PRECISE ORBIT DETERMINATION FOR GRACE USING GPS DATA

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GRACE Science Team Meeting, October 13 and 14, 2005, Austin, Texas

Abstract

The GRACE (Gravity Recovery and Climate Experiment) satellites were launched in March 2002 with a Black-Jack GPS onboard receiver on each satellite. Since then, data quality and background models including the gravity model have been improved significantly. The main purpose of this paper is to investigate how well the GRACE satellite orbits can be determined using GPS data. The orbit accuracy is assessed using a number of tests, including the analysis of orbit fits, orbit overlaps, Satellite Laser Ranging (SLR) residuals and K-Band Ranging (KBR) residuals.

The GRACE Mission

The Gravity Recovery and Climate Experiment (GRACE), a NASA Earth System Science Pathfinder (ESSP) program mission, was successfully launched on March 17, 2002. GRACE consists of two satellites, co-orbiting in a polar orbit and separated by 200 km. Each satellite carries a microwave, dual frequency one-way ranging system, whose measurements will be used along with GPS observations to recover the gravity field of the Earth. The primary objective of the GRACE mission is to map, with unprecedented accuracy, the long- to medium-wavelength spherical harmonic coefficients of the Earth's gravity field and to observe its temporal variations. To satisfy this objective as well as other applications (e.g. atmospheric profiling), accurate orbits for GRACE are required.

Precise Orbit Determination

Determining the orbits of both GRACE satellites is an important step in recovering the gravity field of the Earth. Precise orbits are needed for data quality assessment and verification and finally as reference for the gravity field estimation step. The GRACE satellites generate several types of observations. The primary observations are:

- GPS observations
- Accelerometer observations
- Attitude observations
- Inter-satellite range and range-rate observations
- Satellite Laser Ranging (SLR) observations

For GRACE gravity recovery, several steps are taken to process the observation types listed above. In this paper, only the first step, determining GRACE orbits using GPS data, is presented and investigated. The GPS observations are processed in the form of double-differenced phase converted range measurements using a IGS network of 50+ ground stations. A 24 hour or a 30 hour arc of observations is used to solve for the GRACE satellite initial positions and velocities, double-differenced ambiguity parameters, zenith delay parameters, center of mass offset in the nadir direction, one-cycle-per-revolution drag parameters, one-cycle-per-revolution transverse and normal empirical accelerations, and GPS orbital element correction parameters. This heavy parameterization produces a very precise orbit. Outputs from the initial orbit fit are satellite states, observation residuals, and model values of non-gravitational accelerations and attitude. These outputs are used to further understand the quality of the orbits and observation data. The satellite state is passed through satellite laser ranging (SLR) data to determine the residuals for accessing GRACE orbit accuracy.

The accuracy of the GRACE orbit determination is evaluated by analyzing GPS tracking observation residuals, orbit overlaps and orbit connecting points, by confirmation of the orbit solution with independent SLR tracking, and by computing KBR residuals.

GRACE POD Test Cases

About 120 24-hour and 30-hour arcs (July, 1 – October 31, 2003) were processed with GRACE GPS data. The GPS data were sampled at a 30-second interval.

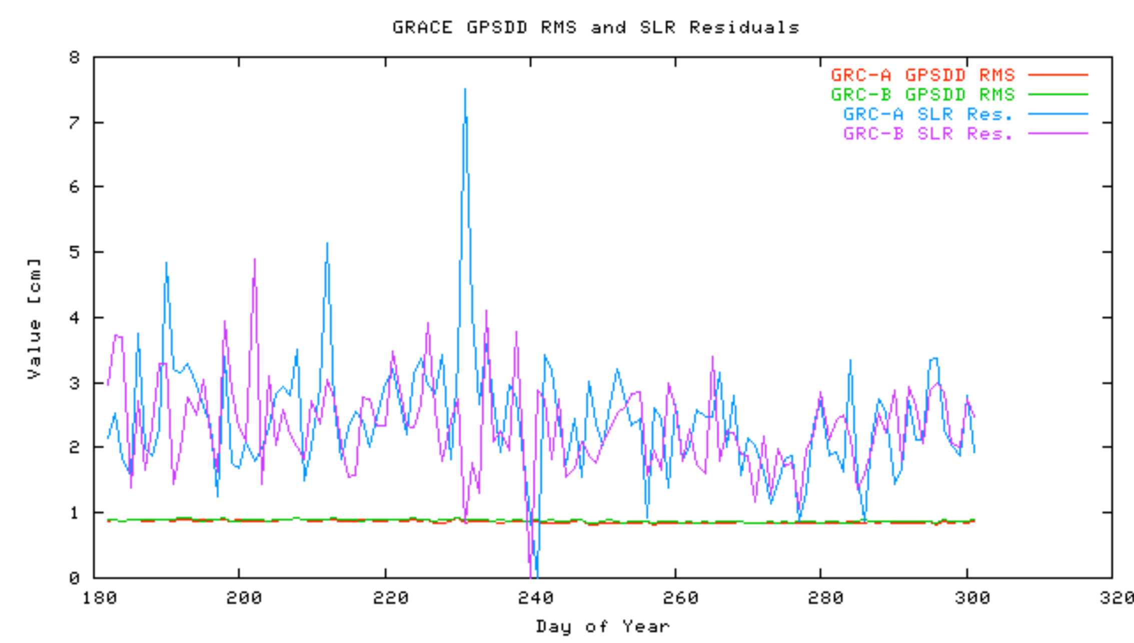

Figure 1. GRACE A & B GPS DD RMS and SLR residuals (24h)

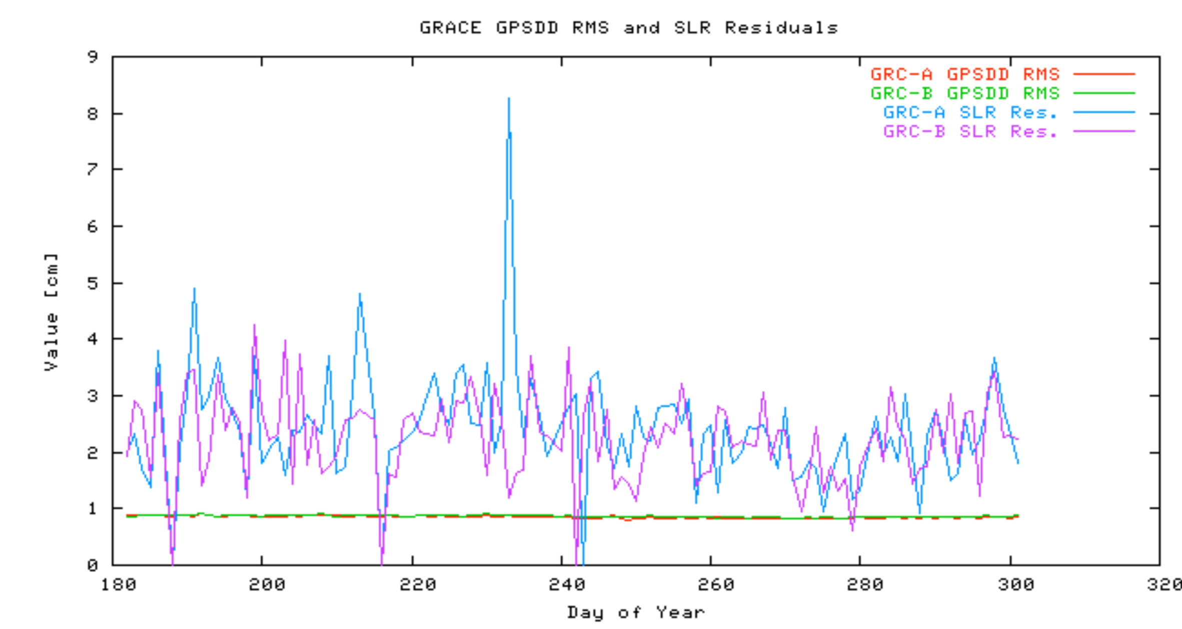

Figure 2. GRACE A & B GPS DD RMS and SLR residuals (30h)

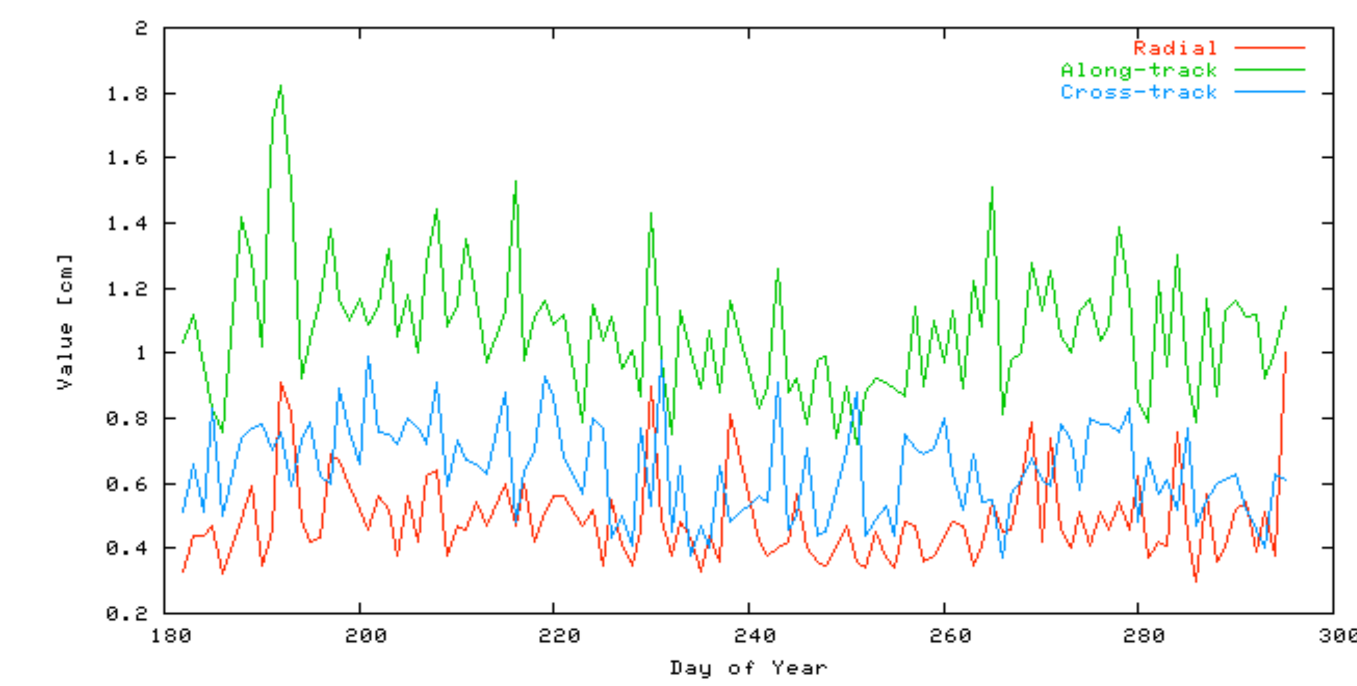

Figure 3. GRACE-A orbit comparison between 24 and 30 hour arcs

Figures 1 and 2 show the GRACE A & B GPS DD RMS and SLR residuals for 24-hour arcs and 30-hour arcs, respectively. Table 1 summarizes the mean GPS DD RMS and SLR residuals for GRACE A & B. According to these results, there are no significant differences between the different arcs, although GRACE-B has slightly better SLR residuals than GRACE-A. Figure 3 is the internal GRACE-A orbit comparison for different arc lengths (24 vs. 30 hours). On average the daily RMS values are not large, but a closer analysis of the ends of the arcs shows larger differences.

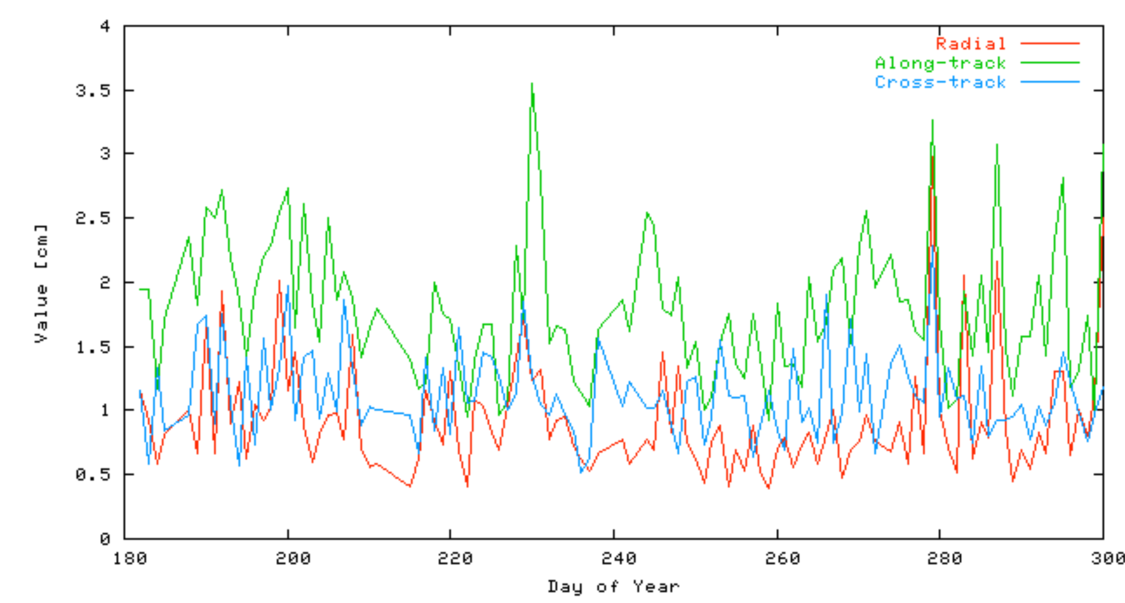

Figure 4. GRACE-A orbit overlap RMS

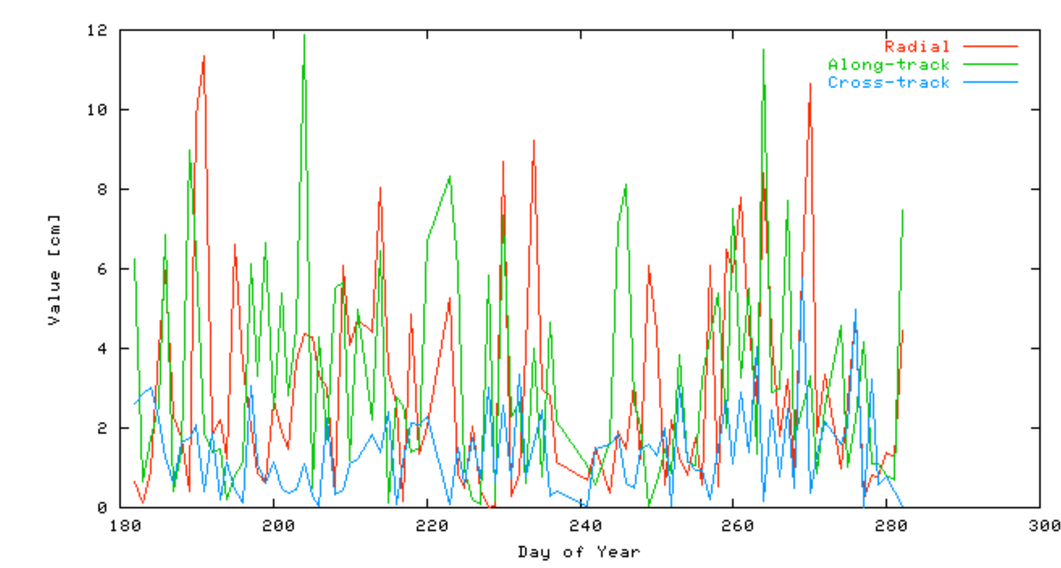

Figure 5. GRACE-A connecting point orbit difference for 24-hour data processing

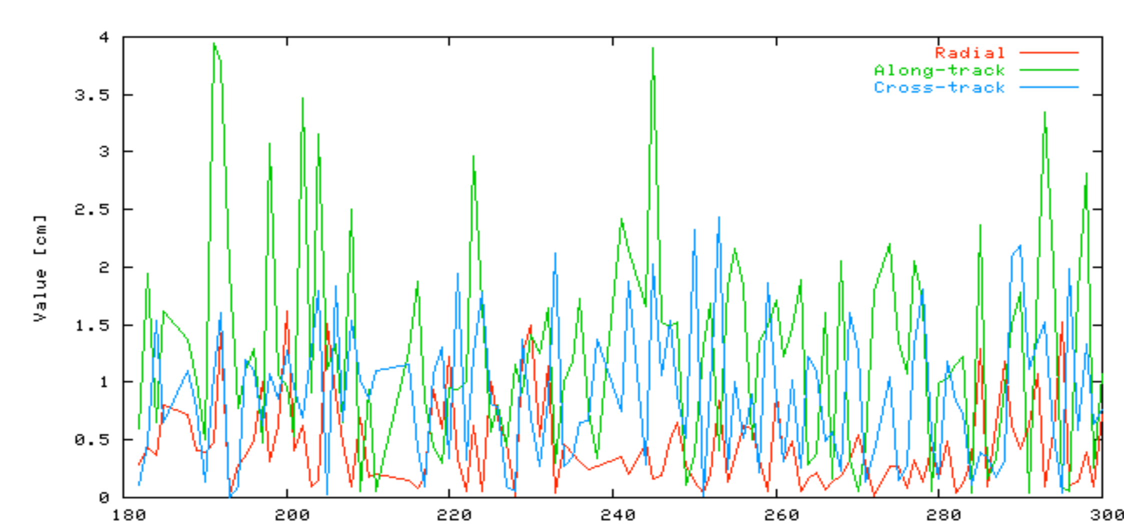

Figure 6. GRACE-A connecting point orbit difference for 30-hour data processing

Figure 4 shows the GRACE-A orbit overlap RMS over full 6-hour overlaps. The mean RMS is 1.0 cm in radial direction, 1.8 cm in along-track and 1.2 cm in cross-track.

Figures 5 and 6 show the orbit differences at the connecting point (day boundary). You can see that there are larger orbit differences for some of the 24 hour arcs (Figure 5). The reason is due to edge effects. Therefore, if we want to have overall good daily orbits for GRACE , the orbits should be produced with longer data arcs (such as 30-hours) on 24-hour centers.

Table 2 summarizes the KBR residuals for arc length 24 and 30-hours. The KBR residuals indicate the relative orbit accuracy. The 30-hour arc is slightly better than 24-hour arc for KBR residuals

Table 1. GRACE A & B GPS DD RMS and SLR residuals [cm]

	24-hour arc		30-hour arc	
	GRACE A	GRACE B	GRACE A	GRACE B
GPS DD RMS	0.86	0.88	0.85	0.87
SLR RMS	2.49	2.38	2.51	2.36
Radial RMS	1.09	0.96	1.08	0.90
Along-track RMS	2.14	1.76	2.21	1.57

Table 2. GRACE KBR Residuals

Arc length	KBR Range [cm]	KBR range rate [um/s]	KBR range acceleration $[nm/s^2]$
24-hour	1.05	9.96	93.10
30-hour	0.98	8.90	81.59

Summary and Conclusions

The precise orbit determination for GRACE using four-month GRACE GPS data has been successfully carried out. There are only small differences between the 24-hour and 30-hour arcs, but the 30-hour arcs can provide a smooth connection between GRACE satellite orbits. As a result, the 30-hour arc data arc length is selected for GRACE POD.

Based on the internal tests (orbit fits, overlaps and connecting points), external comparison (SLR residuals), an accuracy of about 1.0 cm in the radial direction and less 2.5 cm in tangential and normal directions has been achieved for GRACE orbits. From KBR residuals, the relative accuracy between the two GRACE satellites is about 1.0 cm in position and 10 micrometers per second in velocity.