RUSSIAN JOURNAL OF EARTH SCIENCES, VOL. 11, ES1009, doi:10.2205/2009ES000361, 2009

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE

Electronic Geophysical Year: State of the Art and Results

3–6 June 2009 • Pereslavl-Zalessky, Russia

Studies of the Earth's center of mass periodical movements

S. K. Tatevian[1] and S. P. Kuzin[1]

Received 1 June 2009; accepted 11 September 2009; published 27 November 2009.

At present the Earth reference coordinate frame ITRF is realized on the base of space geodesy observations in strictly secular sense with purely linear temporal changes (velocities) without any conventional models. These linear changes include primarily non modeled geophysical motions, mostly of tectonic origin. In the base of all space geodesy techniques (except of VLBI), there are precise orbits of the observable satellites, which are moving under the influence of the Earth gravity field around of the entire Earth's center-of-mass (CM). To keep the convention of the coincidence of the terrestrial coordinate system origin with the entire Earth center-of-mass, the first harmonics ($C_{1,1}$, $S_{1,1}$, $C_{1,0}$) of the gravity field models, used for orbital calculations, are equated to zero. Studies of the ITRF precision and stability, carried out at the different research centers, INASAN included, show that origin of the coordinate system (Geocenter) is moving relatively to the center of mass. Besides the main geophysical effects: atmosphere pressure, oceanic tides and currents, ice melting, have been taken into consideration. The annual and semiannual amplitudes of the geocenter variations are not the same for different types of measurements and fluctuate in the interval 1–23 mm for all three components of the position vector. And Z-component is always 2–3 times more than planar components. The absolute scale of the network is determined with the accuracy around of $0.5 \cdot 10^{-13}$, that is equivalent 3 mm in the station height. The further improvement of the ITRF accuracy and stability is possible with the use of more dense and equally distributed tracking networks, equipped with the different types of modern instruments, allowed to minimize systematic errors, characteristic for every usable technique. In this connection the International Association of Geodesy arrived to a decision on the development of the Global Geodetic Observing System (GGOS), which will consist of about 40 permanent ground tracking sites, space segment of special research satellites and centers of merging, storage and analyses of the data. *KEYWORDS: terrestrial reference frame, origin movements, satellite geodesy, DORIS.*

Citation: Tatevian, S. K. and S. P. Kuzin (2009), Studies of the Earth's center of mass periodical movements, *Russ. J. Earth. Sci., 11,* ES1009, doi:10.2205/2009ES000361.

At present the Earth reference coordinate frame ITRF is realized mainly with the use of space geodesy observations. The coordinates of more than 500 observational sites, equipped with different measuring techniques and fixed at the Earth's crust, determine the reference frame in strictly secular sense with purely linear temporal changes (velocities of the coordinates) without any conventional models. These linear changes include primarily non-modeled geophysical motions, mostly of tectonic origin, that cannot be known a priori with sufficient accuracy. In the base of all space geodesy methods (except of VLBI) there are precise orbits of the observable satellites. And the geocentric coordinates of the ground sites are estimated relative to the center of satellite orbits, which is center of mass (CM) of the entire Earth, including Solid Earth and its fluid envelope (oceans, atmosphere, continental waters, ice masses). To keep the convention of the coincidence of the terrestrial coordinate frame (ITRF) origin with the entire Earth center-of-mass, the first harmonics ($C_{1,1}$, $S_{1,1}$, $C_{1,0}$) of the gravity field

[1]Institute of astronomy RAS, Moscow, Russia

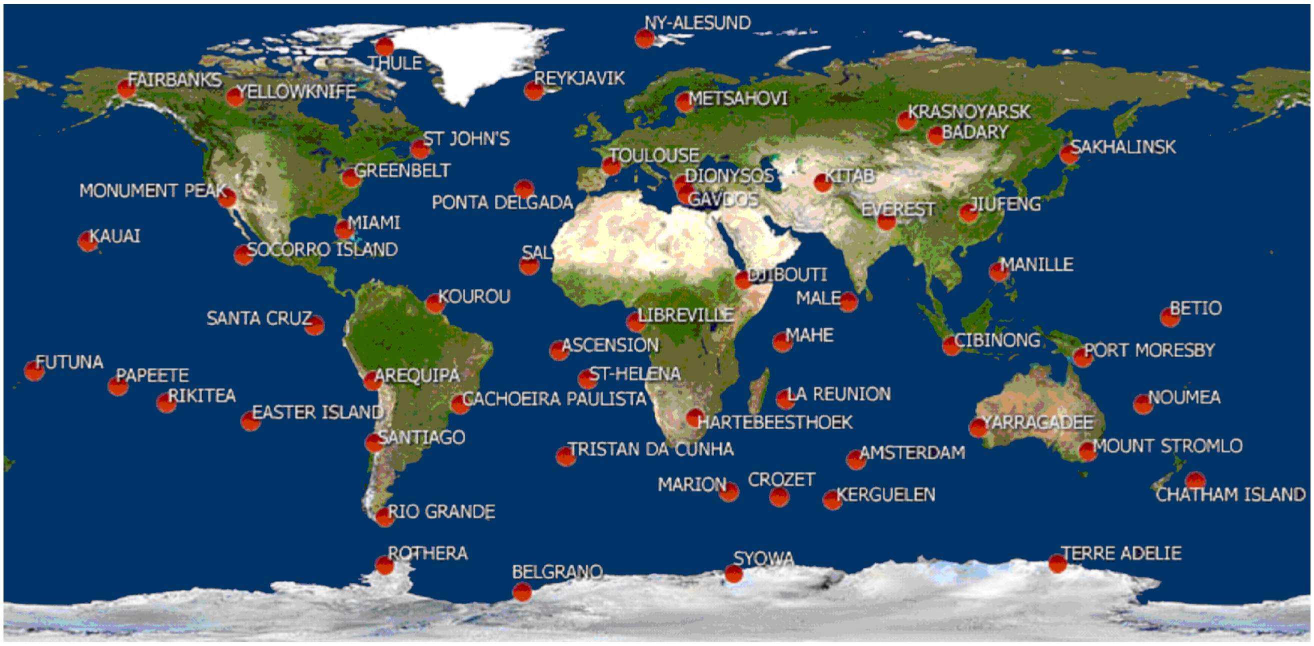

Figure 1. Network of the DORIS ground beacons.

models, used for orbital calculations, are equated to zero. Studies of the ITRF precision and stability, carried out at the different research centers, INASAN included [*Kuzin and Tatevian,* 2005]; *Tatevian et al.,* 2004, show that the origin of the terrestrial coordinate system, attached to the Earth's crust, is moving relatively to the center of satellite orbits, which is CM. This motion, viewed from a rigid crust-fixed frame, is known as "geocenter motion" and is presumably caused by the mass movement of planetary fluids relative to the Solid Earth. The distribution of the fluid masses over the surface of the Earth changes continually with periodicities at 24 hours to annual periods, including tidal, non-tidal and secular components. As pointed out by several researchers [*Blewitt,* 2003; *Creataux et al.,* 2002; *Lavallee et al.,* 2006] the redistribution of surface mass, that gives rise to geocenter motions should also be associated with changes in the lithosphere loading and large-scale deformations of the crust.

Center of mass variations must be properly accounted for in the realization of the tracking station locations within the terrestrial reference frame, that is especially important for the altimeter measurements of sea-level, plate tecton-

Table 1. Variations of Geocenter movements

	Component	Time interval	Annual		Semiannual	
		Years	A, mm	Phase, degr.	A, mm	Phase, degr.
X	DORIS (INASAN)	1992,8061–2008,9816	6.71±0.22	114.84±5.14	3.61±0.50	189.96±6.40
	DORIS (IGN/JPL)	1993,0164–2008,6954	6.75±0.24	94.20±2.39	1.00±0.32	194.31±10.76
	GPS (IGN/JPL)	1992,4695–2007,5688	0.21±0.02	282.87±7.50	2.10±0.02	355.12±0.65
Y	DORIS (INASAN)	1992,8061–2008,9816	5.46±0.08	321.37±6.77	9.30±0.39	352.25±3.19
	DORIS (IGN/JPL)	1993,0164–2008,6954	6.84±0.13	304.44±5.93	14.49±0.45	354.00±2.21
	GPS (IGN/JPL)	1992,4695–2007,5688	0.41±0.02	277.45±3.06	1.05±0.02	182.41±1.01
Z	DORIS (INASAN)	1992,8061–2008,9816	28.92±1.11	290.36±4.88	9.83±2.64	213.21±3.27
	DORIS (IGN/JPL)	1993,0164–2008,6954	27.71±0.83	295.66±5.01	35.54±1.40	348.27±3.45
	GPS (IGN/JPL)	1992,4695–2007,5688	0.58±0.03	108.19±5.66	0.40±0.01	125.18±9.03

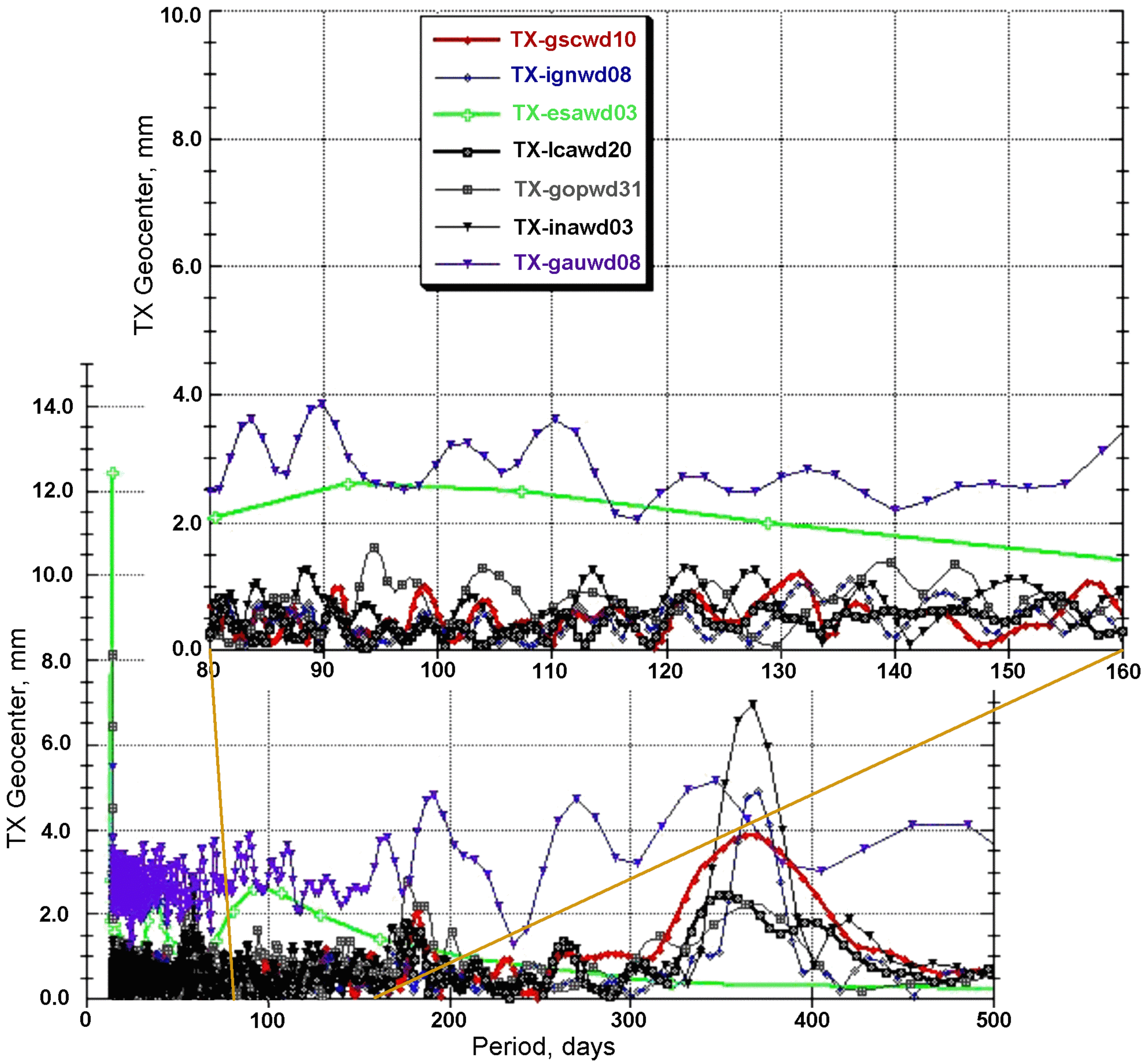

Figure 2. TX geocenter periodogram from IDS ITRF 2008 SINEX series.

ics studies and for improvement of the existed geophysical models. Analyses of the long time series (about of 15 years) of the geocenter coordinates have been performed at the Institute of astronomy – INASAN [*Kuzin and Tatevian,* 2005; *Tatevian et al.,* 2004]. For that station coordinates of global geodetic networks, developed with the use of GPS and DORIS measurements, have been analyzed separately and compared. DORIS [*Berthias et al.,* 1998] is a satellite positioning system, developed to support high accuracy orbit determination, 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 ground network of DORIS beacons consists of more than 50 sites, equally distributed over the Earth's surface (Figure 1). The space segment now is accounted for 6 satellites. Precise beacon positioning reaches the centimeter accuracy and stability in reference frame.

There are different approaches to estimating geocenter motions from space geodetic measurements, including the so-called "network shift" approach, which directly determines the translation parameters between coordinate frames, and "dynamic" method, which estimates degree-1 coefficients of the geopotential [*Dong et al.,* 2003]. In order to compare

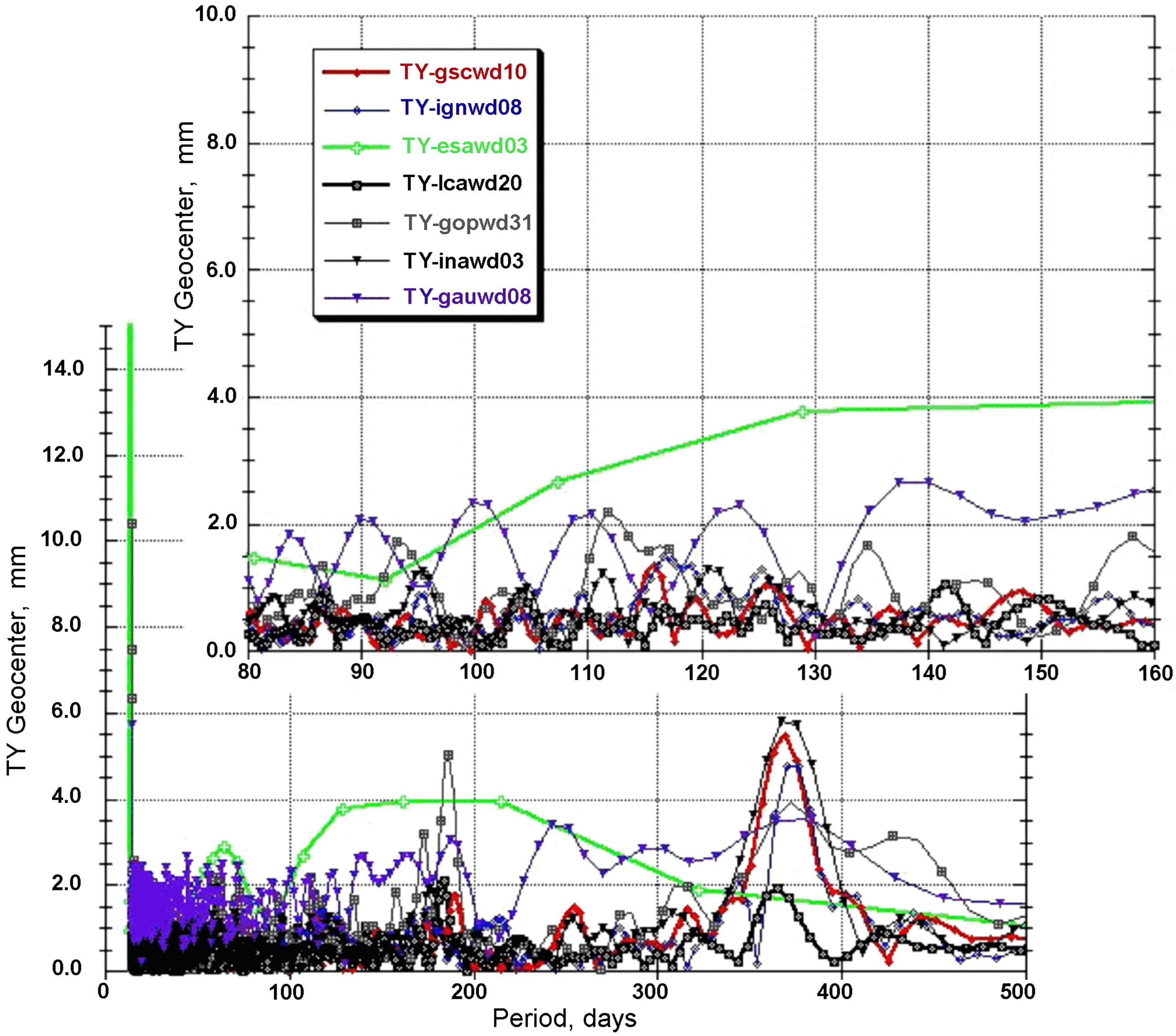

Figure 3. TX geocenter periodogram from IDS ITRF 2008 SINEX series.

variations of the geocenter obtained from the individual DORIS and GPS solutions, we have examined the sets of translation parameters, derived from the GPS daily coordinates for the 15 years period: 1993–2008, stored at the data bank of the International Geodynamic Service (IGS), and from the DORIS weekly solutions, calculated at the INASAN and at the Institute Geographic National (IGN, France) for the same time period (*Kuzin et al.,* in print, 2009). The harmonic and regression analyses have been applied in order to estimate linear trend, amplitudes, periods and phases of variations. Geocenter motions as determined using DORIS and GPS data, are of the order of 0.4–35.5 mm in each coordinate, and secular trend is about 1.7 mm/yr. Amplitudes of Z components are 2–3 times higher than for X and Y for both GPS and DORIS solution, that may be caused by season masses redistribution between Southern and Northern hemispheres (Table 1).

Our results of geocenter positions estimation have been compared with the same data, obtained by other analyses centers of the International DORIS service (ftp://ftp.cls.fr/pub/ids/combinations/ITRF2008-IDS/PWillis). In general there are rather good agreement between different solutions, but it is evident that these studies have to be continued with more data and with improved geophysical models. Geocenter solutions, estimated by all analyses centers, are shown in diagram form. (see Figure 2, Figure 3, and Figure 4).

Accurately determined geocenter variations and a full understanding of the observed geocenter motions provide im-

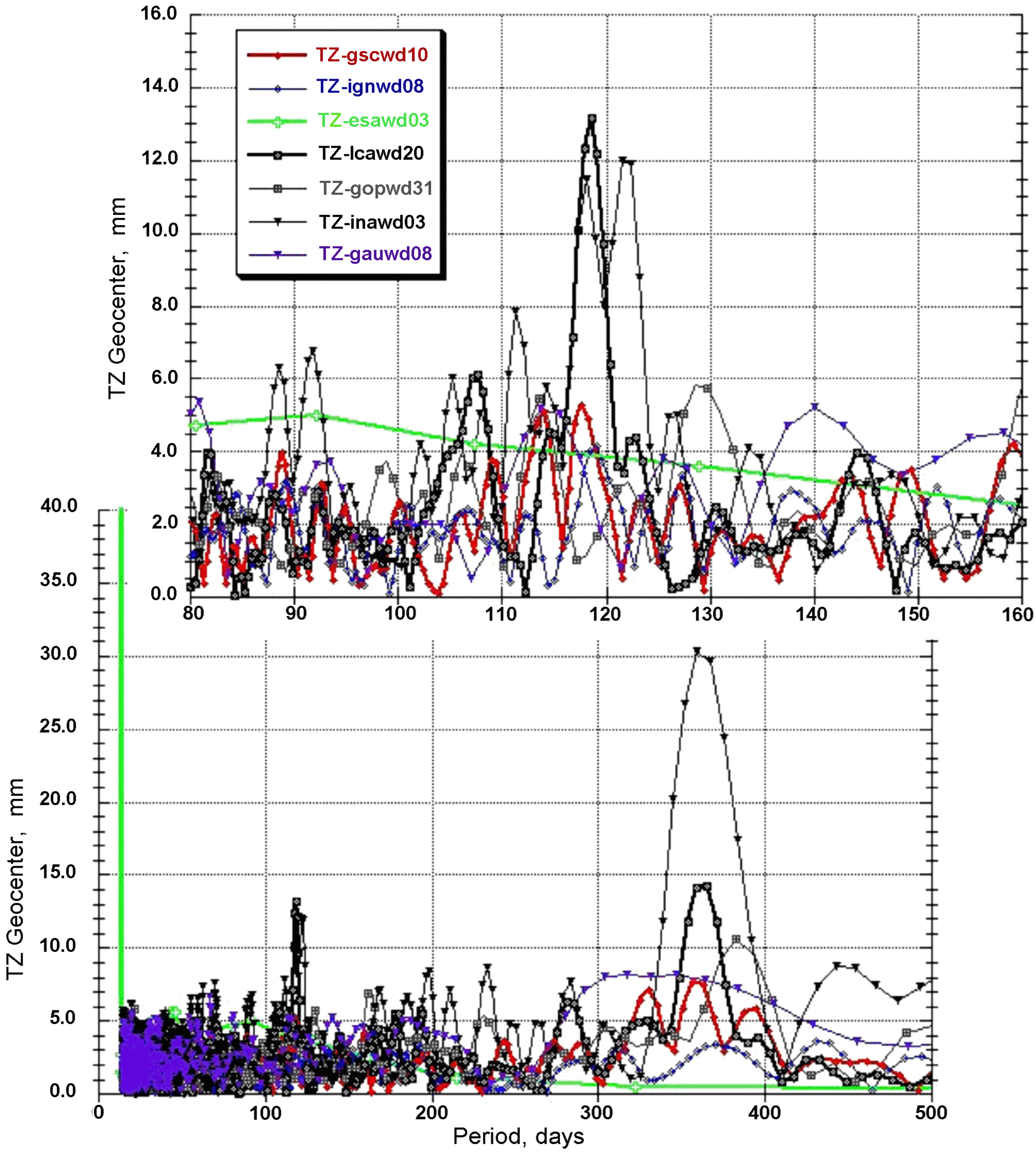

Figure 4. TX geocenter periodogram from IDS ITRF 2008 SINEX series.

portant information about mass redistribution in the Earth system and should provide observational constraints on mass budgets in global atmospheric and hydrological models, especially those of the snow/ice fields in the Antarctic, the Arctic, and Greenland (Figure 5), as well as mean sea level variations (Figure 6), which are of great interest for global climate studies (*Shum et al.,* in print, 2008). Continuous GPS recordings are presently the most accessible and accu-

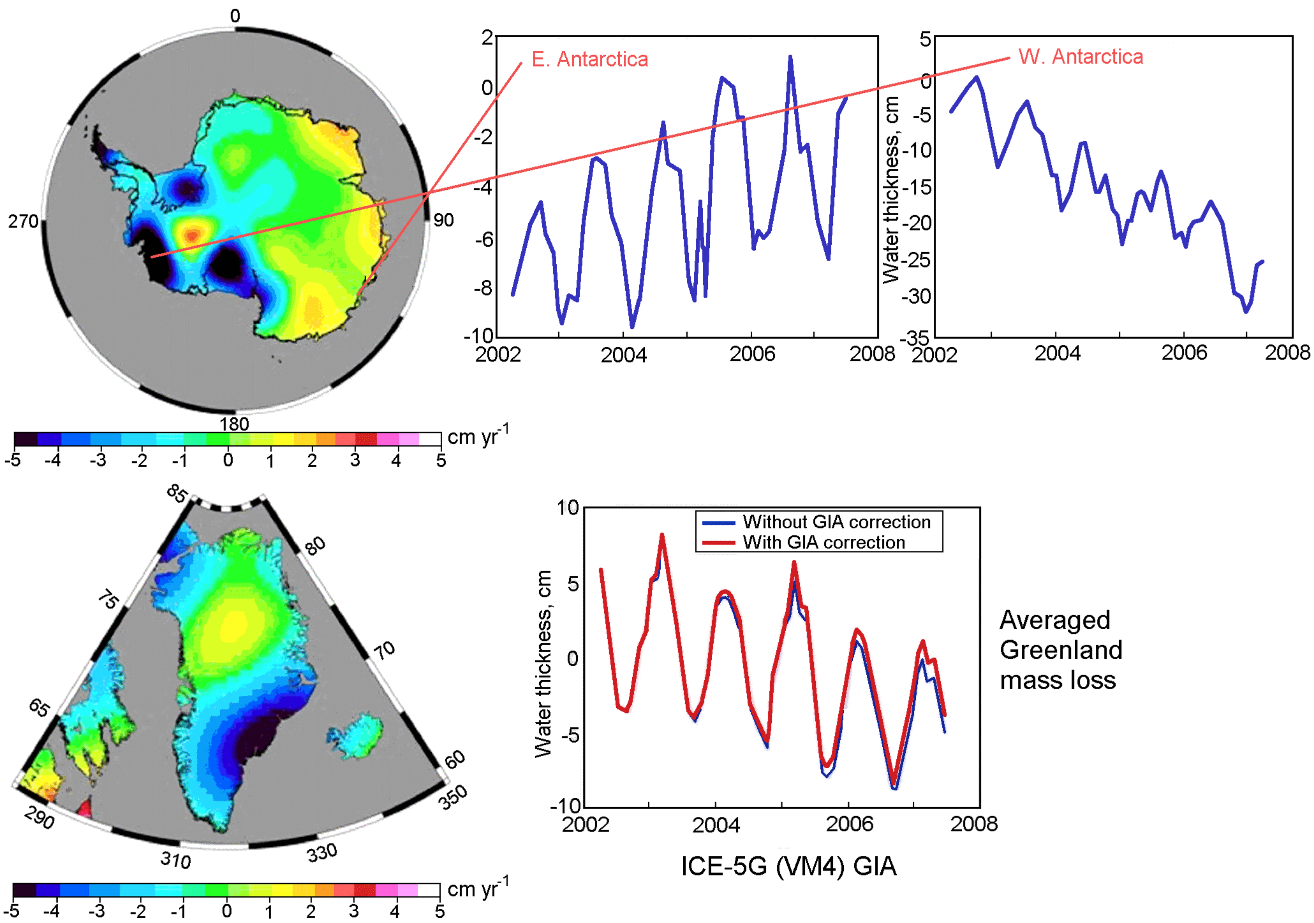

Figure 5. Ice sheet mass balance, observed by GRACE mission, 2002–2007 (*Shum et al.,* in print, 2008).

rate technical solution for monitoring crust motions at tide gauges in order to derive absolute or climate related signals in mean sea level records. The accuracy of the vertical component is very sensitive to the reference frame definition and stability of its origin. The objectives of the new IGS Pilot Project are to install, maintain and analyze a network of core GPS stations collocated with useful tide gauges, in particular GLOSS ones. The most adequate way to handle it seems to be a global scale approach, in consistency with the size of the problem (geocentric reference frame realization, long-term stability, climate change).

Conclusion

An accuracy of geocenter motion estimation is strongly dependent on the geodetic network size and stations distribution over the Earth's surface. The distribution of a global geodetic network is determined by the ocean-land distribution [*Lavallee et al.,* 2006]. Almost 80% of the IGS-GPS sites are in the Northern hemisphere and the result is that the largest differences of the geocenter position vector are in the estimated Z-components. The inequality in the X and Y directions varies only up to 15%, but there are still noticeable tendency toward sites being located in the Europe (X-axis) and in the North America (Y-axis). There is discrepancy between reducing random error by increasing network size and introducing systematic error in the geocenter motion parameters by uneven sites distribution.

The further improvement of the ITRF accuracy and stability is possible with the use of more dense and equally distributed tracking networks, equipped with the different types of modern instruments, allowed to minimize systematic errors, characteristic for every usable technique. In this connection the International Association of Geodesy arrived to a decision on the development of the Global Geodetic Observing System (GGOS), which will consist of about 40 permanent ground tracking sites, space segment of special research satellites and centers of merging, storage and analyses of the data [*Rothacher et al.,* 2008].

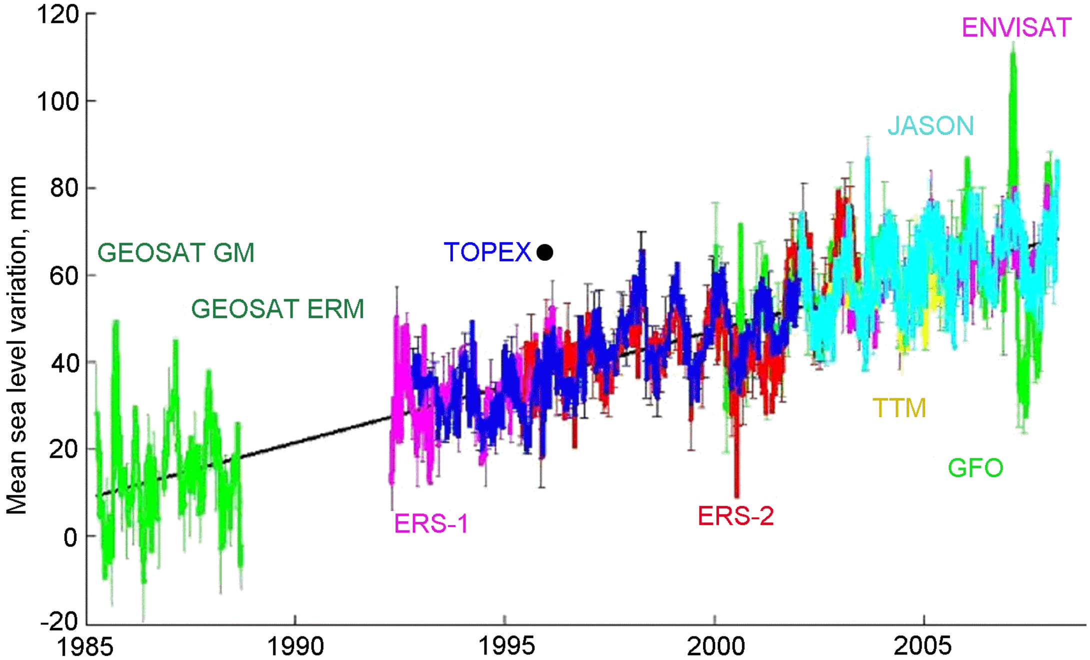

Figure 6. Global sea level rise estimated by altimetry, 1985–2008 (*Shum et al.,* in print, 2008).

References

Berthias, J.-P., A. Houry, A. Piuzz (1998), How good is DORIS for precise orbit determination?, *Proceedings of the DORIS DAYS,* CNES, Toulouse, France, 27–29 April, 1998.

Blewitt, G. (2003), Self-consistency in reference frames, geocenter definition and surface loading of the Solid Earth, *J. Geophys. Res., 108*(B2), 2103. doi:10.1029/2002JB002082

Creataux, J.-F., et al. (2002), Seasonal and inter-annual geocenter motion from SLR and DORIS measurements: Comparison with surface loading data, *J. Geophys. Res., 107*(B12), 2374. doi:10.1029/2002JB001820

Dong, D., et al. (2003), Origin of the International Terrestrial Reference Frame, *J. Geophys. Res., 108*(B4), 2200. doi:10.1029/2002JB002035

Kuzin, S. P., S. K. Tatevian (2005), Issledovaniya dvizheniya geocentra po dannym sputnikovoi geodezii, *Proceedings of IPA RAN* (in Russian), 478.

Lavallee, A., T. Van Dam, G. Blewitt (2006), Geocenter motion from GPS: A Unified observation model, *J. Geophys. Res., 111,* B05405. doi:10.1029/2005JB003784

Rothacher, M., R. Neilan, H.-P. Plag (2008), The Global Geodetic Observing System (GGOS), *"AOGS-2008" 5-th Annual Meeting,* AOGS, Busan, South Korea.

Tatevian, S., S. Kuzin, V. Kaftan (2004), Comparison of Geocenter Variations derived from 10 years of GPS, DORIS and SLR Data, *Proceedings of the APSG-2004 Symposium "Space geodesy and its applications to the Earth sciences",* APSG, Singapore, July 2004.

Tavernier, G., H. Fagard, M. Feissel-Vernier, K. Le Bail, F. Lemoine, C. Noll, R. Noomen, J. C. Ries, L. Soudarin, J. J. Valette, P. Willis (2006), The International DORIS Service: genesis and early achievements, *Journal of geodesy* (in DORIS Special Issue, P. Willis (Ed.)), *80*(8–11), 403. doi:10.1007/s00190-006-0082-4

S. P. Kuzin and S. K. Tatevian, Institute of astronomy RAS, Moscow, Russia (statev@inasan.ru)