Advanced Terrain Mapping of the Gioia Tauro Plain Calabria Region, Italy

ESA GMES TERRAFIRMA

a cura di

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Francesca Cigna, Federico Raspini

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This analysis was carried out in the framework of the Terrafirma Extension project (*http://www.terrafirma.eu.com/*), a pan-European service providing ground motion hazard information in each of the 27 member states of the EU.

Terrafirma is one of ten services being supported by the Global Monitoring for Environment and Security (GMES) programme, funded and promoted by the European Space Agency (ESA).

Terrafirma Stage 3 was launched in December 2009 and will continue until the end of 2012 and has as its aim the sustainability of the terrain motion service.

The project is aimed at providing support to civil protection agencies, disaster management organisms, coastal, rail and motorway authorities, in the process of risk assessment and mitigation by using the latest technologies to measure terrain motion by means of satellite radar data. Terrafirma promotes the use of Synthetic Aperture Radar Interferometry (InSAR) and Persistent Scatterer InSAR (PSI) within three thematic areas for terrain motion analysis: Tectonics, Flooding and Hydrogeology (ground water, landslides and inactive mines), as well as the innovative Wide Area mapping service, aimed at measuring land deformation over very large areas. Terrafirma Stage 3 consortium is lead by Altamira Information, with the Dutch Geological Survey leading the Flood Theme, the Italian National Institute of Geophysics and Volcanology leading the Tectonics Theme, the University of Firenze leading the Hydrogeology Theme, and the German Space Agency leading the Wide Area Mapping task.

This research was conducted in the framework of the Hydrogeology theme, as groundwater management Advanced Terrain Mapping (ATM) Service. Terrafirma Groundwater management products are made using and integrating several datasets acquired during several ESA missions.

1: INTRODUCTION TO THE AREA OF INTEREST

General information

Country: Italy

Region: Calabria

District: Reggio Calabria

Municipalities: 33 (Anoia, Candidoni, Cinquefrondi, Cittanova, Cosoleto, Delianuova Feroleto della Chiesa, Galatro, Giffone, Gioia Tauro, Laureana di Borrello, Maropati, Melicuccà, Melicucco, Molochio, Oppido Mamertina, Palmi, Polistena, Rizziconi, Rosarno, San Ferdinando, San Giorgio Morgeto, San Pietro di Caridà, San Procopio, Santa Cristina d'Aspromonte, Sant'Eufemia d'Aspromonte, Scido, Seminara, Serrata, Sinipoli, Taurianova, Terranova Sappo Minulio, Varapodio).

Geographical location: flat coastal area on the Tyrrhenian side of Calabria Region spreading from Capo Vaticano and Mesima stream (to the north) to the Massif of the Aspromonte and Bagnara Calabra High (to the south).

Altitude a.s.l.: 0 - 400 m ca.

Hydrographical basins: Mesima, Metramo, Petrace (from North to South).

Coordinate system UTM, Datum WGS 84, Zone 33N	
Xmin	571,307.23
Xmax	604,817.72
Ymin	4,235,044.93
Ymax	4,268,766.20

Table 1. Coordinates of the area of interest.

Population, buildings and infrastructures involved

•affected villages: Rosarno, Gioia Tauro, Rizziconi, Polistena, Cittanova, Taurianova, Palmi, and many other smaller villages.
•citizens: 150,000 (300 inhabitants/km^2)
•industry/company units: many, mainly located at the Gioia Tauro Harbour
•infrastructure: State Road n.18; motorway A3; railway network through Rosarno Station.

Mitigation studies and actions

Technical reports: none
In-situ instrumentation: subsidence phenomenon in Gioia Tauro plain has not been previously measured or monitored with ground-based instrumentation.
Mitigation actions: none

Subsidence typology

Causes: groundwater overexploitation, with related water table decline and fine-grained aquifer compaction
State of activity: active
Dimension: 500 km^2

2: DESCRIPTION OF THE DETECTED PHENOMENON

As many densely urbanized and heavily industrialized areas, Gioia Tauro (Italy) is located over unconsolidated sedimentary deposits, which represent one of the most prolific types of aquifers, providing urban water supply. Many urban areas are frequently affected by land subsidence often caused by human activities and, in particular, subsurface water withdrawal, caused by gradual lowering of the water table with related compaction of the aquifer deposits.

In most of the cases, gentle subsidence, extending over large areas, developed slowly (even almost imperceptibly). In most suffering area the consequences of such phenomena are going to become severe, especially considering that the ground subsidence is not smoothly distributed in the affected area.

Ground subsidence in urban areas has a strong economic impact and could generate several problems, such as damage on buildings, loss of structure functionality and well-casing failure. Moreover, in low-lying coastal areas, decrease of ground elevation, combined with a global sea-level rise, may lead to severe flooding and inundations.

From a preliminary analysis of both historical (1992-2001; ERS1/2 images) and present (2002-2006; ENVISAT images) scenarios, a mean subsidence rate of 11 mm/year has been observed in the central part of the plain. Starting from this information a detailed PSInSAR interpretation can lead to a better understanding of ground movements.

Advanced remote sensing techniques, such as multi-temporal InSAR (Synthetic Aperture Radar Interferometry), may contribute to the understanding of spatial and temporal patterns of ground subsidence. These techniques were therefore used for Gioia Tauro to facilitate the analysis of hazard and risk scenarios, and to support the improvement of groundwater management in order to minimize future subsidence, and to help the implementation of best strategies for risk mitigation, land use planning and consequent reduction of economic and social impacts.

3: THE GIOIA TAURO PLAIN

The Gioia Tauro plain (Figure 1) (also known as “Rosarno Plain”) is an urbanized coastal area located on the Tyrrhenian side of Calabria Region (southern Italy). The plain includes 33 municipalities (entirely belonging to Reggio Calabria district), with a total extension of about 500 km^2. The area has nearly 150,000 inhabitants, with a very high population density (300 inhabitants/km^2).

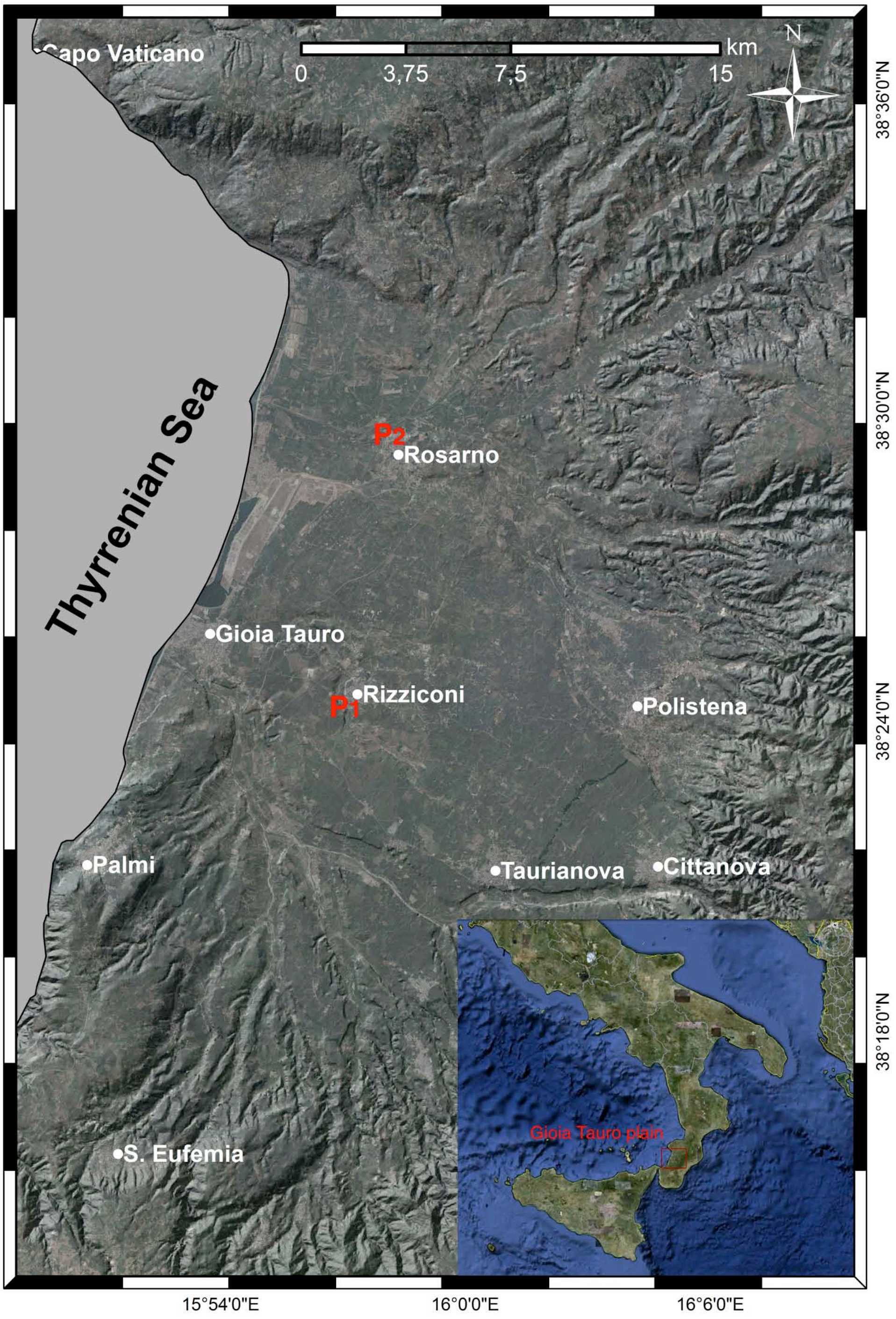


Figure 1. Geographical setting of the area: P1 indicates the reference village of Rizziconi, while P2 indicates the reference village of Rosarno.

3.1: Land use, agricultural activities and groundwater management

Agriculture is the most important economic activity in the area: olive trees and seed crops (mainly wheat) are cultivated extensively (Figure 2). The citrus cultivation represents a key factor for the economic livelihood of local population. In the whole plain, the yearly production of citrus (especially tangerines and oranges) amounts to 700,000 tons, i.e. 3% of the total product of Mediterranean countries or 0.7% of the world product (Source: circa.europa.eu). The farming system in Calabria is based on a very fragmentized model, with hundreds of small plots, self-sufficient from the water supplying point of view. Farms and estates of less than 2 ha made up 69% of the total in 2000 (Source: circa.europa.eu).

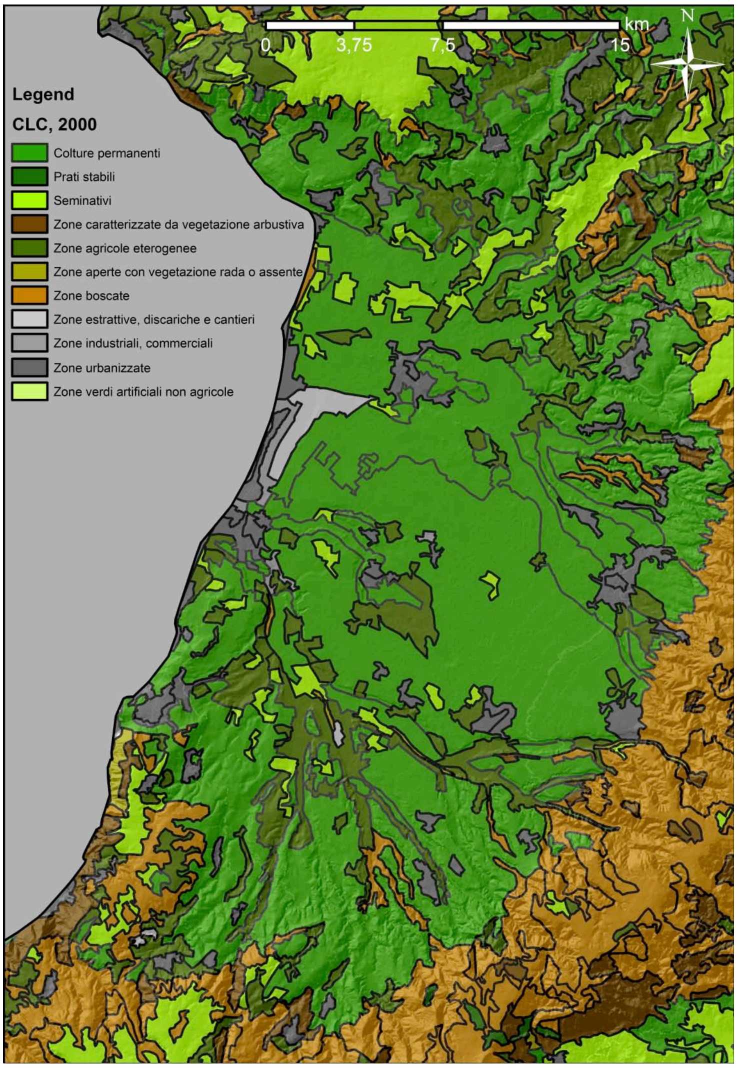


Figure 2. Land Cover Map derived from CORINE (II level classification).

In addition to the municipal network for water supply and distribution (Figure 3), that has serious inefficiencies, many independent and usually uncontrolled water wells have been recently constructed and, in the whole plain, 45% of water needs are currently provided by private water wells (Source: circa.europa.eu).

Recently increased groundwater demands for irrigation purpose have caused the gradual lowering of the water table, with related compaction of the aquifer deposits, to progressively accelerate.

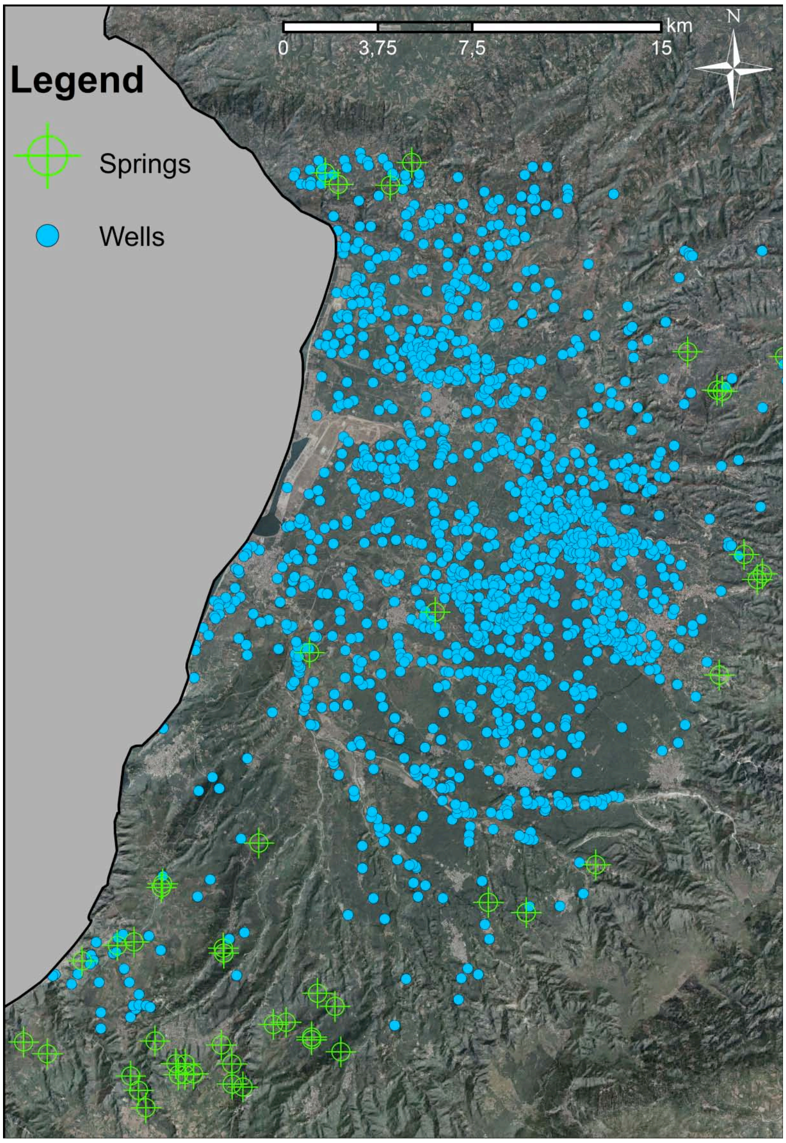


Figure 3. Water extraction location in the Gioia Tauro plain.

Different elements at risk are present in the plain, such as the Gioia Tauro Harbour, the largest container terminal of the Mediterranean Sea (about 440 ha of land and 1.8 million m^2 of stocking yards), the road infrastructure with the State Road n.18 and the motorway A3, and the railway network through the Rosarno Station. Many new works, aimed at improving the harbour and the industrial activity of the area have also been designed and are currently being built or under feasibility studies. In 2008, after the submission of an Environmental Impact Assessment, authorization for the construction of a huge liquefied natural gas terminal in the Gioia Tauro port area has also been obtained. The construction is planned to start in 2011 and the system is expected to be operative in 2014, with a capacity of 12 billion m^3 of gas per year, over 10% of the Italian gas demand.

3.2: Geological setting

From a geological point of view (Figure 4), the Gioia Tauro plain is a 25-30 km long, NNE–SSW oriented half-graben, spreading from the Valley of Mèsima to the Massif of the Aspromonte and elongated between the Calabrian Arc mountains (Serre - Aspromonte ridge, that forms the structural backbone of southwest part of the Calabrian Arc and the Tyrrhenian Sea (Cucci et al., 1996).

The morphology of western-facing mountains slope (towards the Tyrrhenian Sea) is strongly controlled by a normal faults belt that extends for a about 180 km along the inner side of the Calabrian Arc, separating the uplifted mountain ranges from a series of extensional 00sedimentary basins (Tortorici et al. 1995, Monaco & Tortorici. 2000, Jacques et al. 2001, Galli & Bosi, 2002, Tortorici et al. 2003, Catalano et al. 2008). These various fault segments dip west and bound the sedimentary basins of the Tyrrhenian side of the arc (i.e. Mesima, Gioia Tauro, Reggio Calabria and Barcellona basins).

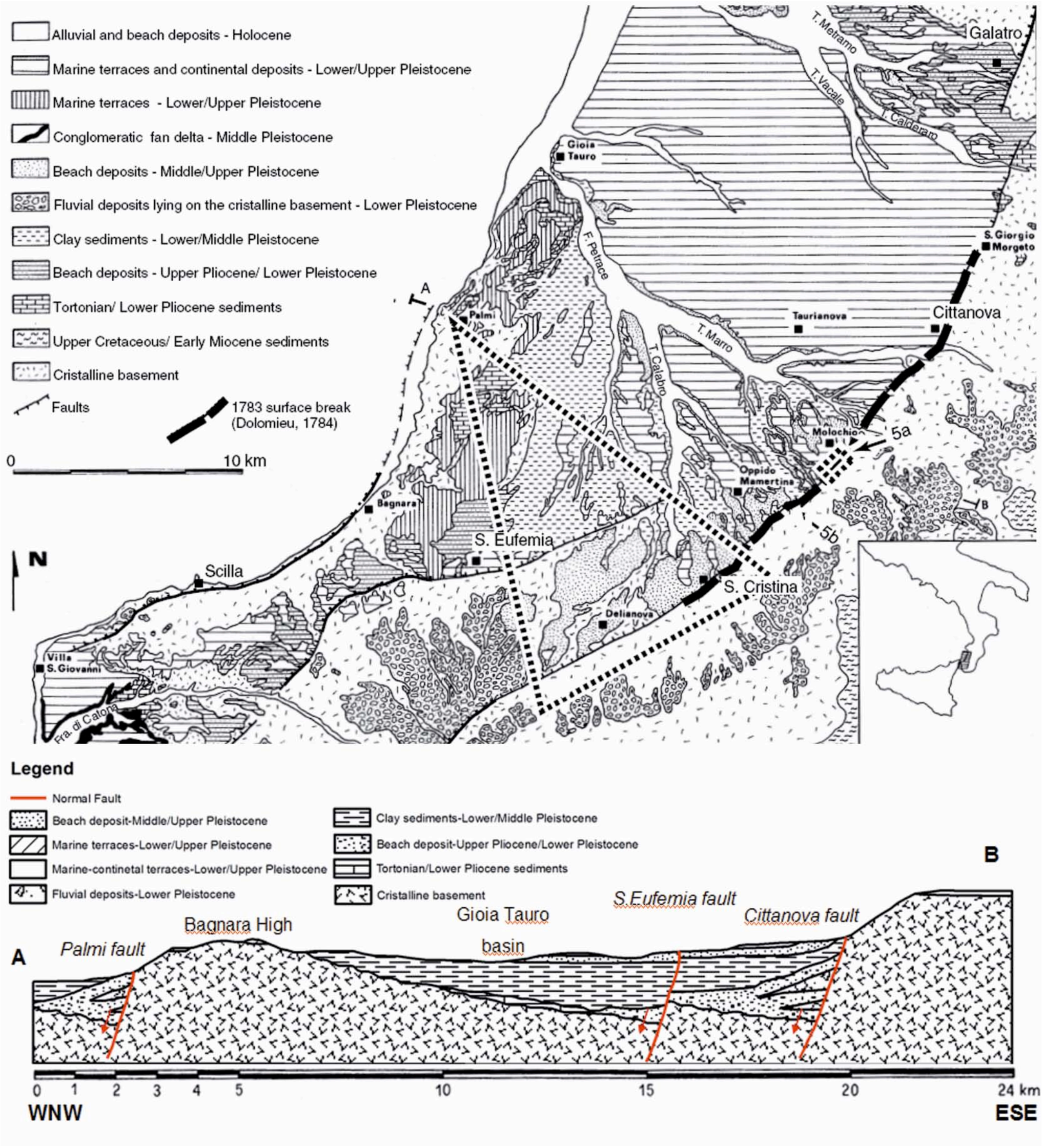


Figure 4. Simplified geological setting of the Gioia Tauro basin. From Jacquest et al., 2001.

The Cittanova Fault bounds to the east the Gioia Tauro basin extending for a length of about 35 km. The fault juxtaposes the basement of the uplifted Aspromonte and Serre mountains with the Pleistocene deposits of the Gioia Tauro basins. To the north-east the Gioia Tauro basin is abruptly truncated and separated from the uplifted promontory of Capo Vaticano by the Coccorino and Nicotera faults, two ESE-striking normal faults. Southward the basin is bounded by S. Eufemia fault, a 18 km ENE-striking normal fault.

While the uplifted blocks are characterized by crystalline basement rocks (gneiss and granites), the plain is filled by a 700 m thick succession of marine and continental sediments of Pliocene and Quaternary Age.

In particular the basin is filled by a 600 m thick succession of Late Pliocene – Early Pleistocene marine sediment, consisting of about 70 m of sands and calcarenites, by a clay and silt sequence several hundreds meters thick, capped by 100 m of regressive sands and conglomerates. The marine sequence is unconformably overlain by the most superficial layers of the plain (up to a depth of 50-70 m from the ground level), that is prevalently constituted by granular saturated soils consisting of Middle-Upper Pleistocene alluvial conglomerates and sands, truncated by a wide planation surface (Tortorici et al., 1995; Jacquest et al., 2001).

3.3: Geomorphologic setting

As previous mentioned, the most impressive geomorphologic feature of the Calabrian Arc is a normal fault belt that extends, more or less continuously, for a total length of about 180 km along the inner side of the arc (Tortorici *et al*., 1995). While the eastern-facing mountains slope rather gently towards the Ionian Sea to the east, the western mountain edge is steeper and controlled by normal faults. The central part of the plain appears to be a continuous, flat, gently seaward dipping surface, while getting closer to the Aspromonte Ridge this surface becomes progressively steeper (Figure 5).

A peculiar morphological feature of the area is represented by the development of several orders of marine terraces, often resting on crystalline rocks. Combining age and elevation of marine terraces and absolute sea level variation, it is possible to evaluate the uplift rates occurred in this area during the Quaternary Age. The morphological features of the fault escarpments suggest slip rates of 0.8-1.1 mm/yr for the last 700 k.y. and values of 0.6-0.9 mm/yr for the last 120 k.y., indicating a uniform rate of faulting since the Middle Pleistocene (Tortorici *et al*., 1995). Tectonic uplift was accompanied by marine terracing along the basin margins and, on land, by deep entrenchment of rivers with the consequent deposition of alluvial and/or transitional coarse grained sediments along the major depressions on top of Lower–Middle Pleistocene pelagic sequences.

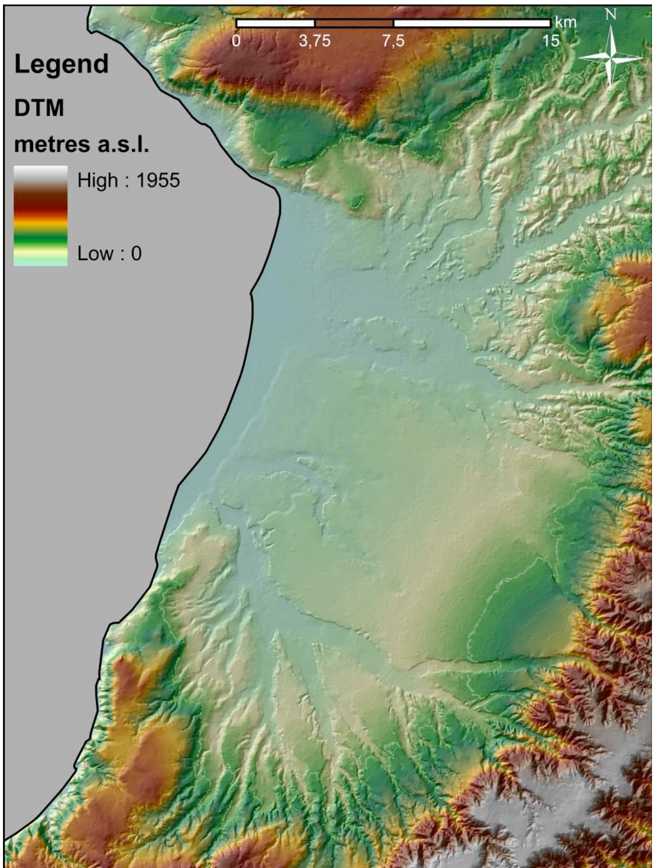


Figure 5. Digital Terrain Model (DTM) for the Gioia Tauro plain.

4: VALUE ADDED PRODUCT: SUBSIDENCE MONITORING

Terrafirma is based upon the revolutionary remote sensing processing technique of Persistent Scatterer Interferometry (PSI) which has the power to map millimetric ground motion phenomena from space.

InSAR (Interferometric SAR) is a technique in which the phase component of the returning radar signals of two or more Synthetic Aperture Radar (SAR) scenes of the same location are processed to allow the detection of ground movements. The relative low cost and non-invasive application has led to them being used in numerous scientific disciplines. One such discipline - natural hazards, and in particular ground motion hazards, fall under two categories - natural and man-made, with a degree of crossover between the two. Since 1992 (Zebker et al., 1986; Gabriel et al., 1989) conventional 2-pass Differential InSAR (DifSAR) has been used by the remote sensing community to further the study and understanding of specific ground deformation hazards over large contiguous areas (Canuti et al., 2004, Tarchi et al., 2004). These hazards can result from natural phenomena such as seismic events, volcanic deformation, landslides and ground collapse; and from more subtle processes such as subsidence, all of which have direct economic, environmental and human safety impacts. The need for more accurate and temporally dependent results has led to the inevitable technical advances seen over the last few years, including PSI.

PSI is a non-invasive surveying technique used to calculate fine motions of individual ground and structure points over wide-areas covering urban and semi-urban environments. The technique uses an extensive archive of satellite radar data (dating back to 1992) to identify networks of persistently scattering (i.e. radar reflecting) features such as buildings and bridges, or natural features such as rocky outcrops, against which precise millimetric motion measurements are calculated retrospectively over the time spanned by the data archive. The unique benefit of PSI is its ability to provide both annual motion rates and multi-year motion histories for individual scatterer points.

The PSI technique take conventional InSAR a step further by correcting for atmospheric artefacts (that can degrade and limit the accuracy of the results), orbital and DEM errors to derive very precise displacement and velocity measurements at specific points on the ground. Extracting phase information from multiple SAR images, these techniques are able to identify ground resolution elements (pixels) dominated by single scatterers, the so-called PS (Persistent Scatterers). These targets allow the measurement of deformation velocities (both average ground deformation rate and displacement time series, acquisition by acquisition) along the satellite Line Of Sight (LOS), with millimetre precision (Ferretti et al., 2001; Colsanti et al., 2003).

Point-wise ground motion information provided by PSInSAR algorithm can have a purely geological or anthropogenic origin as well as a combination of both.

According to Farina et al. (2004; 2006; 2008), the employed methodological approach consists on the possibility of assigning a geomorphologic meaning to the point-wise information provided by PSI technique, through the integration and analysis of several ancillary data.

As support to the results provided by the PSI dataset, a series of auxiliary data, relevant for identification of the ground displacement triggers, were acquired and analyzed. The ancillary data are combined and integrated within a Geographical Information System (GIS), in order to visualize the geographic relationship between the geologic nature of the region and the displacement measurements provided by Permanent Scatterers analysis. This allows us to assess the factors causing the observed ground motion, to lead to the identification of the ground displacement triggers, and to highlight the exact composition of the observed and measured ground motion.

The analysis was carried out by a detailed study based on the following dataset and auxiliary data, which are relevant for identification of the ground motion triggers:
a Digital terrain Model (DTM), with 20 m of pixel resolution;
digital colour orthophotos Volo Italia 2000, with 1 m of pixel resolution;
topographic maps at 1:25.000 scale;
the Regional Geological Map at 1:25.000 scale acquired by the Regional Cartographic Center;
Land Cover Map (Corine Land Cover, 2000) was employed, using the 3rd classification level.

Considering the flat geometry of the Gioia Tauro plain and that land subsidence is thought to be a displacement phenomena characterized by a very high vertical component, ascending and descending geometries are expected to provide very similar values of mean deformation rates of the same target areas. For this reason, and considering the lower PS density for the descending geometry (especially for ENVISAT dataset), only PSI measures along ascending orbits are used for the subsequent processing and geological interpretation.

4.1: Investigation of the spatial distribution of PS

As previous mentioned, the use of radar sensors mounted on board Earth-orbiting satellites started about two decades ago. So far, many algorithms have been developed and significantly improved.

The satellite analysis of land subsidence in the Gioia Tauro basin was performed using the PSInSAR™ (Permanent Scatterers InSAR) algorithm, which belongs to the multi-interferometric approaches (Ferretti et al., 2000; 2001), and integrating several datasets of satellite SAR data acquired by different ESA (European Space Agency) missions.

PSInSAR™ was developed at Polytechnic University of Milan (POLIMI) and licensed exclusively to its commercial spin-off, T.R.E. S.r.l. (Tele-Rilevamento Europa).

Forty-eight SAR images acquired in 1992-2001 by ERS1/2 satellites along descending (when satellite passes over the target area approximately from north to south) and ascending (south to north) orbits were used to study past ground displacements. Eighteen SAR images acquired by ENVISAT satellite along descending orbits and twenty-six images along ascending orbits were then used to monitor recent land deformation.

The PSInSAR analysis provided estimates of yearly deformation velocity, referred to both historical (1992-2001; ERS images) and recent (2002-2007; ENVISAT images) scenarios (Table 2), allowing the analysis of the spatial variability and temporal evolution of Gioia Tauro subsidence.

All the datasets have been processed using the PSInSAR^{TM} technique in the standard mode SPSA, which means that for each PS, the time series of deformation has been provided relative to a reference date (zero). The reference points for the PS processing chain were set outside the plain in an area which is supposed to be stable.

Both ERS and ENVISAT satellites have an orientation angle of 9° N (azimuth) with an inclination of 23°, for this reason the N-S displacements direction component is not detectable.

The values of superficial movements are measured along the satellite line of sight (LOS) and are expressed in mm/yr. The negative sign indicates a movement away from the SAR sensor, while positive values represent a movement towards the sensor.

In the colour scale, green PS indicates points as stable. The gradation from yellow, orange to red represents movement away from the sensor, while the gradation from light blue to dark blue represents movements toward the sensor.

The PS distribution, respectively ERS descending and ascending, ENVISAT descending and ascending, is displayed in Figure 6 and Figure 8. overlaid on a colour orthophoto.

The density of PS turned out to be significantly higher in urbanized areas in comparison to the agricultural and woodland sectors: according to the 1st classification level of the land cover map (CORINE Land Cover, 2000), PS density is distributed as ca. 350 PS/km^2 in urban and artificial lands, 20 PS/km^2 in agricultural and pasture areas, and only 5 PS/km^2 in the woodland and semi-natural areas.

Satellite and orbit	N° images	Time range	N° PS	PS density (PS/km2)		
				Urban areas	Agricul. Areas	Wood land
ERS_desc	48	20/10/1992- 05/01/2001	34,064	532	24	7
ERS_asc	48	08/09/1992- 24/11/2000	31,935	473	25	7
ENVI_desc	18	26/12/2003 01/09/2006	8,161	129	6	1
ENVI_asc	26	29/11/2002- 08/12/2006	22,192	325	18	6

Table 2. Number of images, time period, number of identified PS and average PS density (differentiated for land cover categories) for ERS and ENVISAT data stacks used for the PSI analysis. Desc, descending; Asc, ascending.

4.1.1: ERS dataset results (1992 – 2000)

Permanent Scatterers over the 1992-2000 period indicate that subsidence was widespread throughout Gioia Tauro basin, with a mean value of 11 mm/yr measured along the LOS (Figure 6). PSInSAR results highlight that an ellipse-shaped area, SW-NE oriented, is affected by intense subsidence. This area corresponds to the plain area of the Gioia Tauro basin.

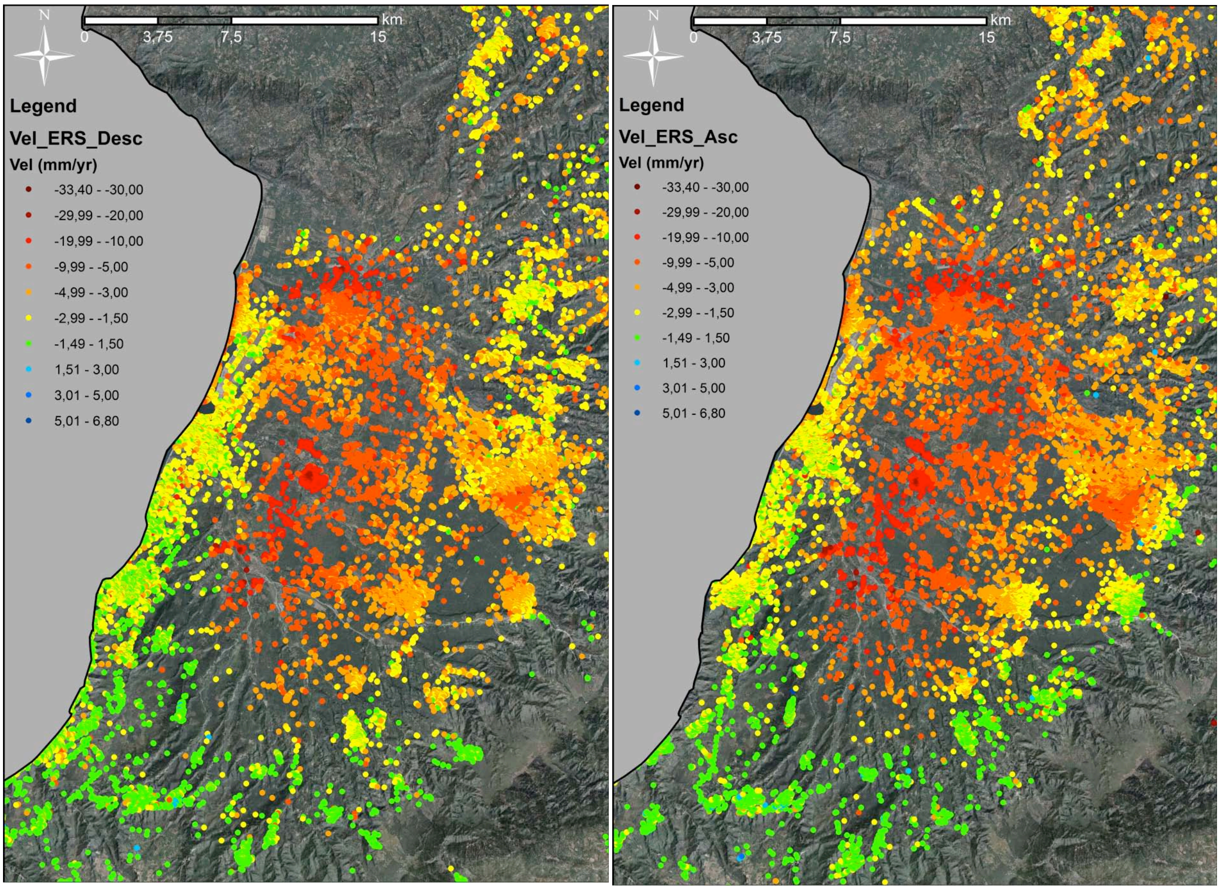


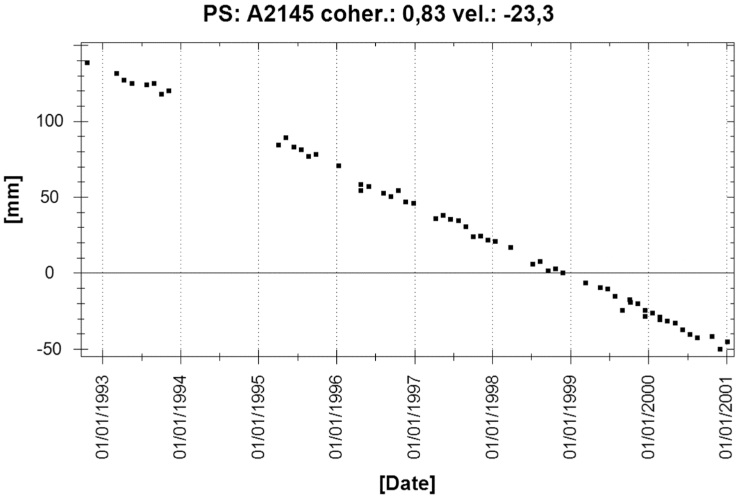
Figure 6. Average displacement rates along the LOS of ERS satellites in 1992-2000.

In particular, the central part of the plain is affected by strong subsidence, with mean deformation velocity of 15 mm/yr.

The maximum deformation velocity detected by PSInSAR along the LOS in the ascending dataset, is 22.8 mm/yr and 18.8 mm/yr, measured, respectively, at Rizziconi (within the central part of the basin, 5 km ESE of Gioia Tauro, P1 in Figure 1) and north of Rosarno (in the northern part of the plain, P2 in Figure 1).

The maximum deformation velocity detected by PSInSAR along the LOS in the descending dataset, is 23.3 mm/year and 15.9 mm/year, measured, respectively, at Rizziconi (P1 in Figure 1) and north of Rosarno (P2 in Figure 1).

Time series (Figure 7) of two PS (for ascending and descending dataset) located in the area of maximum displacement show that, during the investigated period, subsidence is characterized by a constant rate of deformation.



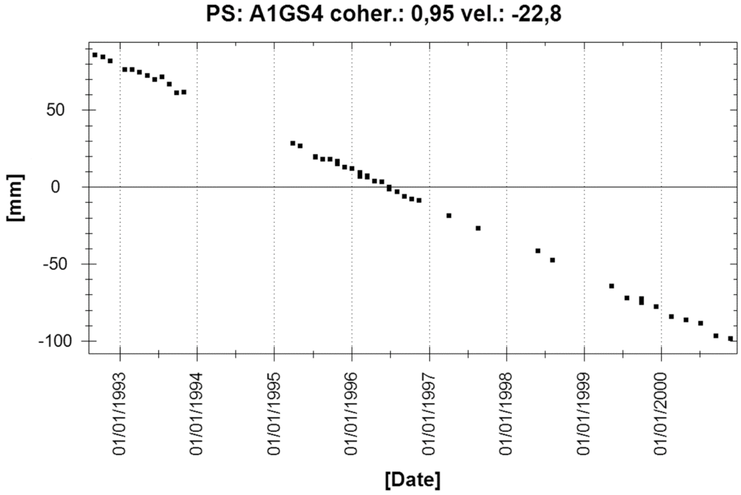


Figure 7. Example of displacement time series of PS located in the area of highest deformation. Ascending dataset (above) and descending dataset (below).

4.1.2: ENVISAT dataset results (2002 – 2006)

PSInSAR results for ENVISAT dataset (Figure 8) indicate, in the time period from 2002 to 2006, a general subsidence decrease, for both intensity and extension of the affected area. Compared with the previous period, average ground deformation rate highlights that the SW-NE oriented ellipse-shaped area corresponding to the central part of the Gioia Tauro basin, is affected by a subsidence with a mean value of 7 mm/yr. Maximum land deformation velocities, detected in 2002-2006 (for ascending dataset) are 17.7 mm/yr and 11 mm/yr, measured at Rizziconi and north of Rosarno, respectively, which remain the areas of maximum subsidence rate. The maximum vertical component along the LOS detected by PSInSAR, in the descending dataset, is 20.4 mm/yr and 14 mm/yr, measured, respectively, at Rizziconi and north of Rosarno.

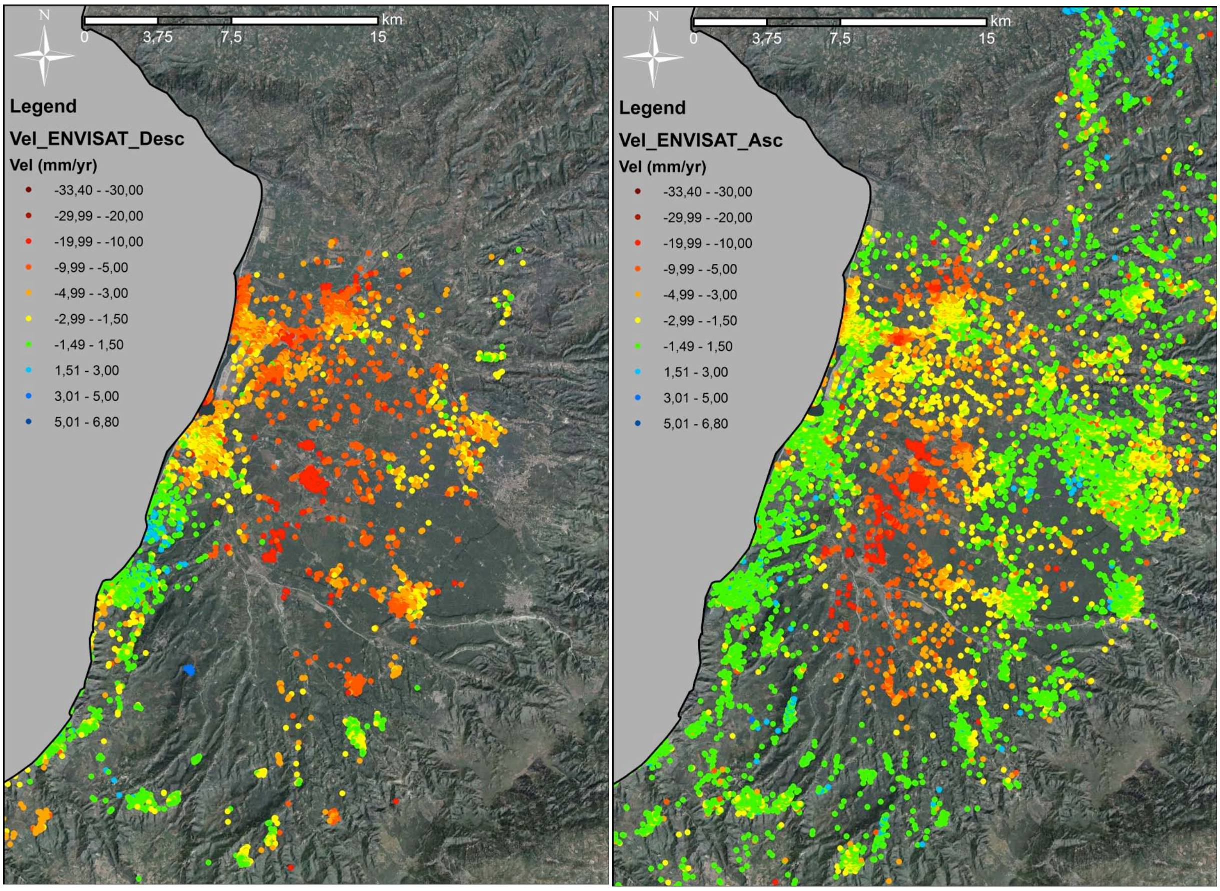
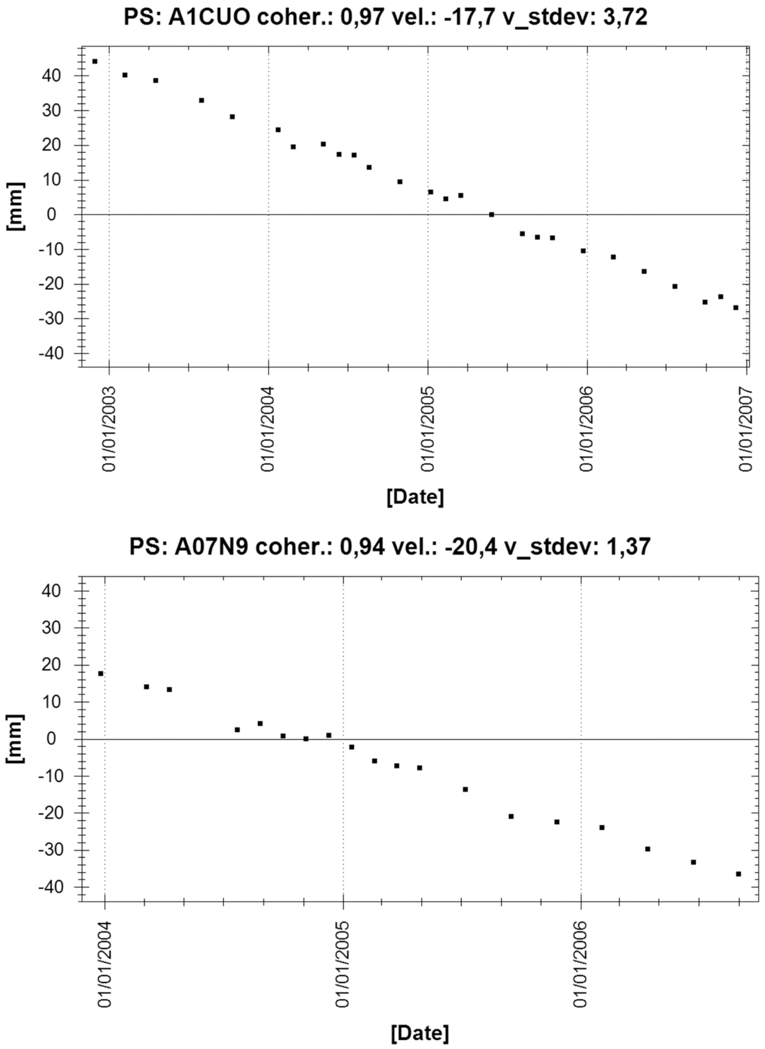


Figure 8. Average displacement rates along the LOS of ENVISAT satellites in 2003-2006.

Time series (Figure 9) of two PS (for ascending and descending dataset) located in the area of maximum displacement show that, during the investigated period, subsidence is characterized by a constant rate of deformation.


PS: A1CUO coher.: 0,97 vel.: -17,7 v_stdev: 3,72

PS: A07N9 coher.: 0,94 vel.: -20,4 v_stdev: 1,37

Figure 9. Example of displacement time series of PS located in the area of highest deformation. Ascending dataset (above) and descending dataset (below).

4.2: <u>Advanced time series analysis</u>

The SPSA analysis provides information about the temporal evolution of the displacement from high backscattering radar benchmarks. For every acquisition of the satellite it is possible to determine displacement values relative to a reference date.

4.2.1: <u>ERS dataset results (1992 – 2000)</u>

With the purpose of evaluating the historical trend of the investigated phenomena, time displacement series have been divided in three different time intervals, with a sampling interval of about 950 days. The first three maps of Figure 10 show the measured displacement in each of the time intervals, while the last map shows the cumulated displacement of the entire time series. The first three maps, almost identical each other, highlight that, during the investigated period subsidence is characterized by a constant rate of deformation.

The ground deformation surface is interpolated with the IDW (Inverse Distance Weighted) method, which is a deterministic interpolation process of assigning values to unmeasured location by using values from scattered set of surrounding measured points (i.e. cumulated displacement detected by PS).

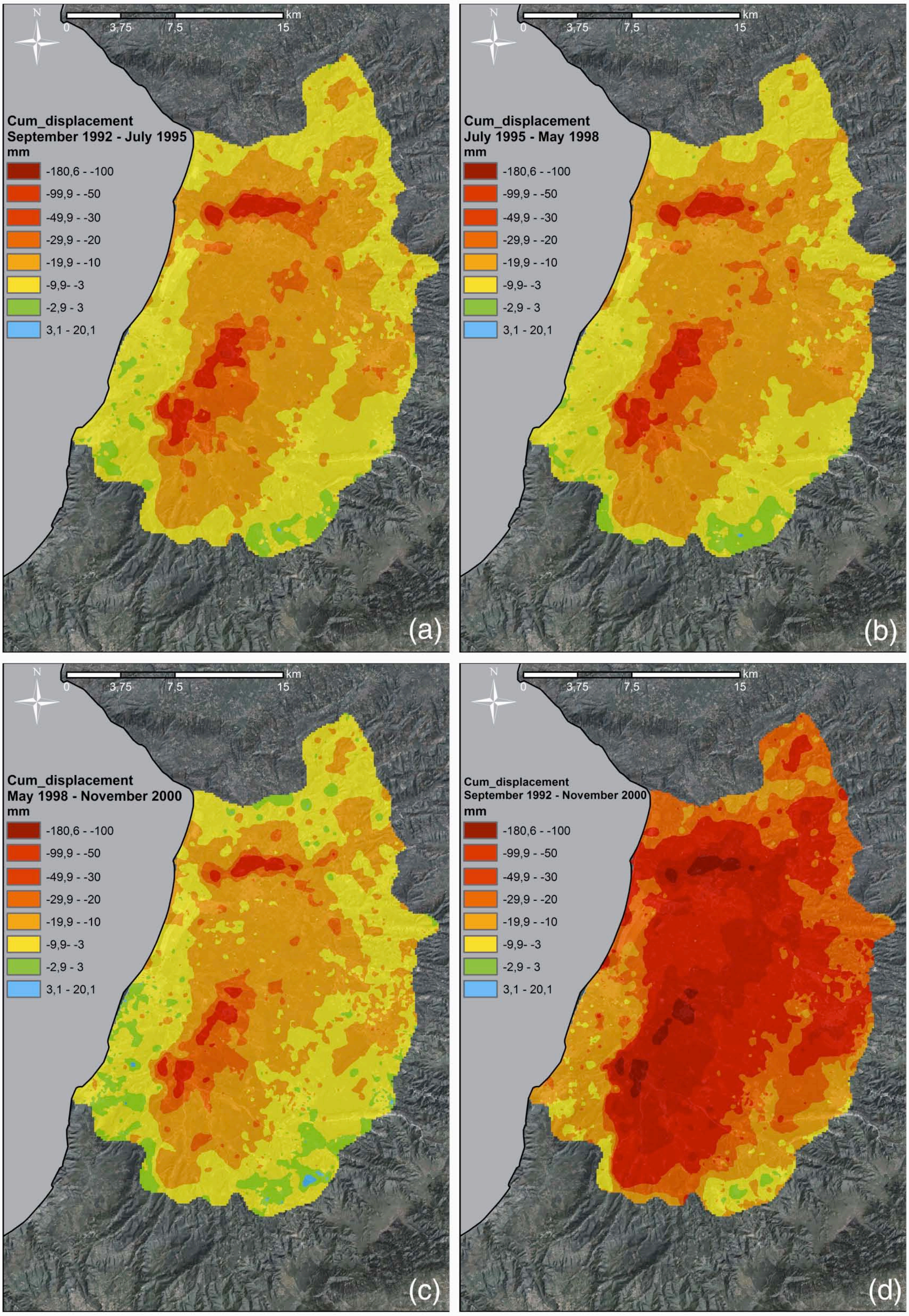


Figure 10. Estimated displacement field (in the LOS direction) in the Gioia Tauro plain. Four snapshots corresponding to four time intervals (the sampling interval is about 950 days): (a) September 1992 – July 1995; (b) July 1995– May 1998; (c) May 1998– November 2000; (d) September 1992 – November 2000.

Maps of the cumulated displacement field confirm the presence of two different areas of maximum subsidence rate: the former (and the main one) is located at Rizziconi, 5 km ESE of Gioia Tauro, in the central part of the basin; the latter is located at Rosarno, in the northern part of the plain.

Cumulating in time the displacement measured through the PS time series in 1992-2000 (ERS dataset), a maximum subsidence of 184 mm and 162 mm was observed at Rizziconi and Rosarno, respectively.

Figure 11 shows a 3D view of the cumulated LOS displacement field in 1992-2000 in the whole basin of Gioia Tauro. The three snapshots of Figure 11 represent a 3D view of the interpolated ground deformation surface, corresponding to three different time intervals (whose length is about 950 days) during 1992-2000: September 1992 – July 1995; September 1992 – May 1998; September 1992 – November 2000.

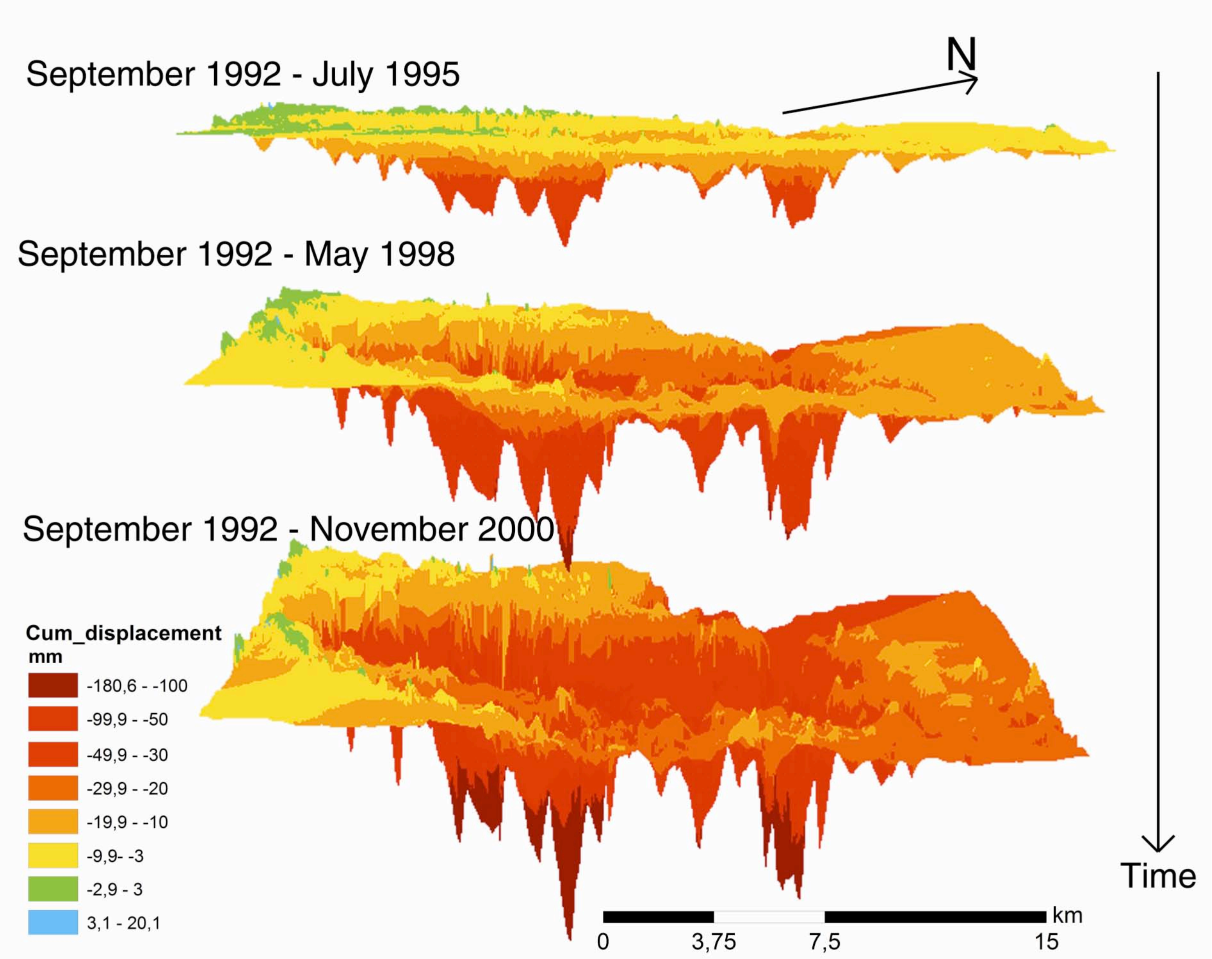


Figure 11. 3D view of cumulated LOS displacement in 1992-2000 along a SW-NE section of the plain.

4.2.2: ENVISAT dataset results (2002 – 2006)

Also for ENVISAT dataset, with the purpose of evaluating the historical trend of the investigated phenomena, time displacement series have been divided in two different time intervals, with a sampling interval of about 750 days. The first two maps of Figure 12 show the measured displacement in each of the time intervals, while the last map shows the cumulated displacement of the entire time series. The first two maps, almost identical each other, highlight that, during the investigated period, subsidence is characterized by a constant rate of deformation.

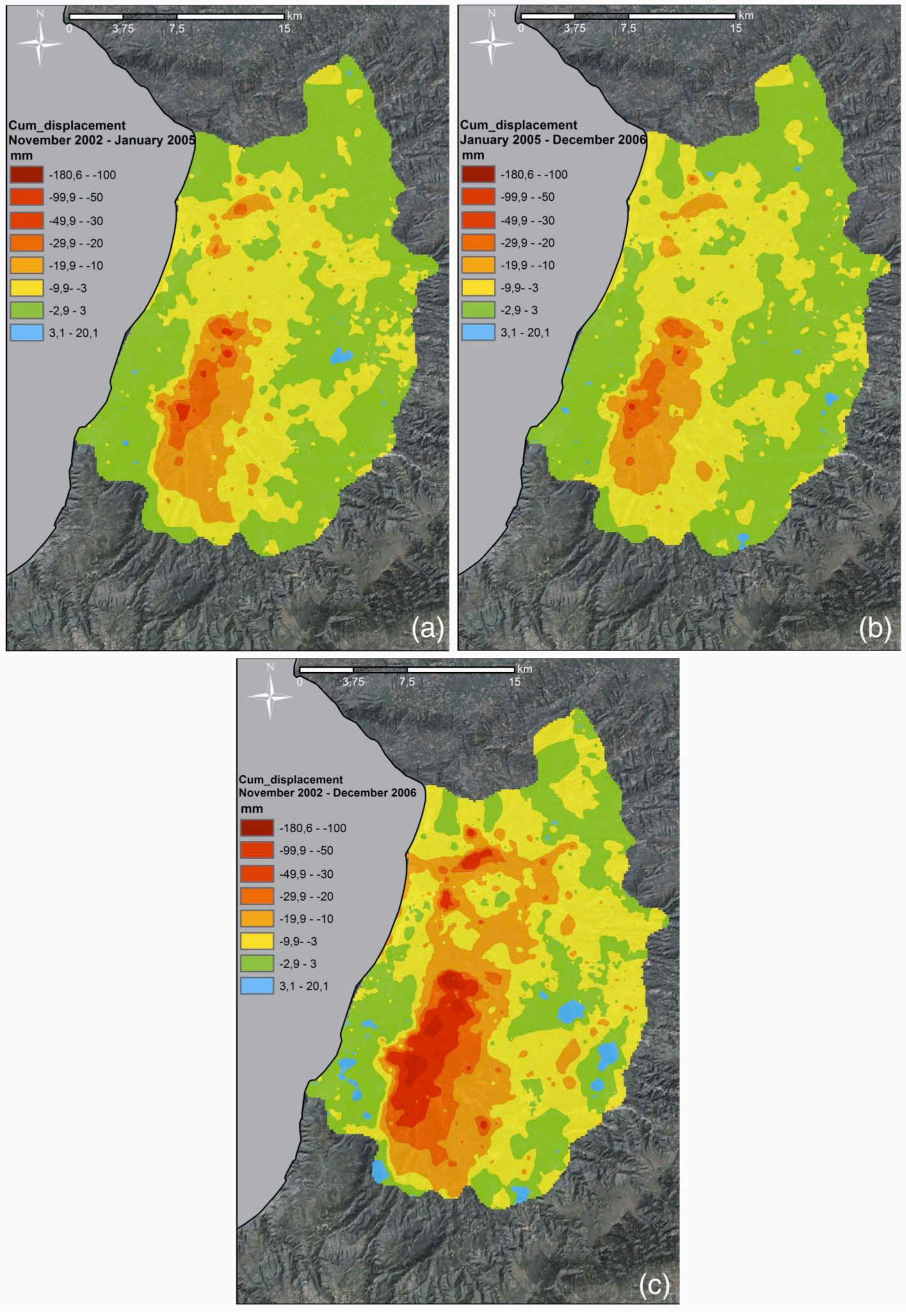


Figure 12. Estimated displacement field (in the LOS dirction) in the Gioia Tauro plain. Three snapshots corresponding to three time interval (the sampling interval is about 750 days): (a) November 2002 – January 2005; (b) January 2005 – December 2006; (c) November 2002 – December 2006.

With respect to the 1992-2002 interval (ERS dataset), for the 2003-2006 interval (ENVISAT dataset) a slightly lower deformation was measured, with maximum subsidence of 74 mm and 48 mm, observed at Rizziconi and Rosarno, respectively.

The two snapshots of Figure 13 correspond to two different time intervals (whose length is about 750 days) during 2003-2006: November 2002 – January 2005; November 2002 – December 2006.

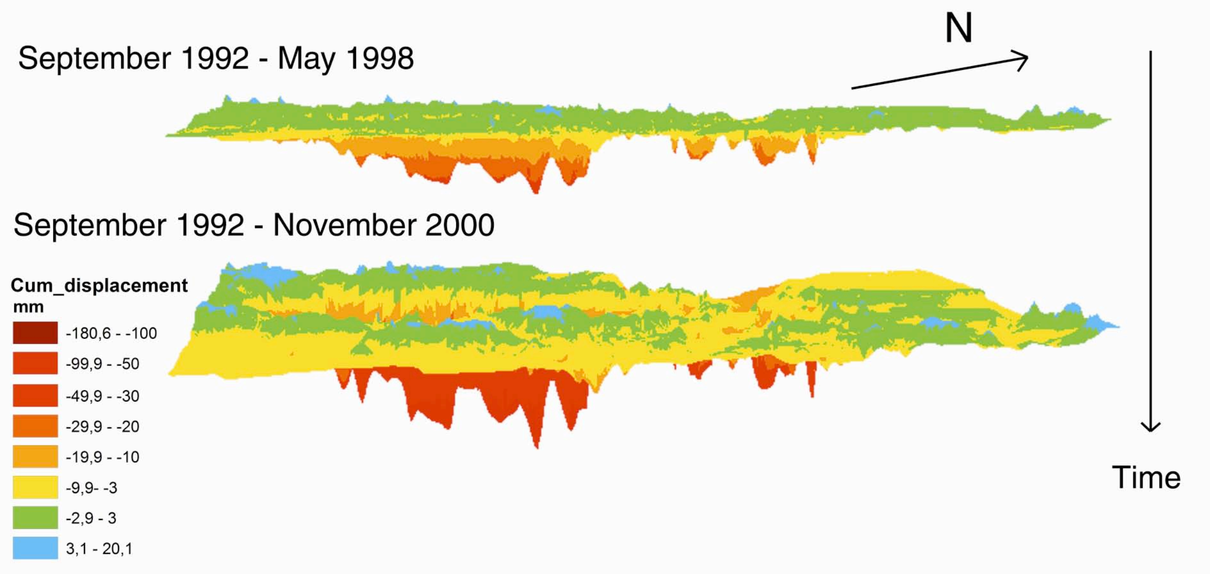


Figure 13. 3D view of cumulated LOS displacement in 2002-2006 along a SW-NE section of the plain.

4.3: Z (vertical) and E-W components of ground displacements

The PS technique measures deformation (both average ground deformation rate and displacement time series) along the line of sight (LOS) of the radar satellite. The ERS and ENVISAT SAR are side looking sensors and normally operate in “right-looking” mode. The LOS direction for ERS and ENVISAT is ca. 23° tilted with respect to the vertical direction.

A satellite can acquire an image in descending orbit (when it passes from north to south) or in ascending orbit (south to north), providing different information of the same target area. However, combining ascending and descending dataset, LOS displacements can be projected into horizontal and vertical components.

However, having at our disposal both the ascending and descending acquisition it is possible to resolve, through a post processing procedure, the displacement along the LOS in z direction (vertical) and in East-West direction (x) displacements (Figure 14).

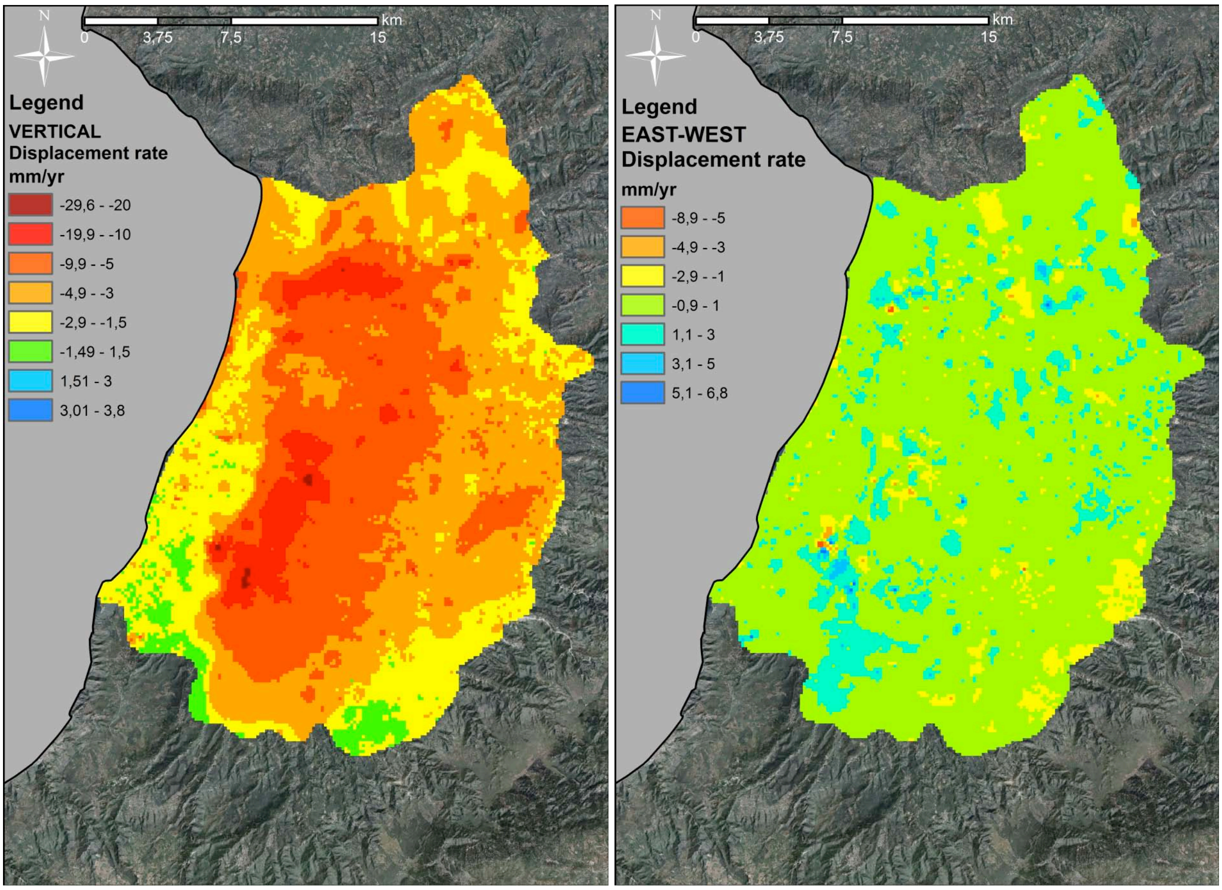


Figure 14. Z and E-W velocity derived from the combination of ERS ascending and descending PS.

Land subsidence is the Gioia Tauro plain is a displacement phenomena characterized by a strong vertical component, hence deformation measurements are mainly vertical – subsidence (negative values, when PS move away from the sensor) and uplift (positive values, when PS move towards the sensor).

5: DISCUSSION

Subsidence phenomenon in Gioia Tauro plain has not been previously measured or monitored with ground-based instrumentation. Neither GPS nor levelling measurements have been carried out in the studied area. For this reason, at the moment, a field validation of the results is not possible. The great amount of observed subsidence in the Gioia Tauro plain is thought to be induced by groundwater overexploitation, with related water table decline and fine-grained aquifer compaction. Comparing the geographic relationship between location of water extraction sites and the deformation maps provided by the PSI analysis (Figure 15), it is possible to highlight a slight correlation between the occurrence of intense subsidence and the distribution of water wells and springs.

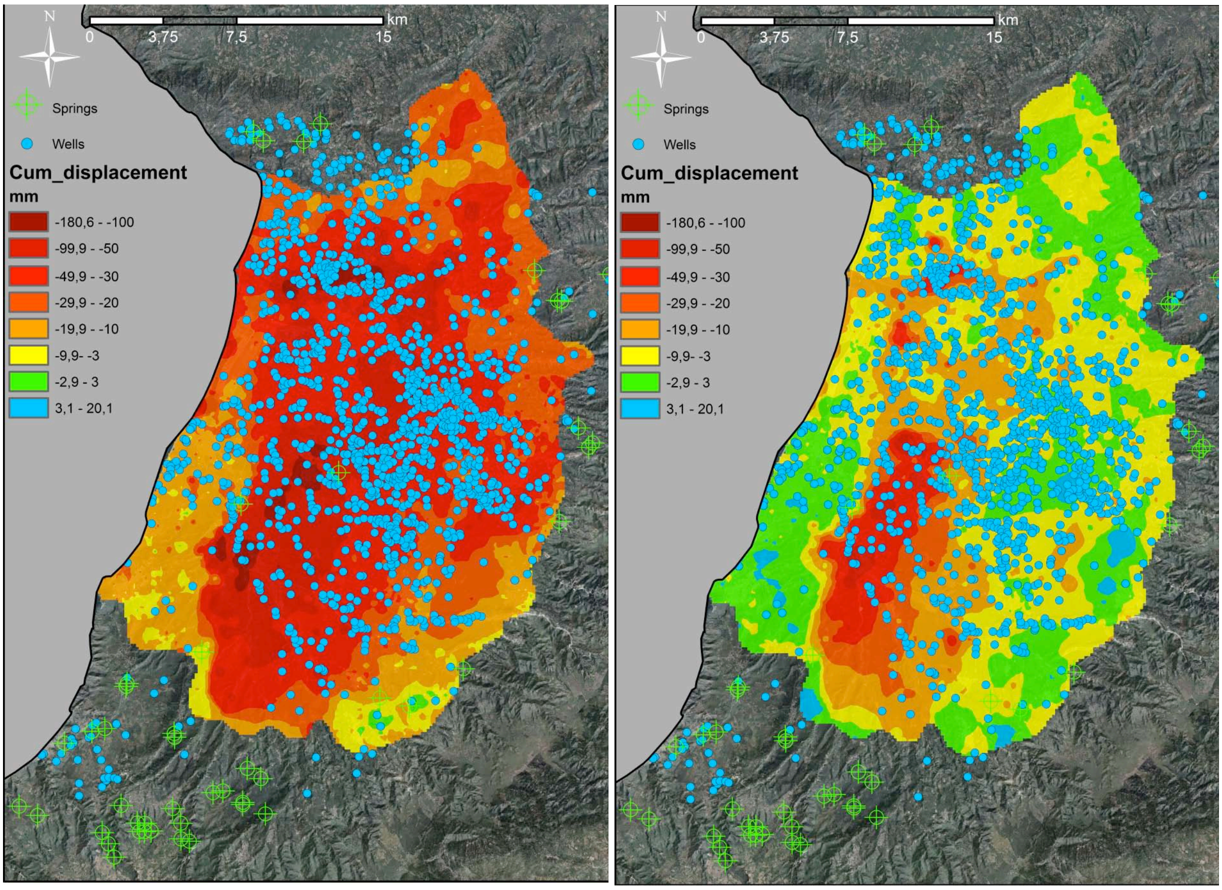


Figure 15. Geographical relationship between land subsidence and water extraction sites.

However, significant spatial variability of deformation velocities throughout the whole basin is also observed. Such variability could be related to several factors: first of all, differences, across the basin, in the geotechnical properties of the aquifers sediments and in the compressible layer thickness can lead to different deformation velocities. Secondary, differences in the pumped water amount, extracted by each of the water wells in the plain, cause different subsidence rates.

The third, and probably, the main reason is related to an incomplete water extraction sites census, a key aspect in the plain, where construction of many independent and usually uncontrolled water wells, in addition to the municipal network for water supply and distribution, is a common feature. Identification of independent wells and respective water extraction rates, will be an urgent topic of discussion and analysis in the future, to better understand subsidence causes and patterns, and consequently improve water and land management strategies for a future sustainable use of groundwater resources.

6: CONCLUSION

The main objective of this work is to illustrate the contribution of Persistent Scatterer Interferometry (PSI) for detecting and mapping subsidence induced by groundwater overexploitation by means of space-borne SAR images. The analysis is performed at basin scale, using and integrating several datasets of PSI data acquired during different ESA missions. These data provide estimates of the mean yearly velocity in the plain area of Gioia Tauro, referred to both historical (1992-2001; ERS images) and present (2002-2007; ENVISAT images) scenarios, allowing the analysis of the spatial variability and temporal evolution of Gioia Tauro subsidence.

Gioia Tauro is a 500 km^2 densely urbanized and heavily industrialized area surrounded by agricultural fields, built over unconsolidated fine-grained sediments. Agricultural areas, mainly devoted to citrus cultivation, are fragmented into hundreds of small plots, characterized by self-sufficiency in terms of water supply. Despite the water supply from the municipal network, many independent and usually uncontrolled water wells have been recently constructed, and the increasing groundwater demands for irrigation have caused the natural sediment consolidation to progressively accelerate.

The results shows that the studied area subsided about 11 mm/yr in the time period from 1992 to 2007, with greatest subsidence occurring between 1992 and 2000 near Rizziconi and north of Rosarno, with a maximum rate of 22 mm/yr and 18 mm/yr, respectively.

The SPSA analysis provided information about the temporal evolution of target points. Displacement time series generally show an overall linear trend of deformation and do not identify an evident seasonal trend, highlighting that, during the investigated period, subsidence is characterized by a constant rate of deformation.

In urban areas, intense land subsidence caused by groundwater withdrawal and associated aquifer-system compaction has a strong economic impact. Consequently, knowledge of the spatial distribution of such phenomenon in Gioia Tauro may help in land use planning, mitigation strategies and reduction of economic impacts and could represent a useful support to a better management of groundwater, in order to minimize future subsidence.

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