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Studies of the Earth's center of mass periodical movements

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Abstract

Conventionally, the origin of the ITRF is defined to be at the center of mass (CM) of the entire Earth system, including the solid earth, oceans, atmosphere and continental waters [*McCarthy and Petit, 2004*]. Center of mass (CM) is realized as the center of artificial satellite orbits. In reality the global geodetic network is fixed to the solid Earth crust and its origin coincides with the center of the solid earth surface figure (CF). Space geodetic techniques have demonstrated the 3-D vector displacement of the center of the figure (CF) relative to the center of mass (CM) at the level of few millimeters to centimeters over time periods from diurnal to seasonal [*Cretaux et al. 2002, Tatevian et al. 2004, Gobinddass, et al. 2009a*]. These variations are defined the geocenter motion and directly affect estimates of all space geodetic measurements that use the ITRF as a 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 system (Doppler Orbitography and Radio positioning Integrated by Satellites) has an advantage, as its ground network consists of more than 50 beacons, equally distributed over the Earth’s surface. DORIS [*Willis et al., 2006a*] is a satellite system, developed to support high accuracy orbit determination for altimetry measurements of the sea level and ground beacon positioning. It is an

uplink radio-electrical system based upon Doppler measurements and dual–frequency to correct for ionosphere effects. The space segment now is accounted for 6 satellites (SPOT2, SPOT4, SPOT5, ENVISAT, JASON1 and JASON 2).

DORIS data processing

The Analysis Center (INA) of the Institute of astronomy (INASAN) performs DORIS data analysis with the use of GIPSY/OASIS II software, developed by Jet Propulsion Laboratory (JPL) [*Webb and Zumberge, 1997*] and significantly expanded for DORIS applications [*Willis et al., 2005, Willis at al., 2009*] by joint IGN / JPL cooperation.

Taking into account recommendations of the International Earth Rotation and Reference Systems Service (IERS) and International DORIS service (IDS), a reprocessing of the DORIS data for the period of 1993.0-2010.0 has been performed aiming to obtain a unified coordinated solution of the IDS analysis centers for the developing of the new version of the Terrestrial Reference Frame - ITRF2008. For this solution [inawd07.snx] the next standards have been applied: gravity model – GGM02C, atmospheric gravity - not applied, Ocean tides- IERS Conventions, atmospheric density- DTM2000, drag parameterization- Cd/1hrs, troposphere mapping function – Niell. A complete description of the models used for inawd07 and the estimation strategy can be found at ftp://cddisa.gsfc.nasa.gov/pub/doris/ products/sinex_series/inawd.

The weekly solutions of coordinates of all 71 DORIS ground sites and Earth Observations parameters (EOP) have been estimated with the use of new improved satellite surface models, submitted by CNES, and with measurement data of the satellites SPOT2, SPOT3, SPOT4, SPOT5, TOPEX, and ENVISAT. Data of JASON-1 were not used at all due to SAA (South Atlantic Anomaly) effect. This effect is related with extra sensitivity of the on-board receiver to radiation over South Atlantic Anomaly and gives meaningful DORIS residuals for POD (Precise Orbit Determination) estimation. Detailed investigation of SAA effect and developed correction model can be found in [*Willis et al., 2004; Lemoine and Cardeville, 2006*], but this model is still in a testing phase by IDS

Analysis Centres. It also should be noted that data of SPOT4 for whole 1998 were rejected because of a systematic error that affects for the z-component geocenter estimation [*Willis et al., 2006b*].

After the transformation of the free-network solution into a well-defined reference frame (ITRF2005) weekly coordinates of the sites were estimated with the internal precision at the level of 5-40 mm for majority of the stations. We estimated simultaneously X-pole, Y-pole coordinates and their rates once per day (4 parameters per day). Mean square residuals (rms) of coordinates over time-span 2000-2004 are estimated as 2.83 mas and 1.70 mas, respectively, with refer to IERS C04 solution [*Gambis et al., 2006*]. As it was shown later by other authors the systematic errors in DORIS solutions [*Gobinddass al., 2009a*] may be caused by mis-modeling errors in orbit determination, in particular due to inadequate solar radiation effect model for the DORIS satellites.

Geocenter estimation

In our study the "geometric" method or network shift approach has been used for the geocenter estimation. This method provides simultaneously the coordinates (and full-covariance matrix) of the estimated reference network and seven parameters of its transformation to the well-defined coordinate system (typically ITRF) with the use of seven Helmert transformation parameters. Three translations parameters are the components of the geocenter 3-D vector.

Studies of the Geocenter movements

The sets of translation parameters, derived from DORIS weekly solutions of coordinates, calculated at the INA center [ina10wd01.geoc] and at the joint IGN/JPL center [ign09wd01.geoc] for the same time span 1993.0-2010.0, have been examined with a view to study variations of the geocenter movements.

As a reference frame the ITRF2005 (exactly, long-term cumulative IGN solution: ign07d02) has been used for every week. For comparison geocenter time series, derived from the GPS daily coordinate solutions at JPL [ftp://sideshow.jpl.nasa.gov/pub/usrs/mbh] for the time period 1992.5-2007.6 has been examined as well. In order to estimate linear trend, amplitudes, periods and phases of geocenter variations a linear regression analysis has been applied with the use of least square method. Annual geocenter variations were evaluated from the solution [ina10wd01.geoc] as 4.7±0.4 mm, 4.6±0.2 mm, 6.2±2.9 mm for X, Y, Z components respectively. Geocenter annual variations, derived from the IGN/JPL solution [ign09wd01.geoc], are 5.6±0.2 mm, 4.7±0.1mm, 2.2±0.9 mm in three components. There are rather good agreement between these DORIS solutions, because the same software GIPSY/OASIS II are used for DORIS data processing. Semi-annual amplitudes of the geocenter variations are also noticeable (5.5-33.5 mm in all components). The linear trend (0.5 mm/year, 0.2 mm/year, 3.3 mm/year for X, Y, Z components) was found out of INA solution as well (**Table 1**). Annual and semi-annual amplitudes, estimated by GPS 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 geocenter components X, Y, Z are presented in **Table 2**.

Adaptive Dynamic Regression Modeling (DRM)

The same time series of 15 years weekly geocenter coordinates (X, Y, Z), (ftp://cddis.gsfc.nasa.gov/pub/doris/products/geoc/ina05wd01.geoc.Z) have been examined with the use of so- called method of adaptive Dynamic Regression Modeling (DRM) [*Valeev, 1991; Valeev and Kurkina, 2006*], 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. Unlike the linear regression analyses, the DRM method envisages the further iterative, step by step, regression analyses of the non-random content of the de-trended series, obtained after first harmonics removing, aiming to avoid errors, caused by noise residuals and inter correlation between estimated harmonics and to find out the additional regularities. When at the appropriate step of analyses the mean square residual becomes unchangeable (without decreasing), process is completed, and residuals are analyzed on their correspondence to the basic requirements of the least square method. As a result of DRM –method the original time series is approximated by the complex mathematical model, which contains trend, periodical components and parameters of the dynamic regression model.

With a view of estimating an accuracy and probability of the developed complex mathematical model of the geocenter movement we used the DRM approach for evaluation of the shortcut model, covering only the 15 years time span (1993.0-2008.0). With this model a forecasting of the weekly geocenter positions for the next, 2008 year has been performed. The results are presented by the graphs (Fig. 1, Fig. 2, Fig. 3) for three components (X, Y, Z) of geocenter variations. The values of weekly geocenter coordinates, evaluated at INA center with the use of DORIS data for the 2008 year (ina05wd01.geoc.Z), are regarded as "observable" (red line). Values, simulated by the model, are plotted by the blue line.

The graphs (fig. 1-3) show that in general a forecasting model of the geocenter shifts consists with the real (derived from the measurements) dynamics of geocenter movements. Summarizing the results of these experimental calculations we can conclude, that: - correlation coefficient between simulated data and "observable" ones for the annual time interval for X component is 0.786 and *RMS* is 7.01 mm. For the first 10 weeks of the 2008 year the simulated data are most consistent with the "observable" ones, and in this case correlation coefficient is 0.852 and *RMS* equals to 2.24 mm. For Y component the correlation coefficient between forecasting values and "observable" ones on the annual interval equals to 0.766, and *RMS* is 7.52 mm. For the time period 10 weeks the correlation is 0.949 and *RMS* is equal to 2.26 mm. A correlation between forecasting and "observable" variations of Z component is 0.802 and 0.815 for the annual and 10 weeks periods respectively. The mean square residuals (RMS) are 29.13 mm and 12.92 mm. More significant error in 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., 2009b] 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 35 to 6 mm.

Table 1. Comparison INA geocenter times series with IGN and JPL 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.)
IGN	**ign09wd01**	**1993.0 - 2010.0**	**5.6 ±0.2**	**106.9 ±3.9**	**5.5 ±0.3**	**358.6 ±3.3**	**4.7 ±0.04**	**319.4 ±6.7**	**7.6 ±0.3**	**350.9 ±3.4**	**2.2 ±0.9**	**289.7 ±47.0**	**33.5 ±1.4**	**357.9 ±2.5**
INA	**ina10wd01**	**1993.0 - 2010.0**	**4.7 ±0.4**	**100.2 ±6.4**	**5.6 ±0.4**	**350.6 ±5.3**	**4.6 ±0.2**	**307.4 ±17.5**	**11.4 ±0.8**	**347.2 ±6.0**	**6.2 ±2.9**	**261.8 ±19.8**	**30.2 ±2.1**	**351.3 ±5.5**
JPL	**–**	**1992,5 - 2007,6**	**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**	**182,41 ± 1,0**	**0,58 ± 0,03**	**108,2 ± 5,7**	**0,40 ± 0,01**	**125,2 ± 9,0**

Table 2. Linear trend of the geocenter coordinates (X, Y, Z), estimated by different solutions.

SOLUTION	X mm/y	Y mm/y	Z mm/y
DORIS/INA (ina10wd01)	0.54 ± 0.07	0.21 ± 0.16	3.34 ± 0.41
DORIS/IGN-JPL (ign09wd01)	0.29 ± 0.04	0.31 ± 0.09	2.45 ± 0.31
GPS/JPL	-0.06 ± 0.05	-0.06 ± 0.00	0.11 ± 0.01

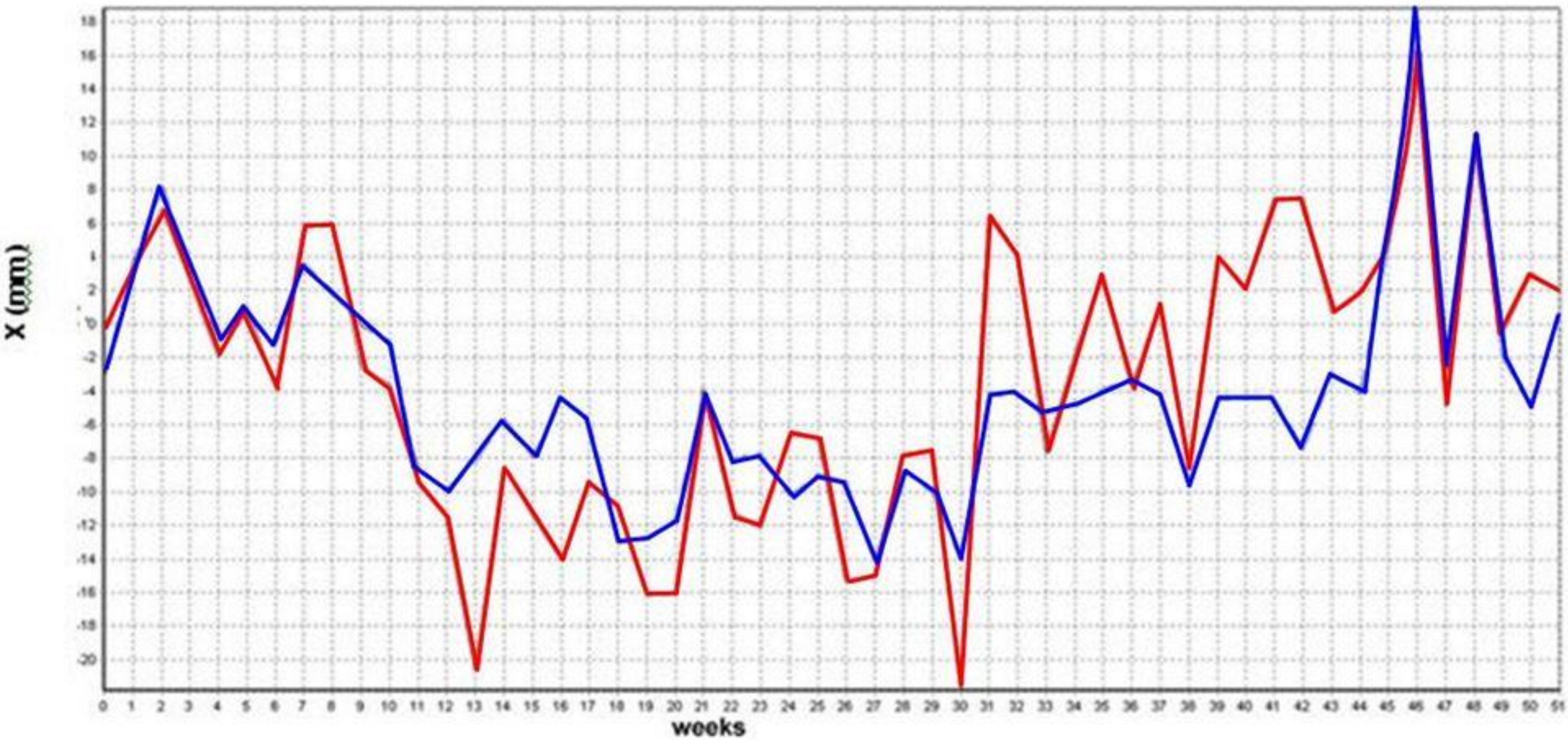

Fig.1. X geocenter coordinate, evaluated at INA DORIS Analysis center (red line) and simulated by the model (blue line) for the 2008 year.

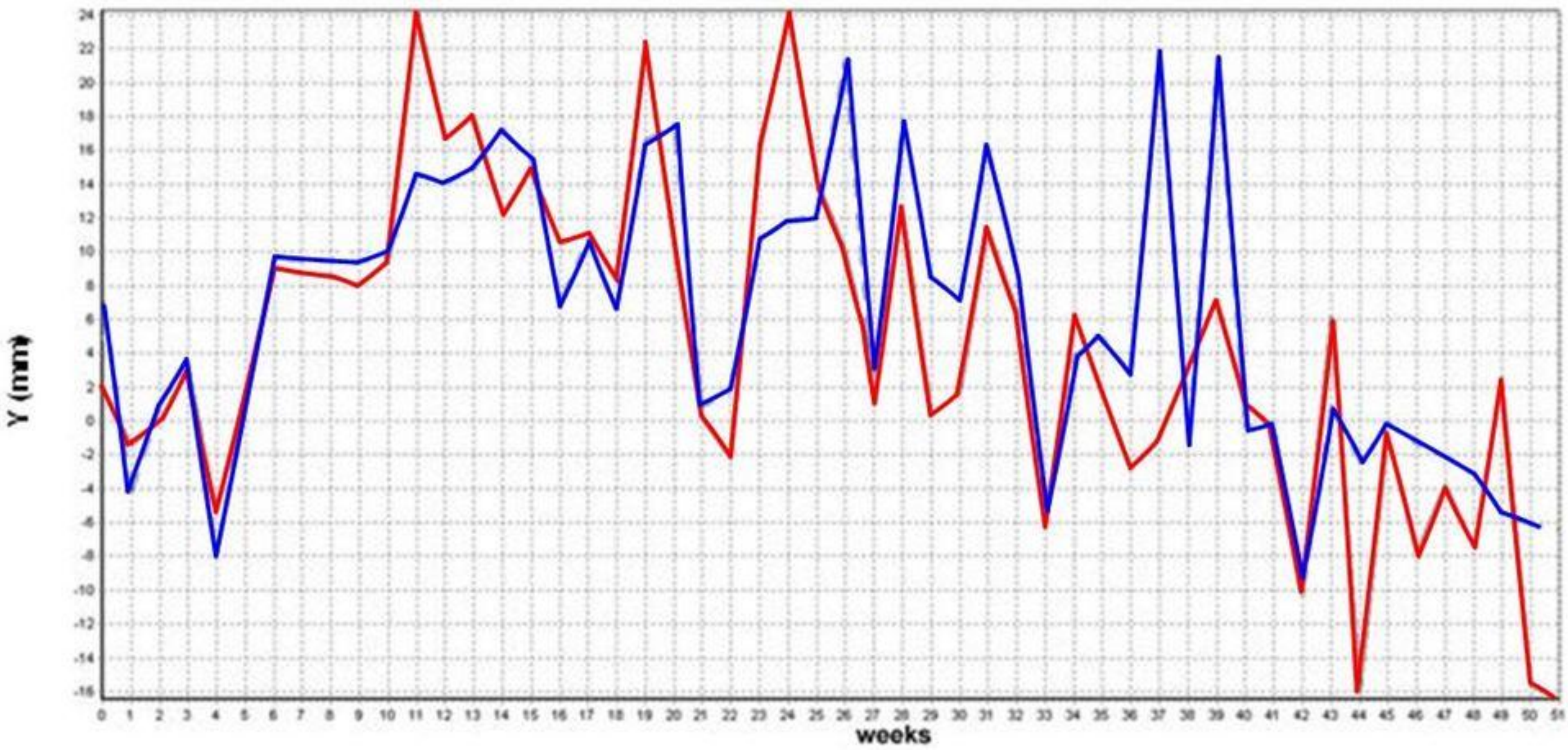

Fig. 2. Y geocenter coordinate, evaluated at INA DORIS Analysis center (red line) and simulated by the model (blue line) for the 2008 year.

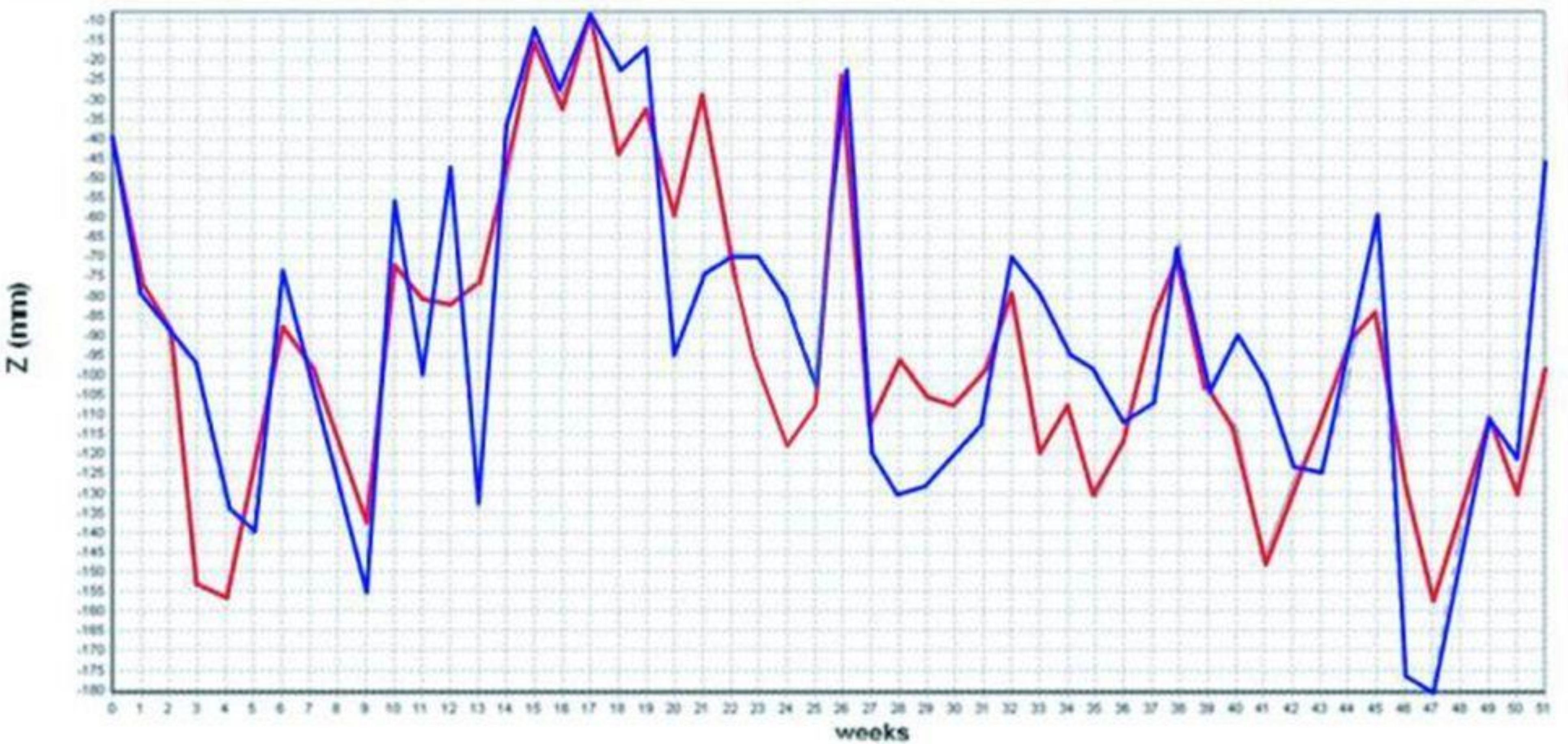

Fig. 3. Z geocenter coordinate, evaluated at INA DORIS Analysis center (red line) and simulated by the model (blue line) for the 2008 year.

Summary

The first attempt to develop a mathematical model of the geocenter movements has been made with the use of long set (16 years) of DORIS measurements. This system was chosen because of almost equal distribution of ground beacons over the globe, that is, on our opinion, very important for the geocenter position determination. At the same time amplitudes of annual and semi annual geocenter variations, evaluated by the analyses of DORIS data, are significantly 2-3 times as much as those, derived from the GPS and SLR measurements, mainly in the geocenter Z-component. As it was shown by several authors [Willis et al., 2009; Gobinddass et al., 2009a], systematic errors in geocenter estimation by the DORIS measurements are satellite dependent, and improved satellites orbital modeling has to be applied to avoid the discrepancies between different geocenter solutions. Nevertheless we assume that general behavior of the geocenter movements, estimated with the use of multi-years DORIS time series, more or less coincide with its real dynamics and may be analyzed aiming to develop the mathematical model of the geocenter variation.

With a view of estimating an accuracy and probability of the developed complex mathematical model of the geocenter movement we used the DRM approach for evaluation of the shortcut model, covering 15 years time span (1993.0-2008.0). With this model, developed with the use of Dynamic regression modeling, a forecasting of weekly geocenter positions for the next, 2008, year has been performed. It was shown, that this mathematical model allows to predict the further geocenter motion during the next 10 weeks with the correlation coefficient = 0.8 and *RMS*: 2.24 mm (X), 2.26 mm (Y) and 12.92 mm (Z). Further investigations in this direction will be performed with different types of measurements, such as SLR and GPS, and with the improved orbital modeling of the DORIS satellites.

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