Basic information about Landslides

Landslide Definition

What is a Landslide?

Movement of a mass of rock, debris or earth down a slope (Cruden, 1991)

Layout

Section 1

- Basic Landslide Types

Section 2

- Landslides Zoning Maps

Section 3

- Multi Temporal Interferometry (MTI) Constraints and Requirements

Section 4

- Bibliographic Review-Landslides Case Studies using MTI

Section 5

- Exploitation of MTI results

Section 6

- BEYOND Area of Interest

Basic information about Landslides

Basic Landslide Types

The type of movement describes the actual internal mechanics of how the landslide mass is displaced: ***fall***, ***topple, slide, spread,*** or ***flow.***

Landslides are described using two terms that refer respectively to *material* and *movement*.

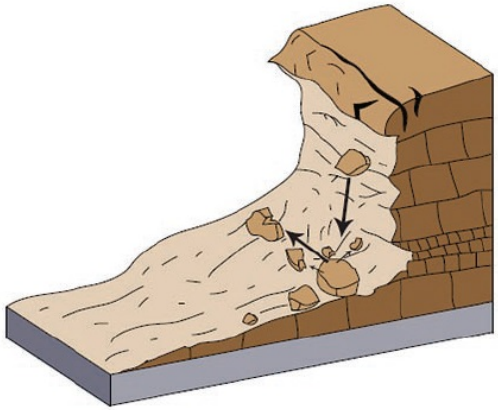
- **Falls**
  - Rockfalls
  - Topples
- **Lateral Spreads**
- **Slides**
  - Rotational
  - Translational
- **Flows**
  - Debris
  - Debris avalanches
  - Earthflows
  - Creep (slow earth flow)

Cruden and Varnes, 1996

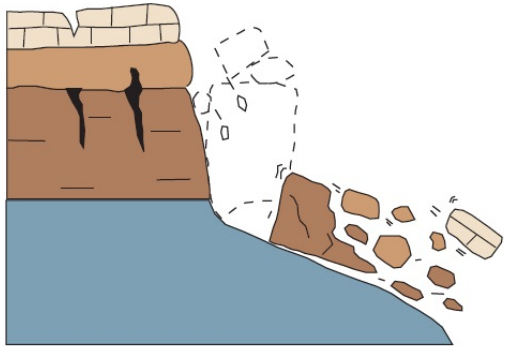
Basic information about Landslides

Basic Landslide Types

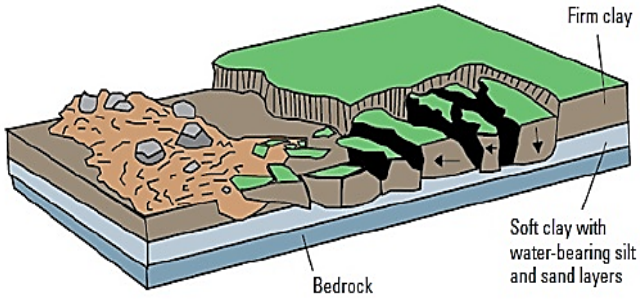
Fall (Rockfall)



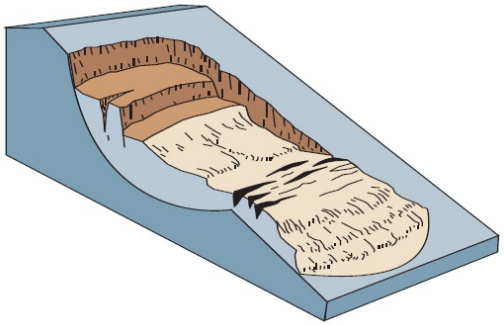
Topple



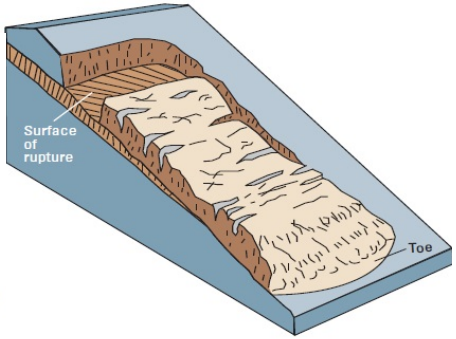
Lateral Spread



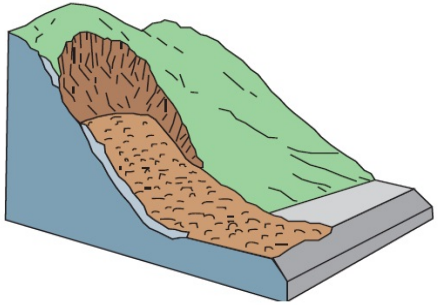
Slides Rotational



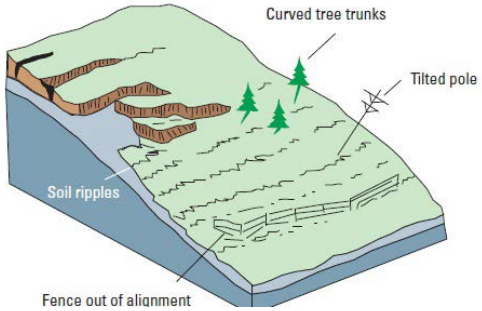
Slides Translational



Debris flow



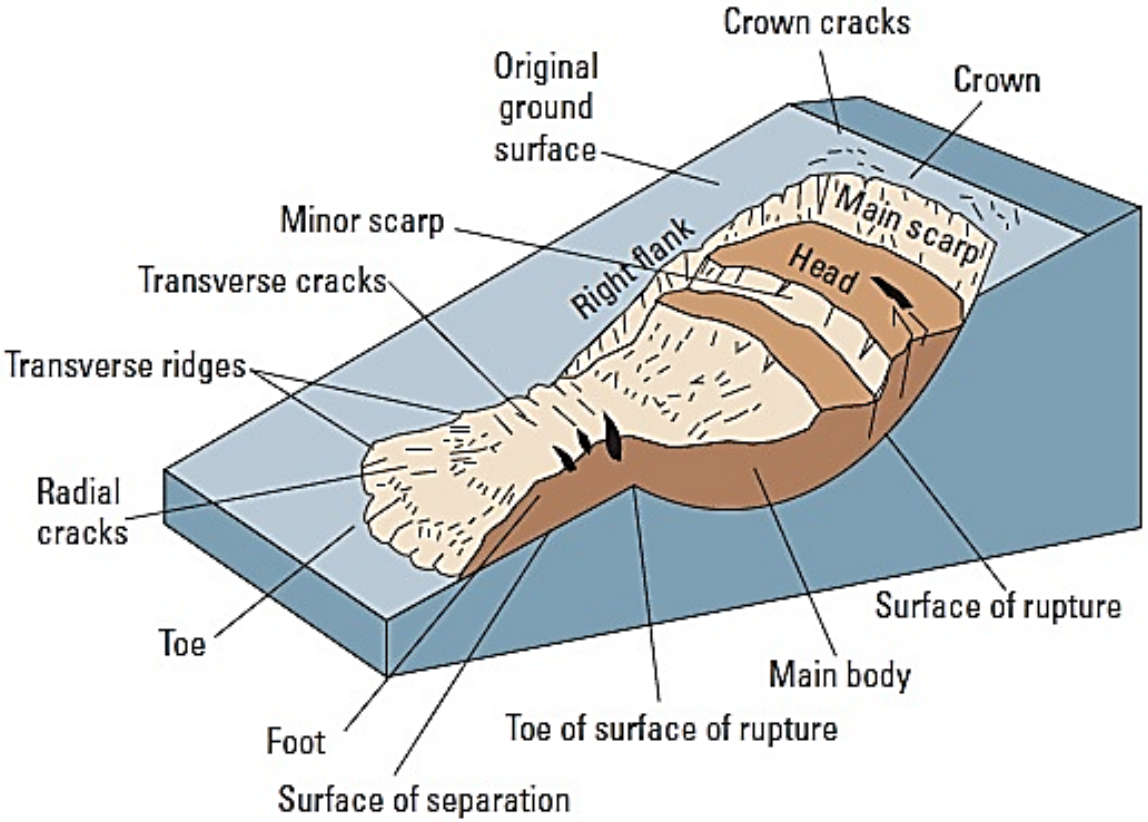
Creep-Slow Earth flow



Cruden and Varnes, 1996

Basic information about Landslides

Parts of a Landslide



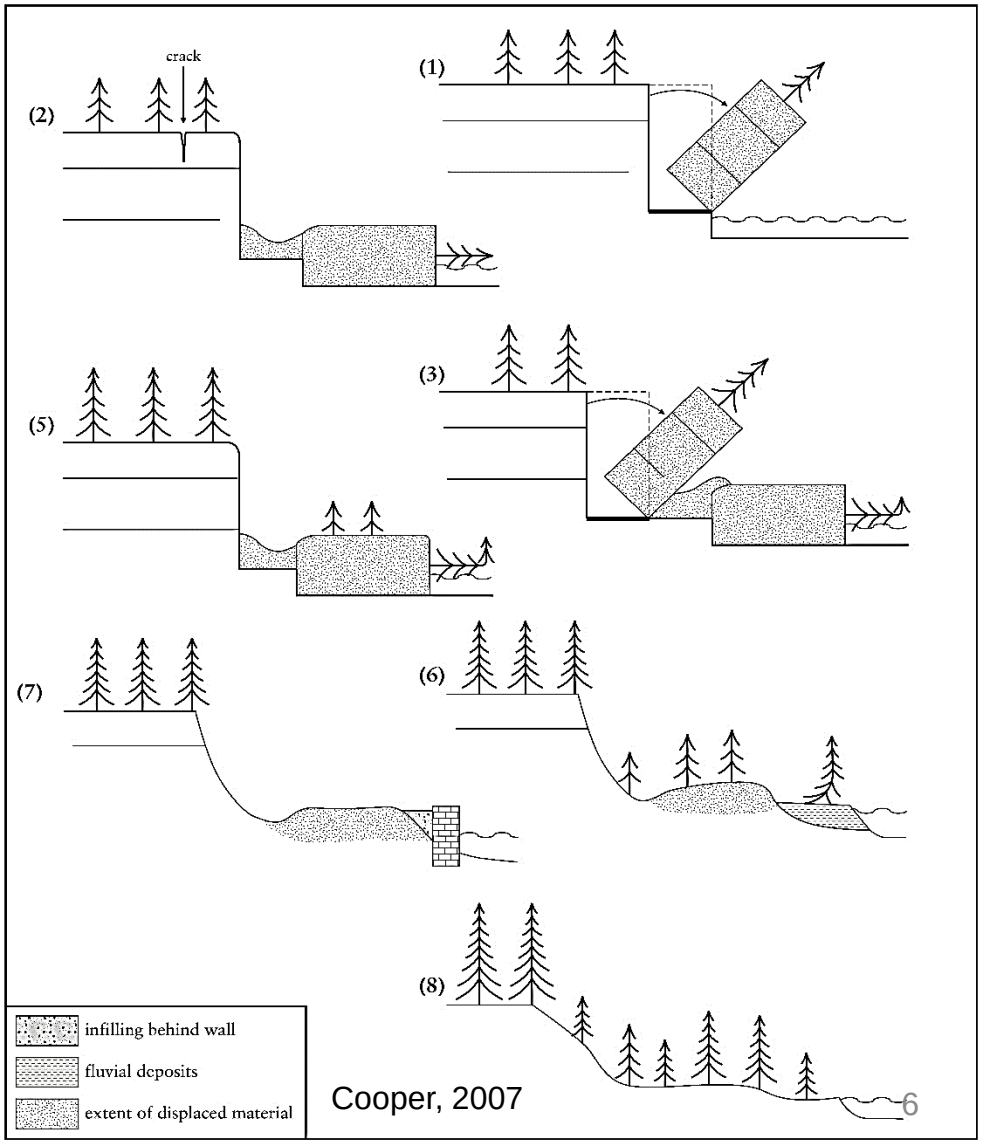
Varnes, 1978

A rotational landslide that has involved into an earthflow

Basic information about Landslides

Landslides State of Activity

1. An **active** LS is currently moving
2. A **suspended** LS has moved within the last 12 months but is not active at present
3. A **reactivated** LS is an active LS which has been inactive
4. An **inactive** LS has not moved within the last 12 months
5. A **dormant** LS is an inactive LS which can be reactivated
6. An **abandoned** LS is an inactive LS which is no longer affected by its original causes
7. A **stabilized** LS in an inactive LS which has been protected by artificial remedial measures
8. A **relict** LS is an inactive LS which developed under conditions different from those at present



Cooper, 2007

Basic information about Landslides

Bibliographic Review

Landslide velocity scale (Cruden and Varnes, 1996).

Velocity class	Description	Velocity (mm/sec)	Typical velocity
7	Extremely Rapid		
	----------	$5x10^{3}$	5 m/sec
6	Very Rapid		
	----------	$5x10^{1}$	3 m/min
5	Rapid		
	----------	$5x10^{-1}$	1.8 m/hr
4	Moderate		
	----------	$5x10^{-3}$	13 m/month
3	Slow		
	----------	$5x10^{-5}$	1.6 m/year
2	Very Slow		
	----------	$5x10^{-7}$	16 mm/year
1	Extremely Slow		

Basic information about Landslides

What Causes landslides?

Overview of factors (conditioning and triggering) controlling the occurrence of LS

- **Topography** *(elevation, slope gradient, direction)*
- **Geology** *(rock types, weathering, discontinuities)*
- **Soils** *(soil types, depth, geotechnical & hydrological properties)*
- **Hydrology** (*groundwater, soil moisture, stream network)*
- **Geomorphology** *(geomorphological environment, old LS, past LS activity*)
- **Land use and anthropogenic factors** *(current land use, drainage, mining, dams)*
- **Earthquakes and volcanoes** *(seismicity, fault mechanism, volcano type)*
- **Weather and climate** *(precipitation, temperature)*

Maps according to the type of zoning

- **LS Inventory maps:** Where do which Landslides occur?
- **LS Susceptibility zoning maps:** Where could Landslides occur?
- **LS Hazard zoning maps:** When do what Landslides occur?
- **LS Risk zoning maps:** What consequences do Landslides have?

Risk=Hazard × Vulnerability

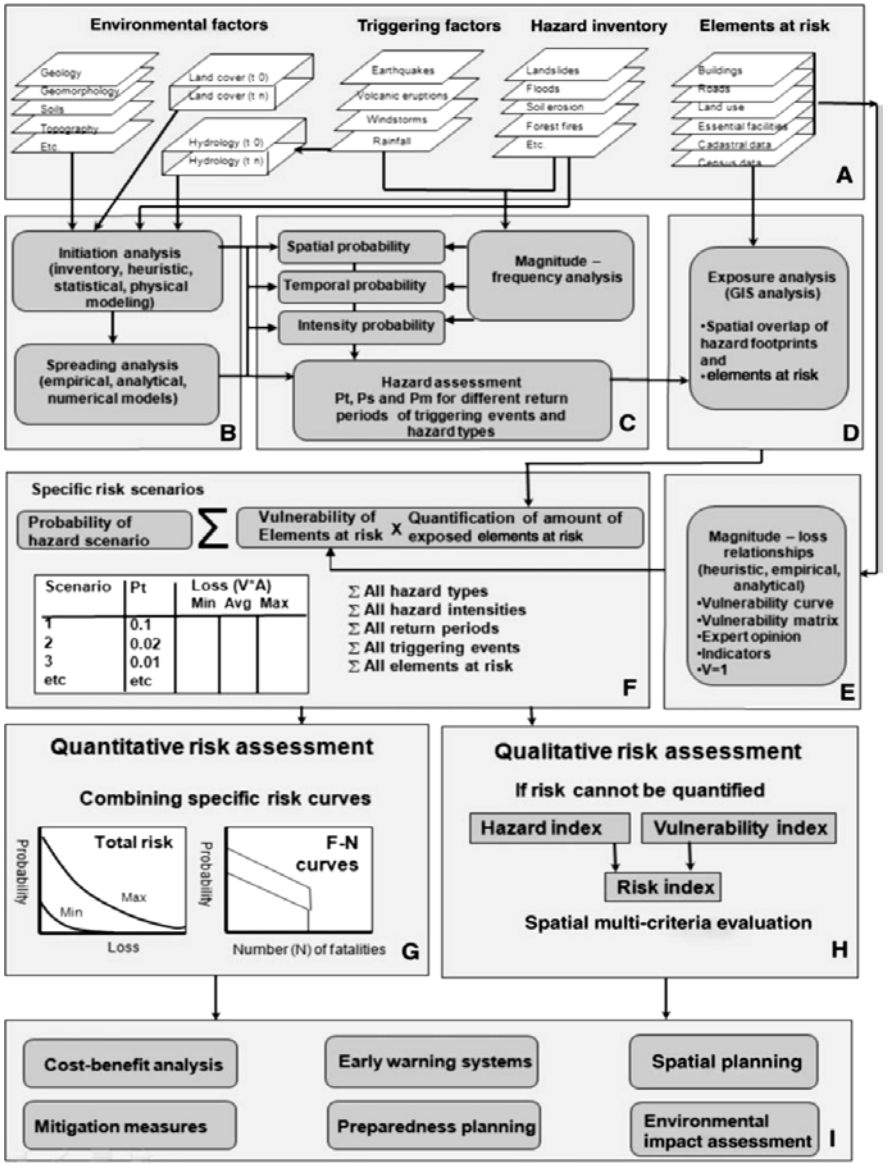
Scales of work

- **National <1:250,000**
- **Regional 1:250,000-1:25,000**
- **Local 1:25,000-1:5,000**
- **Site-specific >1:5,000**

Basic information about Landslides

Landslide Zoning Maps

Framework of multi-hazard landslide risk assessment (based on Van Western et al. 2005)



Basic information about Landslides

Landslide Zoning Maps

Overview of sources of input data for the initiation analysis

- **Laboratory analysis** *(soil properties, rock properties)*
- **Field measurements** *(soil depth, geophysics, soil & rock characteristics, hydrological characteristics, vegetation)*
- **Monitoring networks** *(landslide displacement, groundwater, meteorological data, seismic data)*
- **Field mapping** *(LS, geomorphology, lithology, structural geology, vegetation, land use, elements at risk)*
- **Archive studies and ancillary data** *(past LS events, damage data, changes in land use, elements at risk etc)*
- **Remote sensing** *(aerial photographs, satellite images, multi-spectral imagery, digital elevation data)*

Principles of Multi Temporal Interferometry (MTI)

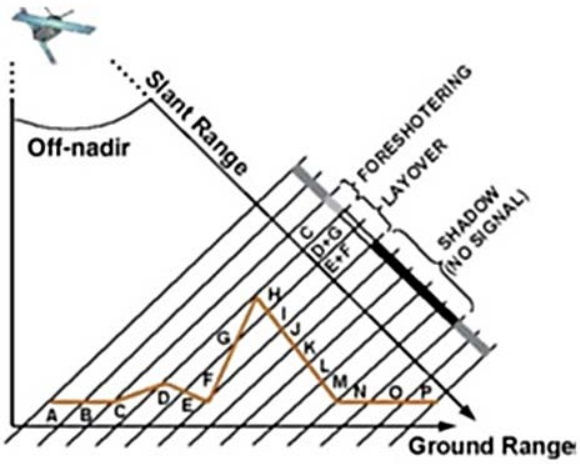
- Exploitation and processing of long temporal series of SAR data
- Identification of radar targets which provide a backscattered phase signal measurable through time
- MTI techniques overcome several limiting factors affecting conventional Interferometry
- Some of the advantages:
  - Possibility to investigate a posteriori past deformation phenomena by exploiting historic ERS and ENVISAT archives
  - Reduction of the decorrelation noise
  - Estimation and removal of atmospheric artefacts

Constraints-Requirements on the MTI use for (landslide) monitoring_1

- **The moving area should be covered by groups of at least 10 to 20 pixels, (about an order of magnitude larger than the resolution of an imaging sensor)**
  - ERS & ENVISAT satellites have 20m of LOS spatial resolution->1pixel=$20^2m^2=400m^2$
  - So, the slide surface should extend 10-20pxlsx$400m^2$ = $4000m^2$-$8000m^2$=0.004-0.008km^2
  - Improvement: Use higher resolution satellite, e.g. TerraSAR-X
- **Minimum required number of SAR scenes equals to 20**
- **A SAR scene every month is the best scenario, as the revisit period for ERS 1/2 (1992-1999) and ENVISAT (2002-2010) scenes is 35 days**
  - So, the time scale of the evolution of a landslide should be more than two years
- **The deformation should be characterized by slow to very slow movements, up to 10-20cm/yr**
  - Difficulty in tracking a deformation greater than wavelength (=5,66cm) divided by 4 (1,4cm) between two visits of the satellite taking also into account the large satellite revisit period of 35days
- **Difficulty in retrieving a coherent density (hence an accurate measurement of velocity) of pixels in vegetated and rural areas**

Constraints-Requirements on the MTI use for (landslide) monitoring_2

- **Low to moderate slope inclination and suitable orientation with respect to the SAR viewing angle**
  - For ERS, facing the radar can cause problems of geometrical distortion in SAR images, such as foreshortening, layover and shadow effects
  - Improvement: Use satellite acquisitions from both ascending and descending orbits

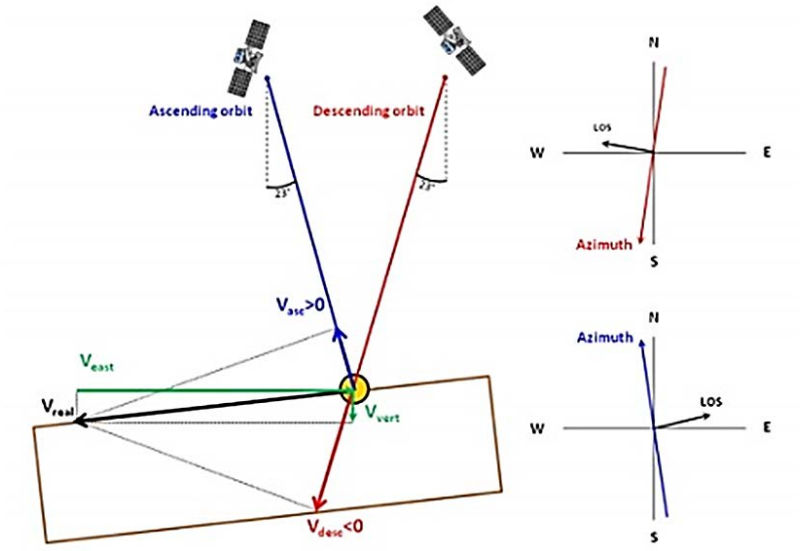


Slope aspect	Ascending ERS passes	Descending ERS passes	Notes
East	• Enhanced range resolution if a<67° • Shadow if Ia|>67°	• Foreshortening if a <23° • Layover if Ia|>23°	Only ascending data suitable
West	• Foreshortening if a <23° • Layover if Ia|>23°	• Enhanced range resolution if Ia|<67° • Shadow if Ia|>67°	Only descending data suitable
North or South	-	-	Both ascending and descending data suitable Low system sensitivity

a: slope angle

Constraints-Requirements on the MTI use for (landslide) monitoring_3

- **Interferometry-based displacements are 1D measurements**
  - The sensor is much more sensitive to vertical deformation than to horizontal deformation
  - The sensor obtains 6-13%, 34-75% and 64-94%, respectively, of the north, east and vertical components of the actual 3D motion



Plus and minus notations indicate target's movement in relation with track's orbit

Basic information about Landslides

Bibliographic Review

Comparable Regional Scale MTI studies

Case	Study area (km²)	Land use	Mapped LS	Elements at risk	CT density	Validation of known LS (≥1 CT)	New detected LS
River Arno Basin (North central Apennines) *Farina et al., 2006*	9000	Farmland and forest	27,000	Buildings, industrial districts and roads	65/km² 350 ERS1/2 (1992-2002)	6.1%	223
Piemonte region (Northern Italy-Alpes) *Meisina et al., 2008*	25000	Slightly vegetated	34,000		92/km² 614 ERS1/2 (1992-2001)	30%	
Umbria region (Apennines) *Berardino et al., 2002*	6500	Vegetation covered	33,500		SBAS Technique 73 ERS1/2 (1992-2000)	2%	
Calabria (South Italy) *Bianchini et al., 2012*	4470	Bare with rock outcrops	4,102		78/km² 108 ENVISAT (2003-2009)	24%	64

Comparable Local Scale MTI studies

Interpretation

- ✓ The applicability and quality of MTI products is not linked to the spatial extent of a study area, but depends on the availability of a sufficient number of CT (density) and their distribution
- ✓ Piemonte vs Arno River
  - o Higher CT availability linked to lower vegetation/forest cover, predominance of rock outcrops, large dimensions of the Alpines slope failures
- ✓ Umbria vs Arno River (similarity of LS types)
  - o Higher percentages of forest and cultivated land at Umbria and difference in processing approaches
- ✓ Calabria (ENVISAT images) better coverage of LS 24% with respect to ERS (typically<<10%)

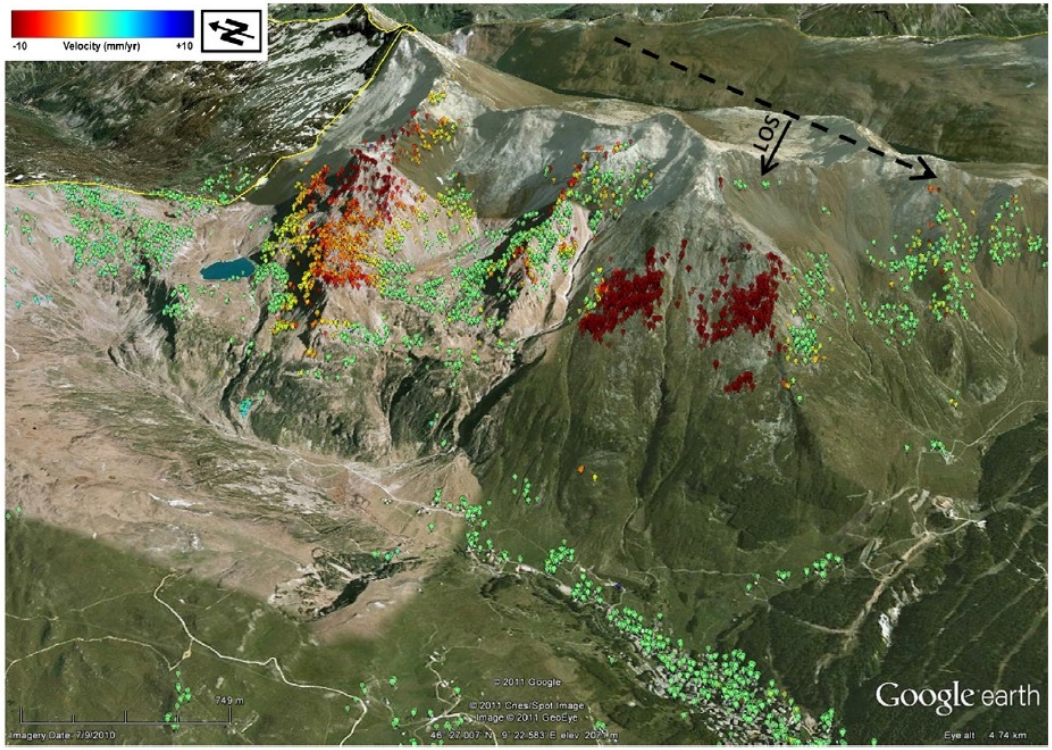
Basic information about Landslides

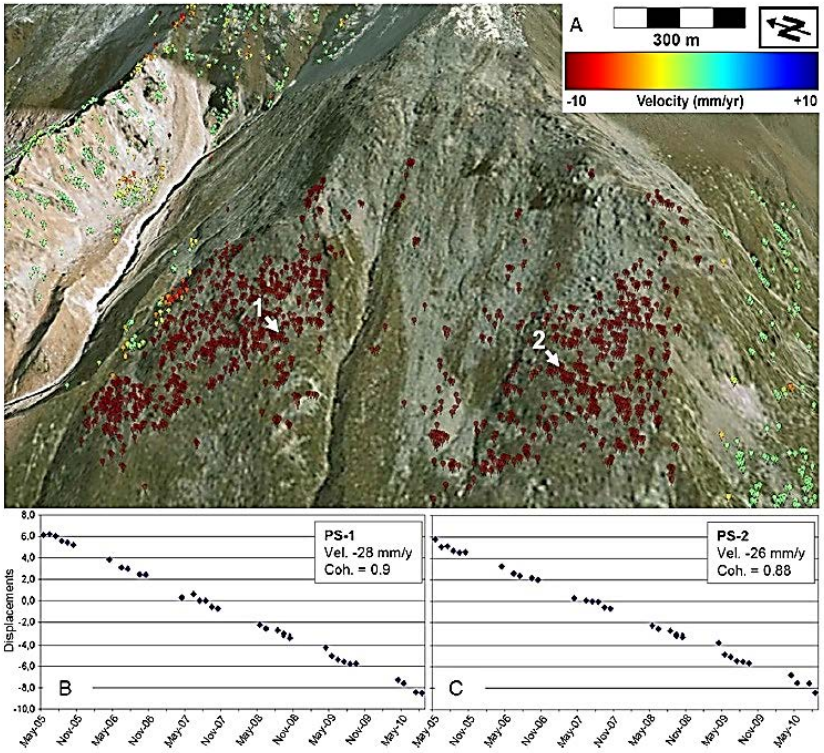
Bibliographic Review

Local Scale MTI studies

Madesimo, Lombardy Region, Central Alps, Italy

✓ 32 Descending ENVISAT images (2005-2010)



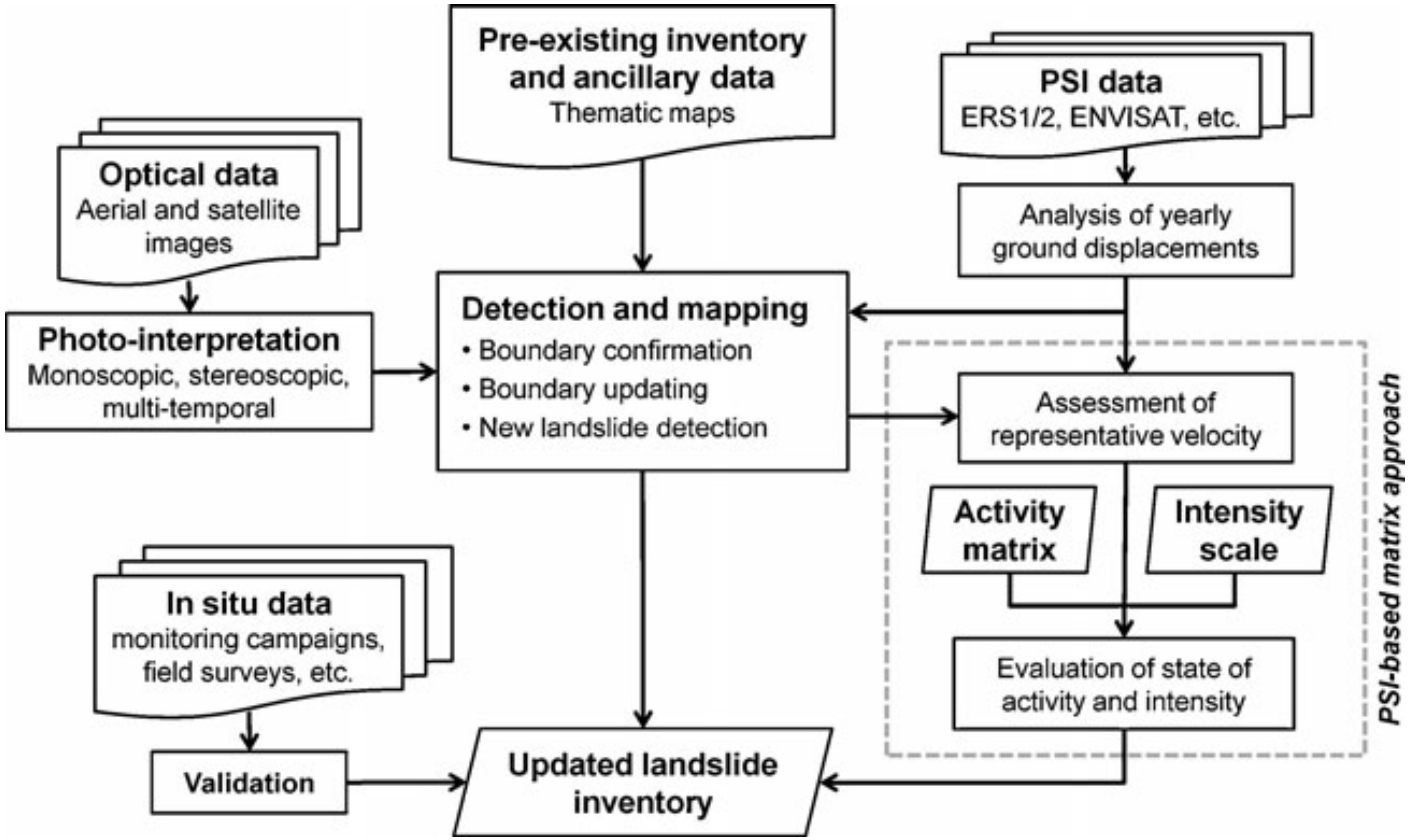


Apuani et al., 2012

Basic information about Landslides

Bibliographic Review

Methodology for the updating of inventory maps and the assessment of state of activity and intensity of slow-moving landslides exploiting PSI-based matrix approach



Cigna et al., 2012

Basic information about Landslides

Bibliographic Review

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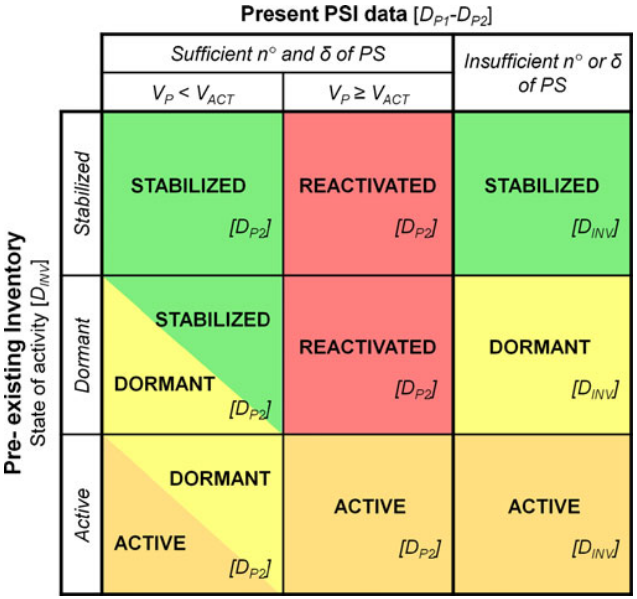
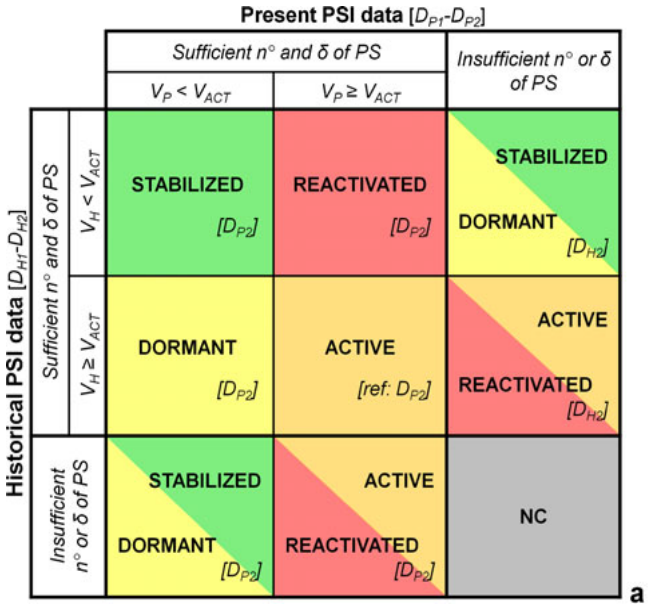


Activity matrix employed for preexisting inventory



Activity matrix employed for new detections

Present (or **historical**) **PSI data** [D_{P1}-D_{P2}] (or [D_{H1}-D_{H2}])

Sufficient n° and δ of PS			*Insufficient n° or δ of PS*
V_P (or V_H) < V_{ACT}	$V_{ACT} \leq V_P$ (or V_H) < V_{INT}	V_P (or V_H) ≥ V_{INT}	
NEGLIGIBLE [D_{P2}] or [D_{H2}]	EXTREMELY SLOW [D_{P2}] or [D_{H2}]	VERY SLOW [D_{P2}] or [D_{H2}]	NC

Example of Intensity scale

V_{ACT} Deformation threshold of activity

V_{INT} Deformation threshold of intensity

Cigna et al., 2012

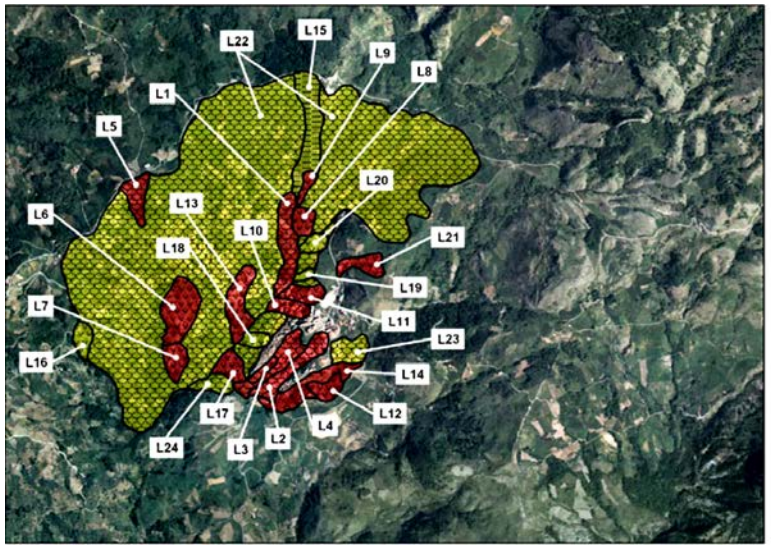
Basic information about Landslides

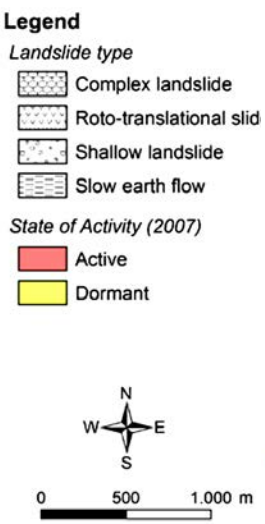
Bibliographic Review

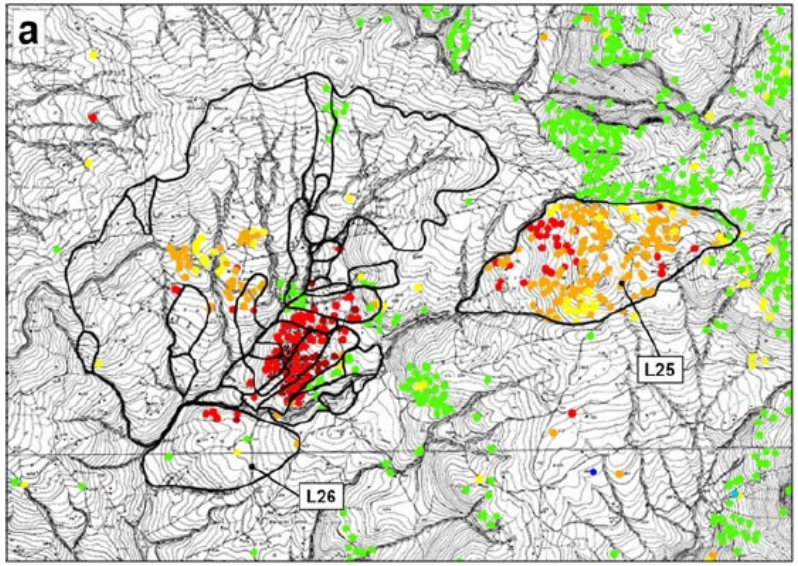
State of Activity and Intensity assessment exploiting MTI results

Verbicaro, Northern Calabria, Italy

✓ 78 Scenes in Descending mode, ERS 1/2, 1992-2000







Preexisting LS mapping

Updated LS inventory and PSI-derived deformation

- 13 PSI-detected events/24 pre-mapped events*
- L25, L26: new detections
- L2, L4, L11, L21, L23: modified boundaries

Cigna et al., 2012

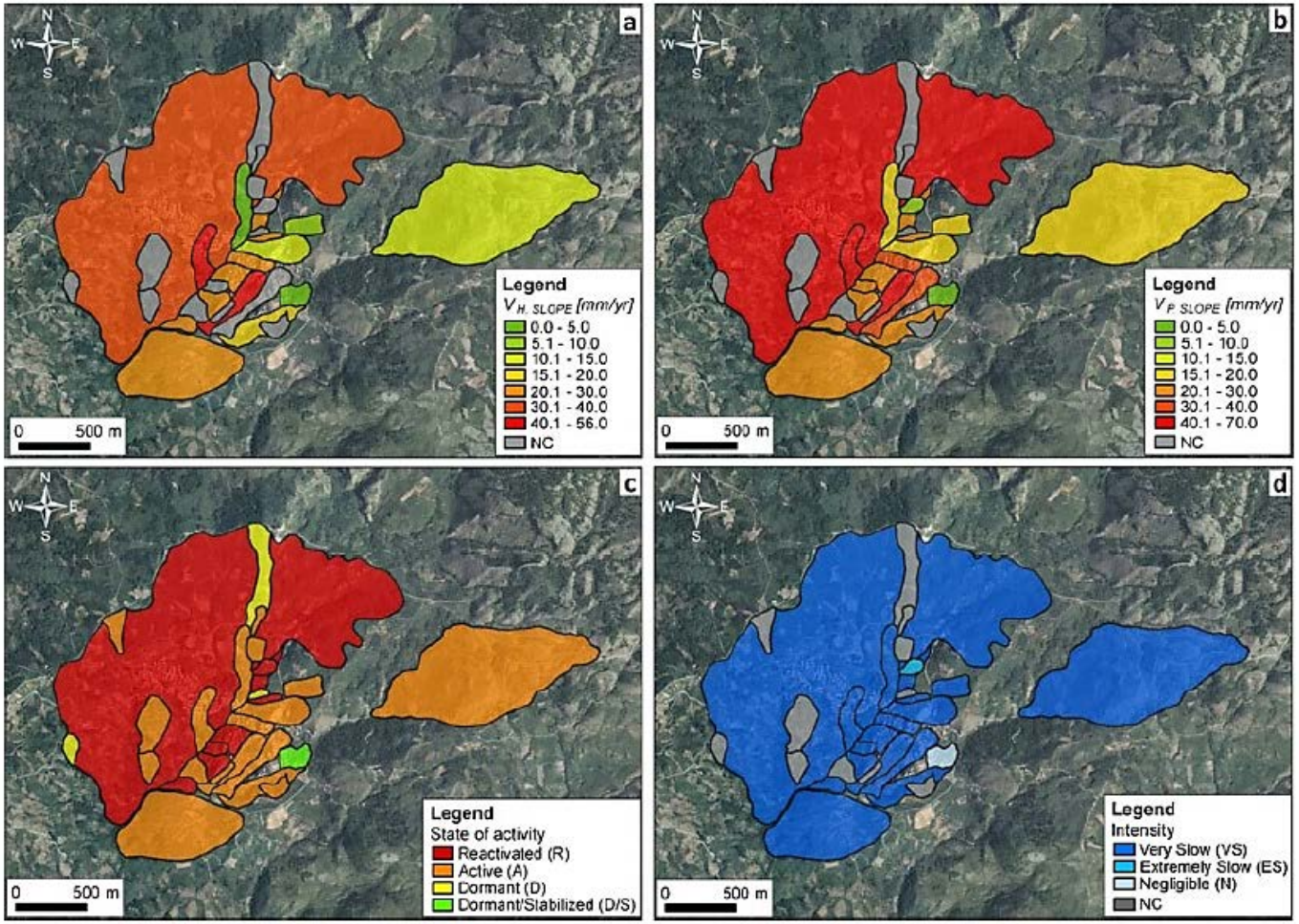
*Less than 4 PS in the LS boundary constitutes an unreliable estimation

Basic information about Landslides

Bibliographic Review

State of Activity and Intensity assessment exploiting MTI results

Verbicaro, Northern Calabria, Italy



(a) Historical ERS 1/2
(b) Present RSAT1/2 representative velocities
(c) Updated States of Activity
(d) Updated Intensity of LS mapped in Verbicaro, overlaid on a color orthophoto.

- L18, L20, L22, L23, L24: modified activity

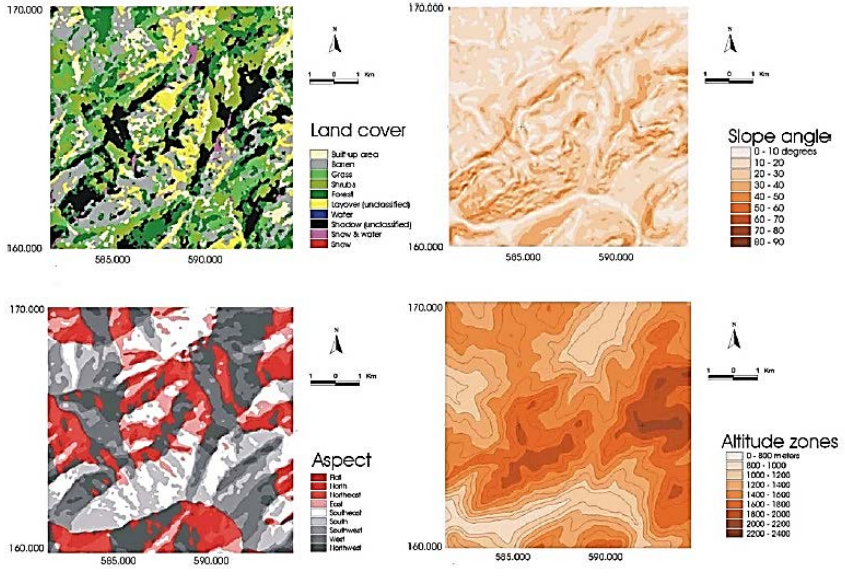
Cigna et al., 2012

Basic information about Landslides

Bibliographic Review

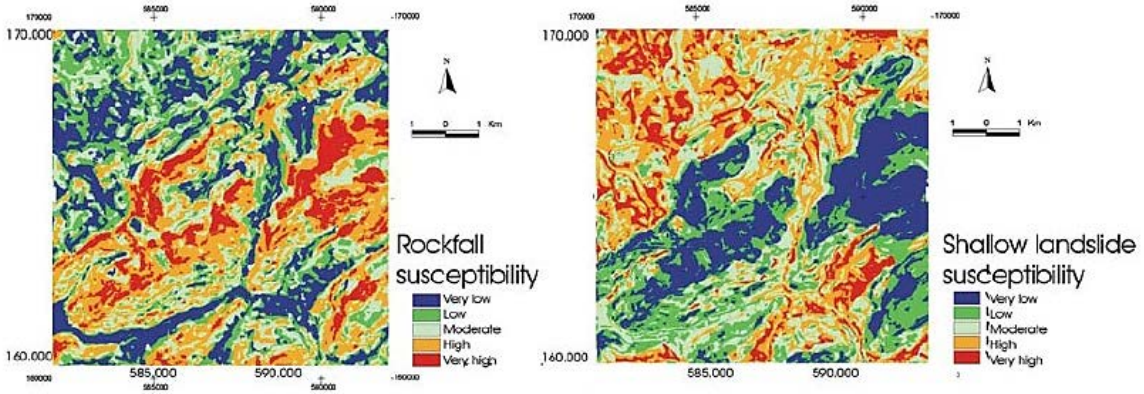
Susceptibility map assessment, Example: Swiss Alpes

Factor Maps

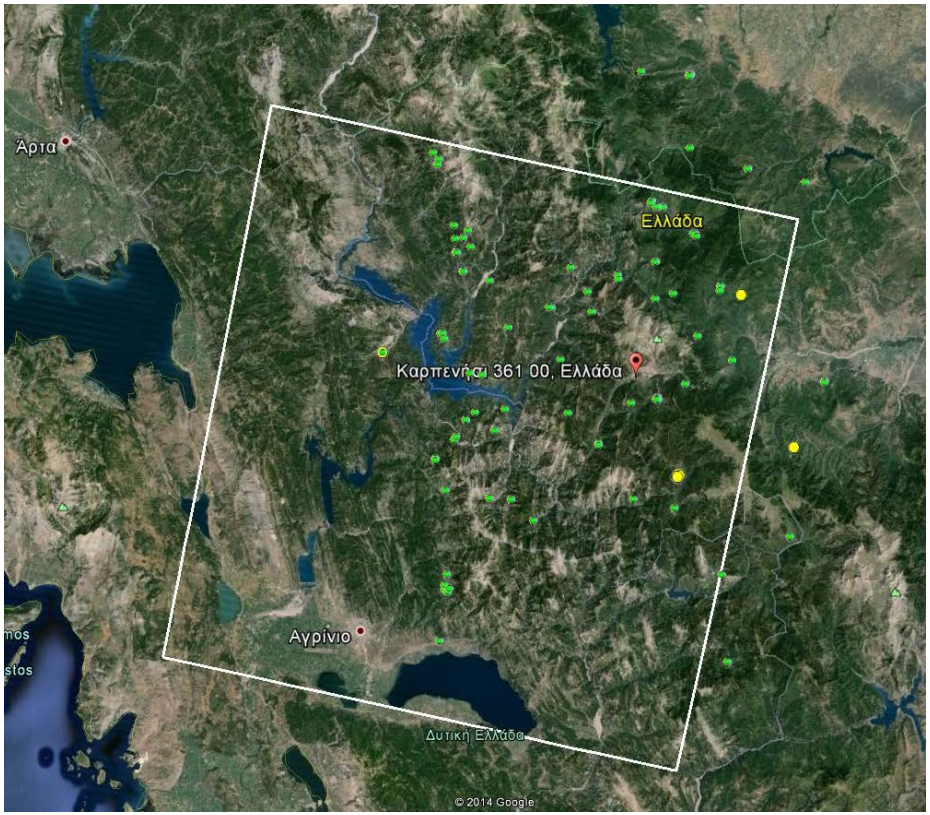


Updated Inventories in terms of:

1.LS boundaries
2.New detections
3.Displacement velocity
4. Activity & Intensity
5.Movement type



Area of Interest and SAR Data

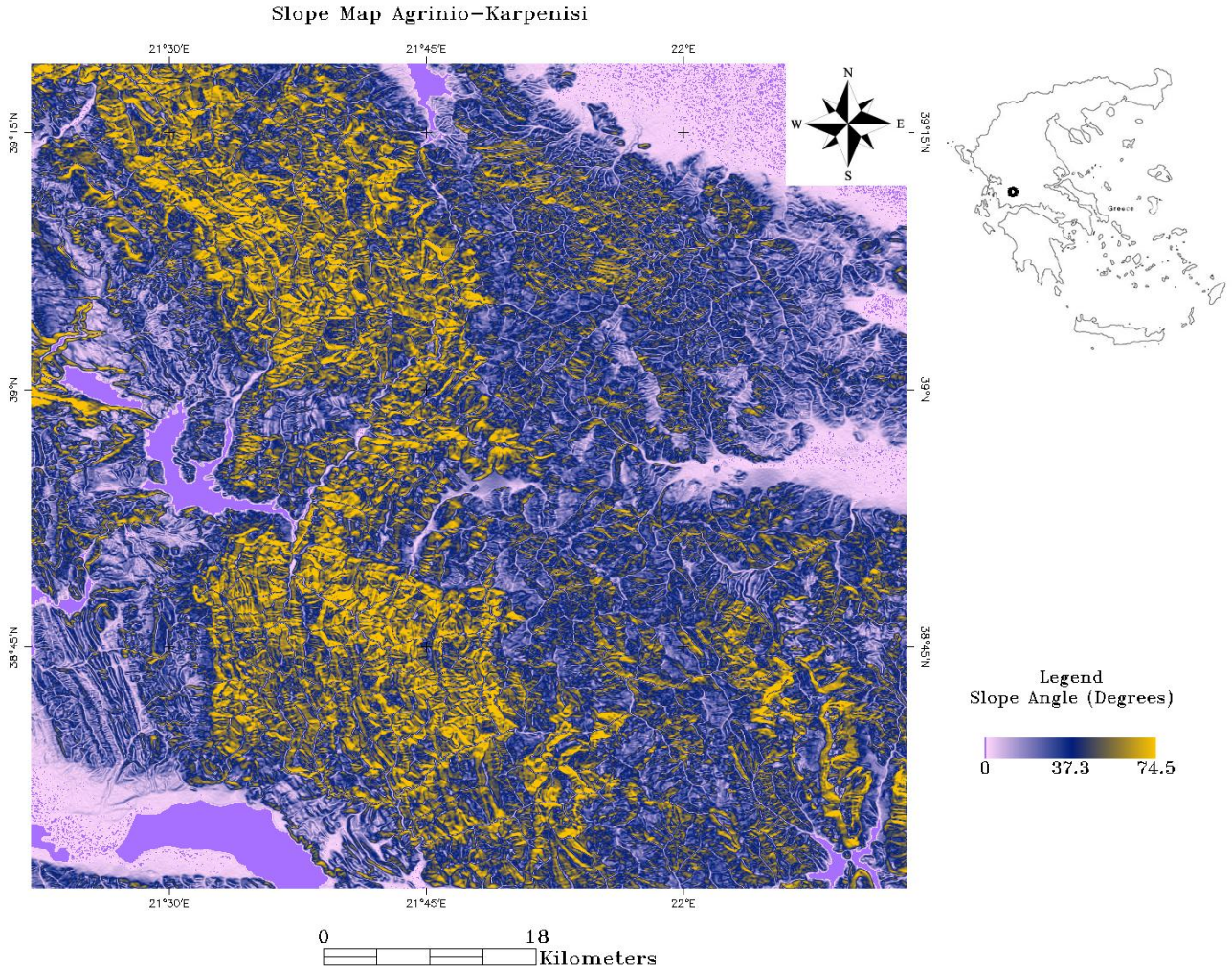


Spatial coverage: 4000 km²

Set	Satellite	Period	Pass Type	Track	Scenes
1	ERS-1	1992-1999	Descending	50	21
2	ERS-2	1995-2000	Descending	50	41
Mass processing of 370 interferometric pairs					

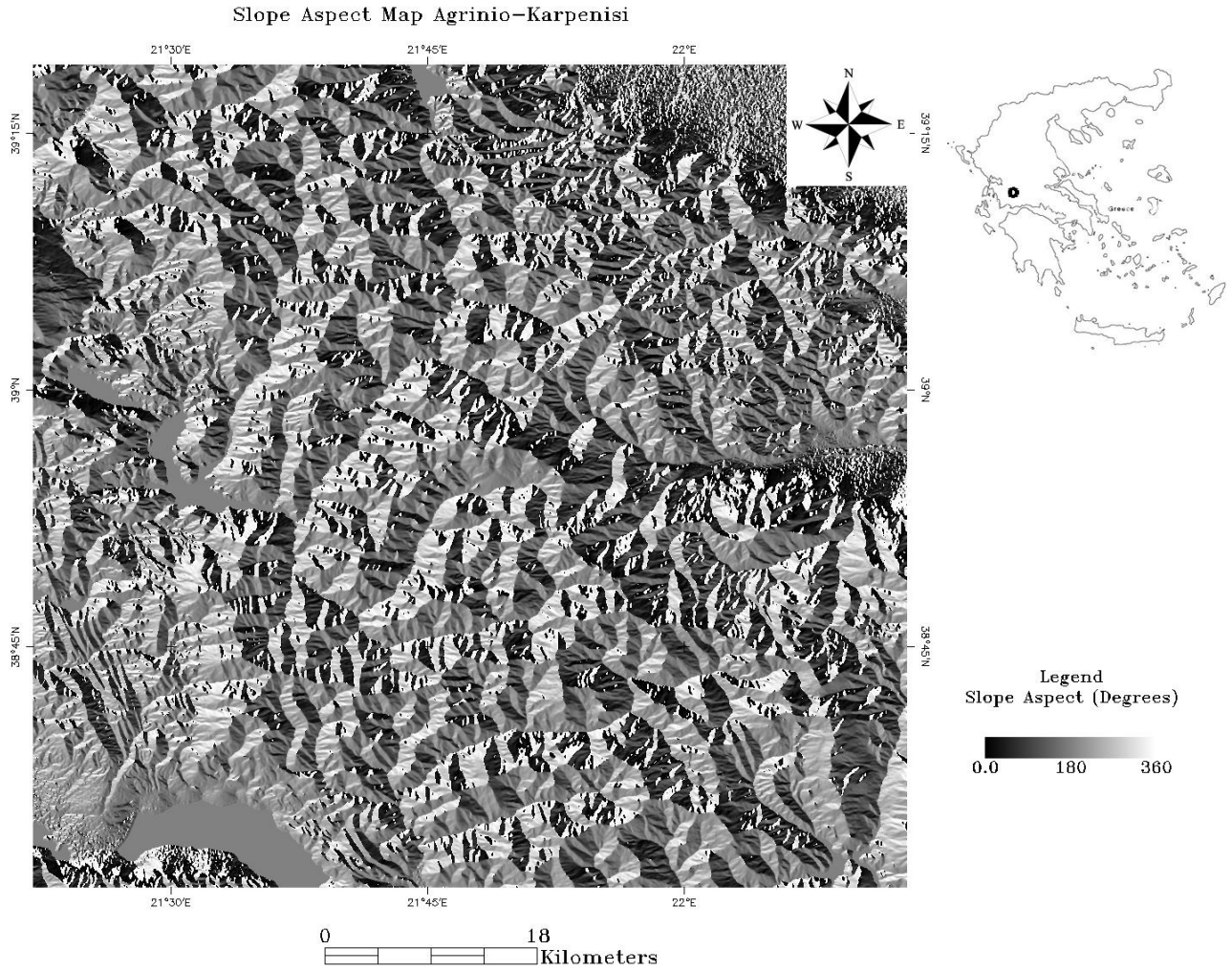
Area of Interest and SAR Data

Περιοχή Μελέτης: Αγρινίου (Ν. Αιτωλοακαρνανίας) – Καρπενησίου (Ν. Ευρυτανίας)



Area of Interest and SAR Data

Περιοχή Μελέτης: Αγρινίου (Ν. Αιτωλοακαρνανίας) – Καρπενησίου (Ν. Ευρυτανίας)



Area of Interest and SAR Data

Περιοχή Μελέτης: Αγρινίου (Ν. Αιτωλοακαρνανίας) – Καρπενησίου (Ν. Ευρυτανίας)

Inventory Data - ΙΓΜΕ - InGeoClouds
(http://portal.ingeoclouds.eu/sitools/client-user/Geohazard_GR/project-index.html)

Features for 140 events

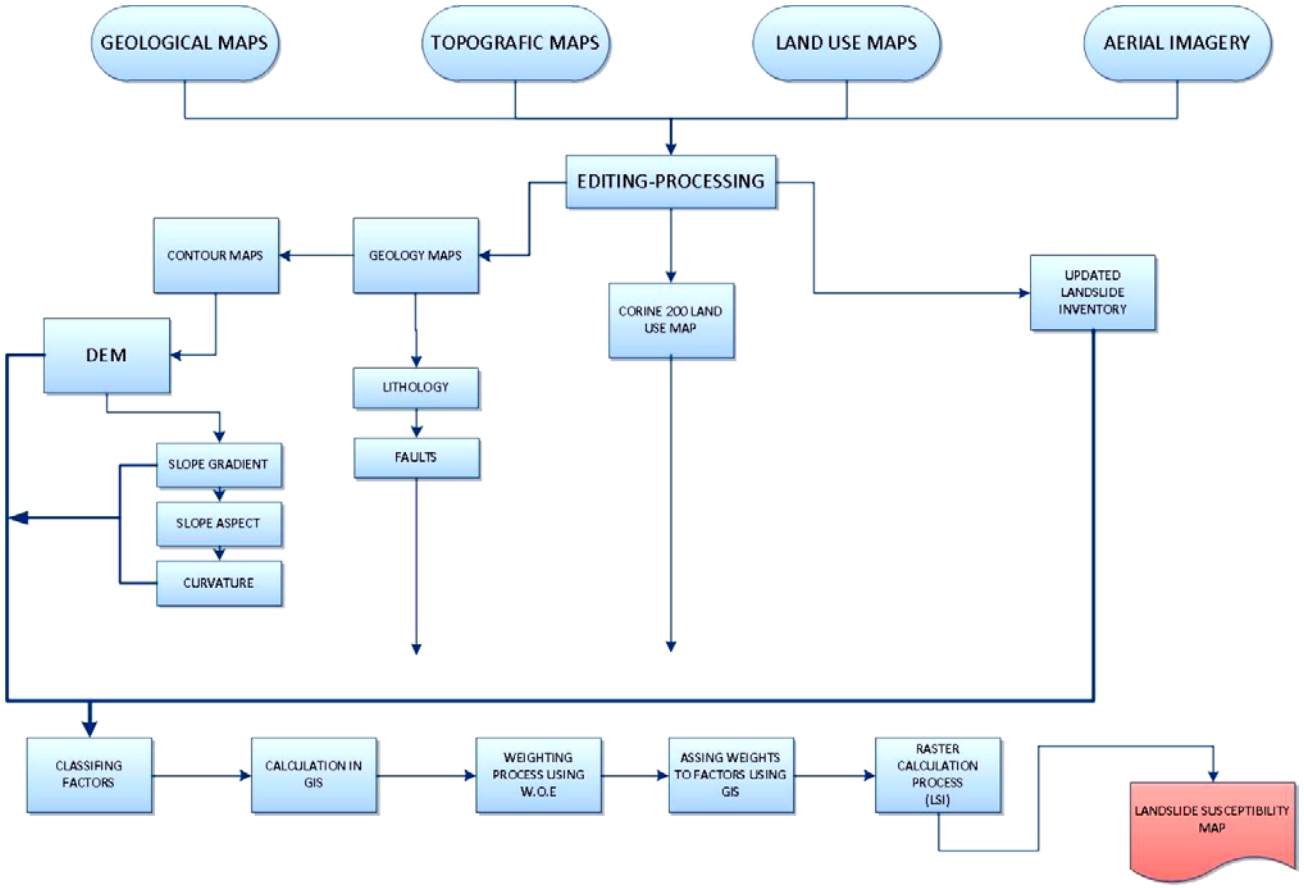
- Coordinates
- Municipality
- Rainfall data
- Altitude
- Land cover
- Year - Χρονική κάλυψη 1953-2010
- Slope tilting
- Lithology
- Movement Type

longitude	id	rainfall	altitude	landcover	municipality	year	latitude	slope_tilting	lithology	movement_type
21.794853518	0	1192	1100	<LABEL3>Coniferous forest/Δάσος κωνοφόρων</LABEL3>	ΙΤΑΜΟΥ	2004	39.138237623	<SLOPE_TILT>(Moderate Steep)/Μέτρια Ισχυρή (31 - 45)</SLOPE_TILT>	<LITHOLOGY>Flysch/Φλύσχης</LITHOLOGY>	<MOV_TYPE>Composite/Σύνθετες</MOV_TYPE>
21.628220776	1	985	600	<LABEL3>Broad-leaved forest/Δάσος πλατύφυλλων</LABEL3>	ΑΓΡΑΦΩΝ	2005	39.166292971	<SLOPE_TILT>(Steep)/Ισχυρή (46 - 60)</SLOPE_TILT>	<LITHOLOGY>Flysch/Φλύσχης</LITHOLOGY>	<MOV_TYPE>Rotational/Κυκλοειδείς-Περιστροφικές</MOV_TYPE>
21.844083071	2	1055	620	<LABEL3>Land principally occupied by agriculture, with significant areas of natural vegetation/Γη που καλύπτεται κυρίως από τη γεωργία με σημαντικές εκτάσεις φυσικής βλάστησης</LABEL3>	ΠΛΑΤΑΝΟΥ	1995	38.686499755	<SLOPE_TILT>(Moderate Steep)/Μέτρια Ισχυρή (31 - 45)</SLOPE_TILT>	<LITHOLOGY>Flysch/Φλύσχης</LITHOLOGY>	<MOV_TYPE>Rotational/Κυκλοειδείς-Περιστροφικές</MOV_TYPE>
21.839421456	3	1052	660	<LABEL3>Broad-leaved forest/Δάσος πλατύφυλλων</LABEL3>	ΠΛΑΤΑΝΟΥ	2006	38.688761378	<SLOPE_TILT>(Moderate Steep)/Μέτρια Ισχυρή (31 - 45)</SLOPE_TILT>	<LITHOLOGY>Flysch/Φλύσχης</LITHOLOGY>	<MOV_TYPE>Rotational/Κυκλοειδείς-Περιστροφικές</MOV_TYPE>
....	....	....	....	....	....	....	....	....	....	....

Area of Interest and SAR Data

Περιοχή Μελέτης: Αγρινίου (Ν. Αιτωλοακαρνανίας) – Καρπενησίου (Ν. Ευρυτανίας)

Susceptibility Map - ΙΓΜΕ - InGeoClouds
(Ναταλία Σπανού, Τεχνικός Γεωλόγος, ΕΚΒΑΑ ΙΓΜΕΜ)

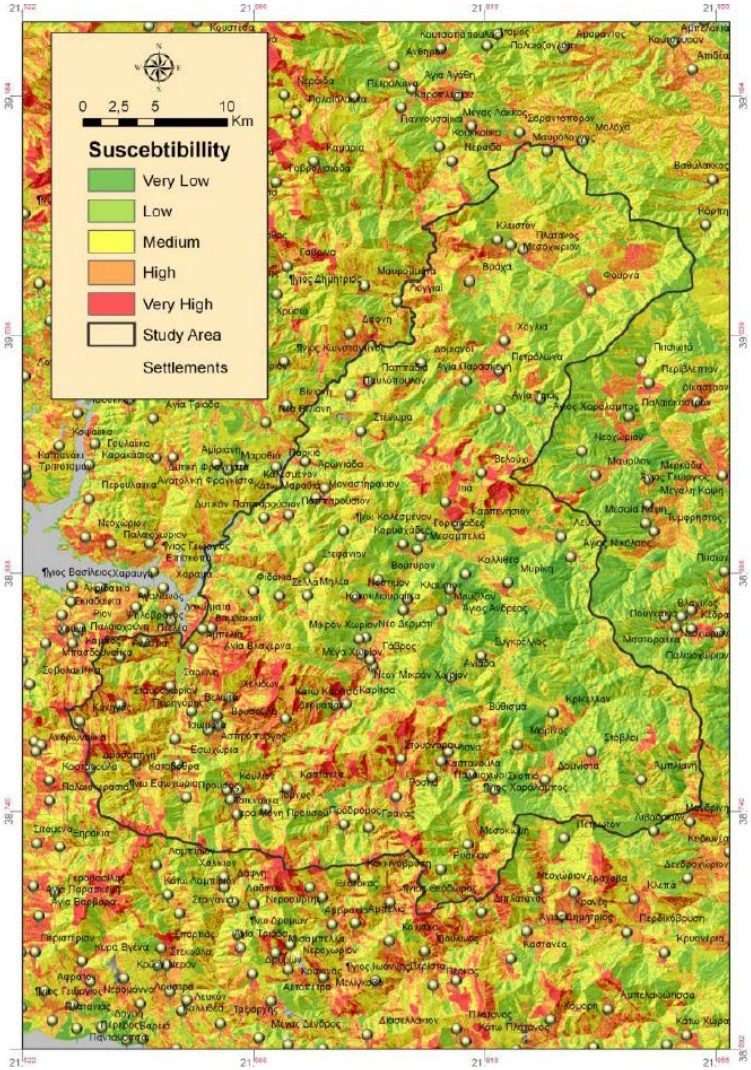


Area of Interest and SAR Data

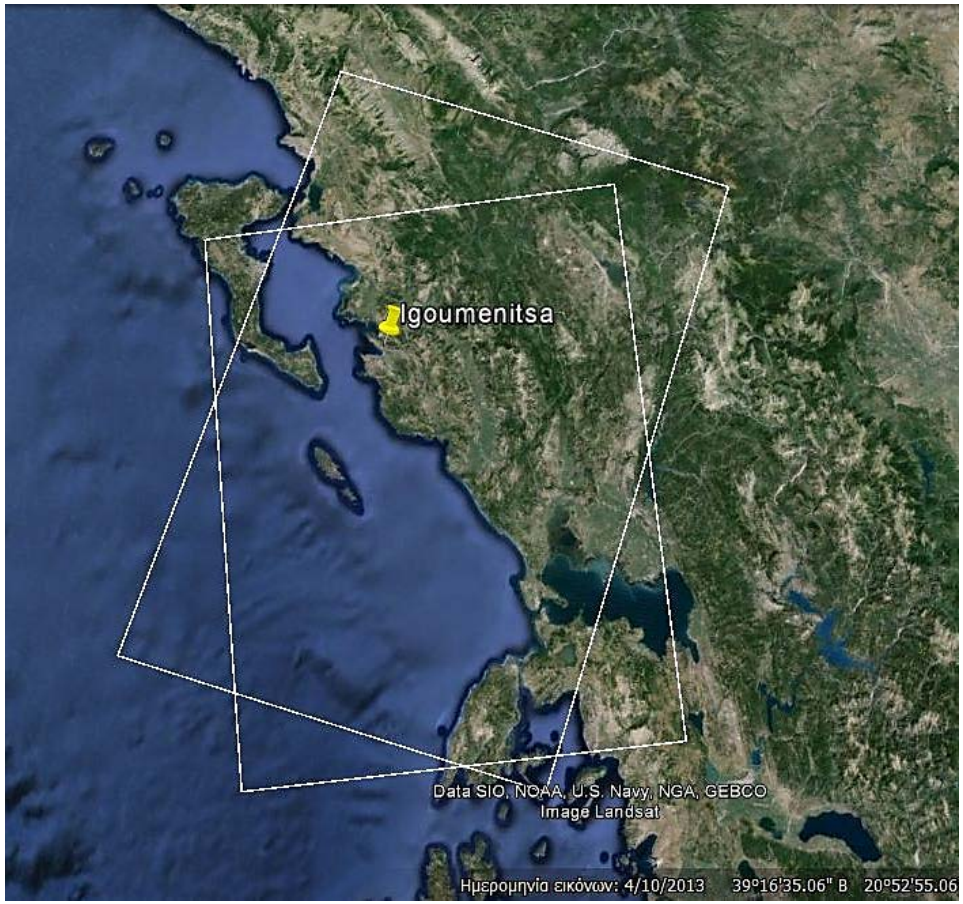
Περιοχή Μελέτης: Αγρινίου (Ν. Αιτωλοακαρνανίας) – Καρπενησίου (Ν. Ευρυτανίας)

Susceptibility Map - ΙΓΜΕ - InGeoClouds
(Ναταλία Σπανού, Τεχνικός Γεωλόγος, ΕΚΒΑΑ ΙΓΜΕΜ)

Μέθοδος: Weights-of-evidence
(Bonham-Carter 1994,
Bonham-Carter et al. 1989)

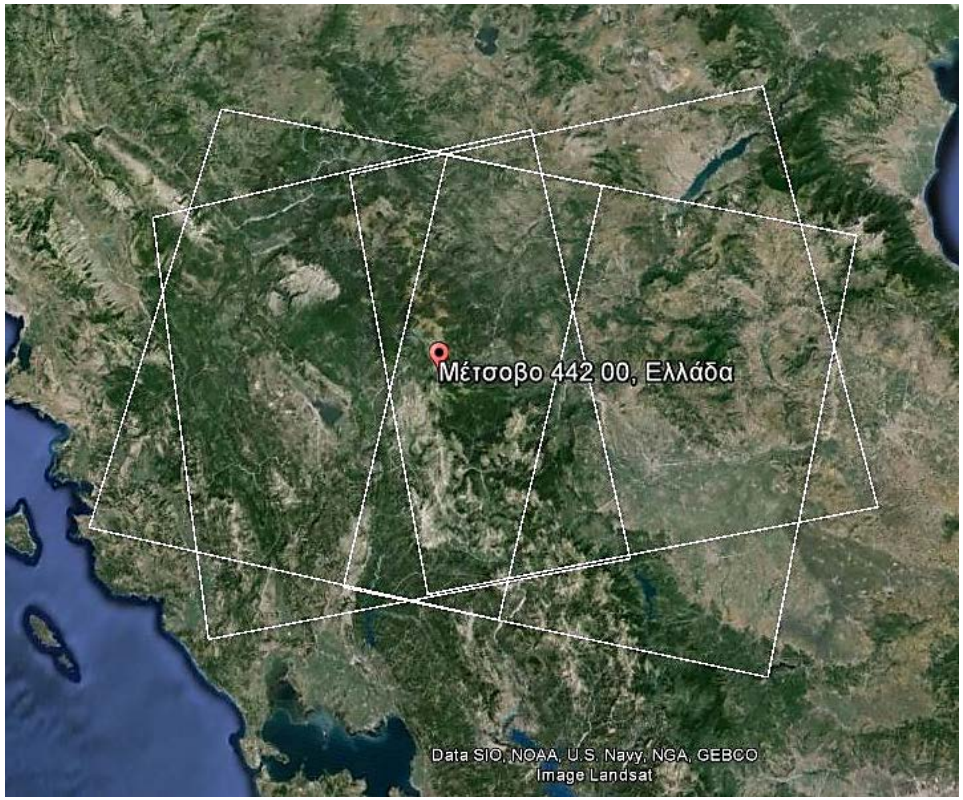


Future Area of Interest and SAR Data Igoumenitsa



Set	Satellite	Period	Mode	Track
1	ERS	1992-2001	A	458
2	ENVISAT	2003-2010	A	458
3	ERS	1992-2001	D	93
4	ENVISAT	2003-2008	D	93

Future Area of Interest and SAR Data Metsovo



Set	Satellite	Period	Mode	Track
1	ERS	1992-1999	A	186
2	ENVISAT	2003-2010	A	186
3	ERS	1992-1994	A	415
4	ENVISAT	2003-2010	A	415
5	ERS	1992-1999	D	50
6	ENVISAT	2003-2010	D	50
7	ERS	1992-1994	D	322
8	ENVISAT	2003-2010	D	322

Future Perspectives

- MTI processing of SAR scenes for the Area of Interest
- Exploitation of MTI velocities-> Spatial and temporal investigation
- Coupling MTI results with field investigation
- Update the existing inventory in terms of landslide boundaries, state of activity, movement type, phase of activity, intensity
- Detection of new landslide events
- Coupling triggering factors' frequency with landslide events
- Update the existing Susceptibility map
- Development of Hazard map
- Further analysis on local or site specific scale

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