ASI ACTIVITIES IN CERGOP II FRAMEWORK: DISCUSSION OF THE RESULTS

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Abstract ASI/CGS contribution to CERGOP II project covered the following topics: landslide monitoring, production and quality check of zenith total delays estimated for a global as well as regional GPS networks devoted to meteorology applications, RTK and navigation tests, critical analysis of GPS long time series helpful for geodynamic as well atmospheric investigations. For what concern the landslides monitoring the two sites under investigation: Aliano and Avigliano are located in Basilicata region, (South of Italy). These sites are affected by a dramatic creep of the ground which in the past was the cause of severe damages to the buildings and roads in the areas. We will show the state of art of the activities comparing GPS with Permanent Scatter IN-SAR technique For what concern the routine production of ZTD we will show a critical comparisons of our solutions with radio balloon observations and a discussion about the assessment of their reliability. Finally the results of a navigation experiment by using differential correction provided by EUREF-NTRIP service will be shown.

1. GPS NEAR REAL TIME ESTIMATION

We process 57 stations (*Fig. 1*) in Near-Real Time mode with GIPSY-OASIS II software and a standard technique of network adjustment.

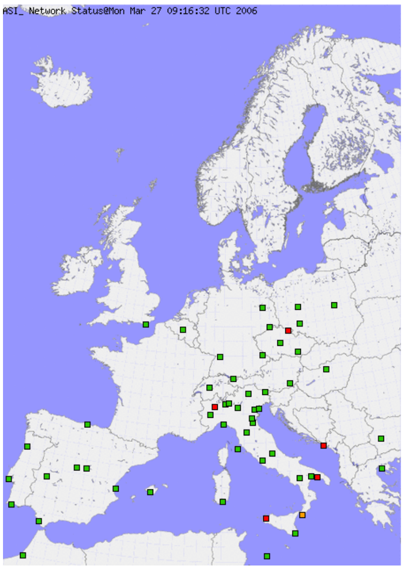


Fig. 1. ASI Ground Based Network - Status March 2006

We evaluate ZTD w.r.t Radiosonde profile and HIRLAM (High Resolution Limited Area Model) numerical weather prediction model considering all the solutions delivered from April 2003 to December 2005. Results show that GPS ZTD is greater than radiosonde ZTD, the bias is about 7 mm with a standard deviations 9 mm (*Fig. 2*). In the comparison statistics between the ZTD values extracted from HIRLAM and those derived from GPS NRT processing (

Fig. 3) we have an average bias of about –4.8 mm and a standard deviation of 11.5 mm. The residuals between HIRLAM and GPS ZTD and IWV have a seasonal signal with a standard deviation higher in summer than in winter. The monthly ZTD standard deviation increases from about 5 mm in winter to about 15 mm in summer for the ZTD and from 1 kg/m^2 kg to 3 kg/m^2 for the IWV.

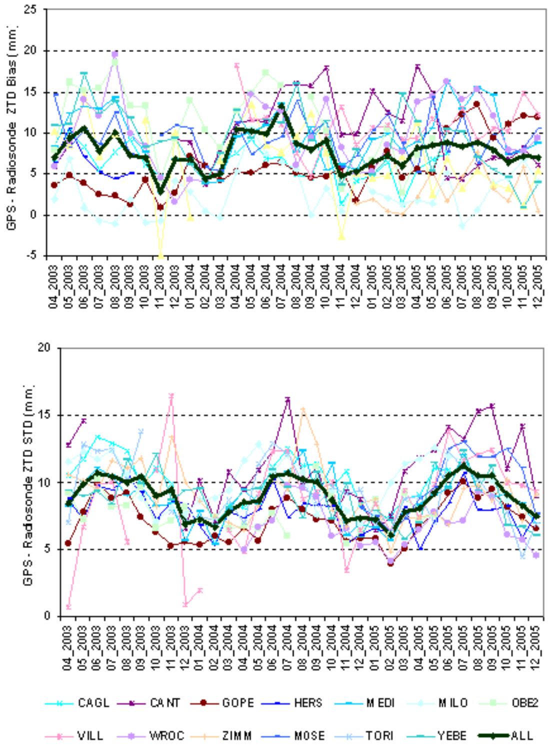


Fig. 2. Monthly variation in ZTD bias (up) and std (down) of Radiosonde vs GPS

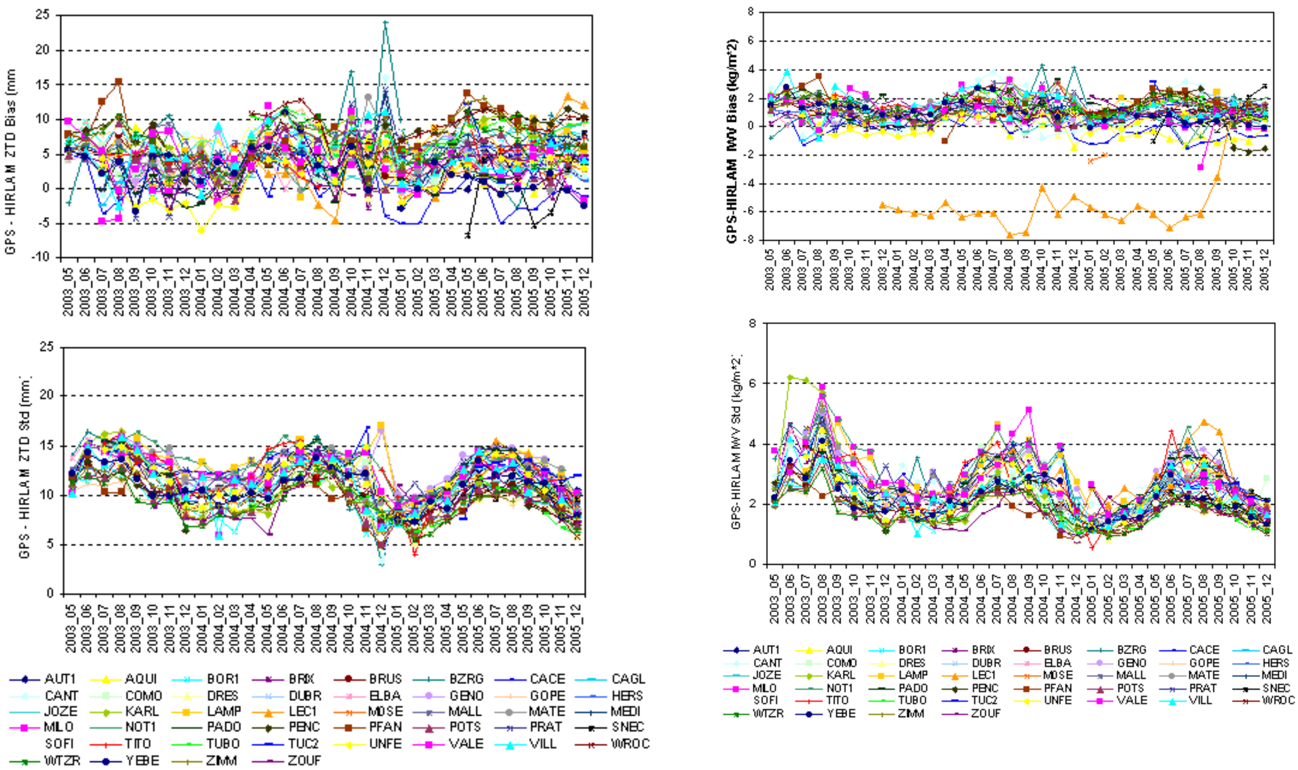


Fig. 3. Monthly Bias (up) and Std (down) of HIRLAM ZTD versus GPS ZTD (left) and IWV (right) . Each line is a different station.

2. ASSESSMENT OF THE UNCERTAINTIES OF NRT GPS ZTD ESTIMATES

When comparing ZTD solutions coming from different ACs we realize that while the ZTD estimates are very high correlated there is a poor correlation between the related sigma This means that the quality indicator for the ZTD, obtained by the GPS processing, is not perfect. A statistical method to assess the degree of reliability of the NRT ZTD and their real uncertainties is proposed and the results achieved applying it to the ZTD estimates provided by different ACs are discussed.If we have different data sets x_i and y_i, measurements of the same observable in time and space, it is possible to assess the real uncertainties of that intrinsically less precise. If y_i is more precise than x_i, we can define the a-dimensional data set z_i as:

$$z_i = \frac{(x_i - y_i)}{\sqrt{\sigma_{x_i}^2 + \sigma_{y_i}^2}} \qquad (1)$$

If x_i and y_i are unbiased and if their internal (formal) error is not underestimated z_i behaves like a Gaussian with μ=0 and σ=1. μ behaves according to the Normal distribution with

$$\sigma_\mu = \frac{\sigma_z}{\sqrt{n-1}} \qquad (2)$$

If μ is significantly $\neq$0, the x dataset is affected by a bias. The variance $\boldsymbol{\sigma^2}$ behaves according the $\boldsymbol{\chi^2}$ function with n-1 degree of freedom. To assess the real values of the uncertainties we should test if σ_z^2 =1 is within the confidence interval. The new parameter to consider is:

$$V = \frac{\tilde{D}(n-1)}{D_{\exp}} \qquad (3)$$

The ***y*** datasets adopted are the EUREF combined ZTD solutions for while the ***x*** datasets are ACRI, ASI, BKG, IEEC, GFZ, GOPE, LPT and SGN NRT solutions. Each analysis centres uses different SW (GAMIT from ACRI, GIPSY from ASI and IEEC, EPOPS from GFZ, Bernese from BKG, GOPE, LPT, SGN) and processing procedures. The EUREF combined solution is mainly based on Bernese solutions.
Histograms of the ‘z’ datasets (Eq. 1) compared with a Gaussian distribution (blue line) having the same μ and σ of the series are reported below for ACRI (Fig 4), ASI (Fig. 5) and GFZ (Fig.6) solutions.

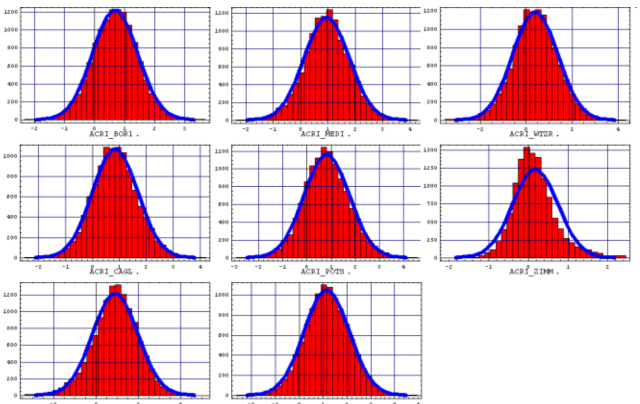


Fig. 4. Histograms of the ‘z’ datasets compared with a Gaussian distribution (blue line) for ACRI solutions

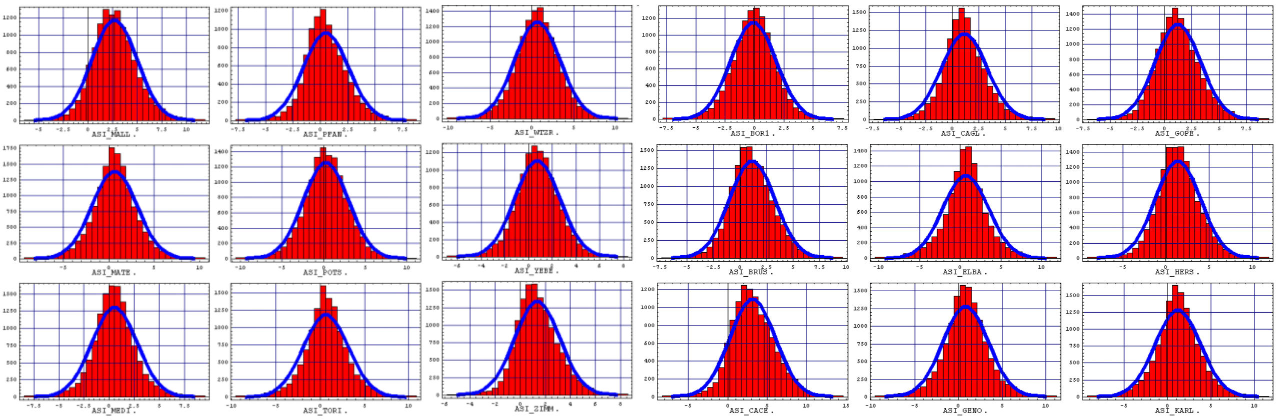


Fig. 5. Histograms of the ‘z’ datasets compared with a Gaussian distribution (blue line) for ASI solutions

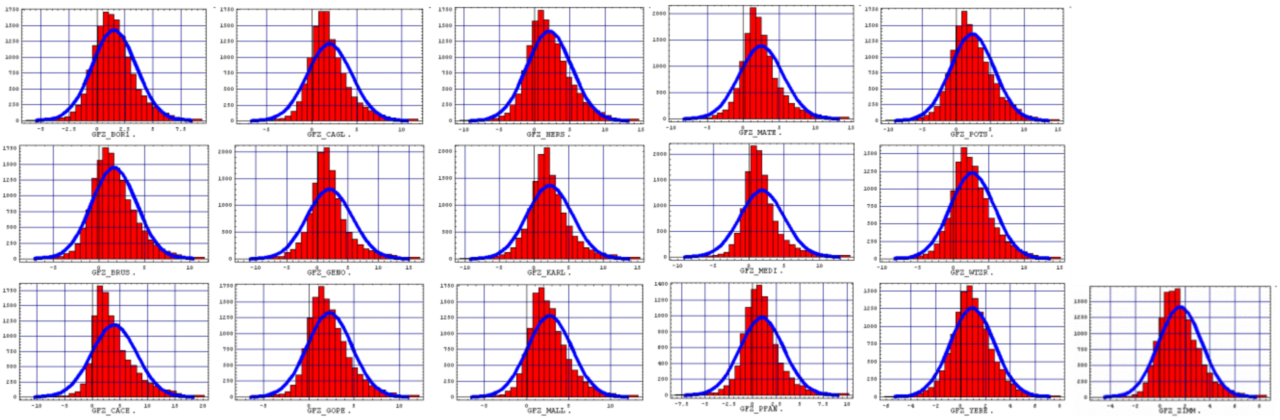


Fig. 6. Histograms of the ‘z’ datasets compared with a Gaussian distribution (blue line) for GFZ solutions

A mean scaled factor and scaled sigma (mm) is computed for each analysis canter and reported in Tab. 1. It can be noticed that:

1. all Bernese solutions (BKG, GOP, LPT, SGN) have underestimated uncertainties (approx by a factor of 3) and their statistical distribution is far to be Gaussian.
2. ACRI solutions (GAMIT SW) have over-estimated uncertainties and their statistical distribution is rather Gaussian,
3. all the uncertainties seem to be correlated more to the analysis strategies (SW, set up etc.) than to the quality of the stations.

	Scaled Factor	Scaled Sigma (mm)
ACRI	0,9	8,3
ASI	2,4	5,6
BKG	2,7	3,2
GFZ	2,8	2,9
GOP	2,8	3,0
IEEC	1,4	7,7
LPT	3,5	3,9
SGN	5,8	3,6

Tab. 1 Mean scale factor and scaled sigma (mm)

3 LANDSLIDES MONITORING

Among the ASI activities in CERGOP II framework in the topic of hazard assessment, the monitoring of some sites affected by landslide phenomena is going on. The sites under investigation are: Aliano, Avigliano and Maratea (fig. 7). These sites are interested by large and active landslides subjected to frequent reactivation causing severe damages to the urban structures. In order to monitor the evolution of the phenomena, in Aliano and Avigliano sites a GPS network has been establish at the end of 2003. The monitoring activities, based on periodically GPS static surveys, started in January 2004 at Aliano site and in February 2004 at Avigliano. The GPS measurements allow to detect both the “absolute” motion of the phenomena and the ”relative” motion in different areas of the landslide. In Maratea area, the results obtained by GPS surveys have been compared with results derived from Permanent Scatter IN-SAR technique.

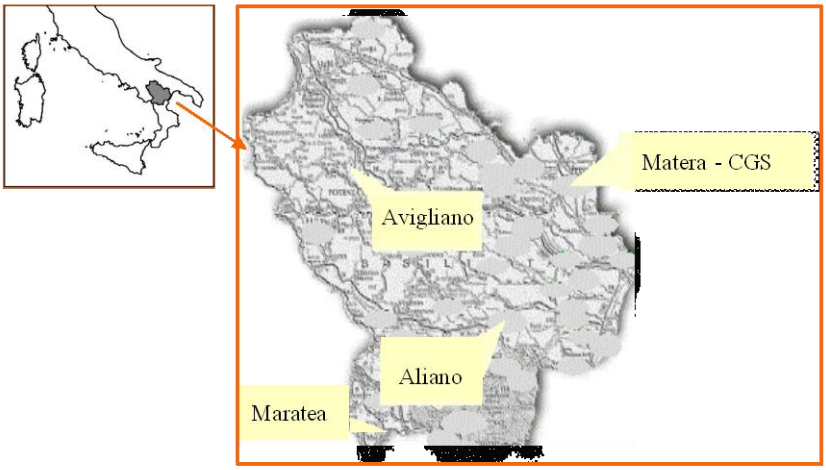


Fig. 7. Location of sites under investigation

3.1 GPS analysis procedure

The coordinates of the two reference points, both in Aliano and Avigliano are estimate with the Bernese 5.0 with a network approach, analyzing the data acquired at: Elba, Matera, Noto, Cagliari, and Aliano or Avigliano respectively. Matera station coordinates are kept fixed to ITRF 2000 values together with the IGS final orbits. The analysis of the coordinate time series of Aliano and Avigliano reference points confirms that they are located in stable areas, so they are useful as reference points for the detections of ongoing deformations in the investigated areas. The reference point of the GPS measures in Maratea belongs to ASI national permanent reference network.

3.2 Results of the GPS campaign

The results of the analysis of the available data from Aliano and Avigliano area are shown in figures 9 and 11 in terms of Delta North, Delta East and Delta Up baseline vector components between each station of measurement and the reference point. The values are residuals calculated for each point between the first measurement campaign (the zero campaign) and each other subsequent campaign.

3.2.1 Results at Aliano site

Some GPS points of measurement (points ALI1 and ALI2, fig. 8 c,d) have been placed on structures built up to stop the landslide evolution.

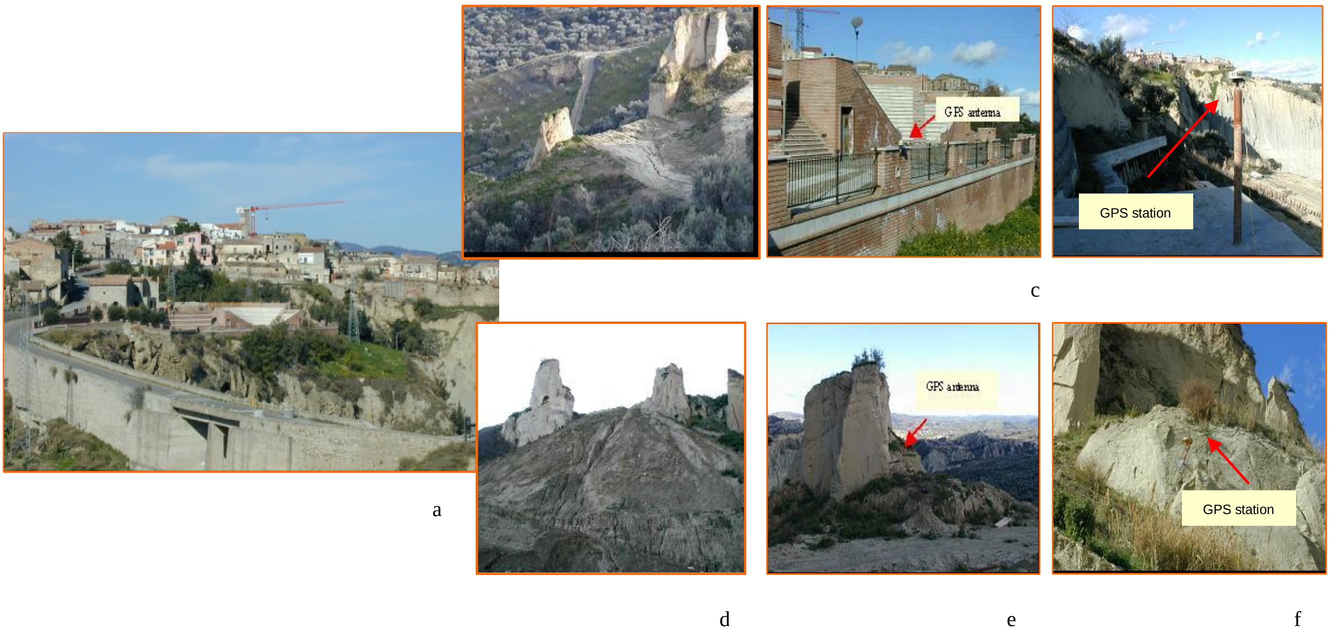
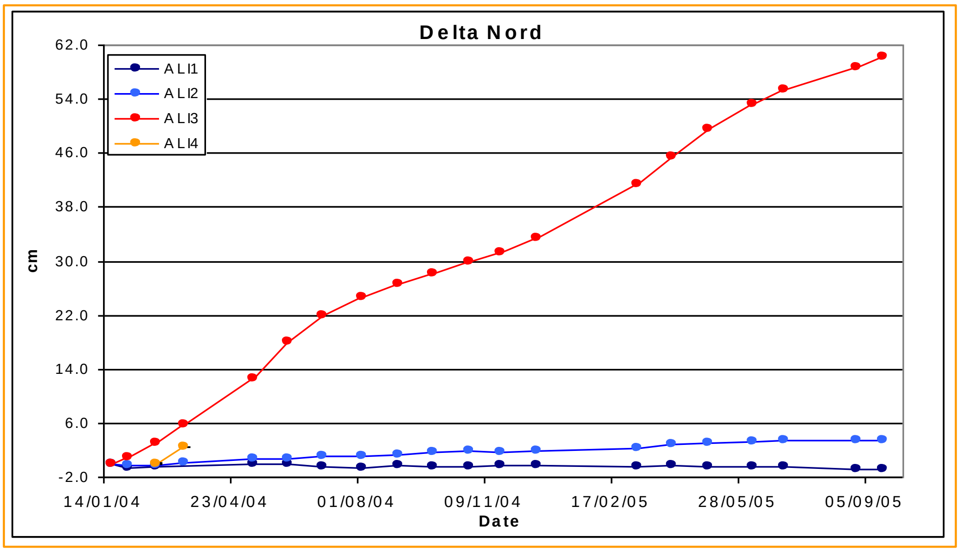
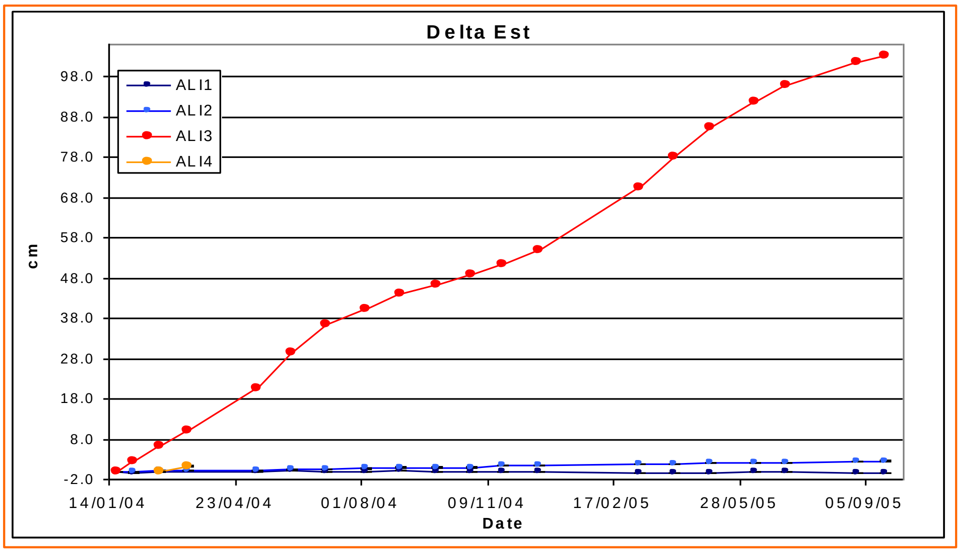


Fig. 8. Aliano landslide: evidence of the landslide displacement (a,b,d) and arrangement of GPS monitoring network

As expected, the points ALI1 and ALI2 in figure 8, show no evidence of displacement in any component of the estimate coordinates series. This behaviour confirms that ALI1 and ALI2 GPS point lie in areas quite stable. Indeed the results obtained on the data collected at point ALI3 (fig 8 e) show (fig. 8) a continuous motion of this part of landslide.
Reclaim works are going on in the area where the point ALI4 lies(fig 8 f). So this point is actually not available for the measures. It will be available again in the next future this point and than the measurement will restart.





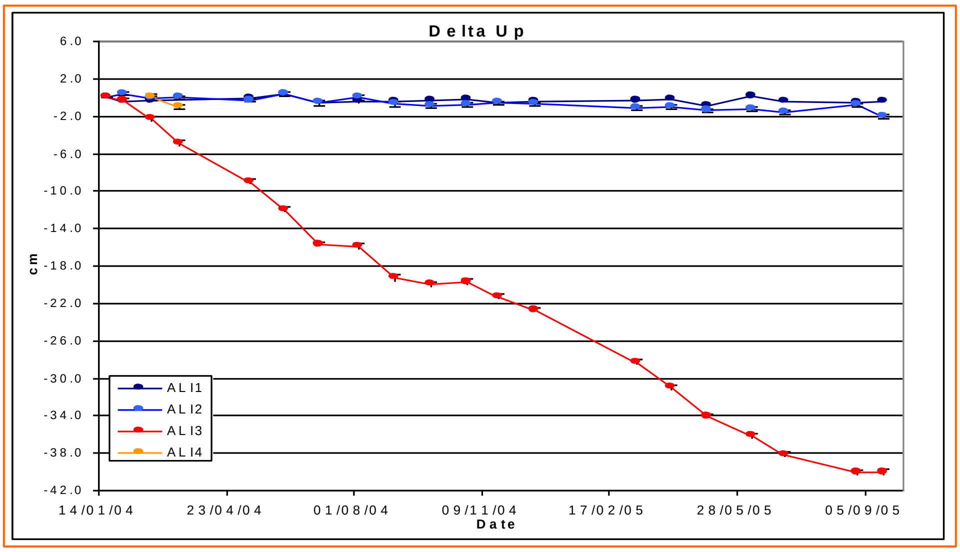


Figure 9. Results in Delta North, East and Up component from Aliano test site

3.2.2 Results at Avigliano site

The geomorphologic evolution of Avigliano landslide (la Braita landslide) is rather complex than Aliano so to allow a better interpretation of the landslide phenomena, careful geo-morphological surveys are carry out periodically (Sdao et al., 2005). The information obtained with these surveys (see fig. 10), cross-checked with the GPS results allow a better interpretation of the evolution of the landslides phenomena.

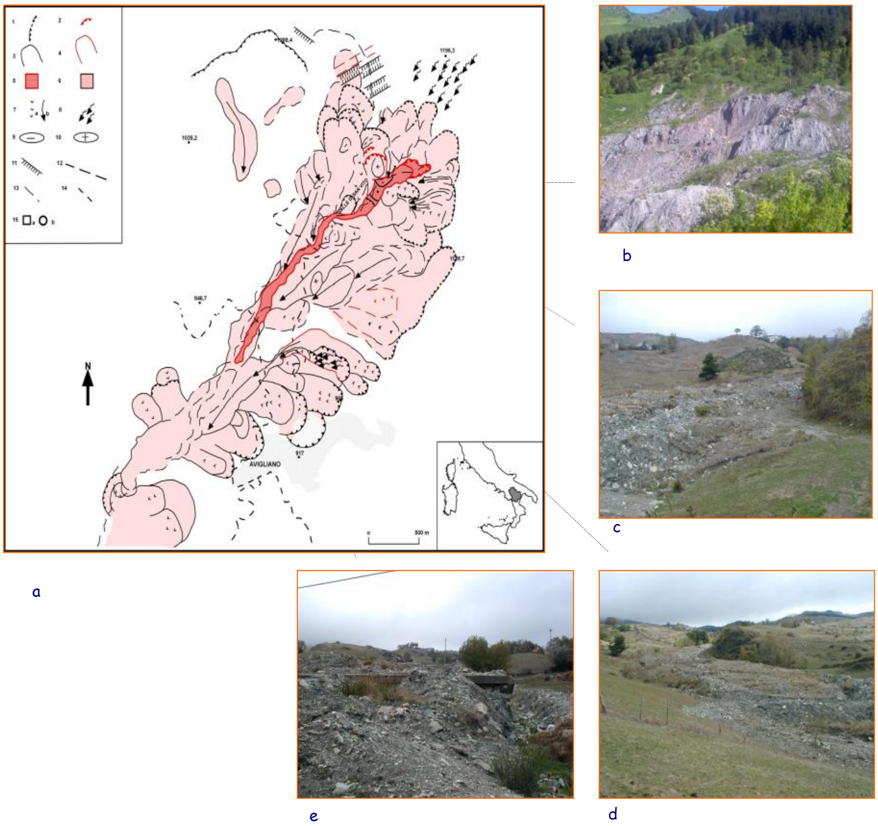


Figure 10: a sketch of the La Braita landslide. Red aera is under investigation. Figure b,c,d,e show the main litological characteristic of the terrain involved in the phenomena and some evidence of the damage caused by the mass movements

Following the approach described in paragraph 3.1 the position of the point AVI0, the reference point for Avigliano network has been estimated for each campaign. The analysis of the AVI0 time series show that it's estimated coordinates repeatability is of a couple of centimetres in the height component and a centimetre in the horizontal ones. As a consequence, only displacement of several centimetres could be taken into account as really representative of landslide evolution. In figure 11 the results of the analysis of GPS data, in terms of Delta North, Delta East and Delta Up component of motion, are shown.

All points show detectable motions in the horizontal component, more evident in the North direction rather than in the East one, except for point AVI3 that show a different behavior. There is no clear evidence of motions in the vertical (Up) component, except, once again, for AVI3 that is the point that shows the clearest evidence of displacement. The behavior of AVI3, located in the central part of landslide area, shows that some displacement are going on, even if the geo-morphologic surveys show no evidence of relevant movements in act along the landslide at present time. So, the detected motion can be considered as a reactivation of the phenomena in the central part of the landslide body.

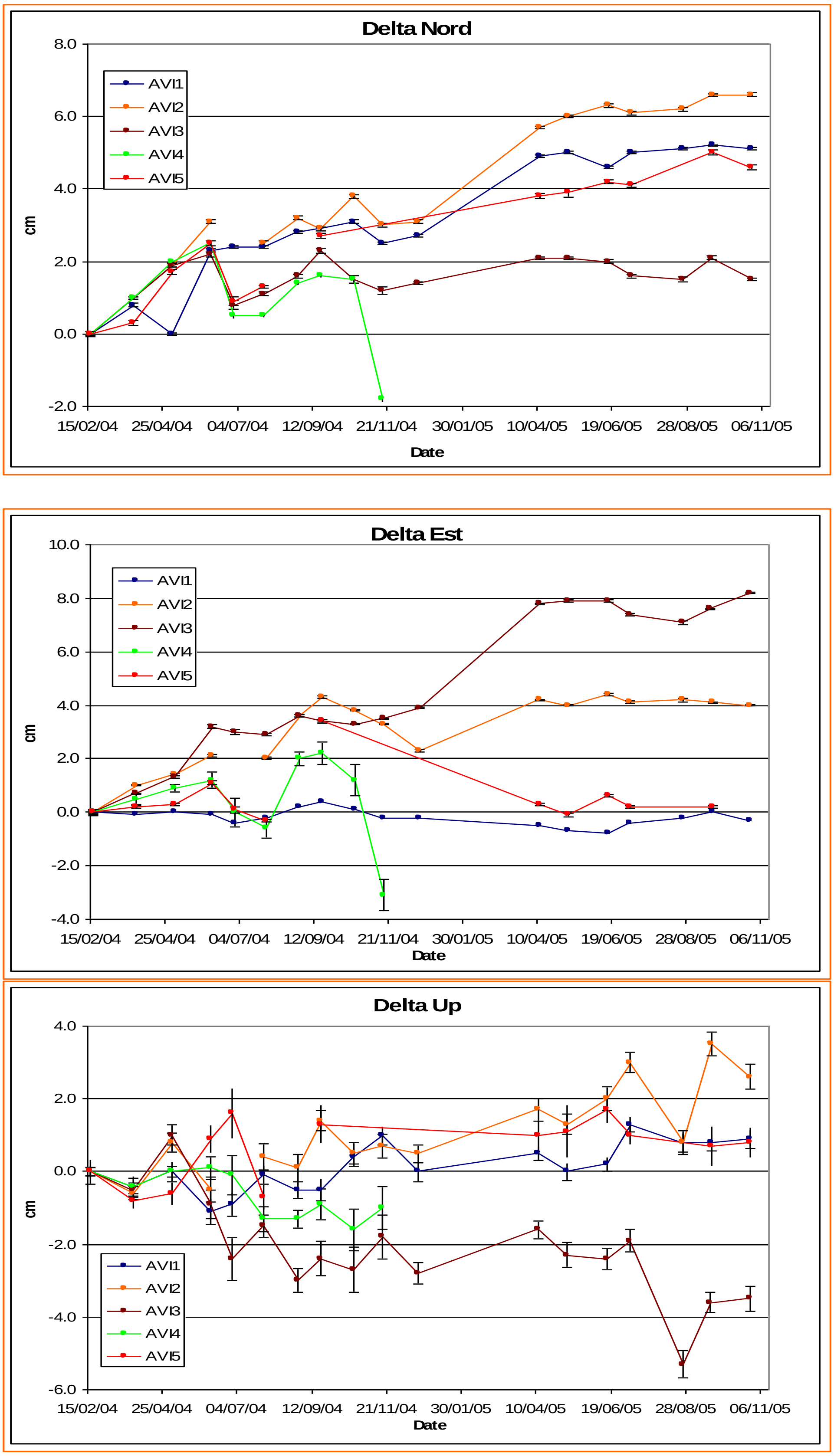


Figure 11. Results in Delta North, East and Up component from Avigliano site

4. ANALYSIS OF MARATEA LANDLSIDES

The Maratea Valley is affected by a large slope instability characterized by continuous slow movements. This area, in the past years, has been subjected to many interdisciplinary studies devoted to a better understanding of the ongoing phenomena that can be identify as a multiple and complex landslide. The different part of the landslide, subjected to different velocities of displacement, in the last years have been affected by frequent reactivations that were the cause of severe damages to the urban structures in the area. The results shown in figure 12 are obtained by Permanent Scatter IN-SAR technique which is useful to detect the time evolution of the vertical ground displacement. The results are show as a map of different part of the landslide identified by different displacement motions.

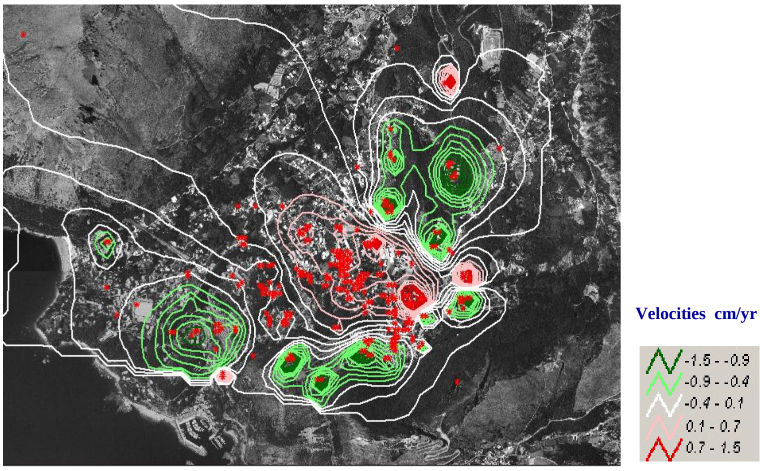


Fig. 12. Velocities obtained form scatter point displacement

In figure 13 the previous results have been compared with horizontal velocities derived by the analysis of GPS data (bleu line). GSP data has surveyed in epoch campaign from 1999 to 2004. The time series of each GPS point of measures have been estimated with respect to a GPS permanent station belong to ASI na-tional GPS perma-nent network. This reference station was placed at the top of the hill above Maratea valley. The yellow arrow shows the mean direction of displacement of the landslides.

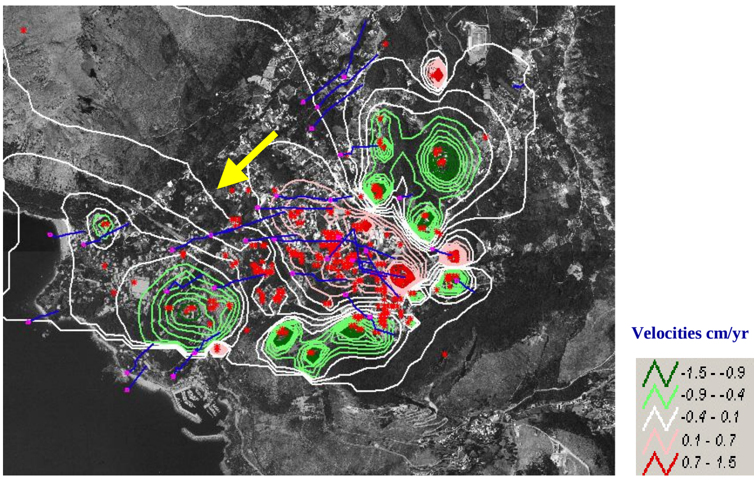


Fig. 13. The blue lines show the displacement velocities obtained by the GPS measurements. The yellow line shows the mean motion of the landslides in Maratea valley

5. GPS REAL TIME POSITIONING

The aim of this experiment is to test the results available in real time in GPS RTK positioning using RTCM corrections available from GPS CORS stations located at different distance with respect to the rover one.
The corrections used are the real-time GNSS RTCM corrections provided by EUREF in the framework of the EUREF-IP service (http://www.epncb.oma.be/_organisation/projects/euref_IP). The RTCM corrections are from Matera, Roma, Cagliari, Torino, Padova e Milano GPS stations of EUREF's EPN network. The corrections are disseminated via Internet and have obtained by means of Ntrip protocol (Internet address above).
In the experiment we used a couple of Leica 1200 GPS System and a portable PC.
From an operational point of view, the adopted procedure is not really kinematics, because the rover station has been kept fixed for each period of measures on markers of well know coordinates. We adopted this measurement scheme because we aim to estimate the accuracy with respect to the base-rover baseline length.
The results show that the precision in 3-D positioning is at few centimetres level if the baseline base-rover is shorter than 10 km and increases up to meter level when the base-rover distance becomes hundreds of km. As synthetically reported in Table 2, the baseline length has no linear effect on the accuracy of the results for distance between few tens of meters up to about ten kilometers.

Baseline (base/rover)	Mean of residuals	STD
> 500 km	~ 100 cm	80 cm
< 50 km	-15 cm	10 cm
< 10 km	~ 10 cm	< 10 cm
< 40 m	~ 10 cm	< 10 cm

Table 2. Mean and Standard deviations of results with respect to the baseline length

When the distance increases, up to 50 km the results get worst. For distance of thousands of km (i.e. baselines between 400 to 900 km) the mean and the associated standard deviations are about 1 m and about 80 cm respectively. These results are directly linked to the observables used in the solutions which is function of the baseline length. For baselines up to about 100 km the differential corrections acts on Phase Pseudorange observables while for grater distance the available observable is the Code Pseudorange.
The results show in figures 14,15,16,17 are examples obtained from different baseline length ranging from few tens of meters up to several thousands of kilometers. The residuals have been obtained differencing, epoch by epoch, the estimated position with respect to the marker coordinates where the rover stations have been placed. The epochs indicated in the graphic of the height residuals are the acquisition epochs of measures.

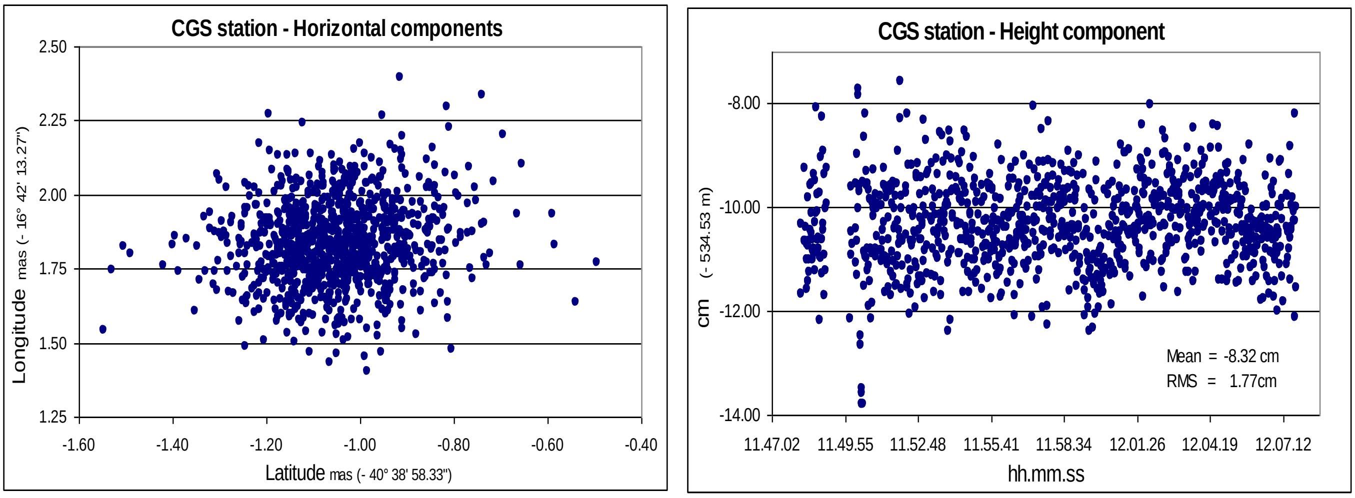


Fig. 14. Coordinate residuals in planar and in height components. The estimate baseline (base to rover station) is about 40 m length

In fig 14, the distance between base and rover GPS station is few tens of meters. The mean values of residuals is less then 2.0 *mas* in Longitude and less than 1.0 *mas* in Latitude; the mean of residuals in height component is about 8 cm. The mean residual value of residuals is about 10 cm in 3-D.

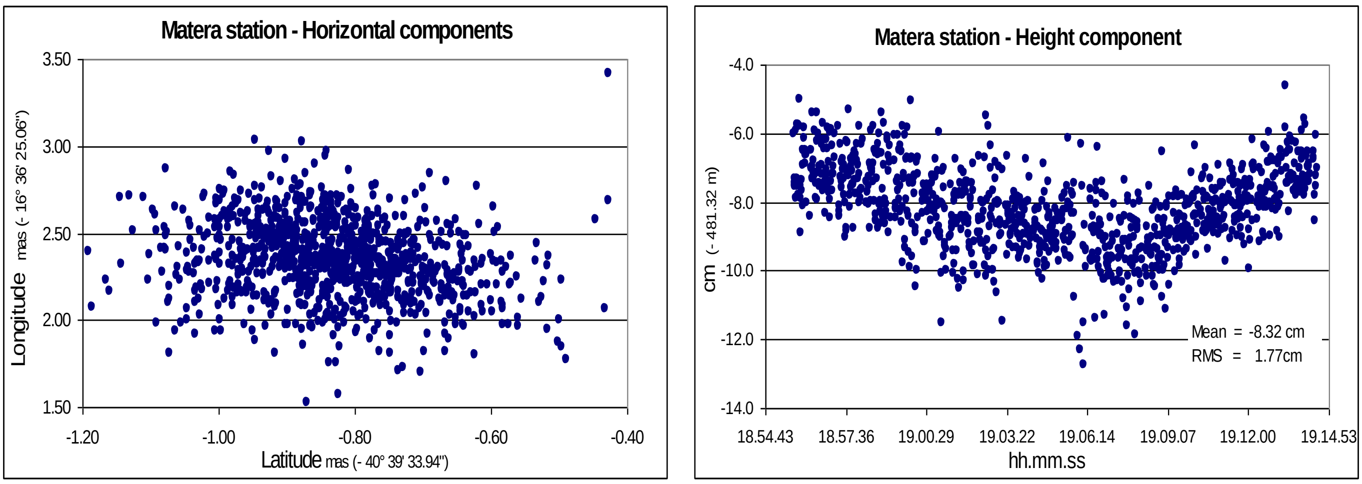


Fig. 15. The results are obtained on baseline of about 10 km length.

In figure 15 the results are obtained on baseline length of about 10 km. In agreement with the results reported in Table 1, the mean of residual value are quite similar to the previous ones, both in planar and in height component. The strange behavior of the height residuals in the middle part of the acquisition interval can be due to the satellite geometry.

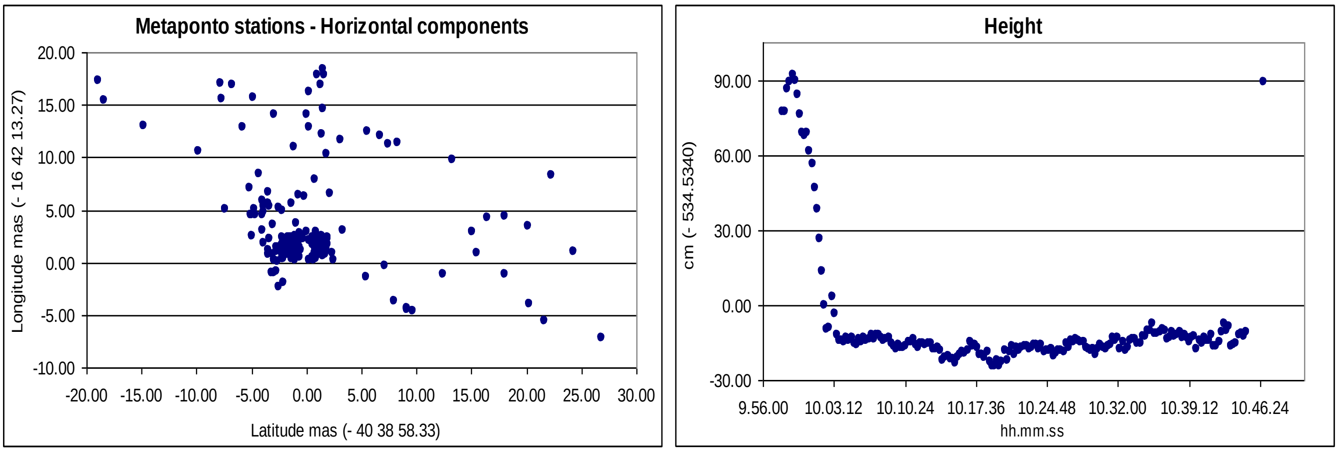


Fig. 16. Residuals from CGS – Metaponto baseline (about 40 kilometers lenght)

The results in figure 16 have been obtained on Matera-Metaponto baseline; the GPS base station was placed at Center for Space Geodesy, while the rover station was in Metaponto, 40 km far away. Looking at the horizontal components of the baseline is clear that the most part of the estimate values are within a range between 0 and 5.0 *mas* in Longitude and –5.0 and 2.0 *mas* in Latitude. The values outside these ranges are acquired at the begin of the acquisition interval, during the initialization time of the GPS station. The same phenomena is detectable in the height residuals, at the beginning of the acquisition the magnitude of the residuals is bigger than the mean. Up to a distance of few kilometers from base station, the time of initialization of GPS rover station, is really short, say 1-2 minutes, but when this distance increases the time needed to initialize the rover station get longer, 5 to 10 minutes. In any case, the mean of the estimate results is about 15 cm in 3-D.

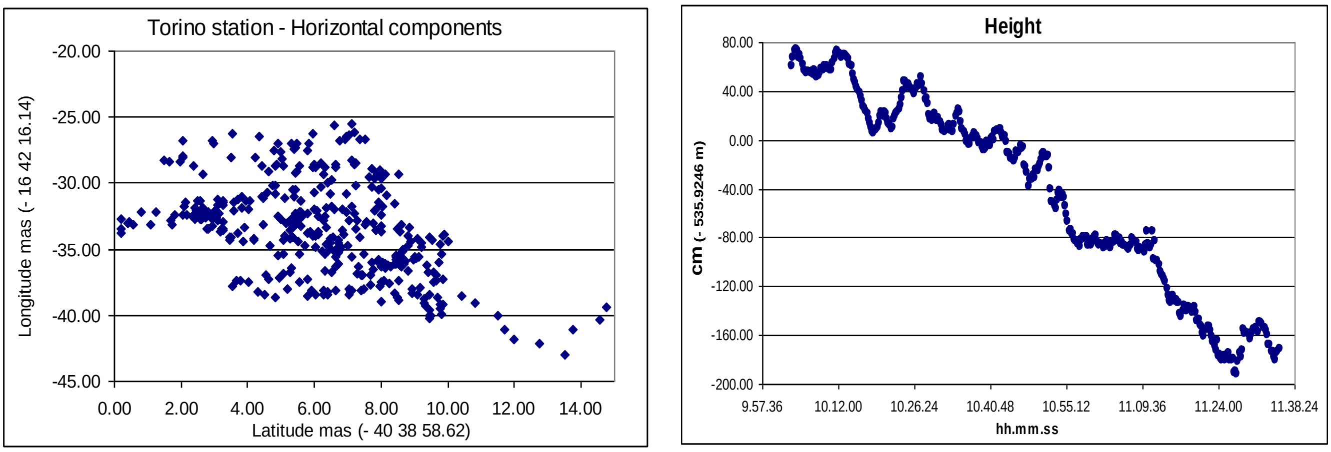


Fig. 17. Residual values calculated on baseline CGS – Torino (about 900 kilometers length)

The results obtained on the baseline CGS – Torino (about 900 km) are really different than the previous ones. The estimated horizontal values are more scattered within a range from 2.0 to 10.0 mas in Latitude and – 25.0 to - 40.0 mas in Longitude, while the height values vary from 80 cm to – 200 cm in an observation time session of about 3 hours. So the quality of these results is strictly linked to the baseline length (about 900 km) that means the availability of Code Pseudorange only as GPS observable, but also to the change in the satellite geometry during the observation session. This last parameter has a great effect in particular on the height determination.

6. STRAIN RATES CALCULATION AND ANALYSIS

In figure 18, the geodetic velocities estimated on a GPS regional network (MAGIC II network), managed by ASI are shown. This is a multi-purpose GPS network devoted to geodynamic analysis, meteorological investigation landslide monitoring and so on. In order to improve the geodynamic information come from the estimate velocities, we compute the strain-rate for evaluating the ongoing deformation in the area. It is well known that GPS stations younger than 2 years haven't a reliable velocity, so we must exclude some stations from this kind of analysis. In figure 18 some examples of strain-rates are shown. The results in figure 19 are obtained using the data of Tito, Matera and Castel del Monte GPS stations. The available data set is longer than two years so this results are quite reliable.

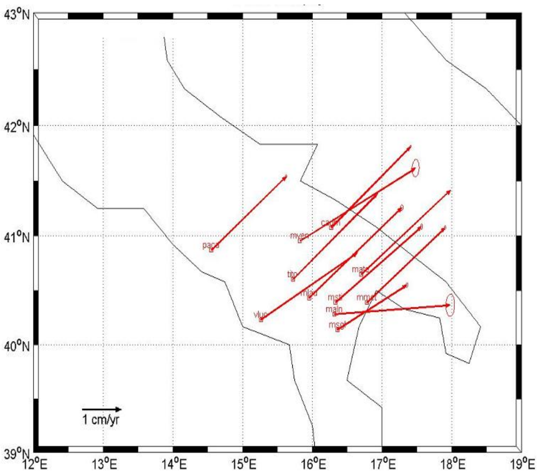


Fig. 18 Velocity field estimated for stations of Magic II network

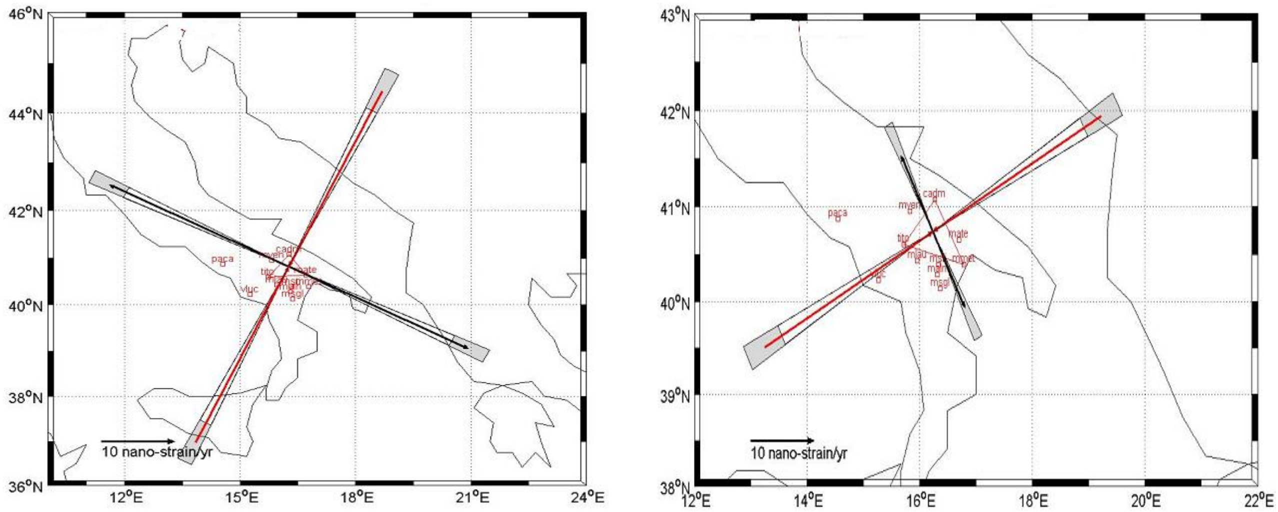
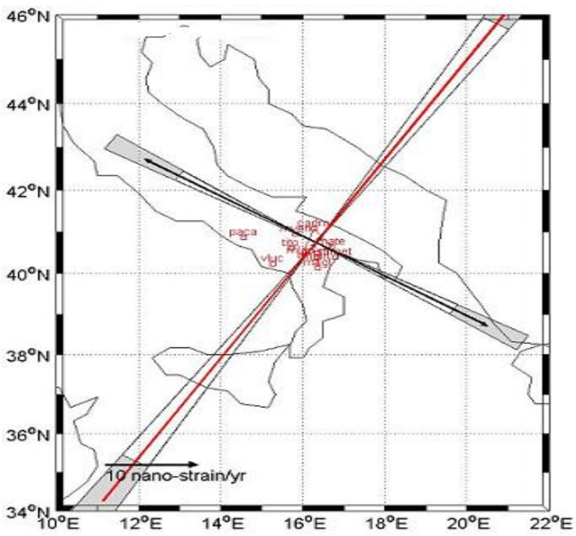


Fig. 18. Strain rate estimated from Tito – Matera - Castel del Monte (left) and Tito – Matera – Metaponto (right)

The estimated nano-strain are in quite good agreement with the tectonic models and the geomorphologic evidence show a compressional regime, roughly directed NE-SW, along the external front of the Appennic chain. Similar results are shown in fig. 18 where Matera station has been substituted by Metaponto station, even if it has a shorter dataset. In fig. 19 the results of Laurenzana, Matera and Castel del Monte are show; the estimated values have to be considered preliminary since Laurenzana GPS time series is shorter than two years. This method of analysis seems to be useful to investigate the tectonic deformations even if longer time series are needed to draw any final consideration.



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