Quality Checking the Raw Data of the EUREF Permanent Network

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Abstract

As part of its coordination task the EPN CB is monitoring the coordinate time series of all the stations in the EPN network. These time series reflect the quality of the estimated station coordinates, essential for a reliable realization of the European Terrestrial Reference System. While discontinuities in the time series are commonly correlated with changes in the antenna/radome configuration, we have focused on the unexplained non-periodic signals and sudden changes in the noise of the time series.

For this investigation we developed, in a first step, some basic tools to monitor the quality of the raw GPS data of the EPN stations in order to give a snapshot of the station tracking: number of visible satellites versus predicted ones, missing L2 measurements and obstacles in satellite visibility, both at low and medium elevation.

In a second step we applied these tools on the more than 5 years of EPN RINEX data. In this paper we will show the results of some case studies performed on the EPN coordinate time series, showing unexplained signals. Some of them demonstrate the clear correlation between these signals and changes in station tracking such as the ones mentioned above.

1. Introduction

The EUREF Permanent Network (EPN) Central Bureau is computing weekly coordinate time series for all EPN stations, when a new combined EUREF SINEX solution (Becker et al, 2001) becomes available. These time series are computed for the primary purpose of monitoring the estimated coordinates of each individual EPN station. The most explicit signal seen in the time series are coordinate discontinuities caused by changes of the antenna/radome configuration at a station. An example of such a time series is given in Figure 1.

The EPN Special Project, *"Monitoring of the EPN to produce coordinate time series suitable for geokinematics"*(Kenyeres and Bruyninx, this volume), is especially dedicated to the estimation of the size of these discontinuities and the creation of corrected coordinate time series that can be used for geokinematic interpretation.

Another type of signal that can be seen in the time series is periodic, mostly annual. An extreme example is given in Figure 2.

In this paper we will concentrate on two other types of signal, which are characterized by:

- A sudden change in the RMS of the time series

or

- A coordinate change uncorrelated with an antenna/radome change

These "disturbances" in the time series indicate that something is happening, or has happened, at the station. The EPN Analysis Coordinator reports, whenever possible, such a phenomena in the reports distributed with the weekly EUREF combined solution.

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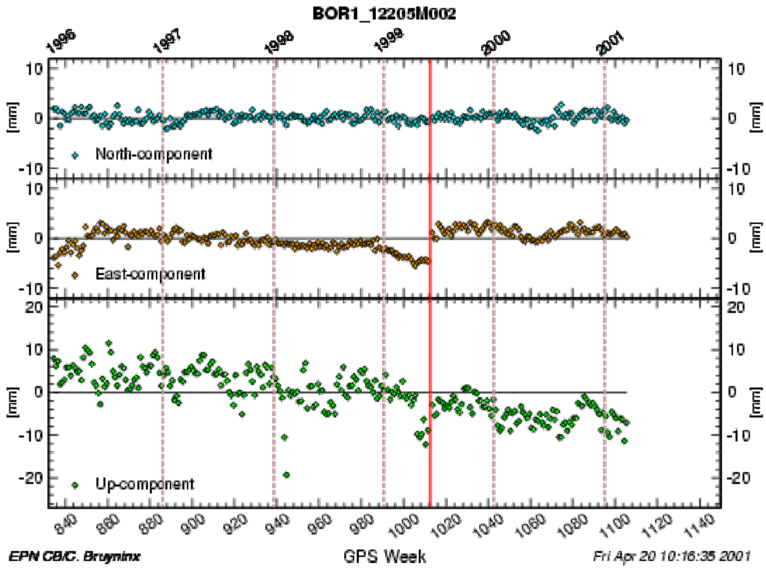

Figure 1- Coordinate time series computed at the EPN CB for the station BOR1 (Borowiec, Poland). The coordinate jump in May 1999 (red line) is caused by an antenna change.

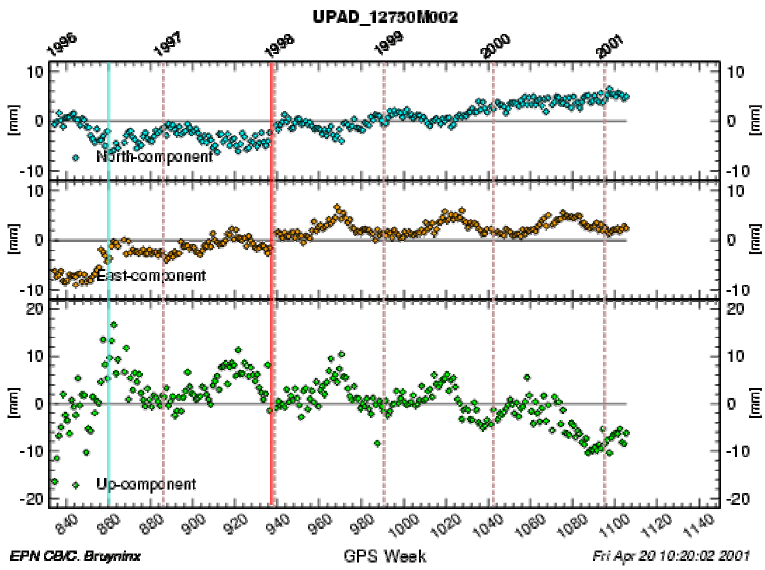

Figure 2- Coordinate time series computed at the EPN CB for the station UPAD (Padova, Italy). A clear annual signal can be seen.

The coordinate time series do not offer an optimal monitoring of the EPN stations: the EUREF combined solutions are available with a delay of about one month. This means that a station can be submitting degraded data for a month before the time series become available. In addition, it is impossible to attribute a single coordinate outlier to a problem in the station tracking. In general, only after several months, a specific increase of noise can be seen in the coordinate time series. At that time, the station has been submitting erroneous data since quite a long time. A regrettable example is shown in Figure 3. This station has been showing coordinate outliers since GPS 1057 (April 9, 2000) which finally resulted in an antenna replacement in October 2000, restoring the situation to normal.
The station manager was first informed about the problem by the “WK 1058 EUREF Analysis Report” distributed through EUREF mail 0517 on May 16, 2000, with more than one month of delay after the first symptoms.

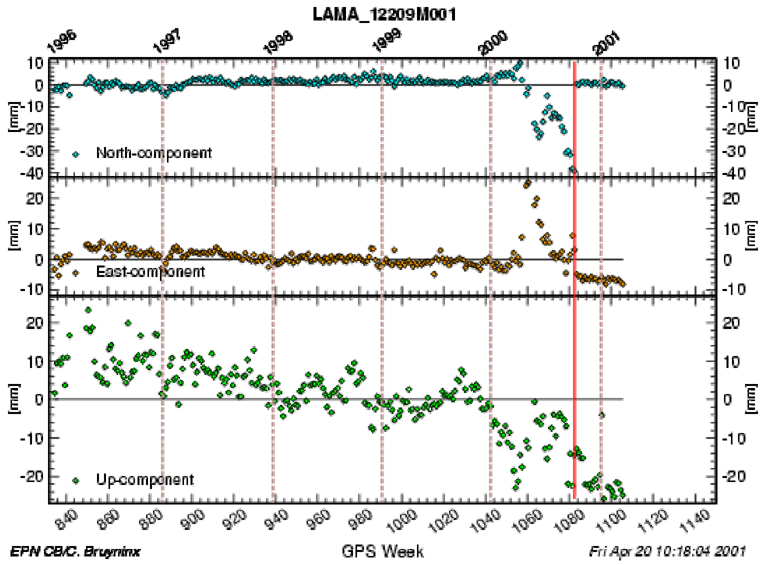

Figure 3 – Coordinate time series computed at the EPN CB for the station LAMA (Lamkowko, Poland) Coordinate outliers can be seen starting at GPS week 1057. The situation was restored to normal after an antenna change at GPS week 1082 (red line).

The philosophy of this work consists of an investigation of the coordinates time series with unexplained signals and to try to correlate these signals with changes in the station tracking performance. In a later stage, this experience will allow to determine some criteria that will help us to give an alarm when the tracking performance of a station has changed in such a way that it will influence the coordinate time series.
For this purpose we have created some basic tools that allow evaluating the quality of the raw GPS data. Although the receiver-dependent binary formats mostly give more explicit information about the Signal to Noise ratio, which is an important indicator of data quality, we have chosen to use RINEX data files, as it is the data exchange format used within the EPN.
By being able to alarm the station manager much faster than before, the developed tools should allow excluding a station from the combined EUREF solution prior to its creation and distribution. This will improve the reliability of the EPN solution and consequently the ETRS89.

2. Developed software

The software we developed is similar to the already existing quality check program TEQC (Estey and Meertens, 1999). However, we preferred writing some self-developed programs in order to have a better insight in what is exactly happening at a station. In addition, it was important for us to display the tracking performance with a simple graph (two graphs in our case) that could be made available at the EPN web site.
The output of the developed programs contains two graphs:

- First, it shows the *azimuth and elevation angles* of the observed satellites at the station. In the latter we will refer to these graphs as AZ/EL graphs.
- The second output shows the *number of measured satellites* versus the predicted number. We will call these NRSAT graphs.

As explained in the introduction, input to the programs are the RINEX observation and navigation files, as distributed within the EPN.

3. Results

We have applied our software on the RINEX data of the EPN network and have encountered the following phenomena:

3.1 Degraded L2 tracking at low elevations

Since all EPN Analysis Centres only use dual frequency GPS data, L1 data without L2 are unusable. As a consequence the resulting elevation cut off used during the data analysis is dependent on the L2 tracking performance at low elevations. This will influence especially the height-component of the estimated coordinates.

Most of the stations that have used during their lifetime non-recent ROGUE equipment (ROGUE SNR-8000, 8100, 12 and not upgraded with ACT) can have a degradation of their tracking performance on L2 at low elevations. A typical example of this effect is shown in the AZ/EL graph (Figure 4) of the station VENE (Venezia, Italy).

This problem is well known and has been evidenced on other stations by Springer and Rothacher (IGS mail 2071). It is caused by the tracking algorithm of these receivers: when the receiver is working at a 30-s sampling rate under AS, tracking on L2 stops when the difference P2-C/A exceeds 12m. In addition, when 8 m < P2-C/A < 12 m, the difference P2-C/A is quantized. This effect is directly correlated with the ionospheric activity since

$$P2\text{-}C/A = 0.105\ TEC/(\cos z) + \text{receiver hardware bias} + \text{noise}$$

With TEC= Total Electron Content, as an indicator of the ionospheric activity

z = zenith angle

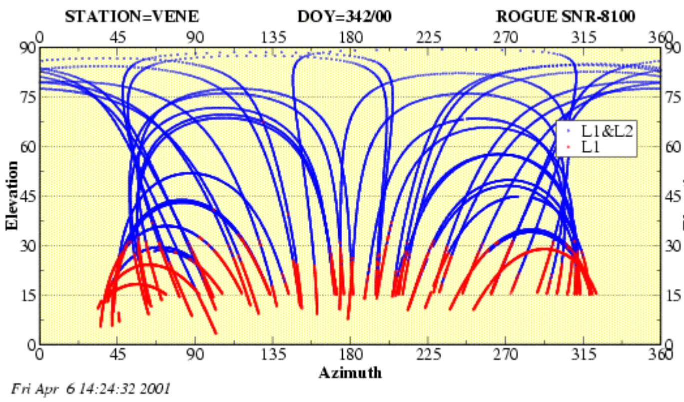

Figure 4 – Azimuth/elevation angles of observed satellites in the station VENE (342/2000)

An historic overview of the percentage of missing L2 data at VENE (Figure 5), above an elevation cut off angle of 15°, shows that the tracking problems started around day 230 in 1999 (August 1999). The direct correlation between the degraded tracking performance and the height component of the coordinate time series (Figure 6) is straightforward: a clear jump is seen in August 1999 (GPS week 1023) after which the repeatability of the height component degrades. The site log file of VENE does not report any change to the receiver/configuration at that time. Our best guess suspects a receiver firmware upgrade.

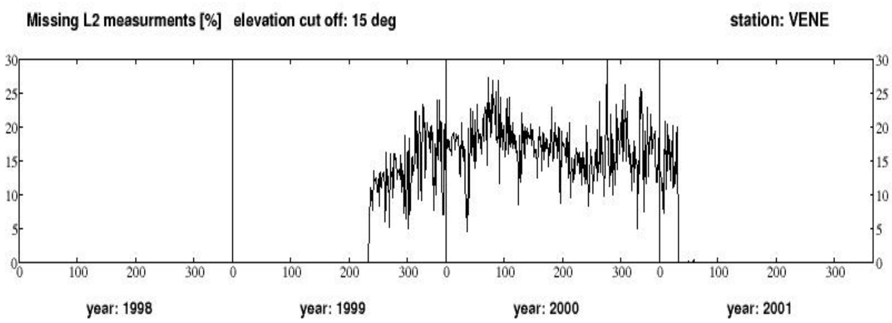

Figure 5 – Percentage of missing L2 data above 15 degrees as measured at the station VENE (From Jan 1, 1998 to March 1, 2001)

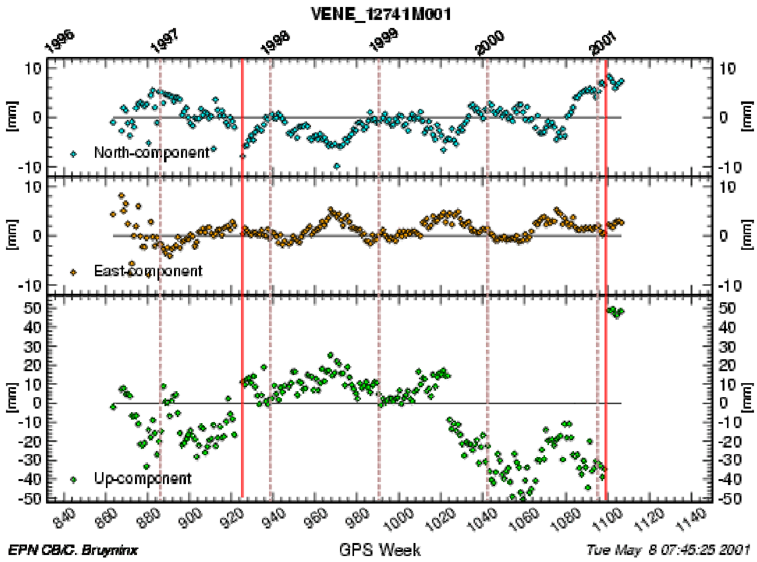

Figure 6 – Coordinate time series computed at the EPN CB for the station VENE.

On Feb. 1, 2001 the ROGUE SNR-8100 receiver of VENE was replaced with a TRIMBLE 4700. The corresponding AZ/EL graph (Figure 7) shows the improvement of the tracking performance. Since that time (GPS week 1099) the height component of VENE has considerably improved. This antenna/receiver change introduced however a jump in the height component of about 9 cm.

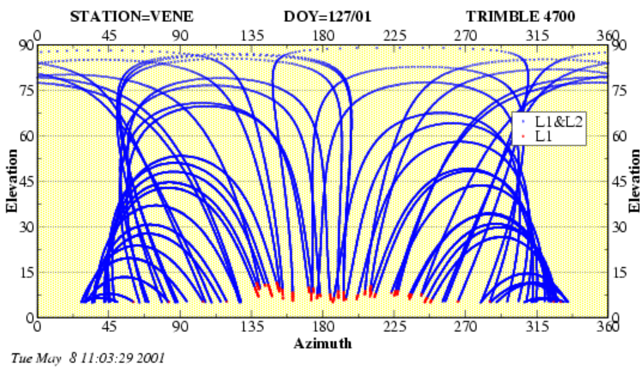

Figure 7 – Azimuth/elevation angles of observed satellites in the station VENE

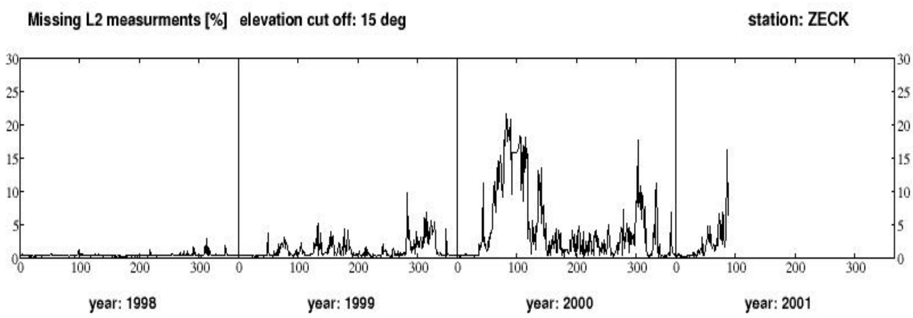

Figure 8 – Percentage of missing L2 data above 15 degrees as measured at the station ZECK (From Jan 1, 1998 to March 1, 2001)

From Figure 5, we could not show a clear correlation between the number of missing L2 data and the state of the ionosphere. For other EPN stations, this effect is much clearer. As a typical example, Figure

8 displays the number of missing L2 data at the station ZECK (Zelenchukskaya, Russia) which is indeed correlated with the ionospheric activity as seen form the TEC values computed by the CODE Analysis Centre (Figure 9).

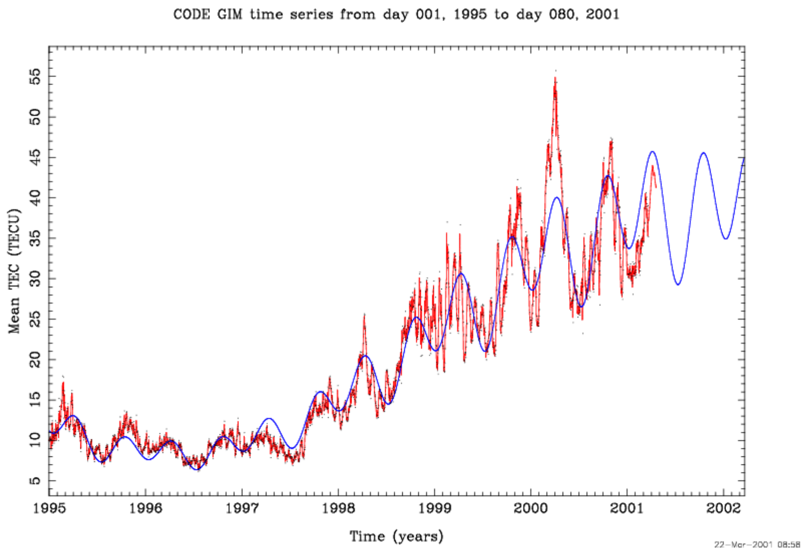

Figure 9 – Mean TEC values as computed by the CODE analysis centre

Presently, twelve EPN stations are still using equipment, which performs worse under conditions of higher ionospheric activity.

3.2 Systematic tracking interruptions

Based on the info available in the NRSAT graphs, we found stations that display systematic tracking interruptions.

- *At regular intervals:*
  This effect is seen at some of the stations submitting hourly data (Figure 10), e.g. BOGO (Borowa Gora, Poland), HELG (Helgoland Island, Germany), HERS (Herstmonceux, UK), MATE (Matera, Italy), MLVL (Marne-la-Vallee, France). Most of these stations are missing 1 to 2 observation epochs at each HH:00. All the affected stations, except MATE (TRIMBLE 4000SSI), are operating ASHTECH Z-XII3 receivers and probably use the same data download software.
  Other sites, also operating an ASHTECH Z-XII3 receiver and submitting hourly data, such as BUCU (Bucuresti, Romania), DUBR (Dubrovnik, Croatia), KIR0 (Kiruna, Sweden), MAR6 (Maartsbo, Sweden), ONSA (Onsala, Sweden), ORID (Ohrid, Macedonia), OSJE (Osijek, Croatia), VIL0 (Vilhelmina, Sweden) and VIS0 (Visby, Sweden) do not show this problem. These last receivers are part of the SWEPOS and BKG network.
  Since no info about the data download software is available in the site log files, we can only guess that the sites showing the tracking interruptions use a different version of this software.

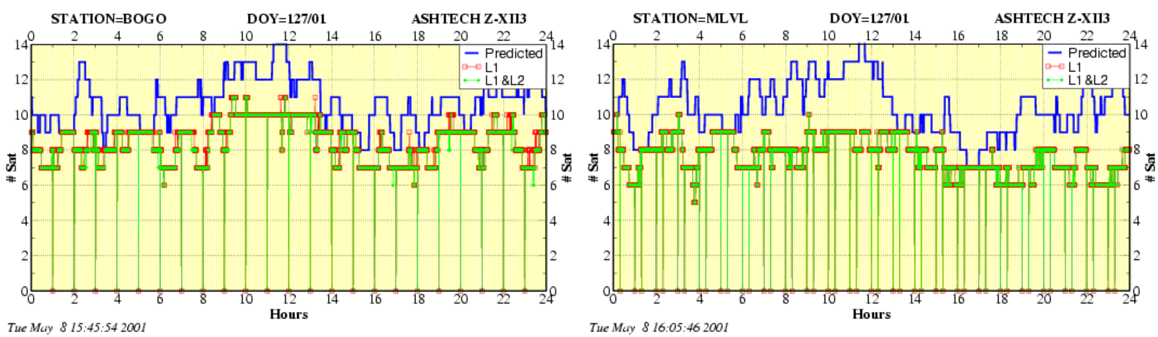

Figure 10 – Number of observed satellites at the stations BOGO (left) and MLVL (right)

- *At irregular intervals :*
  We have seen different sites, which experience tracking problems, but the strangest results were obtained for the site ANKR (Ankara, Turkey).

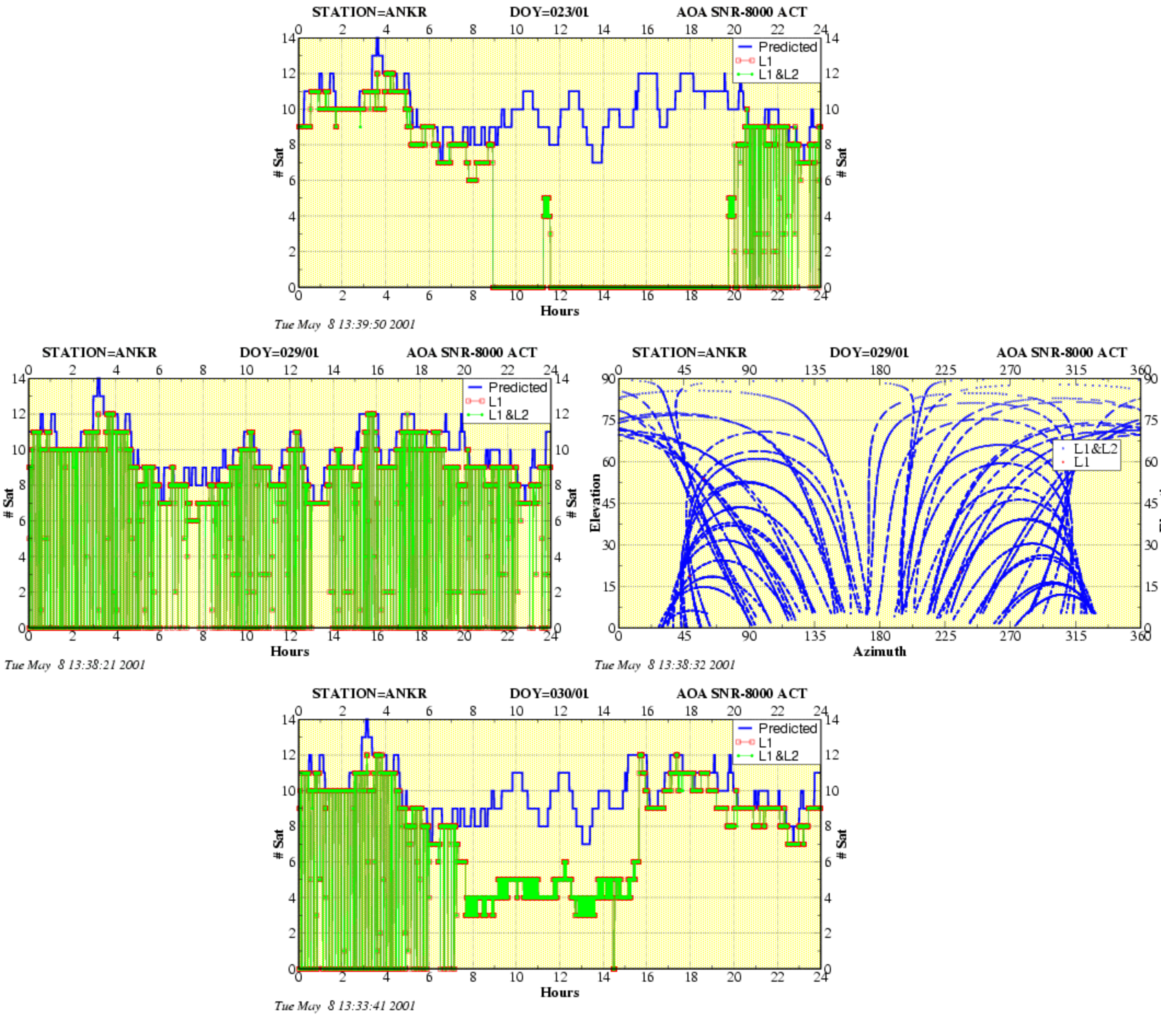

Figure 11 – Number of observed satellites at the ANKR. The graph at the top (23/01/2001) shows the start of a disturbance. The two graphs in the middle are typical AZ/EL and NRSAT graphs during the disturbance. The graph in the bottom (30/01/2001) shows the day when the situation restores to normal.

In January-February, 2001 this station suffered from extreme disturbances. As shown in Figure 11, the station was subject to severe tracking interruptions with an interval of 7-8 minutes and typical duration of 1.5 to 2 min, starting at January 23 and ending at January 30, 2001. For the affected GPS week 1098, no trace of this was found in the combined EUREF solution. In the contrary, the agreement between the different AC's was extremely good. We have presently no idea what happened at this station.

3.3 Changes in the satellite visibility due to elevation cut off changes

Changes in the receiver elevation cut off setting are not documented in the present version of the site log file. However, the new version of the site log will include this information. Thanks to the AZ/EL graphs we were able to evidence the changes in this setting between the range of 0° to 15° for several of the EPN stations. Since the EPN AC's use an elevation cut off angle of 15°, these changes did not influence the EPN coordinate time series.

3.4 Significant obstacles at low elevations

The AZ/EL graphs are a straightforward tool to detect if significant obstacles block the antenna visibility. Some of the stations for which we have seen significant obstacles above 15° are:

- BELL (Bellmunt de Segarra, Spain): an obstacle between the azimuths 115° to 200°, blocking the visibility up to 20 degrees;
- HERS (Herstmonceux, UK): a big obstacle between azimuths 270°-340°, blocking visibility up to 30 degrees of elevation (see Figure 12).

Looking at the coordinate time series of HERS (Figure 13), we see that around GPS week 1002 (March/April 1999), the East and North components of the station display a significant jump. After this jump an increase in the rms of coordinates components is evidenced. In order to find out if this signal has any correlation with the obstacle, we have drawn similar AZ/EL graphs using the RINEX observation files measured before and after this jump. The results are given in Figure 14 and they show that prior to the coordinate jump (DOY 79, 1999) the obstacle was not existing, then at DOY 81 the horizon seemed to be less clear and at DOY 88 the obstacle was there as it still is today, May, 2001.

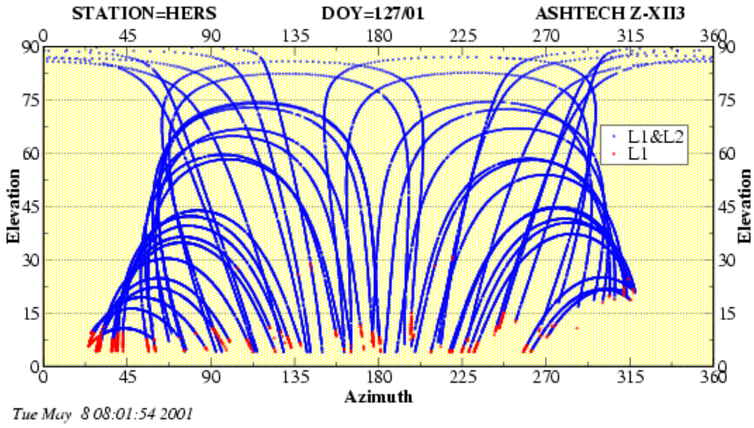

Figure 12 – Azimuth/elevation angles of observed satellites in the station HERS. An obstacle is blocking satellite tracking between azimuths 270° and 340°.

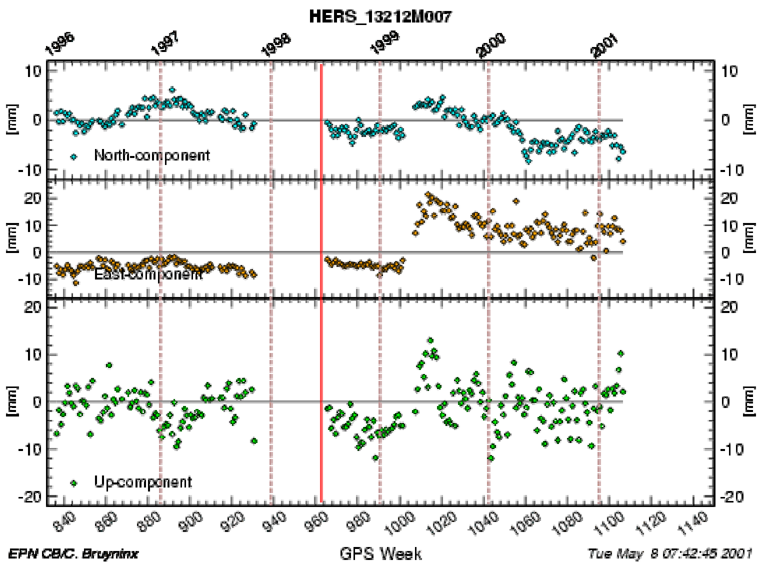

Figure 13 - Coordinate time series computed at the EPN CB for the station HERS. There is a coordinate jump at GPS week 1002. After GPS week 1002 there is an increase in the rms of the coordinates, especially in the East-component.

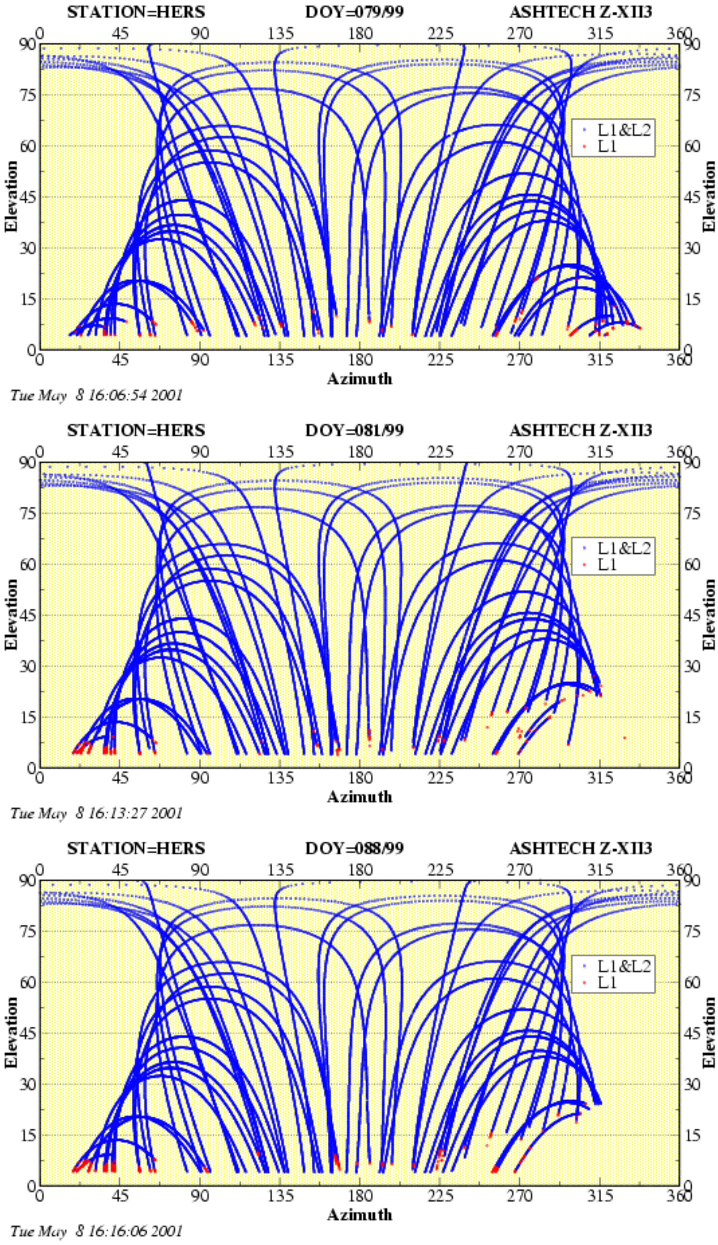

Figure 14 - Azimuth/elevation angles of satellites observed at HERS. On the top: 79/99, no obstacles are blocking the visibility ; in the middle 81/99: limited visibility; in the bottom : 88/99, a clear obstacle is blocking the visibility.

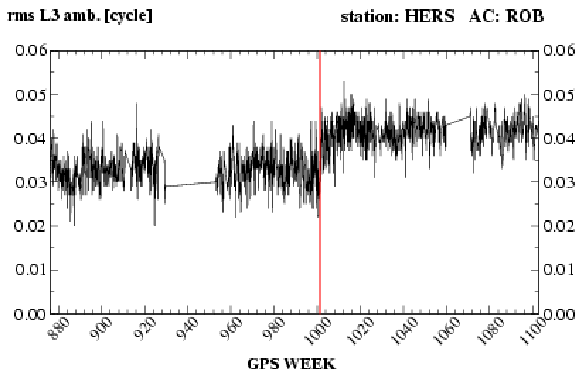

Figure 15 – RMS of the L3 ambiguity on the baseline DENT-HERS: a jump appears around GPS week 1002.

We can also see that the obstacle influenced the ambiguity resolution. In Figure 15, we have plotted the rms of the L3 ambiguity for the baseline HERS-DENT outcome from the daily data analysis (using Bernese) done at the ROB, as one of the EPN Analysis Centres. The increase of this rms from GPS week 1002, indicates that the Bernese encountered more noise during the ambiguity fixing, which is afterwards reflected in the increased noise level in the East component of this station.

Most of the results described above have been communicated to the EUREF community through EUREF mail No 857 (April 2001).

5. Conclusions

We have developed some tools to plot the satellites tracked at a permanent GPS station. We have applied these tools to the EPN network and tried to evidence correlations between signals in the coordinate time series and changes in the station tracking performance.
From the experiments described above, we see that the effects in the up component of a station are the easiest to explain: they are mostly due to a change in the L2 tracking performance at lower elevations.
We have seen one station with a clear correlation between the appearance of an obstacle blocking the antenna sight and an increased rms in the coordinate time series.
It should however be noted, that while in some cases our plots clearly show a degradation of the tracking performance, the quality of the EUREF combined solution does not seem to be affected.
This work is a only a first step towards an automated RINEX data quality checking of the EPN stations.

Not all phenomena in the coordinate time series can be explained by changes in the receiver/antenna configuration or by changes in the station tracking performance. A third error source, which was not investigated up to now, is related to the fact the EPN coordinate time series are based on a combination of individual subnetwork solutions. Changes in the network configuration could influence the coordinates time series too.

6. References

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