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PRELIMINARY ANALYSIS OF THE GPS DERIVED VECTOR BOROWA GÓRA – JÓZEFOSŁAW

ZARYS TREŚCI: Rozpoczęciu w połowie 1996 roku permanentnych obserwacji GPS na stanowisku o kryptonimie BOGO (jeden z ekscentrów punktu nr 0217 europejskiej sieci 0-rzędu EUREF) w Obserwatorium Astronomiczno–Geodezyjnym w Borowej Górze towarzyszy proces gromadzenia unikalnego materiału obserwacyjnego. Obserwowane dane przekazywane są regularnie w plikach dobowych, a od listopada 1998 w plikach godzinnych do ośrodka obliczeniowego IGS w Grazu, gdzie są wykorzystywane w realizacji programów międzynarodowych. W szczególności gromadzony w Grazu materiał obserwacyjny służy do poprawiania orbit satelitów GPS w czasie „prawie rzeczywistym" oraz do badania jonosfery i troposfery. Obserwacje GPS ze stacji w Borowej Górze, podobnie jak obserwacje z innych stacji permanentnych sieci IGS, są dostępne za pośrednictwem sieci komputerowej. Wzajemne bliskie położenie dwóch stacji permanentnych: Borowa Góra i Józefosław (odległość 42 km), a także specyfika ich lokalizacji z punktu widzenia możliwych efektów geodynamicznych, czyni materiał obserwacyjny uzyskiwany przez obie stacje w postaci długich ciągów czasowych wyjątkowo atrakcyjnym dla szeroko zakrojonych badań naukowych. Wyniki uzyskane w niniejszym opracowaniu stanowią zachętę do prowadzenia dalszych, w miarę możności kompleksowych prac badawczych. W prezentowanej pracy dokonano wstępnej analizy składowych wektora BOGO–JOZE obliczonych z 4–godzinnych sesji obserwacyjnych pokrywających 25 dni obserwacji. Przeprowadzono analizę statystyczną oraz dokonano wstępnej analizy widmowej zaobserwowanych szeregów czasowych z uwzględnieniem wpływu kąta obcięcia horyzontu. Wyznaczono również parametry modeli matematycznych funkcji opisujących procesy zmienności w czasie poszczególnych składowych badanego wektora oraz oszacowano błędy poszczególnych modeli.

1. INTRODUCTION

Permanent GPS station BOGO at Astronomic–Geodetic Observatory at Borowa Góra operates since 1996. Data collected by means of Ashtech ZXII3 receiver is transferred on daily basis (from November 1998 on hourly basis as well) to the Local IGS Computing Centre at Graz (Cisak et al., 1999). This data together with data from other permanent GPS stations is used in international programmes such as computation of precise ephemeris in "almost real time" for GPS satellite orbits and investigation on ionosphere and troposphere. Moreover, data collected at BOGO station is widely accessible and is frequently used for processing GPS data from various GPS campaigns. An estimate of the quality of the data from BOGO station is therefore a matter of interest. It is very fortunate that the other IGS permanent station operates in Józefos³aw (JOZE) only 42 km away from Borowa Góra. Relatively short vector BOGO–JOZE can be reliably monitored and its analysis could provide valuable contribution to evaluate the quality of GPS data from BOGO station (Cisak et al., 1999) as well as to estimate the reliability of co–ordinates derived from this data. In addition the location of Borowa Góra at a stable east-european tactonic plate and Józefos³aw close to the edge of Teisseyre–Tornquist tectonic zone adds up additional interesting features to such an analysis.

2. ANALYSED DATA

Data collected by two GPS stations Borowa Gora (BOGO) and Jozefoslaw (JOZE) covering the period of 25 days (from 40 to 65 GPS day 1999) have been processed using the GPPS software in 4–hour blocks. Experiments showed that for the shorter sessions the vector is not always solved for fixed point ambiguities. It is not a surprise when considering 42 km distance between the stations. The components of the BOGO–JOZE vector together with their standard deviations obtained separately for cut–off angle of 5° and 15° for each of 150 4–hour sessions were calculated.

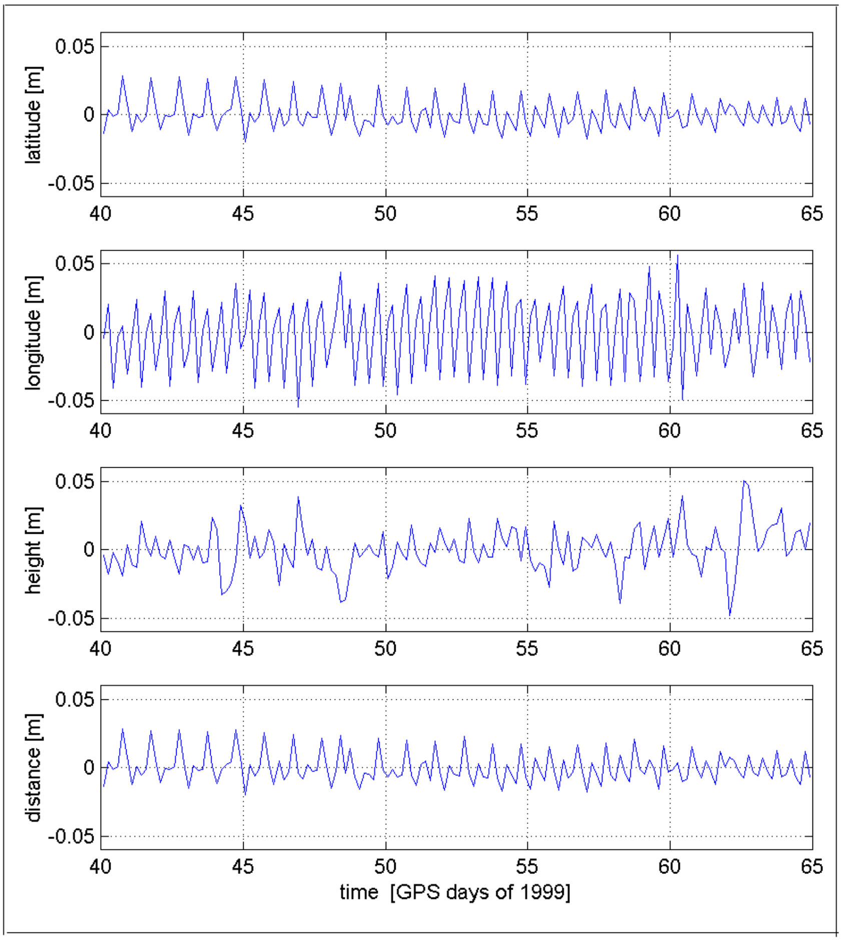

Fig. 1 Time variations of BOGO–JOZE vector components

The residuals with respect to the mean over entire 25 days for each component of the vector, i.e. latitude, longitude, height and distance were considered in the following analysis as signals representing time variations of the BOGO–JOZE vector components. The four signals obtained for 15°cut–off angle are plotted in Figure 1.

Very similar pattern to the one shown in Figure 1 is represented by the signals obtained for 5°cut–off angle. All signals show a strong periodic behaviour. There are few observations which indicate stronger variations in the derived signals for both 5° and 15°cut–off angle solutions. They may need to be carefully reprocessed and statistically tested for outliers. Those observations were not however removed from the following analysis.

The statistics for the signals in terms of rms and maximum absolute magnitude is given for both cut-off angles in Table 1.

Tab. 1

Cut–off angle [degrees]	**Statistics**	**Latitude** (ϕ) [m]	**Longitude** (λ) [m]	**Height** (h) [m]	**Distance** (d) [m]
15	**rms**	0.0109	0.0268	0.0160	0.0110
	maxabs	0.0285	0.0564	0.0503	0.0286
5	**rms**	0.0108	0.0247	0.0171	0.0109
	maxabs	0.0314	0.0506	0.0563	0.0316

Both Figure 1 and Table 1 show almost identical features for signals representing latitude and distance. This similarity is due to location of both permanent stations Borowa Gora and Jozefoslaw almost on the same meridian (north–south orientation of the BOGO–JOZE vector). The components of BOGO–JOZE vector in horizontal co–ordinate system (ϕ, λ, h) expressed in metres are as follows:

$$\Delta\phi = -\,42\,135.9 \text{ m}, \quad \Delta\lambda = -\,259.6 \text{ m}, \quad \Delta h = -\,8.2 \text{ m}$$

while the length of the vector

$$d = 42\,137.6 \text{ m.}$$

Both latitudinal and longitudinal components (distance as well) vary in a remarkable regular way. Variations of those components are clearly periodic with dominating time invariant parameters. The signal representing height component shows much weaker regularity (systematic part) and stronger contribution of noise (random part). The largest variations occur in the longitudinal component. They reach the magnitude of almost 6 cm. In the examined case they do not however substantially affect the derived vector length. The maximum amplitude of variations in the distance between stations does not exceed 3 cm.

In terms of rms shown in Table 1 there is no indication of substantial improvement in the resolved vector components when decreasing cut–off angle from 15°to 5°. It seems that the improvement of geometry resulting from increasing space with satellites being tracked is balanced by the enlarged non–modelled effect of refraction. In particular variations in height grow by 10% simultaneously making the signal more noisy and less reliable when considered in terms of individual observation. More representative estimation of the effect of cut–off angle on the resulted vector components can be obtained by analysis of signals differenced between 15°to 5°cut–off angle solutions for consecutive components of the examined vector. The four differenced signals are plotted in Figure 2.

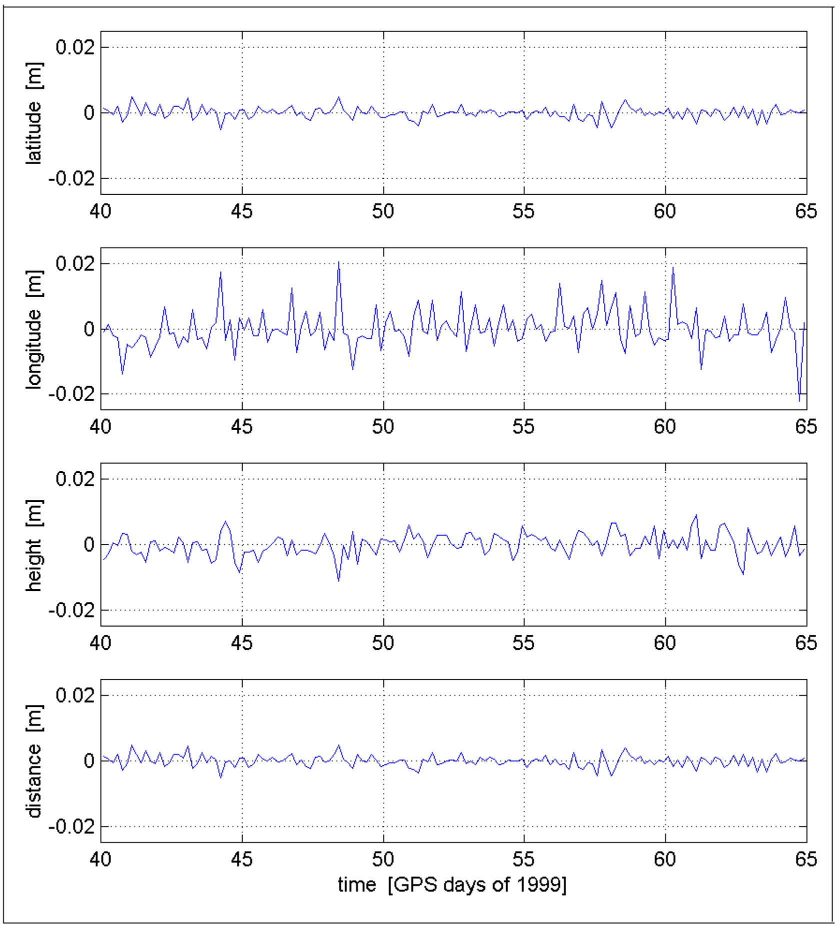

Fig. 2 Time variations of differences between 15°and 5°cut–off angle solutions for BOGO–JOZE vector components

The statistics for the differenced signals in terms of rms and maximum absolute magnitude is given in Table 2.

Tab. 2

Statistics	**Latitude** (ϕ) [m]	**Longitude** (λ) [m]	**Height** (h) [m]	**Distance** (d) [m]
rms	0.00177	0.00596	0.00344	0.00177
maxabs	0.00516	0.02233	0.01110	0.00509

Again the largest variations occur in longitudinal component. The results shown in Figure 2 and in Table 2 indicate that in order to determine co–ordinate difference between two stations from few hour long GPS session at 1 cm precision level a careful analysis of a suitable cut–off angle is required. Therefore it is recommended to collect GPS data with the minimum cut–of angle despite the increase in volume of data files to be recorded.

3. ANALYSIS

The periodic features of the signals have been analysed using the tools of spectral analysis. Power spectra of the signals for 15°cut–off angle are plotted in Figure 3.

Very similar pattern to the one shown in Figure 3 is represented by the signals obtained for 5°cut–off angle. Power spectra of all components of the examined vector show strong spikes for the frequency of 2 cycles/day which corresponds to the period of 12 hours. The largest spikes corresponding to this frequency occur in the signal representing longitudinal component (note that longitudinal component is shown in Figure 3 in different scale than the remaining components). In addition, in variations of latitudinal component (distance as well) the frequency of 1 cycle/day corresponding to the period of 24 hours is distinguished. The 24 hours period is not as sharp in case of the time variations in heights and it is also quite weak in the longitudinal component. Figure 3 shows also that the height has the largest noise amongst components of the examined vector.

The absolute magnitudes of the signals transformed to frequency domain and corresponding to the distinguished frequencies (periods) for both cut–off angles are given in Table 3.

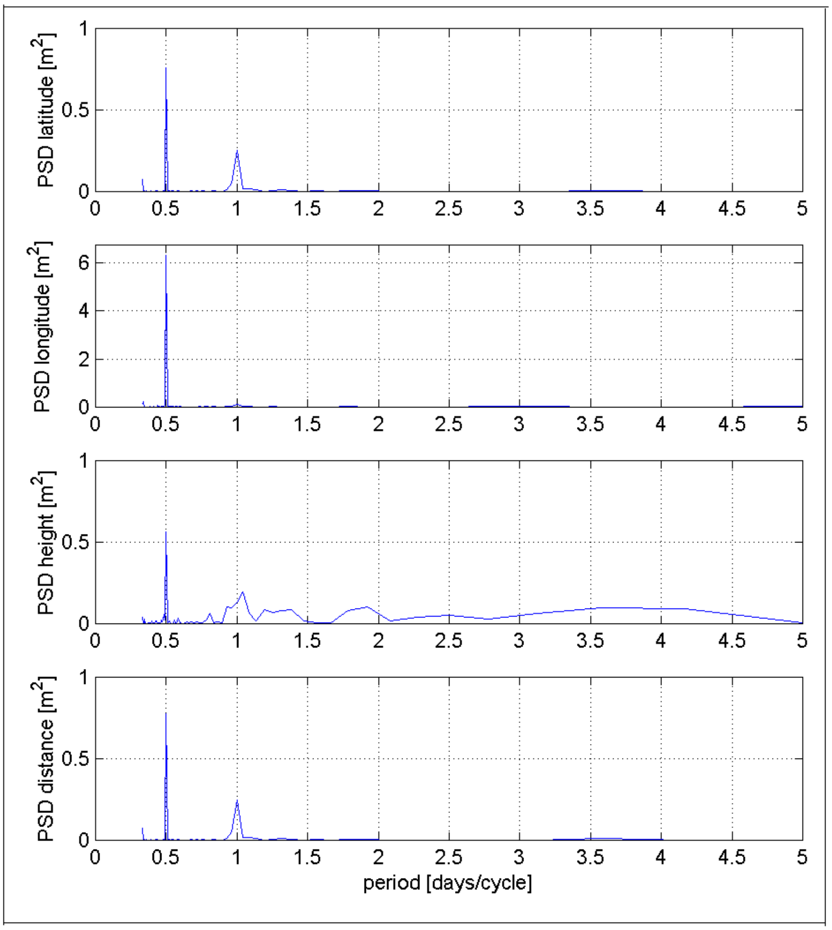

Fig. 3 Power spectrum density of the components of BOGO–JOZE vector

Tab. 3

Cut-off angle [degrees]	**Period** [hours]	**Latitude** (ϕ) [m]	**Longitude** (λ) [m]	**Height** (h) [m]	**Distance** (d) [m]
15	**12** **24** **others**	0.86 0.48 <0.17	2.55 0.36 <0.25	0.76 0.44 <0.32	0.86 0.48 <0.17
5	**12** **24** **others**	0.85 0.45 <0.12	2.32 0.22 <0.22	0.68 0.44 <0.32	0.85 0.45 <0.12

When decreasing cut-off angle from 15°to 5°the noise is getting amplified on all examined signals. Simultaneously the periodicity of time variations becomes slightly less distinguished. It is reflected in decrease of absolute magnitudes of the signals. In particular the weak 24 h period in longitudinal component, still recognizable for 15°cut–off angle almost vanishes in the corresponding signal for 5°cut–off angle. It can be seen in the spectrum of differenced signals between 15°to 5°cut–off angle solutions for consecutive components of the examined vector. Power spectra of the differenced signals are plotted in Figure 4.

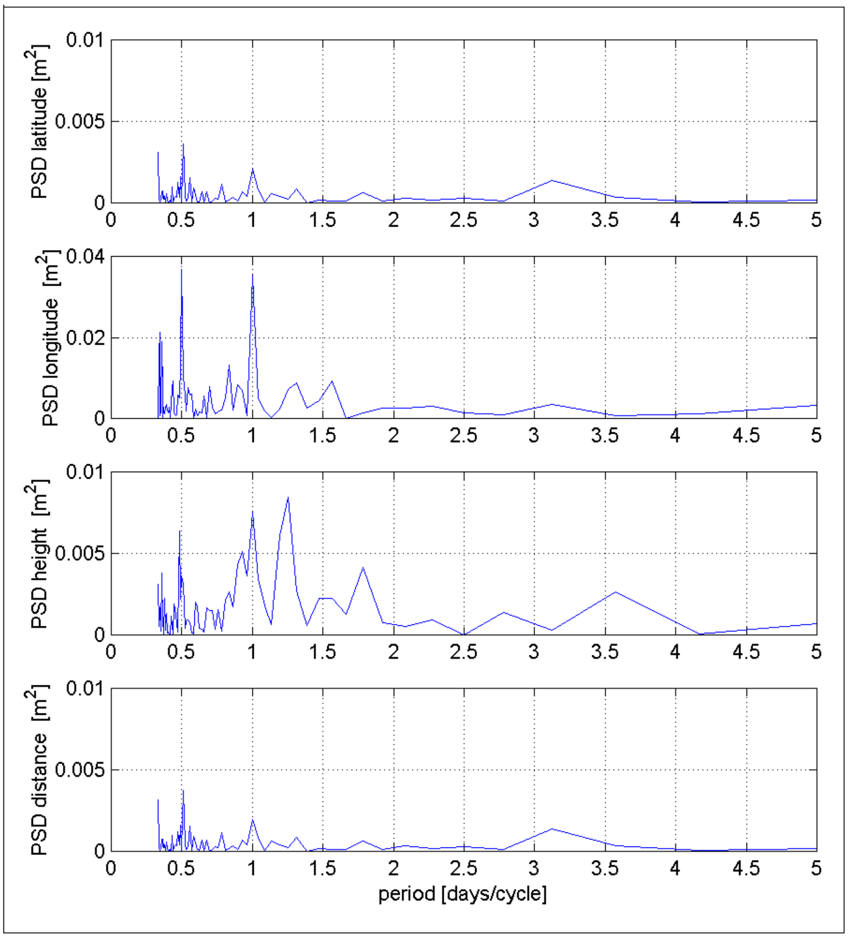

Fig. 4 Power spectrum density of the differenced signals corresponding to the components of BOGO–JOZE vector

The time series for differenced longitudinal component (note that longitudinal component is shown in Figure 4 in different scale than the remaining components) shows strong spikes in power spectrum density for both 12 h and 24 h periods while the periodicity of the remaining differenced components is much less distinguished. The periodicity occurring in differenced signals indicate the decrease of amplitudes of periodic terms when decreasing cut–off angle from 15°to 5°. It can also be noted that in case of from longitudinal component of the examined vector the decrease in cut–off angle from 15°to 5°leads practically to eliminating the variations with 24 h period.

Due to the evidence of periodicity in time variations all signals were modelled with the function of two frequencies f_1 = 1 cycle/day and f_2 = 2 cycle/day

$$A_0 + A_1 \sin(2\pi f_1 + \psi_1) + A_2 \sin(2\pi f_2 + \psi_2)$$

for both cut–off angles 5°and 15°. Parameters A_0, A_1, ψ_1, A_2, ψ_2, were calculated using least squares method both with filtering the noise (using standard deviations of estimated vector components provided by the GPS data processing algorithm for calculating diagonal elements of weight matrix) and without filtering the noise (equal precision of all data resulting in unit weight matrix).

Parameters A_0, A_1, ψ_1, A_2, ψ_2 as well as their standard deviations calculated with filtering noise for the models of all signals for both cut–off angles are given in Table 4.

Derived amplitudes A_1 and A_2 corresponding to the periods 24 h and 12 h respectively representing the model functions for the components of the examined vector as well as their standard errors match the spectral characteristics shown in Figure 3 and in Table 3. For 5°cut–off angle signals as stronger affected by noise show slightly weaker features of periodicity than signals obtained for 15°cut–off angle. Similar modelling of signals was performed with the assumption that the data in the derived time series are equally precise. The obtained amplitudes A_1 and A_2 differ from previously derived by no more than 1 mm.

The statistics for the fit of the model to corresponding signal in terms of rms and absolute maximum magnitude for both cut-off angles is given in Table 5.

Tab. 4

Cut-off angle [degrees]	**Model parameter**	**Latitude** (ϕ) [m]	**Longitude** (λ) [m]	**Height** (h) [m]	**Distance** (d) [m]
15	A_0 [m]	-0.0004 ±0.0004	-0.0005 ±0.0011	-0.0006 ±0.0011	-0.0002 ±0.0004
	A_1 [m]	0.0064 ±0.0006	0.0022 ±0.0011	0.0041 ±0.0015	0.0065 ±0.0006
	ψ_1 [degrees]	186.36 ±5.74	279.03 ±28.83	148.66 ±21.47	188.38 ±5.59
	A_2 [m]	0.0124 ±0.0006	0.0339 ±0.0016	0.0107 ±0.0015	0.0122 ±0.0006
	ψ_2 [degrees]	251.63 ±3.02	309.68 ±2.71	137.53 ±8.16	253.66 ±3.02
5	A_0 m]	-0.0002 ±0.0004	0.0001 ±0.0009	-0.0008 ±0.0012	-0.0000 ±0.0004
	A_1 [m]	0.0061 ±0.0006	0.0034 ±0.0011	0.0048 ±0.0017	0.0062 ±0.0006
	ψ_1 [degrees]	187.15 ±6.00	239.32 ±18.67	164.26 ±20.48	187.66 ±6.05
	A_2 [m]	0.0122 ±0.0006	0.0304 ±0.0012	0.0094 ±0.0017	0.0120 ±0.0006
	ψ_2 [degrees]	250.22 ±3.02	311.36 ±2.30	133.26 ±10.41	251.78 ±3.12

Tab. 5

Cut–off angle [degrees]	**Filtering**	**Statistics**	**Latitude** (ϕ) [m]	**Longitude** (λ) [m]	**Height** (h) [m]	**Distance** (d) [m]
15	**no**	**rms**	0.00543	0.01217	0.01391	0.00547
		maxabs	0.02737	0.07192	0.05340	0.02797
	yes	**rms**	0.00548	0.01230	0.01394	0.00550
		maxabs	0.02836	0.07458	0.05421	0.02875
5	**no**	**rms**	0.00542	0.01101	0.01540	0.00544
		maxabs	0.02246	0.05088	0.05796	0.02279
	yes	**rms**	0.00543	0.01107	0.01542	0.00544
		maxabs	0.02284	0.05068	0.05929	0.02310

Applying the procedure of filtering noise from the signal using standard deviations of estimated vector components provided by the GPS data processing algorithm practically does not change the goodness of the fit of the model to the signal for all components of the examined vector. Contribution of filtering noise is recorded to be larger for less noisy signal with 15°cut–off angle.

Comparison of the rms of the signal with the rms of its non–modelled part (residuum), i.e. the values given in Tables 1 and 5, shows that in case of horizontal components as well as distance, the model function represents substantial part of time variations of the signal. Simultaneously it is clear that modelling time variations of height component by use of the same kind of function is rather poor.

Graphical illustration of the fit of model function to the signals provides a valuable information complementary to the statistics shown in Table 5. Both signal and its residuum with respect to model function derived with filtering the noise, i.e. the remaining part after subtracting model function from the signal for latitudinal, longitudinal, height and distance components of the examined vector, are given in Figures 5, 6, 7 and 8, respectively.

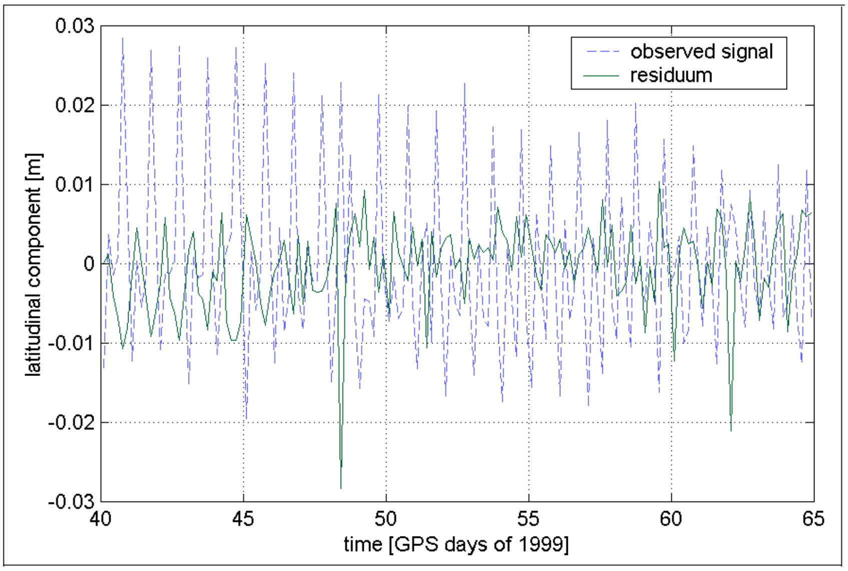

Fig. 5 Observed time series for latitudinal component of BOGO–JOZE vector versus its residuum with respect to model function

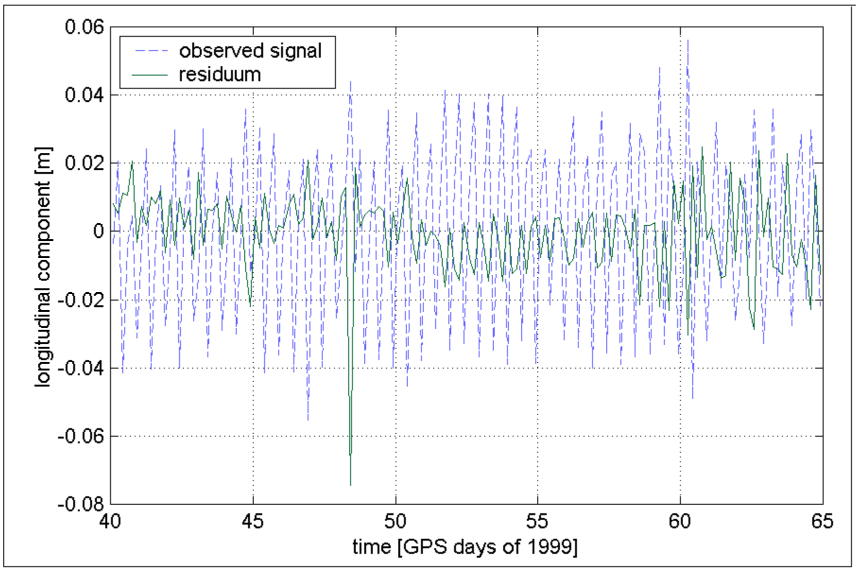

Fig. 6 Observed time series for longitudinal component of BOGO–JOZE vector versus its residuum with respect to model function

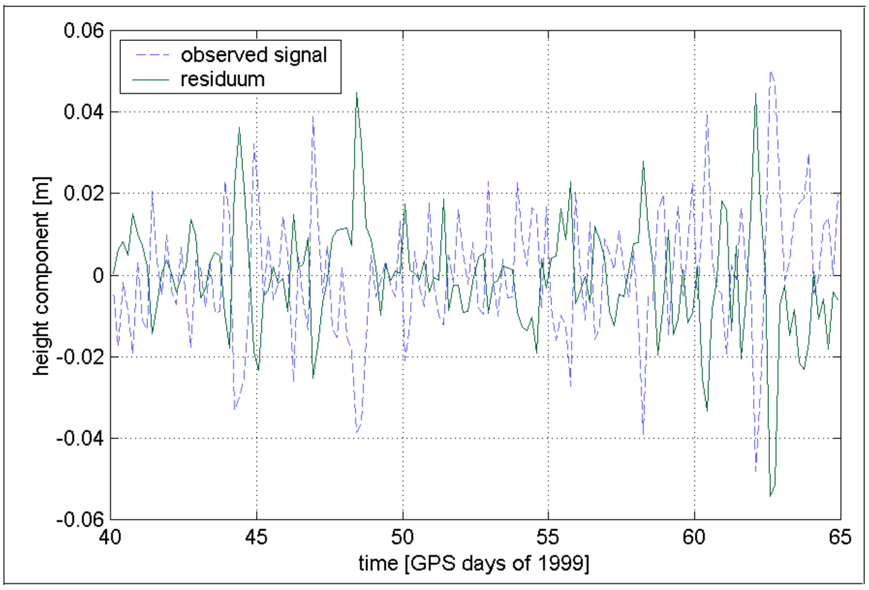

Fig. 7 Observed time series for height component of BOGO–JOZE vector versus its residuum with respect to model function

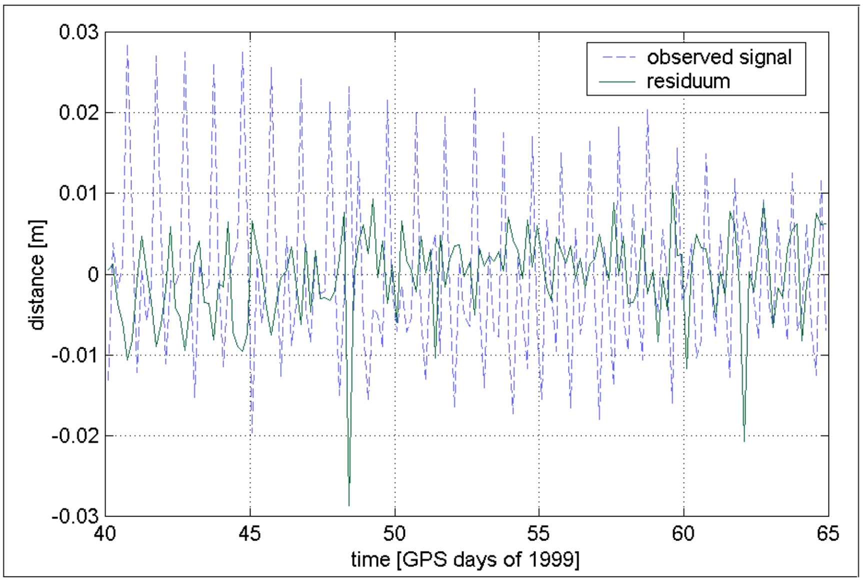

Fig. 8 Observed time series for length of BOGO–JOZE vector versus its residuum with respect to model function

Few large spikes occurring in Figures 5 to 8 reflect most probably the outliers which have not been removed from the data. The existence of these outliers affects strongly the maximum magnitudes given in Tables 1 and 5 magnifying them by a factor of 2. The magnitudes of resulted residuals of the modelled signals do not exceed 1 cm for latitudinal component and the distance, 2 cm for longitudinal component and 4 cm for height component.

4. CONCLUSIONS

All components of 42 km long BOGO–JOZE vector obtained from processing 4–hour data blocks over 25 days show a distinguished regularity in their time variations. These variations can be expressed in terms of two periodic signals with periods 12 h and 24 h, modulated with noise. 12h period is a dominating one while the weaker period of 24 h almost disappears in variations of longitudinal and height components. Periods found in time variations of the components of the examined vector correspond to periods of repeatability of the constellation of GPS satellites. The largest noise is found in height, while latitude (and distance) is least noisy component.

Comparison of statistics separately obtained for the components of the examined vector with 5°and 15°cut–off angles shows no indication of substantial improvement in the resolved vector components when decreasing cut–off angle from 15°to 5°. The decrease of cut–off angle results mainly in weakening the terms representing 24 h period and increasing noise. The analysis of the differenced signal (between 15°to 5°cut–off angle solutions) indicates that the level of discrapancies between corresponding solutions exceeds the level of negligibility. The maximum differences exceed 22 mm in longitudinal component, 11 mm in height component and 5 mm in latitudinal component and the distance. The results obtained indicate that in order to determine co–ordinate difference between two stations from a few hour long GPS session at 1 cm precision level a careful analysis of a suitable cut–off angle is required. Therefore it is recommended to collect GPS data with the minimum cut–of angle despite the increase in volume of data files to be recorded. To achieve higher precision in height determination cut–off angle 15°rather than 5°should be applied.

Time variations of all components of the vector can be modelled with the periodic function of two frequencies 2 cycle/day and 1 cycle/day. Such model functions approximate time variations of consecutive components of the examined vector. The goodness of the fit of the models derived using least squares filtering, expressed in terms of decrease of rms is 50% for latitudinal (and distance) component, 54% for longitudinal component and 14% for height component. The mutual relations between these numbers perfectly agree with the rule of thumb for the precision of the vector components derived from GPS data.

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REFERENCES:

[1] Cisak J., Kryński J., Witkowski T. (1999): Hourly Data Upload at BOGO Permanent GPS Station and Preliminary Attempt Towards Estimate of Quality of Collected Data, Proceedings of the 5th International Seminar on "GPS in Central Europe", 5-7 May 1999, Penc, Hungary.

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WSTĘPNA ANALIZA ZMIENNOŚCI W CZASIE SKŁADOWYCH WEKTORA BOROWA GÓRA–JÓZEFOSŁAW WYZNACZONEGO Z POMIARÓW GPS

Streszczenie

W pracy wykorzystano materiał obserwacyjny z 25 dni uzyskany z permanentnych obserwacji GPS na stacjach w Borowej Górze i w Józefosławiu. Dane GPS zostały opracowane w następujących po sobie sesjach 4–godzinnych dla dwóch kątów obcięcia horyzontu 5°i 15°. Wyniki obliczeń w postaci szeregów czasowych utworzonych dla poszczególnych składowych wektora BOGO–JOZE oraz ich błędów standartowych zostały poddane analizie. Przeprowadzono analizę statystyczną oraz dokonano wstępnej analizy widmowej zaobserwowanych szeregów czasowych z uwzględnieniem wpływu kąta obcięcia horyzontu. Stwierdzono okresowość zmian składowych wektora wyrażające się wyraźnym 12 h okresem i słabszym okresem 24 h. Wyznaczono również parametry modeli matematycznych funkcji opisujących procesy zmienności w czasie poszczególnych składowych badanego wektora oraz oszacowano błędy poszczególnych modeli. Poddano również analizie wpływ kąta obcięcia horyzontu na jakość wyników.

ЯН КРЫНЬСКИ
ЯН ЦИСАК

ПРЕДВАРИТЕЛЬНЫЙ АНАЛИЗ ИЗМЕНЯЕМОСТИ ВО ВРЕМЕНИ СОСТАВЛЯЮЩИХ ВЕКТОРА БОРОВА ГУРА – ЮЗЕФОСЛАВ, ОПРЕДЕЛЁННОГО НА ОСНОВЕ ИЗМЕРЕНИЙ GPS

Резюме

В работе использован материал непрерывных наблюдений GPS в течение 25 дней на станциях в Боровой Гуре и в Юзефославе. Данные GPS были обработаны в чередующихся 4-часовых сессиях для двух углов уреза горизонта 5^0 и 15^0. Результаты вычислений в виде часовых рядов, созданных для отдельных составляющих вектора BOGO-JOZE и их стандартных ошибок, были подданы анализу. Проведён статистический анализ, а также предварительный спектральный анализ

наблюдаемых временных рядов с учётом влияния угла уреза горизонта. Установлено периодичность изменений составляющих вектора, выражающаяся чётким 12 h периодом и слабейшим 24 h. Были определены также параметры модели математических функций, описывающих процессы изменяемости во времени отдельных составляющих исследуемого вектора, и оценены ошибки отдельных модели. Поддано также анализу влияние угла уреза горизонта на качество результатов.

Перевод: Роза Толстикова