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INVESTIGATION ON TIDAL COMPONENTS IN GPS COORDINATES

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ABSTRACT. This paper presents analyses on the GPS coordinates from sub-diurnal solutions of EPN data provided by Warsaw Military University of Technology. The aim of this research is to investigate the way 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 utilized to obtain coordinates of above 70 EPN stations. Additionally several Polish permanent sites with clearly seen oscillations were examined. This processing technique allowed us to recognize diurnal and sub-diurnal residual oscillations which could be next utilized for validation of the tidal models.
Keywords: Earth tides, frequency analysis, geodetic coordinates.

1. INTRODUCTION

The analyses on the GPS coordinates from sub-diurnal solutions of EPN data provided by Warsaw Military University of Technology were performed. The aim of this research is 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 utilized to obtain coordinates of above 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 utilized for validation of the tidal models.

2. DATA

In this study 1-hour solutions with 4-hour windowing of GPS data taken from BKG Analysis Centre were used. The solutions contain a tidal model according to the IERS Conventions (McCarthy and Petit, 2004) and the ocean tidal loading effect calculated using FES2004 model (Lyard et al., 2006).

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 provided information about the frequencies of the site's coordinates. All analyses were performed in the MATLAB® Technical Computing Environment.

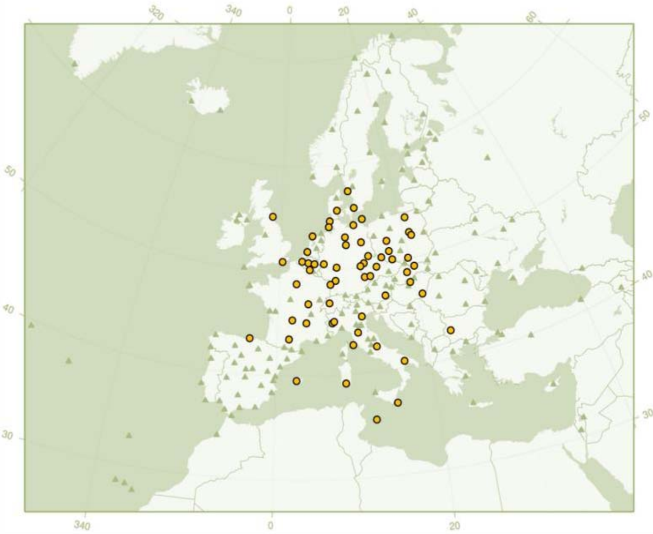

Fig. 1. EPN stations used in analyses

3. OSCILLATIONS IN HEIGHT COMPONENT

Diurnal and sub-diurnal oscillations were found almost in all sites, but in some of them 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 exhibits the largest amplitude, it is about 16 mm. In most of the sites the half-diurnal oscillation is almost two times higher than the diurnal one. There cannot be found any relation between amplitude's size and antennas fitting.

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

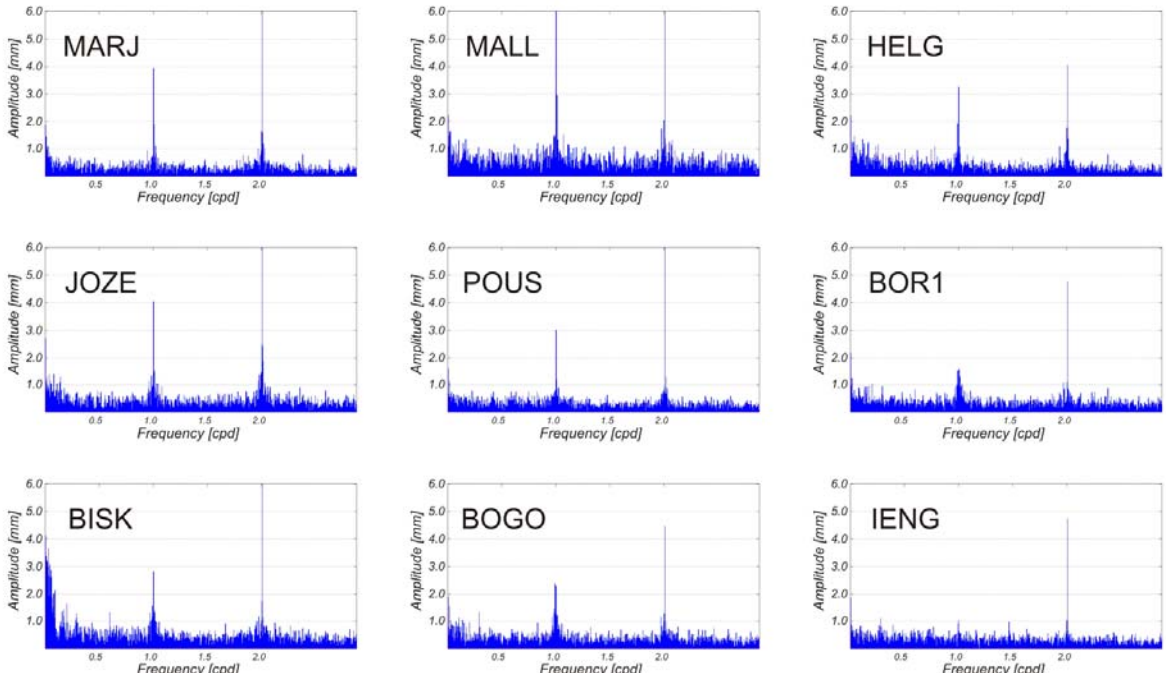

Fig. 4. Periodograms of sites with oscillations in height component
(amplitude higher than 3 mm)

4. OSCILLATIONS IN HORIZONTAL COMPONENTS

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

Fig. 5. Sites with oscillation's amplitude less than 1 mm (left, brown)
and more than 1mm (right, red)

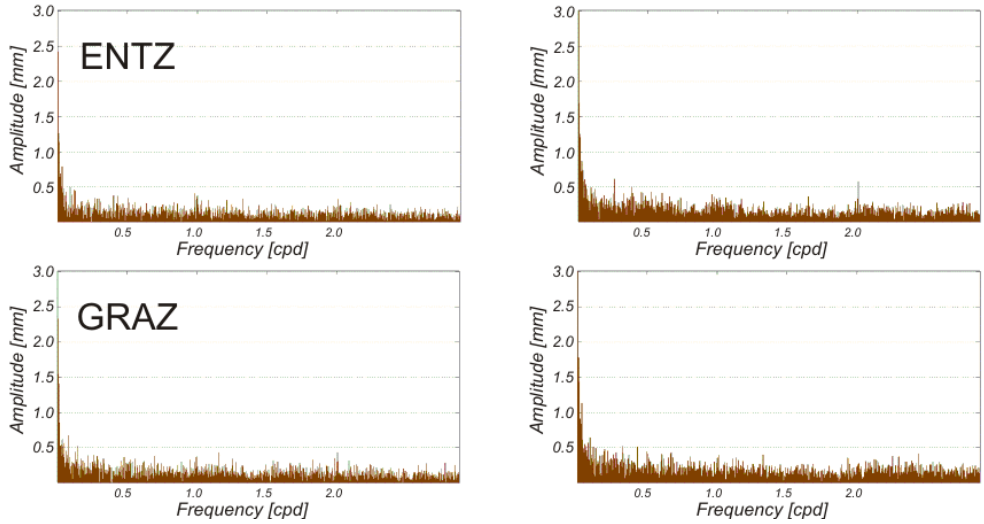

Fig. 6. Periodograms of sites without significant oscillation (less than 1 mm),
left: N-S component, right: E-W component

The second group consists of thirteen sites, mostly from Eastern/Central Europe and two sites located on islands. The highest oscillations were found in MALL site (over 6 mm). As presented in periodograms, SNEC coordinates are much more noisy than the other. The E-W component is noisier and has bigger oscillation than N-S. Diurnal oscillation is higher in N-S component and half-diurnal is bigger in E-W component.

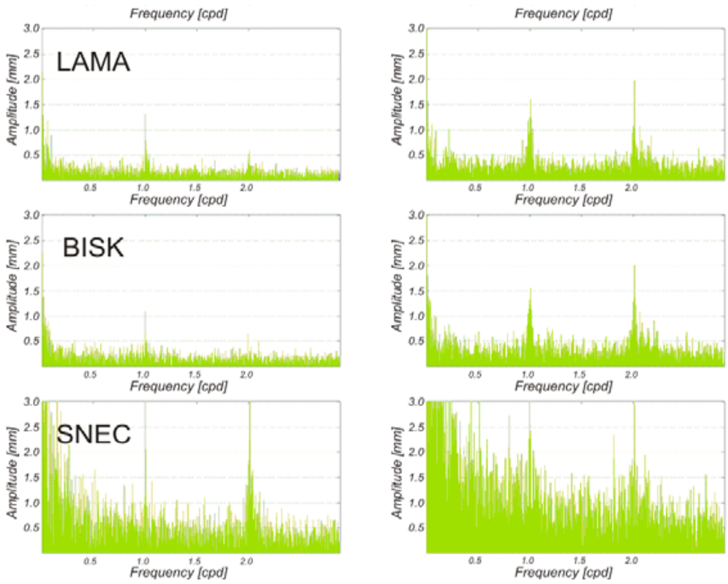

Fig. 7. Periodograms of sites with oscillations in horizontal components (amplitude more than 1 mm),
left: N-S component, right: E-W component

5. TIME – FREQUENCY ANALYSIS

Wavelet transform is derived from Fourier Transform, but it is much more flexible. The FT could not be used to the non-stationary time series, in which stochastic characteristics change in time. If we assume that non-stationary signal consists of several stationary signals the STFT (Short-Time Fourier Transform) could be applied. The signal is divided into small segments which are assumed to be stationary. The main role in such analysis plays the “window”, which is used to divide the signal. In this case we act with indeterminacy. If a narrow window is chosen accurate information about time is obtained, but less accurate information about frequency. In case of a wide window it is just 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 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 a 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.

The values $f_b = 5$ and $f_c = 3$ were used.

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

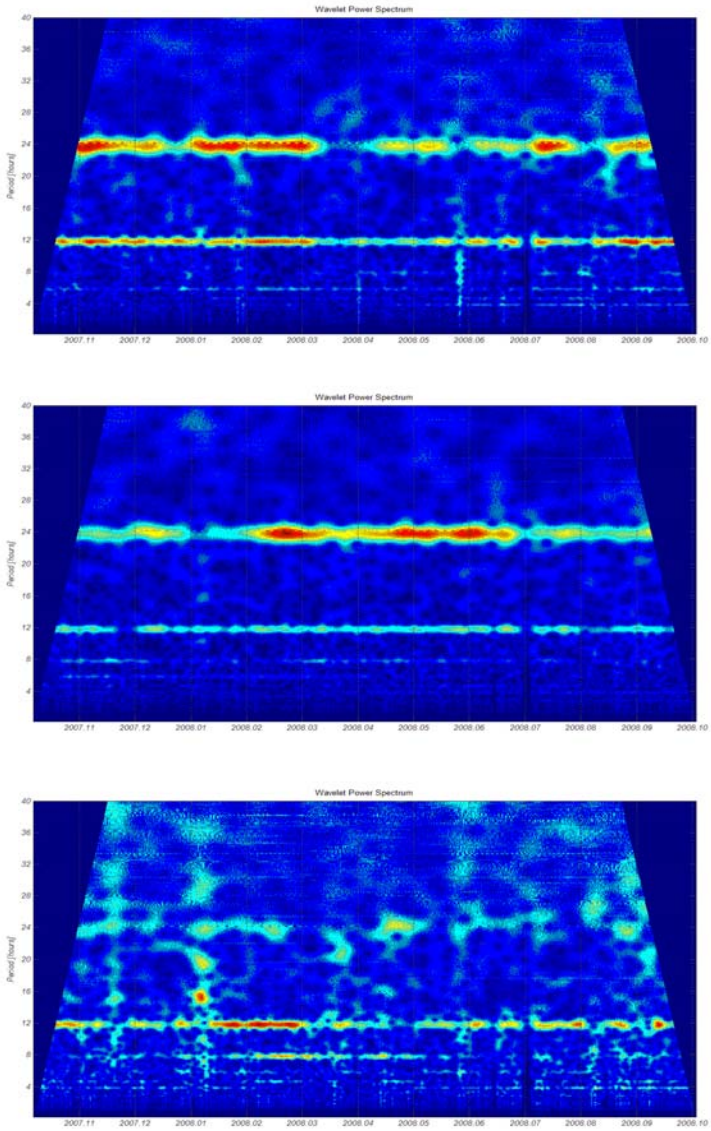

Fig. 8. Wavelet Power Spectrum of MALL sites coordinate, from up: N-S component, E-W component, height

6. TIDAL OSCILLATIONS

Compared to all analysed sites in two of them tidal M2 oscillation could be clearly seen. The amplitude of this wave is very small (less than 1 mm), but still it is observable. These sites are located at the coast, so it is possible that these waves are residuals of ocean indirect effects. Additionally in figures 10-11 solar S1 and S2 tidal frequencies are pointed out.

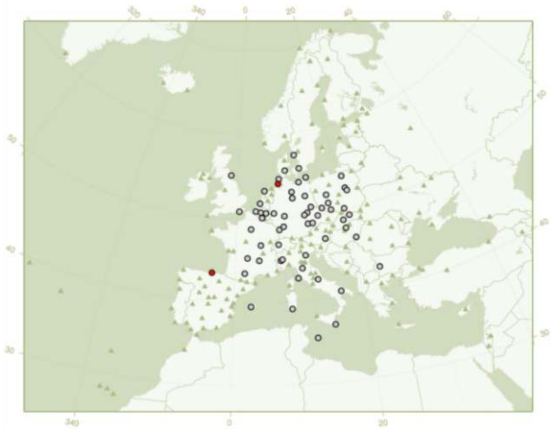

Fig. 9. Sites with oscillation in M2 frequency

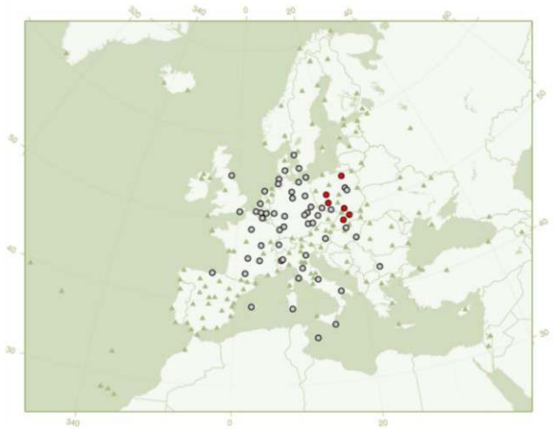

Fig. 10. Sites with oscillation in O1 frequency

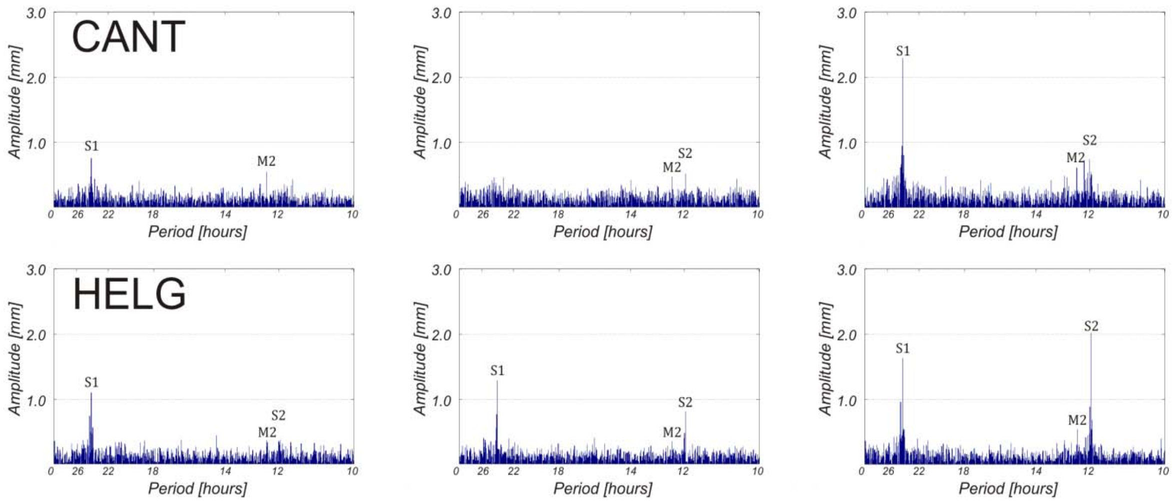

Fig. 11. Periodograms of coastal sites with oscillation in M2 frequency (from left: N-S component, E-W component, height)

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

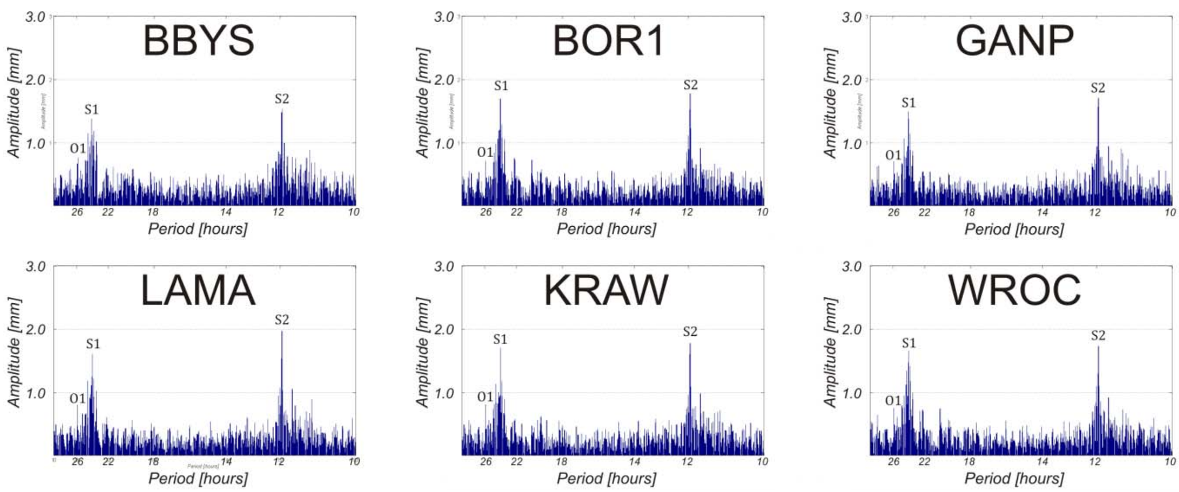

Fig. 12. Periodograms of sites with oscillation in O1 frequency in E-W component

7. CONCLUSIONS

The results show that the 1-hour solution with 4-hour windowing allowed to obtain information about diurnal and sub-diurnal oscillations. We were able to recognize tidal frequencies, but to split up the diurnal and half-diurnal groups of frequencies (PSK1 and S2K2) a longer time series is needed. Almost 50% of the analyzed sites have oscillations in height component and only several in horizontal, height component's amplitude is higher than horizontal components. E-W component is noisier than N-S component and has higher oscillation's amplitude.

Detected oscillations are mostly caused by environmental effects, and they are very small, at the coordinate's accuracy limit. Residual tidal waves are very small, below 1 mm. Individual site's condition and local hydrological model have to be taken into consideration.

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