Preliminary Results of Orbit Estimations for GRACE-A and GRACE-B

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Abstract

This paper addresses the computation of the orbit of the two GRACE satellites. On board each satellite is a retroreflector array and a GPS receiver. Laser data can be used for calibration and validation of other systems if required accuracy goals are attained. This study is based on SLR observations taken by the global network during the period from May 5, 2002, until May 19, 2002. The results, that is the evolution of the distance and velocity between the two GRACE satellites as well as the accuracy of the orbit estimation are presented in this paper. Accuracy attained in this solution is of the order of ±0.5 m (RMS).

Introduction

The GRACE Mission (Gravity Recovery And Climate Experiment) is a joint U.S./German satellite mission. The GRACE mission consists of two identical spacecraft flying about 220 km apart in circular polar orbits 500 km above the Earth at an inclination of 89^0. They were launched on March 17, 2002 from the Plesetsk launch base. A five-year lifetime for the GRACE satellites is expected. Each satellite is equipped with a retroreflector array and a GPS receiver. Two approaches for orbit determination, each tailored for GPS and SLR, have been utilized to evaluate GRACE orbit determination performance. The orbits of low-flying GRACE satellites are strongly influenced by perturbing forces, in particular by the irregularities of the Earth's gravity field. The principal goal of the GRACE mission is to map the Earth's gravity field by observing the changing distance between the two satellites using an extremely precise range rate system.

A similar project was proposed two decades ago in the frame of the Intercosmos Programme, but was never accomplished [*Zielinski*, 1980], [*Zielinski, Kazmierski*, 1981]. A number of scientific results could be deduced from this experiment [*Jekeli*, 2000]:

- information about the distribution and flow of mass within the Earth
- the improved model of the ocean surface and currents, runoff and ground water storage on landmasses, exchange between ice sheets or glaciers and the ocean
- creation of a better profile of the earth atmosphere
- studies of the global climate changes

The main orbit control system for the GRACE satellites is based on the on-board GPS receivers. Satellite laser ranging data are important, both for validation and backup of the GPS precision orbit determination. This study is aimed at the preliminary computation of the orbits of the GRACE satellites in order to assess the attainable accuracy of SLR-based solutions.

Data Processing

The solutions presented here were produced utilizing the GEODYN II orbit determination system [*Eddy et al.*,1990] assuming the modeled forces given in Table 1 (correction to the center-of-mass not included). The GRACE data set used for this purpose contains all normal points provided by the global network of SLR stations (16 in total) during the period May 5, 2002 until May 19, 2002. The station positions were fixed in the ITRF97 system (for epoch 1997.0). The Crustal Dynamics Data Information System (CDDIS) and the Eurolas Data Center (EDC) through anonymous ftp, provided the normal points for 5 sec intervals of GRACE-A and GRACE-B. The 14-day period has been divided into two 7-day arcs. An overview of contributing stations is given in Table 2. In total, 50 passes with 874 normal points for GRACE-A and 37 passes with 901 normal points for GRACE-B are available. The satellite orbits were integrated using Cowell's 11-order predictor-corrector method with an integration step-size of 15 sec.

Table 1. The Computation Model.

DYNAMIC MODEL
Gravity field GRIM5S1 (99,99)
Wahr solid earth tides
NASA/NIMA EGM96 ocean tides
Atmospheric drag DTM87
C_D solved for in half-day intervals
C_R direct solar radiation pressure equal to 1.2
Albedo and infrared Earth radiation
Relativistic effects
Acceleration in along-track and cross-track
REFERENCE FRAME
ITRF97 for epoch 1997.0 (model of station coordinates –fixed)
IERS C04 earth orientation
precession according to IAU 1976 (Lieske model)
Nutation according to IAU 1980 (Wahr model)
Pole tide
Ocean loading deformation, atmospheric pressure loading deformation
PROCESSING MODE
Normal points provided by CDDIS and EDC
Marini-Murray model for tropospheric delay
Center–of-mass correction not used
Station-dependent data weighting
OBSERVATIONS
GRACE-A - two arcs 874 normal points (2002.05.05-2002.05.19)
GRACE-B – two arcs 901 normal points (2002.05.05-2002.05.21)
INTEGRATION
Cowell 11-order predictor-corrector
step-size 15 sec

Results and Conclusions

This section presents an overview of the results that have been obtained for four data spans. Satellite orbits for GRACE-A and GRACE-B for the 14-day interval were computed using the SLR measurements mentioned in the previous section. For each 7-day orbit, 6 keplerian orbit elements (a,e,i,Ω,ω,M), atmospheric drag coefficients C_D (for half-day intervals), and a solar radiation pressure coefficient C_R (one for 7-day interval) were estimated; some results are shown in Table 3. The total number of unknowns is equal to 25 for each arc. The distance changes between GRACE-A and GRACE-B are shown in Figures 1 and 2, the velocity differences in Figures 3 and 4. The distances and the velocities for the period from May 5, 2002 until May 19, 2002 are changing – the short-term changes are of the period of one revolution, the long-term changes are close to a linear trend. Long-term changes of distances per week are equal to 14.420 km, for velocities they are 17 m/sec as shown in Table 3. The average change of distance is equal to 2061 meter per day, for velocity 2.43 m/sec per day. The semi-major axes for GRACE-A and GRACE-B decrease at an average rate of about -29.6 and -36.4 meters per day as is shown in Figure 5. These results are summarized in Table 3.

Table 2. Stations and number of normal points of GRACE, for the period 5.05.2002-21.05.2002.

No	Station		GRACE-A Arc 1 Passes	GRACE-A Arc 1 N. Pts.	GRACE-A Arc 2 Passes	GRACE-A Arc 2 N. Pts.	GRACE-B Arc 1 Passes	GRACE-B Arc 1 N. Pts.	GRACE-B Arc 2 Passes	GRACE-B Arc 2 N. Pts.
1	Simeiz	1873	3	83	0	0	0	0	0	0
2	Riga	1884	4	51	0	0	3	36	0	0
3	Fort Davis	7080	1	2	0	0	0	0	0	0
4	Yarragadee	7090	4	95	3	42	5	92	2	86
5	Greenbelt	7105	2	62	1	18	3	52	0	28
6	Monument Peak	7110	7	136	3	74	2	39	1	81
7	Papeete, Tahiti	7124	0	0	1	7	1	31	1	18
8	Haleakala	7210	0	0	0	0	1	3	1	21
9	Hartebeesthoek	7501	0	0	0	0	0	0	2	57
10	San Fernando	7824	0	0	0	0	0	0	2	124
11	Grasse	7835	1	21	2	38	1	19	2	46
12	Potsdam	7836	1	8	3	36	1	15	2	19
13	Graz	7839	4	73	6	66	4	68	0	0
14	Herstmonceux	7840	2	27	1	19	0	0	2	55
15	Mount Stromlo	7849	0	0	0	0	1	12	0	0
16	Wettzell	8834	0	0	1	16	0	0	0	0
	Total		**29**	**558**	**21**	**316**	**22**	**367**	**15**	**534**

Table 3. Preliminary results of the orbit estimation for GRACE-A and GRACE-B.

	GRACE-A		GRACE-B	
Arc	05.5-05.12 2002	05.12-05.20 2002	05.05-05.12 2002	05.12-05.20 2002
No. of n. points	558	316	367	534
RMS of fit	0.69 m	0.36 m	0.58 m	0.46 m
Estimated orbital elements				
epoch	2002.05.05 0 h	2002.05.12 0 h	2002.05.05 0 h	2002.05.13 12 h
a	6867009.179 m	6866802.118 m	6876954.941 m	6876343.105 m
e	0.0035213	0.0029971	0.0036766	0.0033513
i	89.02268 deg	89.02004 deg	89.02267 deg	89.02049 deg
Ω	348.11914 deg	347.20232 deg	348.11970 deg	347.00527 deg
ω	98.46092 deg	90.30156 deg	99.18517 deg	65.21133 deg
M	78.08881 deg	315.95497 deg	75.81864 deg	285.96576 deg
Changes of:				
Semi-major axis	-29.6 m/day		-36.4 m/day	
Eccentricity	0.000035 /day		0.000039 /day	
Changes of:				
Distance (m)	Systematic trend for week	14420 m/week		
	Periodic for one revolution	4666 m/rev		
Velocity (m/s)	Systematic trend for week	17 (m/sec) for week		
	Periodic for one revolution	4.5 (m/sec) for rev		

Figures 6-9 show the (O-C) residuals obtained from the solutions based on the GRACE-A and GRACE-B SLR data.

Based on the preliminary results obtained, here we can conclude that:

- the short-term (one revolution) and long-term distance changes between GRACE-A and GRACE-B can be determined from the laser data with high precision;

- the fluctuations in the distance/velocity changes resulting from the gravity anomalies, which are detected by the range-rate system, cannot be seen in this kind of solution;
- the pattern of the O-C residuals suggest that some minor systematic effects still exist but the results can be further improved if the center-of-mass correction will be correctly applied;
- the accuracy of a few decimeters is very good for the purpose of the GPS orbit validation and backup.

Acknowledgements

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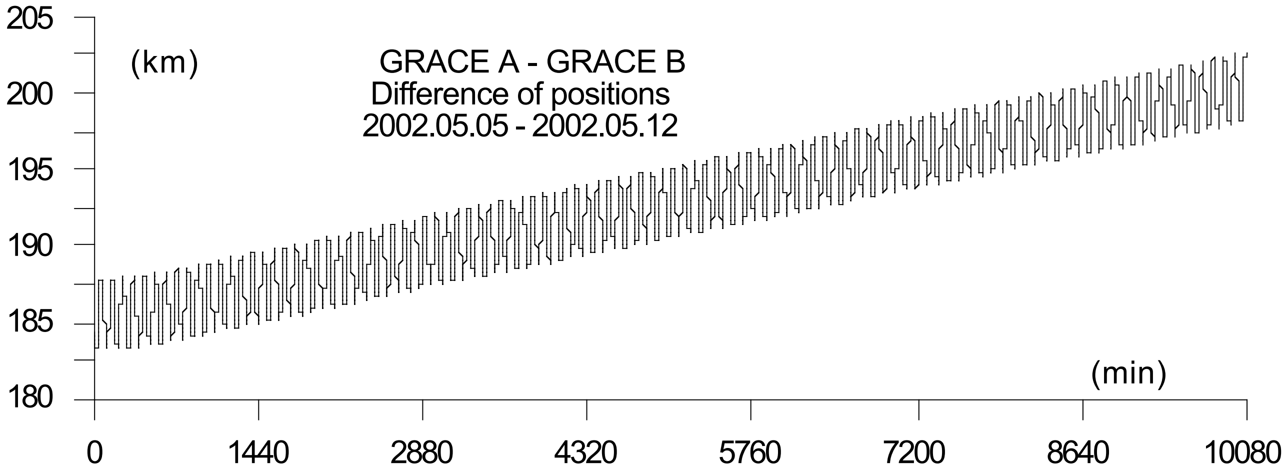

Figure 1. Change of the distance between GRACE-A and GRACE-B (in km).

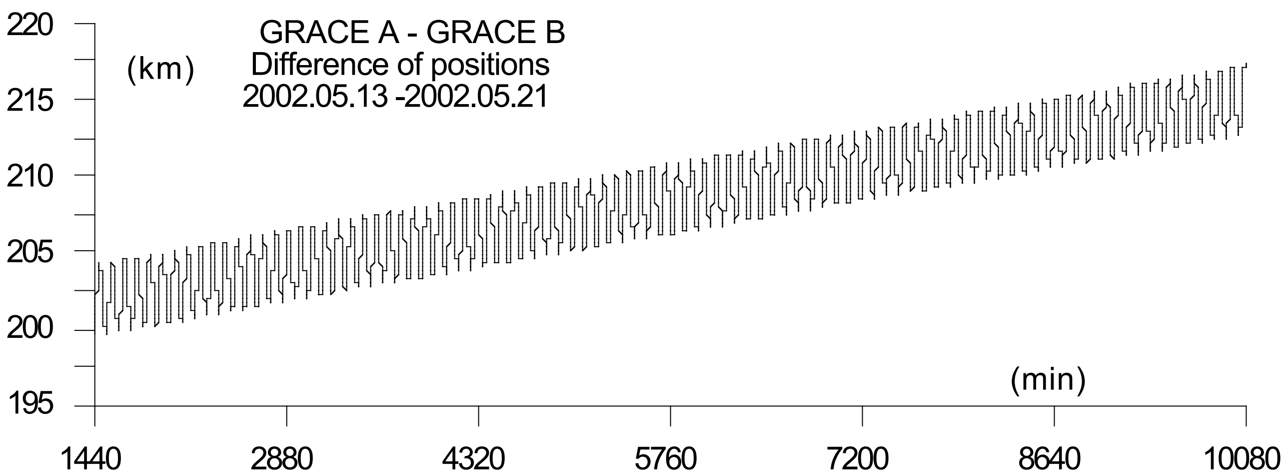

Figure 2. Change of the distance between GRACE-A and GRACE-B (in km).

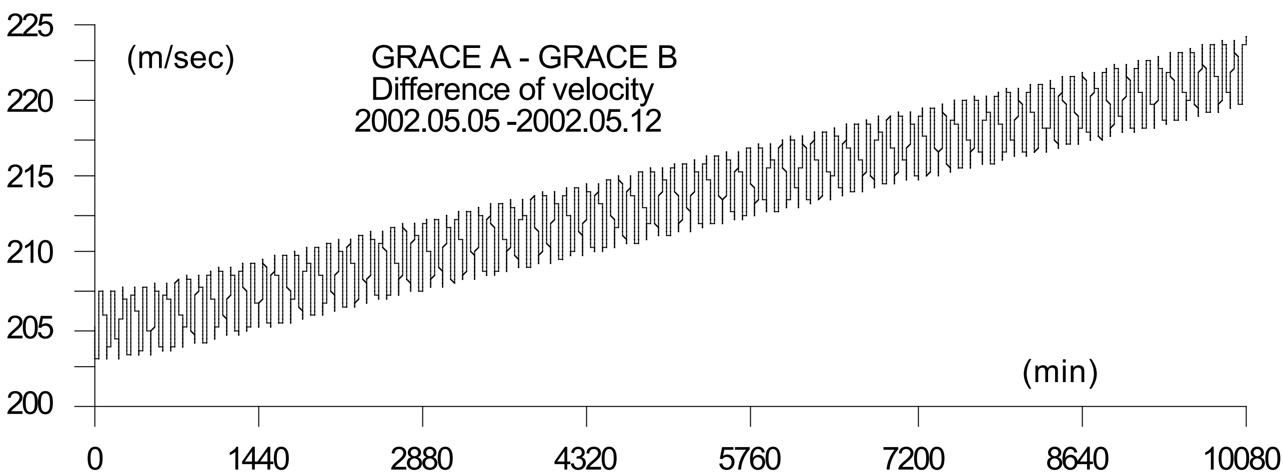

Figure 3. Difference of the velocity for GRACE-A and GRACE-B (in m/sec).

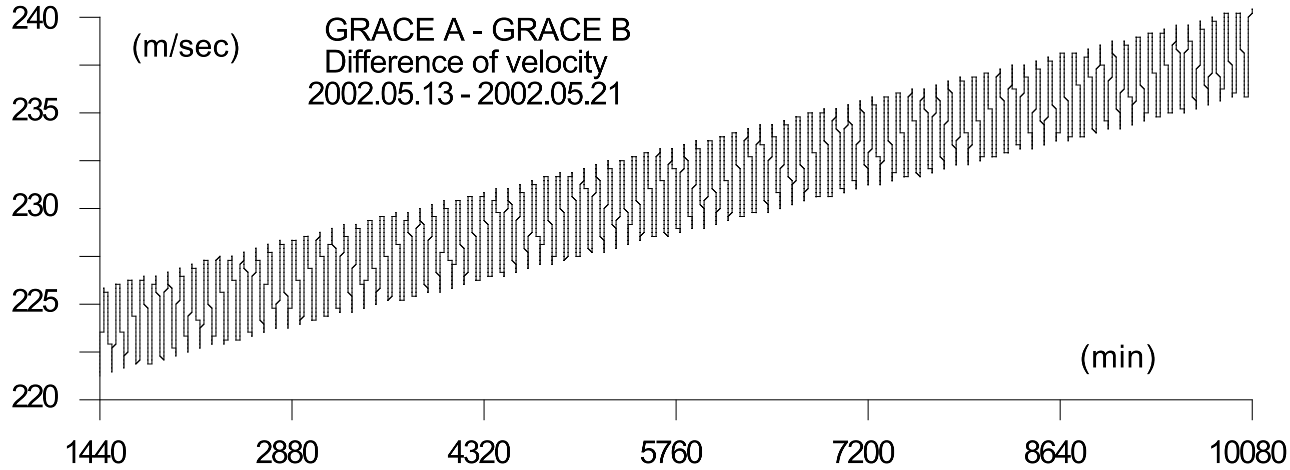

Figure 4. Difference of the velocity for GRACE-A and GRACE-B (in m/sec).

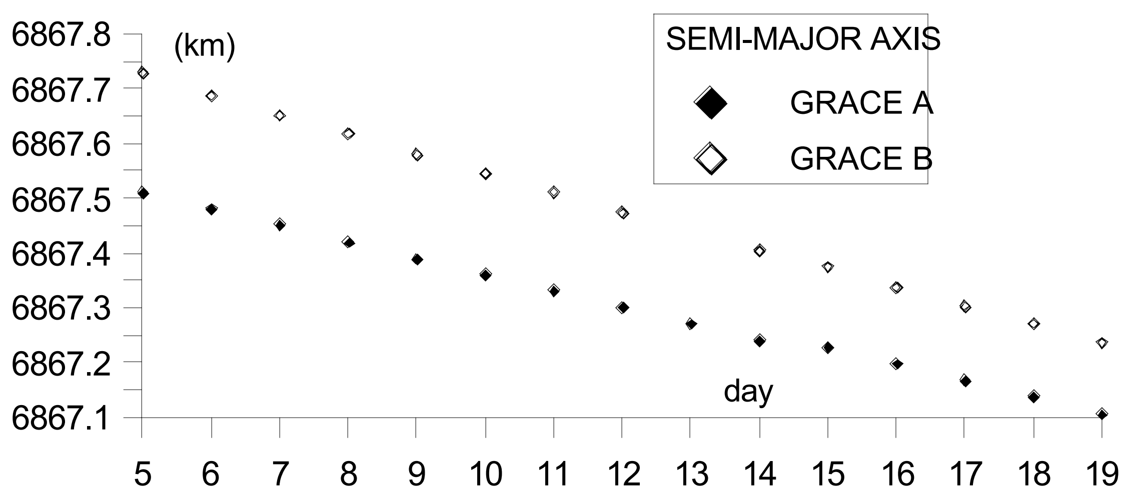

Figure 5. The semi-major axis for GRACE-A and GRACE-B during the 14-day time interval.

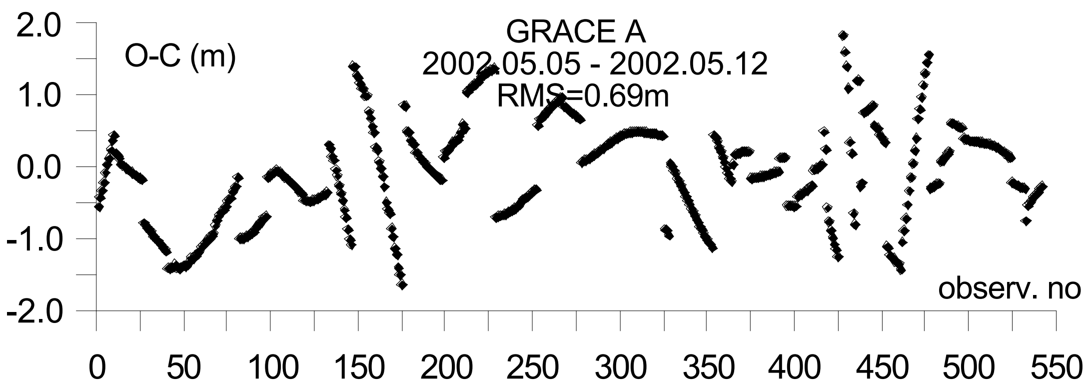

Figure 6. The GRACE-A residuals (O-C) for the time interval 2002.05.05 –2002.05.12.

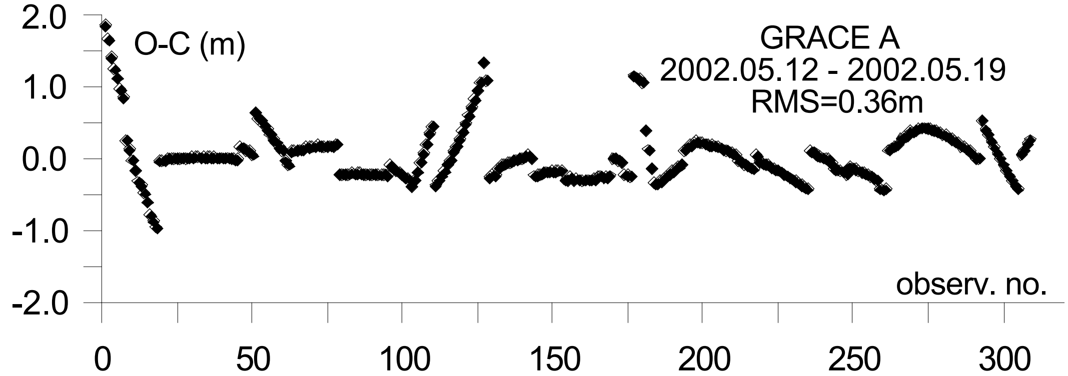

Figure 7. The GRACE-A residuals (O-C) for the time interval 2002.05.12 – 2002.05.19.

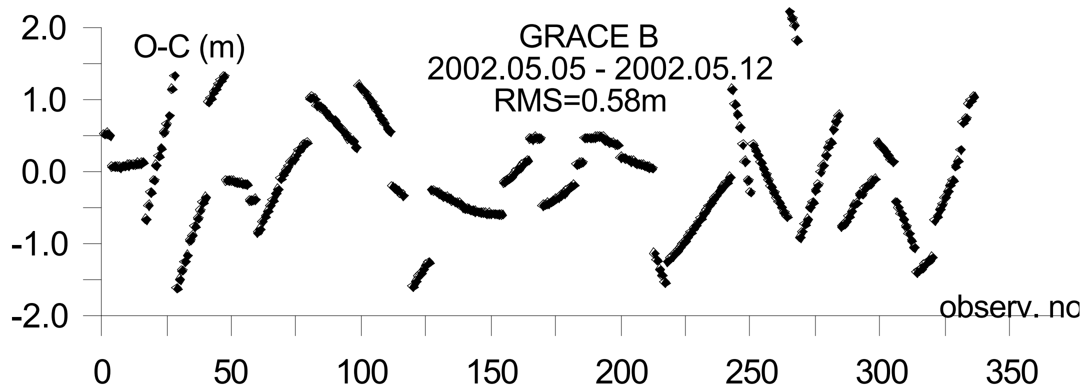

Figure 8. The GRACE-B residuals (O-C) for the time interval 2002.05.05 – 2002.05.12.

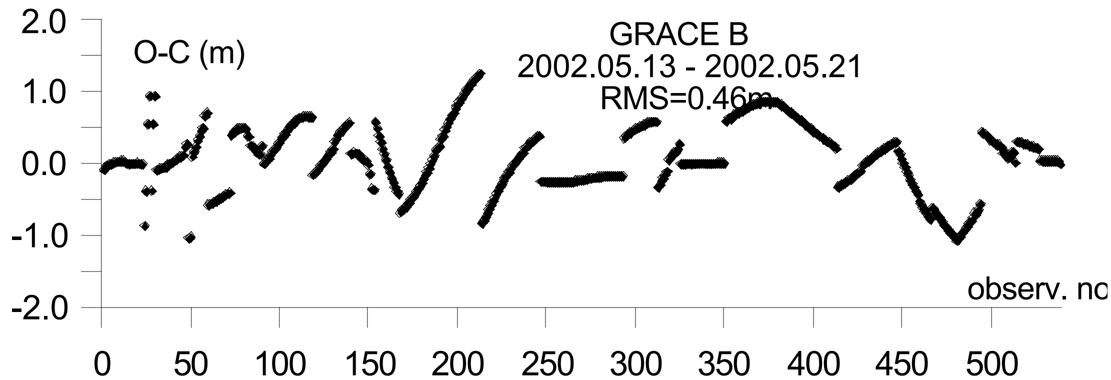

Figure 9. The GRACE-B residuals (O-C) for the time interval 2002.05.13 – 2002.05.21.