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TYRGEONET: a global positioning system geodetic network for the geodynamical survey of the Italian peninsula

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Abstract

The Italian region exhibits a complicated geological and geodynamic setting resulting from the broad-scale collision between the African and Eurasian continental plates and from the dynamics of the Tyrrhenian Sea opening.

The TYRrhenian GEOdetic NETwork (TYRGEONET) was set up by the University of Bologna, the Istituto Nazionale di Geofisica and a group of institutions from several countries with the purpose of monitoring crustal deformations patterns of the Italian region through repeated GPS (Global Positioning System) geodetic surveys. This technique supplies high-precision measurements of over 100 km long baselines, and therefore represents a powerful new tool for investigating both regional stress fields and the evolution of more localized tectonic events. A dense network was first established to provide a basic framework for the interpretation of regional and local movements. Some of the TYRGEONET stations belong to previously established local networks measured using both terrestrial and space geodesy techniques.

Two TYRGEONET campaigns were performed between 1990 and 1991. The first was performed in June 1990, when 33 sites in Italy, France and Tunisia, were occupied using 16 dual-frequency and 9 single-frequency receivers (WM-101, WM-102, Trimble and Ashtech). In September 1990 three sites of the fiducial network (Cagliari, Matera, Lampedusa) were reoccupied to improve the accuracy of the measurement of these long baselines.

The second campaign was carried out in June 1991, when the network was extended to Ionian Greece and Yugoslavia. A total of 36 stations were occupied for an observation period of four to ten days using 32 dual-frequency receivers (WM-102; Trimble; Ashetech). In addition to that, 15 stations of the 1990 network were selected for reoccupation. The spacing of the network was reduced in the central Apennines to insure a better coverage of this highly seismic area.

1. Introduction

The TYRGEONET project started operating in 1989 thanks to the cooperation between the University of Bologna, the Istituto Nazionale di Geofisica, other Italian research institutions and istitutions from other Mediterranean countries, such as: the Centre Spatial de Toulose (F), the Institut de Physique du Globe, Paris (F), the Istitut de la Meterologie, Tunis (TN), the Institut Preparatoire Technique du Nabeul (TN), the universities of Ljubljana and Zagreb (YU), and the University of Thessaloniki (GR). The main purpose of this project is to achieve a better understanding of the geodynamical phenomena that are most relevant to the evolution of the Mediterranean by repeated geodetic surveys. In addition to that the TYRGEONET project supports other studies regarding the detection of active deformation in the central Mediterranean.

During the past few years geodetic measurements devoted both to the observation of crustal deformation in seismic areas and to geodynamical purposes were greatly improved by the development of the NAVSTAR-GPS geodetic system.

The NAVSTAR-GPS (Navigation Satellite Timing and Ranging Global Positioning Systems) is a space geodesy technique which allows the computation of differential positions with centimetric accuracy, even on baselines of hundreds of kilometers and in adverse meteorological condition. This technique does not have some of the limitations that terrestrial techniques have, such as the mutual visibility between observation sites (fig. 1).

GPS measurements supply the coordinates of the observation site in geocentric system WGS84 (World Geodetic System 1984). The coordinates are then computed to obtain precise distances between different points. The accuracy of the results obtained through this process is of 10^{-6} or better (0.1 ppm, that is 1 cm over a 100 km baseline) Repeated measurements of the same **networks** may help understanding the geodynamics of seismic areas. GPS networks can also be used to outline the Earth's broad-scale deformation patterns (Achilli and Baldi, 1989; 1991; Dixon, 1991).

The GPS system and organinization is controlled by the Department of Defense (DoD) and the National Aeronautics and Space Administration (NASA) of the United States of America and is divided in three segments: a space segment, a control segment and a user segment (fig. 2). The space segment covers the constellation of Block I, Block II and Block II-R GPS satellites orbitating on six orbital planes with an inclination of 55°. The final configuration reaches 21 operational plus 3 spare satellites. The orbital path is almost circular with a semimajor axis of approximately 26 000 km. The satellites broadcast signals produced by an atomic clock at the fundamental frequency of 10.23 MHz, modulated on two carriers L_1 (1575.42 MHz) and L_2 (1227.60 MHz) and the codes P and C/A. The navigation message is modulated on both the L_1 and L_2 carriers at a chipping rate of 50 bps.

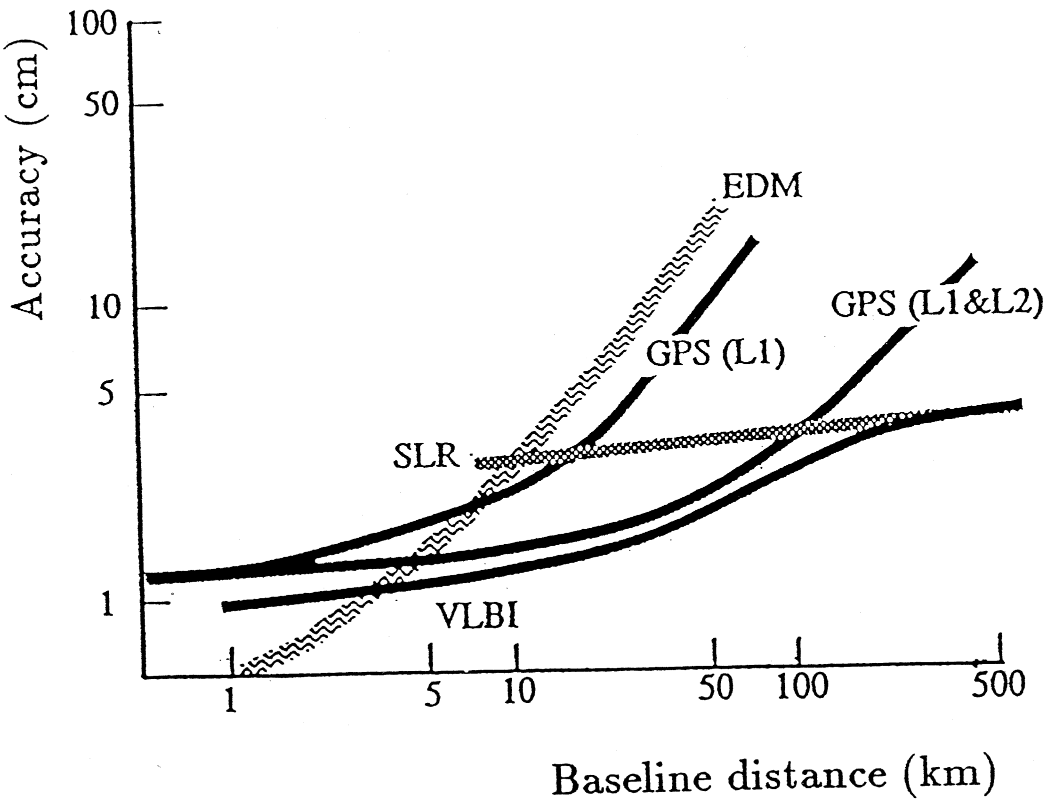

Fig. 1. Accuracy of the geodetic techniques (Wells, 1986).

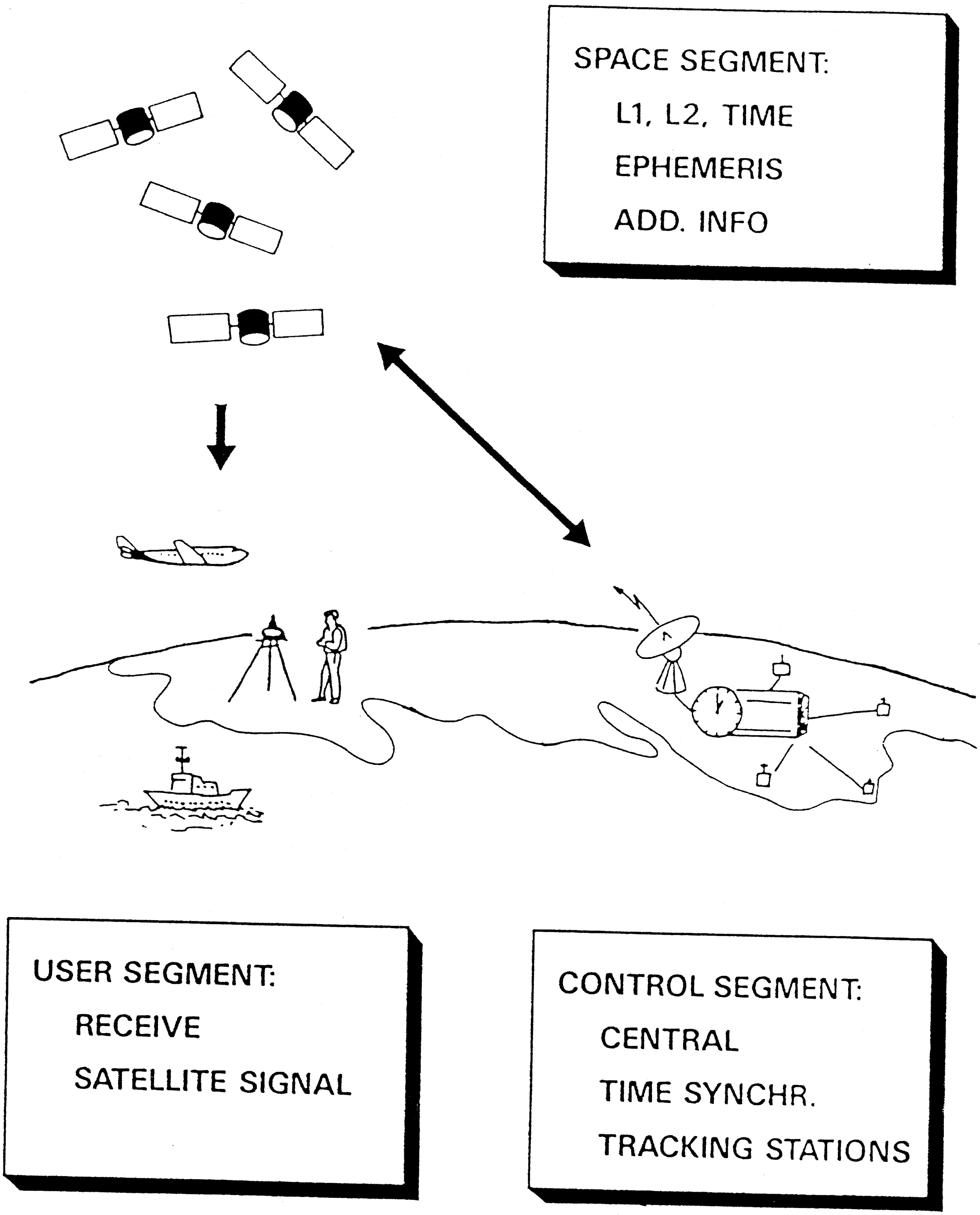

Fig. 2. The GPS system and organization.

After completion of the satellite constellation it will be possible to observe not less than four satellites for every hour of the day, and to compute the four unknowns (latitude, longitude, height and clock correction) yielding the precise coordinates of each observation site in the WGS84 reference system.

The control segment comprises a Master Station located in Colorado Springs (U.S.A.) and some Monitor Stations distributed around the world. The main task of the control system is to compute the satellite orbital data and to control the clocks synchronism and the operational system.

The user segment provides assistance for installing GPS receivers and antennas in the sites to be measured. The receivers record data from several satellites and then compute the position, velocity and time of the observation.

The GPS receivers produce a signal similar to that transmitted by each GPS satellite and subsequently identify the sequence codified on the carriers for each satellite. The phase shift between the incoming signals and the receiver response depends on the distance between the receiver and the satellite.

The GPS code pseudorange type, which corresponds to a ranging measurement, is generally used to obtain low-accuracy absolute positioning for geodetic purposes. Conversely, the use of carrier phase data may yield baseline estimates with an accuracy of 1 ppm or better, using different linear combinations of the two frequencies L_1 and L_2 (table I).

The utilization of different linear combinations of the L_1 and L_2 carriers reduces the effect of ionospheric refraction (L_3), provides solutions that are independent of the clocks and of the geometry of the receiver (L_4), and reduces any unmodelled systematic error (L_5) (Rothacher, 1990).

The GPS data are computed using powerful software packages to obtain the absolute position of individual observers and the distance between them with centimetric accuracy.

2. Geodynamic implications

Among the geodynamic events which mostly influenced the evolution of the central Mediterranean area are the Alpine orogenesis, the rotation of the Sardo-Corso continental block and the Tyrrhenian Sea opening (Scandone *et al.* 1974; Philip, 1987). This tectonic activity results from the dynamics of the Africa and Eurasian plates which contributed to the build-up of mountain ranges all around the Mediterranean since the Upper Cretaceous. Geophysical and geological investigations of the Tyrrhenian Sea bathial plain allowed the recognition of some deformative structures witnessing the extensional stress field that produced the counterclockwise rotation of the Italian peninsula. This observation was later confirmed by paleomagnetic data (Fedi and Rapolla, 1988). This tectonic stress is still in the Mediterranean area and the crustal dynamics results in a strong seismic activity (Udias, 1980). The opening of the Tyrrhenian Sea and the tectonic characteristics of the surrounding areas are a fundamental aspect for the comprehension of the crustal dynamics of the Italian peninsula.

The seismic catalogue of the Istituto Nazionale di Geofisica reports over 30 000 earthquakes

Table I. Linear combination of L_1 and L_2 carriers.

carrier	wavelength	linear combination
L_1	$\lambda = 19$ cm	actual carrier
L_2	$\lambda = 24$ cm	actual carrier
L_3	$\lambda = 0$ cm	iono free $\frac{f_1^2}{f_1^2-f_2^2} \cdot L_1 - \frac{f_2^2}{f_1^2-f_2^2} \cdot L_2$
L_4	$\lambda = \infty$	geometry free $L_1 - L_2$
L_5	$\lambda = 86$ cm	wide lane $\frac{f_1}{f_1-f_2} \cdot L_1 - \frac{f_2}{f_1-f_2} \cdot L_2$

that occurred in the Italian region since the year 1000 B.C. The distribution of the epicenters and the focal mechanisms solution define distinct seismogenic areas. From a geodynamic point of view the southern part of Italy is certainly one of the most interesting regions of the Mediterranean area. In this area earthquakes occur in a wide range of depths, from shallow near the Etna volcanic structure to very deep in the southern Tyrrhenian Sea (Eolian Arc).

The seismicity of southern Italy has been interpreted as a consequence of both the tectonic movements which are still bending the Calabrian Arc and opening the Tyrrhenian sea, and the gravitational deepening of the lithosphere toward the sub- lithospheric mantle.

3. The network

The network is made up of 58 vertices located in Italy and in the surrounding areas (fig. 3). Great care has been devoted to the monumentation and stability of the Tyrgeonet sites by using concrete pillars and ground markers placed on stable rock or on concrete platforms (Satellite Laser Ranging sites). The selected vertices belong to the First Order Italian Geodetic Network of the Istituto Geografico Militare Italiano (IGMI), to the Italian Geomagnetic Network of the Istituto Nazionale di Geofisica and the Istituto Geografico Militare Italiano, and to the Satellite Laser Ranging observation network.

Some of the vertices were selected along a traverse perpendicular to the Apennines (between 41° and 42° parallels) and in the Tyrrhenian area to provide a basic framework for further investigations of the local deformation pattern of Italia seismogenic areas. Two sites were selected in Tunisia and two in France (G.R.G.S. Observatory, Tolouse and Grasse).

The Satellite Laser Ranging sites of Matera, Cagliari, Lampedusa, Grasse, Wettzell and Basovizza were included in the network to be used as fiducial sites for a planned improvement of the orbital parameters of the GPS satellites.

Some of the selected vertices belong to previously established local networks in the Calabrian Arc, Cassino, Aquilano, Colli Albani, Ancona, Cosenza and Lucera areas. Most of these networks are periodically surveyed by terrestrial and GPS techniques to monitor local deformation.

4. 1990 and 1991 surveys

The first GPS TYRGEONET campaign was performed from 25 to 30 June, 1990, using twelve WM-102 and five WM-101 Wild Magnavox, two ASHTECH dual-frequency, two TRIMBLE dual-frequency, and four TRIMBLE single-frequency receivers. These were installed in over 33 stations from 44.0° N to 35.5° S and from 1.5° E to 17° E (Italy, France and Tunisia) and along an Apennines traverse. The GPS observations were then collected during measurement sessions lasting approximately six hours.

In 1991 the network was extended to the Ionian and Adriatic areas by including three stations in Greece and four in Yugoslavia. The number of stations in the central Apennines was increased to achieve a better coverage of that seismogenic area.

During the second campaign, that was performed in June 1991, a total of 36 vertices were occupied for a period of four to ten days using 32 dual-frequency receivers (WM 102, TRIMBLE and ASHTECH). In addition to that 15 stations of the 1990 network were chosen for reoccupation. The GPS observations were collected during measurement sessions lasting approximately eight hours.

Between nine and eleven satellites were observed in each measurement session of both campaigns.

5. Data processing

Data processing was first performed using commercial software packages (PoPs, Trimvec and GPPS) for a quick check of the quality of the observations. The final processing was then carried out using the Bernese V3.2 Software (Rothacher *et al.*, 1990).

6. Observables

Due to the length of the baselines dual-fre-

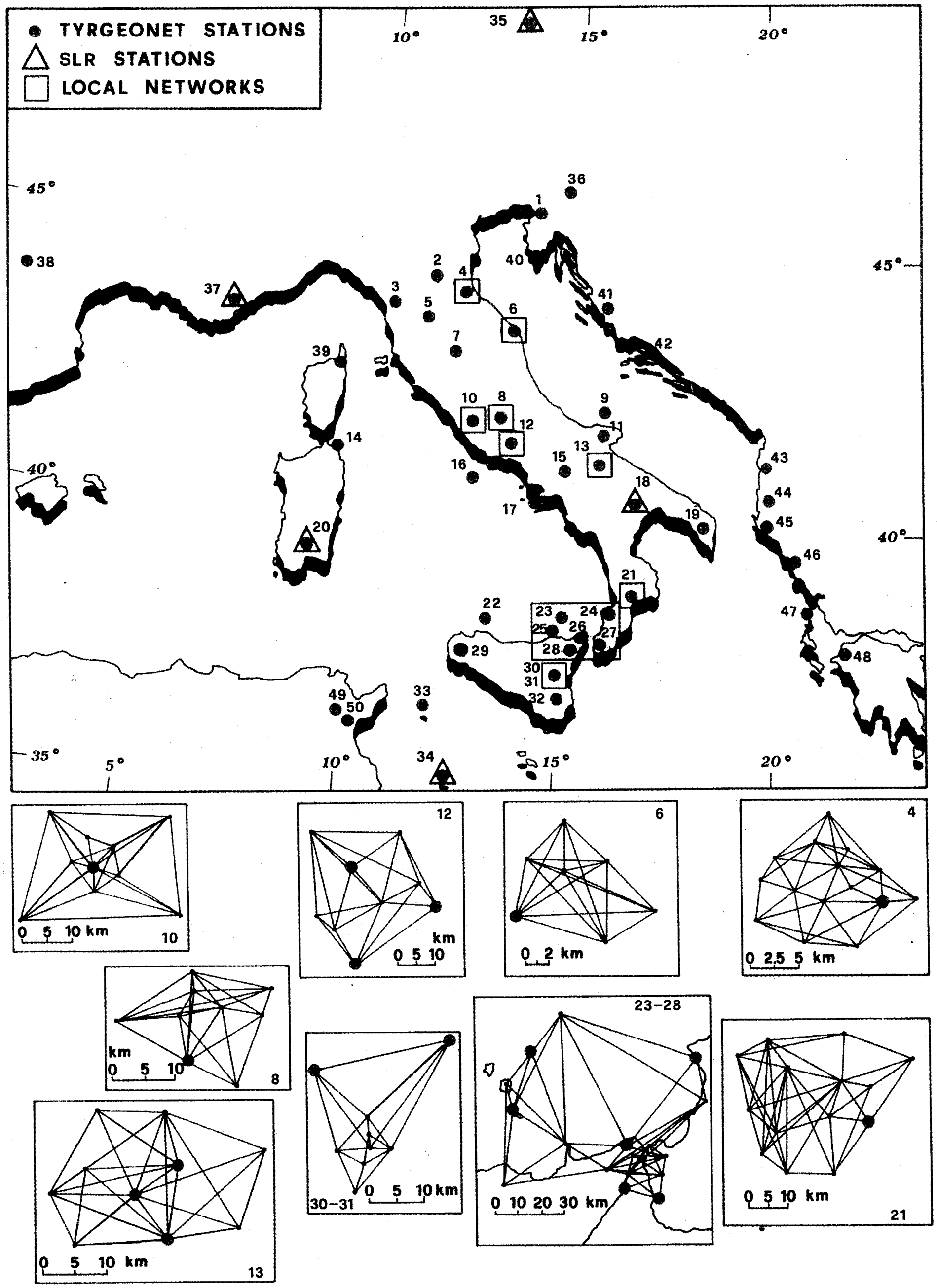

Fig. 3. TYRGEONET vertices and local networks involved in the project: 10 - Colli Albani; 8 - Aquilano; 13 - Lucera; 12 - Cassino; 30,31 - Etna; 6 - Ancona; 23,28 - Arco Calabro; 4 - Forlivese; 21 - Catanzaro.

quency processing was mandatory and the network was adjusted on the carrier phase data using the L3 iono-free combination. The pseudorange codes were only used for the calibration of the receiver clocks with respect to GPS time on the microsecond level. This level is sufficiently accurate for processing double differences. Only observations with elevations higher than 20° were used adopting a sampling rate of 60 seconds.

7. Orbital data

Due to the size of the network the computations had to take into account precise ephemerides (the satellite paths with an accuracy of 20 m or better, derived from *a posteriori* orbital improvement), which were obtained from National Geodetic Survey (U.S.A.).

8. Atmospheric models

Ionosphere: On its way from the satellite to the receiver the GPS signal travels through the atmosphere with a velocity that depends upon the characteristics of the medium and of the signal itself. To obtain more accurate results this effect must be corrected with respect to both the ionosphere and the troposphere ((50÷1000) and (0÷50) km from the Earth surface, respectively). The ionospheric correction was performed using a single-layer model. The correction was computed as a function of the total electron content of layer, the carrier frequency and the elevation angle of the satellites above the horizon. A local ionospheric model for each session of the whole campaign was then derived using the L4 combination as an observable.

Troposphere: The delay due to the troposphere is a function of the frequency of the carrier wave and the temperature and water vapor pressure of the troposphere. A troposheric correction was performed in the computation using the extrapolated standard model of Saastaimonen (1973). The air pressure, temperature and relative humidity were measured by the Italian Air Force Meteorological Service both at the surface and at a height of 5000 m. Although these measurements are available, local corrections for atmospheric refraction have not yet been included in the computation.

9. Ambiguity resolution

Ambiguity resolutions must be taken into account when analyzing GPS data. The ambiguities are the integer number of wavelengths of the observed carrier contained in the distance between the satellite and the two endpoints of the baseline at the time the satellite was first observed. The computation of the number of complete cycles as integer values (resolving the ambiguity) is a desirable step in the computation of the network. In addition to that, the varying length of the baselines, ranging from under 100 km to over 700 km, made it almost impossible to use the same approach for the analysis of all the observations. While longer baselines do not allow the resolution of most of the ambiguities contained in the series of data, for the shorter baselines the ambiguity resolution is in most cases easier. Two different approaches were therefore adopted and the results compared. In SOLUTION A (an L_3-free ambiguity solution) we only computed station coordinates, while in SOLUTION B we also considered and when possible estimated the ambiguity parameters. SOLUTION B was obtained using a multi-step process especially focused on the resolution of the ambiguities. Many iterations were often necessary to obtain a larger resolution percentage. For baselines in the range 100 to 300 km the percentage is generally 80% to 100%. Longer baselines exhibit less than 50% resolved ambiguities.

10. Preliminary results

A small number of selected baselines were carefully analyzed to study tha day-to-day repeatability of the results and a single-baselines/single-session solution was obtained for each day of the campaign (fig. 4). In some instances this procedure helped to detect and eventually improve or reject low-quality observations. One such case occurred on June 30, 1990, when the Matera station stopped working leaving only

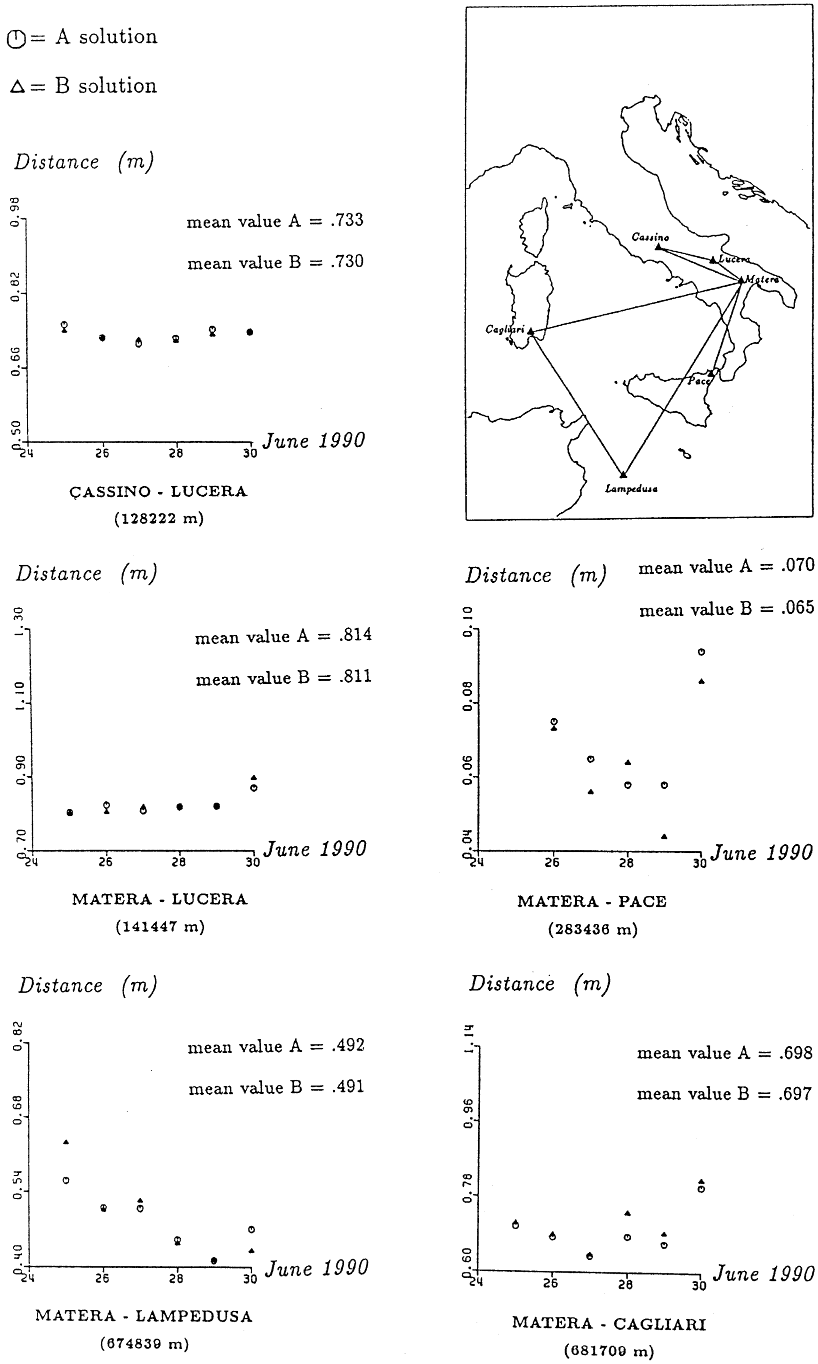

Fig. 4. Daily repeatability on some baselines of the network. June 1990.

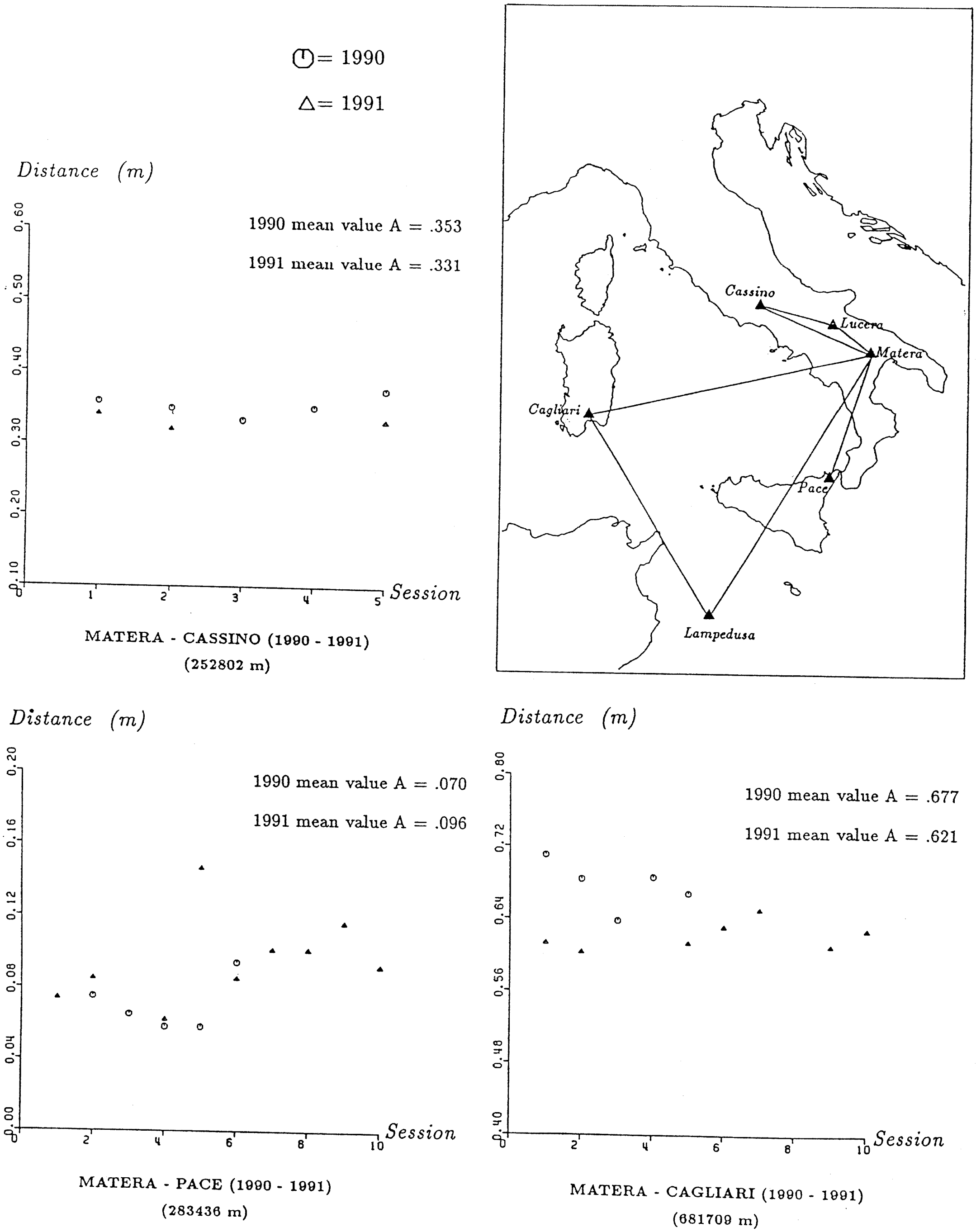

Fig. 5. Comparison of some baselines between 1990 and 1991 surveys.

three hours of valid recordings. Short observations do not yield the same accuracy as longer observations.

The daily average repeatability in length is 2 cm for (100÷300) km long baselines, while for the longer baselines it increases to 10 cm.

A similarity transformation shows that the two solutions are not affected by any detectable scale difference and that the average coordinate residuals are less than 1 cm (Achilli *et al.*, 1991).

Some baselines have been computed with the purpose of evaluating the daily repeatability of the measurements from the 1990 and 1991 campaigns (fig. 5). The preliminary results exhibit a good repeatability both on short (≃200 km) and long baselines (≃700 km), with an accuracy of 0.1 ppm (1 cm over 100 km).

11. Conclusions

The TYRrhenian GEOdynamic NETwork (TYRGEONET) was designed and developed in 1989 to provide a basic framework for geodynamical studies of the Italian peninsula and its surrounding areas.

The preliminary results of the campaigns performed during 1990 and 1991 show that this technique represents a powerful tool for the detection of crustal deformation at local and regional scales, and in general for an accurate study of the geodynamics of the Italian peninsula and surrounding areas. The project will continue in the near future with almost yearly campaigns mainly performed in the most seismically active areas. In addition to that the number of stations of the regional network will be increased.

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