# The CGS VLBI EUR98 Geodetic solution and comparison with the CGS GPS results.

R. Lanotte[1], C. Ferraro[1], A. Nardi[2], C. Sciarretta[2], F. Vespe[3]

1) Telespazio SpA, Centro di Geodesia Spaziale "G.Colombo", Matera, Italy
2) Telespazio SpA, Via Tiburtina 167, Rome, Italy
3) Agenzia Spaziale Italiana, Centro di Geodesia Spaziale "G.Colombo", Matera, Italy

**Abstract.** Nine years of VLBI data acquired within the EUROPE campaign have been analysed to estimate the motion of the stations participating to this campaign. The estimated site velocities and baseline time series are compared to those obtained from the GPS solution carried out at CGS as contribution to EUREF. Both the solutions have been expressed in the ITRF96 reference frame in order to compare them in a unique reference system.

## 1. Introduction

Data acquired from 1990 up to the beginning of 1998 in the VLBI EUROPE campaign have been analysed in the CGS VLBI EUR98 solution, including 42 sessions each lasting 24 hours. Figure 1 shows the network under investigation. Two VLBI solutions, using the CALC/f-SOLVE software system [Rogers et al., 1983; Clark et al., 1985, Petrov 1999], are computed. The first one is an arc solution which provides, for each observing session, estimation of the site coordinates, that is the time series of the baselines. In the following this solution is referenced as "the baseline solution". The second solution is a global solution where site positions and velocities are estimated using all sessions. This solution will be referenced as "the velocity solution". Both the solutions were compared to the GPS solution computed at the CGS as contribution to EUREF.

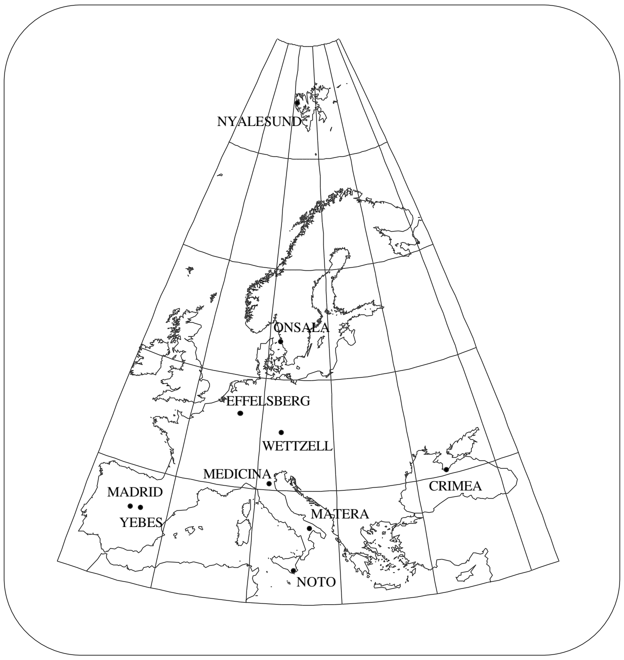


**Figure 1**: The network of the fixed VLBI stations participating to the EUROPE campaign.

## 2. The CGS VLBI EUR98 solution

### The baseline solution

In the baseline solution the so called "reweighting process" is performed for each session by estimating a constant formal error. This constant added to the variance of the observations (derived in the correlation process) has to satisfy the condition that the overall reduced $\chi^2$ of the residual delays in the session was equal to unity. The baseline solution, using the reweighted observations, provides the time series of the geodetic parameters and in particular the baseline vector components.

Clocks were estimated using a reference station and modelling the differences between the reference clock and the others with an unconstrained second order polynomial plus a continuous piecewise linear function with duration of the linear sections of 60 minutes and $5 \cdot 10^{-14}$ constrained in slope.

To take into account the tropospheric delay we have to separate it into its dry and wet components. The dry delay for each observation was estimated at the zenith using the Saastamoinen model and then mapped to the elevation of the observation with the Niell dry mapping function [Niell, 1996]. Wet tropospheric zenith delay was estimated using a continuous, piecewise linear function with duration of the linear sections of 60 minutes and 50 ps/h constrained in slope and then mapped to the elevation of the observation with the Niell wet mapping function [Niell, 1996].

The regional extension of the network under investigation does not allow to reliably determine parameters such as the celestial source positions as well as Earth rotation parameters. For this reason they have been kept fixed using: the IERS celestial reference frame ICRF95 [IERS, 1997] for the source coordinates, the IERS series 97 C 04 for the Earth Orientation Parameter and nutation series [IERS A.R., 1997]. For precession the J2000.0 model has been used.

Figure 2 shows the baseline length variations for all the baselines relevant to Wettzell. These baselines can be considered as representatives for all the baselines in the baseline solution. The baselines are divided in two groups, the first contains the baselines with a rate not significantly different from zero, except for the baseline Wettzell-Yebes that has a vary high error rate. In the second group are the baselines with rate different from zero and these are the baselines containing the Italian sites.

### The velocity solution

In the velocity solution station positions and velocities have been estimated as global parameters, i.e. common to all the analysed sessions. In this solution the previously obtained arc weights are applied. The same parameterization described in the baseline solution has been used, moreover this solution is constrained fixing position and velocity of Wettzell at the value of ITRF96 [Boucher et Al., 1998] for the epoch 1997.0. In order to compare the estimated velocities to those provided by the ITRF96 a four parameters transformation was determinated to take in to account for rotation and scale factor time derivatives. Table 1 reports the estimated station velocities and the ones provided by the ITRF96 in the topocentric Up, East and North reference frame. The horizontal components are in good agreement, some discrepancies are in the Up component in particular for Medicina and Noto.

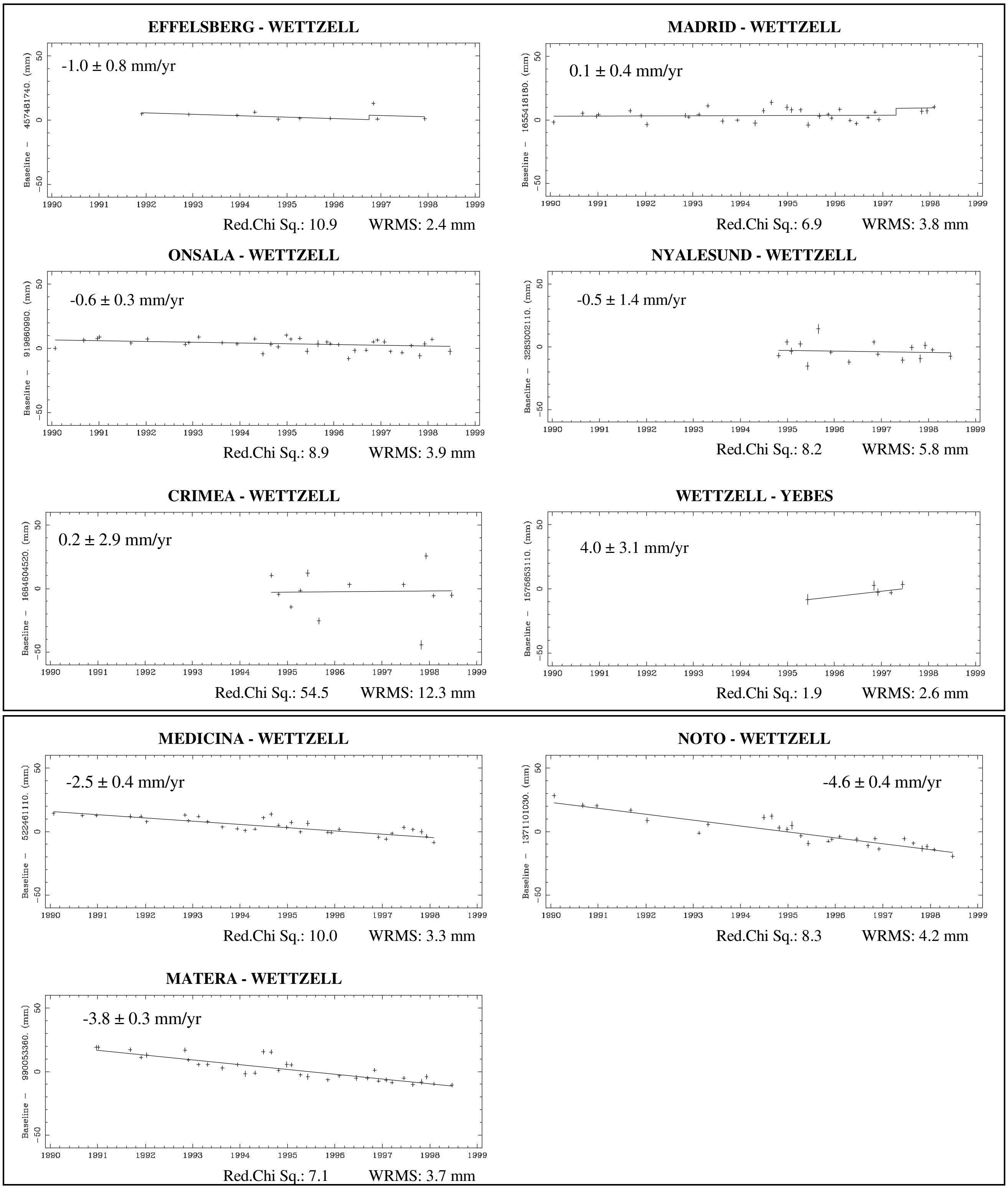


**Figure 2:** Length variation of the baselines including the Wettzell site. The points are the calculated value of the baseline at an epoch with one sigma formal error bar. The straight line on the plots is the line of best fit by least squares. The rate, error rate , reduced chi square and WRMS fit is reported on each plot.

| | | VLBI (mm/yr) | ITRF96 (mm/yr) |
|---|---|---|---|
| CRIMEA | U | 4.0 ± 1.8 | -1.8 ± 11.3 |
| | E | 26.1 ± .3 | 24.1 ± 2.5 |
| | N | 10.0 ± .3 | 8.5 ± 3.1 |
| EFFELSBERG | U | -1.6 ± 1.0 | -3.7 ± 2.5 |
| | E | 18.9 ± .2 | 19.2 ± .7 |
| | N | 12.9 ± .2 | 13.9 ± .6 |
| MADRID | U | 2.8 ± .5 | 3.9 ± .3 |
| | E | 18.9 ± .1 | 19.6 ± .4 |
| | N | 15.2 ± .1 | 15.1 ± .4 |
| MATERA | U | -.4 ± .5 | -.7 ± .2 |
| | E | 23.9 ± .1 | 23.8 ± .4 |
| | N | 17.0 ± .1 | 18.5 ± .4 |
| MEDICINA | U | -4.4 ± .6 | 1.4 ± .1 |
| | E | 23.2 ± .1 | 23.8 ± .3 |
| | N | 15.3 ± .1 | 15.1 ± .3 |
| NOTO | U | -2.2 ± .5 | .7 ± .2 |
| | E | 22.4 ± .1 | 22.4 ± .5 |
| | N | 17.2 ± .1 | 19.1 ± .5 |
| NYALESUND | U | 2.7 ± 1.4 | -2.0 ± .6 |
| | E | 9.2 ± .3 | 10.9 ± .6 |
| | N | 13.5 ± .4 | 14.8 ± .6 |
| ONSALA | U | 1.6 ± .5 | .1 ± .2 |
| | E | 17.6 ± .1 | 17.4 ± .2 |
| | N | 12.8 ± .1 | 13.1 ± .2 |
| WETTZELL | U | -2.2 ± .0 | -2.4 ± .1 |
| | E | 20.5 ± .0 | 20.5 ± .0 |
| | N | 13.5 ± .0 | 13.3 ± .1 |
| YEBES | U | -31.5 ± 9.2 | .5 ± .1 |
| | E | 17.2 ± 1.7 | 18.5 ± 5.4 |
| | N | 12.2 ± 1.7 | 14.3 ± 5.8 |

Table 1: Site velocities in the local topocentric reference frame estimated using the VLBI and comparison with the values provided by the ITRF96.

## 3. The CGS GPS solution

The ASI/CGS participates to EUREF [Bruyninx et al. 1996] as Local Analysis Center providing weekly solutions of the Italian GPS Fiducial Network (IGFN) [Fermi et al., 1997] plus other European sites. The CGS GPS solution has been performed using the software MicroCosm. It is based on four years of daily station coordinates, starting from 1995. Only few stations have data covering the full time span (see table 2). Figure 3 shows the GPS network. The solution is constrained by fixing the position and velocity of Wettzell to the values from ITRF96, satellite ephemerides and EOP to the IGS final values.

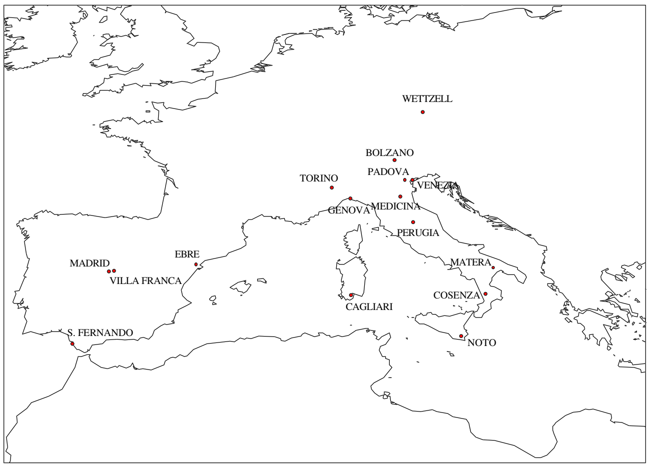


**Figure 3**:

## 4. Comparison of the VLBI and GPS baselines

The two solutions have co-located sites: Madrid, Wettzell, Medicina, Matera and Noto. Data from Madrid are not used in this comparison, due to poor quality of GPS acquisitions. The estimated GPS site coordinates have been reported to the VLBI geodetic marker using the eccentricity vectors from ITRF96. A least square linear fit has been performed on the baselines to estimate a common rate for both VLBI and GPS. As the GPS estimates accumulate in time to be submitted to EUREF, they suffer of upgrading of models in the IGS products (orbits, EOP, ITRF) on which they rely on. To take into account these changes, plus other known receivers problem, "jumps" have been inserted into the linear fit estimation. Figure 4 shows the comparison among the time series of the baselines.

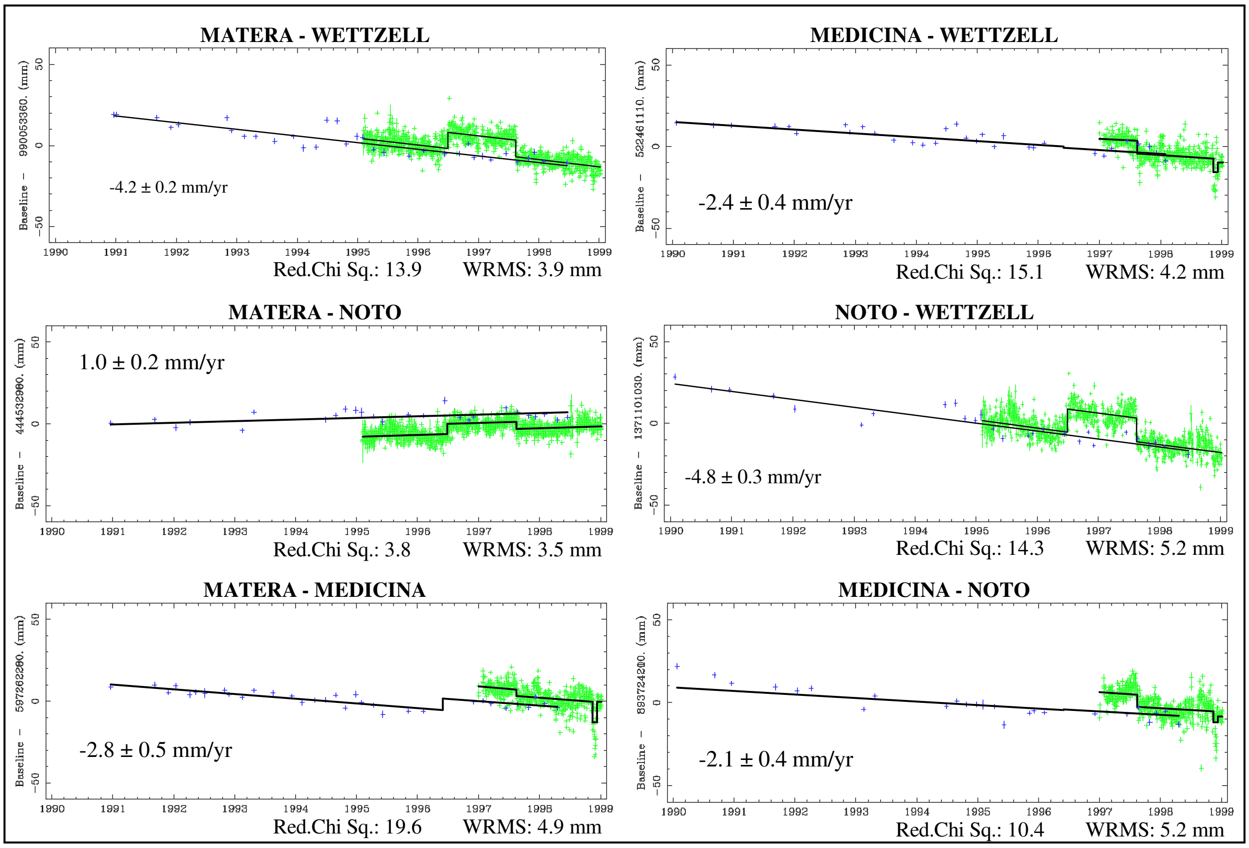


**Figure 4**: Baselines among Wettzell, Matera, Medicina and Noto. VLBI and GPS results are used to estimate a combined rate. The solid line is the combined linear fit.

## 5. Comparison of the VLBI and GPS site velocities

The velocities used in the comparison have been obtained in different ways: for the VLBI directly from the velocity solution while for GPS from a linear fit of the site positions. They have been compared by estimating a 4 parameters transformation using the estimated rates of Noto, Matera and Medicina. In table 2 the two velocity fields in the local topocentric reference frame, Up, East and North components are reported, while in figure 5 the horizontal velocities are plotted.

| | | GPS mm/yr | VLBI mm/yr | Time span of the GPS data in years |
|---|---|---|---|---|
| MATERA | U | -.6 ± .8 | -.5 ± .5 | 4.0 |
| | E | 24.1 ± .4 | 24.0 ± .1 | |
| | N | 17.4 ± .2 | 16.9 ± .1 | |
| MEDICINA | U | .4 ± 1.6 | -4.5 ± .6 | 3.5 |
| | E | 24.5 ± .9 | 23.2 ± .1 | |
| | N | 14.9 ± .5 | 15.2 ± .1 | |
| NOTO | U | -4.2 ± 1.0 | -2.3 ± .5 | 4.0 |
| | E | 21.8 ± .6 | 22.5 ± .1 | |
| | N | 16.6 ± .3 | 17.1 ± .1 | |
| BOLZANO | U | 5.8 ± 2.4 | | 1.0 |
| | E | 15.4 ± 1.3 | | |
| | N | 16.2 ± .7 | | |
| CAGLIARI | U | -.6 ± 1.0 | | 4.0 |
| | E | 22.9 ± .5 | | |
| | N | 12.6 ± .3 | | |
| COSENZA | U | -4.4 ± 6.5 | | 0.6 |
| | E | 21.2 ± 3.5 | | |
| | N | 19.3 ± 2.0 | | |
| GENOVA | U | .7 ± 9.2 | | 0.4 |
| | E | 31.4 ± 4.9 | | |
| | N | 23.7 ± 2.4 | | |
| TORINO | U | 12.4 ± 3.1 | | 1.6 |
| | E | 20.5 ± 1.4 | | |
| | N | 16.9 ± .7 | | |
| PERUGIA | U | -3.5 ± 3.1 | | 1.2 |
| | E | 21.1 ± 1.7 | | |
| | N | 16.8 ± .9 | | |
| PADOVA | U | -10.1 ± 2.6 | | 1.0 |
| | E | 20.3 ± 1.5 | | |
| | N | 17.5 ± .8 | | |
| VENEZIA | U | 3.0 ± .7 | | 4.0 |
| | E | 21.7 ± .4 | | |
| | N | 14.9 ± .2 | | |

Table 2: Site velocities in the local topocentric reference frame estimated using the GPS and comparison with the values estimated using the VLBI.

## 6. Conclusions

The comparison between the VLBI ad GPS results appear to be very consistent both in terms of baselines rate and horizontal velocities (cfr. baselines to Wettzell in Fig. 2 ad table 2). The baseline rates enlighten a non completely eurasiatic nor rigidly coherent motion of Italian sites: Matera and Noto show a significant rate w.r.t. Wettzell and are not motionless w.r.t. each other; Medicina show smaller, but not unsignificant, motion w.r.t Eurasia (Wettzell) and w.r.t. the other two Italian sites.
The origin of some small inconsistencies (within 1 cm in the worst case) in the relative positions of the colocated systems have to be investigated.
The results for most of the GPS Italian sites cannot be considered reliable due to the short time series of the data acquired by these stations.

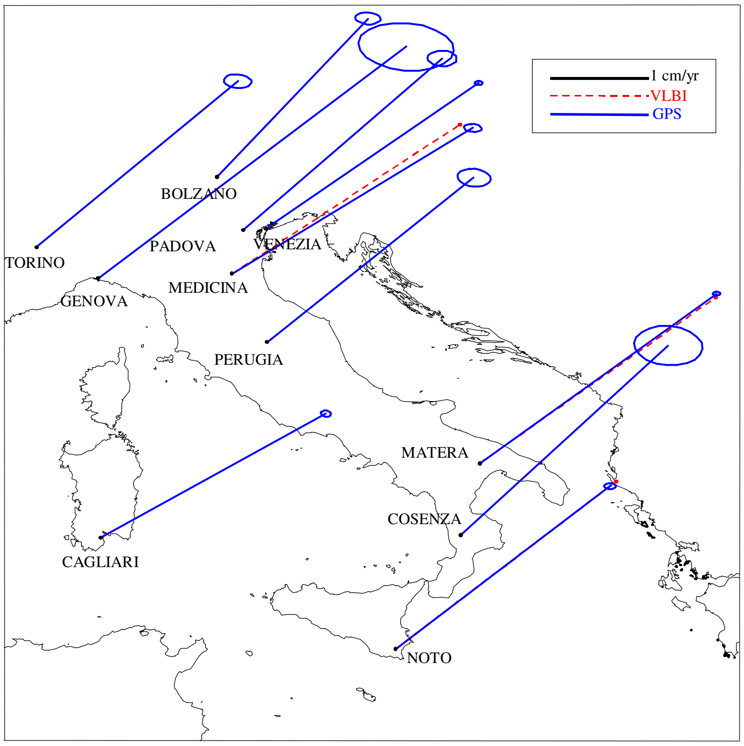


Figure 5: Absolute horizontal velocities of the Italian sites of the Italian GPS Fiducial Network. For Matera, Medicina and Noto, the VLBI horizontal velocities are also showed.

## References

Boucher, C., Z. Altamini, and P. Sillard, Results and Analysis of the ITRF96, IERS Technical note 23, Central Bureau of IERS, Paris Observatory,. May 1998.

Bruyninx, C., W. Gurtner, and A. Muls, The EUREF Permanent GPS Network, Proceedings of EUREF symposium, Ankara, May 1996.

Fermi, M., C. Ferraro, A. Nardi, C. Sciarretta, G. Bianco, F. Vespe, First results of the Italian GPS Fiducial Network, Proceedings of the 4th International Seminar "GPS in Central Europe", Penc, 7-9 May 1997, Warsaw University of Technology, Institute of Geodesy and Astronomy, ISBN 83-85287-26-4, Warsaw 1997.

IERS Annual Report 1997, Central Bureau of IERS, Paris Observatory, July 1998.

IERS Technical note 23, Definition and Realization of the International Celestial Reference System by VLBI Astrometry of Extragalactic Objects Central Bureau of IERS, Paris Observatory, June 1997.

Ma, C., J.M. Sauber, L.J. Bell, T.A. Clark, D. Gordon, W.E. Himwich, and J.W. Ryan, Measurement of Horizontal motions in Alaska Using Very Long Baseline Interferometry, *J. Geophys. Res., 95*, 21,991-22,011, 1990.

Niell, A. E., Global mapping functions for the atmosphere delay at radio wavelengths, J. Geophys. Res., 101, 3227-3246, 1996.

Petrov, L., Fast version of VLBI software SOLVE (f-SOLVE), unpublished, 1999, http://giub.geod.uni–bonn.de/vlbi/development/f-SOLVE/f-SOLVE.html.

Rogers, A.E.E., R.J. Cappallo, H.F. Hinteregger, J.I. Levine, E.F. Nesman, J.C. Webber, A.R. Whitney, T.A. Clark, C. Ma, J.R. Ryan, B.E. Corey, C.C. Counselman, T.A. Herring, I.I. Shapiro, C.A. Knight, D.B. Shaffer, N.R. Vandenberg, R. Lacasse, R. Mauzy, B. Rayhrer, B.R. Schupler, and J.C. Pigg, Very Long Baseline Radio Interferometry: The Mark III system for geodesy, astrometry, and aperture synthesis, *Science, 219*, 51-54, 1983.