

# Detection and Handling of EPN Station Irregularities

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## Introduction

The EUREF Permanent Network (EPN) was set up in 1996 by the IAG sub commission for the European Reference Frame (EUREF) with the primary goal to support and improve the maintenance of the European Terrestrial Reference System ETRS89 and its successive realizations (Adam et al 2002). The last realization of the ETRS89, known as ETRF2000, has been derived from the ITRF2000 through a set of known transformation formulae (Boucher and Altamimi 2002). Because of this straightforward relationship, we will, in this paper, for the sake of simplicity, not make the explicit distinction between ETRF2000 and ITRF2000.

Since its establishment, the EPN has been continuously growing and currently it consists of more than 150 permanent GPS stations distributed over 30 European countries. An up to date description of all EPN components is available from the EPN Central Bureau (CB) website at <http://www.epncb.oma.be>. European National Mapping Agencies constrain the ITRF2000 coordinates of the EPN sites when defining their national Coordinate Reference Systems (CRS) and as such the national CRS are based today on the reference frame provided by the EPN. Using such a procedure, it is of course imperative to know if the ITRF2000 coordinate is still valid today and that no coordinate jumps have appeared since Jan. 2000, the time stamp of the most recent data included in the ITRF2000 realization.

## Station monitoring – the approach

The EPN CB has developed a stepwise approach to monitor the coordinates of the EPN stations. Instead of only looking at the coordinate time series themselves, this approach starts from a data monitoring at the RINEX observation level:

- Step 1 - Monitoring of tracking changes (using RINEX data)
- Step 2 - Creation of coordinate time series
- Step 3 - Correlation of coordinate time series with equipment changes (from the site logs)
- Step 4 - Correlation of coordinate time series with changes in the tracking (from step 1)

The EPN Special Project ‘Time Series Monitoring’ (Kenyeres et al, 2002) will use the information from Step 1 to Step 4 to identify periods that station coordinates are unreliable and estimate coordinate discontinuities.

## Monitoring the RINEX data

The EPN CB runs daily the quality check program TEQC (Estey and Meertens, 1999) and a self-developed program (AZEL) on all the EPN data. Both programs take as input the daily RINEX observation and navigation file. The output of these programs is converted into graphs that are easy to read by non-experienced users. They are made available at the EPN CB web site for and are updated daily when new RINEX data becomes available. We distinguish the following graphs:

1. Yearly overview of the % of the number of observed data with respect to the number of predicted data:

We define the number of observed data as the number of dual frequency (L1, L2) data observed by the receiver. The number of predicted observations is the theoretical number of observations gathered at this

site without any obstructions; it is always computed using the same elevation cut off angle as used for the actual observations. An example is given in Figure 1 where two different quantities are displayed on the graph: a first one (in red) uses the cut off angle as input in the receiver (can change over time) and a second one (in brown) uses a constant 15° cut off angle. In principle, this last percentage should not change unless the tracking behaviour at the station changed.

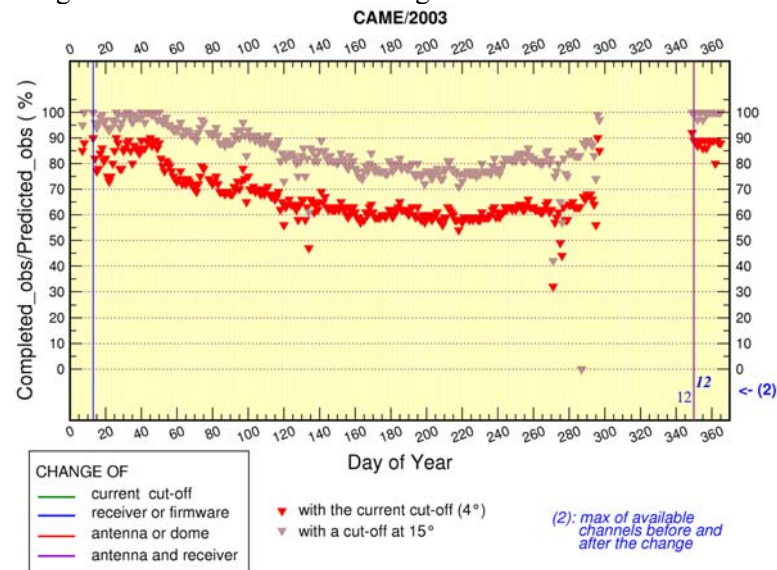


Figure 1: Overview of the % of observed data with respect to the predicted data for the station CAME (Italy) during the year 2003 in which the station experienced equipment problems and reduced tracking. Tracking was restored to normal operations at the end of the year when a new receiver/antenna was installed.

## 2. Recent behaviour and yearly overview of the TEQC parameters

### 2. A. Recent behaviour of the TEQC parameters

By averaging the output from TEQC's quality check mode over 45 days, we create plots that allow evaluating the tracking performance of an EPN station wrt the other EPN stations. The values are:

- the number of complete, dual frequency L1 and L2 observations, gathered at the site. 25 % of the EPN stations have values above 25600.
- the root mean square error (RMS) of the L1 multipath (MP1) and the L2 multipath (MP2). 75% of the EPN stations have MP1 values below 0.57 m and MP2 values below 1 m. However, absolute multipath RMS values do not necessary correlate with site performance.
- the number of observations per cycle slip, inverted and multiplied by 1000. Values less than 5.8 are recorded in 75% of the EPN stations

The error bars in Figure 2 are the standard deviations from the mean values over the last 45 days. In a lot of cases, they are even more important than the absolute values. They indicate, on a day-to-day basis, how the behaviour of the station changes. High standard deviations should encourage the site operator to have a closer look at the data. Also the IGS Central Bureau makes similar graphs available for all the IGS stations.

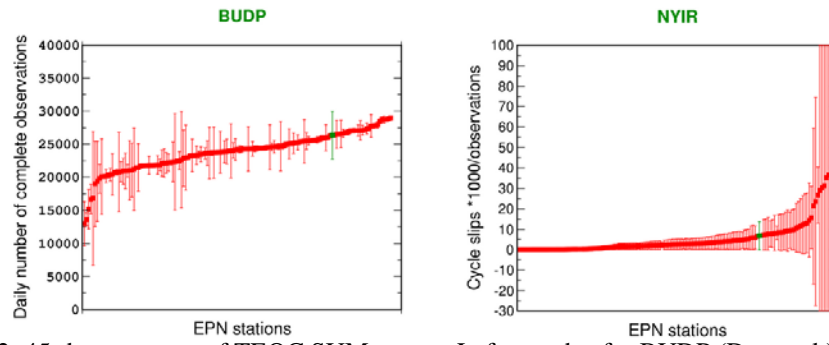


Figure 2: 45-day averages of TEQC SUM output. Left: nr. obs. for BUDP (Denmark) (in green), right: nr. obs. per cycle slip, inverted and multiplied by 1000 for NYIR (Hungary) (in green).

### 2. B. Yearly overview of the TEQC parameters

Using the same TEQC quantities as in 2.A, we create additional graphs that give a yearly overview of these quantities. These graphs are more valuable when investigating correlations with coordinate changes than the graphs in 2.A. An example of some of these plots is given in Figure 3. It shows the station REYK which changed its antenna at day 164 (red line indicated on the graphs). Strangely, the behaviour of the station tracking already changed before the antenna replacement having a direct influence on the coordinate time series in Figure 4

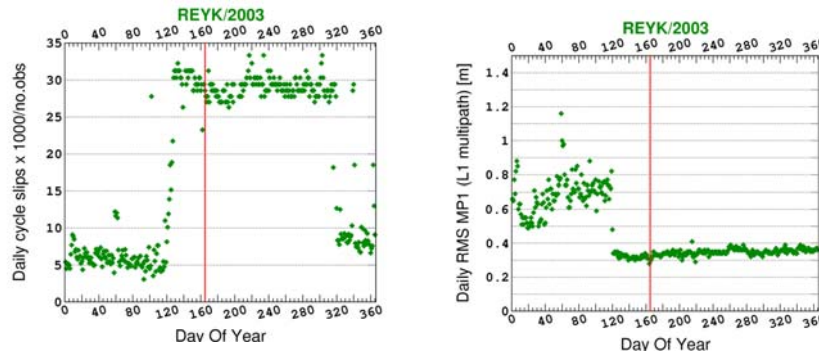


Figure 3 : SUM TEQC output for REYK (Iceland). Left: nr. obs./cycle slip, inverted and multiplied by 1000, right: RMS of L1 multipath. The red line indicates the epoch of an antenna change as indicated by the site log.

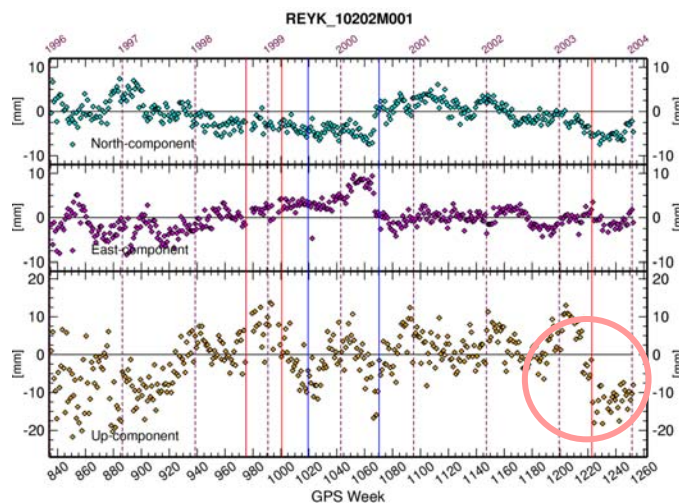


Figure 4: Coordinate time series for the station REYK (Iceland). The circle indicates the time period before the antenna change, where the tracking behaviour of the station changed. This tracking change is clearly seen in the Up-component and corresponds with a coordinate jump of about  $-5\text{mm}$ .

### 3. *Monthly snapshots of satellite tracking*

As explained previously, next to TEQC, we also run the in-house developed program AZEL on all EPN data. AZEL is not run daily, but once a month. The output of AZEL is the basis for two graphs (see Figure 5):

- the number of measured satellites versus the predicted number;
- the azimuth and elevation angles of the satellites observed at the station.

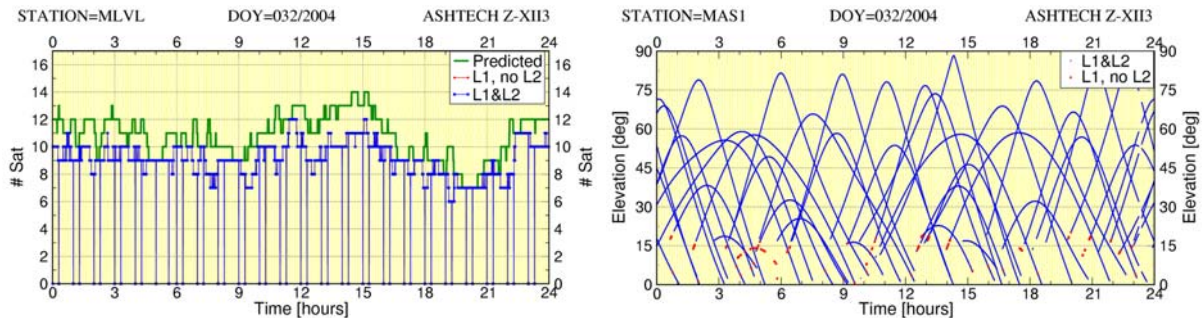


Figure 5: Left: Number of satellites observed (blue) and predicted (green) at MLVL (France). The regular tracking interruptions are caused by the software package (remote33) used to download the receiver; Right: Azimuth and elevation angles of the satellites observed at MAS1 (Canarian Islands). Red points indicate where only L1 is tracked. Satellite lock is acquired mostly above 15° of elevation, which indicates an equipment problem.

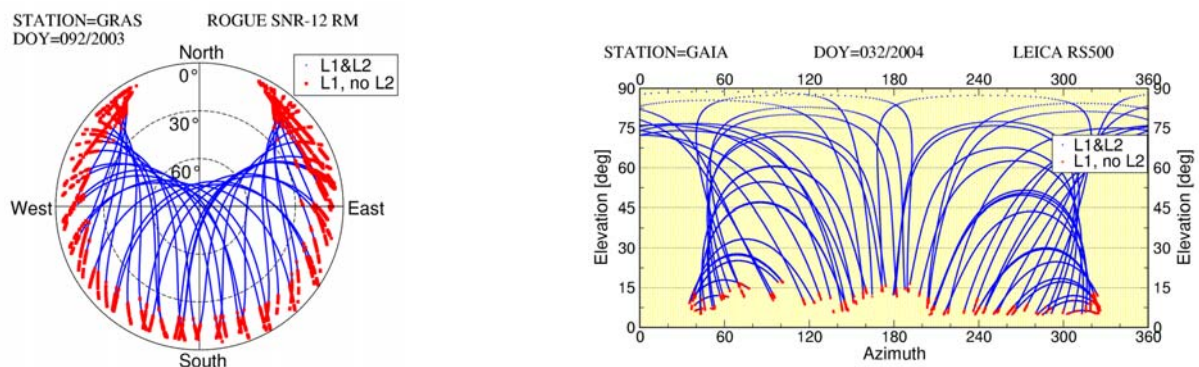


Figure 6 : Azimuth and elevation angles of the observed satellites. Red points indicate where only L1 is tracked. Left: polar plot for GRAS (France) suffering from bad tracking at low elevations. Right: Cartesian plot for GAIA (Portugal) showing site obstacles.

### Case studies

#### *HERS and BZRG*

Looking at the coordinate time series in Figure 7 of HERS (Herstmonceux, UK), we see that around GPS week 1002 (March/April 1999), the East and North components of the station display a significant jump and the noise of coordinates is increases. Looking for the source of this problem, we used AZEL to create the azimuth/elevation graphs using the RINEX observation files measured before and after this jump. The results are given in Figure 8 and they show that, from DOY 81 on, there are less satellites tracked between azimuths 270° and 340°. At DOY 88, the degradation reached it maximum. After some tests (antenna rotation), the site operator found out that problem was caused by the non-uniform directional response of the antenna, which was returned to the manufacturer for repair. On August 8, 2001 the repaired

antenna was reinstalled, and since that time, the estimated coordinates have been fully in agreement with their values prior to March 1999.

A similar situation happened at BZRG (Bolzano, Italy), where the breakdown of the LEIAT504 antenna and a strong nearby earthquake happened almost at the same time (July 2001). However, the ‘displacement’ observed in the coordinates was fully contrary to the geophysical expectations. Thanks to the previous experience with Herstmonceux and the availability of the BZRG azimuth-elevation graphs, the problem could quickly be narrowed down to the antenna.

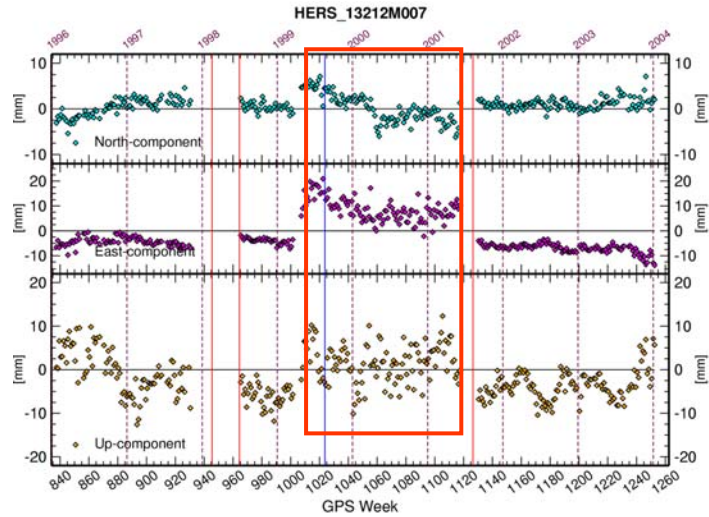


Figure 7: Coordinate time series of HERS (UK). The rectangle indicates the irregular behaviour.

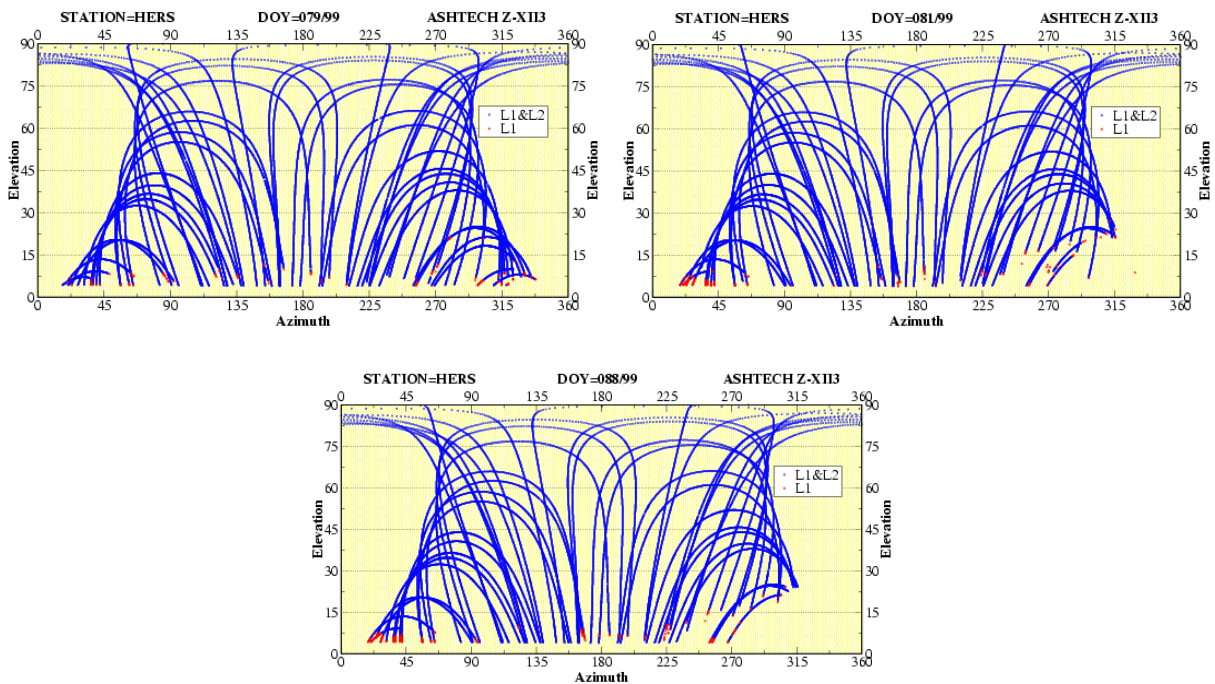


Figure 8 : Azimuth/elevation angles of observed satellites in the station HERS (UK). The antenna has a defect and no low elevation satellites are tracked between azimuths 270° and 340°. Top-left: before the antenna malfunctioning; top-right: start of the antenna malfunctioning; bottom: full antenna malfunctioning.

## ACOR

The coordinate time series (Figure 9) of ACOR (Spain) show a decreasing up-component starting GPS week 1170 (DOY 212). Since we would not find any direct geophysical explanation for this effect, we looked for a change in the station tracking. As can be seen from the percentage of observed data/predicted data in Figure 10, the station started to experience trouble tracking at low elevations from DOY 212, 2002 on. From a discussion with the site operator, we learned that the decreased tracking was due to radio-interferences in the L1 signal caused by a continuous remote controller of a crane in the port. When telecommunication authorities stopped this controller, the situation was restored to normal. However, the conclusion was that the data from ACOR data unusable for densification purposes for the complete the time period with decreased tracking.

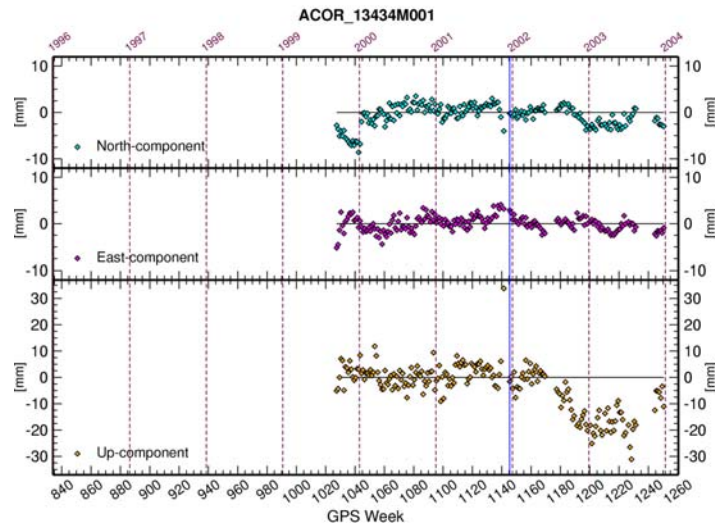


Figure 9: Coordinate time series of ACOR (Spain). Around GPS week 1170 there seems to be an apparent subsidence of the site.

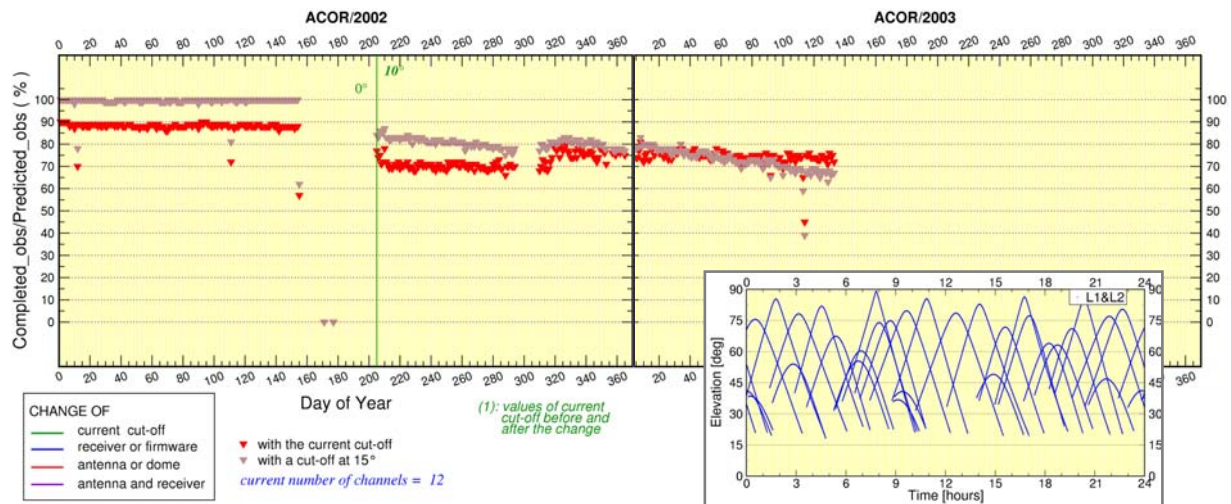


Figure 10: % of observed data/predicted data for ACOR (Spain) during the years 2002-2003. A steady decrease of the % is observed from the summer of 2002 on. The bottom graph shows that this decrease is caused by an increase of the elevation angle at which the receiver acquires satellite lock. Finally no observations above 18° degrees were available and satellite lock was only acquired from 30° on.

## RAMO

A very peculiar example is RAMO (Mitzpe Ramon, Israel) shown in Figure 11, where following an antenna change on DOY 199, 2000, a quasi-annual term, with decreasing amplitude appeared in the East component of the coordinates. Since it is hard to explain this as a geophysical phenomenon, we have again used the tracking monitoring tools to have a closer look at the behaviour of this station. Figure 12 shows the azimuth/elevation angles of the satellites tracked at RAMO for 4 different days, two before the antenna change, and two after the antenna change. From these graphs, we can see that after the antenna change there is a decreased tracking around an azimuth of  $180^\circ$  indicating that the new antenna had a fault.

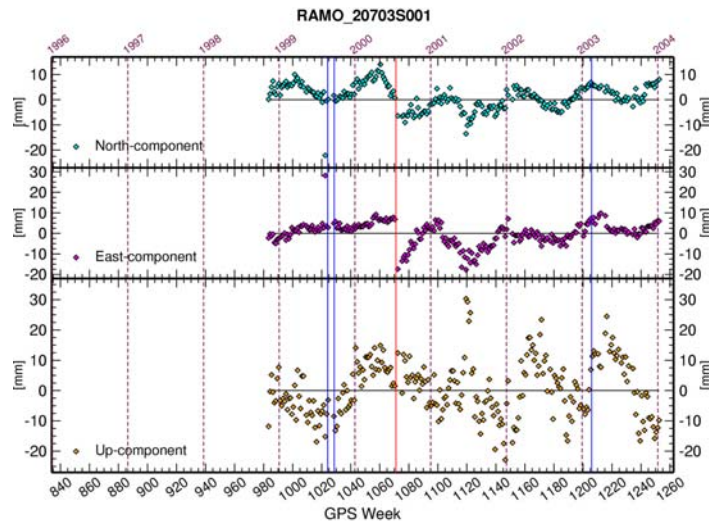


Figure 11: Coordinate time series of RAMO. After an antenna change in the summer of 2000, a periodic effect appeared in the East-component.

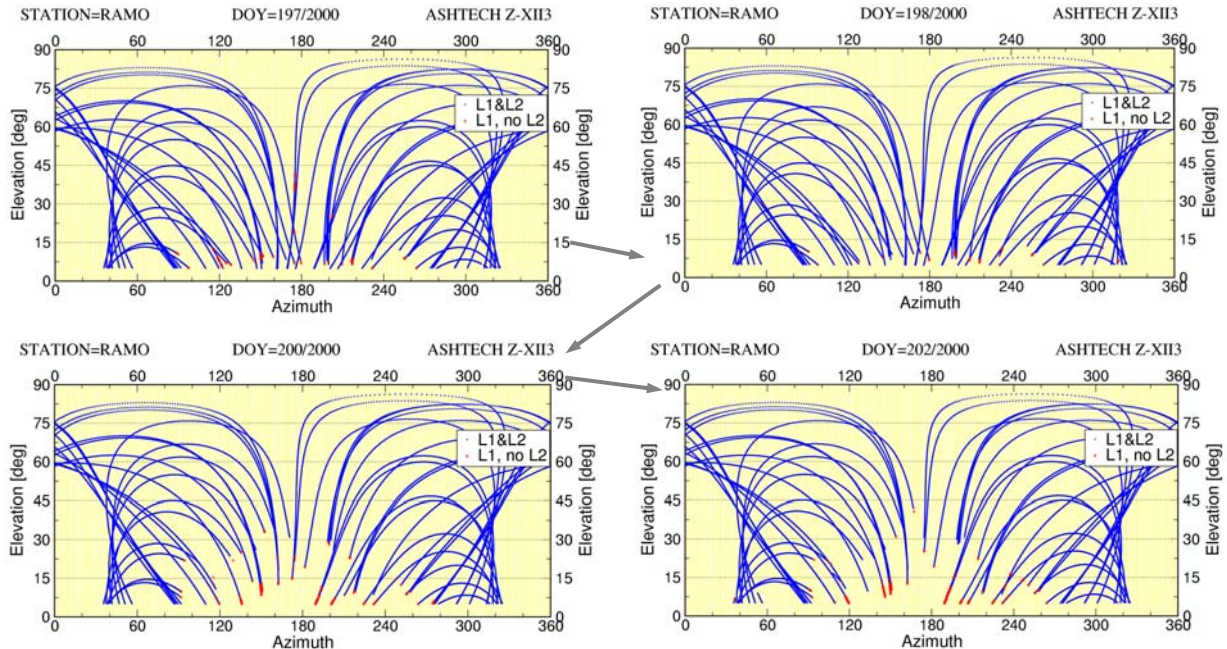


Figure 12: Azimuth/elevation angles of observed satellites in the station RAMO. The antenna has a defect and no low elevation satellites are tracked around an azimuth of  $180^\circ$ . Top: before the antenna malfunctioning; bottom: full antenna malfunctioning.

## Summary

We have shown in this paper the very simple tools that have been developed at the EPN CB to monitor the tracking of a permanent GPS station and we have applied these tools to the stations from the EPN. We have noted that especially the long-term monitoring of the tracking is important and we have demonstrated a clear correlation between tracking changes and irregularities in the computed coordinates.

The EPN Special Project ‘Time Series monitoring’ uses the info from the tracking monitoring to identify for each station time periods with unreliable coordinates and to estimate the coordinates jumps due to equipment changes. Using this procedure, the EPN can be used as a reference frame for all European national densification campaigns.

However, in order to guarantee the reliability of the EPN, it is imperative that site operators take the time to check the performance of their station using the information the CB makes available. Presently, some tracking problems are still detected with too much delay!

## Acknowledgements

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