The Accuracy Verification for GPS Receiver of ALOS by SLR

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Abstract

The Advanced Land Observing Satellite (ALOS) provides precise geographical data for making global precise map. ALOS has a dual-frequency GPS receiver to determine geographic positions corresponding to points on satellite images. In order to confirm the orbit determination accuracy by GPS, we carried out a restricted laser ranging campaign with the support of the International Laser Ranging Service (ILRS). We found the GPS orbit agreed with the SLR orbit to within the resolution range of the SLR analysis.

Introduction

Recently, the positioning accuracy achieved by dual-frequency GPS receivers is within few dozens of cm. However we needed to verify the ALOS onboard GPS receiver because it was newly developed.

Overview of ALOS

Advanced Land Observing Satellite (ALOS), also called "DAICHI", was launched from Tanegashima Space Center in Japan on 24 January 2006. ALOS performs earth observations at a high resolution, which is expected to contribute to a wide range of fields such as map compilation, regional observation, notice of disaster situations and resource mapping. Detailed review of the ALOS mission and its advanced technology were reviewed in Iwata et al [1] and Hamazaki [2]. The orbit information of ALOS is described in Table 1.

Table 1: *The value of the orbit*

Orbit Type	Solar synchronous, sub-recurrent, frozen
Height	691.65km (above the equator)
Period	98.7 min
Eccentricity	1/1000
Inclination	98.16deg
Recurrent days	46 days

ALOS is one of the largest Earth observing satellites ever developed. ALOS has a GPS receiver and a laser reflector as tools for orbit determination.

Orbit Determination accuracy of ALOS

In order to make a precise map, it is necessary to observe the earth with high resolution and specify geographical positions corresponding to observed images. Thus, high positioning accuracy and directional precision are required for ALOS [3]. Orbit determination accuracy is required to be within 1m after processing on the ground. There are two tools for precise orbit determination for ALOS, that is, GPS receiver and laser reflector (LR) for Satellite Laser Ranging (SLR). The ALOS GPS receiver was newly developed for this mission. Detailed description of the GPS receiver is given in Toda *et al* [4]. The result of orbit determination using the GPS data is reported in
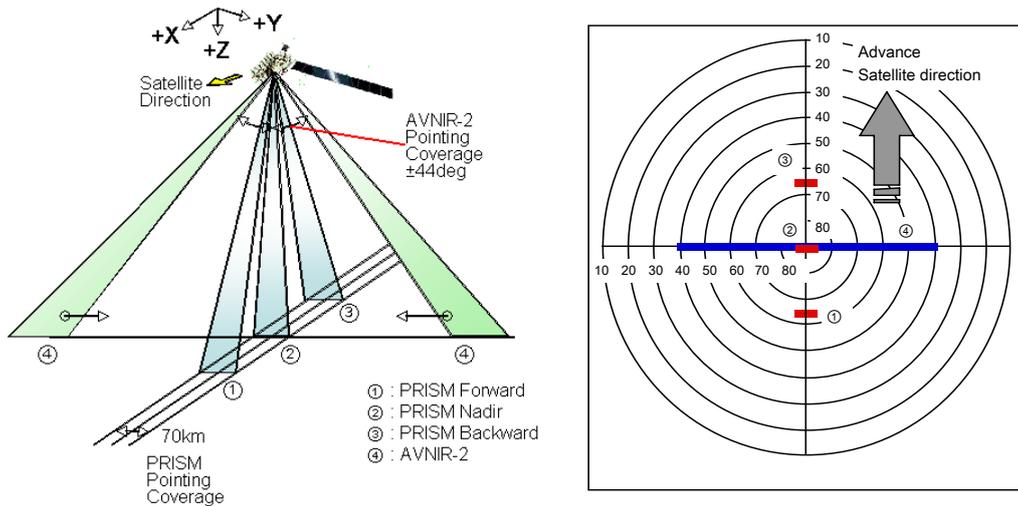
Figure 1. *Image of the ranging restriction.*

Nakamura *et al* [5]. The ALOS LR consists of nine Corner Cube Reflectors (CCR). A more detailed analytical result is described in the ALOS Tracking Standard [6].

Interference between ALOS's earth observation sensors and SLR laser beam

ALOS has two earth observation sensors (PRISM, AVNIR-2) which are vulnerable to the SLR laser radiation wavelength at 532nm. The CCD of each sensor can be destroyed when the incident energy exceeds 5×10^{14}[W/m^2]. We checked the possibility of damage to these sensors using the specifications of some typical SLR stations. As a result, the laser of SLR could damage the CCDs of sensors if the laser beam impinges on the sensors. The results are similar for almost all stations of the world. Therefore we needed to carry out restricted laser tracking to avoid damaging sensors.

Restricted Laser Tracking

The method of restricted laser tracking is standardized by the ILRS[7]. JAXA carried out restricted laser tracking to ALOS using this method. Figure 1 shows the restricted area. The pass of ALOS is sometimes divided into two, three, or four regions.

Table 2: *List of participating station for ALOS Tracking*

SLR Stations	ID	Nation
Mt. Stromlo	STL3	Australia
RIGA	RIGL	Latvia
Koganei(KOGC)	KOGC	Japan
Simosato	SISL	Japan
Monument Peak(Moblas-4)	MONL	USA
Hartebeesthoek (Moblas-6)	HARL	South Africa
Yarragadee(Moblas-5)	YARL	Australia
Tanegashima	GMSL	Japan
Zimmerwald	ZIML	Swiss land
Herstmonceux	HERL	United Kingdom
Greenbelt (MOBLAS-7)	GODL	USA

SLR data acquisition and ILRS campaign

We asked ILRS to provide support for ALOS SLR. Thanks to ILRS support, eleven SLR stations (Table 2) participated in the ALOS SLR campaign. We carried out the

ALOS SLR campaign from UT 00:00:00 on 14 August 2006 to UT 16:00:00 on 31 August 2006. We obtained 100 passes and 2979 data points.

The accuracy of orbit determination using GPS data

First, we review the accuracy of orbit determination using GPS data. The details of method of orbit determination using GPS are described in Nakamura *et al*[5].

The accuracy of orbit determination using GPS data

Figure 2 and Table 3 shows the accuracy of orbit determination using GPS data during ALOS SLR campaign. The accuracy of orbit determination is evaluated by overlap comparison and expressed in terms of the RMS value during the orbit determination period. Figure 2 and Table 3 show that the accuracy of orbit determination using GPS data is within a few cm.
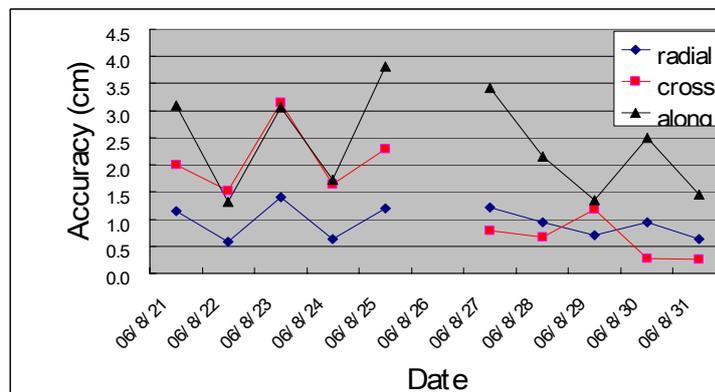
Figure 2. *Accuracy of orbit determination using GPS data (RMS)*
The horizontal axis is date and the vertical axis is the
accuracy of orbit determination.
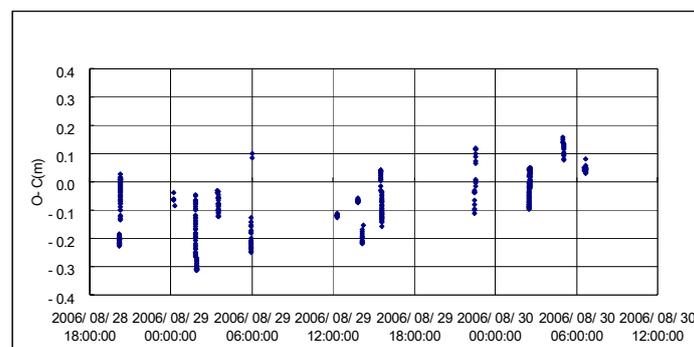
Table 3. *Summary of GPS OD Accuracy (cm)*

	Radial(ave)	Radial(sig)	Cross(ave)	Cross(sig)	Along(ave)	Along(sig)
GPS Overlap	-0.04	0.94	0.03	1.38	0.56	2.39

Analysis

Our SLR analyses used both global arc and short arc methods.

Global arc analysis

We compared GPS data with SLR data and evaluated the residual of SLR data. Figure 3 shows a typical result and Table 4 shows the statistic result.

Figure 3. *Difference between GPS orbit and Laser ranging data (as example)*

Our analysis shows that the SLR data is within -4.8 ± 12.0 cm of the GPS orbits. What is noteworthy is that the standard deviation value is larger than the average value. This means that the difference between GPS-determined orbit and SLR data is well within the margin of error; there is no significant difference.

***Table 4.*** *Results of residual (cm)*

	Average	St Dev
SLR O-C Analysis	-4.78	12.03

Short arc analysis

The above analysis cannot separate the radial, cross, and along components of GPS-determined orbit. Next we performed the orbit determination using only SLR data and compared it with the orbit determination using GPS data in each direction. Because SLR is an independent method from GPS, this analysis provides an objective evaluation of the ALOS onboard GPS receiver specifications.

Several passes are needed to perform orbit determination using SLR data. If we used daily data sets, the accuracy of orbit determination would be degraded because of the irregularity in data density. Therefore we performed the orbit determination using SLR data acquired during periods when more than three stations carried out SLR within a few orbital cycles. This means that our analysis is not the short arc analysis in a strict sense.

We calculated only the six orbital elements for the orbit determination using SLR data. We used a polyhedral model to represent the satellite and also considered the attitude model of ALOS. We didn't estimate the range bias for each station data. (We used the calibration data of each station.) And the analysis was performed for the periods where SLR data existed.
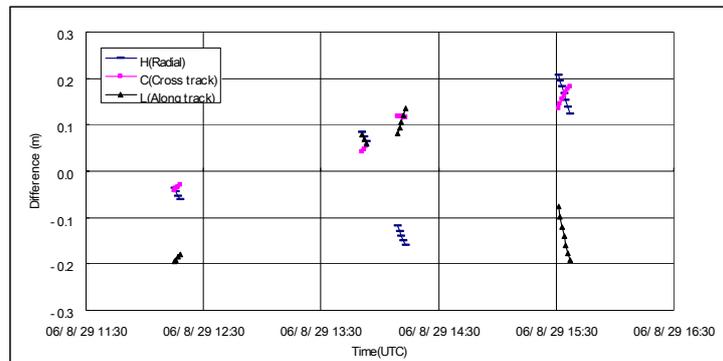
Figure 4. *The difference between the orbit determinations using SLR and* GPS

We compared the two orbit determinations of SLR and GPS approaches, and verified each direction (Cross, Along, Radial) result. The summary of result is shown in Table 5.

Table 5. *Summary of Difference between SLR and GPS (cm)*

	R(ave)	R(sig)	C(ave)	C(sig)	A(ave)	A(sig)
SLR-GPS	-2.98	20.54	-4.69	38.32	-5.44	28.76

These results show that the position estimated by GPS overlap method, and the position estimated by comparison of GPS orbit determination and SLR orbit determination fell within the margin of error (1sigma).

Conclusion

The analysis using the overlap method is a relative evaluation of GPS-based orbit determination and the analysis using SLR data is an absolute evaluation of GPS-based orbit determination. In other words, the overlap method is the evaluation of random error and the analysis using SLR data is the evaluation of bias error.

From this analysis, the error estimated by GPS overlap method was small compared to the error estimated by the analysis using SLR data. This means that the error estimated by GPS overlap method is negligible. The result of global arc analysis shows that there is no significant difference between the SLR and GPS data. Next we checked the difference in each direction between SLR determined-orbit and GPS determined-orbit by short arc-like analysis. As a result, the position estimated by GPS overlap method, and the position estimated by comparison of GPS orbit determination and SLR orbit determination agreed to within the margin of error (1sigma). Because the ALOS onboard GPS receiver was newly developed, we needed to verify the specifications. The result of this analysis showed that ALOS GPS receiver provides correct positioning information, to at least within the accuracy confirmed by our SLR-based analysis. In this analysis, 1 sigma was about 30 cm. This means that the accuracy of the ALOS onboard GPS receiver satisfies the requirement from ALOS mission, which is within 1m (peak to peak).

Acknowledgements

References

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