Selected Gravity Models in Terms of the fit to the GOCE Kinematic Orbit in the Dynamic Orbit Determination Process

Andrzej Bobojć[(1)], Andrzej Drożyner [(2)], Zofia Rzepecka [(1)]

University of Warmia and Mazury, Institute of Geodesy [(1)], Kujawy and Pomorze University in Bydgoszcz [(2)], Poland

e-mails: andrzej.bobojc@gmail.com, drozyner@uwm.edu.pl, zofia.rzepecka@uwm.edu.pl

Introduction: The Gravity Field and Steady State Ocean Circulation Explorer mission (GOCE) delivered valuable measurements of gravity gradients and code-phase observations of Global Positioning System satellites. Besides gravity field models, one of important products was the centimeter-accuracy precise science orbit of the GOCE satellite (PSO orbit). In this study, selected gravity models were compared in terms of the fit of estimated GOCE orbital arcs to the kinematic PSO orbit which was delivered by European Space Agency. This orbit served as the reference orbit. By its kinematic characteristics such an orbit has an important advantage – the independence from any of a priori dynamic models. Therefore it can be used for the performance testing of gravity field models. Thus, the kinematic positions of the GOCE satellite were treated as observations in the estimation of orbital arcs using a dedicated software called the Orbital Computation System (OCS). The OCS system is based on the least squares differential correction algorithm and on the Cowell numerical integration of the 8th order with respect to the inertial reference frame of the J2000.0 standard epoch. Solutions were estimated by the initial state vector correction using sets of the kinematic GOCE positions.

Twelve chosen geopotential models obtained through the International Center for Global Earth Models were used in the adjustment process. The estimated orbital arcs were compared to the corresponding kinematic reference ones. This allowed to compute the RMS differences between the estimated and reference arcs. The performance of selected gravity models was measured by the mean values of the RMS difference calculated for five or ten orbital arcs.

Research: The initial positions for estimated arcs were taken from the GOCE PSO kinematic orbit whereas the initial velocities from the GOCE reduced-dynamic PSO orbit. The estimated arcs had the following initial epochs: (1) 2009 Nov 06 23h 59m 45.00s, (2) 2009 Nov 19 23h 59m 45.00s, (3) 2009 Dec 02 23h 59m 45.00s, (4) 2009 Dec 18 23h 59m 45.00s, (5) 2009 Dec 29 23h 59m 45.00m, (6) 2010 Jan 06 23h 59m 45.00s, (7) 2010 Jan 16 23h 59m 45.00m, (8) 2010 Jan 26 23h 59m 45.00s, (9) 2010 Feb 06 01h 29m 55.22s, (10) 2010 Feb 10 23h 59m 45.00s.

Table 1 shows the mean values (for ten orbital arcs) of the RMS difference between an estimated and reference orbit for particular geopotential models taking into account the 45- and 90-minute orbital arcs. For the estimation process only geopotential model and observations are taken (G-O mode). Such an option is enabled in order to isolate and emphasize an impact of the gravity field models and to obtain an independence of the results of the orbit determination from the specified set of remaining dynamic models used. A significant reduction of errors due to disabling of remaining dynamical models is achieved by establishing shorter orbital arcs with the lengths of about 45 and 90 minutes. The obtained mean RMS values remain at the level of 20 cm (45 min. arcs) and at the level of 50 cm (90 min. arcs) for most gravity models with the exception of the older EGM96 where the RMS values are about twice greater. The best performance can be noticed for the non-latest models EIGEN-51C (RMS 22.50 cm, 52.68 cm), EGM2008 (RMS 52.57 cm), ITG-GRACE2010S (RMS 22.70 cm).

Table 2 contains the mean RMS values for estimated arcs with the same lengths (45 and 90 min.) but in this case the orbit determination process was performed taking into account not only the geopotential model and observations but also the models describing: the Earth and ocean tides (MERIT standards, 1983), the third body perturbations (planetary ephemerides DE200/LE200), the relativity effects (Painleve formulation), the direct and indirect solar radiation pressure (basic formulas taken from the TOP package presented by Drożyner, A. (1995), *Determination of orbits with Toruń Orbit Processor system*, Adv. Space Res. 16, 2). This is referred to as the GDMN-O mode of computation. Generally, one can see that the fit of estimated arcs to the reference orbit has been improved by factor four. The obtained values of mean RMS are at the level of 5 cm (for 45 min. arcs) and at the level of 13 cm (with the exception of ULUX_CHAMP2013S – the RMS of about 15 cm) for 90 min. arcs. Similarly as for Table 1 much worse results (by about factor eight) were obtained for EGM96 model. But unexpectedly this time the best results were achieved for the newest models such as ITSG-GRACE2014S (RMS 5.03 cm), ITSG-GRACE2014K (5.06 cm) and ITU-GRACE16 (13.31 cm – for 90 min. arcs). However, the solutions for EIGEN-51C model (5.11 cm – for 45 min. arcs and 13.34 cm -for 90 min. arcs) are still one of the best.

Table 3 presents groups of the gravity models with the best performance for the different time ranges - parts a), b), c) and the computation modes – G-O and G-DMN-O. The solutions in part a) refer to the time range between 2009 Nov 06 23h 59m 45.00s and 2010 Feb 11 01h 30m 00.00s UTC. It can be clearly seen that for both arc lengths 45 and 90 min, the non-latest models such as EGM2008, EIGEN-51C,ITG-GRACE2010S and EIGEN-5S give the best solutions for the G-O mode. But in the case of the G-DNM-O mode the newer gravity models such as ITU-GRACE16, ITSGS-GRACE2014S, ITSGS-GRACE2014K have the smallest RMS values. As already mentioned above EIGEN-51C is the exception, especially with the second position for the 90 min. arcs. Additionally, in order to increase the temporal resolution of obtained results the mean RMS values were computed for the following time ranges: 2009 Nov 06 23 h 59 m 45.00 s - 2009 Dec 30 01 h 30 m 00.00 s UTC – in part b) and 2010 Jan 06 23 h 59 m 45.00 s - 2010 Feb 11 01 h 30 m 00.00 s UTC - in part c). The mean RMS values are then computed for five orbital arcs instead of ten arcs. Taking into account the G-O mode in part b), it is visible that similarly to part b) the best results refer to the listed above non-latest models, especially to EIGEN-51C model occuring twice in the first position. However, enabling the additional models in the G-DMN-O mode does not change, unlike as in the case of part a), the order of models – i.e. the mentioned non-latest models are still in the first positions, for example, the first position is still occupied by EIGEN-51C model for the 90 min. arcs. Regarding the next time range, i.e. part c), the order of models is changed again for the G-DMN-O mode – the newer models ITU-GRACE16, ITGS-GRACE2014S, ITGS-GRACE2014K have the smallest values of RMS. It seems that these models work better with the given set of additional models for the regarding time range than the slightly older models such as EIGEN-51C, EIGEN-5S , EGM2008 or ITG-GRACE2010S. However, the latter models have still better results in the G-O mode. Generally speaking, the G-O mode definitely prefers these slightly older models whereas the G-DMN-O mode prefers rather the newer ones with the exception of the time range for part b). Comparing the results of the G-O and of the G-DMN-O mode it can be noticed that enabling the given set of additional models, describing the gravitational and non-gravitational perturbations, affects, in some degree, the obtained order of gravity models.

Conclusions: The obtained results of the fit of estimated orbital arcs to the official GOCE kinematic orbit prefer, especially in the G-O mode, the non-latest models – first of all EIGEN-51C model and such models as EGM2008, EIGEN-5S, ITG-GRACE2010S. These models are closer to the GOCE orbit in a temporal sense, which may be connected, for example, with more adequate values of C_{20} coefficient than in the case of newer models with respect to the time range of estimated orbital arcs. On the other hand, the newer models such as ITU-GRACE16, ITGS-GRACE2014S, ITGS-GRACE2014K work better than the slightly older ones with the given set of additinal dynamic and non-dynamic models, which is reflected in better results for the G-DMN-O mode, especially for the time range 2010 Jan 06 23 h 59 m 45.00 s - 2010 Feb 11 01 h 30 m 00.00 s UTC. In order to improve the results of the fit using the slightly older gravity models with the given set of remaining models, scaling factors could be estimated for the latter ones in the orbit determination process.

Table 1. Mean RMS (for ten orbital arcs*) of differences between the estimated 45- and 90-minute orbital arcs and the corresponding reference arcs (kinematic PSO arcs) depending on the applied gravity field model. In the adjustment process only the geopotential model and the observations are used (the G-O mode)

G-O mode (geopotential + observations)

Gravity field model	Mean RMS [cm]	
	45 min. arc	90 min. arc
HUST-GRACE2016S	22.77	53.63
ITU-GRACE16	22.91	53.78
ITSG-GRACE2014S	22.72	53.62
ITSG-GRACE2014K	22.78	53.65
GGM05S	22.78	53.88
TONGJI-GRACE01	22.85	53.85
ULUX_CHAMP2013S	23.14	54.30
ITG-GRACE2010S	22.70 (2)	53.50
EIGEN-51C	22.50 (1)	52.68 (2)
EIGEN-5S	22.72	53.22
EGM2008_360x360	22.74	52.57 (1)
EGM96	41.66	118.05

* Estimated orbital arcs included in the time range between: 2009-11-06 23 h 59 m 45.00 s UTC and 2010-02-11 01 h 30 m 00 s UTC

Table 2. Mean RMS (for ten orbital arcs*) of differences between the estimated 45- and 90-minute orbital arcs and the corresponding reference arcs (kinematic PSO arcs) depending on the applied gravity field model for the satellite motion determined by geopotential and models describing gravitational and non-gravitational perturbations

G-DMN-O mode (geopotential + models descr. grav. and non-grav. perturbations + observations)

Gravity field model	Mean RMS [cm]	
	45 min. arc	90 min. arc
HUST-GRACE2016S	5.14	13.38
ITU-GRACE16	5.19	13.31 (1)
ITSG-GRACE2014S	5.03 (1)	13.40
ITSG-GRACE2014K	5.06 (2)	13.36
GGM05S	5.28	13.90
TONGJI-GRACE01	5.25	13.89
ULUX_CHAMP2013S	5.88	15.03
ITG-GRACE2010S	5.17	13.54
EIGEN-51C	5.11	13.34 (2)
EIGEN-5S	5.12	13.63
EGM2008_360x360	5.31	13.69
EGM96	38.17	109.57

Table 3. Gravity field models with the best performance for different time ranges of estimated orbital arcs and different computation modes

a) Time range: 2009 Nov 06 23 h 59 m 45.00 s - 2010 Feb 11 01 h 30 m 00.00 s UTC (RMS means for 10 arcs)

G-DMN-O mode						G-O mode					
	GRAVITY FIELD MODEL	RMS [cm]		GRAVITY FIELD MODEL	RMS [cm]		GRAVITY FIELD MODEL	RMS [cm]		GRAVITY FIELD MODEL	RMS [cm]
1	ITU-GRACE16	13.31	1	ITSG-GRACE2014S	5.03	1	EGM2008_360x360	52.57	1	EIGEN-51C	22.50
2	EIGEN-51C	13.34	2	ITSG-GRACE2014K	5.06	2	EIGEN-51C	52.68	2	ITG-GRACE2010S	22.70
3	ITSG-GRACE2014K	13.36	3	EIGEN-51C	5.11	3	EIGEN-5S	53.22	3	EIGEN-5S	22.72
4	HUST-GRACE2016S	13.38	4	EIGEN-5S	5.12	4	ITG-GRACE2010S	53.50	3	ITSG-GRACE2014S	22.72
5	ITSG-GRACE2014S	13.40	5	HUST-GRACE2016S	5.14	5	ITSG-GRACE2014S	53.62	5	EGM2008_360x360	22.74
6	ITG-GRACE2010S	13.54	6	ITG-GRACE2010S	5.17	6	HUST-GRACE2016S	53.63	6	HUST-GRACE2016S	22.77
	arc length 90.2 min.			arc length 45.2 min.			arc length 90.2 min.			arc length 45.2 min.	

b) Time range: 2009 Nov 06 23 h 59 m 45.00 s - 2009 Dec 30 01 h 30 m 00.00 s UTC (RMS means for 5 arcs)

G-DMN-O mode						G-O mode					
	GRAVITY FIELD MODEL	RMS [cm]		GRAVITY FIELD MODEL	RMS [cm]		GRAVITY FIELD MODEL	RMS [cm]		GRAVITY FIELD MODEL	RMS [cm]
1	EIGEN-51C	12.41	1	EGM2008_360x360	4.97	1	EIGEN-51C	53.14	1	EIGEN-51C	22.17
2	EIGEN-5S	12.53	2	EIGEN-51C	4.99	2	EGM2008_360x360	53.17	2	EGM2008_360x360	22.39
3	HUST-GRACE2016S	12.61	3	EIGEN-5S	5.00	3	EIGEN-5S	53.68	3	ITG-GRACE2010S	22.44
4	ITSG-GRACE2014K	12.63	4	ITSG-GRACE2014S	5.14	4	ITG-GRACE2010S	54.04	3	HUST-GRACE2016S	22.48
5	ITU-GRACE16	12.67	4	ITSG-GRACE2014K	5.14	5	HUST-GRACE2016S	54.10	5	GGM05S	22.48
5	ITSG-GRACE2014S	12.67	5	HUST-GRACE2016S	5.15	6	TONGJI-GRACE01	54.38	6	ITSG-GRACE2014S	22.55
	arc length 90.2 min.			arc length 45.2 min.			arc length 90.2 min.			arc length 45.2 min.	

c) Time range: 2010 Jan 06 23 h 59 m 45.00 s - 2010 Feb 11 01 h 30 m 00.00 s UTC (RMS means for 5 arcs)

G-DMN-O mode						G-O mode					
	GRAVITY FIELD MODEL	RMS [cm]		GRAVITY FIELD MODEL	RMS [cm]		GRAVITY FIELD MODEL	RMS [cm]		GRAVITY FIELD MODEL	RMS [cm]
1	ITU-GRACE16	13.95	1	ITSG-GRACE2014S	4.92	1	EGM2008_360x360	51.97	1	EIGEN-51C	22.83
2	ITSG-GRACE2014K	14.10	2	ITSG-GRACE2014K	4.98	2	EIGEN-51C	52.22	2	EIGEN-5S	22.87
3	ITSG-GRACE2014S	14.13	3	ITU-GRACE16	5.01	3	ITU-GRACE16	52.61	3	ITSG-GRACE2014S	22.89
4	HUST-GRACE2016S	14.15	4	HUST-GRACE2016S	5.13	4	EIGEN-5S	52.77	3	ULUX_CHAMP2013S	22.92
5	EIGEN-51C	14.27	4	ITG-GRACE2010S	5.13	5	ITSG-GRACE2014S	52.81	5	ITSG-GRACE2014K	22.94
6	ITG-GRACE2010S	14.28	5	EIGEN-51C	5.24	6	ITSG-GRACE2014K	52.88	6	ITG-GRACE2010S	22.97
	arc length 90.2 min.		5	EIGEN-5S	5.24		arc length 90.2 min.			arc length 45.2 min.	
				arc length 45.2 min.							

General Assembly of the European Geosciences Union, Vienna, Austria, 23-28 April 2017