Status of strain in the crust in the Alpine Mediterranean area using a local densification of the European permanent network

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Abstract

Using the EUREF 97 velocities as a velocity datum, we have computed velocities of additional, permanent GPS stations in Italy from week 995 to week 1060 (30 January 1999 to 6 May 2000), and the components of a two dimensional, horizontal strain rate tensor. When examined in the context of independent geological, seismological and geophysical knowledge, the map of the geodetically inferred strain rate field shows several interesting correlation with fault plane solutions and the geometry of pre-existing faults. Our kinematic model features an extensional regime on the Ligurian and Thyrrenean sea, along and West of the Apennines, up to the Adrian shore, and compression in the Friuli region. In the Channel of Sicily, the relative motion of Lampedusa and Noto results in an extension, which fits the aseismic deformation pattern in the Pantelleria Rift system. The maximum deformations occur in the Central Apennines, with and extensional strain rate of 27 10^{-9} yr^{-1}, and in the Southern Apennines, with and extensional strain rate of 23 10^{-9} yr^{-1}. Additional smaller deformation are visible, and often in agreement with seismic data. However they fall below the estimated threshold of sensitivity, which we set at 10 10^{-9} yr^{-1}, and/or are insufficiently constrained by the distribution of the stations. In areas characterized by intense fracturing, and superposition of fault systems with different attitudes and trends, the GPS stations are too sparse to account for the short wavelength changes in stress regime. This lack of spatial resolution is evident in the Western Po Plain, or in the Messina strait, where the regime clearly changes on a shorter scale than the average distance between the GPS stations in those areas. With these exceptions, we conclude that the information coming from the geodetic strain rate data fits the broad scale neo-tectonic pattern inferred from several large scale faults, fault plane solutions of recent, shallow earthquakes, and other geophysical indicators of the stress regime.

1. Introduction

In southern Europe several, very different processes take place in a spatially limited region: opening of the Thyrrenean basin with creation of oceanic crust, volcanism in the southern Thyrrenean sea, indentation of an Adriatic wedge in the Eastern Alps, flexure of the Adriatic lithosphere beneath the Apennines, development of homogeneous SW to NE thrust belts in the Dinarids, and subduction of the Ionic lithosphere beneath the Calabrian Arc. This interplay of different crustal fragments, presumably decoupled from the lithospheric mantle, is described with considerable detail in structural maps (BIGI et al., 1990), in maps of active stress (e.g. MONTONE et al., 1999; FREPOLI, AMATO, 2000). Locally, the geodetically inferred strain has been investigated in the Western Alps (CALAIS et al., 2000), and Central and Southern Italy (ANZIDEI et al., 1997; BALDI et al., 1998) using a combination of permanent GPS stations and epoch – like networks. Because of the requirement of mapping the strain axes in a reference frame which is globally defined, and the reasonably good distribution of permanent stations, one interesting and so far in-exploited option for mapping the large scale strain field is the high precision geodetic network EUREF, which covers Europe with over 100 high quality, continuously operating stations tracking the satellites of the GPS. EUREF contributes to the realizations of the International Terrestrial Reference Frame (ITRF) (BOUCHER et al., 1999) by means of estimates of station coordinates and velocities, using state of the art software and models of the GPS observables. Being conceived primarily for maintaining a geodetic reference system in Europe, the EUREF network is not optimized for strain studies. At the Local Analysis Center at our University all the permanent GPS stations in Italy, including permanent but non-EUREF GPS stations, are routinely processed as an off-line activity to the weekly sub-net analysis for EUREF. Estimates of the velocities are periodically (typically every month) updated, and are constrained to the ITRF97 velocities of EUREF stations with the longest tracking history. The main objective of this paper is to use the velocities of this local densification of the EUREF network to identify areas of active deformation, as inferred from geodetic data, and to attempt a comparison of the resulting pattern of deformation with the geometry of major tectonic lineaments in activity.

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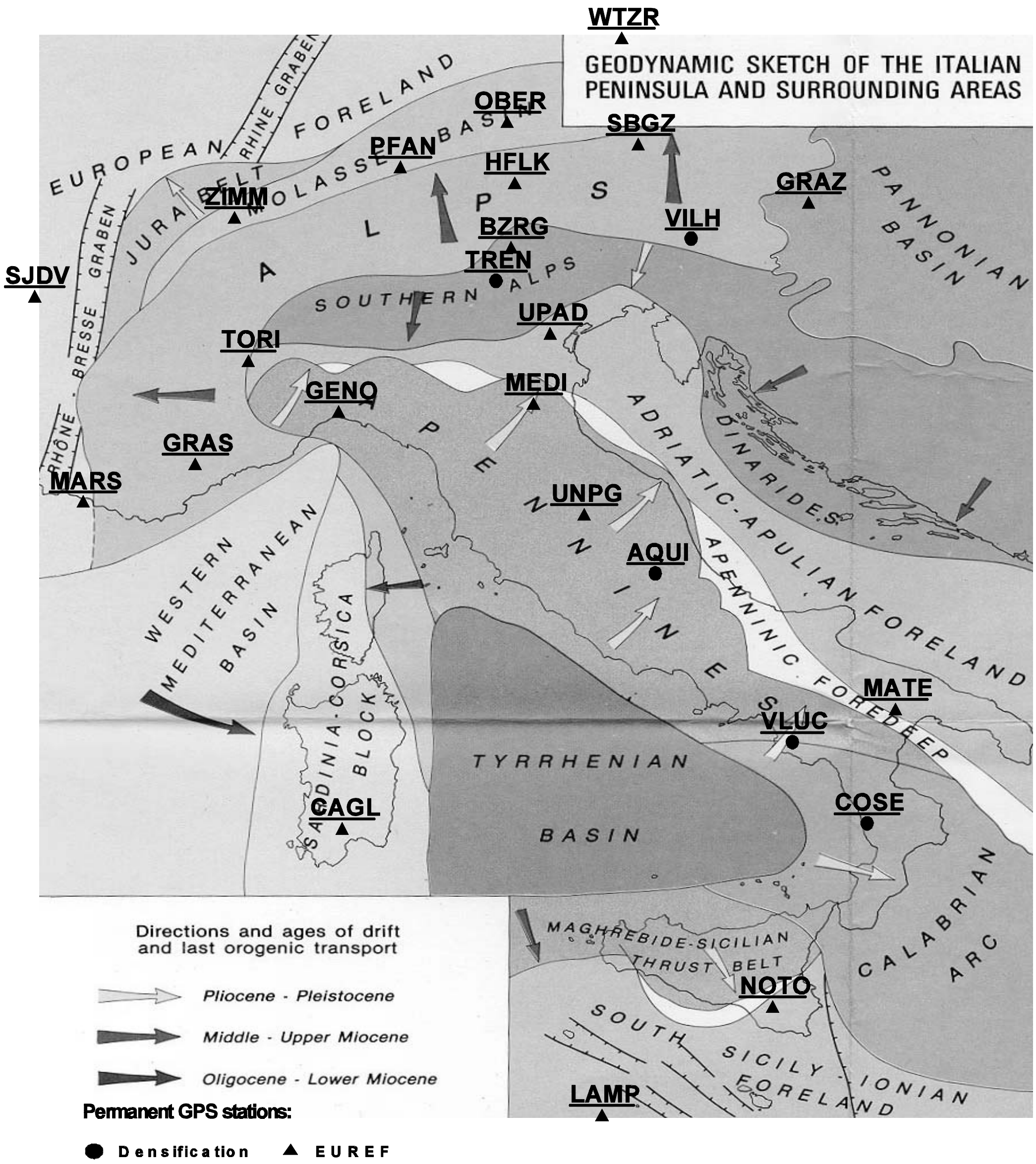

Fig. 1: Geodynamic sketch of orogenic transport in Italy from Miocene to contemporary, and the position of permanent GPS stations analyzed in this study.

2. Data Reduction

The data consist of a) the individual velocities of European GPS stations of the EUREF network for the period 1993 to 1998 at the epoch 1997.0, and b) the raw GPS data files of 16 permanent GPS stations in Italy plus the Austrian station Villach (Fig. 1), for the period January 1999 to June 2000. The details of the computation of the ITRF97 coordinates and velocities, and of their densification in Europe are described elsewhere (BOUCHER et al., 1999). In our weekly analysis procedure, the raw data files of the 17 GPS stations are organized in daily sessions. Processing is done with the software BERNESE 4.0 developed at the Astronomical Institute of the University of Bern (Beutler et al., 1996). The setup of the program is optimized for regional networks. Individual baselines are first processed in QIF (Quasi Iono Free) mode, and the integer ambiguities are saved. Then a network solution is computed using the L3 combination of GPS frequencies, after back-substitution of the integer ambiguities. Zenith tropospheric delays are solved every two hours with an absolute/relative a priori sigma of 5 m, and using a cos(z) mapping function, z being the zenith angle at each station of any given satellite. Elevation cutoff is at 15 degrees above the horizon. The program ADDNEQ is used to combine seven daily solutions into one weekly solution. The same program is used again to stack the weekly normal equation files, remove the constraints of the individual weekly solutions, constrain the velocities of the EUREF stations to the EUREF 97 velocity datum, and solve for the horizontal velocities of the non-EUREF stations. The coordinates of the EUREF stations MATE (Matera), CAGL (Cagliari), NOTO (Noto) and MEDI (Medicina) were constrained to the EUREF 97 values. Tab. 1 summarizes the statistics and the adopted model. Although in some cases sizable vertical motion is to be expected, the estimate of the vertical velocity is affected by a formal uncertainty 2-3 times that of the horizontal velocity. In these conditions it makes no sense to attempt a three dimensional analysis, and we decided to confine the attention to the horizontal coordinates.

Tab.1: summary statistics of the solution for the velocities of non EUREF stations in the EUREF 97 velocity datum.

Parameter	Value
Precise ephemeris	COD<gps-week><day of week>.EPH
Earth Orientation Parameters	C04_<year>.ERP
Antenna Phase Center Model	PHAS_IGS.01
Total number of parameters	125,546
Number of Observations	8,941,251
Number of Single Difference Files	5,501
Sigma of single difference observation	0.0033 m

3. From velocities to strain rate

To estimate a horizontal, two dimensional strain rate field we assume that one of the eigen-vectors of the strain rate tensor is vertical. It will also be assumed that: the selected area is a continuum at the scale of the mean distance between stations,

the East and North components of the horizontal velocity are statistically independent, random variables,

the velocity of each station samples the tectonic deformation at the scale of the distance to the neighboring stations.

The principal strain directions are obtained by interpolating the horizontal components of the velocity to a regular grid of 1x1 degree, and computing the horizontal velocity gradients at the nodes of the mesh by finite differences.

As shown in Fig. 2, the geodetically inferred strain field divides the Italian peninsula along its axis into distinct regimes:

1. extension on the western side, including the SW flank of the Apennines, the Thyrrenean and Ligurian sea; the stations GENO, CAGL, UNPG, and VLUC belong to this extensional area; in addition, the stations on the French coast and in the Dauphiné also contribute to define this pattern; the maximum values are 27 10^{-9} yr^{-1} at (lon=12°E, lat=43°N), with an azimuth of the extensional axis of 60° clockwise from North, and 23 10^{-9} yr^{-1} at (lon=15°E, lat=40°N), with an azimuth of the extensional axis of 30° ; this regime fits on a broad scale the opening of the Thyrrenian sea and the extensional regime of the Western flank of the Apennines;

2. compression on the eastern side, including the Adriatic foredeep, the Adrian sea and Dinarids; the stations BZRG, TREN, UPAD, MEDI, AQUI, and MATE belong to this compressional area, which is also described by the stations in Austria; the maximum values are 18 10^{-9} yr^{-1} at (lon=14°E, lat=42°N), with an azimuth of the compressional axis of 48° clockwise from North, and 15 10^{-9} yr^{-1} at (lon=14°E, lat=43°N), with an azimuth of the compressional axis of 28° ; in the Eastern Po Plain and Eastern Alps the maximum compression of 13 10^{-9} yr^{-1} occurs at (lon=12°E, lat=45°N) and (lon=11°E, lat=47°N), with an azimuth of the compressional axis of 33°; again this strain regime fits, on a broad scale, the concept of an Adriatic microplate indenting the Eastern Alps, and at the same time subducting the Dinarides on the East and the Apennines on the West;

3. compression, but with a different polarity, is the dominant strain pattern in Sicily, as indicated by the stations COSE and NOTO; the maximum value is 15 10^{-9} yr^{-1} at (lon=15°E, lat=39°N), with an azimuth of the compressional axis of -20°; this regime fits qualitatively the expected response of the push of the Africa plate;

4. some degree of extension is visible in the channel of Sicily, between NOTO and LAMP; the maximum value is 7 10^{-9} yr^{-1} at (lon=13°E, lat=36°N), with an azimuth of the extensional axis of 41° . The extension is matched by graben formation in the Pantelleria rift system.