# EUREF Contribution to ITRF2000 and Analysis Coordinator Report for 8/99 – 6/00


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**Abstract.** Since 1996 the EUREF permanent network is built up and now comprises more than 90 permanent GPS tracking sites in Europe. For the new edition of the ITRF a multi year solution with velocity estimation at the mm/yr level was computed from the EUREF products. In addition to the results of this combination the status and new developments during the last year are summarized. They are related to the move of the weekly combination computation to BKG. Quality and problems of the EUREF products are presented. New projects and processing guidelines are discussed.



**Keywords.** EUREF, reference system, reference frame, GPS, permanent GPS networks, ITRF


## 1 Introduction

The EUREF permanent network EPN is continuously increasing, both in view of the number of sites and of the extension. Figure 1 shows the number of sites over time since the start of the EUREF combination in Jan. 1st. 1996. Figure 2 depicts the current configuration of tracking stations included. About 50% of the 93 active EUREF sites are also used by IGS. Sites outside Europe are included to better monitor the motion of the Eurasian Plate versus the neighboring plates. Weekly SINEX (Solution Independent Exchange Format) files of the 12 Analysis Centers (LAC) are combined to produce the EPN combination solution. This combination is computed and distributed at BKG since July 1999, following a redistribution of tasks within CODE (Center for Orbit Determination in Europe). The new position of a EUREF Analysis coordinator was appointed to be a representative of BKG as well.

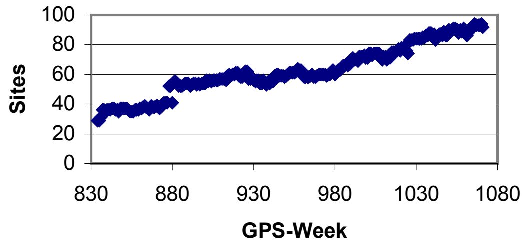


**Fig. 1.** Growth of the permanent network EPN with time.

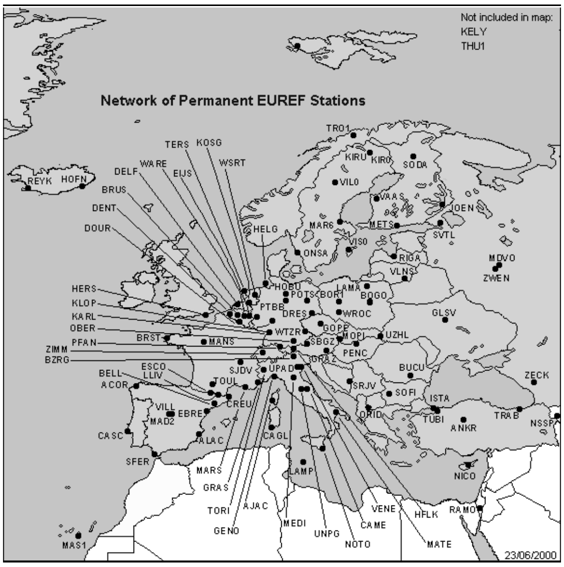


**Fig. 2.** EUREF permanent Network EPN as of June 2000, with 93 stations.

## 2 ITRF2000 Contribution

In 1999 the IERS (International Earth Rotation Service) placed a call for contributions to the next edition of the ITRF, the ITRF2000. EUREF, as a Regional Network Associated Analysis Center of IGS, contributed a multi year combination solution of the EUREF weekly solutions. It is a densification solution to be combined with the contribution of the global GPS and other space technique solutions.

### 2.1 Software selection

The combination was computed using the new version of the program ADDNEQ, named ADDNEQ2. For the use with the EUREF regional network it should basically work like the old program, which is still in use at BKG for the weekly combinations. However, for training and comparison purposes, the new version was used and a short introduction is given below.

The program ADDNEQ2 is a newly developed software tool for the combination of normal matrices. The author of this program wanted to benefit from the experience with older software tools (program ADDNEQ), improve the program's functionality, implement better algorithms and write a source code that is compact, readable, and easy to maintain and modify. The program ADDNEQ2 provides a test concept for the further development of the Bernese GPS Software. The performance of the ADDNEQ2 program is based on a combination of a limited set of basic operations on normal equation matrices. These operations are:

- Changing the auxiliary parameter information.
- Scaling the normal equation systems.
- A priori transformation of the coordinates into different reference frame.
- Changing the a priori values.
- Changing the validity interval of the parameters (it means if any time-dependent parameter is modeled by a piece-wise linear function, it is possible to join two or more intervals together, which reduces the number of parameters).
- Parameter stacking.
- Constraining of the parameters.

Constraining of the parameters may be performed in many different ways. It is, e.g., possible to constrain either the rectangular coordinates of the stations or their ellipsoidal coordinates, it is possible to introduce different forms of the free network conditions etc. The results of the program ADDNEQ2 are available in different formats (e.g. SINEX).

### 2.2 Free Network Conditions

GPS in principle is an interferometric technique. Therefore it is in general not possible to estimate the absolute position of all stations. Some of them (at least one) have to be kept fixed on their a priori positions or so-called free network conditions have to be introduced. Free network conditions are based on the assumption that there are two reference frames:

- a priori reference frame
- The reference frame of the resulting coordinates.

Both reference frames are related to each other by the well-known 7-parameter Helmert transformation with offset, rotation and scale parameter. The idea of free network conditions is based on the requirement that some of these seven parameters are set equal to zero.

The free network condition is imposed by adding fictitious observations to the normal equation system. In local networks, usually 6 or all 7 free network conditions have to be introduced. In global solutions, it is sufficient to constrain only the rotation parameters. This is the minimal constraint for the GPS network.

### 2.3 Estimation of Station Velocities

Station velocities are not estimated directly in the program ADDNEQ2. Instead of that, each station coordinate is modeled by two parameters $x_1$, $x_2$, corresponding to time epochs $t_1$, $t_2$ according to the following Figure 3:

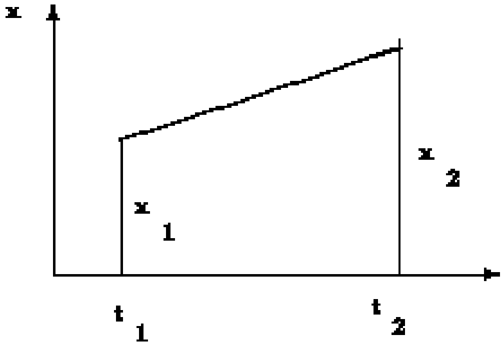


**Fig. 3.** Modeling of time dependent parameters in ADDNEQ2.

Constraining of the station coordinates may be done in many different ways. It is e.g. possible to constrain the parameter $x_2$ relatively to $x_1$, which is nothing but constraining the station velocity. Using the free network conditions described above it is possible to apply them on either one of two epochs $t_1$, $t_2$ or on both of them.

## 3 Numerical Results for ITRF2000

As input to the multi year solution weekly SINEX files were available from GPS week 834 to 1042. However, the first half of 1996 was originally processed in the ITRF93 reference frame. This means, that the reference frame of these solutions is not consistent with the ITRF94 used from GPS week 860 onwards. Therefore the weeks 834 to 860 were omitted and not used for the combination in order not to introduce discontinuities weakening the solution. Moreover the noise in the time series during this period is higher due to inferior orbit quality. The combination solution is summarized in Tables 1 to 3.

The so-called STACRUX-file, containing all information on site changes, antenna changes etc. of EUREF, which is available at the Central Bureau was used to assure the generation of consistent coordinates and velocities. In addition less than 15 outliers were eliminated. At some sites discontinuities in one of the coordinate components occurred which could not be associated to logged changes in eccentricities or antennas.

**Table 1** Summary of EUREF contribution to ITRF2000.

| | |
|---|---|
| Observation interval: | Week 0860 – 1042 |
| Time period | June, 30, 1996 – January 1, 2000) |
| Number of GPS weeks used | 183 |
| Number of weeks neglected | 26 |
| Program used | ADDNEQ2, Bernese |

**Table 2** Sites with offsets in the time series modeled as two independent sets of coordinates.

| Station Name | Start Epoch of Second Coordinate Solution |
|---|---|
| | YYYY MM DD HH MM SS |
| ANKR 20805M002 | 1999 08 15 00 00 00 |
| HERS 13212M007 | 1999 04 25 00 00 00 |
| PFAN 11005S002 | 1999 10 31 00 00 00 |
| TRO1 10302M006 | 1998 12 27 00 00 00 |
| ZIMM 14001M004 | 1998 11 08 00 00 00 |

**Table 3** Statistics of EUREF contribution to the ITRF2000.

| | |
|---|---|
| Number of stations | 95 |
| Additional coordinates of identical sites | 5 |
| Number of sites with velocity estimation | 82 |
| Number of input NEQ-files | 183 |
| Number of Observations: | 9583735 |
| Number of Parameters | 5835305 |
| Number of Unknowns | 600 |
| A posteriori RMS | 0.0036 m |

These sites are listed in Table 2 and for them one velocity but two sets of coordinates for different time periods were estimated. In addition, sites which a recording history shorter than 6 months were constrained to their NUVEL 1A NNR velocities. The quality of the solution is documented by the distribution

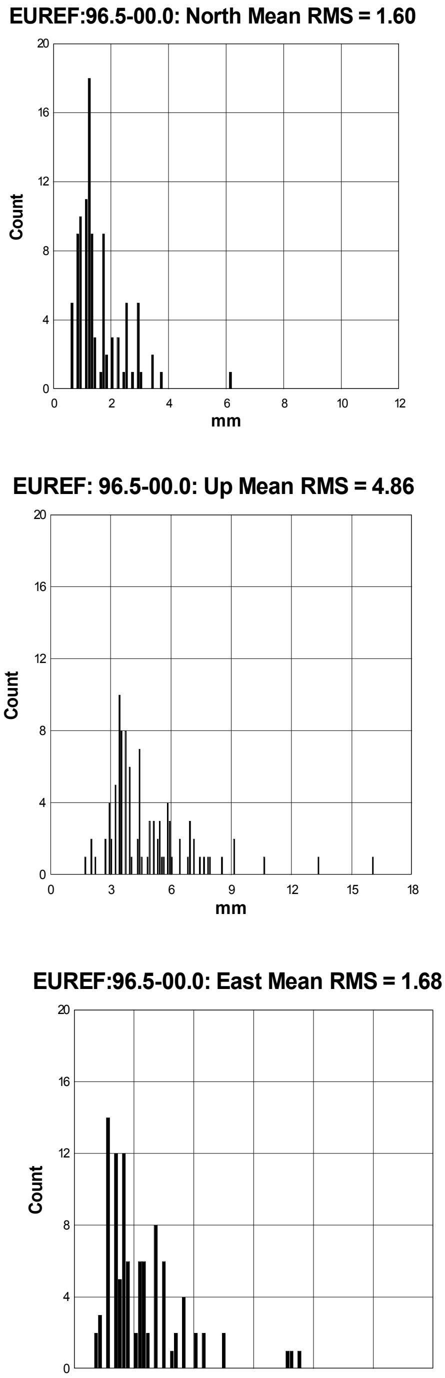


**Fig. 4-6.** Residual rms of weekly solution versus the multi year combination.

of residuals of weekly solutions versus the combined solution, shown in Figures 4 to 6.

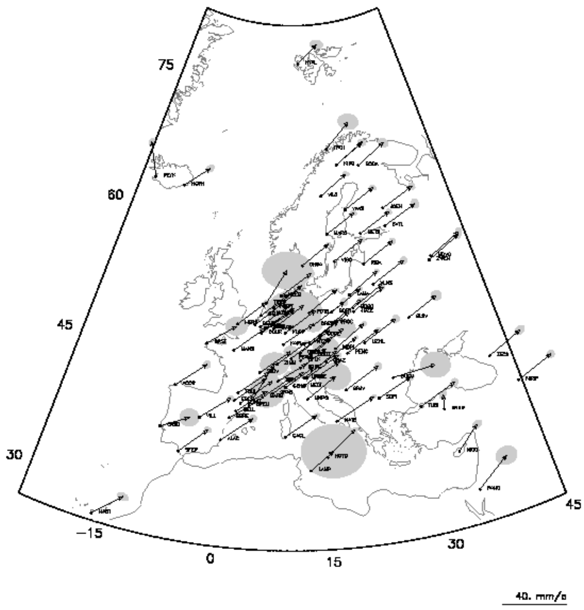


**Fig. 7.** Velocities of the unconstrained solution for the EUREF contribution to ITRF2000. Formal error ellipses are scaled by a factor of 15 for the plot.

Figure 7 shows the resulting velocity field with now about 20 more stations than previously available in the ITRF97. Formal velocity errors are in the order of 0.20 and 0.24 mm/yr and have to be scaled for a realistic error assessment. This, as well as the interpretation of these newly determined dense velocity field for Europe is presently under investigation. Further studies on the optimal technique for connecting to the ITRF, see e.g. (Davies and Blewitt, 2000), as well as the new ITRF2000 values will be used for this study. In a first test the fit of this solution to a global GPS solution of CODE (Springer, pers. comm.) is about 0.9, 2.7 and 4.9 mm at a central epoch for the 38 sites in common.

4 Analysis Coordinator Report

The analysis coordinator AC of the EPN is responsible for the weekly combination procedure at BKG and also for the general performance of processing. He develops advancements in guidelines, strategies and quality control. The AC is one part of the new structure of the EPN as established at its Tenth Symposium in Tromsø, June 22-24, 2000

(Resolution no 2 of the Tromsø Symposium, this volume) with an EPN Coordination Group, an EPN Central Bureau, and EPN Special Projects.

### 4.1 Analysis Centers

Local Analysis Centers process sub-networks out of the EUREF permanent network following the rules and guidelines for distributed processing of IGS and EUREF. Today 12 local Analysis Centers are involved in the data reduction procedure:

1. **ASI,** Centro di Geodesia Spaziale - Matera/I
2. **BEK,** Bayerische Kommission für die Internationale Erdmessung - München/D
3. **BKG,** Bundesamt für Kartographie und Geodäsie - Frankfurt/D
4. **COE,** Center for Orbit Determination in Europe - Bern /CH (CODE)
5. **GOP,** Geodetic Observatory Pecny -Pecny/CR
6. **IGN ,** Institut Geographique National - Paris/F
7. **LPT,** Bundesamt für Landestopographie - Wabern/CH
8. **NKG,** Nordic Geodetic Commission GPS data Analysis Center - Onsala/S
9. **OLG,** Institute for Space Research - Graz/A
10. **ROB,** Royal Observatory of Belgium - Brussels/B
11. **UPA,** University of Padova - Padova/I
12. **WUT,** Warsaw University of Technology - Warsaw/Pl

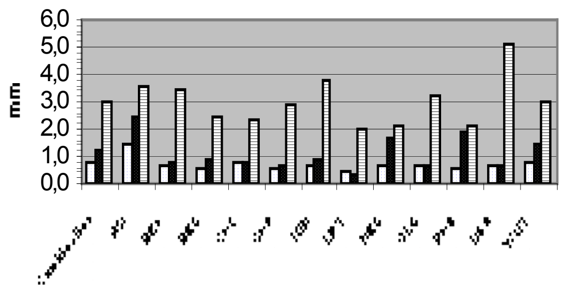


**Fig. 8.** Average rms values of the weekly EPN combination solutions and individual LAC rms (north, east, up). Average rms for the combinations is 0.7, 1.2 and 3mm for the north, east and up components.

The combination of their weekly submissions has an average residual rms in the order of 0.7, 1.2 and 3.0 mm for the latitude, longitude and height components respectively, see Figure 8. By an outlier rejection procedure based on a loosely constrained network solution and, in addition, by checking each weekly solution is against the previous six weeks, anomalous sites are identified and eliminated. In the average about two to three stations of a single LAC, and 1 to 2 stations have to be eliminated completely from the combination. The final combination solution is then submitted to the CDDIS for the global combination into the so-called P-network. The latter is a weekly combination of the results of the seven Global Analysis Centers of the IGS and all regional solutions, see (Davies and Blewitt, 2000) for details on the procedure. As seen in Figure 2, the individual rms of most of the individual solutions is lower than that of the combined solution, especially in height. This indicates, that there are still systematic differences between the results, which show up at the common sites between the different LACs.

Problematic sites known to show systematic differences between the solutions of individual LAC's are e.g. VENE, GRAS, HERS, TUBI, MAD2, LAMA. To each of these sites a special investigator is appointed in order to resolve the reasons for the discrepancies e.g. by

- Looking into the GPSEST estimation ofthe LAC's involved,
- In contacting the other LACs involved
- Looking at the available number of observations versus the used observations
- Computation of local base lines
- Evaluating the data quality at the site. E.g. by teqc

An other important point is the delivery time of LAC's solutions. In view of the high quality of IGS-Rapid obits and CODE-orbits the EUREF processing standards, which presently prescribe the use of official IGS products, will be modified to allow the use of individual IGS Analysis Center products instead of the finals. For Europe e.g. the CODE orbits and EOP may be used. This should lead to an earlier delivery time of LAC's solutions, i.e. decreasing the time delay to 2 instead of 3 weeks. This will allow the coordinator to make quality control before delivery of the products to the CDDIS. Also a feedback to and from the LACs before submission would be possible.

### 4.2 Time series of EPN sites

The analysis of the EPN time series clearly indicates the deteriorating effects of antenna modifications, antenna changes or changes at the site. Even using the updated IGS antenna phase center calibration Tables, residual effects in the mm to cm range may occur. Stations with such problems are ZIMM, PFAN, LAMA, MOPI, MATE, among others. Additional problems show up on some Nordic sites due to snow and other disturbances from weather and environment, leading to an increased noise level in the time series. The installation of the EPN special projects "MONITORING OF THE EUREF PERMANENT NETWORK TO PRODUCE COORDINATE TIME SERIES SUITABLE FOR GEOKINEMATICS" is designated to investigate these effects in more detail. This may lead to increased consistency by quantifying the noise level of each site individually for quality control.

## 5. Alternative processing strategy for EUREF

The LACs are processing the network according to the EUREF guidelines developed in 1996 (Bruyninx et al., 1997). With the use of Bernese Version 4.2 it is now possible for all LAC's to use more advanced processing options as there are:

- Elevation cutoff 15° / 10° / 5°
- Elevation dependent weighting
- Niell mapping function
- Use of Ocean tidal loading corrections (already recommended and implemented).

The processing strategies for the EPN have to be updated following the advancement in modelling (height, troposphere), software, corrections (antenna calibration, Ocean tidal loading etc.) and the densification of the network. After a test phase to be initiated in 2000, which is intended to ensure a smooth transition without deteriorating the time series of coordinates obtained for the EPN so far, a new processing strategy will be implemented for the EPN analysis centres. Discussion on and examples of the consequences of such a change can be found in e.g. (Rothacher et. al, 1998).

A change of the above mentioned parameters might introduce a site-dependent offset in the coordinates. Therefore it is anticipated to perform a test of the consequences of such a change to the EUREF site coordinates. For a week to be defined, the LACs are then asked to process their networks with these options in parallel and in addition to their standard processing.

The goal is to assess the changes to be expected in the EUREF time series in case of a final adoption of new processing options.

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