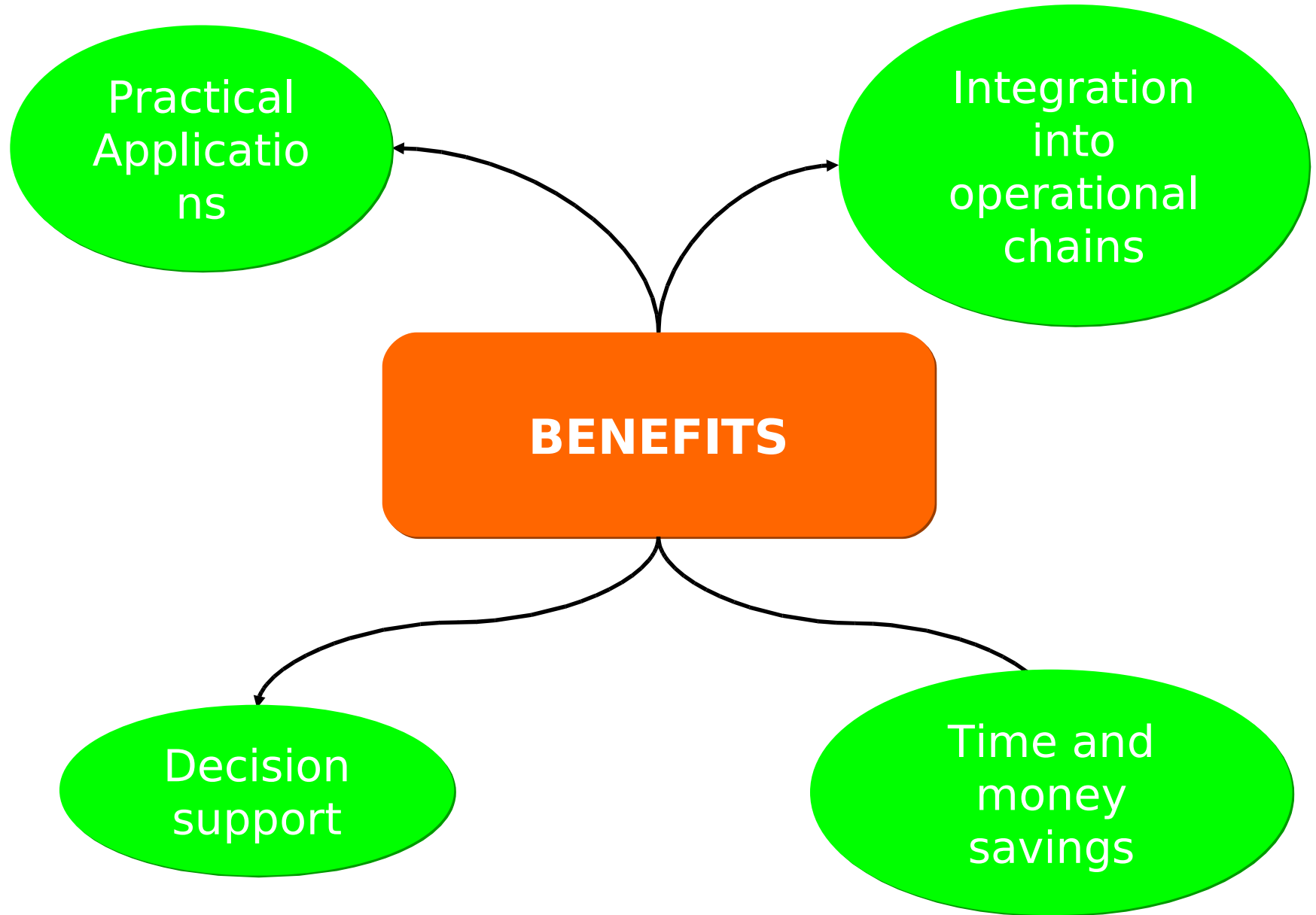
Final consideration

- The PSI analysis is correlated to the geological mechanism of the sliding phenomenon that, even if has not been clarified yet, take into account rotational movement features distinguishing a descent front in the inland Posatora area and an ascent front along the coast line (Confalonieri and Mazzotti, 2001; Cotecchia 2006).
- Furthermore the PSI analysis confirm that new ENVISAT processing could improve the real time monitoring system on the Ancona landslide and the availability of both ascending and descending orbit acquisition could help to understand the dynamics of landslide.

User's role



User's evaluation



User's feedback statements

“The product can be used following emergencies induced by landslides.....or as a **basic information layer** to be used along with other thematic layers to carry out field surveys...”

(DPC, 2006)

“The knowledge of past ground movements using **quantitative measurements** over **wide areas** represents a fundamental benefit for our activity...”

(DPC, 2008)

“A better identification of the **boundaries of unstable areas**, especially in urban sectors of the slope, and of their **state of activity** improves the quality of the emergency plans.”

(DPC, 2008)

Conclusions

- Results confirm the capabilities of multi-interferometric InSAR data, integrated with conventional techniques and field surveys, to support landslide investigation at regional and slope scale.
- The use of PSI approach can positively impact on the current hazard mitigation activities along national and local authorities, especially over urban areas.
- A next step is to tailor the analysis to new EO missions (Sentinel 1, Terrasar-X, CosmoSky Med).

An aerial photograph of a hillside. A road with a metal guardrail runs across the top of the hill. Below the road, a large section of the hillside has eroded, showing exposed soil and rocks. The surrounding area is covered in dry, brownish grass and some green shrubs. The text "THANK YOU FOR YOUR ATTENTION" is overlaid in the center of the image in a bold, red, sans-serif font.

THANK YOU FOR YOUR ATTENTION