PRECISE ORBIT DETERMINATION FOR ALOS

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Abstract

The Advanced Land Observing Satellite (ALOS) has been developed to contribute to the fields of mapping, precise regional land coverage observation, disaster monitoring, and resource surveying. Because the mounted sensors need high geometrical accuracy, precise orbit determination for ALOS is essential for satisfying the mission objectives. So ALOS mounts a GPS receiver and a Laser Reflector (LR) for Satellite Laser Ranging (SLR). This paper deals with the precise orbit determination experiments for ALOS using Global and High Accuracy Trajectory determination System (GUTS) and the evaluation of the orbit determination accuracy by SLR data. The results show that, even though the GPS receiver loses lock of GPS signals more frequently than expected, GPS-based orbit is consistent with SLR-based orbit. And considering the 1 sigma error, orbit determination accuracy of a few decimeters (peak-to-peak) was achieved.

1 Introduction

Japan Aerospace Exploration Agency (JAXA) launched an Earth observation satellite, ALOS, also called “DAICHI”, from the Tanegashima Space Center in Japan on 24 January 2006. ALOS performs Earth observation at a high resolution, which is expected to contribute to a wide range of fields such as map compilation, region observation, grasp of disaster situation and resource mapping. ALOS has three remote-sensing instruments: the Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) for digital elevation mapping, the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) for precise land coverage observation, and the Phased Array type L-band Synthetic Aperture Radar (PALSAR) for day-and-night and all-weather land observation. In order to fully utilize the data obtained by these sensors, ALOS is designed with two advanced technologies: high speed and large capacity mission data handling technology and precision spacecraft position and attitude determination capability. These technologies will be essential to high-resolution remote sensing satellites in the next decade [1].

To achieve the high geometrical accuracy required for ALOS’s sensors, we need to determine ALOS’s orbit very accurately. For this purpose, ALOS carries a double frequency GPS receiver. Precise orbit determination for low orbit satellite using GPS receiver data has been widely studied. The orbit determination for GRACE (Gravity Recovery And Climate Experiment, managed by National Aeronautics and Space Administration (NASA) and Deutschen Zentrums für Luft- und Raumfahrt (DLR)) and CHAMP (CHAllenging Minisatellite Payload, managed by GeoForschungsZentrum Potsdam (GFZ)) has been reported to achieve a few centimeters accuracy [2][3]. JAXA has developed a precise orbit determination system (GUTS) from 1995. We performed precise orbit determination experiments for ADEOS-II carrying a single frequency GPS receiver and achieved 23 cm accuracy [4][5]. In the experiments using GRACE’s double frequency GPS receiver data, we achieved 8 cm accuracy compared with the result of DLR. And also in GPS satellites’ orbit determination, we achieved 6cm accuracy compared with the ephemeris released by the International GNSS Service (IGS).

The orbit determination accuracy required for ALOS is within one meter, which is not considered to be difficult to achieve. But the GPS receiver loses lock of GPS signals more frequently than expected, and there are long period during which the receiver locks less than four GPS satellites. In order to determine the position and time using GPS signals, it is required that the GPS receiver receive signals from at least four GPS satellites. Because of this, by conducting the preprocessing appropriately, we preformed orbit determination using as much data as possible.

Because the ALOS onboard GPS receiver was newly developed, we need to evaluate the data received from the receiver. For this purpose, ALOS has a Laser Reflector (LR) composed of eight Corner Cube Reflectors (CCRs) for SLR operations. We performed orbit determination using only SLR data and compared the SLR-determined orbit with the orbit determined by GPS data.

2 Mission Requirement of ALOS

For precise mapping using satellite imagery, it is necessary to observe the earth with high resolution and determine the geographical positions corresponding to the observation image. Thus, high positioning accuracy and pointing control accuracy are required for ALOS [6], [7], [8], [9]. The accuracy requirements for satellite attitude and pointing control are shown in Table 1. Taking these errors into account, the orbit determination accuracy is required to be better than 1 meter (peak-to-peak). There are two tools for precise orbit determination for ALOS; a GPS receiver and a LR for SLR. ALOS's GPS receiver was newly developed for its mission. Detailed explanation of GPS receiver is described in Toda et al [10].

Tab.1 Required Accuracy for Attitude and Pointing

Pointing Control Accuracy		Roll, Pitch, Yaw: ±0.1 deg
Pointing Stability	Short Period	Roll, Yaw: 2.0×10-5deg/0.37ms (peak-to-peak) Pitch:1.0×10-5deg/0.37ms (peak-to-peak)
	Long Period	Roll, Yaw: 2.0×10-4 deg/5s (peak-to-peak) Pitch:4.0×10-5 deg/5s (peak-to-peak)
Pointing Determination Accuracy (after processing on the ground)		Roll, Pitch, Yaw: ±2.0×10-4 deg

3 System Configuration of GUTS

Fig. 2 shows the system configuration of GUTS. GUTS receives onboard GPS receiver data from JAXA Earth Observation Center (EOC) and GPS ground stations data from JAXA GPS ground station control and the IGS ftp server. The system is mainly composed of three functions: preprocessing, preliminary orbit determination, and precise orbit determination. We use GPS dual-frequency code measurements and dual-frequency carrier phase measurements as observation data and determine the satellite's orbit by estimating orbital elements and some parameters of Dynamical Model and Observation Model. We perform preliminary orbit determination using GPS navigation data and ALOS onboard GPS data (point positioning data), and use the orbit as the initial orbit for precise orbit determination.

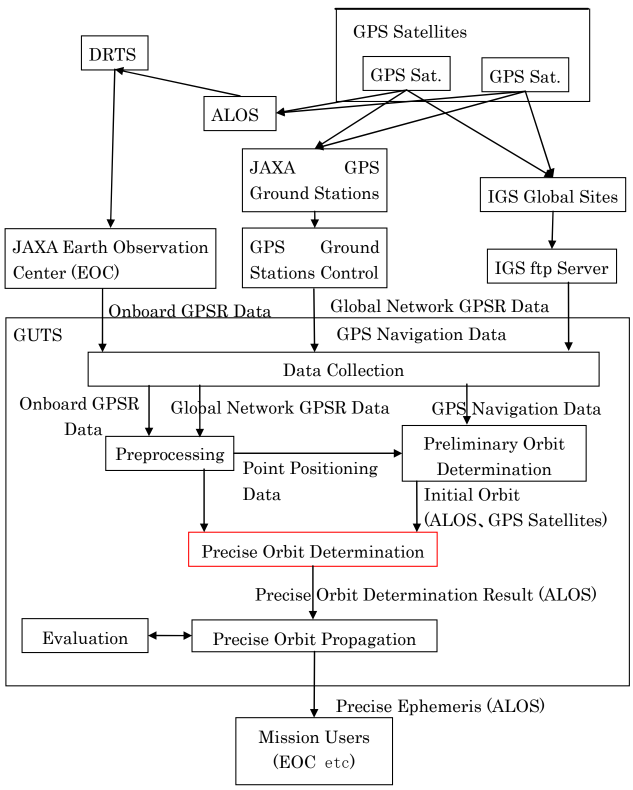

Fig.2 System Configuration of GUTS

3.1 Preprocessing

Before precise orbit determination, GUTS preprocesses the collected data as follows:

- correction of clock offset of onboard GPS receiver data
- detection and correction of cycle slip of onboard and ground GPS receiver data
- correction of ionospheric delay
  (make ionosphere-free combination for pseudorange and carrier phase)
- smoothing and compression

3.2 Preliminary Orbit Determination

GUTS estimates the initial orbit from RINEX navigation data for GPS satellites and from point positioning data for ALOS.

3.3 Precise Orbit Determination

In GUTS precise orbit determination, we use GPS dual-frequency code measurements and dual-frequency carrier phase measurements as observation data and determine the orbit by estimating orbital elements and some parameters of Dynamical Model and Observation Model by Square Root Information Filter (SRIF) and Smoother. First, the GPS satellites' orbits are estimated by using the coordinates of the ground stations published by IGS (SINEX). Then, ALOS orbit is estimated using the determined GPS satellites' orbits. The detail is omitted here, and the outline is described below.

3.3.1 Dynamical Model

Dynamical Model is a set of forces acting on the satellite and is used for propagating the satellite' orbits. The detail is shown in Tab.1.

Tab. 1 Dynamical Model

Model		GPS Dynamics	ALOS Dyanmics
Geo Potential		JGM3(12*12)	JGM3(70*70)
N Body		JPL DE405 (All planets, Sun and Moon)	JPL DE405 (All planets, Sun and Moon)
Solar Radiation Pressure Model (including conical shadow model for Earth and Moon)		Estimated using - GSPM.04b - CODE	Estimated using - Multi-Plane Satellite Model (considering ALOS's attitude)
Earth Radiation Pressure		Albedo infrared second-degree zonal model	Albedo infrared second-degree zonal model
Tide	Solid Earth tides	Based on IERS2003	Based on IERS2003
	Ocean tides	Based on IERS2003	Based on IERS2003
	Solid Earth pole tide	Based on IERS2003	Based on IERS2003
Atmospheric Drag			Estimated using - Multi-Plane Satellite Model (considering ALOS's attitude)
Relativity		Based on IERS2003	Based on IERS2003
Emprical Acceralation		Constant	

3.3.2 Observation Model

The Observation data used for GPS satellites' orbit determination is calculated from ground stations' GPS receiver data. It includes various observation errors other than geometric distances between GPS satellites' phase center and GPS receivers' phase center. In order to correct these errors, some factors are modeled. Modeled factors are described in Tab.2.

Tab. 2 Observation Model

Model	Ground Stations GPS Receiver	ALOS Onboard GPS Receiver
Geometrical Distance	Light Time Equation	Light Time Equation
Satellite Clock/Receiver Clock Offset	Considered	Considered
Ionospheric Delay	Ionosphere-free linear combination	Ionosphere-free linear combination
Tropospheric Delay	Lanyi Model	Lanyi Model
Phase Center Offset of GPS satellites's Antena	Different Model for Each Blocks	Different Model for Each Blocks
Phase Center Offset of Receiver's Antena	Different Model for Each Stations (DCB Correction)	ALOS(X,Y,Z)=(1.812m,-0.855m,-1.563m) (considering ALOS's attidute)
Site Diplacement	Solid Earth tides (Based on IERS2003)	Propageted by ALOS Dynamical Model
	Ocean tides (Based on IERS2003)	
	Solid Earth pole tide (Based on IERS2003)	
Earth Rotation Parameter Variation	Based on IERS1998	Based on IERS1998
Carrier Phase Bias	Considered	Considered
Phase Rotation Effects	Considered	Not Considered

3.3.3 Consideration of Effect of ALOS's Attitude

PRISM's wide field of view (FOV) provides fully overlapped three-stereo (triplet) images (35 km width) without mechanical scanning or yaw steering of the satellite [1]. But ALOS's attitude is controlled so that ALOS can observe the earth as effectively as possible. ALOS performs yaw steering in sync with the move of earth's surface due to earth rotation. So, when we calculate the force acting on ALOS (like solar radiation pressure and atmospheric drag), we must consider the direction of solar paddle and any other effects of ALOS's attitude control. In addition to the dynamical model, ALOS's attitude control causes the periodic change of the relative position of the onboard GPS antenna phase center from ALOS's center of mass. We must also take this effect in consideration for observation model.

3.3.4 Estimation Parameters

GUTS can estimate not only orbital elements but also various parameters relating to the models described above. The estimated parameters for ALOS orbit determination are shown in Tab 3. Note that in GPS satellites orbit determination, the GPS satellite position is estimated assuming that the positions of the GPS receivers (ground stations) are fixed, and in ALOS orbit determination, onboard GPS receiver's position is estimated assuming that the positions of the GPS satellites are fixed.

Tab. 3 Estimation Parameters

	GPS Satellites Orbit Determination	ALOS Orbit Determination
Orbital Elements	Six Elements	Six Elements
Solar Radiation Pressure	GSPM.04b(Scale Factor, y bias) CODE(D0、Y0、B0、Z0)	Solar Radiation Pressure Scale Factor (10 minutes interval)
Atmospheric Drag		Atmospheric Density Scale Factor (10 minutes interval)
Clock	Transmitter/Receiver Clock Offset	Receiver Clock Offset
Carrier Phase Bias	Estimate	Estimate
Tropospheric Delay	Wet zenith tropospheric delay	
Emprical Acceralation	Costant	

4 Features of ALOS onboard GPS Receiver Data

Considering the performance of GUTS described in section 1, it is not so difficult to fulfill the requirement for orbit determination accuracy, if the ALOS onboard GPS receiver locks onto four or more GPS satellites signals constantly. However, the ALOS onboard GPS receiver frequently loses GPS satellites signals because of electromagnetic interference with other sensors. Because of this problem, the ALOS onboard GPS receiver often can not locks onto four or more GPS satellites signals.

4.1 Interference Problem

PALSAR, mounted on ALOS, is a radio wave sensor using L band. There was a concern about radio disturbance due to electromagnetic interference because the transmission frequency (1270MHz) was close to L2 frequency (1227.6MHz) of the GPS receiver. To deal with this problem, an interface was established between PALSAR and GPS receiver so that the receiver will stop receiving L2 signal when the PALSAR signal is transmitted. As shown in Figure 3, GPS receiver stops receiving GPS signals while PALSAR is active. By this method, Electromagnetic interference between GPS and PALSAR was avoided successfully. However, another unexpected electromagnetic interference was observed between the ALOS GPS receiver and other ALOS instruments. This electromagnetic interference caused the GPS signals to be lost when the operations of ALOS sensors increased. In satellite positioning using GPS, at least four GPS signals are required to determine the position and time. So this interference problem causes a degradation of orbit determination accuracy.

Figure 4 shows the percentages of unusable GPS data during the orbit determination period. Approximately 10% of L1 pseudorange data, 23% of L2 pseudorange and L2 carrier phase were discarded. Unusable data of L1 pseudorange and L2 pseudorange were mainly caused by loss of lock on GPS signals. Bad data of L2 carrier phase was mainly due to loss of lock and error of the GPS receiver. We suppose that these erroneous data were caused not by the malfunction of the GPS receiver but by electromagnetic interference with surroundings, because the GPS receiver showed a good performance during the ground test. In particular, the percentage of erroneous L1 data increased after 16 August, from which PALSAR sensor was frequently operated for observation. Over 20% of daily observation data was useless for orbit determination.

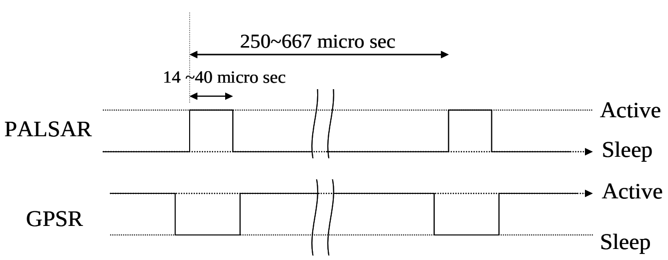

Fig.3 Interface between PALSAR and GPS Receiver

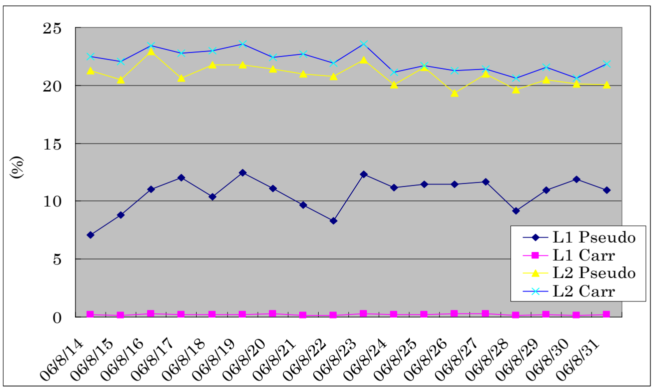

Fig. 4 Data Rejection Rate

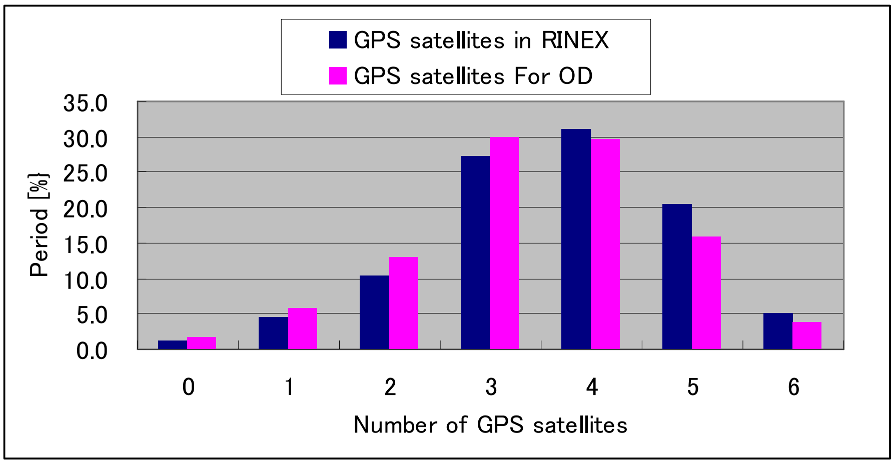

Fig. 5 Number of GPS satellites used for orbit determination (time ratio)

4.2 Parameter Tuning for Preprocessing

Fig.5 shows the percentage of the GPS satellites used for orbit determination. The percentage of four or more GPS satellites tracked, calculated based on RINEX data, is 56.6%. We modified the following parameters of preprocessing to use as much data as possible for orbit determination.

- maximum data loss time for pass regarded as continuous : A pass is divided if it is longer than this time.
- minimal time for pass regarded as effective : A pass is rejected if it is shorter than this time.
- time for carrier smoothing

5 Experiments

5.1 Execution Condition

We used 40-hour data for orbit determination (30-sec interval data for ground GPS receiver data and 1-sec interval data for the ALOS onboard GPS receiver data).

The used preprocessing parameters are shown in Tab.4.

Tab. 4 Preprocessing Parameters

Condition	Time[sec]
maximum data loss time for pass regarded as continuous	2
minimal time for pass regarded as effective	120
time for carrier smoothing	60

5.2 Accuracy Evaluation

The orbit determination arcs have 16-hour overlap period as shown in Fig.6. We compared the two determined orbit during the overlap period (6-hour overlap period excluding the first and last five hours). This evaluation is comparative, but can be used for evaluation of random errors of orbit determination.

ALOS carries a LR for SLR. We also performed absolute evaluation by taking a difference between SLR-data-based range to ALOS and orbit-determination (using GPS data)-based range to ALOS (SLR residuals evaluation). In addition, we performed ephemeris comparison between orbit determined by only SLR data and orbit determined by only GPS receiver data. In SLR-based orbit determination, we chose a period in which relatively a larger amount of data was acquired and estimated the orbit in short arc. Despite this, SLR-based orbit was less accurate during the period without SLR data. So we evaluated ephemeris comparison during the period with SLR data. ALOS has two earth observation sensors (PRISM, AVNIR-2) which interfere with SLR Laser. So, SLR for ALOS had to be performed under a certain restriction for avoiding the damage of the sensors' damage and SLR is performed for a limited period of time; UT 00:00:00 on 14 August 2006 to UT 16:00:00 on 31 August 2006. We obtained 100 passes and 2979 data sets.

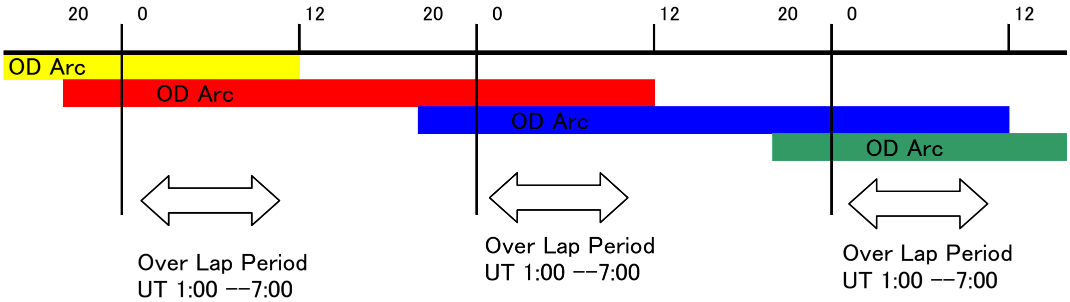

Fig.6 Orbit determination arc and overlap period

6 Results

By tuning the preprocessing parameters, the percentage of period in which four or more GPS satellite is used for orbit determination is 49.5 %.(Fig. 5) This is not enough, of course. But if we try to increase the percentage more, the pass must be divided more frequently, which causes the degradation of the orbit determination accuracy. The result of overlap evaluation is shown in Fig.7. As shown in this figure, the comparison result is less than about 30-centimeter at most. This means that the determined orbits randomly fluctuate a few decimeters.

The result of SLR residuals evaluation using all 14-day SLR data is shown in Tab. 5 and Fig. 8. This result shows that, other than small errors, there seems to be no significant inconsistency between the SLR-data-based range to ALOS and orbit-determination(using GPS data)-based range to ALOS. And also, Tab. 5 shows that the variation of SLR residuals is decreased by considering the ALOS's attitude. The about 4cm averaged residuals may be offset, though we can not say with certainty because the standard deviation is larger than the averaged residuals. The offset may be derived from a difference between LR's optical center and the actual reflection surface of CCRs. By our analysis, the value is about 4cm [11]. More research is needed for this problem. This is one of the future tasks.

The result of ephemeris comparison is shown in Tab. 6. The differences are within the standard deviation in all directions. This result shows that the GPS-based orbit is consistent with the SLR-based orbit considering the 1 sigma error. In other words, the standard deviations are so large that we can not regard the averaged differences as offsets between the GPS-based orbit and the SLR-based orbit.

Considering the random fluctuation derived from the comparative evaluation by overlap comparison and the 1 sigma error of the absolute evaluation by SLR data, orbit determination accuracy of a few decimeters (peak-to-peak) was achieved for ALOS.

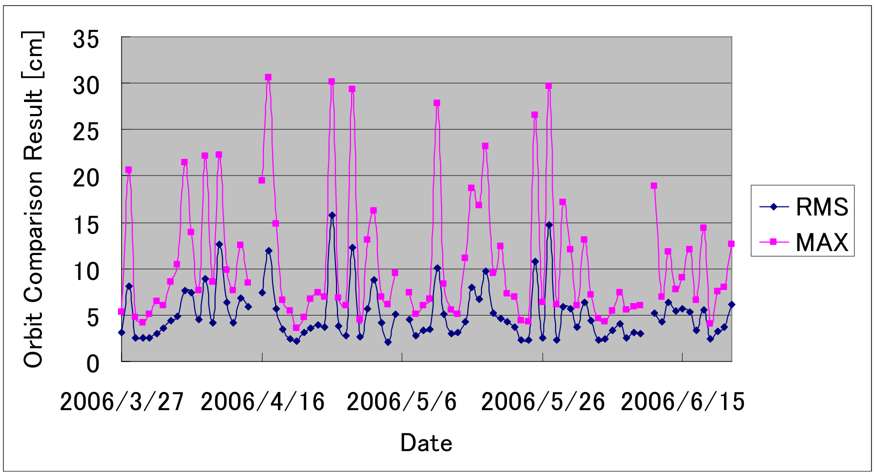

Fig.7 Overlap Comparison Result

Tab.5 SLR residuals
(ALOS's attitude is considered / not considered)

	Considered	Not considered
Average(cm)	-4.42	-4.07
Standard Deviation(cm)	6.59	9.31

Tab.6 Comparison with SLR-based orbit

	Radial	Cross-Track	Along-Track
Average(cm)	-2.98	-4.69	-5.44
Standard Deviation(cm)	20.54	38.32	28.76

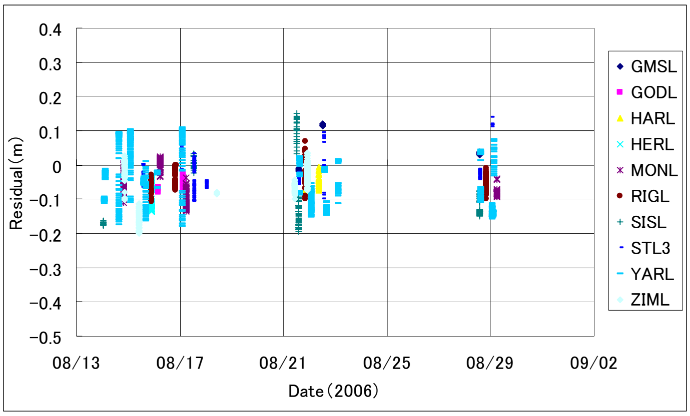

Fig. 8 SLR residuals
(ALOS's attitude is considered)

7 Conclusion

We performed orbit determination for ALOS, which carries a dual-frequency GPS receiver, and evaluated the accuracy by overlap method and comparison with SLR data. The ALOS onboard GPS receiver has a problem of electromagnetic interference with other onboard sensors and because of the problem, often loses lock onto GPS satellite signals. We performed preprocessing parameter tuning and tried to use as much data as possible. As a result, even though period of locking more than four satellites is not enough, we achieved a few decimeters orbit determination accuracy.

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