

First GPS measurements across the Central-Western Mediterranean area

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Abstract

This paper concerns the displacement field of the central-western part of the Mediterranean basin estimated by the analysis of three repeated GPS surveys (1995, 1996 and 1997) consisting of 8 sites of a network. This network includes for the first time the stations of Algiers and Arzew, located in Northern Algeria, an area not yet investigated by regional GPS surveys. Lampedusa station is located in the Sicily Straits rifting area while the other five stations of Cagliari, Wettzell, Madrid, Matera and Noto belong to the IGS permanent tracking network. The statistical analysis of 1995, 1996 and 1997 data show significant displacements at five stations. The displacement vectors of the African sites show a convergence between the African and the Eurasian plates at a rate of 0.8 ± 0.4 cm within a two year time span. A comparison between the displacements estimated in the present work and the ITRF96 determinations for the five permanent stations allow us to evaluate the motion of Lampedusa, Algiers and Arzew in the IERS Terrestrial Reference System.

Key words GPS – Mediterranean geodynamics

1. Introduction

The Mediterranean area is characterized by a complex tectonics mainly due to the collision between the African and Eurasian plates. Lithosphere fragmentation and deformation is evidenced by high seismic and volcanic activities that run along a belt extending from the Azores triple junction to Anatolia.

In this region the global geodynamic models Nuvel-1 and Nuvel-1A (DeMets *et al.*, 1990), based on geological and geophysical data, evaluate a convergence velocity between Africa and Eurasia of about 6-8 mm/yr. However, these models cannot provide the present day rate of crustal deformation that can be estimated only by geodetic observations performed over wide areas, along and across the collision belts of the plates.

A marked improvement in our knowledge of current plate motions has been given by the global GPS experiment in 1991 and by the institution of the IGS network which, at present, involves more than 70 permanent GPS stations distributed all over the world. The results of the analysis of a 5 year time span of these data allowed the estimation of angular velocities for eight tectonic plates (Larson *et al.*, 1997).

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Several researches performed by various geophysical methods in the Central Mediterranean, Ionian Sea, Tyrrhenian Sea and Apennines confirm the present tectonic activity of this area that shows extensional, compressional and transcurrent features due to the presence of regional and local tectonic complications (Amato *et al.*, 1997; Morelli, 1997; Anzidei *et al.*, 1996; Mantovani *et al.*, 1990; Finetti, 1982).

As regards the geodetic surveys, only the central and eastern part of the Mediterranean was recently investigated by SLR, GPS and VLBI (Kahle *et al.*, 1993; Zarraoa *et al.*, 1994; Oral *et al.*, 1995; Robbins *et al.*, 1995; Anzidei *et al.*, 1996, 1997; Noomen *et al.*, 1996; Davies *et al.*, 1997; Reilinger *et al.*, 1997). These measurements allowed us to estimate the present day deformation pattern of this area, that displays a northward motion of Arabia, the lateral westward escape of Anatolia, the NE-SW expansion of the Aegean basin, the extension of the Gulf of Corinth and the counterclockwise rotation of Southern Italy.

In this paper we focus our attention on the central and western part of the Mediterranean basin, to evaluate the present rate of deformation not yet investigated by space geodetic techniques.

The area displays a frequent seismicity mainly located along the collision belt extending from the triple junction of the Azores islands to Middle East, running through Italy and Greece (Udias, 1982; Pondrelli *et al.*, 1992). In Algeria, the largest earthquakes occurred along its northern side and are related to the main tectonic structures of this area. From historical and recent seismological data it is possible to distinguish three main seismic areas close to Oran, El Asnam and Algiers, located approximately between the Algerian GPS stations. The largest seismic event of October 10, 1980, $M = 7.3$, was located in the El Asnam area and produced important vertical and horizontal deformations (Ruegg *et al.*, 1982). Since 1995, only one moderate seismic event has occurred in the area (Pondrelli, personal communication).

Concerning the border area between the African and the Eurasian plates (south of Iberian peninsula, Alboran Sea and Northern Algeria), the predominant regional stress computed from earthquake focal mechanisms is compressional, N-S or NW-SE oriented (Buforn *et al.*, 1995).

2. GPS measurements and data analysis

Three GPS campaigns were performed in June 1995, June 1996 and June 1997 on a network consisting of 8 sites. This network includes 5 IGS permanent stations (Cagliari, Madrid, Matera, Noto and Wettzell) and three other sites (Lampedusa, Algiers and Arzew). Six measurement sessions were carried out in 1995, eight in 1996 and seven in 1997. Data from Rogue, Trimble 4000SSI and Ashtech ZXII dual frequency receivers at 30 s sampling rate and 24 h per session were used in the computations.

The processing procedure consists of three main steps: 1) GPS data processing; 2) network adjustment of each campaign; 3) comparison between the three network solutions (after the removal of systematic effects due to scale and rotations) by statistical analysis to evaluate the significance of the observed coordinate differences.

GPS data were processed with the Bernese GPS software v. 4.0 according to well tested procedures for regional campaigns (Rothacher *et al.*, 1996). Precise satellite ephemerides, satellite clock corrections and antenna phase centre variation files provided by CODE at Bern University were used in the computation.

Each observing session was processed separately, obtaining one network solution per session. Each network solution, consisting of the parameter estimations (coordinates, ambiguities, tropospheric delays) and the covariance matrix was obtained keeping fixed the coordinates of one different site.

Table I. Deformation analysis $F_t = 3.04$ (5% significance level).

Site	1997-1995
Algiers	7.02
Arzew	3.10
Cagliari	0.07
Lampedusa	9.36
Madrid	0.96
Matera	27.00
Noto	8.54
Wettzell	0.04

One set of network coordinates for each year, together with the associated error ellipsoids, was obtained by a minimal constrains adjustment of all the separate session solutions. The three adjustments (1995, 1996 and 1997) were performed by NETGPS (Crespi, 1996), keeping fixed the coordinates of Matera.

To remove any systematic effects on coordinate differences (Bányai, 1991; Crespi *et al.*, 1993), four parameters (scale and rotations) between two sets of coordinates were estimated; in this computation the 1997 coordinate set was taken as reference for the other two years. The estimated parameters were used to express

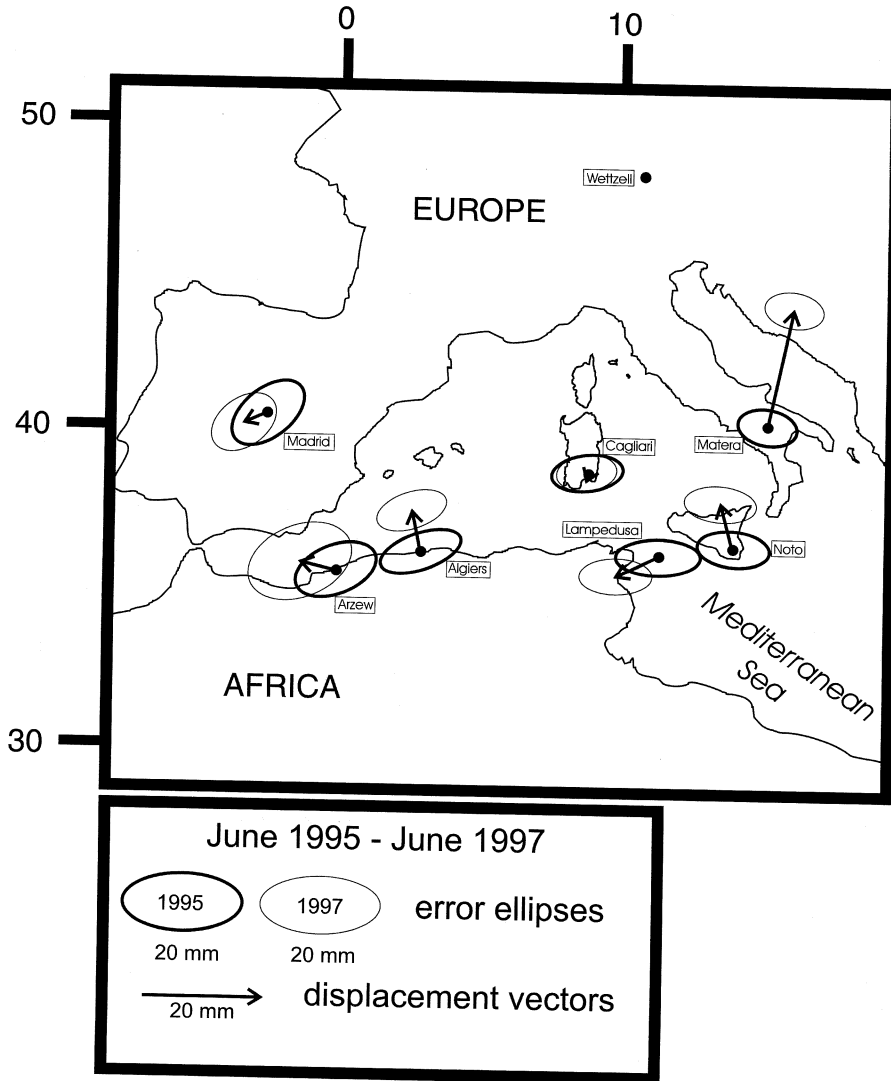


Fig. 1. 2D displacement vectors and corresponding error ellipses computed keeping fixed Wetzell GPS station.

the 1995 and 1996 coordinates into the 1997 reference system.

Concerning the statistical analysis, the procedure here followed was already described in detail (Crespi, 1996) and successfully applied in Anzidei *et al.* (1996) and Crespi and Riguzzi (1998). In brief, it consists in separating the sites into two groups: the first including the sites that do not show significant coordinate differences (the *datum*) and the other grouping the sites whose coordinates are statistically changed. The evaluation is made by an iterative procedure based on the classical F (Fisher) test, under the hypothesis of normal variate observations.

The test did not single out any significant deformation between data sets within a one year time span. Consequently, in the following we focus our attention on the 1997-1995 comparison. The results are reported in table I where the theoretical F_c value and the corresponding experimental values for each site are listed; note that sites with $F > F_c$ show significant coordinate differences.

3. Results

Figure 1 shows the 2D displacement vectors and the error ellipses at 95% confidence level keeping the Wettzell station fixed. Therefore, in our computation we analyzed the displacement vectors of the GPS network with respect to Wettzell to refer the deformations to the stable inner Eurasian plate. Significant displacements

were detected at Algiers, Arzew, Lampedusa, Matera, and Noto stations.

The relative motion between the African and the Eurasian plates is confirmed by the present analysis and it is exhibited by the displacement vectors of Arzew (0.6 ± 0.6 cm), Algiers (0.7 ± 0.4 cm) and Noto (0.8 ± 0.4 cm) within the 1995-1997 time interval. Our results are similar to the mean velocities predicted by some current geodynamic models (Argus *et al.*, 1989; DeMets *et al.*, 1990). Note that the evidenced differential motion between Algiers and Arzew agrees well with the presence of an active fault system that in the past produced large earthquakes (Ruegg *et al.*, 1982).

The displacement exhibited by Lampedusa (0.8 ± 0.4 cm) can be related to the Sicily Straits tectonics, being located close to the Lampedusa and Medina plateaus and separated from the Adventure and Ragusa-Malta plateaus by an active rifting area (Finetti, 1982).

The displacement vector of 2.0 ± 0.5 cm exhibited by Matera toward NE, the largest of the whole network, shows the convergence between the Italian peninsula and the Balkan area, as already evidenced by other analyses (Noomen *et al.*, 1996; Springer *et al.*, 1997).

A more general view of the geodynamic behaviour of the area is given by representing the site displacements into the International Reference Frame computed by the International Earth Rotation Service (IERS). The most recent global solution is the ITRF96, computed from VLBI, SLR, GPS and Doris techniques using the most representative geodetic observation sites in the world (Boucher, 1998).

Table II. Planar components of displacements (1997-1995) from our computations and ITRF96 solution.

Site	ΔN (cm)	ΔE (cm)	ΔN_{EUR} (cm)	ΔE_{EUR} (cm)
Algiers	3.7 ± 0.1	3.9 ± 0.1
Arzew	3.3 ± 0.2	3.5 ± 0.2
Cagliari	2.7 ± 0.2	4.1 ± 0.2	1.84	2.72
Lampedusa	2.4 ± 0.2	3.5 ± 0.2
Madrid	2.9 ± 0.2	3.5 ± 0.2	3.00	3.92
Matera	3.6 ± 0.2	4.7 ± 0.3	3.70	4.76
Noto	3.4 ± 0.1	4.0 ± 0.2	3.82	4.48
Wettzell	2.5 ± 0.3	3.9 ± 0.2	2.66	4.10

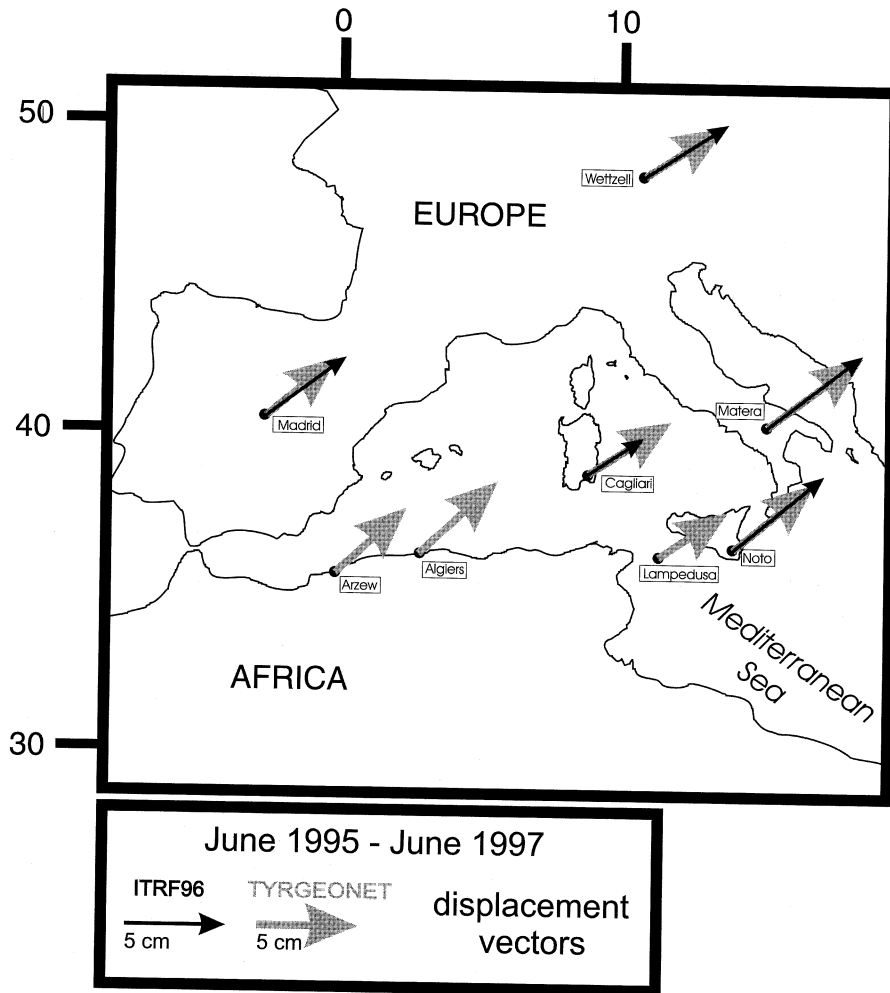


Fig. 2. 2D displacement vectors from the results of this paper and from ITRF96 determinations (computed by IERS using VLBI, SLR, GPS and Doris techniques at global selected stations).

A 7-parameter transformation of the coordinates computed for the five permanent stations in this paper (Cagliari, Madrid, Matera, Noto and Wettzell) and by the ITRF96 solutions referred to 1997.0 epoch were estimated to express the displacements of Lampedusa, Algiers and Arzew sites into the same system. Table II lists the planar components of the displacement obtained from the above mentioned comparison together with the associated errors. Figure 2 shows the 2D

displacement vectors computed in this paper and the corresponding ITRF96 estimates.

Acknowledgements

The Authors wish to thank C. Noll of the CDDIS who provided GPS data of the permanent stations. This work was partially supported by the Italian Space Agency (ASI).

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(received October 19, 1998;
accepted December 15, 1998)