Diurnal and sub-diurnal oscillations in GPS coordinates

Andrzej Araszkiewicz, Janusz Bogusz, Mariusz Figurski
Centre of Applied Geomatics, Military University of Technology, Warsaw
e-mail: aaraszkiewicz@wat.edu.pl, jbogusz@wat.edu.pl, mfigurski@wat.edu.pl

Abstract

This paper presents the results of the frequency and time-frequency analyses of the coordinates of permanent GPS sites obtained from short-time solutions. The aim was to estimate the usefulness of GPS observations for the short-period geodynamical studies, and check how tidal models in Bernese fit to individual sites conditions. This study shows that East-West component is noisier than North-South and the East-West oscillations have greater energy, this can be the influence of using short-time solutions. There are some oscillation in tidal frequency on few of analysed sites coordinates. These oscillations could be explained by the residual ocean tidal loading effect. More detailed description of the observed oscillations needs further studies on the method of precise coordinates determination with sub-daily sampling rate. The paper contains preliminary results of analyses on the short-time GNSS solutions conducted in the Centre of Applied Geomatics of the Warsaw Military University of Technology.

Introduction

The analyses of the GPS coordinates from sub-diurnal solutions based on EPN data were performed by Warsaw Military University of Technology. The aim of this research was to find out how the tidal models used in Bernese software (solid Earth and ocean tides as well) fit to the individual conditions of EPN stations. The 1-hour solution technique of GPS data processing was used to obtain coordinates of more than 70 EPN stations. Additionally several Polish permanent sites with clearly seen oscillations were examined. This processing technique allowed us to recognize residual diurnal and sub-diurnal oscillations which could be next used for validation of the tidal models.

Data

1-hour interval time series of sites coordinates were needed for the analyses. 1-hour observation are too short to generate precise coordinates so authors decided to use 4-hour solution of GPS data processed with 1-hour interval. The data was taken from BKG Analysis Centre. The solutions contain tidal model according to the IERS Conventions (McCarthy and Petit, 2004) and ocean tidal loading effect calculated using FES2004 model (Lyard et al., 2006).

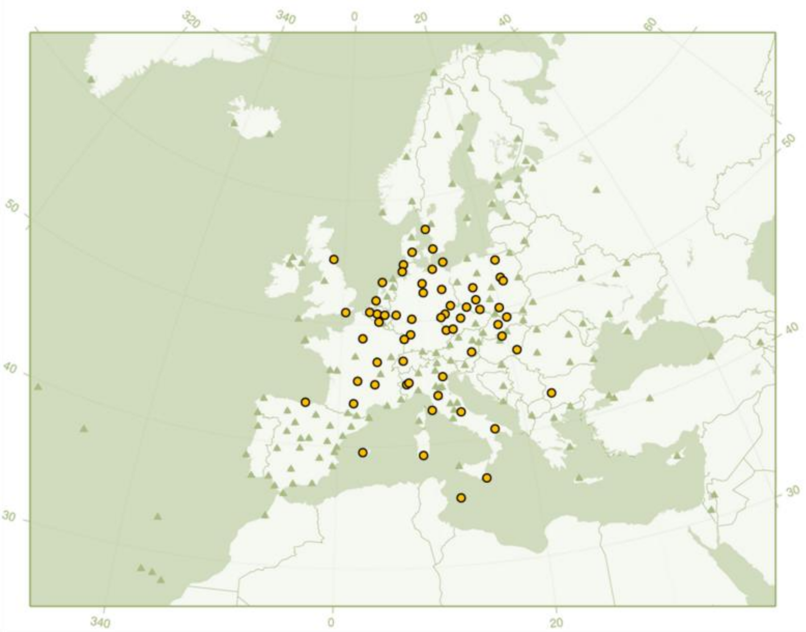

Fig. 1 EPN stations used in analyses.

Coordinates from over 70 EPN stations were analyzed for diurnal and sub-diurnal oscillations existence. Time series from 1400 to 1500 GPS week were calculated using BERNESE 5.0 software (Beutler et al., 2006). Fast Fourier Transformation allowed to obtain information about the frequencies of the site's coordinates. All analyses were performed in the MATLAB® Technical Computing Environment.

Oscillations in height component

Diurnal and sub-diurnal oscillations were found almost on all sites. On some stations the oscillations were higher than in the others. The sites were divided into two groups with respect to the amplitude: less than 3 mm and more than 3 mm. MALL station characterizes the greatest amplitude, it is about 16 mm. In most of the sites half-diurnal oscillation is almost two times higher than the diurnal. There cannot be found any relation between amplitude's size and antennas fitting.

Fig. 2 Sites with oscillation's amplitude less than 3 mm (left, brown) and more than 3 mm (right, red).

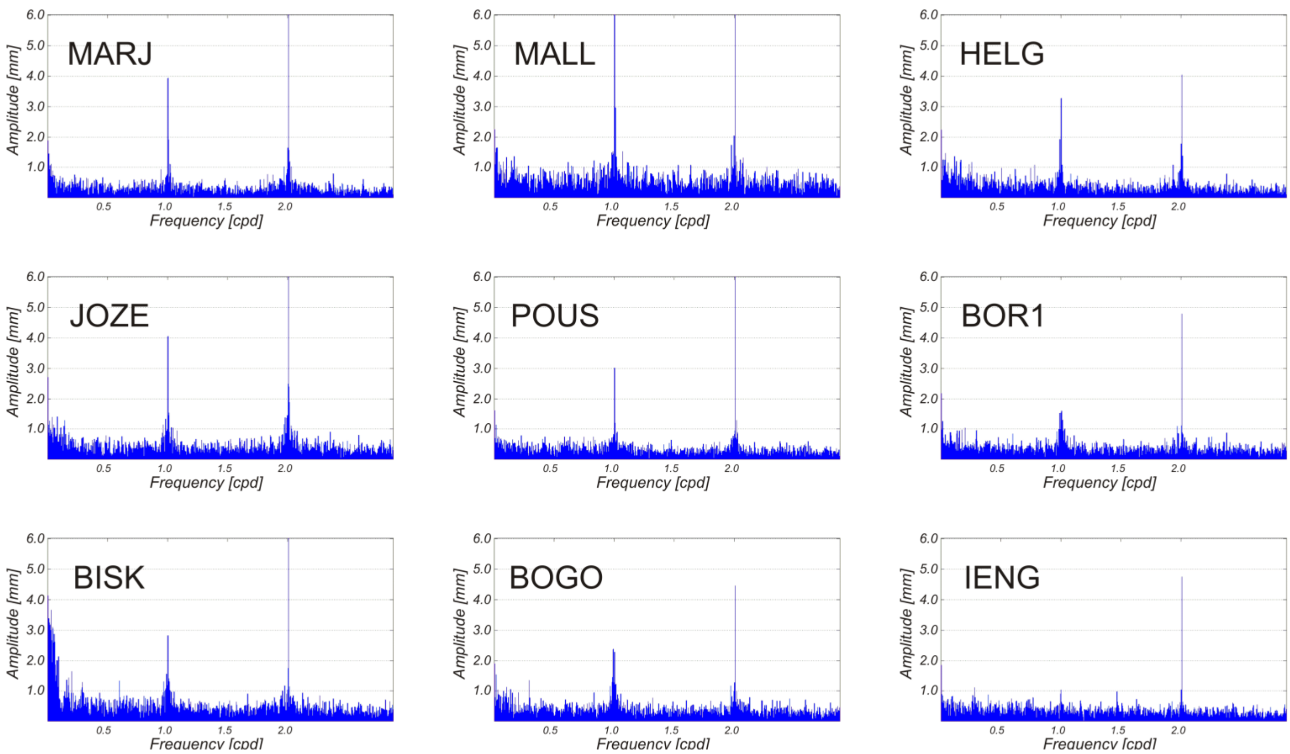

Fig. 3 Periodograms of sites with oscillations in height component (amplitude higher than 3 mm).

Oscillations in horizontal components

Fig. 4 Sites with oscillation's amplitude less than 1 mm (left, brown) and more than 1mm (right, red).

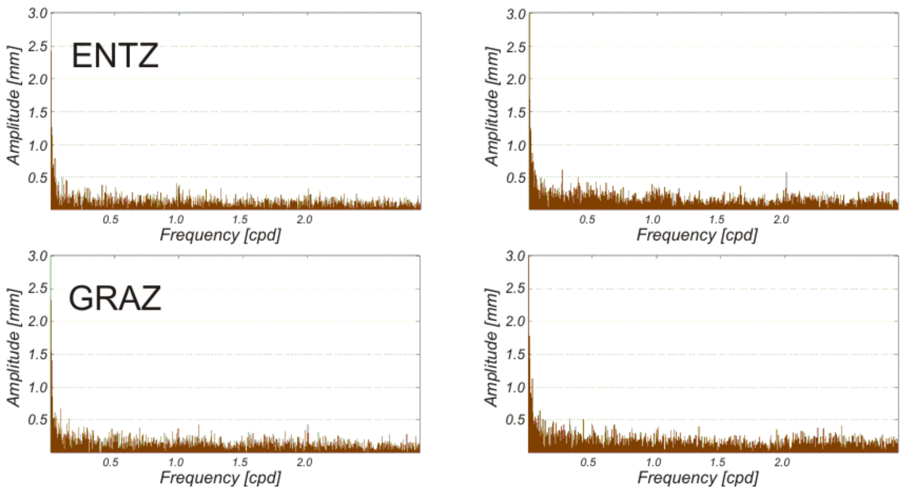

Fig. 5 Periodograms of sites without significant oscillation (less than 1 mm), left: N-S component, right: E-W component.

Similarly to height the horizontal components were divided into two groups. 1 mm was taken as the threshold. Most of stations with oscillations below 1 mm are located in Central/Western Europe.

The second group consists of thirteen sites, mostly from Eastern/Central Europe and two sites located on islands. The highest oscillations can be found in MALL site (over 6 mm). The E-W component is noisier and has bigger oscillation than N-S. This can be the effect of short-time GPS solution usage. For such a solution better ionosphere and troposphere model might be implemented. Diurnal oscillation is higher in N-S component and half-diurnal is bigger in E-W component.

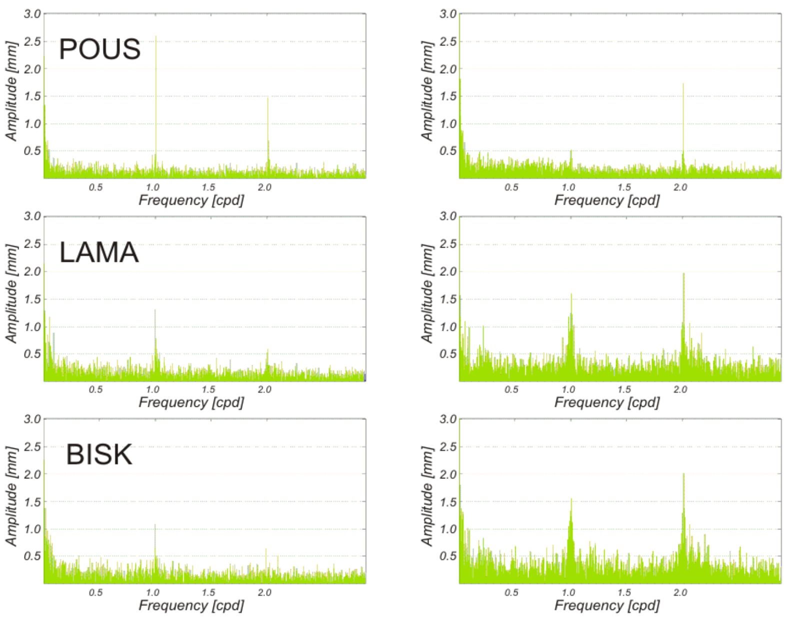

Fig. 6 Periodograms of sites with oscillations in horizontal components (amplitude more than 1 mm), left: N-S component, right: E-W component.

Time – frequency analysis

Wavelet transform derives from Fourier Transform, which is much more flexible. The FT is not very good to use to the non-stationary time series, which are changing in time. If we assume that non-stationary signal consists of several stationary signals the Short-Time Fourier Transform (STFT) could be applied. The signal is divided into small segments which are assumed to be stationary. The main role in such analysis plays a "window", which is used to divide the signal. But in this case we act with indeterminacy. If a narrow window is chosen the accurate information about time is obtained and less accurate about frequency. In case of wide window it is the other way round. Continuous Wavelet Transform (CWT) assumes that the signal is a composition of several functions (wavelets in this case). CWT of a signal is a sequence of projections onto rescaled and translated versions of an analysing functions of wavelets (Mallat, 1999):

$$CWT_x^{\psi}(s,\tau) = \int_{-\infty}^{\infty} x(t)\psi_{s,\tau}^{*}(t)dt$$

where:

$$\psi_{s,\tau}(t) = \frac{1}{\sqrt{|s|}}\psi\left(\frac{t-\tau}{s}\right), \quad s,\tau \in R, \quad s \neq 0$$

The equation presents wavelet function, which depends on two parameters:

s - scale coefficient,

t - time shift.

In this study the complex Morlet wavelet was used (Goupillaud et al., 1984):

$$\psi(x) = \frac{1}{\sqrt{\pi \cdot f_b}} e^{2i\pi f_c x} e^{-\frac{x^2}{f_b}}$$

which depends on two parameters:

f_b - bandwidth parameter,

f_c - center frequency.

Basing on experiences and empirical studies, the authors noticed, that the best results of wavelets analyses of this specific data were received for the following equation:

$$f_b = 5\ ,\ f_c = 3$$

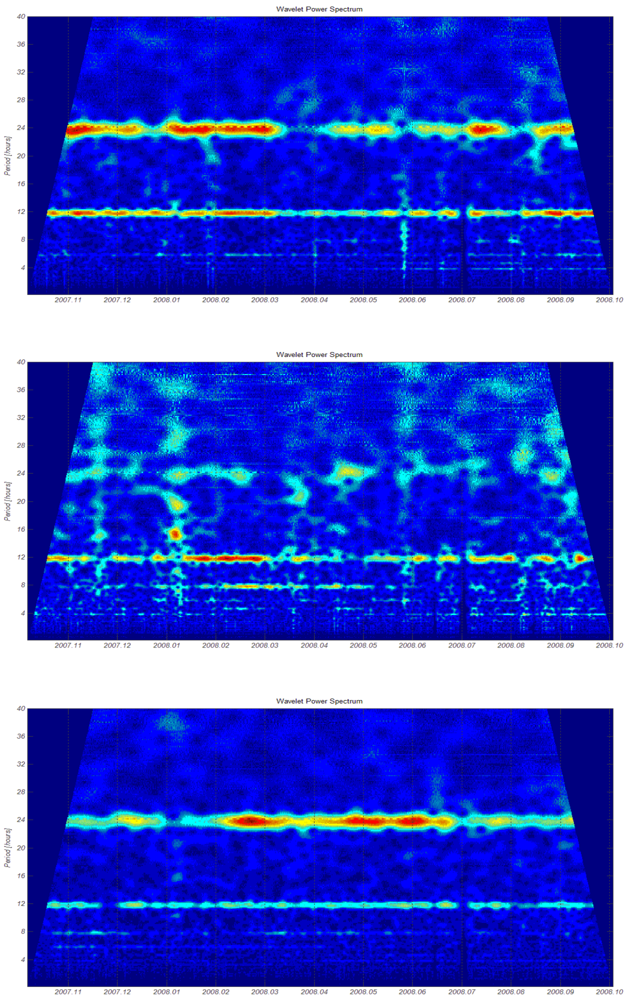

Fig. 7 Power Spectrum of MALL sites coordinate, from up: N-S component, E-W component, height.

Wavelet analysis confirmed that the diurnal and half-diurnal oscillations were excited by environmental effect. A great correlation between energy of amplitude and time of the year is visible in Fig. 7 and 9. Oscillations near the 12th and the 24th hour are probably caused by the temperature effect, they have the same frequency as the tidal waves S1 and S2.

Source of the oscillation

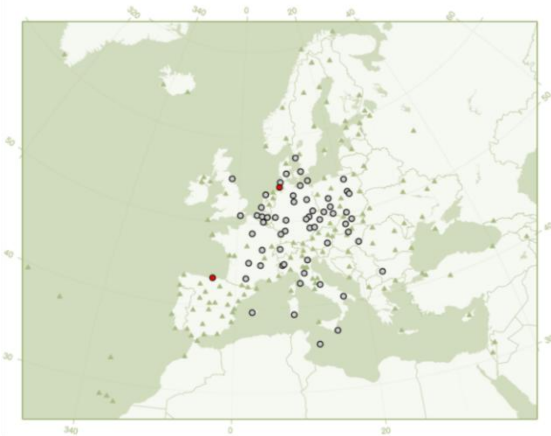

Fig. 8 Sites with oscillation in M2 frequency

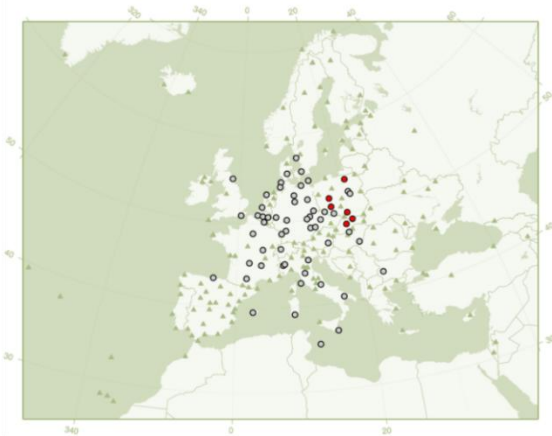

Fig. 9 Sites with oscillation in O1 frequency

In most of considered stations, coordinates' existing oscillations are probably the thermal effect, which have the same periods as tides waves (diurnal and semidiurnal). However there are some stations which have oscillation in pure tidal frequency, beyond thermal oscillations. In the two of them, tidal M2 oscillation could be seen. It should by noticed that their amplitudes' value (up to 1 mm) are three times smaller than coordinates' accuracy. They can be clearly seen without extra accurate time series. The authors made a decision to not underestimate them. Sites with this oscillation are located at the coast, so it is possible that these waves are residuals of ocean indirect effect. Additionally, in figures 10-11 solar S1 and S2 tidal frequencies are pointed out.

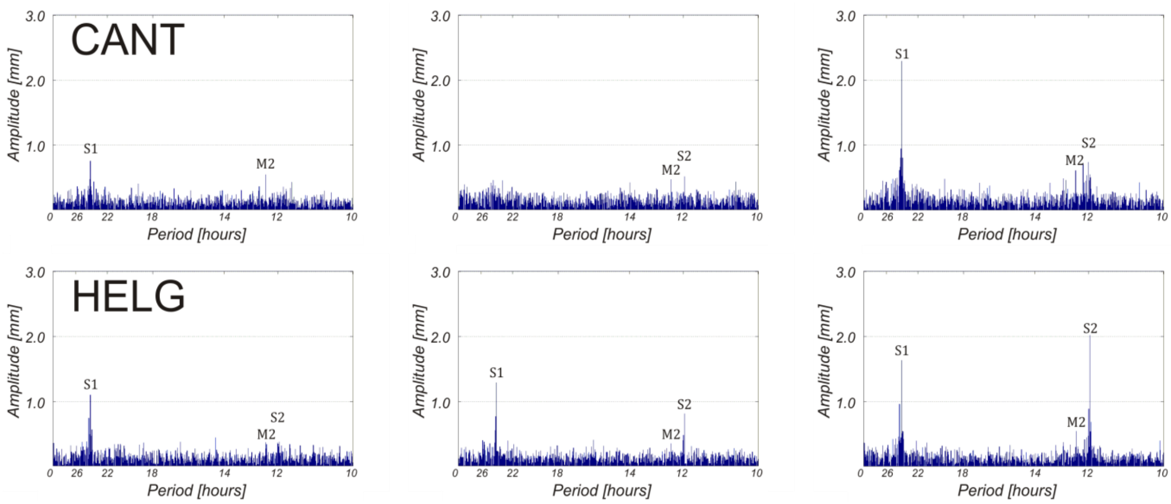

Fig. 10 Periodograms of coastal sites with oscillation in M2 frequency (from left: N-S component, E-W component, height).

Six inland stations contain oscillations in O1 tidal frequency. Amplitude of these waves reaches 1 mm, but this oscillation can only be observed in E-W component (ocean loading, ionosphere influence?).

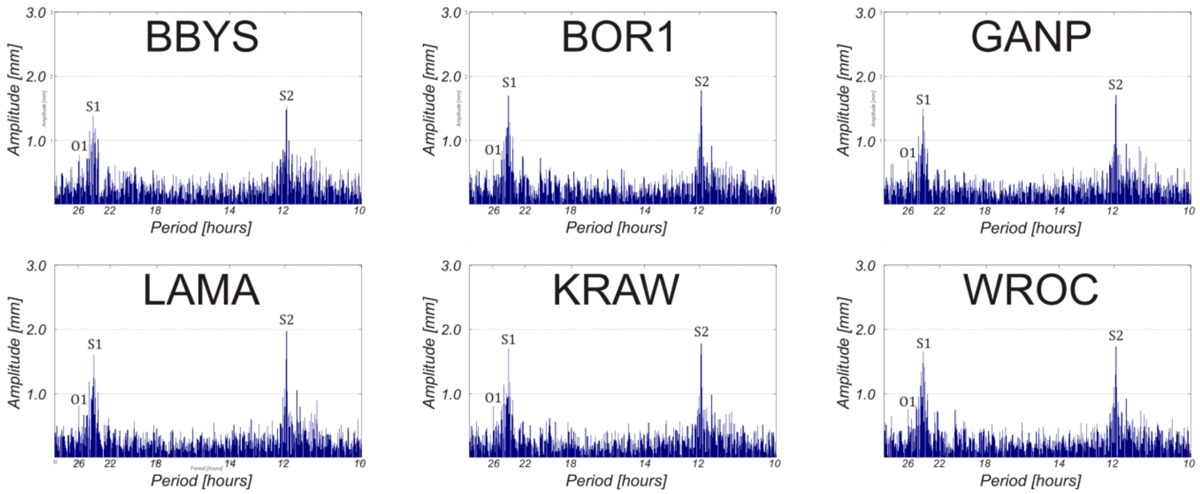

Fig. 11 Periodograms of sites with oscillation in O1 frequency in E-W component.

Summary

The results show that the 4-hour solution with 1-hour interval allowed to obtain information about diurnal and sub-diurnal oscillations. We were able to recognize tidal frequencies, but to separate the diurnal and half-diurnal groups of frequencies (PSK1 and S2K2) longer data is needed. Almost 50% of analyzed sites have oscillations in height component and only several in horizontal, height components amplitude is higher than horizontal components. E-W component is noisier than N-S component and has higher oscillation amplitude. Interpretation of these results has to be done upon the full knowledge of the models implemented at the stage of data processing. More sophisticated models of physical effects, e.g. better ionospheric (scintillations, fluctuations of TEC, moving ionosphere perturbations TID) and tropospheric (4D model of water vapour distribution) models should be implemented.

Detected oscillations are mostly environmental effects, and they are very small, not much higher than coordinate' accuracy. Residual tidal waves are below 1 mm in further analyses, so this could be the sign that tidal model used in Bernese Software fits well good to individual conditions of EPN stations. To find certain source of detected oscillation all individual site's condition and local hydrological model have to be taken into consideration.

References:

1. Beutler G., Bock H., Brockmann E., Dach R., Fridez P., Gurtner W., Habrich H., Hugentobler U., Ineichen D., Jaeggi A., Meindl M., Mervart L., Rothacher M., Schaer S., Schmid R., Springer T., Steigenberger P., Svehla D., Thaller D., Urschl C., Weber R. (2006): Bernese GPS software version 5.0.
2. Goupillaud P., Grossmann A., Morlet J., "Cycle-octave and related transforms in seismic signal analysis", Geoexploration, 23, 85-102, 1984.
3. Lyard F., Lefevre F., Letellier T., and Francis O., "Modelling the global ocean tides: modern insights from FES2004", Ocean Dynamics, 56:394–415, 2006.
4. Mallat S., „A wavelet tour of signal processing", 2nd Edition, Academic Press, New York 1999.

5. McCarthy Dennis D. and Petit Gérard (eds.), “ IERS Conventions (2003)”, IERS Technical Note, No. 32, Frankfurt am Main, Germany: Verlag des Bundesamtes für Kartographie und Geodäsie, ISBN 3-89888-884-3, 2004, 127.