An open GIS for the significance analysis of displacements arising from GPS networks repeated over time: an application in the area of Castrovillari

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Abstract: - As is well known, GIS is a powerful tool to process, analyze and display spatial and temporal data whose standard applications are already tested and widely used in various application areas.

At the laboratory of Geomatics, Mediterranean University of Reggio Calabria, we implemented a project for the complete realization of an open GIS for calculating the significance of the shifts resulting from GPS data acquired networks, repeated over time, without a priori information on the stability of the points themselves.

The monitoring of geodynamic phenomena is constantly evolving thanks to the use of increasingly refined techniques. The increasing availability of data acquired over time, through the GPS system allows creating specific models able to simulate the situation in question.

The main objective of this contribute is to provide the results from a long series of GPS data acquired over time on a network straddling an active fault, for the estimation of surface deformation in Castrovillari.

The geodetic observations based on GPS can also provide useful information to the refinement of models of geophysical monitoring and prevention of natural disasters in areas of high seismic risk in presence of active faults.

Key-Words: - Geophysical monitoring - GPS – Geodynamic phenomena – Surface deformations - Geodetic observations

1 Introduction

This study has as objective the monitoring and control of the active fault in Castrovillari (CS), assessed through the analysis of a GPS experimental network already used in the past by other researchers for the study of geodynamic models / seismic [9, 10].

The Geomatics Laboratory of the Faculty of Engineering of the University "Mediterranea" of Reggio Calabria worked to acquire this network (consisting of 10 vertices positioned near the most active fault other three vertices located outside the fault itself) a large amount GPS data.

The Geomatics Laboratory made a long series of measurement campaigns from 2007 to date (up to once monthly/weekly) in order to assess the surface deformation of the network points and possibly estimate the speed with which these movements take place

The long process of data acquisition has the ambition to be able to provide, through a rigorous and timely processing of the data, a useful contribution to the assessment of the earthquake-fault. when the same data is integrated into more complex models in collaboration with scholars from other fields.

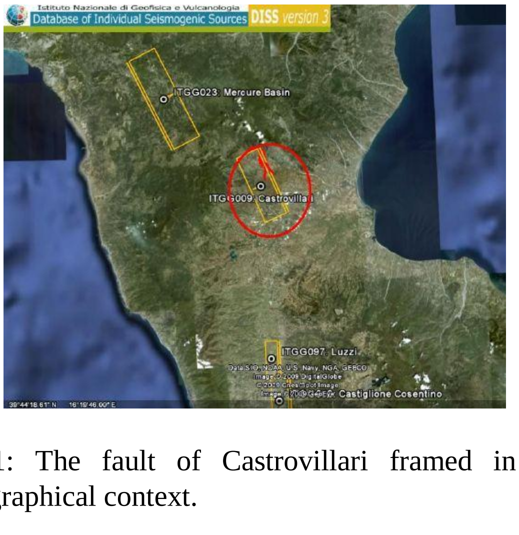


Fig.1: The fault of Castrovillari framed in its geographical context.

2 Geo-topographical characteristics of the Castrovillari fault

As known Calabria is situated in a very complex geodynamic and high seismic risk location.

The fault of Castrovillari (Fig 1), located in the region of the Pollino, presents a mechanism purely normal.

It is characterized by a value of the angle of dip of 60°, characteristic of all the faults in the southern region of the Apennines , from the fault of Melandro - Pergola, located further north, up to the fault of Castiglione-Agri located south The only exception is the fault of Luzzi which has a value of d slightly higher, at 65°.

The Fig.2 shows a schematic geological-structural elements of higher order in the area around the Calabrian Arc:

1) Adriatic microplate (Promontory African *Auct.*). The solid arrow in Puglia refers to the displacement vector calculated for the Matera VLBI station; arcs of a circle, roughly parallel to the arrow, indicate the traces of displacements of material points of the Adriatic microplate in recent geological times [2];
2) the northern margin of the African plate in south-eastern Sicily and the Strait of Sicily. The solid arrow in south-eastern Sicily refers to the displacement vector calculated for the Noto VLBI station; arcs of a circle, roughly parallel to the arrow, indicate the traces of movement of material points of the African plate in recent geological times.
3) the slope of Malta, interpreted as current separation zone between the African plate and the Adriatic microplate;
4) deformed system of Sicilian Maghrebides and Atlas, linked to the Africa-Europe convergence with low values of speed retraction of the axis of flexure in the lower plate (Africa);
5) Southern Apennines, up to 0.65 Ma, in compression system linked to the subduction of the Adriatic plate with high speed retraction of the axis flexure, today extending system with minimal effort axis NE -SW to NE linked to the relative motion of the Adriatic microplate compared to Europe in absence of withdrawal phenomena in flexural Apulian lithosphere;
6) Calabrian Arc, with its structures and compression (External Calabrian Arc) and extensional (Valley of the crater, Mesima Valley) and behind the well-known Wadati - Benioff plane (dashed lines) and the oceanic basin South-Tyrrhenian.

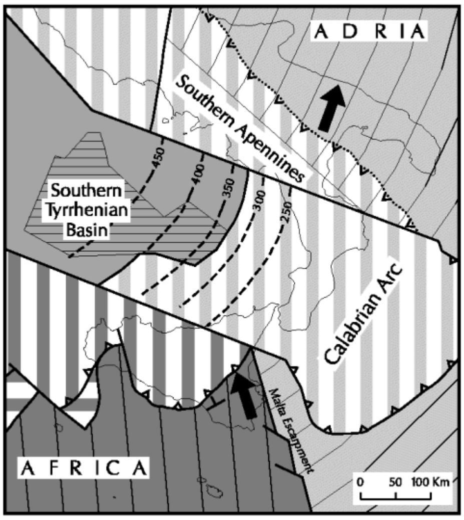


Fig.2: Schematic geological features of the study area.

In our case to consider a mechanism purely normal is a simplification, since the distribution of the rake is certainly more complex in reality. However, since are not available models in the literature that describe a variable value of rake, and the behavior of the fault is in extensional dominance, the hypothesis of adopting a mechanism purely normal in any subsequent analysis involving studies from other sectors is also more than reasonable, given the partial correlation with the evolutionary model resulting from the processing of GPS data as shown below.

3 Method of data acquisition

The network subject of this study was set up, designed and used over time by the Polytechnic Institute of Milan as part of a project aimed at monitoring of active faults.

Starting from the network established, the laboratory of Geomatics, University " Mediterranea" of Reggio Calabria, worked over the years to detect, up to once per week/month, the points of the network from the years 2007 to date.

It should be noted preliminarily that the methods of data acquisition and processing (due to the scarcity of resources, tools, GPS receivers and staff in the laboratory of Geomatics, to be used in different measurement sessions) was different compared to the one from the initial research project authors, even though the purposes of the research are the same.

In order to have comparable results with what is already available and present in the bibliography, the same network was recorded at various times (assessing a single annual value) and determined, for comparison, the annual surface deformation with respect to the start time.

In the acquisition phase it is used the classic method of centering by means of topographical base, which still allows to obtain sufficient accuracy for the purpose.

In particular, we have found the ten points of the network at the turn of the active fault Castrovillari (Fig.3), using also three pillars outside two on the east side and one on the west side, located in the stable area and therefore presumably a possible candidate to define system reference.

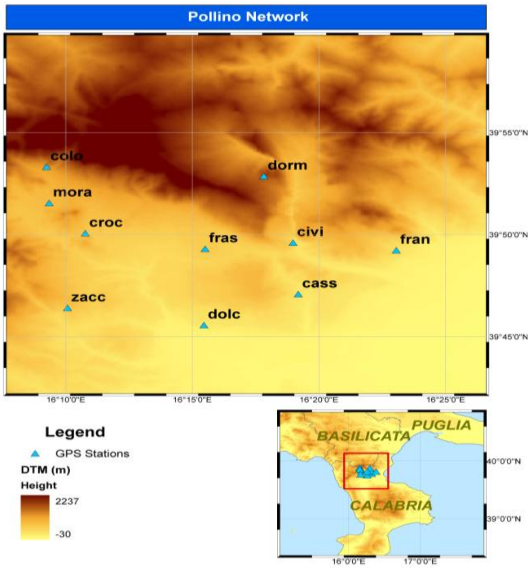


Fig.3: The Pollino non-permanent stations network and the Castrovillari fault.

Fig.4: The used GPS system.

The diagram of used pad, in relation to the small availability of tools and personnel used for different measurement campaigns, is that of triangulation for detecting two time points network via GPS measurements (Fig.4).

In fact, not having the possibility to be stationed at the same time on all the points of the network for a certain time period, we carried out the following mode of survey shown in Fig 5 using from time to time, for each measurement campaign, three GPS dual frequency in static mode in order to have for each measurement cycle two independent bases.

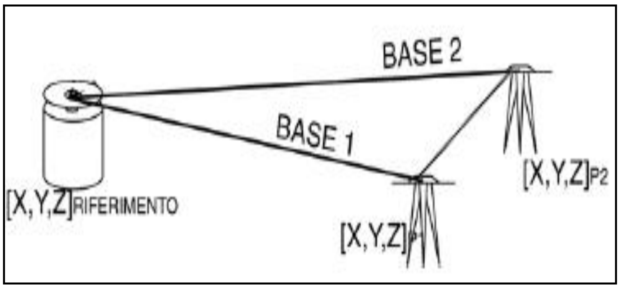


Fig.5: Method of GPS Surveying used by the Laboratory of Geomatics.

Subsequently, the cornerstone exterior was varied and with the same procedures were measured the other points of the network, in such a way as to detect all thirteen points of the network under study.

It has thus been incorporated in a number of years a unique global network (although temporally delayed in time) capable of providing for comparing spatial/temporal deformation of the surface at the turn of the active fault area of Castrovillari.

The campaign data acquisition was performed for about three hours for each pair of network points. Were subsequently made the offsets evaluating the differences of coordinates and noting the possible displacements.

In the following graphs Figg.6, 7, 8 are reported "type results" of data processing, along the directions x , y, z; for the period September 2007 to November 2012.

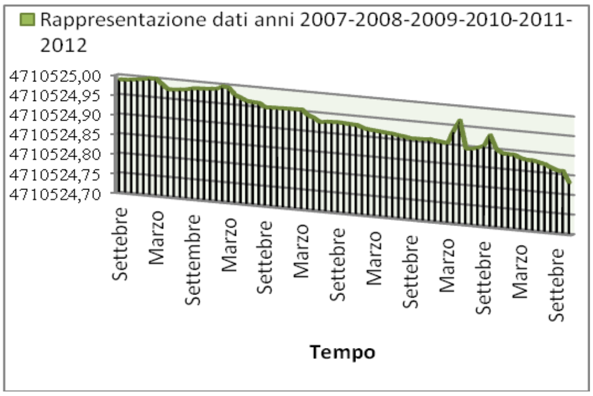


Fig.6: Representation of the displacements along the x axis (m) relating to the study period.

Postponing to subsequent considerations the analysis of deformation, we observed only that "visually" by the graphs in Figg.6, 7, 8 it is clear a constant deformation of small entities (slightly more evident in the x and y components, almost absent along the z-component) on all components with peak deformation that should be clearly interpreted as outliers.

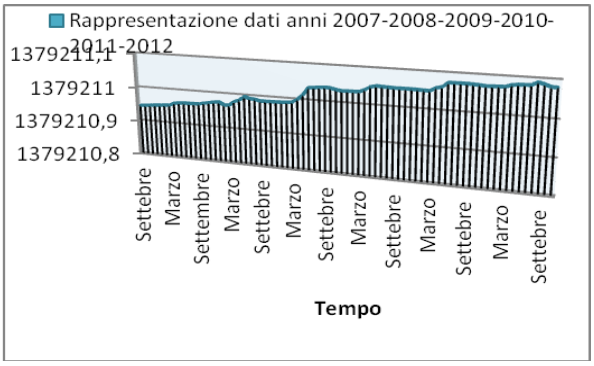


Fig.7: Representation of the displacements along the y axis (m) relating to the study period.

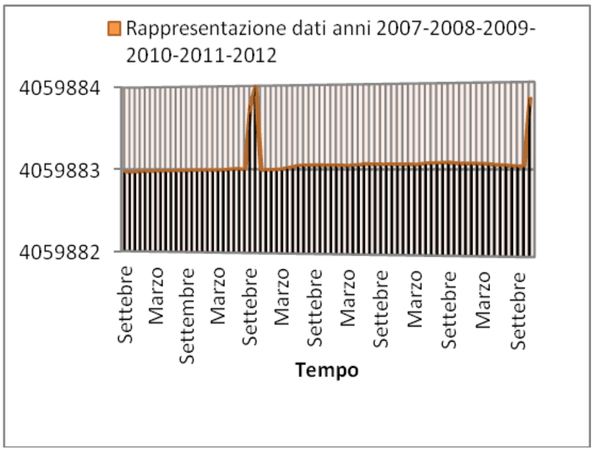


Fig.8: Representation of the displacements along the z axis (m) relating to the study period.

4 Data processing

The ultimate goal of the analysis concerns the assessment of the significance of differences in the coordinates in GPS surveys independent and with some points in common even in the absence of a priori information about their stability.

From measured data it was possible to calculate the Datum and then the variation displacement relative to all the ten points of the considered network, through a software specially crafted able to provide a statistical analysis of the three-dimensional geocentric coordinates.

More specifically, we wanted to first check whether these long GPS surveys are able to highlight, over the years, significant shifts with appropriate statistical tests comparing the coordinates estimated in the surveys carried out in several years.

The different measurement sessions were therefore compensated in multi-baseline mode using for modeling global propagation effects of the troposphere/ionosphere the Hopfield/ionofree model.

The compensation of the networks (Table 1, Table 2) over the years, have been performed with an open program [12] that allows the use of a stochastic model correctly, possibly assessed for basis group and provides useful statistics to find outliers (waste - normalized residuals of the equations of observation) and to evaluate the reliability of networks (local redundancy of the observations) .

Preliminarily, the networks have been offset to minimum constraints by fixing the barycentric point and returning coordinates in a datum comparable with that present in the bibliography [9,10].

Stat.	**X(m)**	**σ_x (m)**	**Y(m)**	**σ_y (m)**	**Z(m)**	**σ_z (m)**
cass	4710524,9888	0,012	1379210,9459	0,006	4059882,9691	0,008
civi	4707844,1800	0,013	1378122,3973	0,009	4063553,8464	0,011
colo	4707845,1863	0,016	1363659,8931	0,014	4069139,0261	0,016
croc	4710674,6182	0,014	1366752,2551	0,010	4064274,4122	0,012
dolc	4713635,3683	0,012	1374581,5595	0,014	4057630,1983	0,018
dorm	4705203,7349	0,021	1375629,2265	0,019	4068710,7078	0,017
fran	4706569,7647	0,019	1383811,7868	0,015	4062967,0936	0,016
fras	4709588,9094	0,026	1373465,2036	0,023	4063131,6622	0,021
mora	4709602,9444	0,014	1364320,3007	0,009	4066432,8988	0,008
zacc	4715072,7814	0,015	1366983,3397	0,011	4059047,5249	0,013
terr	4700432,8564	0,013	1374553,3620	0,019	4067245,2625	0,015
albi	4700225,9876	0,018	1387935,0073	0,011	4069523,6755	0,010
ferm	4718227,1748	0,020	1368837,5643	0,015	4058563,4592	0,012

Table 1: Compensated coordinates and their SQM year 2007 (initial network).

Network	$\hat{\sigma}_0$	χ^2_{SP}	$\chi^2_{95\%}$	S_{max}(m)	S_{med}(m)
2007	1,09	71,3	76,2	0,065	0,026
2008	1,11	80,6	82,1	0,061	0,022
2009	1,14	100,3	100,6	0,058	0,025
2010	1,12	68,5	69,4	0,055	0,021
2011	1,10	75,2	75,8	0,054	0,018
2012	1,13	81,4	82,3	0,051	0,015
$\hat{\sigma}_0$	estimation of the standard deviation of unit weight				
χ^2_{SP} $\chi^2_{95\%}$	experimental value of the test statistic for the overall model and the upper limit to the level of significance of 5%				
S_{max} S_{med}	maximum, and average values of the semiaxes of the ellipsoid standard error				

Table 2: Global Parameters of compensation.

5 Statistical analysis: the movements significance

Objective of the analysis is the assessment of the significance of the differences of coordinates in two independent GPS surveys having some points in common even in the absence of a priori information about their stability.

The starting point of the analysis itself is the availability of Cartesian components of the basics of GPS and their covariance matrix obtained from processing phase measurements (both purified from outliers and expressed in the same reference system). The result consists in the separation of the points common to two reliefs in two groups:

- Points with coordinates changes were not significant (final datum)
- Points with significant changes in the coordinates

starting from the coordinate differences $\delta\ \hat{x}$ with their covariance matrix $C_{\delta\delta}$ obtained from the minimum compensation to the constraints of the two surveys. To this purpose is used the procedure (well-known in the literature) [13], which allows to automatically select the final datum using an iterative procedure based on the classic Fisher's exact test in assumption of normal distribution of the observations and, therefore, of the coordinate differences $\delta\ \hat{x}$.

In this procedure, starting from these differences obtained in an initial datum containing a part or all of the points in the network (it is the minimum compensation to constraints in which is fixed the center of gravity of the points included in the datum), are tested point by point differences of the three coordinates, thus excluding the datum points for which these differences are significant; the process stops when the datum is not changed from one iteration to the next.

The operations carried out for the choice of Datum refer to a series of tests.

We want to solve the following problem.

Let X be the vector of estimated parameters in a problem sqm and both $C_{\hat{x}\hat{x}}=\sigma_0^2\cdot N^{-1}$, the corresponding covariance matrix; making an assumption H_o ($x=\bar{x}$) on the values of the components of x, we want to decide at a level of significance assigned *a* if H_o is plausible or if the vector estimated $\hat{x}$ is significantly different from $\bar{x}$.

The problem is rather simple if we suppose to know σ_0^2.

Indeed, if x = $\bar{x}$ (dim x = m) we have that:

$$(\hat{x}-\bar{x})^{+}C_{\hat{x}\hat{x}}^{-1}(\hat{x}-\bar{x})=\sigma_0^{-2}(\hat{x}-\bar{x})^{+}N(\hat{x}-\bar{x})=x_m^2 \qquad (1)$$

perfectly suited to evaluate the hypothesis H_o, as if H_o was right, the empirical value

$$\sigma_0^{-2}(\hat{x}-\bar{x})^{+}N(\hat{x}-\bar{x})=x_0^2 \qquad (2)$$

is an extraction from an x^2 with *m* degrees of freedom and can therefore be compared with the critical value x_α^2,,deciding that

$x_0^2 \leq x_\alpha^2$ → H_o is accepted

$x_0^2 > x_\alpha^2$ → H_o is rejected

In fact it is easy to see that if $\bar{x}$ is different from x, true average value of $\hat{x}$, the quadratic form tends to swell in average.

$$\begin{aligned}&E\{(\hat{x}-\bar{x})^{+}N(\hat{x}-\bar{x})\}=E\{(\hat{x}-x)^{+}N(\hat{x}-x)\}+2E\{(\hat{x}-\bar{x})^{+}N(\bar{x}-x)\}+\\&+E\{(\bar{x}-x)^{+}N(\bar{x}-x)\}=E\{(\hat{x}-x)^{+}N(\hat{x}-x)\}+\{(\bar{x}-x)^{+}N(\bar{x}-x)\}\geq\\&\geq E\{(\hat{x}-x)^{+}N(\hat{x}-x)\}=\sigma_0^2\end{aligned} \qquad (3)$$

If σ_0^2 is unknown,

$$\begin{cases}\dfrac{1}{m}(\hat{x}-x)^{+}N(\hat{x}-x)-\sigma_0^2\dfrac{X_m^2}{m}\\\dfrac{1}{n-m}U^{+}Q^{-1}U-\hat{\sigma}_0^2-\sigma_0^2\dfrac{X_{n-m}^2}{n-m}\end{cases} \qquad (4)$$

Recalling that the two quadratic forms are stochastically independent, dividing member to member we have:

$$\frac{\frac{1}{m}(\hat{x}-x)^{+}N(\hat{x}-x)}{\sigma_0^2}=F_{m,n-m} \tag{5}$$

Therefore, the sample value (empirical) of the function (3) can be compared with the critical value F_α of a Fisher F a (m, n-m) degrees of freedom: if true H_o ($x=\bar{x}$)

$$F_0=\frac{\frac{1}{m}(\hat{x}-\bar{x})^{+}N(\hat{x}-\bar{x})}{\hat{\sigma}_0^2} \tag{6}$$

must be less than F_α with probability (1-a), while if H_o is false, F_α tends to increase, so

$$\begin{cases} F_0 \le F_\alpha & \rightarrow \quad H_o \text{ is accepted} \\ F_0 > F_\alpha & \rightarrow \quad H_o \text{ is rejected} \end{cases} \tag{7}$$

To simplify the discussion, it was decided to use

$$F_o=\frac{\Delta\hat{\underline{x}}^t Q_{\Delta\Delta}^{-1}\Delta\hat{\underline{x}}}{m\hat{\sigma}_o^2} \tag{8}$$

$$Q_{\Delta\Delta}^{-1}=\left(Q_{xx}^{(1)}+Q_{xx}^{(2)}\right)^{-1} \tag{9}$$

Cofactors matrix of the differences related to the common points in the two epochs

$$\hat{\sigma}_o^2=\frac{r_1\hat{\sigma}_{o1}^2+r_2\hat{\sigma}_{o2}^2}{r_1+r_2} \tag{10}$$

r = degrees of freedom = n-m +3 (constraint on the translation).

If it turns out:

$F_0 \le F_{m,\ r1+r2}$

then H_0 is true, and consequently, there were no significant shifts

$F_0 > F_{m,\ r1+r2}$

then H_0 is false and, consequently, there are significant shifts.

In the case considered, we evaluated the significance of differences in the independent coordinates in the GPS surveys in the period 2007-2012 suitably associated two by two (2007-2008, 2008-2009, 2009-2010, 2010-2011, 2011-2012) referring 10 common points. The measurements were offset by an open program that provides the full covariance matrix of the estimated parameters allowing the subsequent statistical analysis of significance. It is clear that the statistical test used assumes that the coordinates of the findings to be compared are expressed in the same reference system: in particular, the starting hypothesis on membership of the Cartesian components in the same reference system is acceptable only in a first approximation due to a series of errors that could lead to a global rotation with scale variation. It was therefore carried out a proper analysis to estimate the parameters day rotation, and scale to bring networks in 2008, 2009, 2010, 2011 and 2012 in the same reference of the network in 2007.

These parameters (Table 1) (as expected because of the limited extension of networks), were not significant, and therefore have not been applied.

Compar. years	Scale and SQM	Rotatons on ω φ κ and SQM		
2007-2008	$(7{,}5\pm17{,}6)\cdot10^{-7}$	$(-0{,}5\pm0{,}5)\cdot10^{-5}$	$(-0{,}2\pm0{,}4)\cdot10^{-5}$	$(-0{,}2\pm0{,}4)\cdot10^{-5}$
2008-2009	$(5{,}4\pm18{,}5)\cdot10^{-7}$	$(-0{,}2\pm0{,}3)\cdot10^{-5}$	$(0{,}3\pm0{,}5)\cdot10^{-5}$	$(0{,}3\pm0{,}5)\cdot10^{-5}$
2009-2010	$(6{,}8\pm17{,}9)\cdot10^{-7}$	$(-0{,}3\pm0{,}6)\cdot10^{-5}$	$(-0{,}5\pm0{,}3)\cdot10^{-5}$	$(-0{,}5\pm0{,}3)\cdot10^{-5}$
2010-2011	$(4{,}7\pm18{,}2)\cdot10^{-7}$	$(-0{,}4\pm0{,}5)\cdot10^{-5}$	$(0{,}4\pm0{,}2)\cdot10^{-5}$	$(0{,}2\pm0{,}2)\cdot10^{-5}$
2011-2012	$(7{,}2\pm17{,}7)\cdot10^{-7}$	$(-0{,}7\pm0{,}2)\cdot10^{-5}$	$(-0{,}6\pm0{,}4)\cdot10^{-5}$	$(-0{,}6\pm0{,}4)\cdot10^{-5}$

Table 3: Coordinates local datum offset and their SQM.

The tests were therefore carried out twice by fixing two different levels of significance: $\alpha = 0.05$ and $\alpha = 0.01$.

In the first processing carried out not without making any assumptions about the set of points, or from compensation which is set free in the center of gravity of all the common points 4 points out of 13 were stable in all periods considered, with $\alpha = 0.05$ while $\alpha = 0.01$, the number of stable points increases in some cases even at 5-6 out of 13.

It is then conducted a second processing time to define a set of stable points from a datum consisting of just three points outside TERR, ALBI, FIRM, which are considered unrelated to deformation. There were obtained the final datum with the same three points in addition to the external vertex FRAN in one of two processes (Table 5): this result provides a partial confirmation of the hypothesis that the external points are unrelated to the movement of the internal ones.

To define a common final datum was therefore chosen the three points consisting of the "external" to the fault Terr - Albi - Firm.

Compar.	Initial Datum	Final Datum $\alpha = 0.05$	Final Datum $\alpha = 0.01$
2007-2008	Global Barycentre	Terr – Albi –Firm-Fran	Terr- Albi .Firm – Fran -Dorm
2008-2009	Global Barycentre	Terr- Albi –Fran	Terr- Albi –Fran – Zacc - Cass
2009-2010	Global Barycentre	Terr – Albi – Firm - Fran	Terr- Albi .Firm – Fran - Zac
2010-2011	Global Barycentre	Terr- Albi .Firm - Zac	Terr – Albi –Firm – Zac - Dorm
2011-2012	Global Barycentre	Terr – Albi – Firm – Cass	Terr – Albi – Firm – Cass – Fran

Table 4: First analysis of significance displacements.

Compar.	Initial Datum	Final Datum $\alpha = 0.05$	Final Datum $\alpha = 0.01$
2007-2012	Terr- Albi-Firm	Terr – Albi - Firm	Terr – Albi - Firm - Fran

Table 5: Second analysis of significance displacements.

Depending on the results obtained by setting different offsets for the common datum, it was possible to create a diagram illustrating the movements:

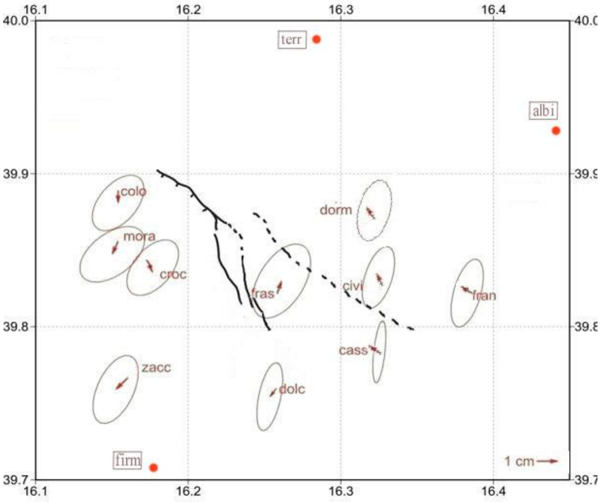


Fig.9: Representation of the displacements along the z axis (m) relating to the study period.

The following diagram shows a tendency to a certain stability of the divergent movements with respect to the fault (elongation of the same), in particular a shift of the points West South West to the South, and points East-North-East to the North.

This shift can be estimated to be 30 [mm/year]. In addition, taking into account that the active fault Castrovillari is Normal-type transcurrent, it would confirm that behavior through the coordinates of the type highlighted with elevation data processing. In particular, the points of the area West tend to rise with respect to the ground level and points east zone would tend to fall by about 2.4 [mm/year].

The data relating to measurement campaigns 2007-2012 were also plotted three-dimensionally in order to have a global vision of movements over time. Fig.10 shows as an example the three-dimensional diagram relating to the station Dolcetti.

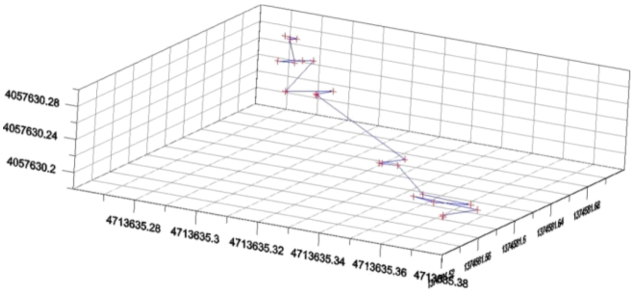


Fig.10: Three-dimensional diagram of the measurement campaign in the non-permanent station of Dolcetti.

As further confirmation of the considerations first listed, were also determined the average speed of drift of each grid point.

Starting in fact geographical coordinates (N, E and H), it was possible to estimate the average speed of drift of the individual stations in Table 6 over the time frame of all the campaigns carried out, and to determine the three separate components vN, vE and vh. The velocities are represented by the slopes of the straight lines interpolating sets in the plane and space-time and are obtainable thanks to the theory of least squares. The table below shows the speed found:

Station	vN	vE	vh
	[m/year]	[m/year]	[m/year]
cass	0,0167364	0,0228673	0,00156368
civi	0,0161034	0,0283652	8,69E-05
colo	0,0173729	0,0227104	0,00172642
croc	0,0187531	0,0240203	0,00271845
dolc	0,0171953	0,0228036	0,00085413
dorm	0,0186807	0,0239287	0,00354137
fran	0,0171493	0,0258553	0,00200169
fras	0,0174935	0,0230408	0,00392339
mora	0,0187789	0,0229254	0,00135488
zacc	0,0179724	0,0259112	0,00352795

Table 6: Average drift speed of the stations.

6 GPS/GIS

The application implemented at the Laboratory of Geomatics, still under testing and validation, starting from the GPS acquisitions in two consecutive years on the common points of the network, can:

- View the network on GIS support (Fig.11);
- Carry out a free compensation of individual networks in the two reference years (Fig.12);
- Make the choice of the datum through statistical tests (Fig.13);
- Calculate the new coordinates of the points in the identified Datum network (transformation) (Fig.14);
- Carry out the calculation of displacements resulting from free compensation (Fig. 15);
- Carry out the calculation of movements arising from in constrained compensation in the identified Datum (Fig. 16);
- Display deformations (Fig. 17);

The following is a series of screens made of GIS, depicting the application of the methodology to the area of Castrovillari.

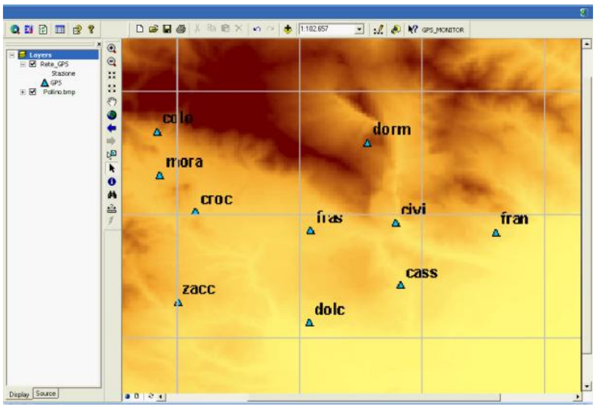
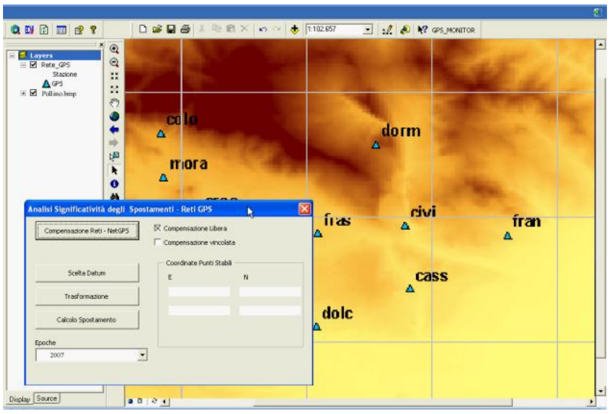
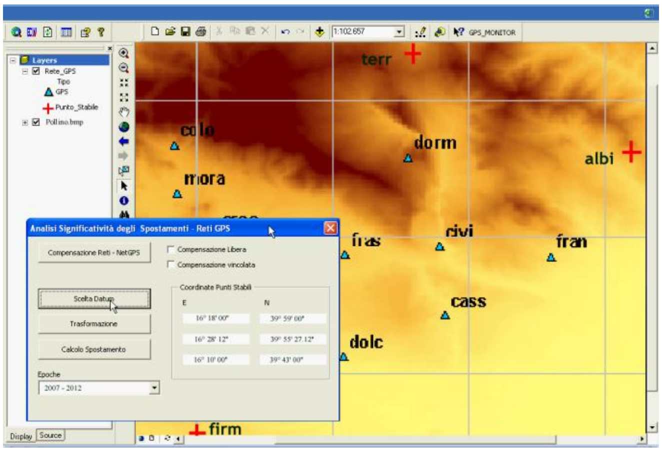


Fig.11: The Pollino non-permanent stations network.



☒ Compensazione Libera
☐ Compensazione vincolata
Epoche: 2007

Fig.12: Free compensation network 2007.



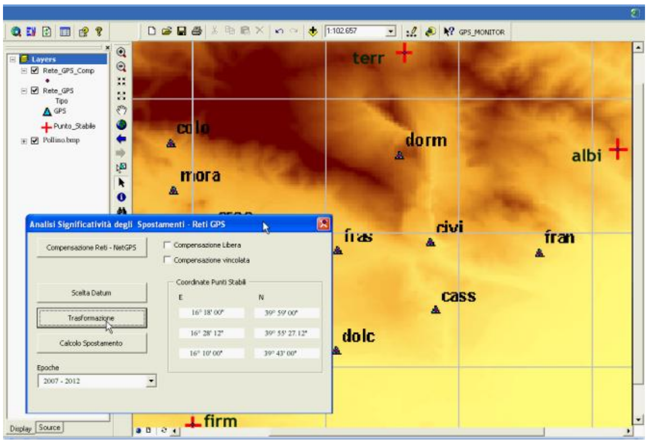
☐ Compensazione Libera
☐ Compensazione vincolata

Coordinate Punti Stabili

E	N
16° 18' 00"	39° 59' 00"
16° 28' 12"	39° 55' 27.12"
16° 10' 00"	39° 43' 00"

Epoche: 2007 - 2012

Fig.13: Datum choice.



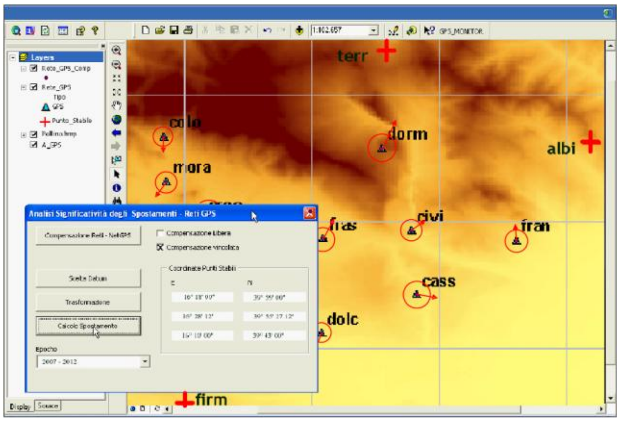
☐ Compensazione Libera
☐ Compensazione vincolata

Coordinate Punti Stabili

E	N
16° 18' 00"	39° 59' 00"
16° 28' 12"	39° 55' 27.12"
16° 10' 00"	39° 43' 00"

Epoche: 2007 - 2012

Fig.14: Transformation.



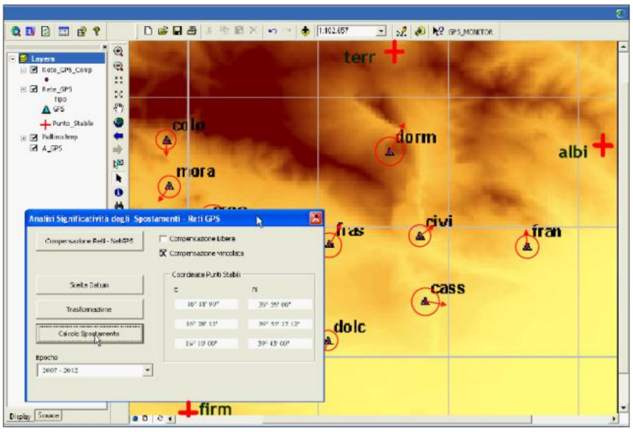
☐ Compensazione Libera
☒ Compensazione vincolata

Coordinate Punti Stabili

E	N
16° 18' 00"	39° 59' 00"
16° 28' 12"	39° 55' 27.12"
16° 10' 00"	39° 43' 00"

Epoche: 2007 - 2012

Fig.15: Calculation of free movement with compensation.



Analisi Significatività degli Spostamenti - Reti GPS

Compensazione Reti - NetGPS

☐ Compensazione Libera

☒ Compensazione vincolata

Scelta Datum

Trasformazione

Calcolo Spostamento

Coordinate Punti Stabili

E	N
16° 18' 07"	39° 55' 00"
16° 28' 12"	39° 55' 27.12"
16° 10' 00"	39° 43' 00"

Epocha: 2007 - 2012

Fig.16: Calculation of displacements with compensation tied in the Datum.

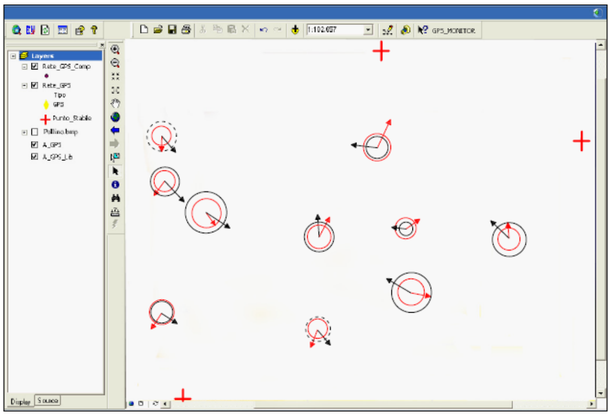


Fig.17: Comparison of displacements.

From the GPS data in possession, it is assumed a normal-transcurrent fault that relates the relative displacement of the area with the East and West area, in addition, the eastern zone tends to rise with respect to the ground level of about 2-4 (mm/year) compared to the West. As can be seen from Fig.9, appears evident the effect of the correct choice of Datum on GPS networks repeated over time for analysis of deformations.

7 Conclusion

The large number of GPS data acquired over time make it possible to highlight a speed of displacement of the earth's crust in the active fault Castrovillari; this shift is of the order of 30 (mm/year).

Geological studies carried out in the subsoil show a moving speed of 3-9 (mm/year).

From the GPS data in our possession, it is assumed a normal - transcurrent fault that relates the relative displacement of the area with the East and West area; in addition, the eastern zone tends to rise with respect to the ground level of about 2-4 (mm/year) compared to the West.

The ambitious study of the surface deformation of the crust in the area of Castrovillari aims to highlight the possibility of a scientific comparison between subsurface deformations and surface deformations, in order to improve the knowledge of the geo-structural fault active. Furthermore the area of Castrovillari, for the presence of such active fault, should be considered as a potential generating future earthquakes with magnitude higher. In addition, despite the GIS package is still in the experimental and implementation stage, is evident the potential of the same in the handle analysis of deformations of GPS networks repeated over time.

In particular, the use of GIS allows to better visualize the importance of the choice of when Datum must be carried out analysis of deformations.

References:

[1] V. Barrile, M. Crespi, Compensazioni ed analisi di rilievi GPS per il controllo di deformazioni nell'area Etnea, *Atti del 14° Convegno del Gruppo Nazionale di Geofisica della Terra Solida*, Rome, Oct. 23-25, 1995 pp. 309-318.

[2] C. Meletti, M. Stucchi, F. Galadini, I. Leschiutta, P. Scandone. Criteri e procedure per la compilazione di un inventario speditivo delle sorgenti potenziali di terremoti distruttivi finalizzato alla compilazione di una nuova mappa delle zone sismogenetiche per l'area italiana, *Ricerche del GNDT nel campo della pericolosità sismica*, 2000, 3-14.

[3] L. Biagi, I fondamentali del GPS, *Geomatics Workbooks*, Vol. 8, 2009.

[4] A. Cina, *GPS. Principi, modalità e tecniche di posizionamento*, Torino, Celid, 2000, pp. 9-23.

[5] S. Faini, *L'inversione geofisica di osservazioni geodetiche*, Milano, 2010.

[6] A.M. Kűnzle, *Inferenza statistica di misure geodetiche di modelli di inversione geofisica*, Milano, 2010.

[7] Y. Okada, Internal deformation due to shear and tensile faults in a half-space, *Bull. Seism. Soc. Am.*, Vol. 82 No. 2, April 1992, pp 1018-1040.

[8] R. Sabadini, A. Aoudia, R. Barzaghi, B. Crippa, A.M. Marotta, A. Borghi, L. Cannizzaro, L. Calcagni, G. Dalla Via, G. Rossi, R. Splendore, M. Cosetto, First evidences of fast creeping on a long-lasting quiescent earthquake normal-fault in the Mediterranean, *Geophys. J. Int.*, 2009.

[9] R. Barzaghi, Determinazione dello stile di deformazione e dello stato di sforzo nelle macrozone sismo genetiche italiane, *Framework Program 2000–2002*, Annual Report - 2nd year of activity, 2003.

[10] R. Barzaghi, Determinazione dello stile di deformazione e dello stato di sforzo dell’arco calabro, *Framework Program 2000–2002*, Annual Report – 1st year of activity, 2002.

[11] F.R. Cinti, M. Moro, D. Pantosi, L.A. Cucci, G. D’Addezio, New constraints on the seismic history of the Castrovillari fault in the Pollino gap (Calabria, southern Italy), *J. Seismol.*, Vol. 6, 2002, 199-217.

[12] M.Crespi, D.Sguerso, *Manuale del programma di compensazione di reti GPS NETGPS*, Internal report DIIAR Politecnico di Milano, 1993.

[13] M. Barbarella, M. Crespi, M. Fiani, Analisi statistica della significatività degli spostamenti, *Atti del 13º Convegno del Gruppo Nazionale di Geofisica della Terra Solida*, Rome, 319-330.

[14] B. Betti, M. Crespi, D. Sguerso, Stabilità del sistema di riferimento nella determinazione di reti GPS, *Bollettino SIFET*, Vol. 4, 1994, pp. 67-88.

[15] V. Barrile, G.M. Meduri, G. Bilotta, Monitoring and GPS controls, over time, of the active fault in Castrovillari, *Latest Trends in Energy, Environment and Development, Proceedings of 7th International Conference on Environmental and Geological Science and Engineering (EG '14)*, Salerno, 2014, pp. 169-175.

[16] A. Zollo, A. Emolo, *Terremoti e onde. Metodi e pratica della sismologia moderna*, Liguori Ed., Naples, 2011.

[17] M. Riente, F. Catanzariti, *Terrae motus. Conoscere per prevenire*, GeoStru, Ingenium Ed., Dairago (MI), 2013.

[18] V. Barrile, G.M. Meduri, G. Bilotta, Laser scanner technology for complex surveying structures, *WSEAS Transactions on Signal Processing*, Vol. 7, No. .3, pp. 65-74.

[19] V. Barrile, G. Armocida, G. Bilotta, GIS supporting the Plan of BTS (Base Transceiver Stations) for mobile network in urban context, *WSEAS Transactions on Communication*, Vol. 8, No. .8, pp. 775-784.