EPN Monitoring: Status and Plans

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1. Introduction

This document summarises the major changes to the EUREF permanent network (EPN) since the EUREF symposium of May 16-18, 2001, held in Dubrovnik, Croatia (*Bruyninx and Roosbeek, 2002*). In addition, based on case studies, we outline the network monitoring tools used and developed at the EPN Central Bureau.

2. Status of the EUREF Permanent Network

2.1 Tracking network

Figure 1 shows the status of the EUREF permanent tracking network as in June 2002. The number of stations is 130. 49 % of them belong also to the IGS network. The 13 new EPN stations that joined the EUREF network since June 2001 are given in Table 1.

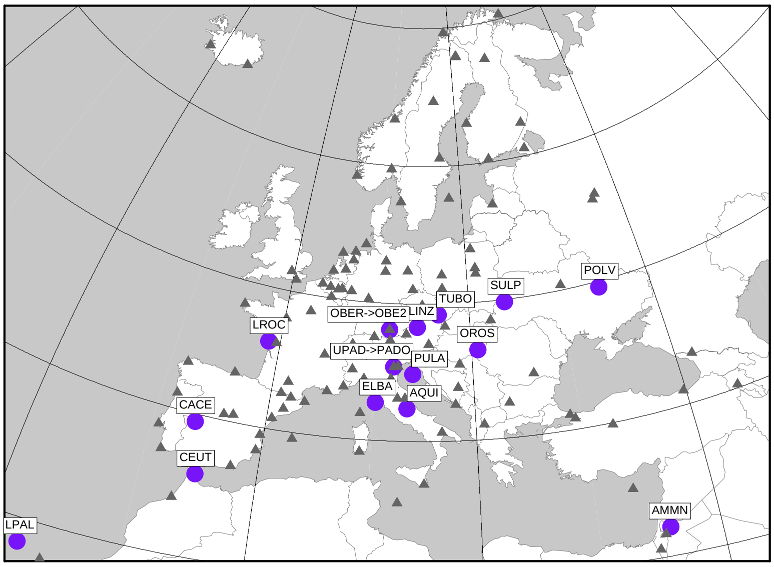

Figure 1 – Stations included in the EUREF permanent network (status June 2002); the big circles show the stations added to the network after June 2001

Station	4 char ID	Country	Lat. (N)	Lon. (E)	Agency	Date
Oberpfaffenhofen	OBE2*	Germany	48.10	011.30	GFZP	12-08-01
Caceres	CACE	Spain	39.48	353.66	IGNE	19-08-01
Linz	LINZ	Austria	48.31	014.28	MLSO	19-08-01
Poltava	POLV	Ukraine	49.60	034.54	SRIGC	09-09-01
Brno	TUBO	Czech Republic	49.21	016.59	RIG	23-09-01
L'Aquila	AQUI	Italy	42.37	013.35	T S.p.A.	14-10-01

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San Piero	ELBA	Italy	42.75	010.22	T S.p.A.	14-10-01
Lviv	SULP	Ukraine	49.84	024.01	NULP	21-10-01
Padova	PADO*	Italy	45.41	011.90	UP	02-12-01
Oroshaza	OROS	Hungary	46.55	020.67	FSGO	09-12-01
Ceuta	CEUT	Spain	35.90	354.69	IGNE	09-12-01
Pula	PULA	Croatia	44.89	013.84	GP d.o.o.	03-03-02
Amman	AMMN	Jordan	32.03	035.88	SOPAC	17-03-02
La Palma	LPAL	Spain	28.45	342.47	IGNE	12-05-02
La Rochelle	LROC	France	46.16	358.78	CLGUR	12-05-02

*: relocation of existing EPN station

GFZP	:	GeoForschungsZentrum Potsdam, Germany
IGNE	:	Instituto Geografico Nacional, Spain
MLSO	:	MA-Linz, Surveyors Office, Austria
SRIGC	:	Science and Research Institute of Geodesy and Cartography – Kiev, Ukraine
RIG	:	Research Institute of Geodesy, Topography and Cartography Geodetic Observatory Pecny, Czech Republic
T S.p.A.	:	Telespazio S.p.A., Italy
NULP	:	National University “Lviv Polytechnic”, Ukraine
UP	:	University of Padova, Italy
FSGO	:	FOMI Satellite Geodetic Observatory, Hungary
GPd.o.o.	:	Geoservis Pula d.o.o., Croatia
SOPAC	:	Scripps Orbit and Permanent Array Centre, US
CLGUR	:	Centre Littoral de Géophysique, Universite de la Rochelle, France

Table 1- New EUREF permanent tracking sites since June 2001

The graph in Figure 2 shows how the EPN has expanded since its start in Jan. 1996.

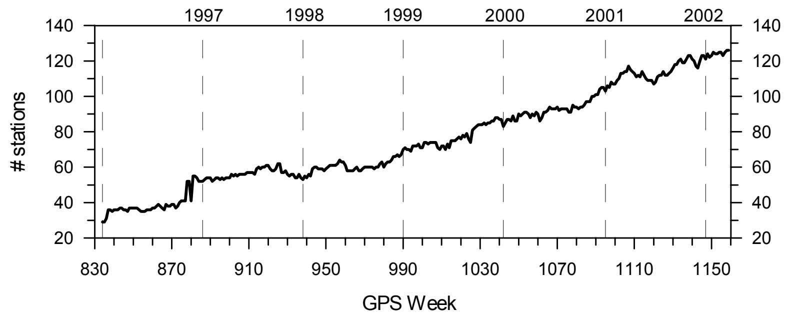

Figure 2 - Growth of the EPN Network

Table 2 gives a list of candidate EUREF permanent tracking sites.

Station	4 char ID	Country	Lat.(N)	Lon.(E)	Agency	Status
København	BUDP	Denmark	55.75	12.60	Nat. Survey and Cadastre	
Diyarbakir	DYR2	Turkey	37.91	40.27	UNAVCO	Recent data not yet present
Gjøvik	GJOV	Norway	60.78	10.68	University College of Gjøvik	Data not yet present
Boras	SPT0	Sweden	57.71	12.89	Nat. Land Survey Of Sweden	Hourly data necessary
Obninsk	MOBN	Russ. Feder.	55.11	36.56	RDAAC-JPL-IRIS	Hourly data necessary
Smidstrup	SMID	Denmark	55.65	09.70	Nat. Survey and Cadastre	
Suldrup	SULD	Denmark	56.85	09.85	Nat. Survey and Cadastre	
Reggio Calabria	TGRC	Italy	38.10	15.65	Agenzia Spaziale Italiana	Hourly data necessary
Trento	TREN	Italy	46.07	11.12	Geological Service, Trento	Data not yet present. Hourly data necessary
Prato	PRAT	Italy	43.88	11.09	Lab. di Topogr. e Fotogram.	Hourly data necessary

Table 2 - Candidate EUREF permanent tracking sites.

In the past year, a lot of EPN stations have made a considerable effort to deliver hourly tracking data, bringing the total number of stations to 72 (Figure 3), which is 55 % of the EPN stations.

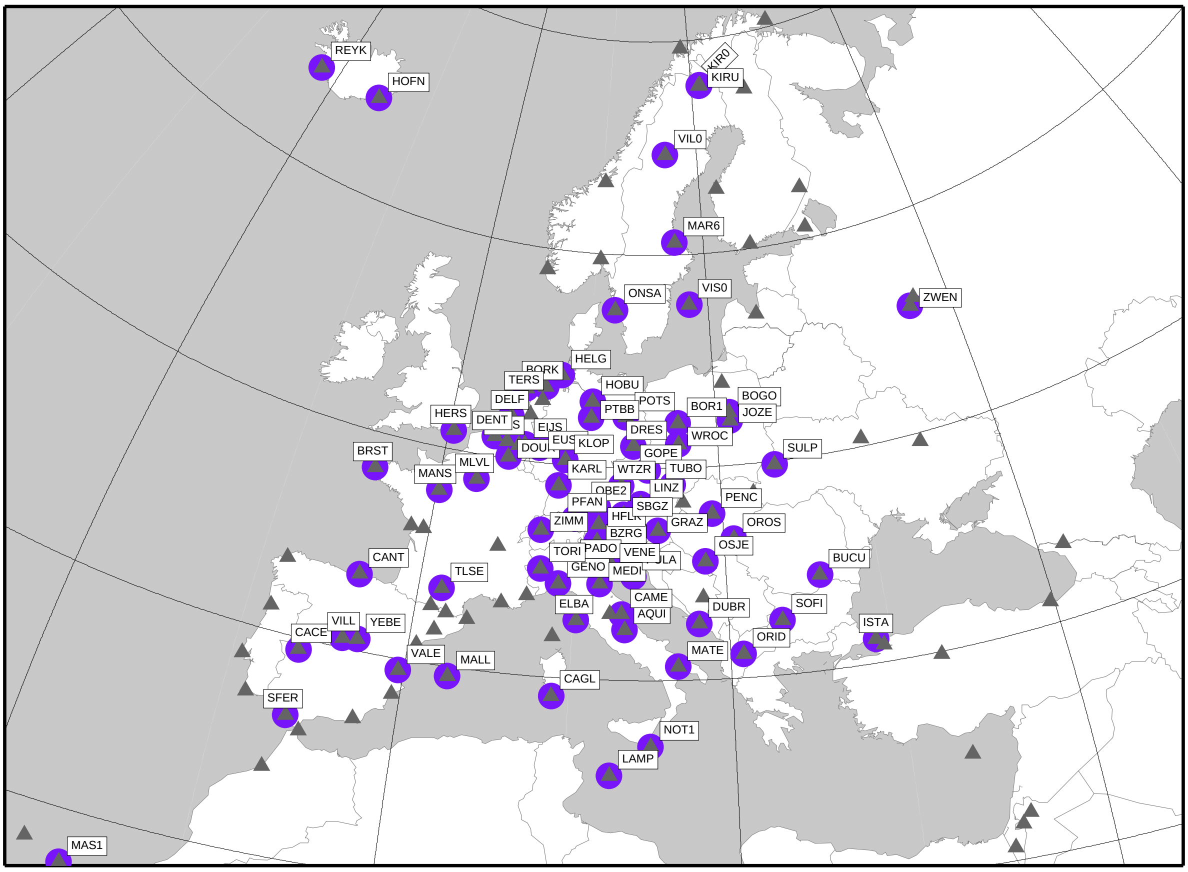

Figure 3 - EUREF stations submitting hourly tracking data

2.2 New hourly Data Centre

Since May 2002, a new hourly data centre was installed at the Geodetic Observatory Pecny, Czech Republic (GOP). This local data (ftp://pecny.asu.cas.cz) is concentrating on the distribution of hourly tracking data from the EPN stations.

2.3. New Local Analysis Centres

In the past year, two new Analysis Centres have started to submit weekly solutions for an EPN subnetwork. They are:

- The Instituto Geográfico Nacional de España (IGE, Spain) started its contribution to the EUREF combined solution in September 2001 (GPS Week 1130). IGE concentrates on the Spanish network of permanent tracking stations (see Figure 4).
- The FOMI Satellite Geodetic Observatory, Budapest, (SGO, Hungary) started submitting solution in December 2001 (GPSweek 1143) for a network of stations distributed mainly in Eastern and Southern Europe (see Figure 4)

Both Analysis Centres use the Bernese software package for the computation of their EPN solutions.

Figure 4 – EPN subnetworks processed by the IGE (left) and SGO (right) analysis centres

3. EPN AC Workshop

A third EPN Analysis Centres (AC) Workshop took place from May 31 to June 1, 2001 in Warsaw, Poland.

3.1. New AC Guidelines

At this workshop, it was agreed to update the analysis strategy of the EPN AC’s starting from GPS week 1130. The new guidelines include the following topics:

- Use IGS Orbits
- Apply Ocean Loading Corrections
- Use 10° elevation cut off angle and apply elevation dependent weighting. AC's who can not use an elevation dependent weighting scheme are recommended to continue using a 15° elevation cut off angle
- No a priori troposphere model, estimate zenith path delays using Dry Niell Mapping function
- Include rms of unit weight in weekly SINEX submission
- Fix ambiguities

3.2 Contributions to the troposphere Special Project

The goal of the EPN Special Project on the Troposphere is to generate an EPN troposphere product, presently concentrating on a post-processed ZTD product. This activity will not require any substantial additional computations from the ACs as the ones presently done for their routine submission to the EUREF combined SNX solution.

Guidelines for the generation of the TROP_SNX files (standard format for the exchange of ZTD) are:

- Estimate hourly troposphere parameters
- Create daily Troposphere SINEX (in SINEX_TRO format) solutions using a step-wise procedure:
  1. Save troposphere parameters in daily normal equation files,
  2. Use normal equations from step 1. to generate a weekly SINEX solution tied to the ITRFxx
  3. Re-generate the daily SINEX_TRO files with coordinates fixed to the values of step 2.
- Include troposphere estimates from a global network as a priori values (optional)

3.3 Contributions to the Time Series Special Project

One of the goals of the EPN Time Series Special Project is to determine a unified velocity field over Europe and its surrounding zones. Since the network of EPN stations is not dense enough for this purpose, this project aims at expanding the present EPN network with additional stations. The chairman of the "Time Series" Special Project (A. Kenyeres) has asked AC's to provide him with:

- List of the non-EPN stations routinely processed by the AC
- Site history of the non-EPN stations
- SINEX solutions from the non-EPN stations

4. EPN Coordinate Time Series

In the past years, there has been quit a number of confusion concerning the 'standard' coordinate time series made available at the EPN CB web-site. As explained in previous papers, these standard coordinate time series are the result of one cumulative solution (completely reprocessed each week at the EPN CB), based on the EPN weekly combined solutions. They do not display directly the coordinates given in the EPN weekly combined solutions as computed at BKG independent from each other. In order to remedy to the confusion, the coordinate time series have been extended by introducing two different types of time series: the ITRS and ETRS89 time series. Both use the EPN weekly combined solution as basis, without recreating a new cumulative solution. Four different types of time series are now made available. They are:

1. The ITRS time series (updated weekly)
   Purpose:
   - Evaluate influence of the different ITRS realizations on the station coordinates
   - Visualise large periodic signals in the EPN combined solution
   - Easily distinguish between constrained and unconstrained stations in the EPN combined solution

   Procedure:
   - Extract for each EPN station the weekly estimated (X,Y,Z) coordinates, as is, from the weekly EPN combined solutions. These solutions are linked to the successive realizations of the ITRS at the epoch of observation.
   - Then, these weekly station coordinates are converted to a local (N,E,U) system with respect to the mean coordinates of that station
   - The resulting coordinate time series display for each EPN station the so-called 'ITRS' time series

2. The ETRS89 time series (updated weekly)
   Purpose:
   - Evaluate influence of the different ETRS89 realizations on the station coordinates
   - Visualise common signatures in the EPN combined solution
   - Easily distinguish between constrained and unconstrained stations in the EPN combined solution

   Procedure:
   - Extract for each EPN station the weekly estimated (X,Y,Z) coordinates, as is, from the weekly EPN combined solutions. These solutions are linked to the successive realizations of the ITRS at the epoch of observation.
   - Then, the extracted weekly coordinate solutions are converted into the corresponding ETRS89 realisation, using the transformation formula published by Boucher and Altamimi.
   - In a last step the weekly ETRS89 (X,Y,Z) coordinates are converted to a local system (N,E,U) with respect to the mean coordinates of that station
   - The resulting coordinate time series display for each EPN stations the so-called 'ETRS89' time series

3. The standard coordinate time series (updated weekly)
   Purpose:
   - Detect coordinate outliers and coordinate jumps (+ correlation with equipment changes)

   Procedure:
   - Compute a new cumulative solution based on all weekly EPN combined solutions
     i. Software used: ADDNEQ program of the Bernese V4.2
     ii. Geodetic datum of the cumulative solution is fixed (Helmert transformation) to the ITRF97 (epoch 199,4) coordinates of BOG, GLSV, GRAZ, KOSG, MATE, ONSA, PENC, POTS, VILL, WARE, WTZR and ZECK.

iii. No a priori site velocities have been introduced nor estimated

- Compute residuals of the 6-parameter transformation between the cumulative solution and the weekly EPN solution in a (N,E,U) frame
- Compute detrended time series to improve the visualisation of irregularities for stations with large coordinate variations
- The resulting coordinate time series display for each EPN station the so-called 'standard' time series

4. The improved time series (updated periodically)
   Purpose: geokinematic interpretation
   Procedure: refer to http://www.epncb.oma.be/series.html for more details.

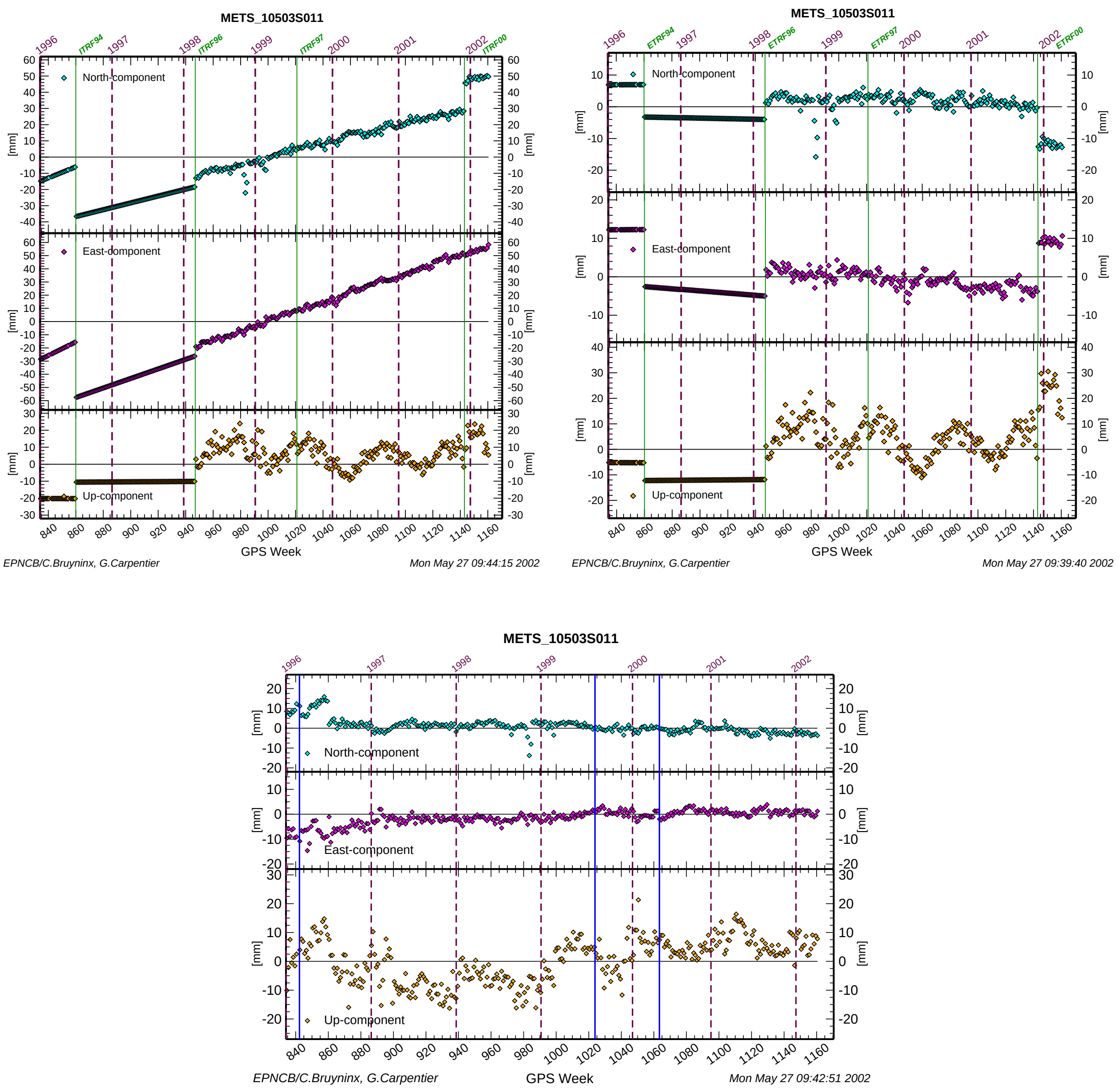

Figure 5 – Different coordinate time series available at the EPN CB web site. Upper left: ITRS time series; upper right ETRS89 time series; bottom: Standard time series

In Figure 5, we compare the Standard, ITRS and ETRS89 time series for the station METS (Metsahovi, Finland). From the ITRS time series, it is clearly seen why the weekly estimated EPN coordinates (as given in the EPN weekly combined solutions) is not suitable for any outlier detection nor geodynamic interpretation. This in one hand due to the velocity of the site, which is expressed in the ITRS and on the other hand due to the coordinate jumps which are caused by the switches from one ITRS realisation to another.

Interesting is that the ITRS graphs give direct information on these sites that were constrained for the generation of the EPN weekly combined solution. In the case of METS, the site was constrained at the time the EPN solutions was linked to the ITRF94 and ITRF96. For the latter realisations, it was dropped as reference station and the coordinates were estimated without constraints. Note the large coordinate jump in the North-component from the ITRF97 to the ITRF2000. This mainly due to the translation between both frames

The same effect can be seen from the ETRS89 time series. In this case, we can distinguish between the different realisations of the ETRS89. In addition, the ETRS graphs show a motion of METS towards the West and this with 1 to 2 mm/year. This confirms earlier results obtained by Altamimi who detected in the ITRF2000 a counter clockwise rotation for METS with respect to the NUVEL NNR 1A model

Due to the reference frame changes, both the ITRS and ETRS89 time series are not the best tool to detect coordinate outliers and their correlation with equipment upgrades. This is exactly the reason why the EPN CB created the standard time series. For the generation of the standard coordinate time series, we first remove all constraints from the EPN solutions and then combine them all in a cumulative solution constraint (in the Helmert sense) to the ITRF97. In a second step, the weekly EPN solutions are compared to the cumulative solution (again in the Helmert sense) and the corresponding residuals are the basis for the standard time series. In this way, the standard time series become independent of reference frame changes, as can be seen from Figure 5.

5. Monitoring of the station tracking performance – case studies

At the EPN CB, the following tools are used for the monitoring of the station tracking performance:

- Different types of time series
- Azimuth/elevation graphs (more in Takacs and Bruyninx, 2002): since the summer of 2001, the EPN CB is creating monthly for each EPN station the azimuth/elevation graphs. In addition, to have a complete historical tracking overview, the graphs were also created for all the stations retrospectively up to Dec. 1999

These tools have allowed us to detect several problem stations in the past. In the following, we will follow up some of case studies discussed last year and in addition, we will show some of the typical problems encountered in the EPN stations over the last year.

5.1 Follow up of previously detected anomalies

Herstmonceux (HERS):

Last year, the azimuth/elevation graphs allowed us to report about a possible obstacle blocking the antenna of this station. This problem appeared in April 1999 and significantly degraded the coordinate repeatabilities, especially in the East-component. After some e-mail exchanges with the station manager it seemed that the problem was caused by a malfunctioning antenna which had an azimuth dependent tracking problem. The antenna was sent back for repairs and was reinstalled in August 2001. From that date, as can be seen from the standard coordinate time series in Figure 6, Herstmonceux has been performing well.

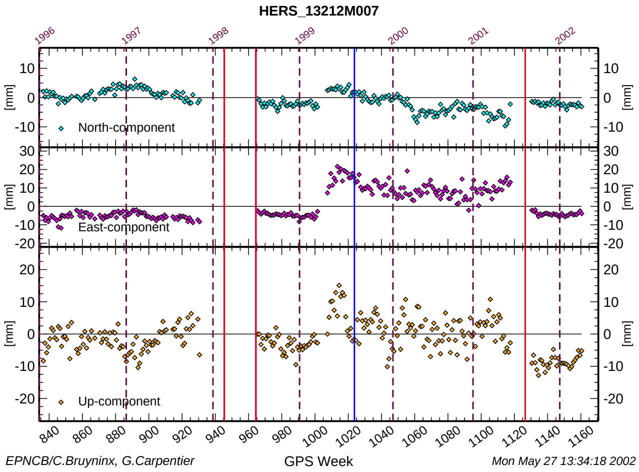

Figure 6 – Standard coordinate time series for Herstmonceux, UK (HERS)

5.2 Typical problems encountered in the last year

Antenna changes

Antenna changes typically cause coordinate discontinuities, mostly in the height component. For this reason all unnecessary equipment changes are highly discouraged. Since May 2001, several EPN stations changed antenna, most of them for well-considered reasons: Rogue equipment upgrades (CAGL, DENT, DOUR, GRAZ, KELY, PTTB and ZECK) or replacement of damaged/malfunctioning antennae (BOGO, HERS, GSR1, SFER). A few stations changed antenna for reasons unknown to the EPN CB: EUSK, KARL, KLOP, HOFN and OROS. Most impressive jumps caused by the antenna changes are between 3 to 6 cm in the height component and this for the stations EUSK, KARL, KLOP and HOFN (see Figure 7).

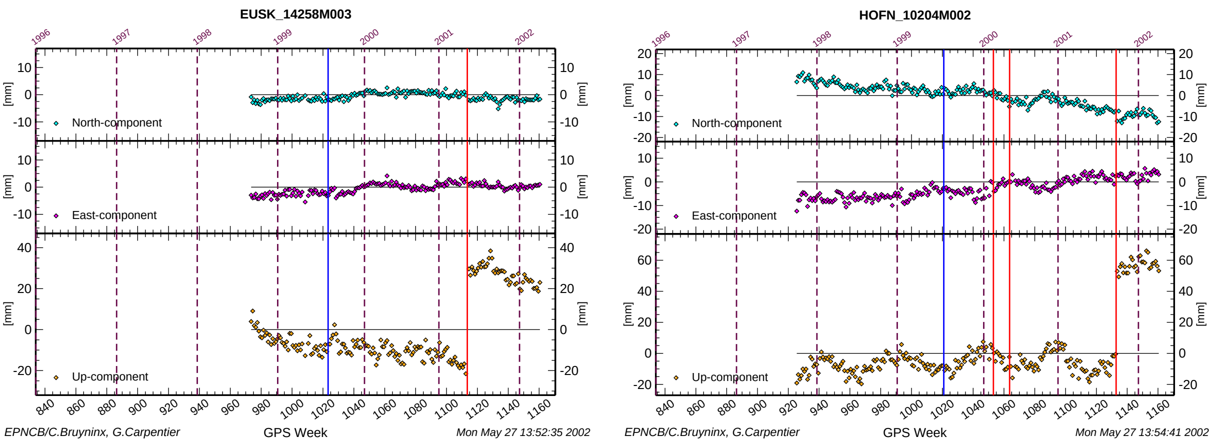

Figure 7 – Standard coordinate time series for Euskirchen, Germany (left) and Hofn, Iceland (right)

Introduction of new analysis strategy

As mentioned in Section 3.1, it was decided at the AC workshop that a new analysis strategy would be introduced starting from GPS week 1130 (September 2001). The main change consisted in a switch of the elevation cut off angle from 15 to 10 degrees and therefore changes in the estimated station height component were expected. Now, nine months later, it has become clear that the effect of the new analysis strategy did not cause coordinate jumps in the majority of stations.

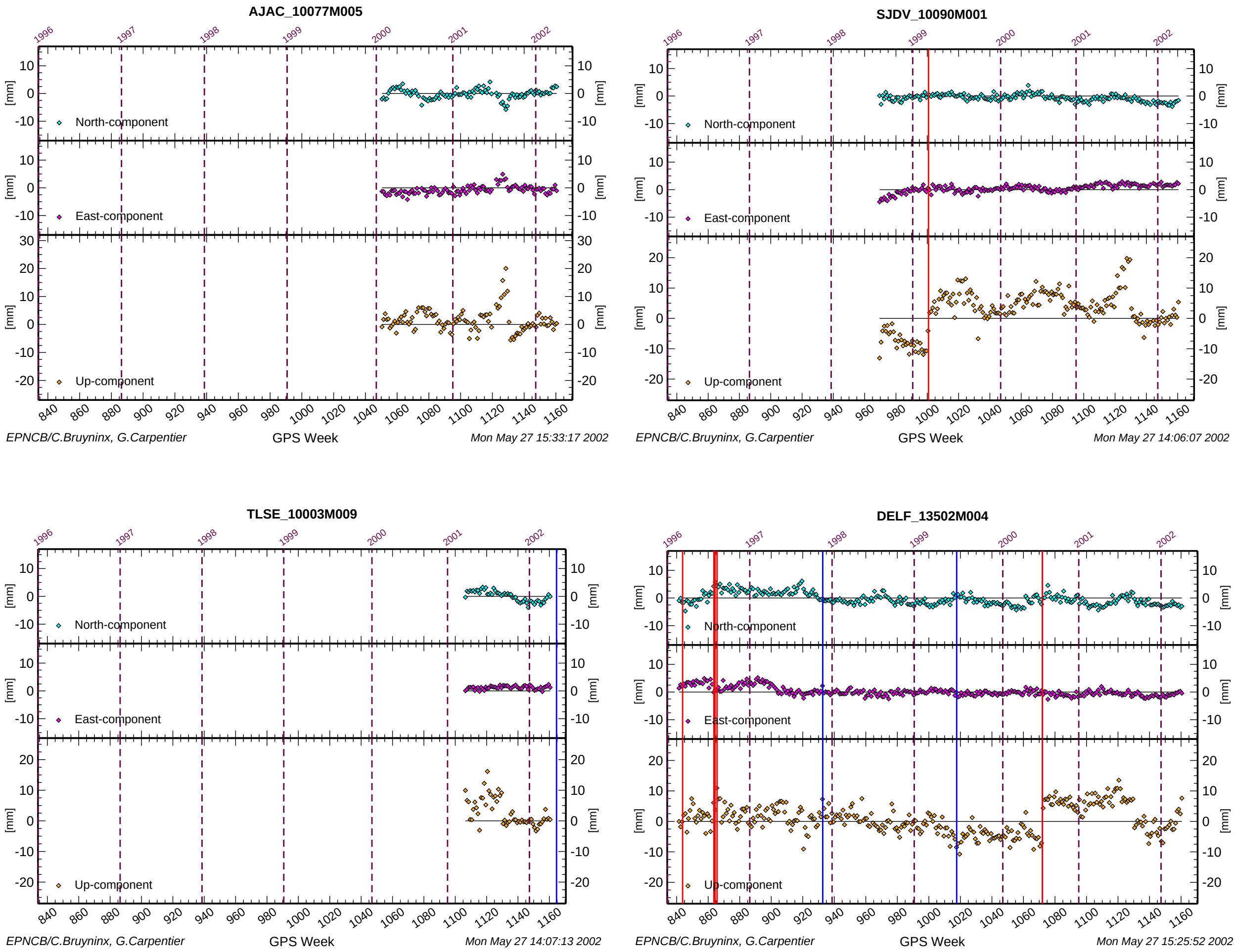

Figure 8 – Standard coordinate time series for AJAC (upper left), SJDV (upper right), TLSE (bottom left), DELF (bottom right)

However, we noticed a few exceptions to this rule; some of them are shown in Figure 8. It concerns (we only list the most striking ones): AJAC (Ajaccio, Corsica, France), DELF (Delft, Netherlands), MALL (Mallorca, Spain), MLVL (Marne-la-Vallee, France), GRAS (Grasse, France), SJDV (Saint Jean des Vignes, France) and TLSE (Toulouse, France).

The introduction of the new AC strategy clearly improved the repeatability of the height component of TLSE. This is because the elevation dependent weighting handles better the bad "low elevation" tracking data (see Figure 9, left) from the ROGUE SNR-8000 installed at TLSE. Since the upgrade, on May 2, 2002 of the ROGUE SNR-8000 firmware to version 3.2.32.11 (as recommended in IGS mail 3758), the tracking problems at TLSE have been reduced (right side of Figure 9). A similar situation has occurred in GRAS where a ROGUE SNR-12 is functioning. Here no firmware upgrade was performed yet.

While both AJAC and SJDV are stations with a nice tracking history, it seems that the apparent improvement of the repeatability of the height component is a by-product from the improvements at the nearby stations GRAS and TLSE. This supposition was confirmed when we noticed a similar behaviour on other the nearby stations (e.g. MARS, MLVL, MALL, MANS) who are often part of the same subnetwork as processed by some AC's.

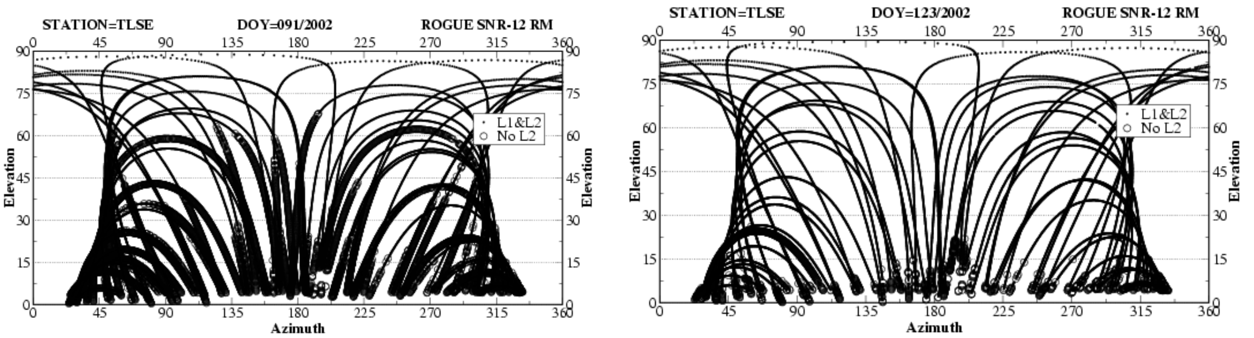

Figure 9 – Azimuth/elevation graphs for TLSE. Left: degraded tracking on L2 (April 2002); Right: tracking improvement on L2 after the firmware upgrade (May 2002)

The coordinate jump detected in the height component of DELF will need some further investigations. It is presently not clear if it is pure coincidence that it appears simultaneously with the switch of the AC strategy.

Other changes in coordinate time series

We have displayed in Figure 10 four standard time series where coordinate jumps/outliers appeared without correlation with equipment update. For OBE2 (Oberphaffenhoven, Germany), MDVO (Mendeleevo, Russia), VENE (Venezia, Italy) we respectively have two times a jumps in the East component and one in the height component, all of roughly about + 1 cm.

The problem in BZRG (Bolzano, Italy) is very similar to what was detected last year at Herstmonceux: since July 2001 the antenna showed occasional tracking problems around an azimuth of 45 degrees. This problem was not systematic and was therefore hard to detect. As an example, Figure 11 shows the different tracking behaviour observed at BZRG.

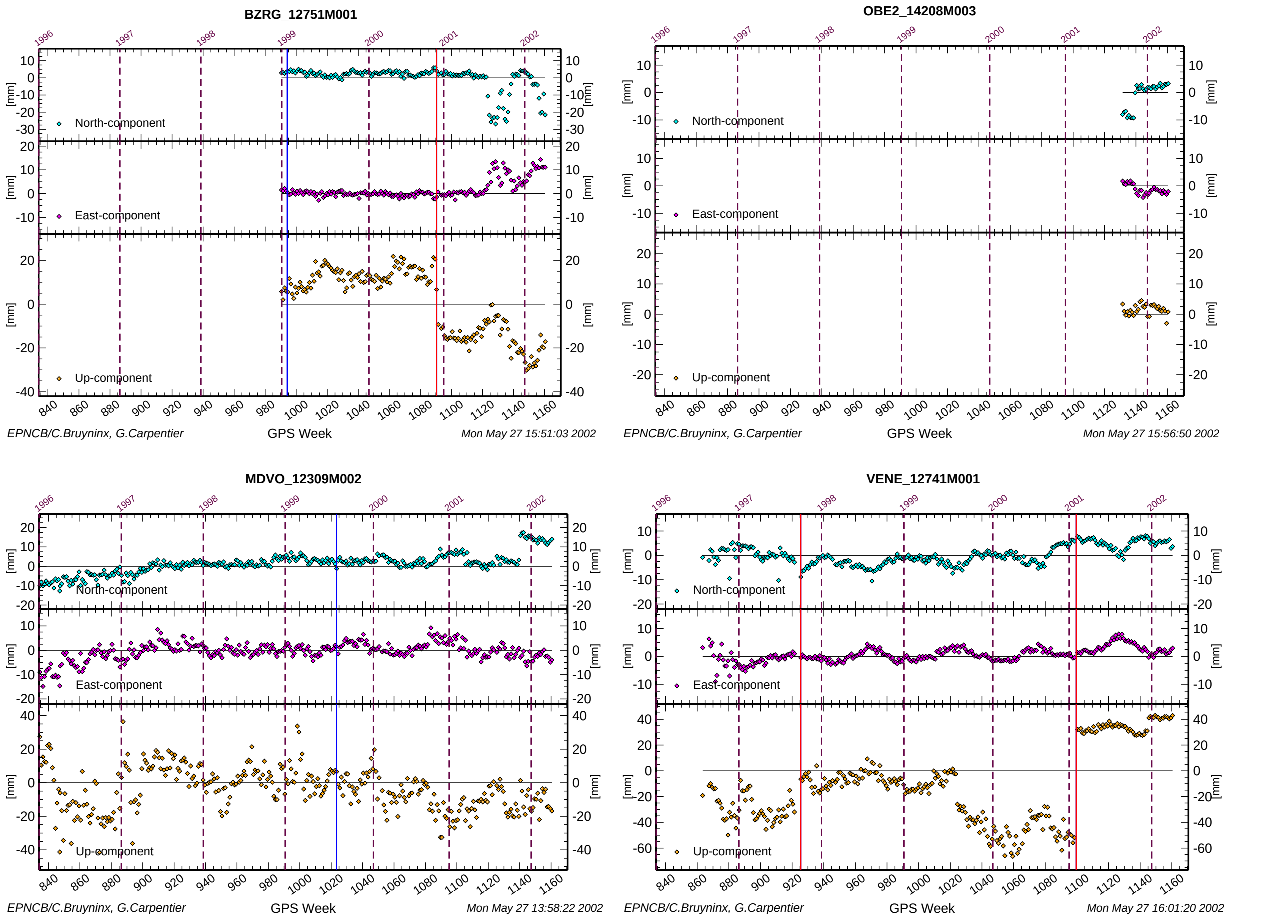

Figure 10 – Standard coordinate time series for BZRG (upper left), OBE2 (upper right), MDVO (bottom left) and VENE (bottom right)

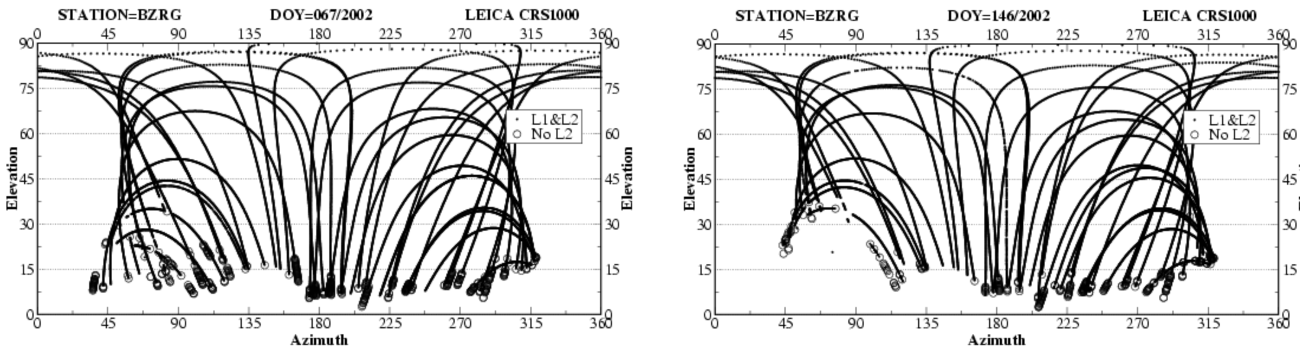

Figure 11 - Azimuth/elevation graphs for BZRG. Left: normal tracking (March 2002); Right: degraded tracking with missing data at azimuth around 60 degrees (May 2002)

6. On-going developments at the EPN CB

6.1 EUREF mail

In February 2002, the distribution of the EUREF mails switched from AIUB, Switzerland to the EPN CB. The EUREF mail usage procedures have remained unchanged except for the address. Mails for the EUREF mail exploder now need to be sent to eurefmail@oma.be.

6.2 Site log submission

The growing number of EPN station submitting hourly data together with the short processing latencies used by some AC's urged the EPN CB to provide the EUREF community with the necessary tools to promptly relay any equipment changes. Up to now, these changes, reported in the site logs, were processed manually, which could sometimes cause delays of several hours. In order to remedy to this shortcoming, the EPN CB has created an automated site log submission utility. It will allow updating site logs by submitting them to a dedicated e-mail address. Within a few minutes, both the ftp and web sites will be updated for this info and an updated SINEX template will be generated.
This new utility will become fully operational after the switch to the new site log format, mid June 2002.

6.3 Rapid quality checks

Inspired by the weekly-distributed IGS Station Reports, we have started at the EPN CB an initiative to create rapid quality checks for the EPN network. In a first step, statistics about the percentage of Observed Data with respect to the Predicted Number will be generated. Observed data taken into account for the generation of the statistics must have all four observables: P1 or C/A code, P2 code, L1 phase and L2 phase. The number of predicted observations is computed starting from the actual station cut off angle. The generated statistics are partially based on the TEQC utility (Estey and Meertens, 1999).

The final results will be a yearly "Quantity plot", updated daily when new data becomes available, and this for each EPN station. This Quantity plot will display the time evolution of the % of Observed/Predicted data (called "OP"), as given in Figure 12. The final version of the graphs will indicate (similar to the time series) when equipment changes have occurred and when cut off angle changes were introduced (together with their values). In addition, since the Predicted values are implicitly considering a 12-channel receiver, the number of channels of the receiver installed at each station will be also mentioned on the graphs in order to allow an appropriate interpretation for receivers with fewer channels.

The example given Figure 12 shows different effects:

- At the beginning of the test, this station operated a poor performing ROGUE SNR-8000 receiver characterized by a percentage around 65 %.

- On March 18, 2002 (DOY 78), this receiver was replaced by an ASHTECH Z-XII3T raising the OP percentage to 90%. Our programs computed that the station was tracking at an elevation cut off angle of 10 degrees.
- On DOY 109, the ASHTECH was detected a change in the elevation cut off angel from 10 degrees to 15 degrees. Due to this switch, the OP increased to 96 %.
- On DOY 127, on request of the EPN CB (AC are processing at 10 degrees), PTTB switched to an elevation cut off angle of 7 degrees. This switch corresponds with a decrease of the OP to 80%. This does not mean that the station is performing worse; it only illustrates that there is a considerable number of missing data at lower elevations.

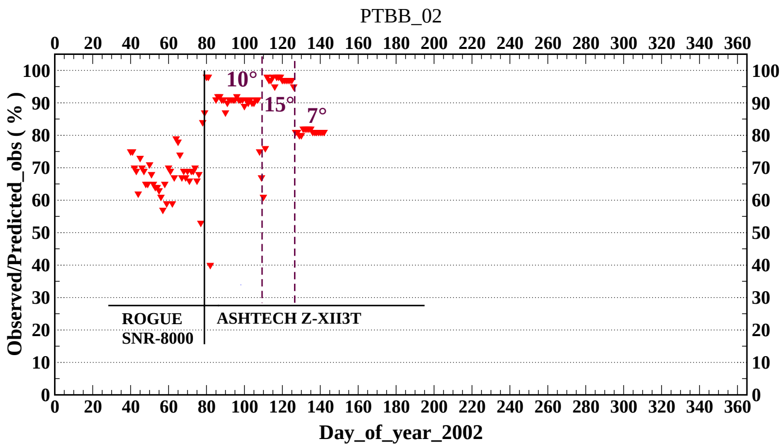

Figure 12: Percentage of predicted/observed data for the station PTBB (Braunschweig, Germany)

7. News from the IGS

7.1 IGLOS Pilot Project

At the time of writing, the IGLOS (International GLONASS) Pilot Project is expected to start in June 11, 2002. Main uncertainties are caused by the lack of healthy GLONASS satellites (7 to 8). The GPS/GLONASS combined tracking network comprises presently about 50 stations.

It was originally planned that with the start of the IGLOS Pilot Project, the IGS precise ephemeris (SP3 files) would contain both GPS and GLONASS orbits. However, due to the extreme latency of the availability of the GLONASS orbits (4 weeks), this is presently not possible. In addition, the reliability of the GLONASS orbits can presently not be guaranteed due to the fact that only two microwave technique AC's (BKG and ESA) and one SLR-based AC are submitting solutions.

7.2 Format Changes and discussion

The following formats are presently under discussion (or will soon change) within the IGS:

- ***Site log:*** In support of GLONASS data and to improve the geophysical information available in the site logs, the International GPS Service is presently changing the format of the site log forms. Within the EPN, we will switch to the new site log simultaneously with the IGS. New site logs will become official on June 11, 2002. Details about the site log switch can be found in Bruyninx and Roosbeek, 2002.
- ***SP3 format (precise orbits):*** Within the IGS there is presently a discussion to change the SP3 format in order to be able to separate between the estimated and predicted part in the orbit file.
- ***ANTEX format***: In order to standardize the exchange of antenna calibration values a new format for the exchange of Phase Centre Variations is presently under development. The implementation is foreseen for the beginning of 2003.

- ***RINEX format:*** An update of the RINEX format is foreseen based on the draft distributed within the frame of the IGS LEO Pilot Project. The implementation will be due for the beginning of 2003.
- ***SINEX format:*** The new SINEX V2.00 format has been distributed in IGS mail 3903. This new format definition was necessary fix the different SINEX implementations used with the IGS, ILRS and IVS services.

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