Frequency Analysis of GPS Coordinate Time Series from the ROB EUREF Analysis Centre

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Abstract

The Royal Observatory of Belgium (ROB) is one of the analysis centres which contributes to the EUREF solution. Within that frame, the ROB computes GPS coordinate time series for a network of European stations. We will apply the Fourier Transform on a subset of these coordinate time series to search for dominant frequencies. In a second step, a time-frequency analysis will be performed using the continuous wavelet transform.

The frequencies outcome of both methods will be compared to frequencies of the deformations associated with known geophysical phenomena such as ocean loading and atmospheric loading.

1. Introduction

Observation sites experience displacements due to various effects, e.g. the time varying attraction of the Sun and the Moon on the Earth causes periodically uplifts of the Earth's crust and the oceanic water.

The most important effects are:

a) The solid Earth tides whose radial component can reach 30 to 40 cm. Its effect has to be modelled in the parameter estimation process. The effect is similar for adjacent stations. In Brussels, it varies between 30 and 40 cm.

b) Ocean tide loading, which is the deformation of the Earth's crust (mainly along the coasts) due to the tides in the oceans which redistribute oceanic masses. In Brussels the magnitude of the ocean loading is about 2-3 cm, but it can go up to 10 cm is particular coastal stations.

c) Atmospheric pressure loading, which is the effect of the irregular and time varying distribution of the atmospheric pressure at the surface on the Earth's crust. It is mainly noticeable in height where it can reach a few cm. Again, the effect is similar for adjacent stations.

Ideally the correction for these time-variable geophysical effects has to be done at the observation level. In the case of GPS data processing, the Solid Earth tides correction is always applied.

The correction for the effect of ocean loading is presently implemented (but not always applied) in most analysis software; it necessites station-dependent input tables with amplitudes and phases for the different tidal waves.

The atmospheric loading correction depends on the atmospheric pressure above and around the station and needs therefore atmospheric pressure data as input. Methods used to compute the effect of the atmospheric loading are complex and heavy to implement. For this reason, this effect is generally not taken into account in most GPS data analysis software.

We will investigate if the effects that have not been modelled during the GPS data analysis show up in the computed station positions. For this investigation three and a half year of daily GPS-derived positions have been analysed using both the Fourier transform and the continuous wavelet transform.

2. GPS data analysis

The GPS coordinates time series used for this study have been computed by the Royal Observatory of Belgium (ROB) within the frame of its activities as EUREF local data analysis centre.

The data processing strategy used to compute the daily solutions is described in ftp://omaftp.oma.be/pub/astro/euref/center/analysis/ROB.LAC.

Neither ocean loading, nor atmospheric loading corrections have been applied. The Solid Earth Tides have been corrected following the IERS Conventions 96.

Based on the normal equations of the daily network estimates, the ROB computes weekly solutions that are submitted to EUREF. The EUREF Combination Centre (BKG, Frankfurt) combines these weekly solutions combines with the weekly solutions of the other EUREF local analysis centres to obtain the official EUREF solution.

The full GPS data set used covers more than 4 years of observations and begins in January 1996. Daily normal equations were saved since GPS week 876 (October 1996); they are all computed with the Bernese 4.0 software. Before GPS week 908, an elevation cut-off angle of 10° was used. Afterwards, following the recommendations of the Analysis Centres Workshop (April 1997, Brussels) (BRUYNINX, 1997) a 15° cut-of angle was used.

Due to the principle of distributed processing used within EUREF, the ROB subnetwork has changed considerable

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since start of the data analysis. Because of a solution redundancy within EUREF, some stations that were processed in the beginning of the data analysis were not processed later on. Other stations were installed rather recently and do not have long time series. Figure 1 gives for each station in the ROB subnetwork the number of times it was included in the daily estimation process.

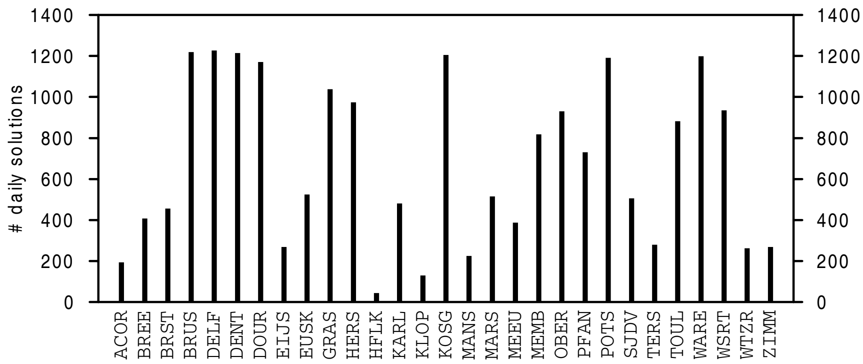

Figure 1: Number of daily coordinate estimations available for each station in the ROB subnetwork

We have combined these daily normal equations, covering about 3 and a half year of observations (October 1996 – February 2000), into a so-called "*multi-year solution*". The combination was done using the ADDNEQ program of the Bernese 4.2 software (BROCKMANN, 1996). ADDNEQ takes care of removing all constraints from the daily solutions before making the combination. The coordinates of all the stations were estimated without performing any velocity estimation. The geodetic datum of the coordinates was defined by forcing the multi-year solution to have no translation and no rotation with respect to the ITRF97. The coordinate differences between the daily free network solutions and the multi-year solutions (after a 7-parameter transformation) produce the coordinate time series. The parameters of these daily Helmert transformations have been determined using the full network available at that specific day.

We expect that part of the signals common to the entire network could be absorbed by the transformation of the daily solution into the *multi-year solution,* which is necessary to compute the residuals. Consequently these signals could be eliminated from the coordinate time series.

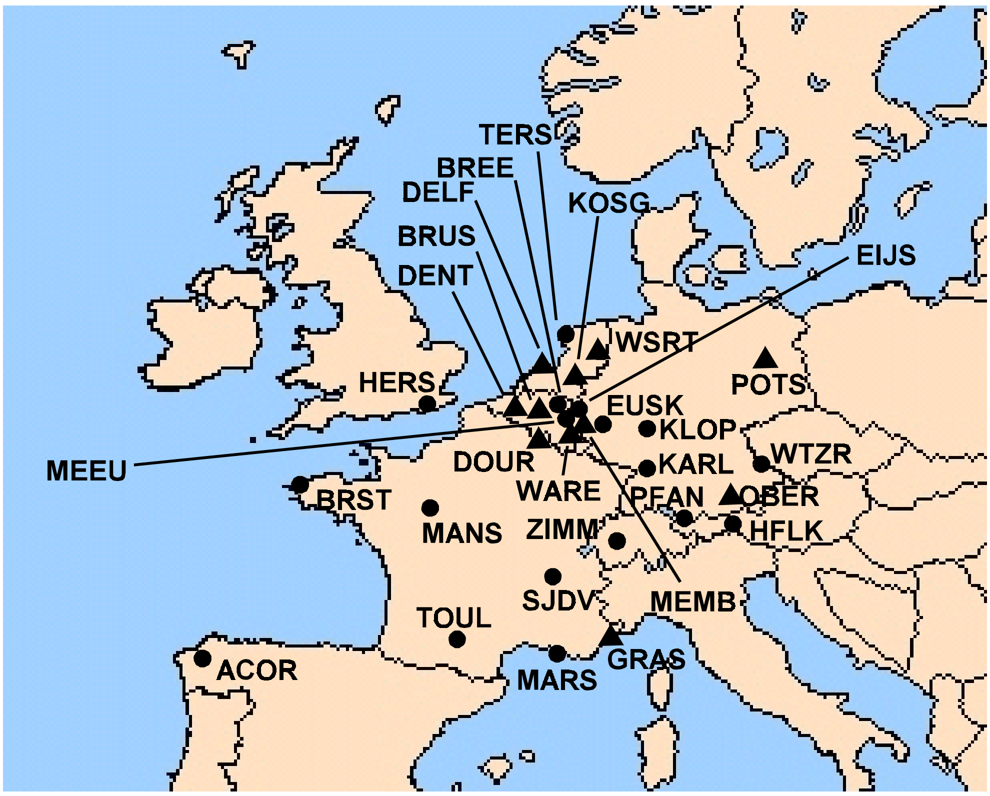

Figure 2: Map of the stations included in the ROB subnetwork (October 1996 – February 2000)

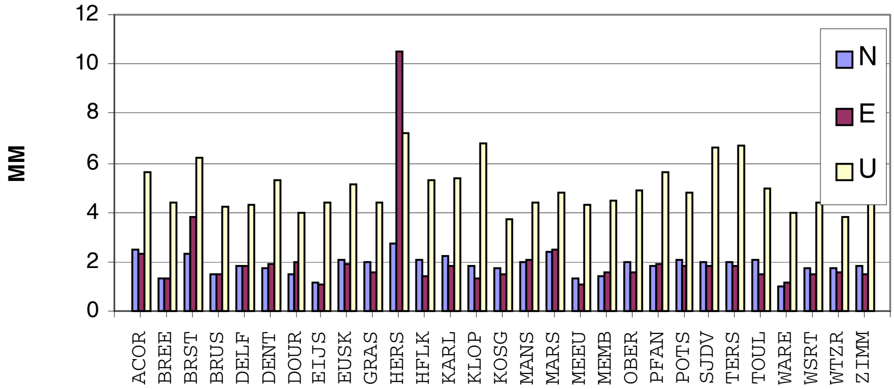

Figure 3: Computed coordinate rms (North, East, Up) for stations included in the ROB network

The resulting coordinate rms for each station is given in Figure 3. We have obtained mean rms values of about 2 mm for the horizontal components and 6 mm for the vertical one.

The stations used for the investigation of their coordinate time series were choose based on the following two criteria:

- long time series (Figure 1)
- reliable coordinate estimation (Figure 3).

Based on these considerations we have selected the following stations: BRUS, DENT, DOUR, WARE, DELF, KOSG, POTS, GRAS, OBER, WSRT, MEMB (triangles in Fig. 2).

Although long time series were also available for the stations HERS and PFAN, we did not use these stations in our investigations. The coordinate rms of HERS is larger than for the other stations; this station has a problem with the quality of its tracking data. For PFAN, an antenna change occurring in October 1999 caused a large coordinate jump of about 4 cm in height, and half a centimetre in both horizontal components.

3 Frequency and time-frequency analysis

The aim of this section is to investigate the periodicities in the coordinate time series by a spectral and time-frequency analysis.

For each of the stations, the coordinates time series are split up in a North, East and Up-component. Each of these components has been analysed independently.

Thanks to the rigorous selection of our stations, the number of gaps in the coordinate time series was minimal: from 1,7% to 7 % of data are missing, except for one station GRAS. These small gaps (usually less than 8 days) have been filled using a cubic spline interpolation. This spline interpolation uses piecewise cubic curve between each two points. The spline function has continuous second and first derivative at the beginning and end of each interval. The missing points are estimated by evaluating the value of this curve for that time.

In a first step, we have applied a Fourier transform on the three components of all stations. A lot of peaks are visible in the spectrum; a lot of them are close to the significance level which was defined as 2.7 the stdev of the Fourier transform.

As an example, the results of the frequency analysis obtained for BRUS and DELF are displayed in Figure 4. The circled peaks indicate the frequencies that exceed the significance level.

As can be seen in the Table 1, some frequencies seem to be more present in the coordinate time series. The peaks found usually correspond to periods from 11 to 14 days and also from 40 to 50 days. There are also high peaks at the beginning of the spectrum which correspond to a very large period (about 300, 400 days). The time series are not long enough to determine this frequency more precise.

Table 1: Periodicities found in the coordinate time series

Period	In which Series	Probable Origin
11 → 14 days	BRUS N-U, DENT U, KOSG E-U, OBER N-U, POTS E...	Ocean loading
40 → 50 days	BRUS N, DENT E, DOUR N, GRAS U, MEMB N,...	Atmospheric loading?
Long periods	Nearly All	Seasonal effects

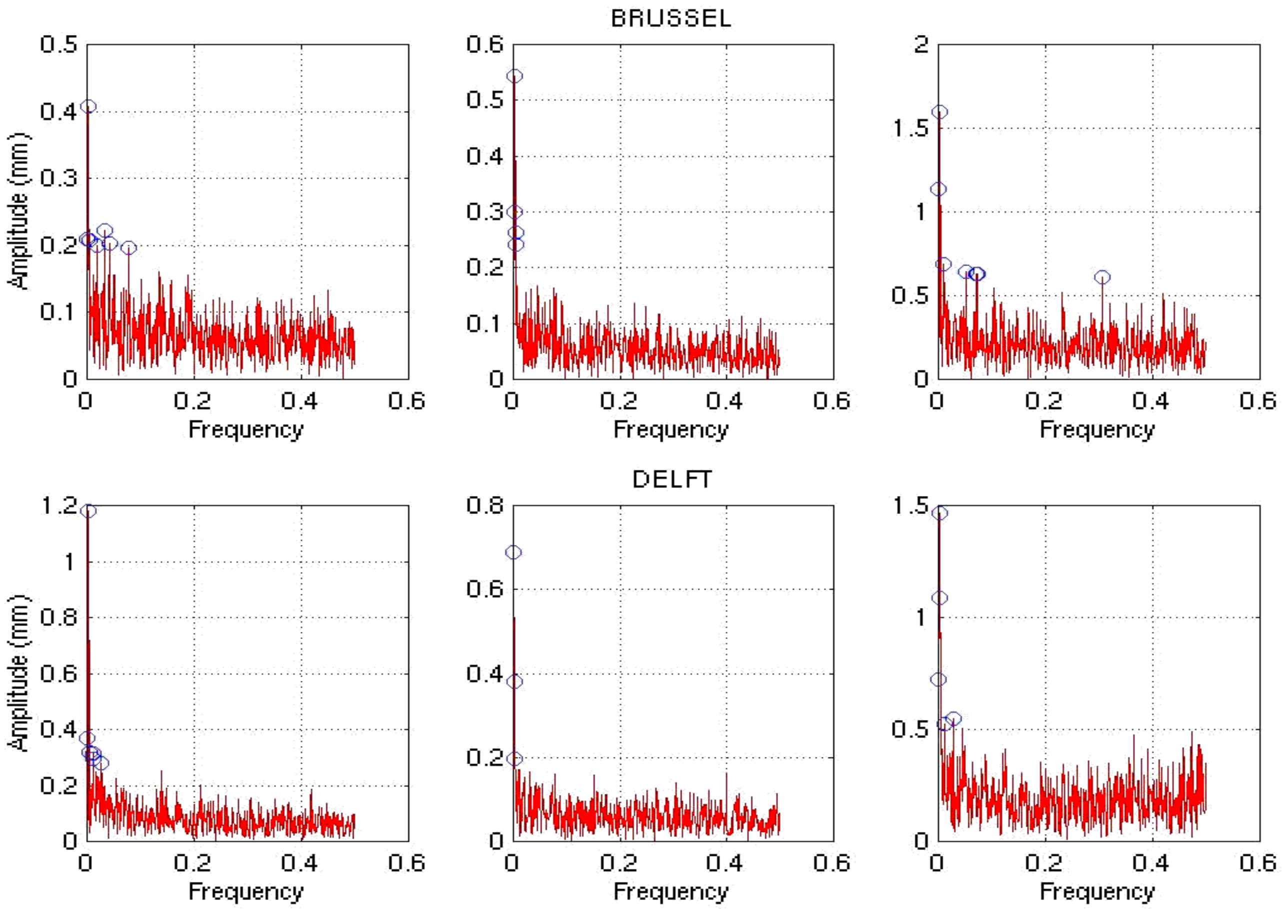

Figure 4: Results of Fourier analysis for the three coordinate components for the station BRUS and DELF, expressed in 1/days

If we except the peaks at the beginning of the spectrum, the amplitude of the significant peaks is about 0.2 – 0.3 mm for the horizontal components and about 0.5 mm to 1 mm for the vertical one. It is clear that these amplitudes are very small compared to the respectively repeatabilities of the coordinates.

Additionally, a time-frequency analysis has been performed on the individual stations time series in order to investigate the time variation of the different periodicities. We used a continuous wavelet analysis (ANTOINE, 1994). Two parameters are to be considered: a, the scale parameter and b, the time translation parameter. As we use the Morlet wavelet, the scale parameter a is strictly equal to the period analysed. The wavelet transform can be visualised by a 2-dimentional plot on the time-scale plane. A continuous horizontal band in the wavelet transform indicates that a frequency is present in the signal and that its amplitude is constant with time.

The results of the time-frequency analysis are:

- For the periods from 4 to 50 days, we can observe generally a 'spotted' graph instead of straight bands. This means that the amplitude of these frequencies is not constant with time. The spotted bands are usually found for periods between 10 and 15 days and also between 40 and 50 days.
- For the very large periods, we can observe a continuous band (around 350-400 days) but here again, the time coverage is not long enough to determine precisely the exact value of this frequency. Furthermore, this band is not strictly horizontal, which means that this periodicity present in the signal has not a well-fixed frequency (it seems that the value the frequency is changing with time).

In Figure 5, we have plotted the values of the 7 parameters of the Helmert transformation between the daily free network solution and the multi-year solution. TX, TY and TZ are the three translation parameters. R1, R2 and R3 are the rotation angles and S is the scale factor.

A first thing that we can see from this plot is that there is a sudden jump in TY, R1 and R3 at GPS week 985 and a jump back at GPS week 1027. It is presently unclear to us if these jumps can be linked to real physical phenomenon or even what is causing it.

We can also clearly see an annual signal in the estimated scale factor. In addition to this, the scale factor seems to decrease with a trend of $2x10^{-3}$ [mm/km] a year, something that we will have to look into in more details later.

Investigating the frequencies in these 7 parameters by computing a Fourier transform, shows again large peaks at the beginning of the spectrum which correspond to large period (probably an annual and also some smaller ones of about 100 to 200 days). Some other peaks are also visible: about 80 days (TX, TY, R1, R2, and R3) and 50 days (TX, TZ, R2, and S).

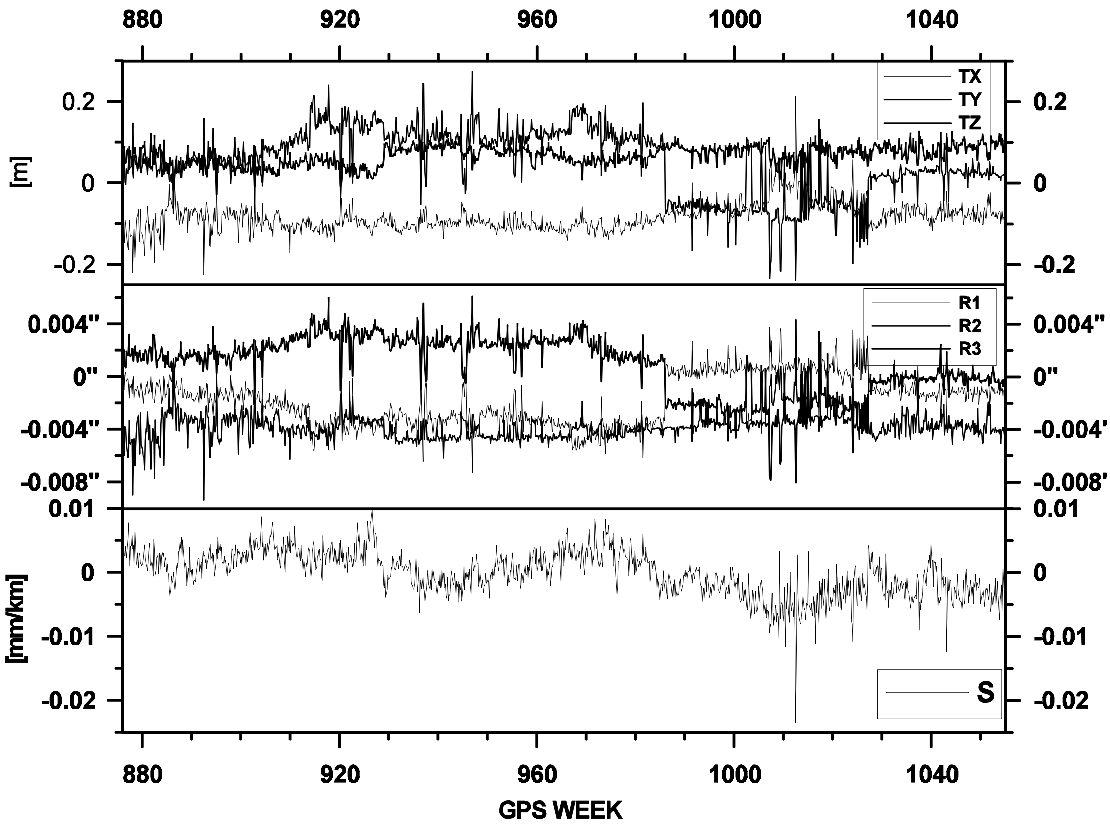

Figure 5: Values of the 7 parameters of the Helmert transformation between the daily solutions and the campaign solution

4. Interpretation and Conclusions

One of the conclusions from this work is that both the Fourier analysis and the wavelet analysis of the GPS-derived coordinate time series show the presence of signals in the time series.

However, the amplitudes of all the signals detected in the coordinate time series are of the same level as the noise of GPS-derived coordinates. The small amplitudes, and the fact that the derived frequencies are close to the significance level (2.7 x stdev of the Fourier transform), are probably due to the limited region covered by our network. It is clear that the interpretation of these signals needs to be done with the proper reserve.

The signals found in the coordinate time series have periods of 10 to 15 days and 40 to 50 days. The time frequency analysis learned us however that these signals are not stable in time.

The first periodicity band includes the period of 13,6 days, which is the frequency of the O_1 tidal wave. This periodicity band could therefore be due to the effect of ocean loading, although because of the small amplitude of the O_1 wave this is difficult to confirm.

The Fourier analysis of the 7 parameters of the daily Helmert transformations did not detect any signals with a period between 10 to 15 days. This means that there is no indication that part (or all) of the signal was absorbed by the transformation. We did expect to see the effect of ocean loading more explicit at coastal stations. It is clear that part of the effect is averaged out due to the computation of daily coordinates. A possible next step in our investigations could be to quantify the effect (and periods) of the ocean loading in each station by using the available amplitudes and phases for the dominant tidal waves for that station (SCHERNECK, 1999).

The second periodicity band includes the periodicity close to 50 days which has been reported (LANGLEY et al, 1981) in data from the changes of the Atmospheric Angular Momentum (exchanges of angular momentum with the atmosphere). This signal could be correlated with some kind of signal in the atmosphere.

Signals with similar periodicities were detected in the parameters of the 7-parameter transformations. This indicates that part of this signal is already absorbed by the transformation before the creation of the time series. We feel that this periodicity band needs more attention and investigation.

To our surprise, a new, presently not identified, period of about 80 days was found in some of the parameters of the Helmert transformation. In addition to this, the expected annual, seasonal period was present in our coordinate time series.

We will investigate all this more in the future. Part of the investigation will include reducing the number of parameters in the Helmert transformation used for the residual computation.

5. References

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