ARISTOTLE UNIVERSITY OF THESSALONIKI
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SCHOOL OF GEOLOGY

PERMANENT SCATTERERS FOR LANDSLIDE DISPLACEMENT MONITORING

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INTODUCTION

Landslides usually cause property damage and sometimes human casualties and influence the socio economic conditions of many countries. Landslide impact in Italy has been well addressed by the statistical analysis of the data collected in recent years by GNDCI (National Group for Geo hydrological Disaster Prevention) of the CNR (National Research Council) (Guzzetti, 2000).The total amount of damage caused by landslides in Italy in the last century has been evaluated at 1-2 billion euro/year, corresponding to about 0,15 % of the National domestic product. In the same period there have been 59 deaths/year due to mass movements.

As part of the terrafirma project of the European Space Agency (ESA) a methodological approach has been developed to integrate interferometric information coming from the Permanent Scatters (PS) analysis with the interpretation of optical images (Colombo et al., 2003a,b; Farina et al., 2004). The method relies on the possibility of assigning a spatial meaning to the point-wise ground displacement measurements provided by the PS technique, through the interpretation aerial-photos and optical satellite imagery, topographic maps and ancillary data. Due to the remote sensing character of the above approach, which allows the acquisition of data over wide areas, and extremely high precision of the radar measurements (Colesanti et al., 2003), this method can be applied at different scales. Over large areas it is suitable to complement and integrate information derived from well established techniques for landslide mapping and at local scale it can be used for monitoring the superficial displacements of specific landslides.

The area of study of the presented project is the peninsula of Calabria (communes of Reggio Calabria, Catanzaro and Vibo Valentia), Southern Italy and the output product was concentrated so as to update the existing landslide inventory map. In addition, detailed monitoring of superficial displacements of some well known mass movements was performed, aimed at evaluating variations over time of the deformation rates and spatial extents of the unstable areas.

Apart from the air photos, the existing topographic base of different scale and the landslide inventory maps, a number of DTM (digital terrain model) information was used, such as DEM (3D terrain model), slope and aspect maps. These together with the PS information improved the final product .The project was implemented in GIS environment with the aid of software ArcGIS 9.0.This is an informatics platform that gives the opportunity to record, analyze and represent digital data, both in vector and raster format, in an geographic and reference system.

Figure 2.1 presents the area of study; provinces of Vibo valentia 558,5 km^2, Catanzaro 312km^2 and Reggio Calabria 3181,8km.

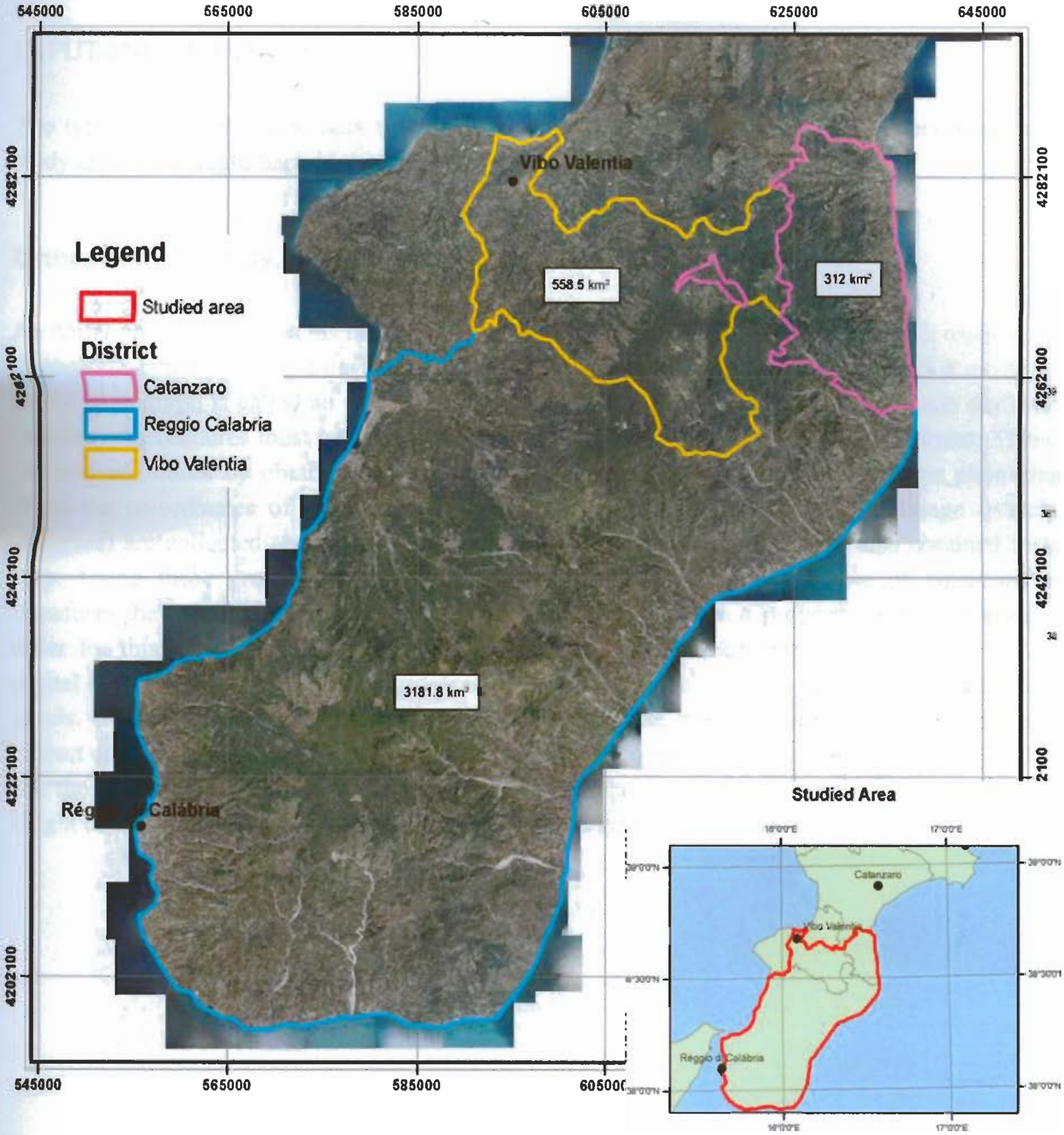


Figure 2.1 Studied area; provinces of Vibo valentia 558,5 km^2, Catanzaro 312km^2,Reggio Calabria 3181,8km^2

INPUT-INCOME DATA

The typologies of the used data that were used so as to analyze the landslide phenomena on the study area are brought back in this section.

Orthophotos fly Italy 2002 (figure 2.2)

An aerial photograph contains radial and terrain distortions. However, it is possible to correct these distortions, either by using a devise called an orthophotoscope or by digital means. Such a corrected aerial photograph is called an othophotograph. In order to produce an orthophotograph digitally, a number of procedures must be followed. The aerial photograph must be in digital format. This can be achieved either by obtaining an image with a scanner system or by scanning the photograph. Next the co-ordinates of easily identifiable features that can be seen on the image (which is distorted) are collected and the correct co-ordinates of the same features are also obtained from a map. Using these ground-control points, the computer produces a number of equations that transform the location of all the pixels on the distorted image to a properly orientated image. In order for this transformation process to be accurate, it is also necessary to input a file (called a digital elevation model and is being described beneath) which stores the height of all the scanned pixels. If such a file does not exist, it is possible to create one by using a computer program to extract one for the area covered by two over-lapping stereo aerial photographs.
For the purpose of this work, the digital colored orthophotos, were used for the entire area of study (flight of Italy 2002), with 1 meter of resolution to the ground in monoscopic configuration.

Figure 2.2 Digital color orthophotos Volo Italia 2000 (1 meter ground resolution)

Regional topography maps (figure 2.3)

Topographic maps with small scale factor were used so as to estimate, through the survey of anomalous curving of the contour line, eventual countertendency combinable of slope instability, the existence of steep slope. Such characteristics are often reliable to indicate areas of instability.

In this project the regional topography maps were used (carte topografiche regionali or carte tecniche regionali or CTR) of all the territory of Calabria (Provinces of Reggio Calabria, Catanzaro and Vibo Valentia) scale 1:10.000 downloaded from the regional site of Calabria.

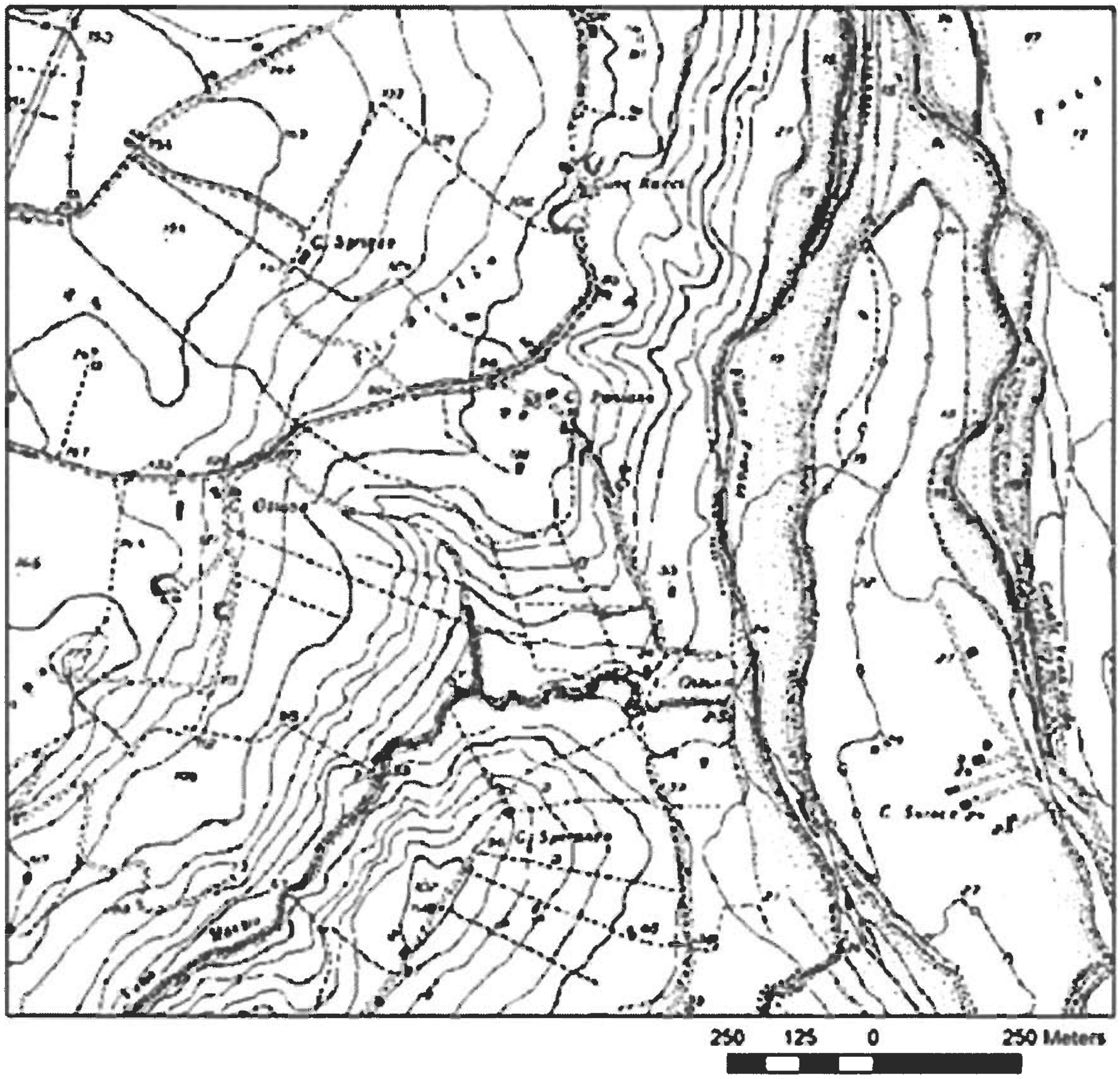


Figure 2.3 Topographic maps 1:10.000 scale

Topography maps IGM 1:25.000 (figure 2.4)

The topographic maps IGM in scale 1:25.000 (carte topografiche IGM 1:25.000) present the orography contour line with an equidistance of 25 meters, were acquired from the Geographic Military Institute for all the territory of interest of the project and used as the base for the creation of duplex Atlanta.

Otherwise in cases that there the technical topographic maps were not available (CTR or Carte Techniche Rrgionali 1:10.000) IGM maps were used as the topographic base of the editing.

Landslide inventory maps or landslide data sources (figure 2.5)

The inventory maps of the landslide phenomena and the landslide data sources are representing a fundamental base for the beginning of the analysis of the slope instability so as to integrate the landslide with the PS technique.This kind of information was taken from the Regions, the Authority of Basin and as far as urban areas are concerned they were taken from the administrations of the Communes or the Provinces.

The archives more used were: PAI (Piani per l`Assetto Idrogeologico/Plane of Idrogeological order) and IFFI (Inventario dei fenomeni franosi in Italia/Inventory or catalogue of the landslide phenomena in Italy)

PAI (Plane of Idrogeological order): Constitutes an indispensable instrument of reference, already known and prescriptive for the territorial and urbanity plane, in which the physics phenomena that individuate and determinate idrogeolical risk take place individually in connection with the territory and together define the intensity, graduating the danger and the risk of explosion of the population as well as the anthropogenic constructions.

IFFI (Inventory of the landslide phenomena): Furnishes the first quarter synthetic on the distribution of the landslide phenomena on the national territory, constituting an cognitive instrument of base for the valuation of the danger of landslide and the programming of the interments of the defense of the soil.

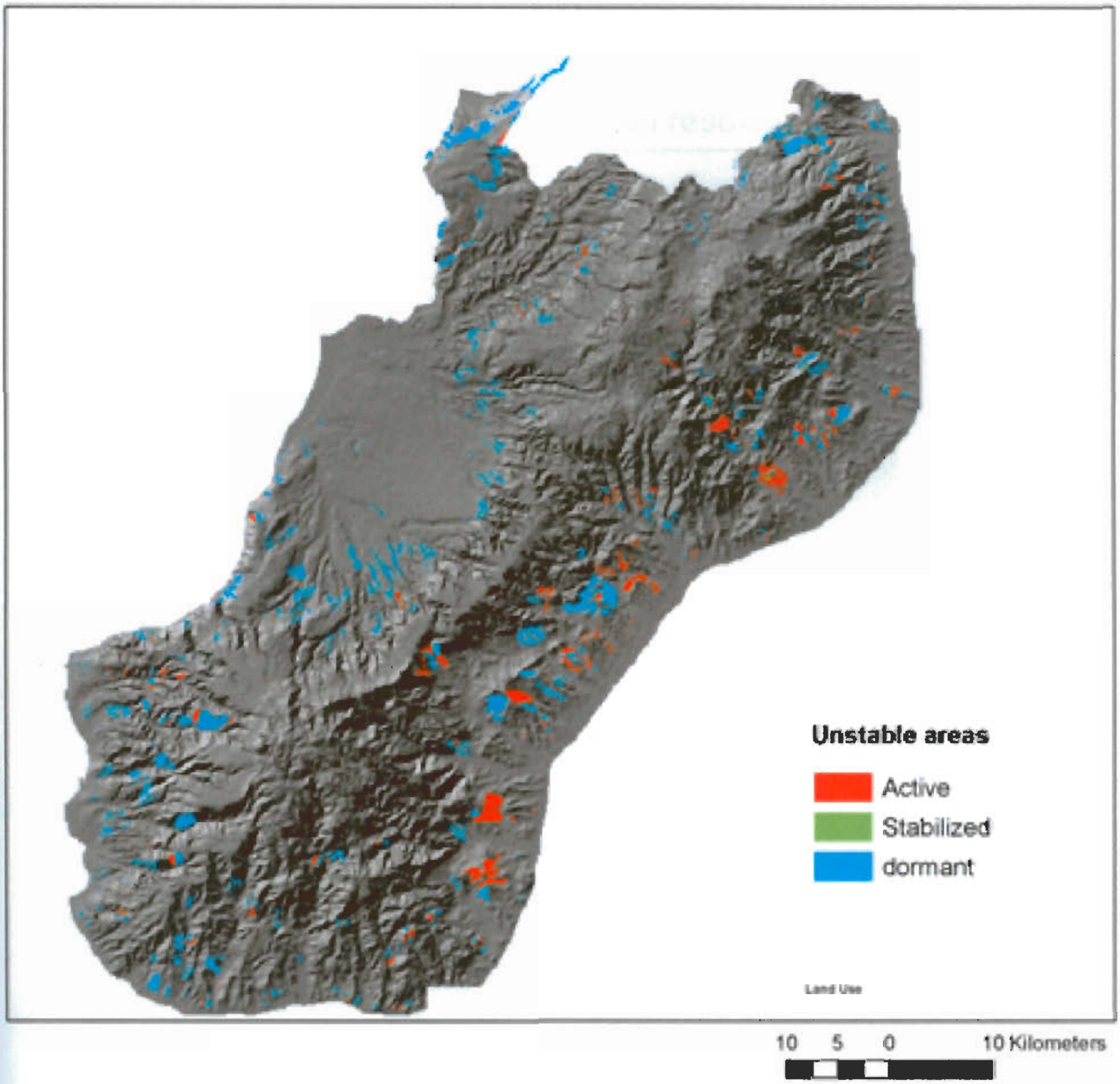


Figure 2.5 Landslides inventory maps

Digital elevation model (figure 2.6)

The numeric models of the superficial relief of terrain are being defined Digital Terrain models (DTM). Such terms generally refer to any numeric representation of the topography surface both raster and vectorial (digital), that is a form of altimetrical matrix (GRID) or an irregular net of triangulation (TIN).

For this project a DTM with 20 of 20 resolution for all the extension of the territory object of study, was used acquired from the Military Geographic institute of Italy.

The DTM was indispensable to derivate the slope and aspect maps: moreover in cases that there were not repaired the regional topography was supported by the photo interpretation through the contour and the derivation from a topographic map of level curves in vectorial (digital) form.

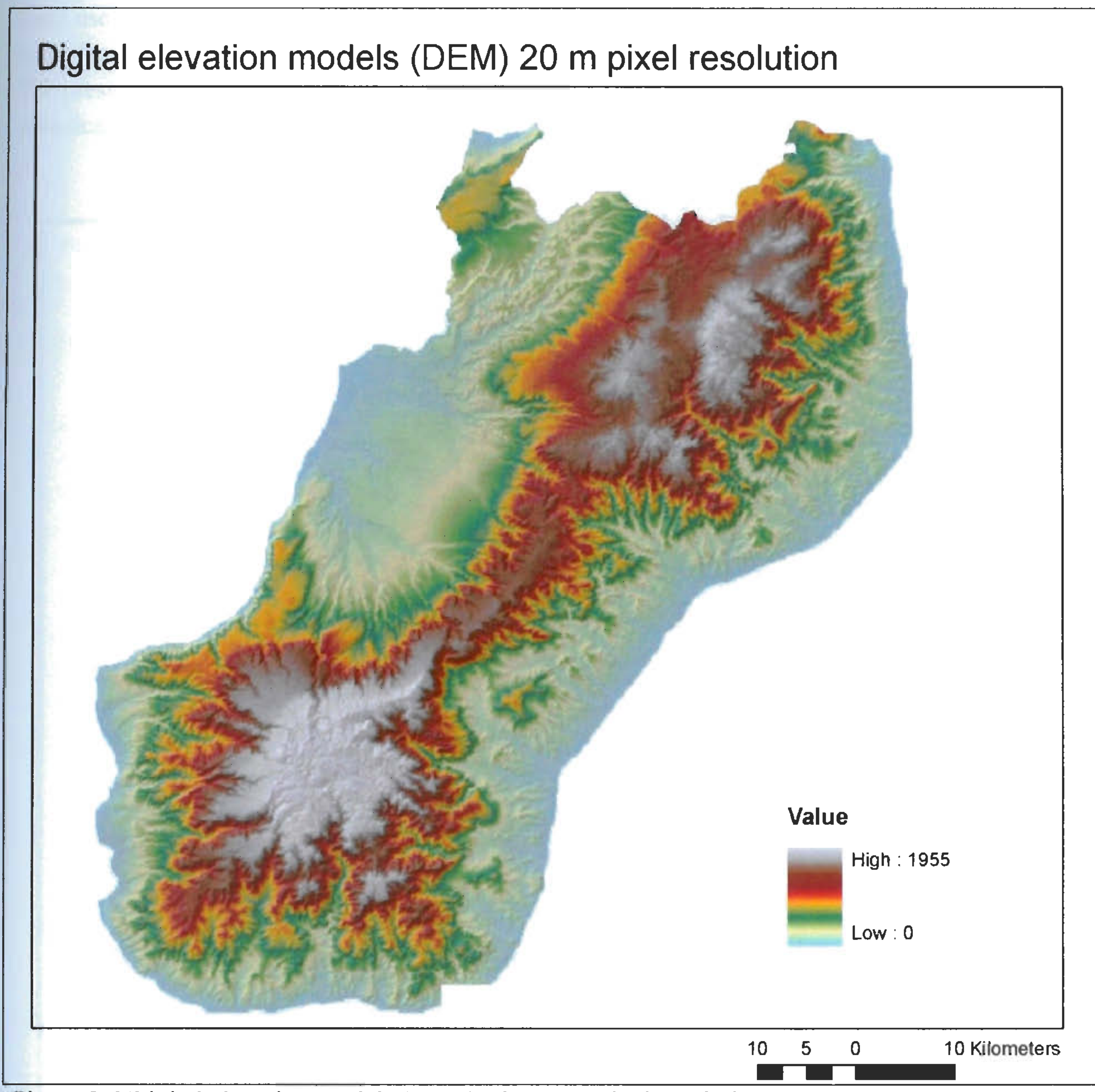


Figure 2.6 Digital elevation models (DEM) 20 meters pixel resolution

Land use maps (figure 2.7)

Land use maps in general are being used so as to support the landslide analysis and in this case to relate the PS resolution with the final updated landslide inventory.
The presented project was employed with the use of Corine Land Cover 2000, in order to export statistical data related to the PS distribution.

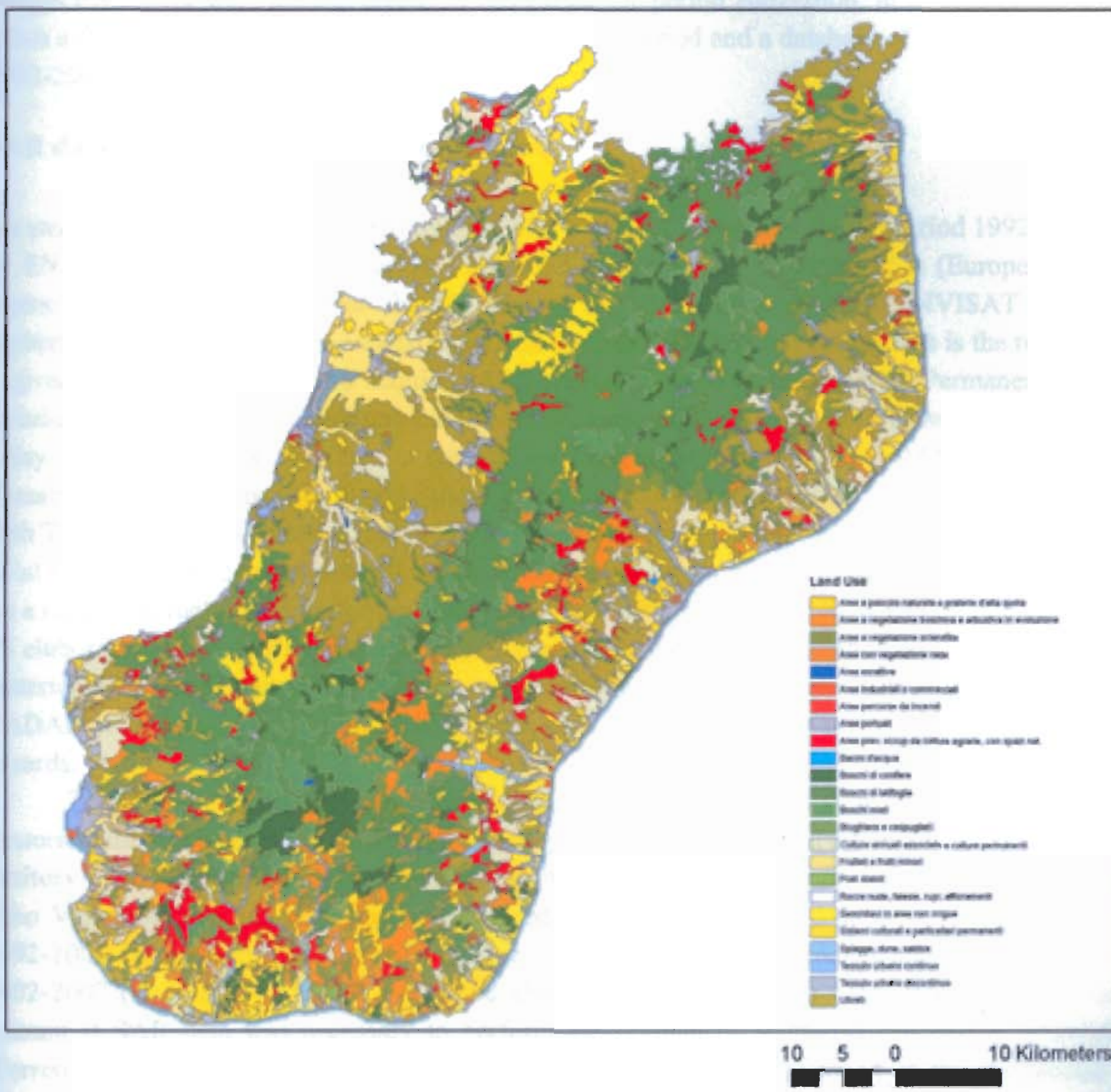


Figure 2.7 Corine land cover 2000 1:100.000 scale

InSAR DATA

Radar dataset used for the project were SAR images acquired by ERS1, ERS2 and ENVISAT.
100 ERS1, ERS2 in descending orbit (time period 1992-2002)
87 ERS1, ERS2 in ascending orbit (time period 1992-2002)
16 ENVISAT in descending orbit (time period 2002-2006)
36 ENVISAT in ascending orbit (time period 2002-2006)
This means that 187 ERS images were used to create 257 720 PS for the period 1992-2002 and 52 images ENVISAT were used to create 90 703 PS for the period 2002-2006. In an area of 4.052 km^2 exists a PS database of 66,1 PS/km^2 for the 1992-2002 period and a database of 22,4 PS/km^2 for the 2002-2006 period (images 4 images)

SAR dataset and interferomertic processing

An amount of SAR images acquired by the ERS1 and ERS 2 satellites for the period 1992-2001 and by ENVISAT satellites for the period 2002-2007 were collected from the ESA (European Spatial Agency) archive so as to create the PS datasets for all the area of study. ENVISAT is a more sophisticated instrument more sophisticated and flexible than ERS but mainly this is the reason why it gives a result less adapted to acquire SAR material so as to be used for the Permanent Scatters technique for which repeated observations with the same point of view are necessary. From 2002 to today not all the Italian territory is covered by images for this scope. RADARSAT-1 from the Canadian Spatial Agency, by having more a commercial gestation than scientific one, has signed with TRE a commercial accord that provides a systematic acquisition of SAR images from the same point of view every 24 days over all Italian territory starting from March 2003.
As a result, the meliorated and completed cover of all the territory with SAR images suitable for the PS elaboration as well as the matured experience of the interpretation method and integration of the material used for the monitoring of the slope instability, has strongly increased the use of the RADAR techniques for the aim of landslides, and so, for the higher prevent possible from such hazards.

To limit the effects of geometrical distortions induced by the side- looking view of SAR sensors, data was selected both from descending and ascending orbits(figure 2.30) over the entire territory of the area of study (territory of Calabria (Provinces of Reggio Calabria, Catanzaro and Vibo Valentia). The number of scenes acquired is not the same for all datasets. For the period of 1992-2001 (ERS1 and ERS2 satellites) were used about 187 SAR images and for the period of 2002-2007 (ENVISAT satellite) were used about 52 SAR images for each dataset. Such a large amount if SAR data was necessary to perform the Permanent Scatterers processing (PSInSAR) (Ferretti et al., 2000,2001). This interferometric configuration, developed at the Politecnico di Milano (POLIMI) and based on the analysis of a large dataset of SAR images (at least 20- 25 scenes), overcomes the main drawbacks of conventional differential SAR interferometry (Din SAR)for ground displacement retrieval. Temporal decorrelation due to vegetation coverage dramatically affects interferometric coherence, with the effect of obtaining good results only for urban areas or bare rock. In addition atmospheric components of the interferometric phase, which cannot be estimated when using only two SAR scenes, only permit a cent metric precision of the ground displacement measurements. For these reasons, with conventional DInSAR, reliable results can be obtained only in the case of large landslides that occur on gentle slopes (generally less than 20-30°) and in sparsely vegetated environments.

Permanent Scatters processing over the whole dataset of SAR images only takes into account pixels with high quality signal levels, in terms of amplitude and coherence values, and identifies individual radar benchmarks called Permanent Scatters (PS) where accurate deformation measurements can be carried out. PS usually correspond to man-made structures as well as natural reflectors, such as exposed rock that can be indentified with a georeferencing accuracy related to the original spatial resolution of the employed SAR images (for ERS1 and ERS2 data the accuracy is about 4 m in azimuth and 8 m in slant range).

The PS technique has been applied to the monitoring of ground deformations included by different natural and anthropogenic phenomena, such as tectonic motions volcanic uplifts, land subsidence (Ferretti et al., 2000; Musson et al., 2004; Salvi et al., 2004) and in a few cases also to landslides (Colesanti et al., 2003; Colesanti and Wasowski, 2004; Ferretti et al., 2005).

The standard PS analysis was employed for the whole area of study (territory of Calabria (Provinces of Reggio Calabria, Catanzaro and Vibo Valentia) scale 1:10.000 downloaded from the regional site of Calabria) with the aim of mapping landslides at a regional scale. The analysis was carried out with SAR data both from ascending and descending orbits with the processing of various datasets from the period 1992-2002 (ERS1, ERS2 satellites) and from the period 2002-2006 (ENVISAT satellite). Due to the fact that the area of study is huge there was not realized advanced PS analysis.

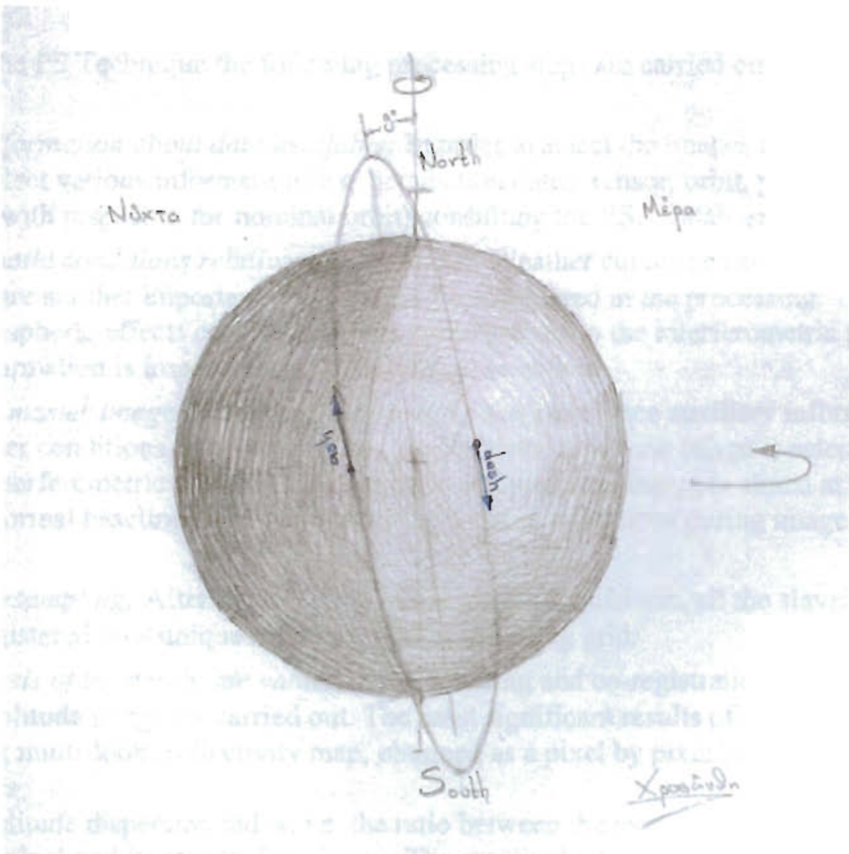


Figure 2.30 Both from descending and ascending orbits data selected

Basic idea and the main processing steps

Differential SAR Interferometry (DInSAR) method is able to detect millimetric surface deformation along the sensor – target direction (Line-of-Sight, LOS). But, nevertheless, the operational applicability of this method for ground displacement mapping is hampered mainly by two facts, namely the

- Decorrelation due to variations in the complex reflectivity of individual sampling cell as a function of the acquisition geometry (*geometric decorrelation*) and/or time (*temporal decorrelation*) (Zebker and Villasenor, 1992).
- Atmospheric artefacts (*atmospheric phase screen, APS*) superimposed on each interferogram, mainly due to the effect of the local water vapour content on the phase of the propagating SAR signal (Hanssen, 2001, Zebker *et al.*, 1997).

Geometric and temporal decorrelation of the SAR signal can prevent large portions of interferograms from providing any information. APS generates phase patterns, which are often extremely difficult to be discriminated from the phase contribution due to ground deformation (Hanssen, 2001), at least using only one interferogram.
The Permanent Scatterers approach is a two-step processing technique aimed at isolating the different phase terms (APS, deformation and residual topography) on a sparse grid of phase stable point-wise radar targets. The PS approach is based on the exploitation of long time series of interferometric SAR data (at least 25-30 images). The technique allows overcoming both main limiting factors, because PS are privileged radar targets only slightly affected by decorrelation and they can be used to estimate and remove the atmospheric phase screen. A detailed description of the Permanent Scatterer technique is given in (Ferretti *et al.*, 2000, 2001).

In order to apply the PS Technique the following processing steps are carried out.

- *Collection of information about data available:* In order to select the images necessary to the processing, we collect various information (e.g. acquisition dates, sensor, orbit, precise state vectors, baselines with respect to the nominal orbit) consulting the ESA database (Delft, 2002).
- *Analysis of climatic conditions relative to the data set*: Weather conditions at the time of the acquisition are another important parameter to be considered in the processing. In fact, many atmospheric effects can add spurious contributions to the interferometric phase. In particular, this information is important for master image selection.
- *Selection of the master image and identification of the test site:* Once auxiliary information about the data set (weather conditions, orbit parameters, etc.) are available, one image is selected as the "master" for the interferometric analysis. The selection of the master image is aimed at minimising the dispersion of normal baseline values and takes the weather conditions during image acquisitions into account.
- *Focusing and resampling:* After the selection of the master acquisition, all the slaveimages are focused and co-registered on a unique reference master sampling grid.
- *Statistical analysis of the amplitude values:* After focusing and co-registration, a statistical analysis of the amplitude images is carried out. The most significant results of this analysis are:
  - o multi-image (or multi-look) reflectivity map, obtained as a pixel by pixel incoherent average of all available images
  - o map of the amplitude dispersion index, i.e. the ratio between the average amplitude return value of each individual pixel and its standard deviation. The amplitude dispersion map is the main instrument used to identify Permanent Scatterers Candidates (PSC).

- *Generation of the Digital Elevation Model:* To estimate the local topography, ERS SAR Tandem data (with 1 day time interval) are exploited jointly using a multibaseline approach (Ferretti *et al.*, 1999, 1997). Due to the very short temporal baseline of 1 day only coherence is in general very high over most surfaces and the surface deformation can be neglected. To reduce the impact of atmospheric variations a filtering process is carried out in the wavelet domain (Ferretti *et al.*, 1999). Tandem interferograms characterised by a low value of the normal baseline and/or low coherence over wide parts of the imaged area are not involved in DEM generation. Since large normal baseline interferograms are involved in the PS processing, inaccuracies in the reference DEM cannot be neglected; e.g. in a 1200 m baseline interferogram the height of ambiguity corresponding to one phase cycle, is around 7.5 m).
- *Generation of differentials interferograms:* After DEM reconstruction, the interferograms between all the slave images and the master are compensated for the topographic phase contribution.
- *Estimation and removal of the atmospheric phase:* The generation and the relative compensation of the atmospheric effects on the images can be considered the most innovative step of the entire technique, in fact this operation allows one to separate motion from the other components of the interferometric phase. The atmospheric phase term, which is estimated for each PSC, is re-sampled and filtered (outlier removal) to the regular grid of the master image by using Kriging interpolation (Wackernagel, 1998), which makes use of the high spatial correlation of atmospheric phenomena described by the Kolmogorov turbulence model (Hanssen, 2001)). This method is only applicable in areas with a sufficient density of PSC (about 5 to 10 PSC/km2).
- *Generation of the map of the average displacement rate:* The separation of the topographic and atmospheric phase term is based on their characteristics: the topography phase contribution is proportional to the normal baseline, whereas deformation is correlated in time. This step is applied on the available set of differential interferograms, which were compensated for APS, on a *pixel-by-pixel* basis identifying all Permanent Scatterers.
- *Generation and analysis of the time series of the Permanent Scatterers:* Beside the map of the average displacement rate, it is possible to reconstruct the complete displacement time series, highlighting possible time non-uniform motion phenomena. The accuracy on each measurement is extremely high, ranging from 1 to 3 mm.

The **main products** generated by means of the Permanent Scatterer Technique are:

- Map of the PS identified in the image and their co-ordinates: latitude, longitude and precise elevation (accuracy on elevation better than 1 m).
- Average LOS deformation rate of every PS (accuracy usually between 0.1 and 1 mm/yr., depending on the number of available interferograms and on the phase stability of each single PS).
- Displacement time series showing the relative (i.e. with respect to a unique reference image) LOS position of PS in correspondence of each SAR acquisition. Time series represent, therefore, the LOS motion component of PS as a function of time (accuracy on single measurements usually ranging from 1 to 3 mm).

At this point it should be noted that, as in all differential interferometry applications, results are not absolute both in time and space. Deformation data are referred to the master image (in time) and results are computed with respect to a reference point of known elevation and motion (in space).

METHODOLOGY

PS data is information that on its own results insufficiently, as the measurement of the terrain deformation does not estimate the entire moving area but only the movement along the line of sight, in other words is information that refers to a point (punctual information) of superficial movement. The composite experience matured on this field from DST has permitted to individuate the effective process so as to get the optimal interpretation of the PS information.

The proposed methodology is concentrated on the integration of all data available (optical, Radar, e.t.c.), derivate from the archive already existing, acquired to result in an analysis and a monitoring even in small scale on the existence of slope instability.

The major part of the work was to update all the existing information of landslide over the area of study- territory of Calabria (Provinces of Reggio Calabria, Catanzaro and Vibo Valentia). The basic tool with witch was given the major confidence was the PS (Permanent Scatterers technique) information in confront of the PAI or IFFI information that was used as the base of all process done.

The elaboration of all basic data, the geographic material and radar images was accomplished on GIS environment with the use of the application ArcGis 9.0., informatics Platform that permits the gestation, elaboration and archiving together data both in raster format and in digital representation, guaranteeing among other the maximum flexibility in terms of geographic system of reference.

Initial processing

To begin with, there is created an ArcMap (.mxd file) project, in which can be imported and visualized all necessary themes of the analysis as different layers. As a co-ordinated system it is recommended the UTM WGS (32 N and 33 N), because such co-ordinated system is used at national level as standard. Secondly is suggested to integrate the initial information from the pre-existing archives with the information that derivate from the photointerpretation of the multitemporal images and from radiointerpretation. The next step consists of the acquisition of the inventory maps existing, for the territory that was analyzed, and their homogenization. Commonly verification was recommended, digitalization and georeferense of the available maps from the IFFI database.

In figure 2.8 is described a flow diagram of the methodology used, for all the area of study.

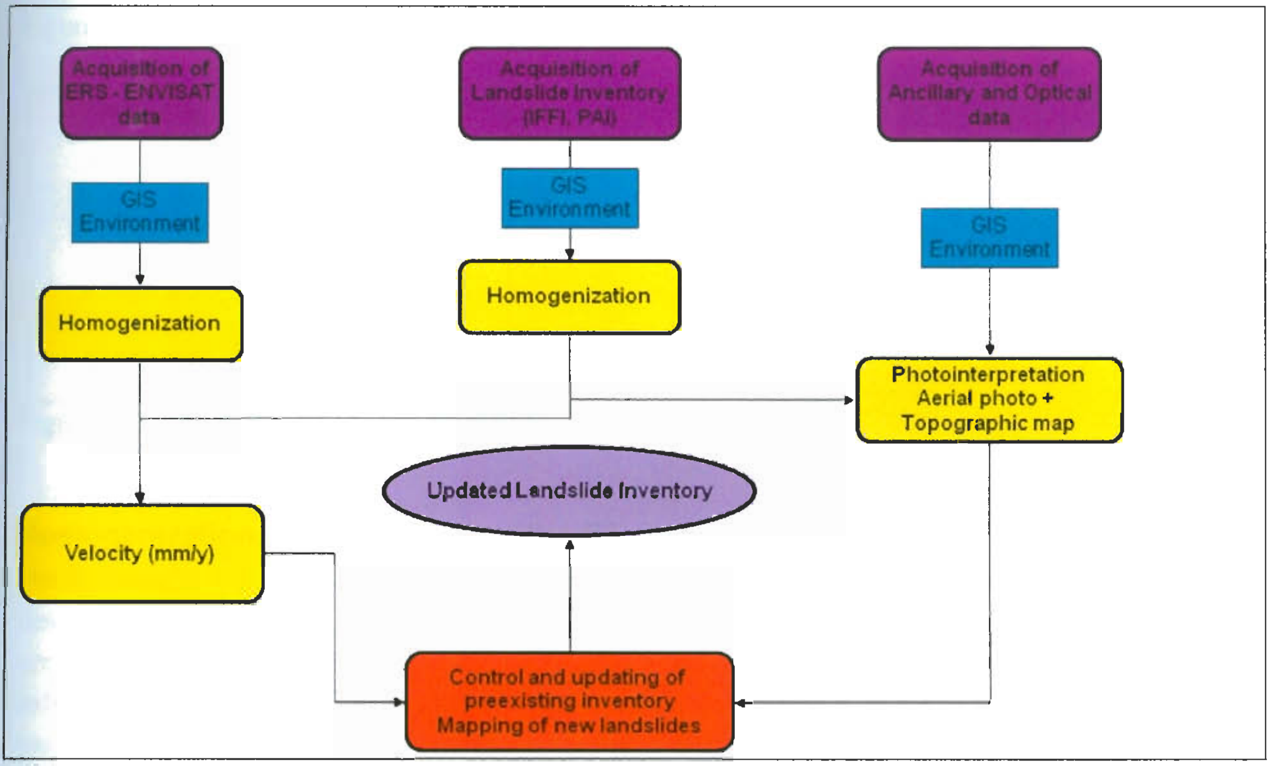


Figure 2.8 Methodology of all process done

PS Visualization

The SAR interferometric datasets are formed in .dbf format (figure 2.9), so the first operation to accomplish was their visualization, which is being realized by a following number of certain commands in the ArcMap .mxd project, associating the co-ordinated continual of the inside information of the PS data-base with the X and Y co-ordinates of the .mxd project. The most frequent co-ordinates are resulted in UTM WGS84 projected or in WGS84 geographic. Their visualization is being affected in function of the medium velocity, in which, their value is normally grouped in a finished number of classes in which the limits can be selected in function of the requirement.

The legend that seems to offer the optimal visualization is the one precisely demonstrated in figure 2.10. It was selected to visualize PS descending with a different symbol than the ascending (representing circles or squares), using a scale of colors from red to blue starting from the velocity of disposal which is indicated with the – (minus) sign and arriving to the velocity of approach which is indicated with the + (plus) sign.

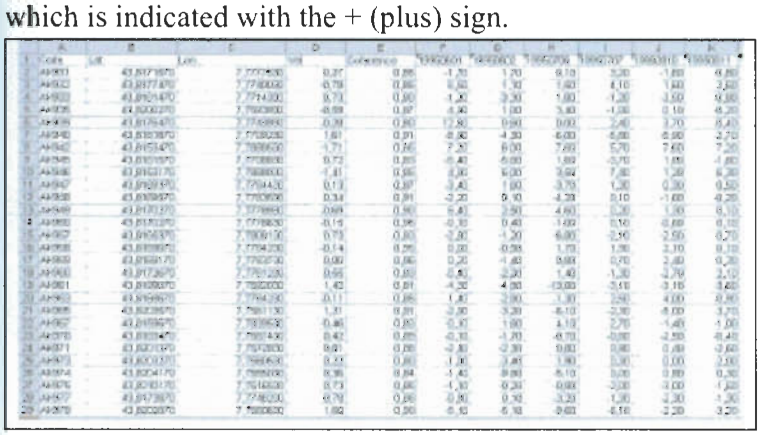


Figure 2.9 .dbf formats of the SAR interferometric datasets

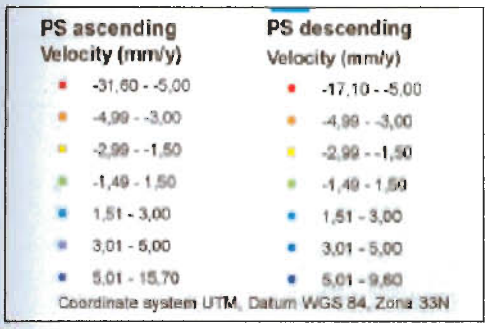


Figure 2.10 legend of the PS information

Homogenization and escalation of the PS

Fundamentally PS data that comes from different orbits has to be homogenized (ascending and descending) (figures 2.11, 2.12, 2.13, 2.14). The velocities that are formed from interferometric data are relative velocities, in other words differential velocities, calculated respective to a point of reference called "reference point". Different datasets have different "reference points" and that's the reason why different dataset may have velocities a little misleading. In these cases estimation is necessary when such difference in points close to each other can be considered, and by operating a statistic evaluation, we can remove them.

Other factors that can be tendered in consideration are the tectonic deformations of every region, normally in basin scale, as some mm/year. Such deformations can be reflected as small offsets on the velocity of the entire population of the present PS in that area. For this kind of difficulties it is possible to statistically calculate the medium value of such offsets, by analyzing the distribution of frequency of the velocity and remove them.

In figure 2.15 is represented the removal of 2 mm from all PS information from a certain dataset so as to get a more valid interpretation.

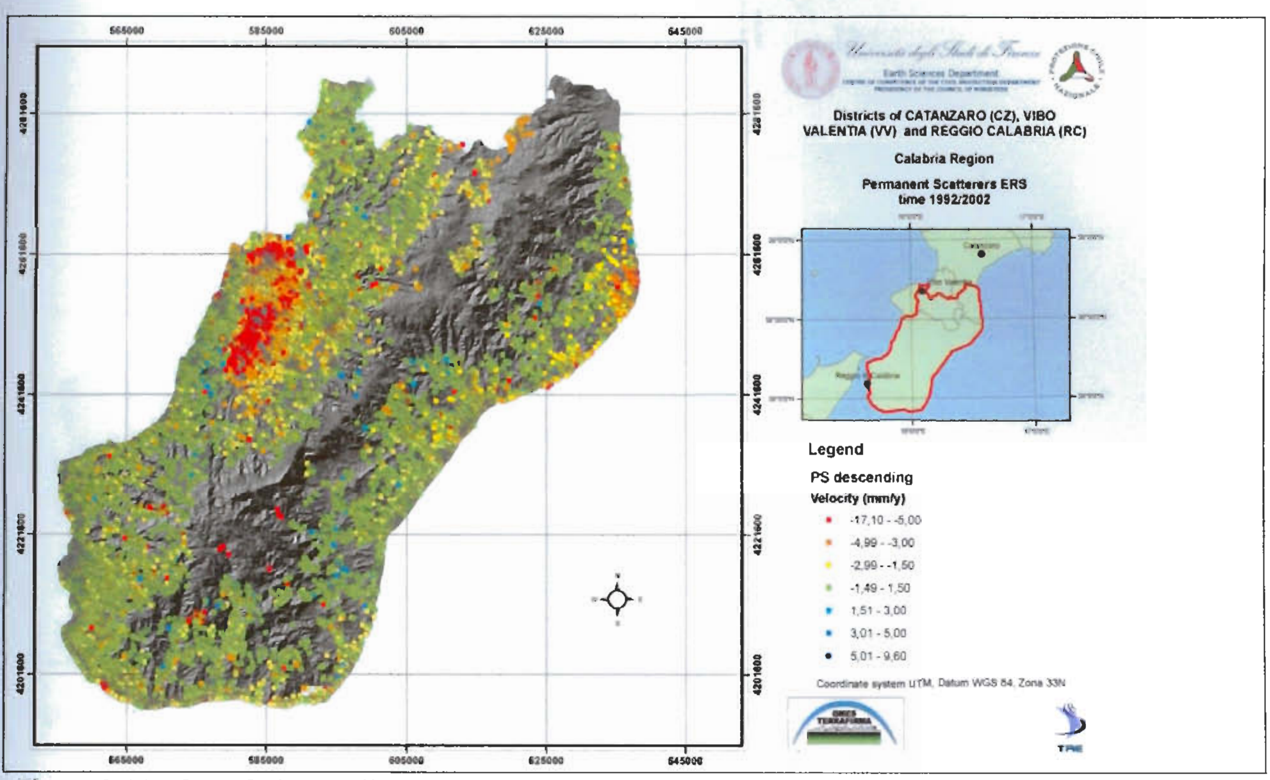


Figure 2.11 PS ERS descending 1992 - 2002

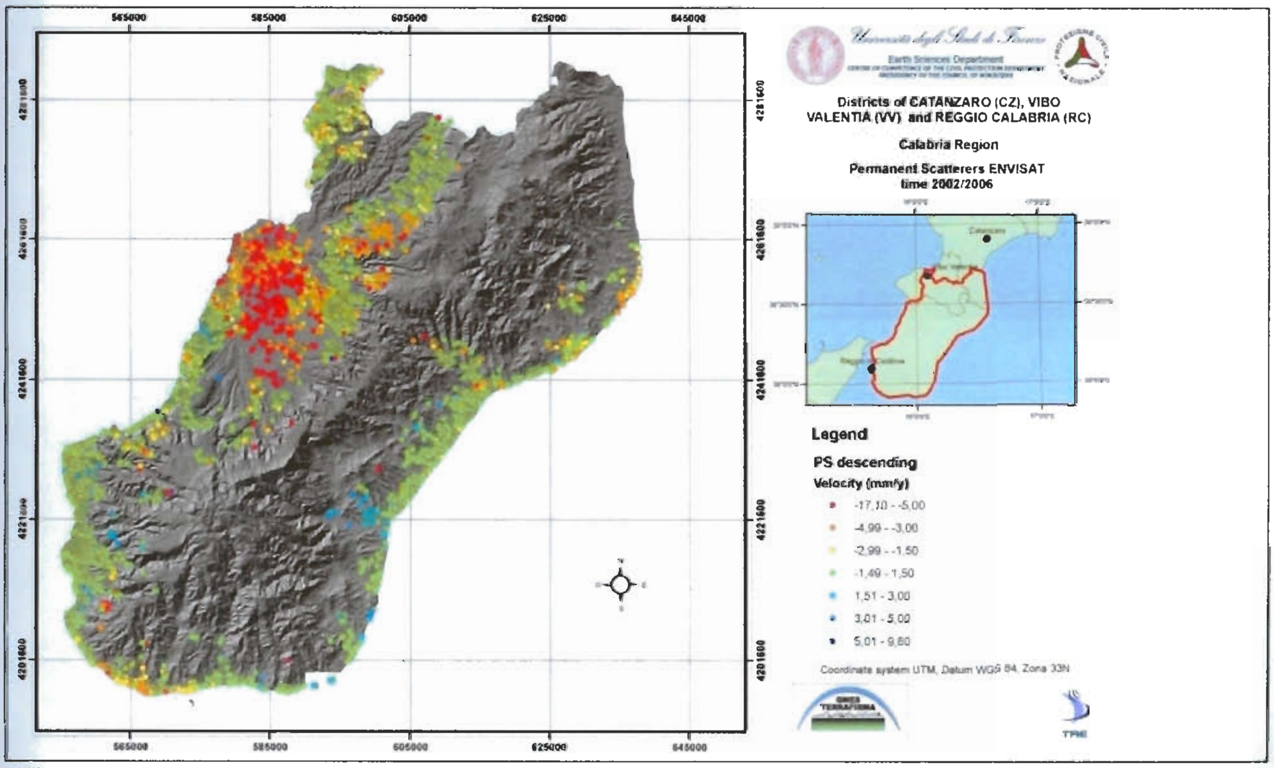


Figure 2.12 PS ENVISAT descending 2002 - 2006

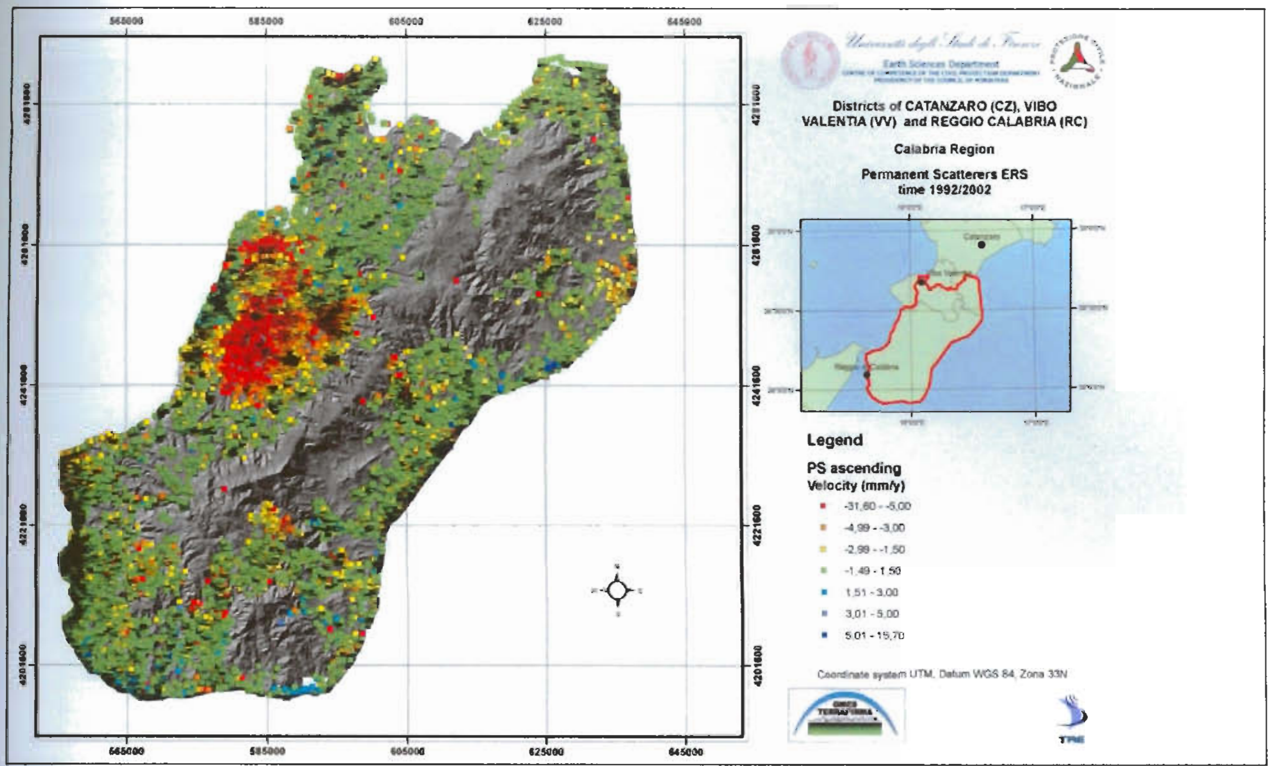


Figure 2.13 PS ERS ascending 1992 - 2002

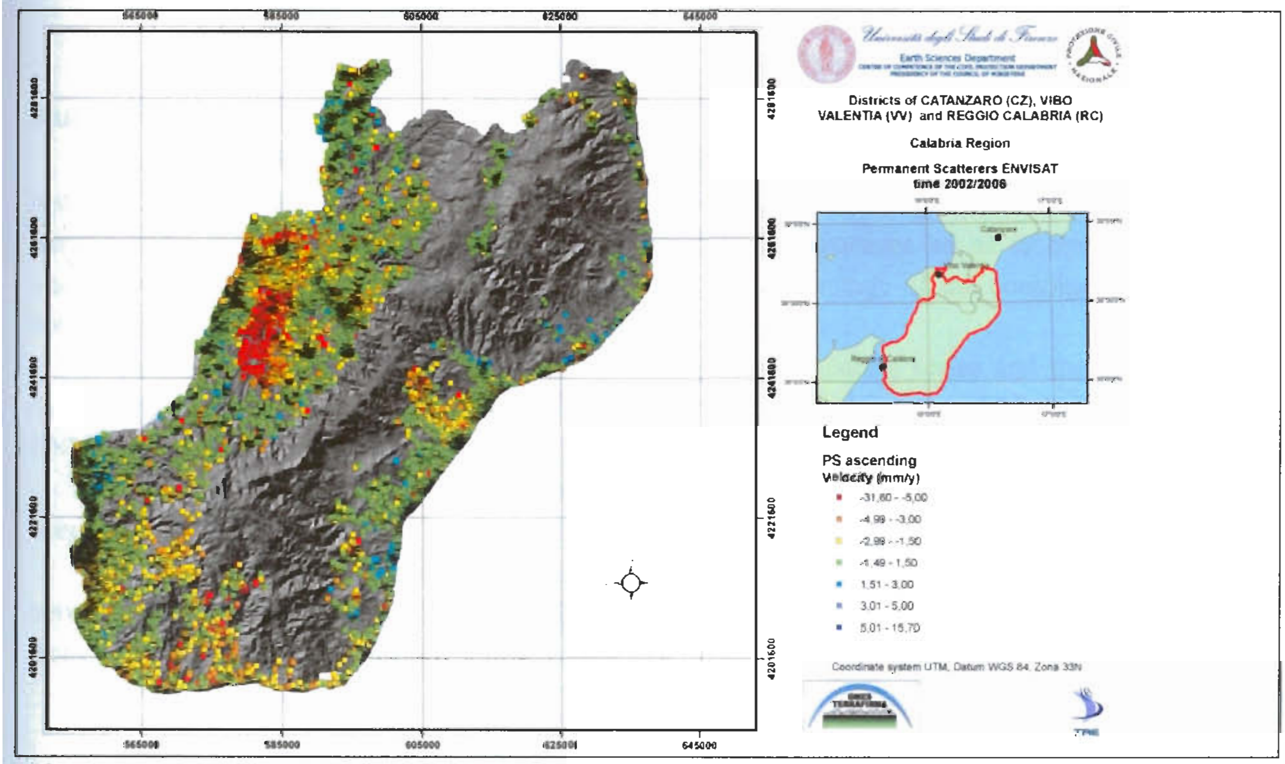


Figure 2.14 PS ENVISAT ascending 2002 - 2006

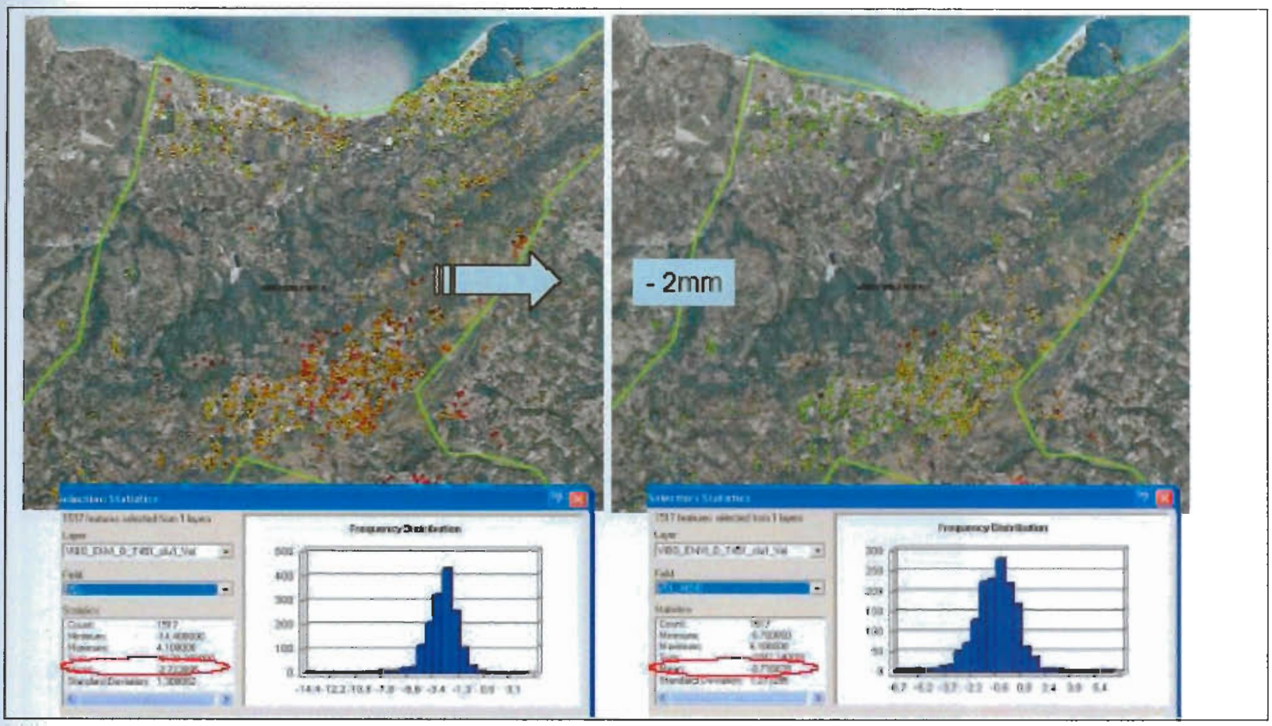


Figure 2.15 Homogenization and escalation of the PS. Removal of 2 mm from all PS information from a Vibo Valentia ENVISAT descending dataset.

Multi temporal interpretation

Continuing the processes, after the visualization of the PS, the topographic maps and the historic optic images are imported (orthophoto Volo Italia 2000 disponsible for all the Italian territory).The topographic maps are being visualized in transparence so as to overlap the optic images during the analysis (figure 2.18), in order to take advantage of the combined information both from the optical data and the topographic map.

In this point all PS points are groped, based on their historic series and the orbit so as to have together all PS information groped: ERS descending, ERS ascending, ENVISAT descending, ENVISAT ascending.

In the same project we have the dtm file, from which the slope map and the aspect map have been exported.

It proceeds to the photointerpretation and the radarinterpretation operating a crossed control between velocity data formed from the PS information, and geomorphologic information acquired from the topography maps and the optic images.

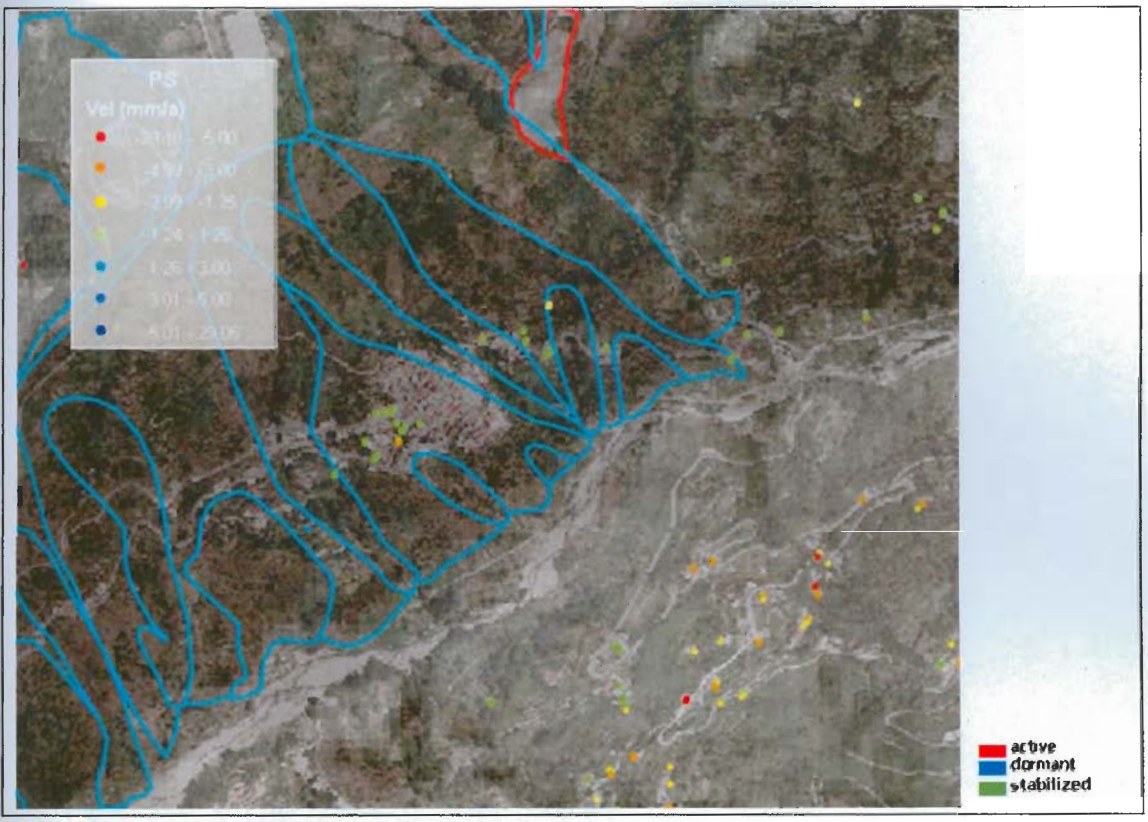


Figure 2.16 overlap of PS over landslide inventory

Check and valuation of the velocity

The PS interpretation takes action by working together with all informatics data dispensable (topographic maps, optic images, DTM, slope maps, aspect maps) and by using the visualization of the PS points (figure 2.18). A number of the landslides from the archives (P.A.I., I.F.F.I.) is selected, the ones that contain PS information. Every selected landslide has inside differences on the quality and the quantity of the PS information (points). The first step is to acquire from the data bank, the statistic values related to the interested PS. Such values are reassumed from the maximum, the minimum and the medium velocity.

The analysis that has been realized with the PS information permits to confirm or modify the Perimeter of the preexisting landslides and individuate eventually new movements and slope Instabilities no yet mapped.

In case that a new landslide is about to be designed, the evidence of the movement has to be well valued, on all other information dispensable which is the topographic map and the optical Images (orthophotos of 2000 and google images of 2003 figures 2.17, 2.18).Combining all geomorphologic evidence such as clear variation of curvature and escarpments from the topographic map 1:10000, escarpments, absence of soil, stripped substrate, altered drainage from Google Quick bird 2003,escarpments, absence of soil, stripped substrate, clear difference of vegetation between inside and outside Volo Italia 2000 (figure 2.19).

The evaluation of the status of activity is based in relation to the time series of the PS acquired from the satellites ERS1-ERS2 (1992-2000) and the recent ones ENVISAT-RADARSAT by analyzing and configuring the existing difference for different dispensable historic periods of interest.

Figure 2.17 Google check

Figure 2.18 Check, valuation of the velocity and new landslides added to the updated **database of the landslide inventory map**

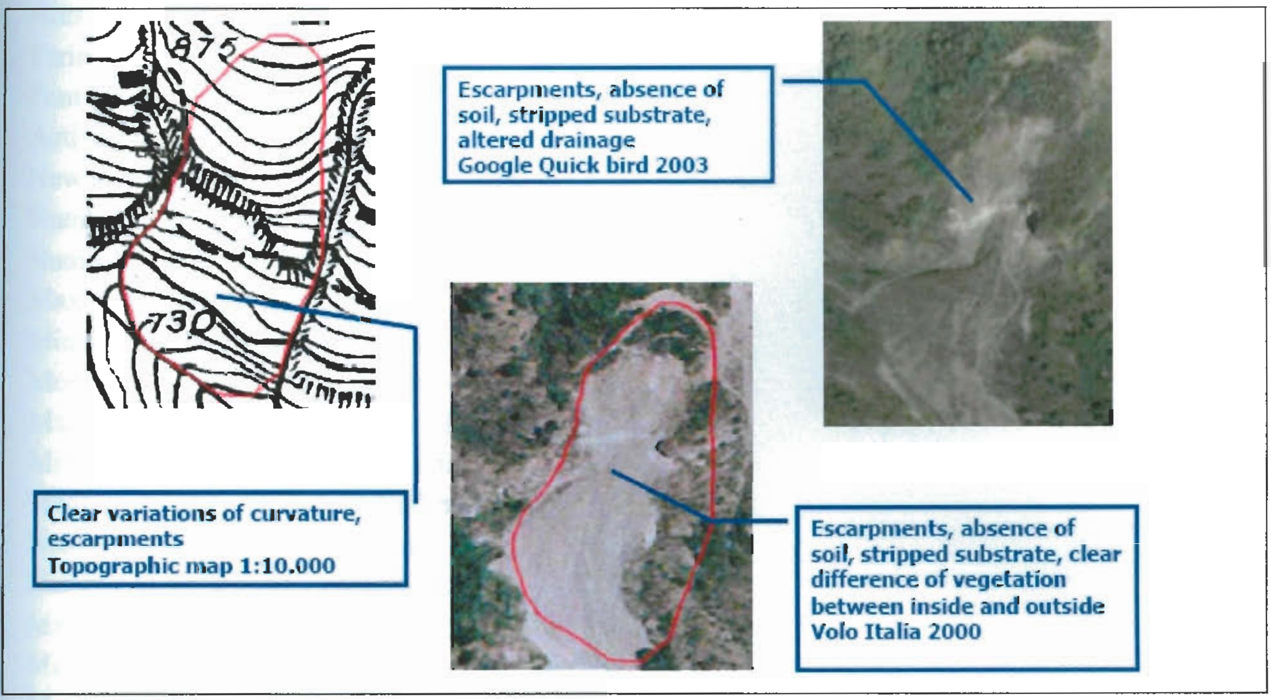


Figure 2.19 Geomorphologic evidence of a landslide

Matrix of activity

The use of the information that come from the fotointerpretation and the radiointerpretation forms a fascinating method to evaluate the state of activity of the landslide phenomenon. The interferometric data indicate that a velocity of some mm/year can refer to a historic series ERS (92-00) and to recent series ENVISAT (2002-2006). Not always we do have the possibility to acquire information that comes from the time series, so in this case the information coming from the fotointerpretation is being used.

As a result here comes a suggestion of a matrix of activity of the landslide based on the velocity of the PS information that is demonstrated in figure 2.20.

MATRICE ATTIVITA'	ERS < 2mm	ERS > 2mm
ENVI/RADAR SAT < 2 mm	Inattiva	Quiescente
ENVI/RADAR SAT > 2 mm	Attiva	Attiva

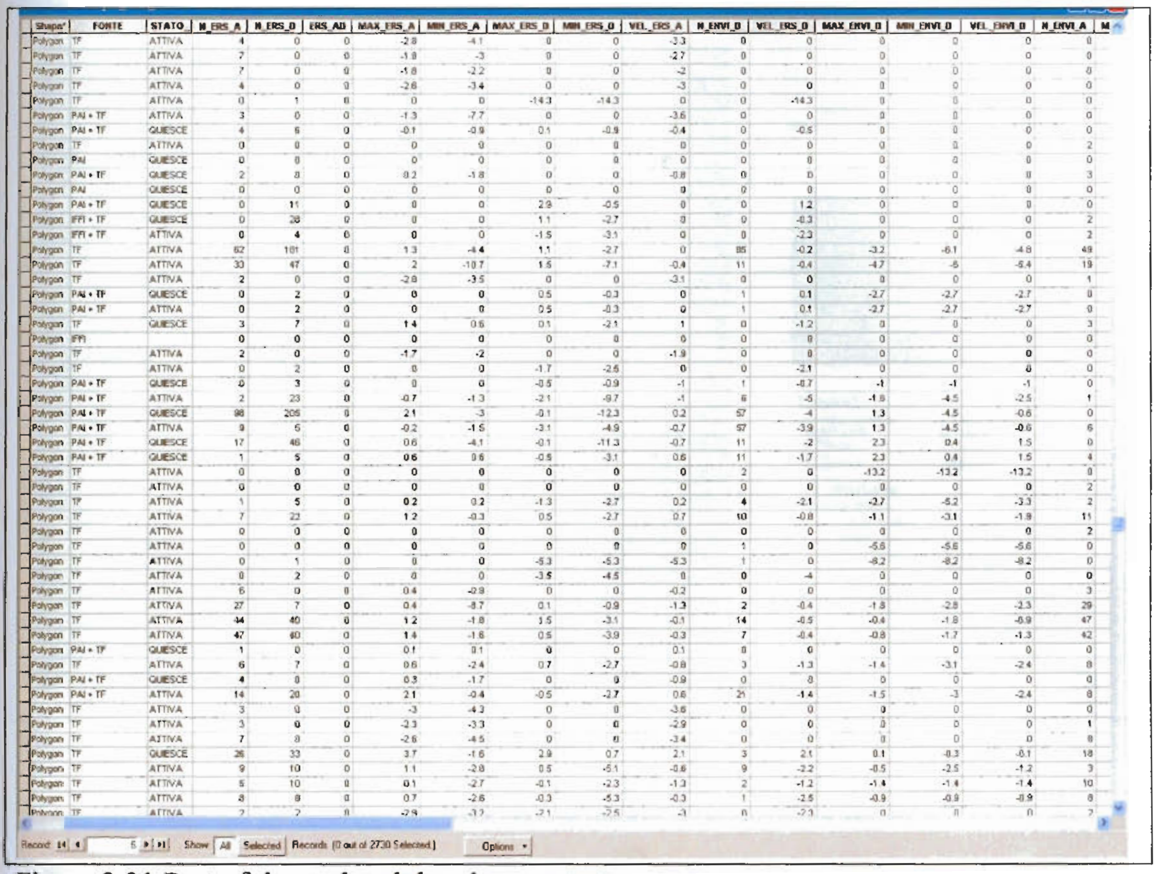
Figure 2.20 Matrix of activity

Strategic information that is contained in the data-base

A database of the landslide phenomena is being realized that contain the new areas of landslide divided and all the perimeters exported from the existed archives, redesigned and updated.
For every land slide phenomenon is reported

Area
Perimeter
Font (origin of data)
Activity state
New activity state
Number of ERS ascending
Number of ERS descending
Maximum velocity of ERS descending
Minimum velocity of ERS descending
Medium velocity of ERS descending
Maximum velocity of ERS ascending
Minimum velocity of ERS ascending
Medium velocity of ERS ascending
Number of ENVISAT ascending
Number of ENVISAT descending
Maximum velocity of ENVISAT descending
Minimum velocity of ENVISAT descending
Medium velocity of ENVISAT descending
Maximum velocity of ENVISAT ascending
Minimum velocity of ENVISAT ascending
Medium velocity of ENVISAT ascending
The area and the perimeter are calculated automatically by a command inside the ArcMap project.
The fond indicates the origin of the data so we have tree typologies:
Archives (PAI and IFFI)
Modified archives (name of the archive + modified font)
New radar data

The classification of the activity state of the landslide activity was changed based on the use of the matrix as it was exposed before. The number of the PS ERS and ENVISAT descending and ascending contained on the inside of the landslide phenomenon calculate the maximum velocity, the minimum velocity and the medium velocity on the inside of the landslide. Part of the updated data-base is demonstrated on figure 2.21.



Shape*	FONTE	STATO	N_ERS_A	N_ERS_D	ERS_AD	MAX_ERS_A	MIN_ERS_A	MAX_ERS_D	MIN_ERS_D	VEL_ERS_A	N_ENVI_D	VEL_ERS_D	MAX_ENVI_D	MIN_ENVI_D	VEL_ENVI_D	N_ENVI_A	M
Polygon	TF	ATTIVA	4	0	0	-2.8	-4.1	0	0	-3.3	0	0	0	0	0	0	
Polygon	TF	ATTIVA	7	0	0	-1.8	-3	0	0	-2.7	0	0	0	0	0	0	
Polygon	TF	ATTIVA	7	0	0	-1.8	-2.2	0	0	-2	0	0	0	0	0	0	
Polygon	TF	ATTIVA	4	0	0	-2.6	-3.4	0	0	-3	0	0	0	0	0	0	
Polygon	TF	ATTIVA	0	1	0	0	0	-14.3	-14.3	0	0	-14.3	0	0	0	0	
Polygon	PAI + TF	ATTIVA	3	0	0	-1.3	-7.7	0	0	-3.6	0	0	0	0	0	0	
Polygon	PAI + TF	QUIESCE	4	6	0	-0.1	-0.9	0.1	-0.9	-0.4	0	-0.5	0	0	0	0	
Polygon	TF	ATTIVA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
Polygon	PAI	QUIESCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Polygon	PAI + TF	QUIESCE	2	0	0	0.2	-1.8	0	0	-0.8	0	0	0	0	0	3	
Polygon	PAI	QUIESCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Polygon	PAI + TF	QUIESCE	0	11	0	0	0	2.9	-0.5	0	0	1.2	0	0	0	0	
Polygon	IFFI + TF	QUIESCE	0	28	0	0	0	1.1	-2.7	0	0	-0.3	0	0	0	2	
Polygon	IFFI + TF	ATTIVA	0	4	0	0	0	-1.5	-3.1	0	0	-2.3	0	0	0	2	
Polygon	TF	ATTIVA	62	101	0	1.3	-4.4	1.1	-2.7	0	85	-0.2	-3.2	-6.1	-4.8	49	
Polygon	TF	ATTIVA	30	47	0	2	-10.7	1.5	-7.1	-0.4	11	-0.4	-4.7	-6	-5.4	19	
Polygon	TF	ATTIVA	2	0	0	-2.8	-3.5	0	0	-3.1	0	0	0	0	0	1	
Polygon	PAI + TF	QUIESCE	0	2	0	0	0	0.5	-0.3	0	1	0.1	-2.7	-2.7	-2.7	0	
Polygon	PAI + TF	ATTIVA	0	2	0	0	0	0.5	-0.3	0	1	0.1	-2.7	-2.7	-2.7	0	
Polygon	TF	QUIESCE	3	7	0	1.4	0.6	0.1	-2.1	1	0	-1.2	0	0	0	3	
Polygon	IFFI		0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Polygon	TF	ATTIVA	2	0	0	-1.7	-2	0	0	-1.9	0	0	0	0	0	0	
Polygon	TF	ATTIVA	0	2	0	0	0	-1.7	-2.6	0	0	-2.1	0	0	0	0	
Polygon	PAI + TF	QUIESCE	0	3	0	0	0	-0.5	-0.9	-1	1	-0.7	-1	-1	-1	0	
Polygon	PAI + TF	ATTIVA	2	23	0	-0.7	-1.3	-2.1	-9.7	-1	6	-5	-1.8	-4.5	-2.5	1	
Polygon	PAI + TF	QUIESCE	98	205	0	2.1	-3	-0.1	-12.3	0.2	57	-4	1.3	-4.5	-0.6	0	
Polygon	PAI + TF	ATTIVA	9	5	0	-0.2	-1.5	-3.1	-4.9	-0.7	57	-3.9	1.3	-4.5	-0.6	6	
Polygon	PAI + TF	QUIESCE	17	46	0	0.6	-4.1	-0.1	-11.3	-0.7	11	-2	2.3	0.4	1.5	0	
Polygon	PAI + TF	QUIESCE	1	5	0	0.6	0.6	-0.5	-3.1	0.6	11	-1.7	2.3	0.4	1.5	4	
Polygon	TF	ATTIVA	0	0	0	0	0	0	0	0	2	0	-13.2	-13.2	-13.2	0	
Polygon	TF	ATTIVA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
Polygon	TF	ATTIVA	1	5	0	0.2	0.2	-1.3	-2.7	0.2	4	-2.1	-2.7	-5.2	-3.3	2	
Polygon	TF	ATTIVA	7	22	0	1.2	-0.3	0.5	-2.7	0.7	10	-0.8	-1.1	-3.1	-1.9	11	
Polygon	TF	ATTIVA	0	0	0	0	0	0	0	0	0	0	0	0	0	2	
Polygon	TF	ATTIVA	0	0	0	0	0	0	0	0	1	0	-5.6	-5.6	-5.6	0	
Polygon	TF	ATTIVA	0	1	0	0	0	-5.3	-5.3	-5.3	1	0	-8.2	-8.2	-8.2	0	
Polygon	TF	ATTIVA	0	2	0	0	0	-3.5	-4.5	0	0	-4	0	0	0	0	
Polygon	TF	ATTIVA	6	0	0	0.4	-2.9	0	0	-0.2	0	0	0	0	0	3	
Polygon	TF	ATTIVA	27	7	0	0.4	-8.7	0.1	-0.9	-1.3	2	-0.4	-1.8	-2.8	-2.3	29	
Polygon	TF	ATTIVA	44	40	0	1.2	-1.8	1.5	-3.1	-0.1	14	-0.5	-0.4	-1.8	-0.9	47	
Polygon	TF	ATTIVA	47	40	0	1.4	-1.6	0.5	-3.9	-0.3	7	-0.4	-0.8	-1.7	-1.3	42	
Polygon	PAI + TF	QUIESCE	1	0	0	0.1	0.1	0	0	0.1	0	0	0	0	0	0	
Polygon	TF	ATTIVA	6	7	0	0.6	-2.4	0.7	-2.7	-0.8	3	-1.3	-1.4	-3.1	-2.4	8	
Polygon	PAI + TF	QUIESCE	4	0	0	0.3	-1.7	0	0	-0.9	0	0	0	0	0	0	
Polygon	PAI + TF	ATTIVA	14	20	0	2.1	-0.4	-0.5	-2.7	0.6	21	-1.4	-1.5	-3	-2.4	8	
Polygon	TF	ATTIVA	3	0	0	-3	-4.3	0	0	-3.6	0	0	0	0	0	0	
Polygon	TF	ATTIVA	3	0	0	-2.3	-3.3	0	0	-2.9	0	0	0	0	0	1	
Polygon	TF	ATTIVA	7	0	0	-2.6	-4.5	0	0	-3.4	0	0	0	0	0	8	
Polygon	TF	QUIESCE	26	33	0	3.7	-1.6	2.9	0.7	2.1	3	2.1	0.1	-0.3	-0.1	18	
Polygon	TF	ATTIVA	9	10	0	1.1	-2.8	0.5	-5.1	-0.6	9	-2.2	-0.5	-2.5	-1.2	3	
Polygon	TF	ATTIVA	5	10	0	0.1	-2.7	-0.1	-2.3	-1.3	2	-1.2	-1.4	-1.4	-1.4	10	
Polygon	TF	ATTIVA	8	8	0	0.7	-2.6	-0.3	-5.3	-0.3	1	-2.5	-0.9	-0.9	-0.9	8	
Polygon	TF	ATTIVA	2	2	0	-2.8	-3.2	-2.1	-2.5	-3	0	-2.1	0	0	0	2	

Record: 14 ◂ 5 ▸ ▸| Show: All Selected Records (0 out of 2730 Selected) Options

Figure 2.21 Part of the updated data-base

Examples

CARAFFA and SANT'AGATA del BIANCO

Figures 2.22, 2.23, 2.24 demonstrate the way PS are visualized (PS descending in figure 2.22, PS ascending in figure 2.23) and the way the database was updated by creating a new landslide and by modifying an existing one from the P.A.I. archive (figure 2.24).

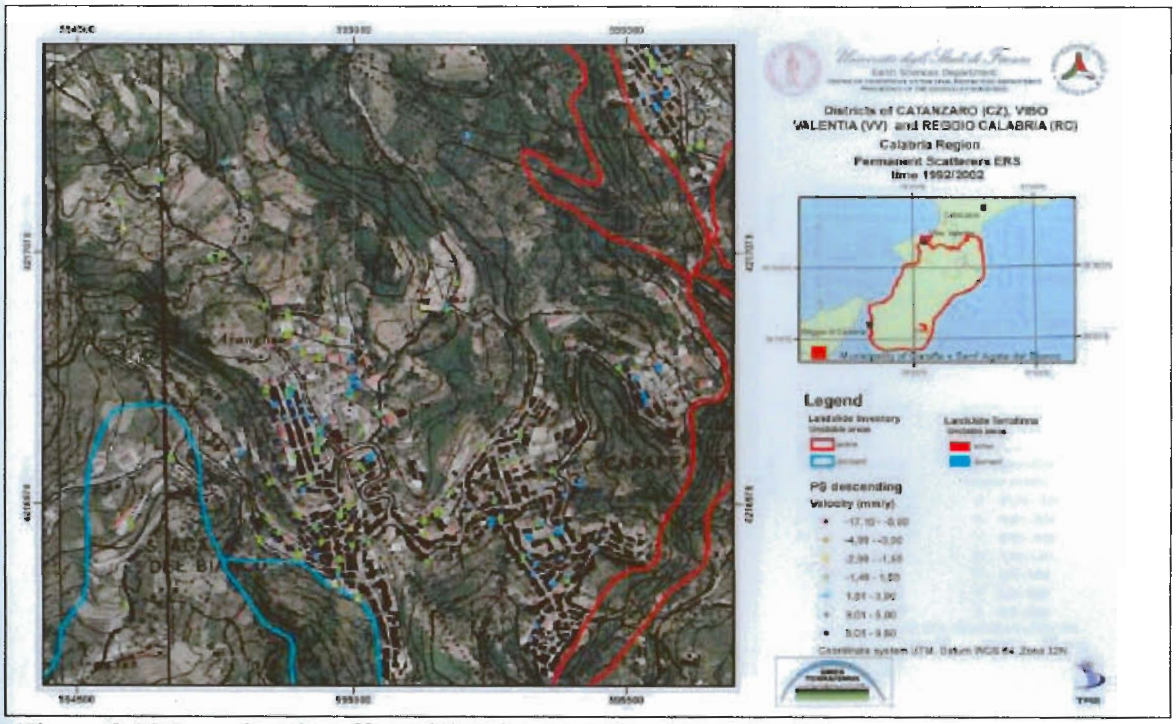


Figure 2.22 Location Caraffa and Sant'Agata del Bianco PS ERS descending

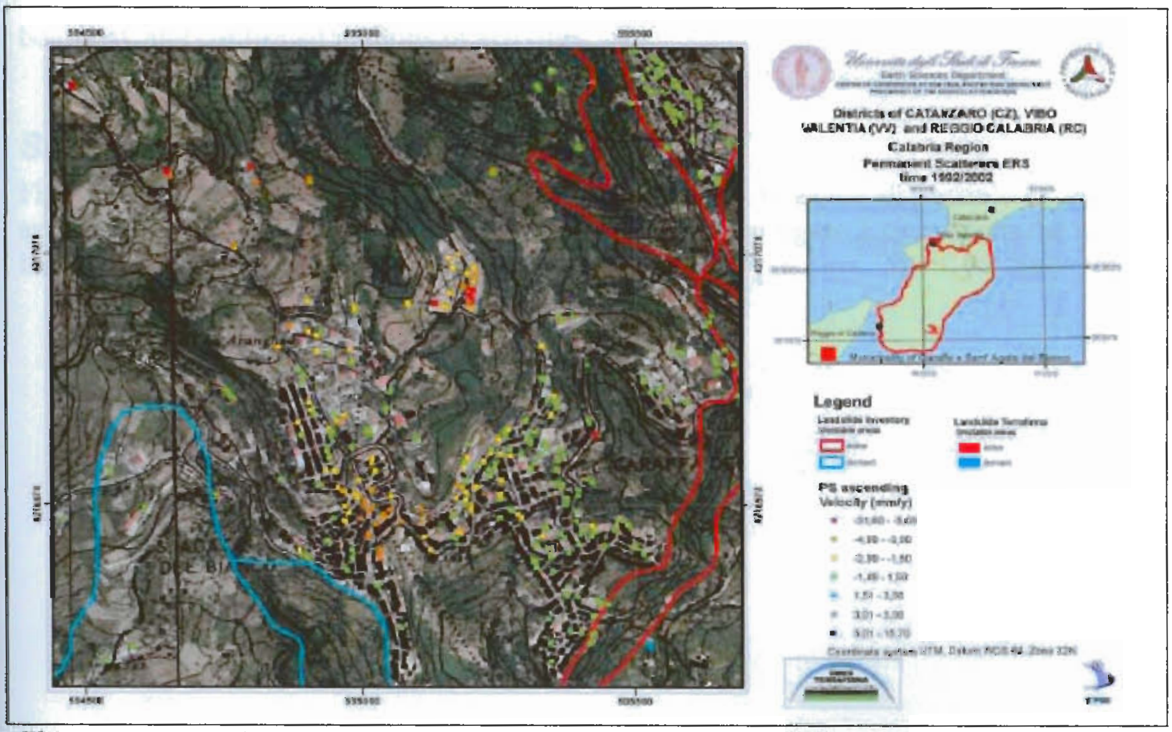


Figure 2.23 Location Caraffa and Sant'Agata del Bianco PS ERS ascending

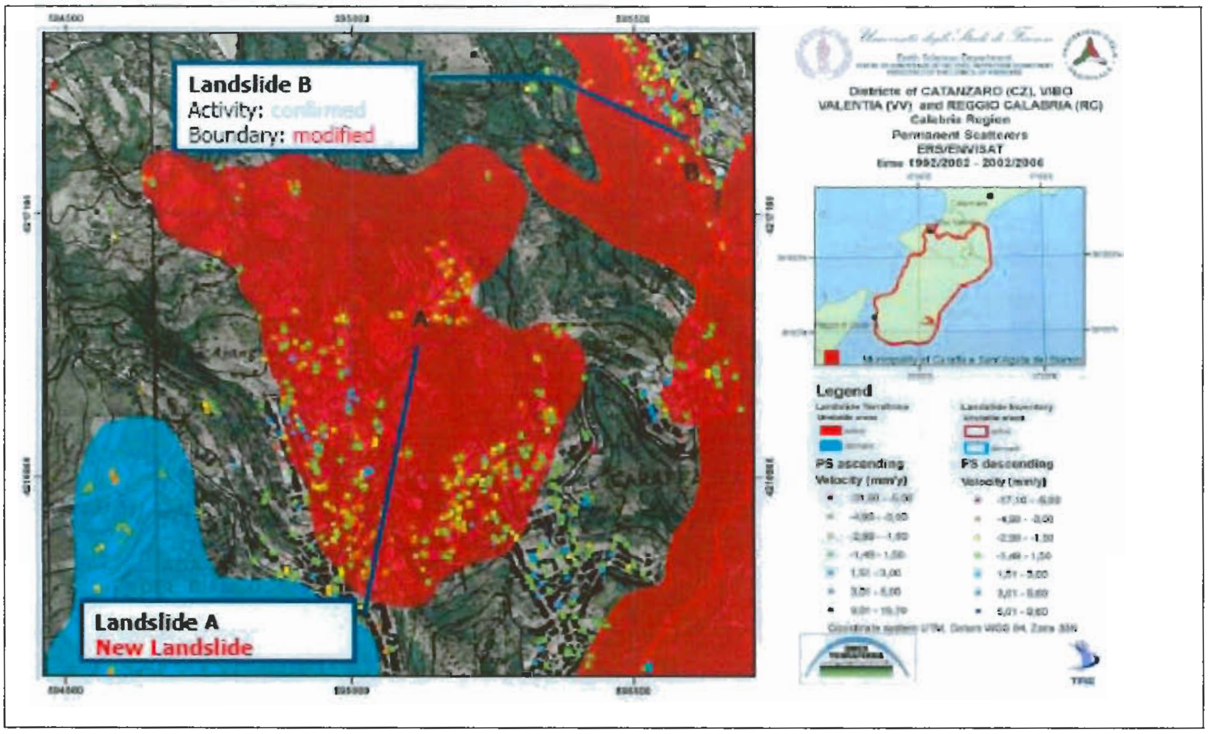


Figure 2.24 Location Caraffa and Sant'Agata del Bianco. All PS data visualized, ascending and descending and database modification. Landslide A is new and landslide B is modified in terms of boundary and confirmed in terms of activity

SANTO STEFANO IN ASPROMONTE

Figures 2.25, 2.26, 2.27, 2.28, 2.29, demonstrate a location in which all possible PS information is available. Almost all PS information indicates movement so figure 2.29 explains the way two landslides have been modified.

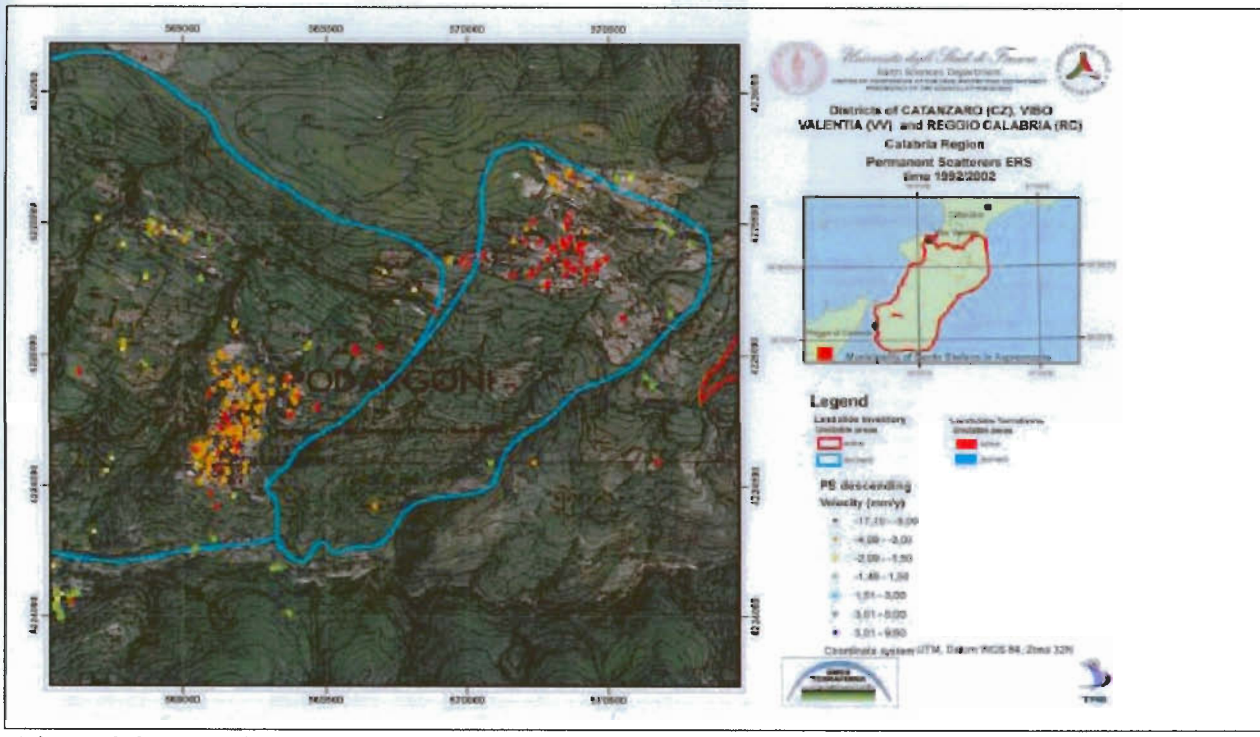


Figure 2.25 Location Santo Stefano in Aspromonte PS ERS descending

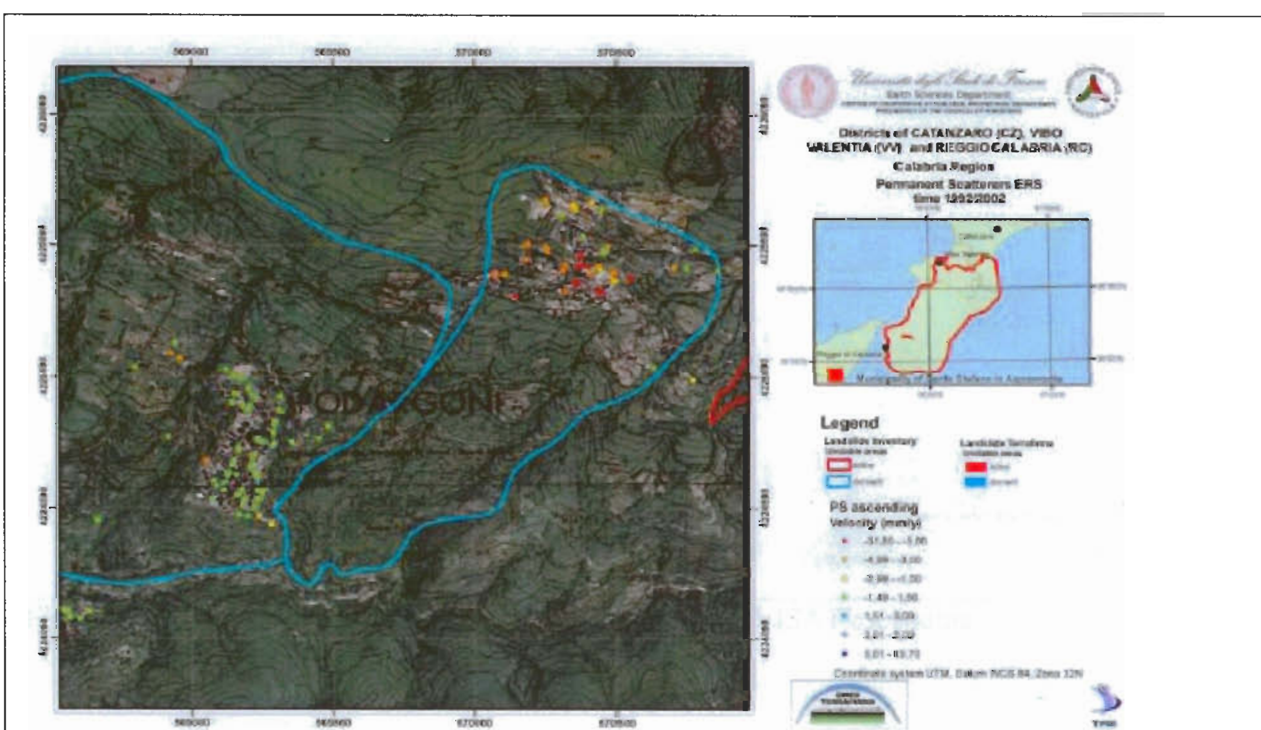


Figure 2.26 Location Santo Stefano in Aspromonte PS ERS ascending

Figure 2.27 Location Santo Stefano in Aspromonte PS ENVISAT descending

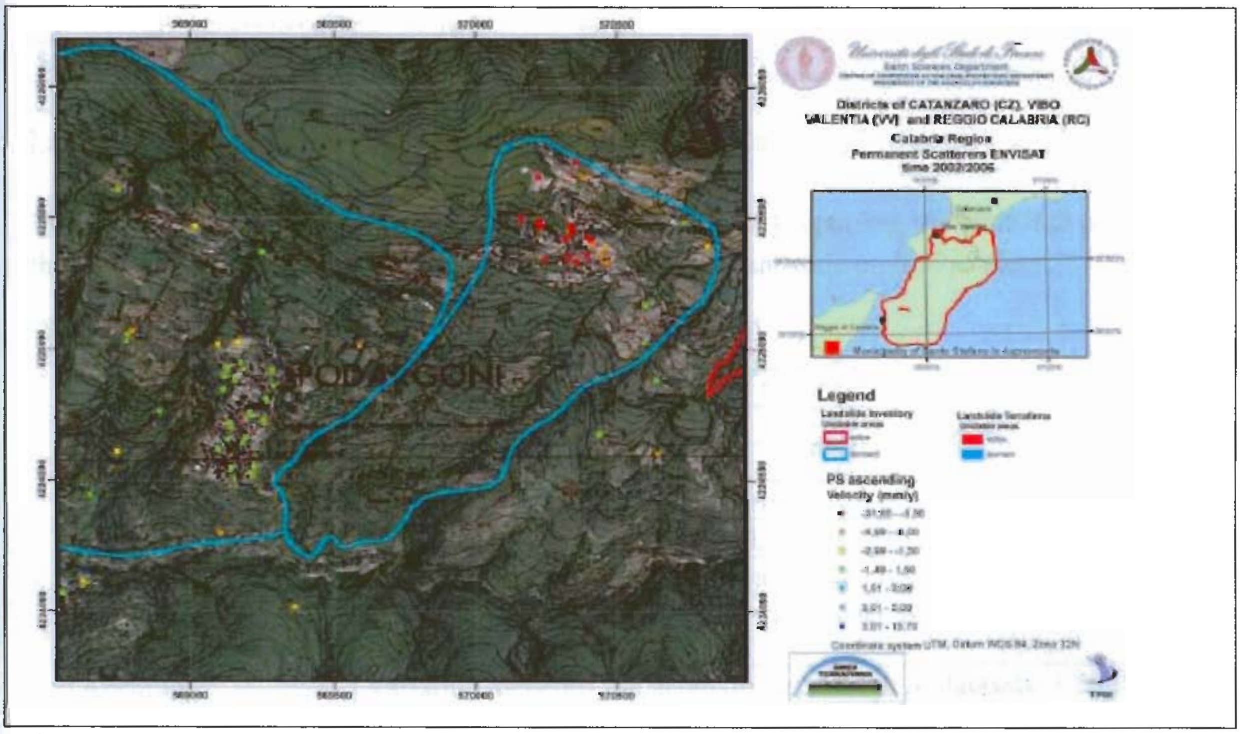


Figure 2.28 Location Santo Stefano in Aspromonte PS ENVISAT ascending

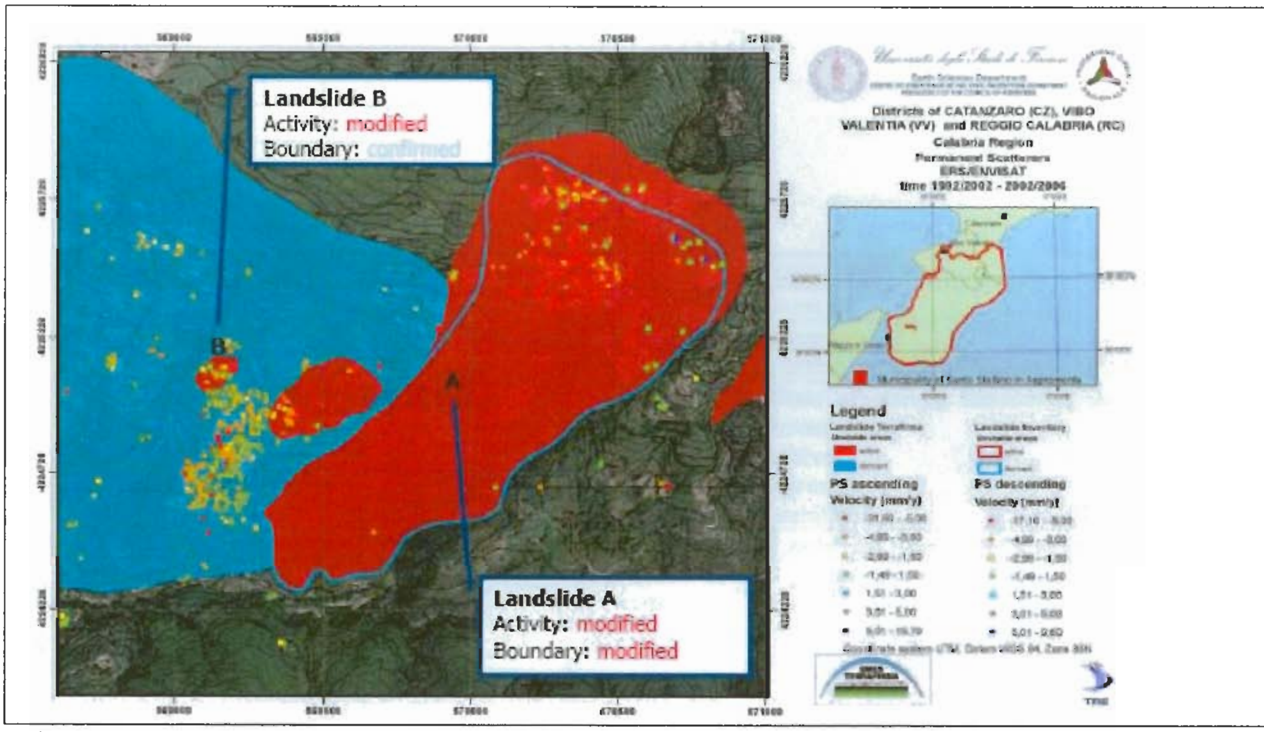


Figure 2.29 Location Santo Stefano in Aspromonte. With all possible PS information available is modified the activity of both landslides A and B, and the boundary of A landslide.

Technical specifications

Landslide Inventory Calabrian basin, districts of Reggio Calabria, Catanzaro and Vibo Valentia

The product consists of a GIS layer (e.g. ArcGis shapefile) reporting the landslide polygons. Here the version of the specifics is summarized, related to the landslide motion product.

Layer's name:	Terrafirma Landslide Inventory Calabria
Path:	
Code:	
Description:	landslide inventory: areal element
Ente depositario:	Department of Earth Sciences, University of Firenze
Genesis:	Updating of pre-existing landslide Inventory based on the integration of remote sensing optical and radar data with an existing landslide inventory.
Accuracy:	Variabile, depends on acquisitions sources of datasets: 1:5000 1:25000
Coordinate System:	UTM Wgs 84 zona 33N
Update metadato	Last updating 4 Settembre 2007
Availability:	
Employment authorization	
Validation:	

Coordinate system UTM, Datum WGS 84, Zone 33N

XMIN	*555970.464224*
XMAX	*637166.736201*
YMIN	*4197207.066191*
YMAX	*4287739.125254*

ITEM	TYPE	DESCRIPTION
AREA	FLOATING	Area m²
PERIMETER	FLOATING	Perimeter
ID	INTEGER	Identity number of the landslide area
STATE	STRING	State of activity concerning the preexisting inventory: active dormant stabilized
TYPOLOGY	STRING	Landslides typology of preexisting inventory
COMPARISON	STRING	Updating activity: No PS Conferma (confirmed landslides) Var_lim (changed boundary) Var_att (changed activity) Var_lim_att (changed activity and boundaries)
NEW STATE	STRING	Updated state of activity: Active Dormant stabilized

DISTRICTS	STRING	Districts name
SOURCE	STRING	Information source: original inventory map (PAI, IFFI) Terrafirma (TF) PAI + TF IFFI + TF
NUMBER OF ERS PSI	INTEGER	Number of ERS PSI within the polygon
Max velocity ERS PSI	FLOATING	Maximum velocity of PSIs within the polygon
Min velocity ERS PSI	FLOATING	Minimum velocity of PSIs within the polygon
AVERAGE VELOCITY ERS PSI (all acquisitions)	FLOATING	Average velocity computed from all the acquisitions of PSI within the polygon
NUMBER OF ENVISAT PSI	INTEGER	Number of ENVISAT PSI within the polygon
Max velocity ENVISAT PSI	FLOATING	Maximum velocity of PSIs within the polygon
Min velocity ENVISAT PSI	FLOATING	Minimum velocity of PSIs within the polygon
AVERAGE VELOCITY ENVISAT PSI (all acquisitions)	FLOATING	Average velocity computed from all the acquisitions of PSI within the polygon

Conclusions

1. The PS density over the whole area: 66 PS/km² ERS 22 PS/km² ENVISAT
2. About 40% of the landslides have PS information: 1271 out of 3276
3. There are 20385 measurement points (5.7% of all PS) that give displacement information related to landslides
4. There have been designed 340 new landslides
5. 22% of preexisting landslides have changed boundaries, about 9% have changed state of activity
6. There have been difficulties in the homogenization of different PS datasets (related to different reference points and possible atmospheric artifacts not properly removed)
7. Low density of ENVISAT PS and lower accuracy of the velocity estimation with respect to ERS PS was detected. As a result there have been difficulties in the discrimination between active and dormant landslides.

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