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Geocenter dynamics investigations using DORIS and GPS tracking data

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ABSTRACT

The gravitational center of the Earth plays a crucial role as the origin of the terrestrial reference system. An accuracy of geocenter motion estimation is strongly dependent on the geodetic network size and stations distribution over the Earth's surface. From this point of view DORIS and GPS systems have an advantage, as their ground network beacons and receivers equally distributed over the Earth's surface. For our analysis we used the 14-years time series of the geocenter coordinates obtained by processing of DORIS and GPS measurements. Two methods of spectral analysis of geocenter coordinates have been applied in our study. Amplitudes of annual and semi-annual variations of geocenter, derived with the use of two different methods are in very good agreement between each other. By the use of dynamic regression modeling several other harmonics with periods of 1, 2 months and 2, 3 years, but with very small (as compared with noise) amplitudes were found out. The first attempt to develop a mathematical model of the geocenter motion has been made with the use of Dynamic Regression Modeling approach. Two types of mathematical models: complete (all harmonics) and truncated (only annual, semi-annual and 118 days), developed by the use of DORIS data, have been compared with observable geocenter positions on the time interval 1190 days. In the issue of our studies a possibility to predict the preliminary geocenter positions with the accuracy about 2-4 mm seems feasible over time period up to 10-12 weeks with the use of truncated models.

Introduction

Conventionally, the origin of the ITRF is defined to be the center of mass (CM) of the entire Earth system, including the solid earth, oceans, atmosphere and continental waters. Space geodetic techniques have demonstrated the 3-D vector displacements of the center of the Earth's figure (CF) relative to the center of mass (CM) at the level of a few millimeters to centimeters for the periods from diurnal to seasonal. These variations are defined as the geocenter motion and directly affect estimates of all space geodetic measurements that use the ITRF as a reference system. Two 14-years (1993.0-2007.0) time series of the geocenter coordinates obtained by processing of DORIS and GPS measurements were used in our investigations. For that DORIS weekly solutions of coordinates calculated at the Institute of Astronomy RAS (INA analysis center) with the use of GIPSY/OASIS II software, developed by JPL (ftp://cddis.gsfc.nasa.gov/pub/doris/products/geoc/ina05wd01.geoc.Z) and GPS daily solutions of geocenter coordinates, estimated at the JPL IGS analysis center with the same software package (ftp://sideshow.jphl.nasa.gov/pub/usrs/mb), were used.

Studies of the geocenter movements

Two methods of spectral analysis of geocenter coordinates have been applied in our study.

1. The linear regression analysis

The linear regression analysis has been used in order to estimate linear trend, amplitudes, periods and phases of geocenter variations. For analysis the next approximation is used:

$$J(t) = a_0 + b_0 t + A_0 \sin\left(\frac{2\pi(t - t_0)}{T} + \phi_0\right),$$

where A_0 is the amplitude of the signal; T the period of the signal (in years); ϕ_0 the initial phase of the signal; a_0 the offset; b_0 the trend; t the time; t_0 the arbitrary initial time (we take t_0 – 1st January).

2. Dynamic regression modeling

The same time series of 14-years geocenter coordinates (X, Y, Z), have been examined with the use of so-called method of adaptive Dynamic Regression Modeling (DRM) (Valeev and Kurkina, 2006, Kuzin et al., 2010), which is realized by the special software AC DRM. This method includes: a stochastic description of the time series and its studies with the correlation, spectral and wavelet analysis; estimation and removal of the non-random trend component; estimation of harmonic components. As a result of DRM-method the original time series are approximated by the complex mathematical model, which contains trend, periodical components and parameters of the dynamic regression model. In this paper we omitted the details of stochastic description and noise analysis of the evaluated time series.

Results of spectral analysis and prediction model

Annual geocenter variations derived from DORIS INA solution (Kuzin et al., 2010) by the linear regression analysis were estimated by least square method as 6.9 ± 0.3, 5.4 ± 3.5, 26.9 ± 1.0 mm for X, Y, Z components respectively.
Semiannual amplitudes of the geocenter variations are also noticeable (1-10 mm in all components).

The linear trend (-0.8, -0.3, 0.5 mm/year for X, Y, Z components) was found out of INA solution as well. Annual and semiannual amplitudes, estimated by GPS (JPL) data are lower (0.21-2.1 mm), and values of linear trend are almost negligible. Amplitudes and phases of the evaluated annual and semiannual variations of the DORIS and GPS geocenter components X, Y, Z are presented in Table 1. Analysis of the same time series of the geocenter motions with the method of adaptive Dynamic Regression Modeling allowed to find out several additional harmonics with valuable amplitudes. For DORIS X-component seven harmonics were derived. Among them four harmonics with periods 25, 52, 62, 170 weeks have noticeable amplitudes: 2.4, 6.7, 1.4, 1.4 mm respectively. From the set of DORIS Y-component four noticeable harmonics were derived with periods 25, 40, 52, 75 weeks and amplitudes 1.4, 1.1, 5.1, 1.4 mm respectively. The harmonics with periods 8, 10, 17, 52, 226 weeks were derived for DORIS Z component. Amplitudes of these components are higher, than for X and Y, and equal 2.9, 11.0, 15.5, 28.4, 6.8 mm respectively. Application of the DRM method for GPS geocenter time series analysis gives the next results. For GPS X-component harmonics with periods 26 and 48 weeks were obtained with the amplitudes 0.25, 0.25 mm respectively. For GPS Y-component harmonics with periods 25, 38, 52 weeks were derived with the amplitudes 0.28, 0.24 and 0.62 mm respectively. For GPS Z-component we have harmonics with periods 10, 38, 52, 97 weeks and amplitudes 0.63, 0.68, 1.7 and 0.9 mm respectively. It is important that amplitudes of annual and semiannual variations of geocenter, derived with the use of two different methods of spectral analysis are in very good agreement between each other.

The evaluated DORIS annual amplitudes are of the order of 5–7 mm for X and Y components and 26-28 mm for Z component. The evaluated GPS annual amplitudes are of the order of 0.2-0.6 mm for X and Y components and 0.6 -1.7 mm for Z component. Semiannual amplitudes of the geocenter variations are also noticeable in all components. More significant error in DORIS Z-component, corresponding to a translation of the Earth along its rotation axis, may be partly explained by large systematic errors in orbital calculation strategy of some of the DORIS satellites. In the latest studies (Gobinddass et al., 2009) was shown that better handling of solar pressure radiation effects on SPOT-2 and TOPEX satellites significantly improves the measurement noise of the Z-geocenter component and accordingly, amplitudes of the annual signal decrease from 28 to 5 mm. This effect can be seen in Table 1 for the updated INA DORIS solution (ina10wd01). The results of DRM analysis for DORIS and GPS geocenter time series are given in Table 2.

Experimental estimate of the mathematical model of the geocenter movement

With a view of estimating an accuracy and probability of the developed complex mathematical model of the geocenter movement we used the same DRM approach covering 14 years time span (1993.0–2007.0). With this model a forecasting of the weekly (DORIS) and daily (GPS) geocenter positions for the next, 2007, year has been performed. Comparison of the results shows, that in general a forecasting model of the geocenter shifts confirms the real motion (derived from the measurements) of geocenter movements. Table 2 presents the results of a correlation analysis between "observable" and predictable values for 2007.

From this table one can see rather high correlation dependence between "observable" and forecasting geocenter movements values for DORIS data X component till 25 weeks, Y component till 25 weeks and Z component till 15 weeks. For GPS data these values are 15, 25 and 10 weeks for X, Y and Z components respectively. Due to complexity of the mathematical DRM model for X, Y and Z components of the geocenter movements we investigated possibility to use truncated model describing geocenter motion and consisting mainly from annual and semiannual components with the same amplitudes as in DRM model (Fig. 1-3).It should be noted that we applied truncated model only for DORIS data and for time period 170 weeks. Differences between the full and truncated models are ± (1–4) mm for DORIS X component, ± (1–2) mm for DORIS Y component and ± (1–10) mm for DORIS Z component.

References

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Kuzin S.P., Tatevian S.K., Valeev S.G., et al. Studies of the geocenter motion using 16-years DORIS data. Advances in Space Research 46 (2010) 1292–1298.
Valeev, S.G., Kurkina, S.V. Program realization of the DRM method for time series analyses and processing. Izvestiya Vuzov, Geodesy and aeropfotosyemka (in Russian), no. 5, pp. 10–21, 2006.

Diagrams of geocenter positions, estimated by the truncated (yellow line), complete (pink line) mathematical models and by the real DORIS observations (blue line)

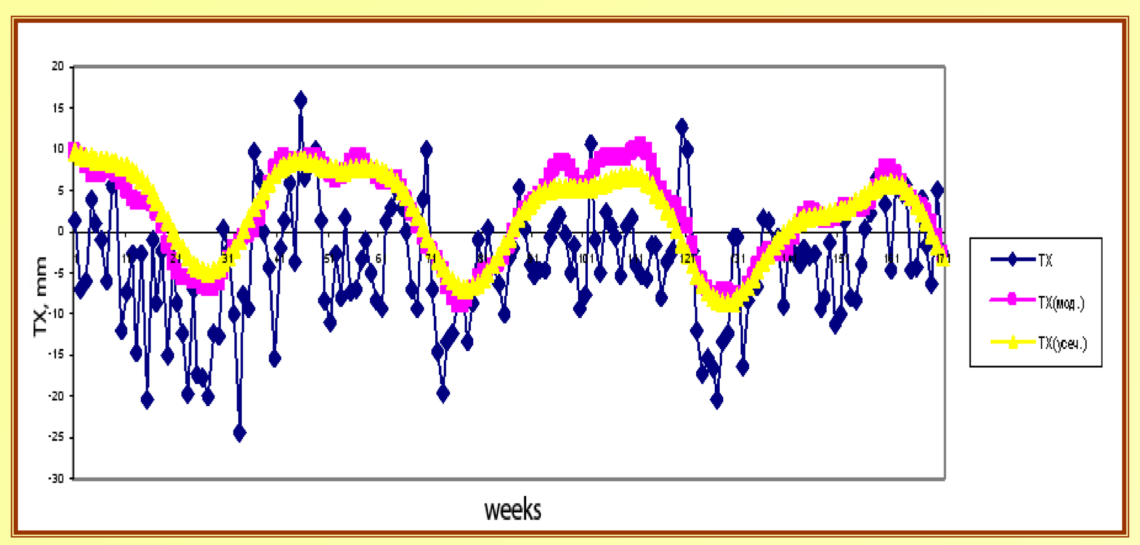

Fig. 1

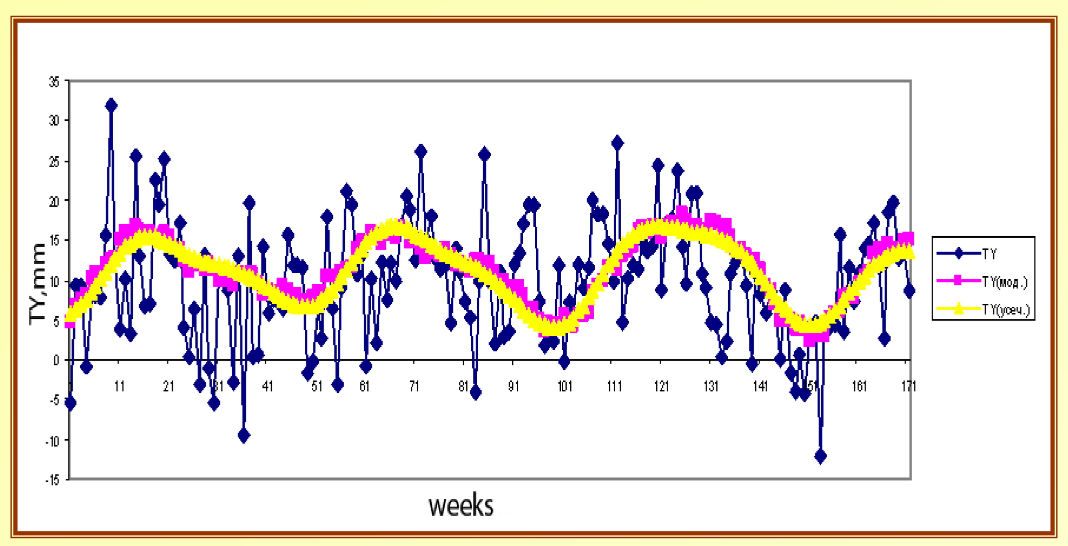

Fig.2

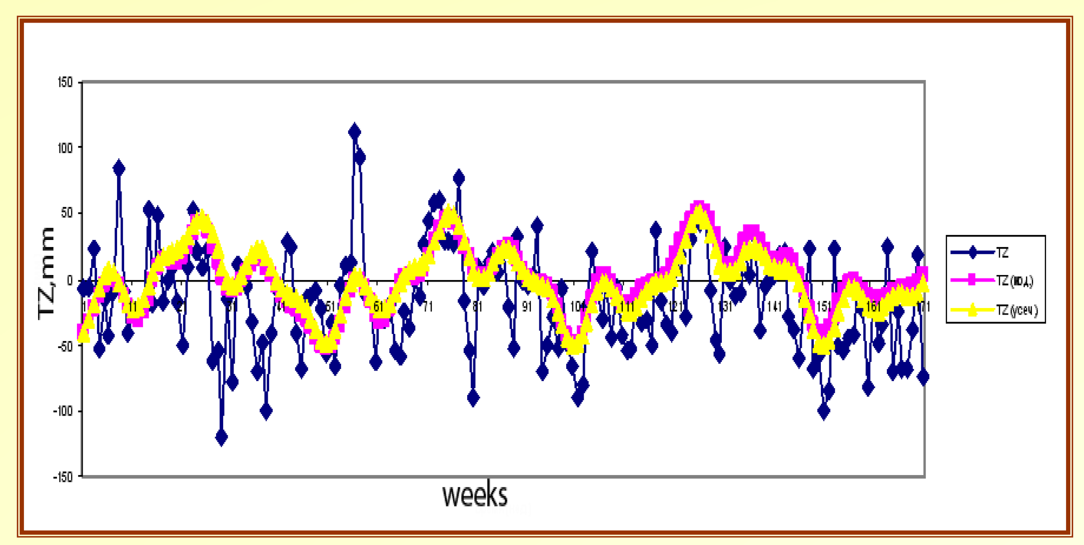

Fig.3

Table 1. Comparison INA DORIS geocenter times series with JPL GPS geocenter times series

AC	Time series	Interval	T_X				T_Y				T_Z			
			annual		semiannual		annual		semiannual		annual		semiannual	
			A_1 (mm)	φ (deg.)	A_2 (mm)	φ (deg.)	A_1 (mm)	φ (deg.)	A_2 (mm)	φ (deg.)	A_1 (mm)	φ (deg.)	A_2 (mm)	φ (deg.)
INA	Ina05wd01	1993.0-2007.0	6.90 ±0.27	110.2 ±4.9	0.52 ±0.65	229.5 ±5.5	5.44 ±3.52	317.8 ±6.9	9.93 ±0.40	353.4 ±45.4	26.88 ±1.03	291.2 ±5.1	5.08 ±1.24	286.4 ±25.6
INA	Ina10wd01	1993.0-2007.0	1.68 ±0.66	85.6 ±19.2	5.21 ±0.46	346.5 ±8.0	4.12 ±0.73	13.4 ±6.3	1.01 ±0.29	334.1 ±45.4	4.75 ±2.19	252.9 ±13.8	7.96 ±2.40	56.0 ±3.7
JPL	–	1993.0-2007.0	0.21 ± 0.02	282.9 ± 7.5	2.10 ± 0.02	355.1 ± 0.7	0.41 ± 0.02	277.5 ± 3.1	1.05 ± 0.02	182.4 ± 1.0	0.58 ± 0.03	108.2 ± 5.7	0.40 ± 0.01	125.2 ± 9.0

Table 2. Correlation coefficients between observations and predictions of geocenter motion for 2007

Component	Period (weeks) in geocenter time series						
	52	25	15	10	8	6	4
	DORIS						
X	0,375	0,772	0,640	0,868	0,868	0,943	0,970
Y	0,540	0,609	0,772	0,741	0,721	0,627	0,951
Z	0,450	0,614	0,640	0,675	0,298	0,387	0,488
	GPS						
X	0,220	0,232	0,753	0,797	0,448	0,722	0,923
Y	0,375	0,765	0,789	0,745	0,661	0,786	0,409
Z	0,0583	0,327	0,422	0,616	0,718	0,740	0,972

Summary

Two sets of translation parameters, derived from DORIS weekly solutions of geocenter coordinates, calculated at the INA DORIS Analysis center [ina05wd01.geoc] and GPS daily solutions obtained by JPL IGS Analysis center for the same time span, were analyzed. The first attempt to develop a mathematical model of the geocenter motion has been made with the use of Dynamic Regression Modeling approach for spectral analysis of the long set (14 years) of geocenter coordinates, estimated by DORIS and GPS measurements. It was shown, that the obtained model may be used for prediction of the further geocenter motion during the next 25 weeks for DORIS X and Y components and 15 weeks for DORIS Z component. Prediction results for GPS system are valid for 15, 25, 10 weeks for X, Y and Z components respectively. With the purposes of forecasting and obtaining preliminary results for geocenter motions it is possible to use truncated model instead of full DRM model with the similar accuracy as with a full mathematical model of geocenter motion. Further investigations in this direction will be performed with different types of measurements, such as SLR and with the improved orbital modeling of the DORIS satellites.

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