Study on Geophysical Influences to the GPS Coordinates

J.Bogusz, M. Kruczyk, T. Liwosz, M. Pfeil, J. B. Rogowski[1]

Abstract

Astro-Geodetic Observatory in Józefosław is one of the EUREF/ IGS sites. In the Observatory there are several continuous observations performed such as:

- GPS observations using two receivers;
- Tidal measurements with LC&R gravimeter;
- Astrometric observations aimed at latitude changes determinations;
- Meteorological measurements.

Warsaw University of Technology EUREF Analysis Centre works in the frame of the Observatory. The bank of regional observations is also conducted. The results of the processing of the observations mentioned above could be used to verification of the tidal and non-tidal deformation models that are used in GPS data processing performed by WUT EUREF LAC. This paper presents the results of the tidal and astrometric analyses and their comparison to the standard IERS models. It also deals with the non-tidal deformation model comes from the atmosphere in the meaning of the height (GPS) and gravity (gravimetry) corrections.

1. Introduction

Studies on geophysical influences to the position of the station determined by satellite techniques are the main part of the scientific activities of the Warsaw University of Technology EUREF Local Analysis Centre. Geophysical influences create the deformations of the Earth crust and produce the horizontal and vertical changes of the coordinates. Due to this fact, knowledge of the local deformation model is very important element of the GPS data processing in permanent networks. Analysis of the accuracy of the local deformation models that are used to the GPS data analysis of Józefosław stations are presented in this paper. Permanent GPS, latitude astrometric, tidal gravimetric and meteorological observations are used to these analyses. Result of determination of velocity vector of Józefosław station are also presented. The accuracy of the permanent GPS measurements in the global or regional networks such as IGS or EUREF reach a few millimeters in horizontal coordinates and 1 cm in the height. The researches at 1-hour GPS observation analyses and new challenges in GPS data processing make the deformation models to be indispensable in modern geophysical researches. The accuracy of these models should assure the determination of the corrections to the GPS coordinates with the precision better than a few millimeters. The scheme of important deformational processes that affect GPS coordinates is presented on Fig.1.

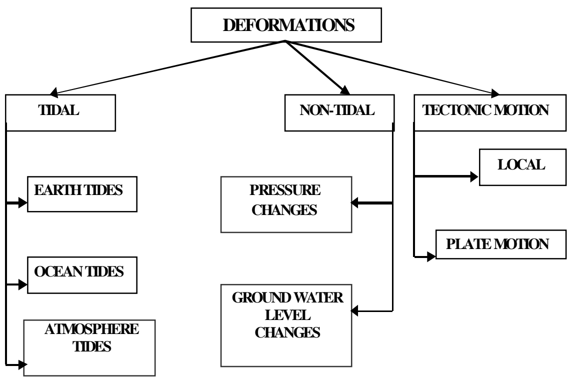

Fig.1 Types of deformations

2. Gravimetric Earth Tides Analyses

Influence of the solid Earth tides to gravity can be presented using following formula:

$$\Delta g = G\frac{\partial W_2}{\partial r} = -Gm\left(\tfrac{r}{\rho}\right)^3 g\left(3\cos^2 z - 1\right)$$

$$G = 1 - \frac{3}{2}k + h \quad \cong 1.17$$

Five series of tidal observations were analysed. Values of parameters of the main tidal waves are presented in Tab. 1.

[1] Janusz Bogusz, Micha Kruczyk, Tomasz Liwosz, Magdalena Pfeil, Jerzy B. Rogowski, Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology, Pl. Politechniki 1, PL-00-661 Warszawa, Tel.: +48+22-660-77-54, Fax +48-22-660-77-54*6, E-mail: jb@gik.pw.edu.pl / kruczyk@gik.pw.edu.pl / tl@gik.pw.edu.pl / magda@gik.pw.edu.pl / jbr@gik.pw.edu.pl

Table 1. Results of the gravimetric Earth tides analyses.

Tidal wave	1st series		2nd series		3rd series		4th series		5th series	
	Amplitude [mGal]	Phase [°]	Amplitude [mGal]	Phase [°]	Amplitude [mGal]	Phase [°]	Amplitude [mGal]	Phase [°]	Amplitude [mGal]	Phase [°]
Q1	541	684	7.5	-0,867	4,94	-7345	6.63	-1757	5.52	789
O1	31.97	0,103	27.84	-0,737	26,57	-0,287	30.12	-0,818	31.03	-0,939
P1	15.41	0,224	15	0,110	51,96*	-1,960	61,40*	-0,920	14.11	-0,099
K1	44.23	0,002	40.16	-0,428					44.35	0,597
N2	5.77	1358	6.82	0,353	5,85	-4700	6.58	-92	7.64	226
M2	34.52	332	33.08	0,145	31,71	-1109	34.79	-488	34.57	-170
S2	15.03	1423	14.31	-889	10,73*	-1399	13,09*	-1022	14.98	-0.907

* In the 3rd and 4th series the time of observation was too short to separate P1, S1, K1 and S2, K2 waves. These values denote PSK1 and S2K2 waves.

3. Changes of the Vertical From Astrometrical Observations

Deviations of the vertical observed as latitude changes can lead to astrometric coefficient L:

$$\Delta\varphi = (1+k-l)\frac{\partial(-W_2)}{g a \partial\varphi}$$

$$\Delta\varphi = \Lambda\tfrac{3}{2} m\left(\tfrac{a}{r}\right)^3 \sin 2z \cos A \qquad \Lambda = (1+k-l) \cong 1.15$$

Continuous latitude observations have been taken by means of Zeiss zenith telescope since 1959 at Astro-Geodetic Observatory in Gasifies³aw. Thanks to reduction using Hipparcos catalogue we have tried to determine astrometric coefficient $L=1+k-l$ for tidal deformations in the plumb line variations for M2 wave separately and for complete luni-solar tidal effect. Best results of 7-parameter model LS-method fitting occurs for years 1977-82 respectively:

$L(M_2) = 0.81 \pm 0.98$

L(entire effect) = 0.6 ±0.46

This results are still insufficiently precise to evaluate exact value of L (correct value should be close to 1.15) see Fig. 2. to asses quality of the adjustment.

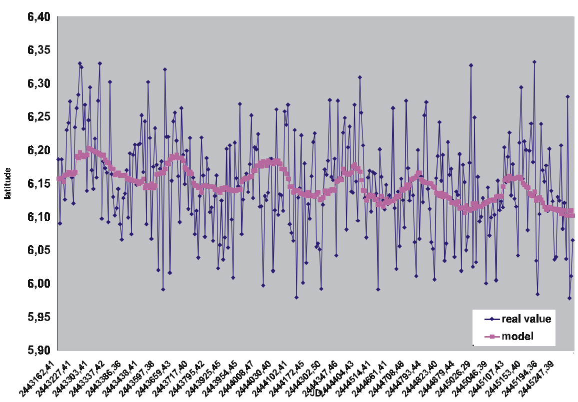

Fig. 2. Results of 7-parameter model fitting with tidal changes of the latitude (["]).

4. Tectonic Plate Motion

To determine velocity vectors the most accurate model is NUVEL-1A, based on geological data. To compute this velocities one can use following formulas:

$$V_X = \left(\omega_{(Y)}\cdot Z_0 - \omega_{(Z)}\cdot Y_0\right)$$
$$V_Y = \left(\omega_{(Z)}\cdot X_0 - \omega_{(X)}\cdot Z_0\right)$$
$$V_Z = \left(\omega_{(X)}\cdot Y_0 - \omega_{(Y)} X_0\right)$$

where:

X_0, Y_0, Z_0 are coordinates of analyzed stations, w is coefficients taken from the table 2.

Fig. 3. Comparison of velocity vectors determined from different methods.

Tab. 2 Coefficients of the rotation vector.

Plate	$w_{(X)}$ [°/10^6 years]	$w_{(Y)}$ [°/10^6 years]	$w_{(Z)}$ [°/10^6 years]
EURA	-0,0590	-0,1434	1887

6. GPS Observation Analyses

Tidal Site Displacement (for GPS derived coordinates):

$$\Delta r = \sum_{j=2}^{3} \frac{GM_j R_e^4}{GM_{\oplus} R_j^3} \left\{ h_2 r \left(\tfrac{3}{2} (R_j r)^2 - \tfrac{1}{2} \right) + 3 l_2 (R_j r) \left(R_j - (R_j r) r \right) \right\}$$

Where:

GM_j – gravitational parameter for the Moon (j=2) or the Sun (j=3);

GM_{*}- gravitational parameter for Earth;

R_j – magnitude of the unit vector from geocenter to Moon or Sun;

R_e – Earth's equatorial radius;

r – magnitude of the unit vector from the geocenter to the station;

h_2 – nominal degree 2 Love number;

l_2 – nominal degree 2 Shida number

Determination of the *h, k* and *l* numbers is only possible according to the observations mentioned above. It is possible to replace GPS determinations with the clinometric observations, but this type of observations is not so widespread in the world. But determination of the tidal parameters from the GPS observations requires the changes in the routine data processing. In the next parts of this paper study the assessment of practical need of implementation some changes in the models applied in the Józefosław Observatory will be carried out according to the results of the tidal gravimetric analyses. Results of GPS data processing and their spectral analyses coming from 1 day and 1 hour solutions are presented above.

7. Conclusions

Joint analysis of the astrometric, gravimetric and GPS observation did not allow us to improve the tidal model that actually is used by Warsaw University of Technology EUREF Analysis Centre (compatible with IERS standards). It was mainly caused by the low accuracy of the astrometric measurements in spite of the systematic error removal and recalculation to the HIPPARCOS catalogue. Further research under the tidal model improvement will be held as a part of GPS data processing using BERNESE software.

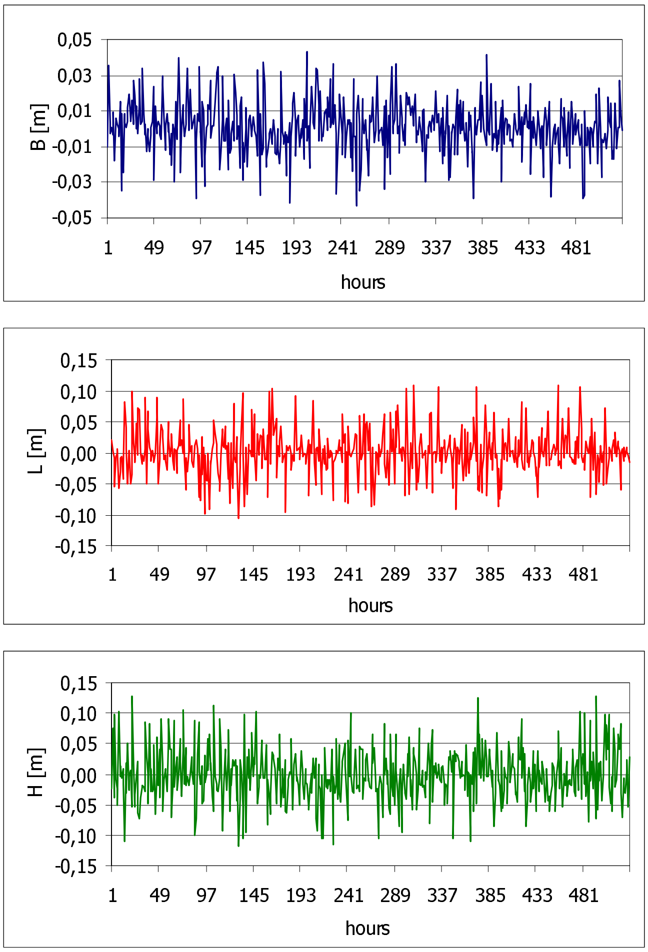

Fig. 4 Changes of the coordinates obtained from 1-hour GPS observations filtered to 3σ.

Tab. 3. Amplitudes and phases of B, L, H components for appropriate periods

Component	A_1 [m]	A_2 [m]	A_3 [m]	φ_1 [rad]	φ_2 [rad]	φ_3 [rad]
B periods: 6, 12, 96 h	-0.00216 0.00088	-0.00309 0.00088	0.00263 0.00088	0.231093 0.405881	-0.75001 0.28349	1.292e+12
L periods: 8, 12, 132 h	-0.00803 0.00219	-0.00553 0.00219	0.00728 0.00219	1.364559 0.272756	0.320909 0.396041	-3.29e+10
H periods: 6, 12, 84 h	0.01168 0.00262	-0.00721 0.00262	-0.00719 0.00265	-0.53805 0.22412	-1.38292 0.36314	-9.30e+10

Tab. 4. Amplitudes and phases of annual and semiannual waves

Station	A_r [m]	m_{A_r} [m]	A_p [m]	m_{A_p} [m]	φ_r [°]	m_{φ_r} [°]	φ_p [°]	m_{φ_p} [°]
BOGO	0.00543	0.00035	0.00324	0.00035	69.60	3.72	354.18	6.26
BOR1	0.00368	0.00039	0.00152	0.00040	100.22	6.12	353.28	15.06
JOZE	0.00178	0.00037	0.00313	0.00038	90.34	12.05	30.47	6.94
LAMA	0.00582	0.00041	0.00102	0.00041	94.96	4.05	80.35	23.03
WROC	0.00615	0.00031	0.00235	0.00031	83.63	2.85	354.98	7.55