Studying the geodynamics of the Etnean area by means of VLBI and GPS

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Abstract. VLBI (Very Long Baseline Interferometry) and GPS (Global Positioning System) space geodesy techniques can contribute to the study of crustal deformations in the Mediterranean Sea area. In particular, the correlation between volcanic and seismic activity of Mt. Etna and crustal deformations between Noto and Matera stations was analysed.

By analysing VLBI data we obtained the behaviour of the baseline which crosses the Etnean area, from 1990 to 2004, representing the time variations of the distance between the two stations situated on different plates; the linear trend showed a general increasing, pointing out an extension of the crust between them.

VLBI data are very sparse even if the time series was quite long; therefore, to fill gaps in the information, we analysed GPS data. GPS technique performs continuous observations and we were able to highlight both extensions and compressions in details. We compared the baseline Noto-Matera with the volcanic eruptions of Mt. Etna and we found out a relationship between eruptions and the distance between the two stations: it increases before an eruptive event so there is extension between them; on the contrary, during the eruption it decreases, so emphasizing crust's compression. The comparison with the strain release showed that the main seismic release happens during the extension of the crust before the eruptions so it helps the uplifting and the beginning of the event. The uprising of the mantle occurs before the eruptions and it causes the inflated crust lying over it and the volcanic fractures are opened and the magma up rises inside them.

Moreover, this analysis showed that the crustal deformation of Etnean area is characterized by the geodynamics involving the movements of the plates where all the stations we studied are located.

Keywords. Very Long Baseline Interferometry, Global Positioning System, baseline Noto-Matera, Mt. Etna, strain release curve, volcanic activity, geodynamic processes.

1 Introduction

In this work, we have investigated the crustal deformation between the two station of Noto and Matera. The choice of the baseline Noto-Matera is connected to its crossover of the Etnean area. This region undergoes the convergence between the African and European plates; therefore, the geodetic studies of the crustal deformation between the two stations Noto and Matera can give information about the geodynamic processes of this area (see Figure 1).

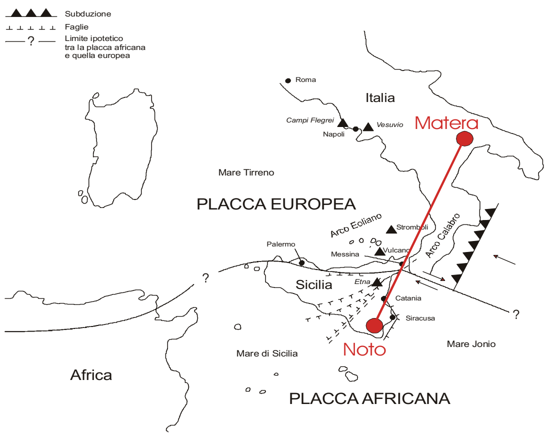

Fig 1 Structural map of the area between Noto and Matera crossing the volcano Mt.Etna. The red solid line shows the baseline Noto-Matera.

The Mediterranean area is constituted by a complex mosaic of plates and micro plates which move each other to arrange the relative movement between the blocks of Africa/Arabia and Eurasia. The Etnean area is an area of convergence between the two plates, Africa and Europe, even if there are some regions of local extension E-O which cause tholeitic and alkaline volcanism of Monti Iblei and Mt.Etna (Barberi et al. (1974)). The two stations of Noto and Matera are situated, respectively, on the Hyblean Plateau of the African plate and on the Adriatic micro plate which is considered by many authors an independent block. Therefore the studies of crustal deformation between the two stations can explain the relative movement and the direction of movement of the plates over they are located. As a matter of fact, progress, in last decades, of the space geodetic techniques (VLBI, SLR, GPS) permits to have precise information about the movement of many sites of Mediterranean Sea.

GPS and VLBI data were processed and the results of their observations were analysed with the purpose of investigate differences in estimated baseline length by both techniques and compare it with the seismic and volcanic activity of Mt.Etna.

15 years of VLBI data acquired within the EUROPE campaign have been analysed to estimate the motion of the stations participating to these experiments. The estimated site velocities and baseline time series are compared to those obtained from the GPS solution, performed in order to have a denser solution. Both the solutions have been expressed in the ITRF00 reference frame in order to compare them in a unique reference system. VLBI coordinates for European stations were obtained from processing of all available experiments collected on European and global VLBI network, GPS data were obtained from processing a regional network acquiring on a daily basis.

2 Geodetic methods

2.1 VLBI data

We have analysed data collected at the stations belonging to the VLBI European network: Noto, Matera and Medicina (Italy), Wettzell and Eflsberg (Germany), Nyales20 (Norway), Onsala60 (Sweden), DSS65 (Spain) and others not very often used, to obtain position and velocity of each VLBI station. All the experiments performed since 1990, when Matera started to record VLBI observations, to 2003, when Matera observations stopped, because of mechanical problems, were selected. The acquired data have been analysed with CALC/SOLVE software package (Caprette et al. (1990)) taking into account the precession's effects, nutation, motion of the pole, UT1, Earth solid tides, ocean loading, polar tides and relativity. By analysing VLBI data we have obtained the time series 1990-2003 of the baseline Noto-Matera (see Figure 2), which represents the time variation of the distance between the two stations; its linear trend shows a general increasing of the length (0.4 ± 0.2 mm/y), thus highlighting an extension of the crust between the two stations.

Looking at baselines Wettzell-Noto and Wettzell-Matera, it's possible to observe that the two Italian stations get nearer to Wettzell; they move with a different velocity from North to South because the African plate drives towards the European plate. Matera moves towards NNE and Noto towards North, with a small component towards West; the geodynamic movements of the two different plates, where the two stations are located, cause these two different directions of movements: Noto is situated on African plate and Matera is situated on Adriatic plate. The movement NNE of the Matera station represents the indentation of the Adriatic plate towards the eastern Alp with a little counter clockwise rotation with respect to Eurasia while, the movement North of Noto, situated on the Hyblean Plateau, represents the convergence between African and European plates and also may be explained by an active extension in the Sicily channel (Mueller et al. (1992); Rebai et al. (1992); Montone et al. (1999)). Therefore, the two different directions of Noto and Matera attest the actual crustal extension between them, according to the geological evidences of the active tectonics in the Calabrian Arc.

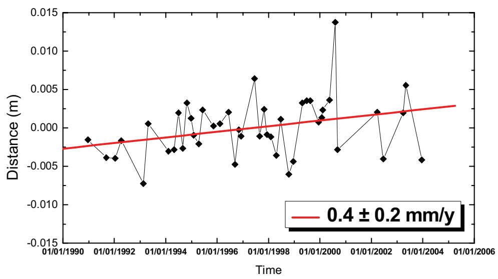

Fig. 2 VLBI baseline Noto-Matera from 1990 to 2003

2.2 GPS data

In addition to the processing of VLBI data, we have computed the daily coordinates of the GPS stations available in the study area, in order to compare, in more detail, the Noto-Matera baseline and the seismic and volcanic activity of Mt.Etna. The regional geodetic network, here considered, was composed of 18 permanent GPS stations: Aquila, Cagliari, Cosenza, Grasse, Graz-Lustbuehel, Elba, Lampedusa, Maratea, Matera, Medicina, Noto, Trapani-Milo, Reggio Calabria, Tito, Perugia, Wettzell, Vallo della Lucania, Zimmerwald; the BPE module of Bernese software V5.0 (Dach et al. (2007)) was used to process the data from 1996 to 2004 to obtain the time series of daily coordinate solutions of the all stations expressed in ITRF2000. IGS final orbits and the Earth rotation parameters have been used; the ambiguities were estimated with the QIF strategy, the estimation of the tropospheric delay for each station was accomplished with the use of Saastamoinen model (1973) and Niell mapping function (Niell (1996)). Absolute antenna phase variations and offset were used (Schmid et al. (2005)). Possible antenna offsets were estimated at discontinuities in the time series related to known equipment change or where a clear discontinuity was observed; moreover, outliers were eliminated.

Thus, by processing of GPS data we have obtained the baseline Noto-Matera. It was carried out a spectral analysis to highlight and thus eliminate the periodic oscillation present within the baseline (annual signal). The linear trend shows, from 1996 to 2004, an increasing of the baseline's length of 0.67±0.01 mm/y, which could mean that an extension of the crust between them occurred (see Figure 3).

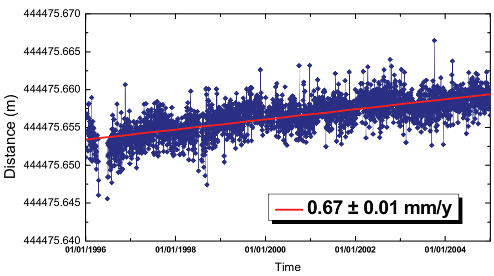

Fig. 3 GPS baseline Noto-Matera from 1996 to 2004.

Moreover, it was computed the value of the displacement, absolute and relative, of each station into ITRF2000 combining together all the daily solutions, at level of Normal Equations. The maps of the absolute and relative velocities (Figure 4 and 5, respectively), in accord with the geological model, indicate the geodynamic movements of the plates. Absolute velocities at all the stations show a movement towards NNE due to the spreading of the Middle Atlantic ridge, while relative velocities show the movement of all the GPS stations respect the reference station of Wettzell which is situated on stable European plate.

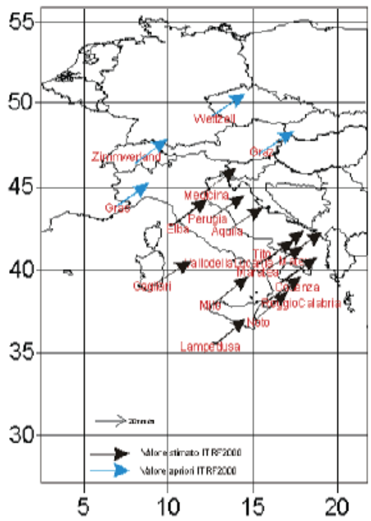

Fig. 4 Map of the absolute movements of the stations into ITRF2000

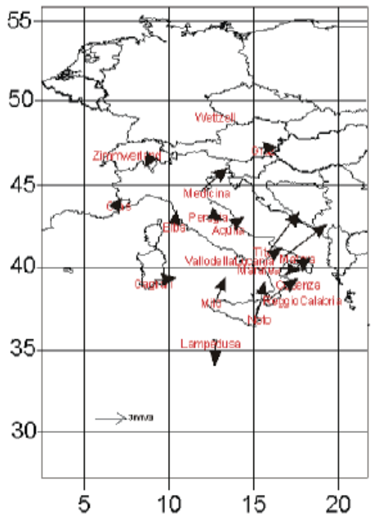

Fig. 5 Map of relative horizontal movements with respect to Wettzell

3 Comparison of geodetic and geophysical data

In this work we have compared the crustal deformations measured by the space geodetic techniques of VLBI and GPS between Noto and Matera stations with the seismic and volcanic activity of Mt.Etna. The two baselines Noto-Matera, obtained with both GPS and VLBI, have a similar linear trend that indicates an increase of the distance between the two stations from 1990 to 2004, translating in crustal extension (see Figure 6). We have compared selected parts of the two curves, noting that, when VLBI registers a crustal extension, the GPS shows the same behaviour; this remark is valid, also, in the case of a compression. Thus, the two curves show the same result even if the magnitude of the displacement is different; actually, the VLBI dataset is poorer than daily GPS observations, because of instrumental problems of the radiotelescopes and especially because of the sparse geodetic VLBI observations, due to the need for radioastronomical experiments.

In the first part of the VLBI curve, from 1990 to 1993, a decrease in the baseline is present and thus, a crustal compression between them coinciding with the eruptive period of Mt.Etna between 1991-1993; however, we cannot make any supposition about the correlation between the crustal deformation and the activity of the volcano in this period because of the very few VLBI measurements and the lack of GPS data to fill the gaps.

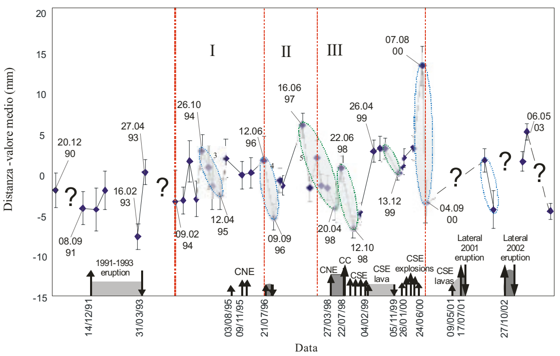

Fig. 6 Comparison of VLBI and volcanic activity of Mt.Etna. At the bottom the arrows show the periods of eruptions

After this first period, it is possible to split up the VLBI curve into three time intervals comparable with the volcanic activity of Mt.Etna: for the first period (02/94-06/96), in which VLBI measures are not statistically significant, it is not possible to point out any movement between the two stations and at the same time there is not any important volcanic event.

The second period (06/96-10/97) is characterized by a sequence of increases and decreases of the Noto-Matera baseline, preceding the third period (10/97-12/2003), when important crustal deformations occurred simultaneously to the sequence of eruptive events concerning Mt.Etna, from 1998 to 2002.

VLBI curve shows two larger values of crustal distension, precisely as regards the measurements of 16/06/97 and 07/08/2000, followed by the strong crustal compression previous and simultaneously to the volcanic activity; this behaviour can be related to the recharge of the volcanic system with the uplift of the mantle and it is followed by the eruptive activity. In fact, the strong distension, present in the second period of VLBI curve, which causes the uplift of the mantle, is the prelude to the compression in the third period when, from 1998 to 2000, there is a sequence of eruptive episodes with the material coming from superficial regions of the volcanic edifice.

Another distension, measured on 07/08/2000 causes a new recharge from the mantle originating the next important volcanic period with the two lateral eruptions of 2001 and 2002. This behaviour of crustal deformation can be explained by a model here proposed: the eruptions are preceded by the uplift of the mantle that determines a bulge of the overlaying crust; the crust is fractured and the magma up rises within the cracks, thus inducing the distension of the crust and then the eruptions. During the eruptions, on the other hand, the crust under the volcanic area is affected by the compressions because the increase of the erupted magma volume cannot be balanced from underneath and so the volcanic system collapses and the fractures close. VLBI data from 2001 and 2003 are very sparse, thus the correlation with volcanic activity occurred during the two important eruptions of 2001 and 2002 is not feasible, in detail.

In order to have a better knowledge of the correlation between geodetic and geophysical observations, GPS daily data are used to study the processes of crustal deformation occurred during these two eruptions (see Figure 7). As a matter of fact, GPS data are able to point out the movements between the two antennas: the crustal extension is recorded before the two eruptions and the decreasing of the baseline, that means the crustal compression, is recorded during the eruptions in according to the proposed model.

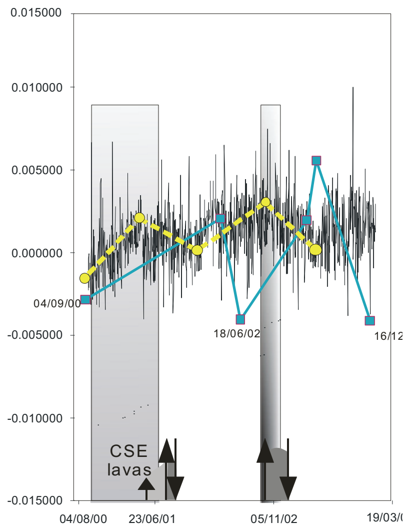

Fig. 7 VLBI baseline (solid blue line) and GPS baseline (dashed yellow line) compared with the eruptions of 2001 and 2002

Correlating VLBI data and the strain release, the larger seismic release is recorded during the distension preceding the eruption because of the opened fractures and the magma up rising easily within them.

As a further outcoming of this work, the vertical components (Up) of the topocentric coordinates of the two GPS antennas located at Reggio Calabria and Noto, the two stations nearer to the volcano, therefore mainly influenced by the geodynamic processes, and the crustal deformations measured with VLBI have been correlated. It's possible to show that, during the crustal extension before an eruption the Up components droop because the magma bulge up rises under the volcano system, while the lateral area undergoes a collapse; during the crustal compression, on the contrary, the Up components increase due to the collapse under the volcano system.

Previous works about GPS-based deformations of Mt.Etna (see e.g. Bonaccorso et al. (2004)), have demonstrated the volcano edifice is characterized by an inflated phase before erupting, while, during the eruptions, the volcano system is deflated in association with the outflow of magma.

4 Discussion and conclusion

The study of the crustal deformations in the Etnean area is inserted in a complex geodynamic setting because of the interactions between the different structural domains in which is divided the central Mediterranean Sea. Therefore, the geodetic measurements are aimed at researching the boundary between Eurasia and Numibia plates to suggest a geological arrangement of the Etnean area. The velocity vectors of the stations, belonging to the regional network, have been estimated by means of GPS technique. The results show the deformation along the boundary of the plate, which is different according to the lithospheric structures. The stations' movements showed in the velocities maps are congruent with the movement of the plates where they are located: from Sicily channel to Calabria and then Puglia, the movement's directions rotate towards East from African plate to Adriatic plate. Lampedusa station drives towards South with the effect of the spreading of Pantelleria ridge, which is also the responsible for the movement of Noto station towards North. All the stations near the Tyrrhenian edge undergo the Tyrrhenian extension and the subduction of the Ionian lithosphere with the roll-back of Calabrian Arc. Matera and Tito stations, which are located on Adriatic plate, show a movement NNE in accord to the geological models that consider the Adriatic plate an independent block from the African plate rotating anti-clockwise. (see Figure 8) (Anderson and Jackson (1987); Westaway (1990); Favali et al. (1993); Console et al. (1993); Oldow et al. (2002)).

Therefore, these studies about the correlation of the VLBI and GPS data with the seismic and volcanic data of Mt.Etna have showed that the crustal deformation of the Etnean area is inserted in a geodynamic contest which determines the movement of the stations, related to the plates over they are located.

The correlation among the crustal deformation between the two stations Noto and Matera and the seismic and volcanic activity of Mt.Etna has proved that the length variation of the baseline Noto-Matera is connected to the eruptive periods. Thus, it was proposed a dynamic model to explain the volcanic processes occurring during the crustal deformation and to connect the Etnean activity with the geodynamic processes involving all the area between Noto and Matera.

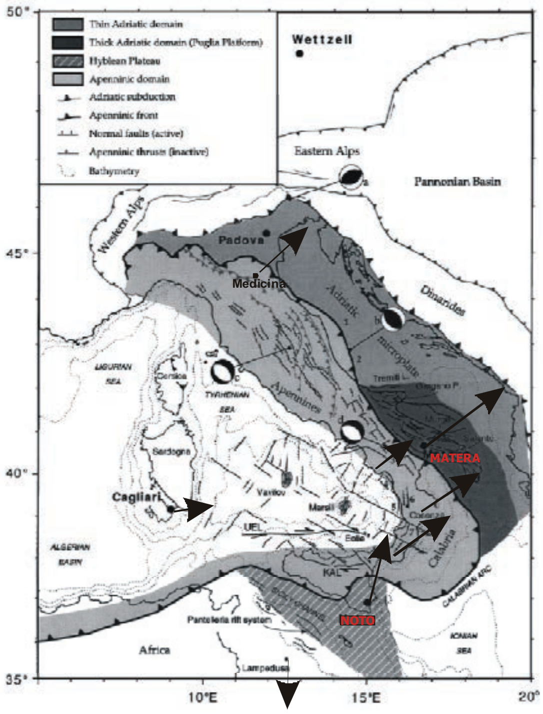

Fig. 8 geological map of Italy and relative movements of the Italian stations

Further GPS and VLBI data will be analysed in order to improve the proposed geodynamic model and to verify if the correlation between crustal deformation and Etnean activity will be still present.

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