GPS-based Orbit Determination for LEO Satellites Using Double-Differenced Carrier-Phases

Z. Kang , B. Tapley , S. Bettadpur

Center for Space Research, The University of Texas at Austin

Corresponding Author: Zhigui Kang kang@csr.utexas.edu, (512) 471-0163

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Abstract: With the successful application of GPS-based Precise Orbit Determination (POD) for Low-Earth Orbiting (LEO) satellites, the accuracy of the orbits has increased due to improvements in both the dynamical and geometrical models, the observation accuracy and the methods for using both improvements. In this presentation, we describe recent advances in GPS-based POD for LEO satellites. The results presented here demonstrate that better absolute orbit accuracy is obtained using high-low double-differenced (DD) carrier phases formed by two GPS satellites, one ground station and one LEO satellite; while better relative orbit accuracy can be achieved using high-high DD carrier-phases formed by two GPS satellites and two LEO satellites. If both high-low and high-high GPS DD observations are used for LEO POD, both the relative and absolute orbit accuracy is increased. In addition, the impact of ambiguity resolution on the LEO POD accuracy is investigated. The criterion for most current ambiguity fixing methods is based on the variances of the estimated real-valued DD bias. A new approach, is discussed which is based on the difference between the estimated and adjusted DD ionosphere free phase biases based on the resolved wide-lane and narrow-lane integers. For our investigation, we utilized data from the GRACE (Gravity Recovery and Climate Experiment) satellites. The orbit accuracy was assessed using a number of tests, which include analysis of orbital fits, Satellite Laser Ranging (SLR) residuals, K-Band Ranging (KBR) residuals and external orbit comparisons. The results show that improved orbit accuracy for the GRACE satellites can be achieved through the combination of high-low and high-high GPS DD observations as well as the ambiguity resolution. The inter-satellite baseline accuracy is improved by factor of two and a half, from 5 mm to 2 mm. Both the SLR residuals (1.4 cm) and the external orbit comparison (1.6 cm) indicate that the 3-D orbit accuracies are better than 2 cm. The external orbit comparison also shows the radial and cross-track orbit accuracies are better than 1 cm.

Background and Motivations

•Since the launch of TOPEX satellite in August 1992 equipped with an experimental GPS receiver for Precise Orbit Determination (POD), GPS-based POD is used for more and more satellites (CHAMP, GRACE, GOCE…).

•The orbit accuracy has been improved significantly from 3 cm to 1 cm in the radial direction due to the improvement of data and GPS orbit quality, mean gravity model and background models.

•In order to achieve higher absolute and relative accuracy results for the GPS-based POD, it is necessary to develop a scenario to understand how efficiently and precisely to determine the LEO's orbits.

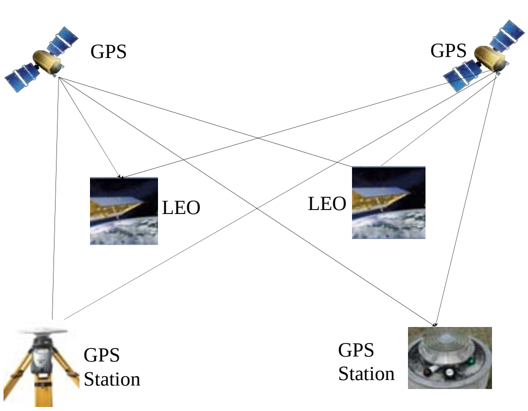
Objectives

1) Analyze different data processing scenarios for GPS-based orbit determination of LEO satellites.

2) Study the impact of different data processing scenarios on GPS-based orbit determination of LEO satellites.

3) Investigate the effects of the different scenarios on the orbit accuracy based on a comparison of different assessments (orbit fits, SLR residuals, KBR residuals and external orbit comparison).

Fig. 1. GPS-Based LEO Orbit Determination System



GPS Double-Differenced Combinations

Double –Differenced (DD) Measurements are formed by two GPS satellites and two GPS receivers that may be a LEO satellite and a ground station or two ground stations or two LEO satellites.

GPS DD combination types:

•Low-low GPS DD combination: two GPS satellites and two ground stations

•High-high GPS DD combination: two GPS satellites and two LEO satellites

•High-low GPS DD combination: two GPS satellites, one LEO satellite and one ground station

Ambiguity Resolution Strategies

The ambiguity resolution is a method to constrain the real-valued estimates to their nearest integer values. In a good situation, the differences between the estimated real-valued ambiguity and resolved integer ambiguity can be as close as a few millimeters (observation fit level). Based on this fact, we have developed and implemented a new approach to easily and quickly fix the DD ambiguities. The main difference between our and other methods is different decision criteria for ambiguity fixing: our criterion is the difference between the estimated and adjusted DD ionosphere free phase biases based on the resolved wide-lane and narrow-lane integers; the criterion of most current methods is the confidence test based the variances of the estimated real-valued DD bias.

Table 1. Orbit Determination and Data Processing

Tracking Data and GPS orbits	
GPS tracking data	GPS DD, 30 second sampling
GPS orbits	IGS final GPS ephemeredes (fixed)
Estimated parameters	
LEO's initial state	3D epoch position and velocity
GPS carrier phase ambiguity	One per combination per pass
Troposphere zenith delay	One per station in a 2.5 hour arc
Empirical parameters in T and N	1-cpr accelerations per revolution
Drag coefficient (C_d)	One per orbital revolution
GRACE GPS antenna correction	One per arc in nadir (Z) direction

Test Data and Test Cases

Test data: 2008 GRACE data

Data Sampling: 30 s (0, 30 … for ground data; 10, 40, … for LEO)

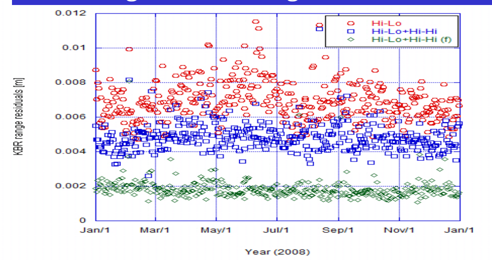
Test cases:
1) high-low GPS DD
2) high-low plus high-high GPS DD
3) case 2 plus ambiguities resolution

Table 2. GPS DD RMS and SLR Residuals

Test case	GPS DD Hi-Lo	GPS DD Hi-Hi	SLR for GRACE-A	SLR for GRACE-B
High-low	0.98		1.43	1.39
Hi-Lo + Hi-Hi	0.97	4.1	1.43	1.56
Hi-Lo + Hi-Hi (fixed)	0.97	4.4	1.43	1.38

The GPS DD RMS permits the estimation of the quality of the force and observation models. The SLR residuals show the absolute orbit accuracy. Table 1 summarizes the GRACE GPS DD RMS and SLR residuals. According to these results, there are no significant differences for high-low, high-low plus high-high, and high-low plus high-high by fixing ambiguities. There are smaller GPS DD RMS and larger SLR residuals for high-high case. This means that the precision of GPS onboard receiver is higher, and there are no troposphere effects.

Fig. 2. KBR Range Residuals



The KBR residuals can be used for evaluating the relative orbit accuracy of the GRACE satellites. Fig. 2 shows that the KBR range residuals for high-high (5 mm) are smaller than that for high-low case (7 mm). Processing high-low and high-high data by fixing ambiguities (2 mm) can improve the relative orbit accuracy.

Fig. 3. GRACE-A Orbit Comparison with JPL

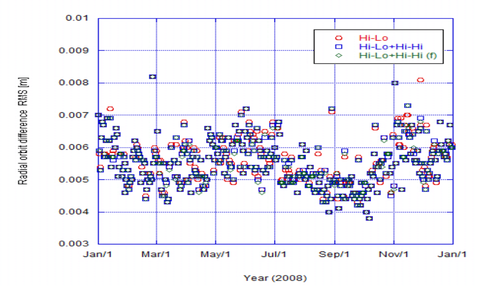


Table 3. GRACE-A Orbit Comparison with JPL [mm]

Test case	Radial	Along-track	Cross-track	3 D position
High-low	5.7	13.0	6.9	15.8
Hi-Lo + Hi-Hi	5.7	13.1	6.9	15.9
Hi-Lo + Hi-Hi (f)	5.7	12.9	6.9	15.7

The CSR determined GRACE orbits were directly compared with GNV1B orbits from JPL. There were no any removing biases and similar transformations for the comparison. The comparison results can be used to evaluate the absolute orbit accuracy.

Summary and Conclusions

•The absolute orbit accuracy can be preserved using high-low GPS DD data.

•The relative orbit accuracy can be preserved using high-high GPS DD data.

•The both absolute and relative orbit accuracy can be obtained using both high-low and high-high GPS DD data.

•Through ambiguity resolution, the relative orbit accuracy can be significantly improved using high-high GPS DD data.

•Based on the various tests (GPS DD RMS, SLR residuals and external orbit comparison), an accuracy of better than 1.0 cm in radial and cross-track directions, and better than 1.5 cm in along-track has been achieved for GRACE orbits.

•According to the KBR range residuals, the relative accuracy between two GRACE satellites is about 2 mm in position.