Measuring crustal motion in Europe with geodetic VLBI

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Abstract Crustal motion in Europe is measured using geodetic Very Long Baseline Interferometry (VLBI). The project started in 1990 and usually 6 observing sessions per year are performed observing on intra-European baselines. Starting first concentrating on central and southern Europe, the network was extended to the North and East in recent years by the inclusion of further observatories. The meanwhile nearly 9 years of observations allow the determination of crustal motion in Europe with high accuracy. In this paper results for baseline evolution and topocentric station evolution are presented. For the future the determination of the vertical component is the main focus point.

1 Introduction

The European geodetic Very Long Baseline Interferometry (VLBI) group, a community formed by members of facilities involved in geodetic VLBI, initiated a purely European geodetic VLBI programme in January 1990. Until mid 1998 a total number of 44 sessions has been observed so far.

The goals of the project are to determine crustal motion in Europe and to provide a stable reference network for other geodetic techniques used for densification purposes. Coordination of the observing programme and the correlation of the data is done by members of the Geodätisches Institut der Universität Bonn (GIUB). For the correlation the Mark-IIIA correlator at the Max-Planck-Institute für Radio Astronomy (MPIfR) in Bonn is used. Financial support for the operation of this multi-national network is provided by the European Union (EU), see Campbell [1996, 1997].

2 The geodetic VLBI network in Europe

The geodetic VLBI network in Europe today consists of 10 stations: Effelsberg (Germany), Madrid (Spain), Matera (Italy), Medicina (Italy), Noto (Italy), Ny Ålesund (Norway), Onsala (Sweden), Simeiz (Ukraine), Wettzell (Germany) and Yebes (Spain) (see figure 1). The first purly European observations in 1990 were scheduled with the stations Wettzell, Onsala, Madrid, Medicina, Matera and Noto. In 1991 Effelsberg was equipped permanently with the necessary hardware and participation in geodetic observations was made possible. From 1994 on the two stations Simeiz and Ny Ålesund extended the geodetic network to the East and to the North. With the Yebes observatory a second station in Spain joined the network in 1995.

In the first two years of the project only 3 sessions were observed. In the following years 6 sessions per year were planned. Due to correlator restrictions only 4 of them could be observed in 1993. Since Effelsberg is a mainly astronomical station, it can only participate once or twice a year in geodetic VLBI sessions.

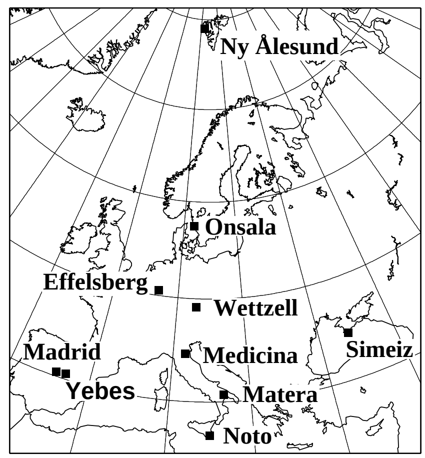

Fig. 1: European geod. VLBI network

3 Geodynamic situation

The network extends from 37° to 79° northern latitude and from −4° to 34° eastern longitude. It can be divided in three main parts, a) the northern, b) the central and c) the southern part. Part a), i.e. the Spitsbergen archipelago and Fennoscandia, is characterized by post-glacial rebound effects. Isostatic rebound responses after the vanishing of the Pleistocene ice shield cause vertical and, much smaller, horizontal motions in this area. In the center of the uplift area maximal vertical and horizontal deformation rates are predicted to be 12 mm/year and 2 mm/year, respectively [Mitrovica et al., 1994]. Part b), central Europe north of the Alpine system, is regarded as the essentially 'stable' part. Part c), i.e. the Mediterranean region, is strongly influenced by the collision of the African plate with the Eurasian plate. The African plate rotates counterclockwise and pushes north-north-westward against the Eurasian plate. This leads to lithosphere shortening of up to 50 mm/year [Mueller and Kahle, 1993] and results in complex geotectonic horizontal crustal motions mostly in northerly directions. Vertical crustal movements are an order of magnitude smaller than horizontal movements [Lambeck, 1988].

4 Data analysis

The 44 sessions between January 1990 and June 1998 were analyzed with the CALC/SOLVE/GLOBL VLBI data analysis software package [Ma et al., 1990]. Relative clock parameters with respect to a reference clock in each session were estimated every 6 hours, atmospheric zenith path delays every 60 minutes using the NMF 2.0 mapping functions [Niell, 1996]. Additionally horizontal gradient parameters in North and East direction were estimated every 8 hours. The analysis approach is a so called 'baseline-solution', i.e. each session was treated separately in a least squares adjustment and station coordinates relative to a reference station were estimated. Earth orientation has to be kept fixed in this approach and so orientation parameters together with radio source positions were adopted from a global VLBI solution by the GSFC VLBI group [Ma and Ryan, 1998].

The standard SOLVE/GLOBL software was refined in two aspects: a) a frequency and latitude dependent solid Earth tides model was introduced following Haas [1996] using the harmonic expansion of the tidal potential by Tamura [1987] and frequency and latitude dependent Love and Shida numbers by Wahr [1981] together with a Free Core Nutation (FCN) period of 430 sidereal days. b) ocean tide loading effects were introduced using a recent ocean tide loading model by Scherneck [1996] based on the CSR3.0 ocean tide model by the University of Texas [Eanes and Bettadpur, 1995], expanded by a large number of interpolated ocean tides. The effects of atmospheric loading and thermal deformation of the telescopes were not accounted for so far in the analysis.

The results of the individual least squares adjustments give a time series of geocentric station coordinates. Calculation of baseline lengths gives insight into the repeatability of the measurements and the quality of the individual sessions. Additionally station drift components in horizontal and vertical directions can be derived.

5 Results for baseline lengths and their evolution

The total number of baselines in the network is 43, the two baselines Yebes-Effelsberg and Yebes-Simeiz have not yet been observed. Since Wettzell has a central position in the network and was used as the reference station for the analysis, only baselines including Wettzell are discussed. Table 1 lists the baselines with the number of observation sessions, the baseline lengths, the baseline length rates with standard deviations, the weighted root mean square errors (wrms) of the regression lines and the measurement accuracy in parts per billion (ppb).

Figure 2 shows the individual results of the baseline length measurements with their formal errors together with a linear regression line. The dashed line represents the predicted baseline length change according to the NUVEL-1A-NNR plate tectonic model [De Mets et al., 1994] which is zero in a Europe fixed frame.

Table 1: Baselines including Wettzell: number of observation sessions (n), baseline length (l), baseline length rate (r) with standard deviation, wrms (w) of regression line and measurement accuracy (a) as ratio of wrms over baseline length

Baseline to	n	l [km]	r [mm/y]	w [mm]	a [ppb]
Effelsberg	10	457	-0.1 ± 0.5	2.7	5.9
Madrid	32	1655	$+0.9 \pm 0.3$	4.1	2.5
Matera	35	990	-3.8 ± 0.3	3.7	3.7
Medicina	32	522	-2.7 ± 0.2	2.0	3.8
Noto	29	1371	-4.6 ± 0.4	4.3	3.1
Ny Ålesund	16	3283	$+0.9 \pm 1.1$	4.9	1.5
Onsala	36	919	-0.1 ± 0.3	3.9	4.2
Simeiz	13	1684	$+0.5 \pm 2.3$	10.8	6.4
Yebes	5	1575	-2.6 ± 1.7	1.4	0.9

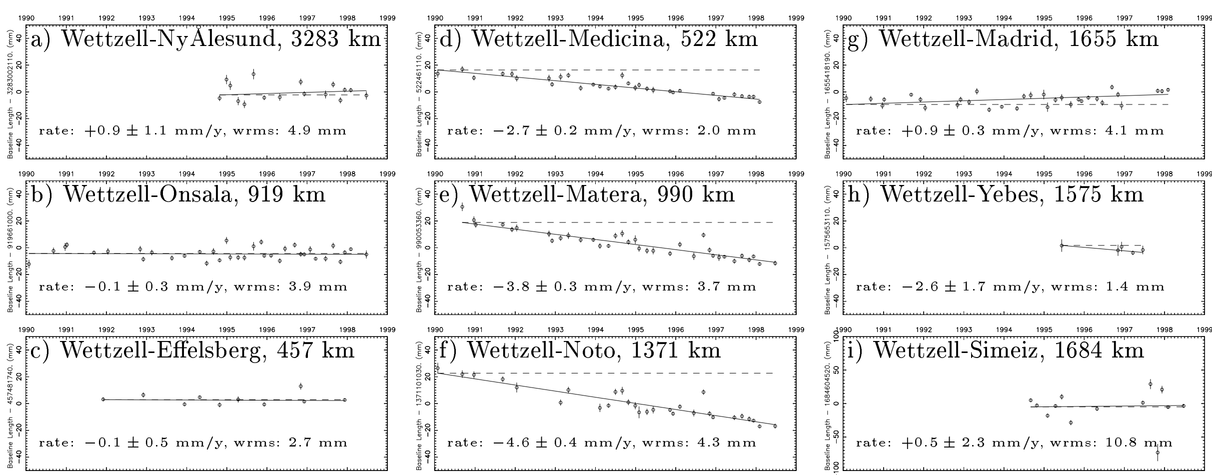

Figure 2: Baseline length results on baselines including Wettzell

The first column in figure 2 shows baselines from Wettzell to the North, the second column shows the baselines to the South (Italy) and the third column shows baselines to the West (Spain) and East.

The baselines a), b), c) in northerly direction show no significant length rates. Baseline a) to Ny Ålesund has only been observed four years so far and the results heavily dependent on the short observing time. Baseline b) to Onsala is the one with the longest observation history and most observations in the network. On the intra-German baseline c) to Effelsberg there are only 10 observation sessions so far but they cover a sufficiently long period. The session in November 1996 probably had deficiencies since its result obviously deviates from the other results and deteriorates the wrms.

The baselines d), e), f) from Wettzell to the Italian stations show strongly significant baseline length rates. Although the repeatabilities are excellent, there are still periodicities to be recognized in all three baseline plots. Especially the summer months of 1994 and 1996 show longer baseline length results than is expected from the regression line. A possible reason for this may be the larger amount of atmospheric water vapor in summer and its effect on the radio signal propagation.

Baseline g) to Madrid has a long observation history and a small baseline length rate is significantly determined. Baseline h) to the Yebes does not yet have enough observations to determine a reliable baseline rate. Baseline i) to Simeiz shows an incomparable large scatter. Mainly technical problems at the Simeiz observatory [Bajakova et al., 1996] are the reason for the poor results. Hopefully the new Hydrogen Maser which was installed at the end of 1997 will help to improve the repeatability in the future. The baseline length results for the latter two stations are premature so far.

6 Results for horizontal and vertical station movements

Additionally to the baseline results, horizontal and vertical drift components for the stations were calculated. A global drift of the European plate was subtracted from the individual station coordinates according to the NUVEL-1A-NNR plate tectonic model [De Mets et al., 1994] and so yielded a European fixed system. Cartesian coordinates were transformed into ellipsoidal ones using the GRS80/WG84 ellipsoid parameters and so time series for the evolution of the stations in East and North direction and ellipsoidal height resulted. Horizontal and vertical station velocities with respect to the Eurasian plate were determined from these time series. Figures 3 and 4 show the results in a graphic representation, table 2 lists the determined horizontal and vertical velocities. The stations Ny Ålesund, Yebes and Simeiz are not discussed and not shown in figures 3 and 4 since their observation history is not long enough to give reliable topocentric velocities.

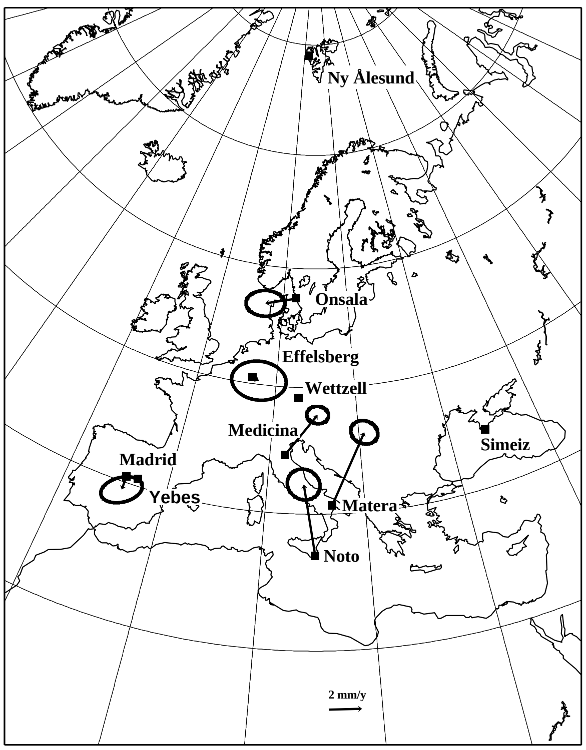

Figure 3: Horizontal station movements

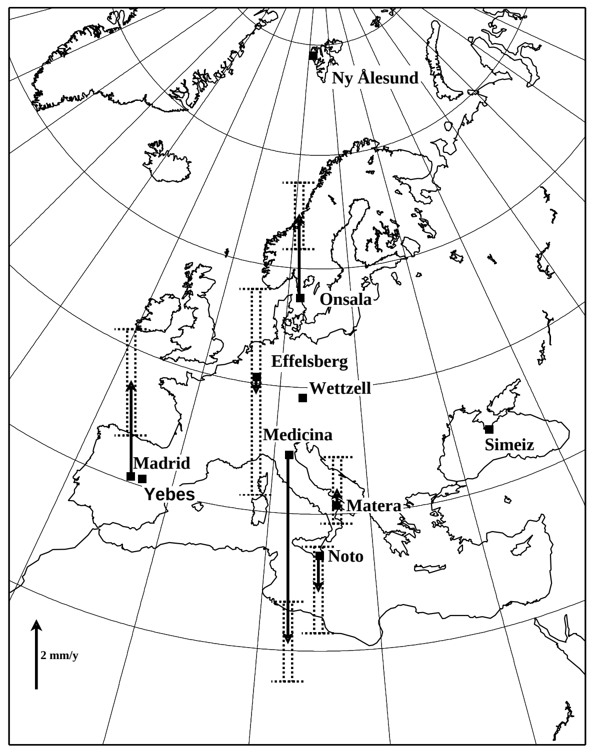

Figure 4: Vertical station movements

The results show clearly, that the Italian stations are heavily affected by the northward push of the African plate. The motion of Noto and Matera confirms that these two stations are situated on the Adriatic promontory of the African plate which is penetrating far into the European domain [Mueller and Kahle, 1993]. Even at Medicina the thrust by the African plate is still large enough to produce a consistent motion in a north-easterly direction.

The horizontal results for Onsala, Effelsberg and Madrid show that these parts of Europe currently do not encounter any tectonic motion comparable in size to that of the Mediterranean. A small west-south-west drift of Onsala can be due to post-glacial rebound in Fennoscandia [Mitrovica et al., 1994].

Mitrovica et al. [1994] predict post-glacial uplift of Onsala of +1.7 mm/year which compares reasonable with the result of 2.4 ± 1.0 mm/year presented here. Probably the uplift of Madrid has rather local than geotectonic explanation since conventional survey supports this suspicion. Man made deformations in the Po valley due to ground water and gas extraction explain the subsidence of Medicina [Tomasi

Table 2: Horizontal and vertical velocities

Station	East rate [mm/y]	wrms [mm]	North rate [mm/y]	wrms [mm]	Height rate [mm/y]	wrms [mm]
Effelsberg	$+0.4 \pm 0.7$	3.9	-0.2 ± 0.5	2.7	-0.4 ± 3.1	9.3
Madrid	-0.0 ± 0.5	4.3	-0.8 ± 0.4	4.2	$+2.8 \pm 1.6$	14.0
Matera	$+2.0 \pm 0.3$	3.1	$+4.3 \pm 0.3$	3.7	$+0.4 \pm 1.0$	11.6
Medicina	$+1.8 \pm 0.3$	3.4	$+2.5 \pm 0.2$	2.2	-5.6 ± 1.3	7.9
Noto	-0.7 ± 0.4	4.1	$+4.3 \pm 0.4$	4.5	-1.0 ± 1.3	10.5
Ny Ålesund	-8.8 ± 4.0	13.7	-0.1 ± 1.3	5.8	$+0.6 \pm 3.4$	11.0
Onsala	-1.8 ± 0.5	3.8	-0.3 ± 0.3	3.8	$+2.4 \pm 1.0$	15.0
Simez	$+0.7 \pm 2.4$	10.4	$+1.2 \pm 1.8$	3.4	$+5.2 \pm 7.5$	45.7
Yebes	-3.1 ± 2.3	3.0	-1.5 ± 1.9	0.8	-42.7 ± 8.8	6.3

et al., 1997]. Since the analysis treated Wettzell as reference station with zero vertical motion, any real vertical motion at Wettzell has to be added to the numbers presented here. The predicted subsidence of Wettzell due to post-glacial rebound is 0.1 to 0.4 mm/y [Mitrovica et al., 1994]. This topic is under further investigation.

9 Conclusions and outlook

Operating now nearly 9 years, the European geodetic VLBI network provides reliable and high accurate geodetic results for baseline length measurements and station coordinates. However, the three recently added stations need still more observations to improve their reliability.

The results can be used to infer present-day tectonic activities in Europe. In addition network may serve as precise reference for densification of local and regional networks with other geodetic techniques.

Since horizontal station motion is already observed giving excellent results, the main interest focuses now on the vertical component. The approach to improve the determination of the vertical is to optimize equipment, observing strategies, refraction models and analysis methods. This includes the application of atmospheric loading effects and corrections due to thermal deformation of the radio telescopes.

For the future a further extension of the network to the East and the North is desirable. This would allow an improved tie to the stable east part of the European plate and an improved determination of post-glacial rebound effects.

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