The EUREF Permanent GPS Network

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Abstract. The EUREF permanent network is built up since 1996 and comprises about 90 permanent GPS tracking sites in Europe. It serves as the realization of the ITRS and the European reference system ETRS89. The organization of the network follows the IGS guidelines and standards. It is a densification of the global IGS network and integrated to the global polyhedron of permanent GPS sites monitoring long and short-term variations in geocentric station coordinates. In this paper we give a description of the status, performance and precision of the network and the resulting coordinate time series. The applications and further developments in view of geodetic, geophysical and meteorological applications are shown.

1. Introduction

Within the IAG commission X, EUREF is a sub-commission, which is responsible for the maintenance of the European Reference System ETRS89. Members of the group are mainly federal survey authorities, universities and research institutes interested in the realization of a unified horizontal and vertical reference frame. Since 1995, the epoch-wise EUREF GPS campaigns were replaced to a great extent by the installation of the EPN, the EUREF Permanent GPS Network. This was fostered by the global IGS network seeking for regional densifications and in 1996 the EPN was accepted as a regional Network Associate Analysis Center (RNAAC) of the IGS for Europe. The initial number of 30 stations grew to more than 90 stations to date

EUREF, in general, is not only concerned with the EPN and GPS, but also with the definition, realization and introduction of a unified European vertical reference system. This also includes physical information from repeated leveling and other gravity-field related measurements of the potential. In combination with the EPN and the EUREF epoch network stations, an integrated, unified European Spatial Reference System for geospatial referencing of GIS data is to be installed.

The EPN and EUREF activities, due to their accuracy and continuity, increasingly contribute to a variety of scientific investigations, like geokinematics and meteorology. This contribution was formally endorsed by the 9th EUREF Symposium in Prague (Czech Republic) in June 1999. By a major reorganization of the EPN in analogy to the structures which proved successful in the IGS and the installation of special projects in 2000, EUREF is facilitating and promoting the use of the EPN data for studies in all relevant fields. This includes also the integration with other networks in multi-disciplinary applications.

2. EPN Management and new Structure

Since its start in 1995, the activities within the EPN are coordinated and guided by the EUREF Technical Working

Group (EUREF TWG). The permanent network was coordinated by a dedicated the network coordinator. With the growth of the network and the tasks involved, EUREF now accepted a re-organization at its 10th assembly in Tromso, Norway, June 22nd-24th, 2000.

The new structure is described in detail at the EUREF homepage (ORB, 2000). Three units were defined which manage and develop the EPN. These are

- The EPN Coordination Group CG
- The EPN Central Bureau CB
- The EPN Special Projects SP

The EPN CG coordinates all activities related to the EPN an is composed by the network coordinator (C. Bruyninx, ORB), the data flow coordinator (G. Stangl, OLG), the analysis coordinator (M. Becker, BKG), a representative of the TWG (W. Gurtner, AIUB) and the special projects liaison persons. The CB is in charge of the general day to day management of the EPN stations, data and products. It provides internet based databases and access to the EUREF products, maintains e.g. site logs and associated information, and monitors the quality of data and products (ORB, 2000). The special projects are intended to study newly developing demands and activities based on EPN data and their potential use. Presently two special projects are ongoing, the "*Generation of an EUREF-troposphere product*" (G. Weber, BKG) and "*Monitoring of the EPN to produce coordinate time series suitable for geokinematics" (A. Kenyeres, FOMI).* Special projects, if successful, may, turn to EPN products after a 4 year project term.

3. EPN Status

3.1. Tracking Network and Data Flow

In Figure 1, the present configuration of the EPN is shown. It comprises almo st 100 sites in EUROPE. However, so called associated EUREF sites e.g. in Israel (RAMO) or Armenia (NSSP) are included for the study of the motion of the European plate versus the neighboring plates. All EUREF sites are obliged to comply to the EUREF standards, i.e. to fulfill stringent requirements on their documentation, maintenance, data availability etc, see (ORB, 1996).

About half of the EPN sites are also belonging to the IGS network. This is accomplished by the fact, that EUREF strictly follows the IGS standards, e.g. in using the antenna phase center corrections of IGS and all other conventions.

Data are submitted in Hatanaka-compressed RINEX-format to 6 local, one regional (BKG) and one global (IGN) data centers in 24 h batches. Since 1998 efforts have been taken to switch to hourly data submission as needed for near real time applications. Since June 2000 38 out of the 93 stations are submitting hourly data. These are available at the regional and global data center within a few minutes after each full hour. BKG (2000) keeps statistics on latency and availability. The problems of incomplete or missing files, which also cause gaps in the concatenated daily data files, fallback strategies as well as the problem of mirroring the regional data center are presently investigated by the data flow coordinator in order to develop robust procedures for near real-time applications.

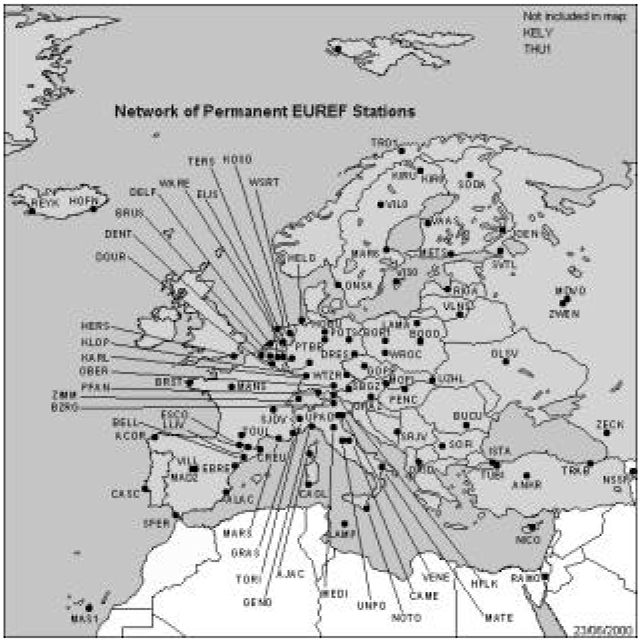

Figure 1. EUREF permanent Network EPN as of June 2000, with 93 stations.

3.2. Data Analysis

The stations EPN are grouped so as to form sub-networks which can be distributedly processed in presently 12 local analysis centers ((LAC). The overlap is designed to have each GPS station be processed by at least three LAC's. Presently 90% of the sites are processed by three LAC's, 8% by four and 2% by two only. Analysis Centers and the number of sites processed is given in Table 1.

Table 1. Analysis Centers of the EPN

Acronym	Name	Software	Stations
ASI	CGS Centro di Geodesia Spaziale "G. Colombo", I	Micro Cosm 9800.	19
BEK	Bayerische Kommission für die Internationale Erdmessung, D	Bernese 4.2	35
BKG	Bundesamt für Kartographie und Geodäsie, D	Bernese 4.2	37
COE	Center for Orbit Determination in Europe, CH	Bernese 4.3	37
GOP	Geodetic Observatory Pecny, CR	Bernese 4.2	22
IGN	Institut Géographique National, F	Bernese 4.2	15
LPT	Bundesamt für Landestopographie, CH	Bernese 4.2	16
NKG	Nordic Geodetic Commission, S	Bernese 4.2	26
OLG	Austrian Academy of Sciences, A	Bernese 4.2	28
ROB	Royal Observatory of Belgium, B	Bernese 4.2	21
UPA	University of Padova, I	Bernese 4.2	16
WUT	Warsaw University of Technology, P	Bernese 4.2	26

The LAC are processing the network according to the EUREF guidelines developed in 1996 (Bruyninx et al., 1997) in order to produce homogeneous solutions. Weekly SINEX files of each sub-network are submitted to BKG, which are used to generate a weekly regional network (R-network) solution for submission to the IGS. The average residual rms of these weekly combination is in the order of 0.7, 1.0 and 3.0

mm for the latitude, longitude and height components respectively, see Figure 2. By an outlier rejection procedure based on a loosely constrained network solution and in addition each weekly solution is checked against the last six weeks. 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 Centres of the IGS and all regional solutions, see (Davies and Blewitt, 2000) for details on the procedure.

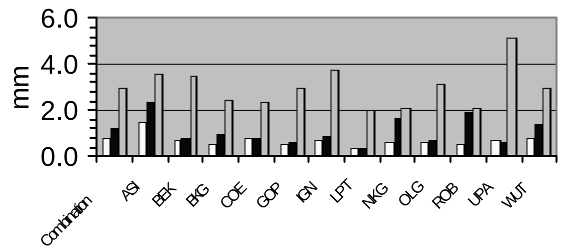

Figure 2. Average rms values of the weekly EPN combinations solutions for the 1999 and individual LAC rms (north, east, up). Average rms for the combinations is 0.7, 1.2 and 3mm for the north, east and up components.

4. EUREF Products

Presently the main products of the EPN are the weekly solutions and the weekly combination solution. They are accessible via ftp or in the internet at the Central Bureau in Brussels (ORB, 2000). In addition a wealth of information is presented at the CB, including detailed site-documentation with status, log-files documenting all changes at the site and its hardware-setup. Time series generated from the weekly solutions fixed to the ITRF97 reference frame are available which show the noise, the trend and any discontinuities and problems of the data or the site. The time delay in providing the products presently amounts to about three weeks after the observations. This is due to the fact that preferably the IGS final products for Earth orientation and GPS Orbits are used in the EUREF LAC's. However, to date the quality of individual Global Analysis Centers orbits is sufficiently accurate to be used in an network of the size of EPN. This may lead to a more rapid delivery of products.

In addition to the official EUREF products and sites, each of the 12 LAC computes its own densification of its EUREF network-part. These stations serve for the densification and maintenance of the reference frame on a national level. The BKG LAC for example processes about 20 sites in Germany in addition to the 37 EUREF sites.

As contribution to the generation of the respective next issue of the ITRF realization, EUREF computed a multi-year combination of the weekly results. For ITRF2000 presently under evaluation, results from GPS week 860 to 1042 were jointly adjusted. The data and results are summarized in Table 2. A set of 82 coordinate and velocity estimates for the European area was determined, see Figure 3. Formal 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.

Table 2. EPN contribution to ITRF2000.

Observation-Interval:	*GPS Week 0860 – 1042*
Time period	June, 30, 1996 – Jan. 1, 2000
Number of GPS weeks used	183
Number of weeks neglected	26
Program used	ADDNEQ2, (Bernese 4.2)
Number of stations	95
Additional coordinates of identical site	5
Number of sites with velocity	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

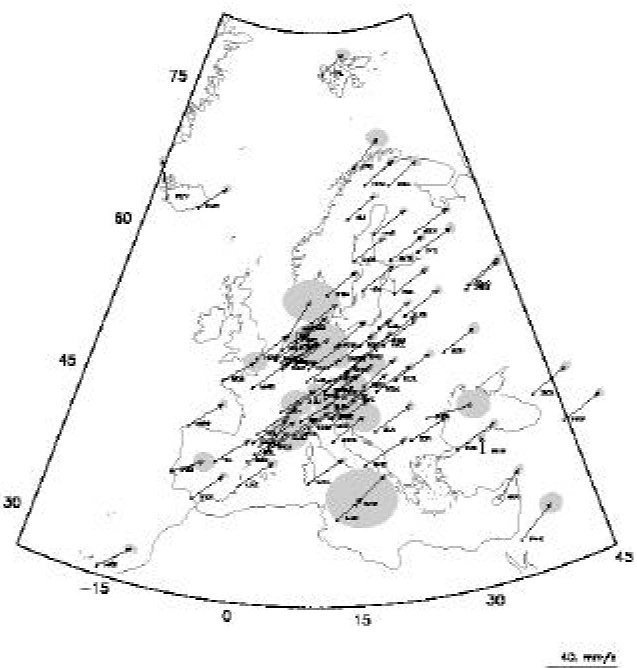

Figure 3 Velocities of the unconstrained solution for the EUREF contribution to ITRF2000. Formal error ellipses are scaled by a factor of 15 for the plot.

5. Outlook and Applications

The EPN products and solutions will be of great impact for the users interested in coordinate times series. Due to the increasing density of the network it will be valuable for the interpretation of present day kinematics within Europe and its adjacent plates. In addition the vertical component of station coordinates is of increasing importance in view of the Global Change phenomena and the definition of a vertical reference system for Europe. It is to be expected, that the combination of GPS and precise geoid computation will replace the slow and too costly leveling in regional scales. However, for this task still a number of open problems in the GPS height determination has to be solved, e.g. the questions of elevation-cutoff, troposphere estimation strategy and the proper integration of regional and local networks to the global reference, see e.g. (Rothacher and Beutler, 1998).

For the EPN the following points will be of major interest in the next years.

- The use of the EPN for tropospheric water vapor determination. Whereas for long term climatological studies a consistent series of tropospheric zenith path delay (ZPD) is required, the weather forecast needs near real-time data. Pilot studies within the COST 716 project are under way using suitable subsets of the EPN (VanderMarel and Pesec, 1999). For this topic a special project within EPN was established which will investigate the optimal strategies for ZPD estimation.

- The processing strategies for the EPN have to be updated following the advancement in modeling (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 AC’s. Discussion on and examples of the consequences of such a change can be found in (Rothacher et. al, 1998).

- The integration of additional sites or other regional or local networks into the EPN. Presently the EPN does not accept new sites close to existing sites if they do not provide additional information. This is due to the fact, that EUREF and EPN are sought to establish a long lasting reference frame over entire Europe, with highest possible precision and a homogenous distribution of the sites. If on the other hand, tide gauge stations provide permanent GPS observations; this would be a valuable addition. How to integrate them, on a site-by-site basis or in the distributed processing approach, as a further sub-network analyzed separately, has to be discussed. In general, all multi-sensor sites, e.g. water vapor radiometer sites, tide gauges, will be of interest to the EPN in view of global change studies, provided they full fill the requirements of EUREF on the site quality, documentation and maintenance.

- The use of the EPN for geokinematic will be fostered and supported by the special project on the monitoring of the coordinate time series. This is intended to clearly separate man-made effects, local monument instabilities or special location dependent effects (Multipath, climate, snow) on the GPS estimation results from true site motion in the global reference frame.

Acknowledgments. We thank all members of the EUREF EPN community for their contributions and their continuing effort to improve the network and the analysis.

References

BKG, http://www.ifag.de/Geodaesie/igs.htm, Bundesamt für Kartographie und Geodäsie, Frankfurt, 2000.

Davis, P., G. Blewitt, Methodology for global geodetic time series estimation: A new tool for geodynamics, JGR, Vol. 105, N0 B5, 11083-11100, 2000.

ORB, http://homepage.oma.be/euref/guidelin.html, EUREF Central Bureau, Brussels, 2000.

ORB, http://homepage.oma.be/euref/management.html, EUREF Central Bureau, Brussels, 2000.

Bruyninx, C., D. Ineichen and T. Springer, The EUREF RNAAC: 1997 Annual Report, in International GPS Service for Geodynamics, 1997 Annual Report, Jet Propulsion Laboratory, Pasadena, California, 1997

Rothacher, M., T.A. Springer, S. Schaer, G. Beutler, Processing strategies for regional GPS Networks, in: Brunner (Ed.) Advances in Positioning and Reference Frames, Int. Assoc. of Geodesy Symposia, Vol. 118, Berlin Heidelberg, pp 93-100, 1998.

Rothacher, and Beutler, G., The Role of GPS in the Study of Global Change, Phys. Chem. Earth, Vol. 23, No. 9-10, pp1029-1040, 1998.

Vander Marel H., P. Pesec, Exploitation of ground based GPS for climate and numerical weather prediction applications -Status of Cost action 716, Proc. of "Symposium of the IAG Sub commission for Europe held in June 1999 Prague", Ed. E. Gubler, J.-A. Torres, H. Hornik, EUREF Publication, No. 8, pp. 51-53, 2000.

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