Determination of the deformation style and state of stress of the Calabrian Arc

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Introduction

During the last year, the researches of the four RU involved in this project were strictly co-ordinated in order to properly define the investigations aimed at estimating the deformation style of the Calabrian Arc. As stated in the project, this analysis has been carried out both on a regional and on a local scale. The main goal of this research is to integrate, at these scales, geophysical and geodetic models in order to properly define interactions between the two disciplines. As it is well known, geodetic observations based on GPS can give valuable information which can be used to refine geophysical models. Furthermore, contacts were taken with other research groups involved in the GNDT project (namely the group which is co-ordinated by Amato) to share investigation techniques and to start defining a stricter co-operation on common scientific problems. This project was also carried out in strict contact with the Calabria Regional Authority which has shown a strong interest in such a research. Due to that, it was possible to plan the realisation of a new GPS permanent station close to Crotone, which will be monumented and handled by the Calabria Regional Authority.

The 2002 scientific activities

In details, the geodetic side of the project, which was developed by the Politecnico di Milano and the University of Trento RUs, was mainly focussed on methodological aspects. Deep investigations were performed on the impact of the Phase Center Variation (PCV) of the GPS antennas on precise positioning. There is a strong debate in the GPS geodetic community on PCV and its impact on high precision positioning. Particularly, this is of great relevance in non-permanent GPS networks where antenna changes on points can occur from one campaign to the other. So, it is extremely important to quantify possible baseline variations induced by antenna mixing.Currently, the UNAVCO PCV parameters (http://www.ngs.noaa.gov/ANTCAL/) are used: they are the so called “relative” PCV parameters, so named because of the technique which is used in defining them. Recently, the GEO++ firm estimated, according to a new method, the so called “absolute” PCV parameters (http://anton.geopp.de/gnpcvdb/) which are also azimuth dependent (this is not the case when using “relative” parameters which are only elevation dependent). To test the quality of these two sets of parameters, an experiment was properly set up. A very short 4 m baseline was monumented on a stable concrete structure on top of the Politecnico di Milano. Forced centering for two antennas were realised to avoid disturbances related to antenna mount.

With such a short baseline, the impact of spatial correlated phenomena (e.g. the residual tropospheric effect) is negligible and baseline variations can be directly related to antenna changes. During the whole experiment period, one antenna was keep fixed (a MICROCENTERED L1/L2 TRIMBLE) while different antennas were

mounted on the other end of the baseline. Three different MICROCENTRED L1/L2 TRIMBLE and one COMPCT L1/L2 TRIMBLE were tested. For each antenna couple, observations were carried out for four consecutive days: data handling was performed using the Bernese 4.2 software both using “relative” and “absolute” parameters. It turned out that “relative” parameters have worse performances than “absolute” parameters when mixing antennas of different type. In-fact, no significant baseline variations were seen when using MICROCENTRED antennas both with “relative” and “absolute” parameters. On the other hand, significant variations (up to 5 millimetres in the Z component) were estimated when mounting the COMPACT antenna and processing data with “relative” PCV parameters. However, in the same configuration, this discrepancy vanished in processing the baseline with “absolute” PCV parameters. So, from this preliminary test, it seems that for high precision non-permanent GPS networks antenna mixing can be done only by processing the data with “absolute” PCV parameters. Naturally, this is only a very limited test which will be soon extended to other antenna types such as ZEPHYR GEODETIC TRIMBLE and a second COMPACT L1/L2 TRIMBLE antenna.

Furthermore, the Politecnico di Milano UR actively promoted a research which aims at defining the impact of temporal correlation in permanent GPS station daily solutions. It is known that daily solutions display auto and cross-correlations between X, Y and Z components. This can be verified by directly estimating empirical auto and cross-covariances. In such a way, one can show that correlations exist up to ten-fifteen days. Usually, these correlations are negleted in estimating weekly solutions or in computing linear trends in adjustment procedures.

This lead to an over estimation of the solution precisions which are too optimistic. In the framework of the GNDT project, the Politecnico RU, in co-operation with “La Sapienza University” and INGV, defined an original method to properly consider these correlations (R. Barzaghi et al., 2002). A test experiment was carried out in this context taking three years data (1998, 1999, 2000) from four ASI permanent GPS stations, Matera, Cagliari, Noto and Medicina. Daily coordinates of Matera, Noto and Medicina were computed by fixing the ITRF97 coordinates of Cagliari. Daily baselines were estimated in an homogeneous way using the QIF Bernese 4.2 procedure. After a three year de-trending, empirical auto and cross-correlations were estimated and then fitted with proper model functions. As a first step, only auto-correlations were considered because including cross-correlation implies a further step which, for the moment, cannot be completely performed. Nevertheless, it can be seen that the impact of auto-correlations only is relevant since the st.dev. of the estimated quantities are larger than the corresponding values obtained by neglecting correlations. As an example, we can consider the estimated velocity parameters (in terms of North, East and Up local component) of the Matera station in 1998 and 2000 (1999 estimates are biased due to an antenna change).

	1998 estimates (no correlations)	1998 estimates (with correlations)	2000 estimates (no correlations)	2000 estimates (with correlations)
$V_{North\ (mm/y)}$	15.7±0.8	16.1±1.3	17.2±0.7	16.3±0.9
$V_{East\ (mm/y)}$	18.6±0.8	15.4±1.4	19.8±0.7	18.6±1.1
$V_{Up\ (mm/y)}$	3.4±3.4	3.4±1.4	0.1±3.1	2.1±1.1

As one can seen, velocity st.dev. estimated without auto-correlations are very small in the planar component and much more relevant in the Up component. The behaviour of these st.dev. is remarkably different if auto-correlations are taken into account because the st.dev. are much more homogeneous in the three components. So, this research seems to be promising: in the future, an effort will be made in order to include also cross-correlations to have a rigorous stochastic model for the adjustment procedure used to estimate velocity parameters.
Finally, as mentioned before, a new permanent station will be monumented in Calabria, close to Crotone (see Fig. 1). The GPS site was selected in strict co-operation with the RUs of the University of Milano and Trieste. This GPS permanent station will be realised according to the highest standards, mounting the antenna on a concrete pillar based on solid rock (in the area rock is 1 to 2 m below ground level). Furthermore a high precision levelling network will be realised to monitor possible deformation in the area surrounding the GPS site, as it has also been done around the permanent GPS station in Nocara. This is performed to detect local instabilities which must be separated from the geodynamical signal.

Figure 1. The permanent GPS site in Crotone.

Also, during the second year of the project, geophysical investigations were carried out by the Trieste University RU to better define the lithosphere-asthenosphere system in the Calabrian Arc region (including Southern Tyrrhenian and Ionian Seas), and to compare the results with the main geodynamics models and the geological, geochemical and petrological data available in literature.
Dispersion curves of group and phase velocities contain much information about the velocity structure of the crust and upper mantle, thus the surface-wave tomography is performed using the algorithm developed by Yanovskaya and Ditmar (1990). 2D maps (discretized by a 1°x1° grid) of the dispersion data are obtained for the period range from 10 sec to 100 sec. Each 1°x1° cell is characterized by a mean distinctive dispersion curve of group and phase velocities. The cellular inversion in the sampled

area is performed. In such a way, mean cellular structures, each one associated to a cell, are defined. To give a comprehensive interpretation of the obtained elastic lithospheric properties in the Italian region, recently proposed geodynamic models and petrological and geochemical studies about the Plio-Quaternary Italian volcanic provinces are considered. In the central area of the Southern Tyrrhenian Sea a very shallow Moho and a very low V_S, just below a very thin lid, are found in correspondence of the huge volcanic bodies (Magnaghi, Marsili and Vavilov) in the basin, with the V_S in the lid being quite large in the area that separates Marsili from Magnaghi-Vavilov Seamounts.
In correspondence of the Aeolian Islands, Vesuvio, Phlegraean Fields and Ischia, of Etna, a “mantle wedge”, which represents their shallow-mantle magma source, in the uppermost mantle is detected. In the Etna this layer is consistent with the hypothesis of the presence of an asthenospheric window feeding the volcano.
In the Calabria region a lithospheric doubling is a very clear feature, as well as the subduction of the Adriatic-Ionian lithosphere underneath the Vesuvio and Phlegraean Fields, and of the Ionian lithosphere, towards Northwest, below the Southern Tyrrhenian Sea. In the Ionian lithosphere a relatively low velocity layer, which could be the result of the serpentinization of peridotites during the Jurassic extensional phase, is present.
The main results are summarized in the following figures, where 3 sections are considered.

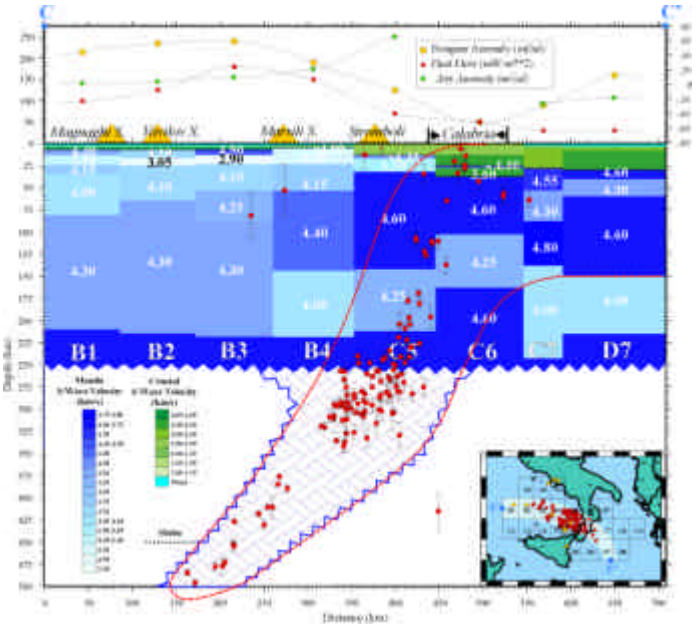

Figure 2. The vertical section along CC’, extended to 500 km. The shallow, intermediate-depth and deep seismicity, with the depth error bar as given in the ISC catalogue is plotted. The events fall into a band (the light-blue one in the insert), about 100 km wide, centered on the line CC’. The red dashed line outlines the downgoing slab. The mean values of the heat flow (Della Vedova et al., 1991; Mongelli et al., 1991), of the Bouguer anomaly (Marson et al., 1995) and of the Airy anomaly (Bowin et al., 1981) are plotted in the upper part of the figure (the italic scale, on the right, is for the Airy anomaly). From East to West the triangles delineate, in the order, the position of the volcanic edifices of Magnaghi-Vavilov, Marsili and Stromboli along the section. In the insert, the location of all the active volcanoes in the Tyrrhenian area is shown.

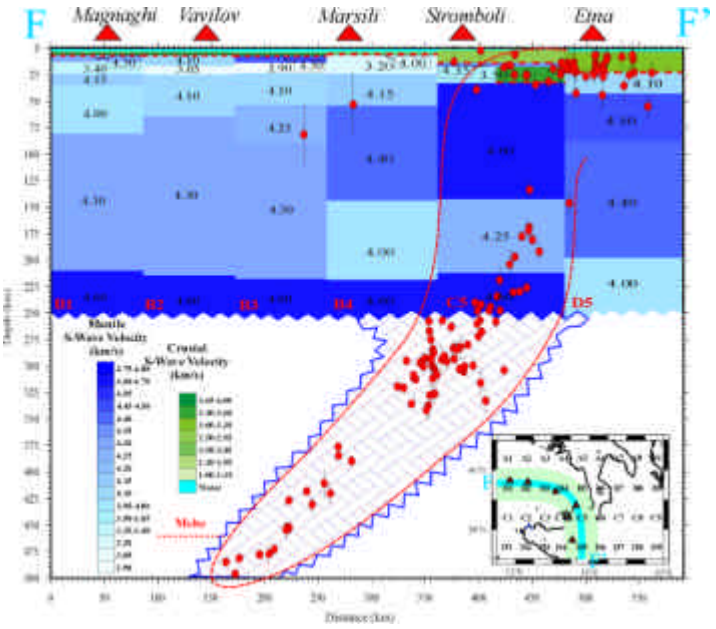

Figure 3. The vertical section along FF', in the insert, extended to 500 km. The shallow, intermediate-depth and deep seismicity, with the depth error bar as given in the ISC catalogue is plotted. The events fall into a band (the light-blue one in the insert), about 100 km wide, centered on the line FF'. The red dashed line outlines the downgoing slab. Part of the "Janus" layer in cell C5 is assigned to the crust and part to the mantle on the base of seismicity distribution. From east to west the triangles delineate, in the order, the position of the volcanic edifices of Magnaghi-Vavilov, Marsili, Stromboli and Etna along the section. In the insert, the location of all the active volcanoes in the Tyrrhenian area is shown, and by red triangles those crossed by the line FF'. The picture well reproduces the main features in the sketch proposed by Doglioni et al. (2001).

Finally, the RU of the University of Milano focused the research on the general study of the back arc retreating during the subduction of oceanic lithosphere and on the geophysical modeling of the deformation rates responsible for the seismicity near the principal subduction regions. The aim is to apply the methodology of this general study to the case of the Calabrian Arc, where the lithosphere seems to retreat due to a purely gravitation subduction of the lithosphere into the asthenopheric mantle, with the purpose of a correct interpretation of the geodetic deformation retrieved by the new permanent and non-permanent GPS stations installed in the area of Calabrian Arc.

During this first phase the UNIMI research unit used bi-dimensional finite elements models, in vertical section, to study both the purely gravitational retreat of the back arc and the style of deformation in the mantle wedge below the overriding lithosphere. The deformation of the lithosphere-asthenosphere system during subduction is obtained by solving the coupled system of equations for energy and momentum equilibrium for an incompressible fluid, with temperature dependent viscosity.

The comparison between model predictions and observed data, with respect several observable, such as heat flux, gravity anomaly and topography, in proximity of the trench allowed to define a general reference thermo-mechanical model for oceanic

subduction that could be used for the application to the Calabrian Arc, planned for the second year of the project.

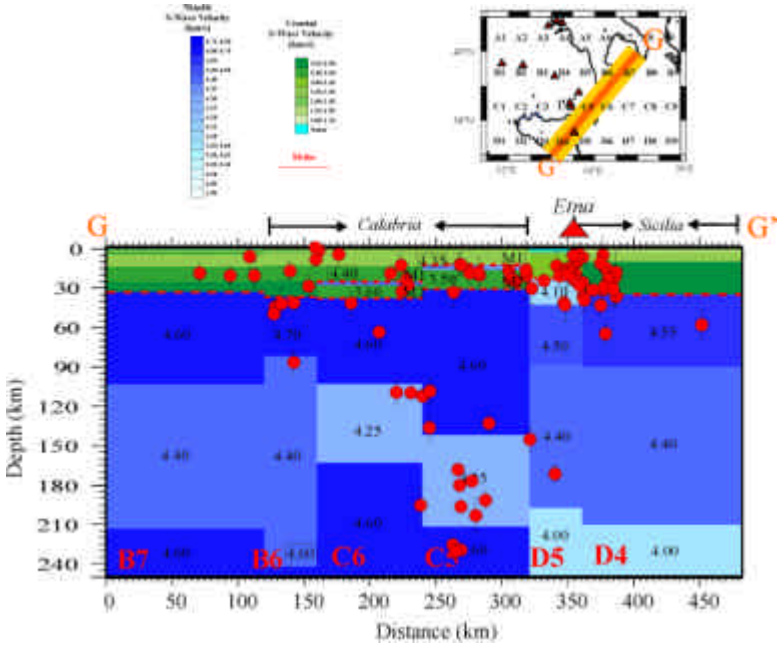

Figure 4. The section along GG'. The shallow, intermediate-depth and deep seismicity, with the depth error bar as given in the ISC catalogue is plotted. The events fall into a band (the yellow one in the insert), about 100 km wide, centered on the line GG'. The triangle indicates the position of Etna. In the insert, the location of all the active volcanoes in the Tyrrhenian area is shown. The picture well reproduces the asthenospheric window in cell D5, in correspondence of the Etna volcano, present in the sketch proposed by Gvirtzman and Nur (1999) but excludes the questioned mantle flow indicated east of Calabria.

This general study supports the crucial role of the back arc retreat in the subsequent deformation style of the subducted lithosphere, at both shallow and deep depth. Particularly, the surficial back arc retreat converts in a decrease of natural verticalization of the subducted portion of the lithosphere, with consequent important impact n the topography, surface gravity anomaly and stress distribution.
The research activity of the first year of the project resulted in two thesis, one already discussed during the accademic year 2001-2002 (Title: Modellizzazione termomeccanica della deformazione litosferica profonda in corrispondenza delle regioni di subduzione e implicazioni sul regime dello sforzo superficiale; student: Catia Rizzetto) and one still ongoing (Title: Effetti della subduzione sul campo di gravità superficiale. Applicazione all'Arco Calabro; student: Elisa Spelta), and two manuscripts submitted for publication on international peer review journals:

Conclusions

During the second year of the project, the geophysical structure of the Calabrian Arc was deeply investigated and modelled.
The estimated models will be then tested against GPS deformation pattern which will be derived both from permanent and non-permanent GPS networks.
Furthermore, a new GPS permanent station in Crotone will be soon operating together with the two existing stations of Nocara and Piano Lago (CS), allowing the definition of a more refined geodetic deformation model of the entire Calabrian Arc.
GPS data analysis was also deeply investigated in order to get reliable and stable results. Particularly, the impact of PCV pattern was successfully analysed to improve repeatability: improvements were obtained by using "absolute" PCV parameters instead of "relative" ones. Finally, proper stochastic models were tested to account for correlations in GPS permanent station data in order to correctly estimate deformation rates.

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