A-3.2.2 Studies on Algorithms of Satellite Orbit Prediction for Laser Ranging Observation

Contact person Masayuki Fujita
Japan Hydrographic Department
Maritime Safety Agency
5-3-1 Tsukiji, Chuo-ku, Tokyo 104, Japan
Tel: +81-3-3541-4387 Fax: +81-3541-4387
E-mail: mfuji@cue.jhd.go.jp

Total Budget for FY1995-FY1997 8,093,000 Yen (FY1997; 2,352,000 Yen)

Abstract

We performed satellite laser ranging observations to RIS on the ADEOS during the period from Oct.1996 to Jun.1997 at the Simosato Hydrographic Observatory. Acquired data were sent to the data center at Communications Research Laboratory every day for its orbit prediction. Tracking data for the ADEOS were also obtained at global SLR stations.

We constructed a Box-wing-shaped model of ADEOS for improving orbit prediction accuracy and performed orbit prediction experiments using global SLR data of ADEOS. As a result, it was shown that along-track estimation of empirical accerelation is preferable and that applications of center of mass correction and the shape model significantly improved the predicted result. It was also shown from the long period data ananlyses that the accuracy of the prediction in which our models are incorporated is several hundreds of meters after about a week in the along track component and that an ocsillatory error with the period of once per revolution increases with time.

Key Words ADEOS, SLR, orbit prediction, Box-wing model, center of mass correction

1. Introduction

The ADEOS, Japanese earth observing satellite which was launched in August 1996, carries sensors such as ILAS and/or RIS for the observation of atmospheric trace gases. In order to improve an accuracy of these observation, it is necessary to make a high precision orbit determination and prediction. Especially, the RIS observation, for which laser tracking from the ground is necessary, requires a high precision orbit prediction. In this study, we develop an algorizm of precision orbit prediction based on the satellite laser ranging technique.

2. Recearch Objectives

The ADEOS has an extremely asymmetric shape with the large solar panel and the relation of the position between the center of mass and the laser reflector varies with time. It is expected that the modeling of these factors will improve an accuracy of the orbit prediction. This study aims at improving the orbit prediction accuracy of the ADEOS using laser tracking data mainly by modeling the shape of the satellite.

3. Research scheme and results

3.1. Modeling of ADEOS

3.1.1 Center of mass correction

The RIS is equipped with the ADEOS as a reflector of laser light for the purpose of measuring atmospheric trace gases in the atmosphere and it is also utilized for the SLR observation. The relation between the optical center of the RIS and the center of mass is represented as (X,Y,Z) = (1415.7, 101.4, 748.2) (mm)1), where X is the direction of flight and Z is nadir.

Although the SLR measures the distance from the station to the optical center of the RIS, orbits of the satellite must be represented as the position of the center of mass. So the correction of the above geometrical relation is needed, which is called the center of mass (hereafter referred to COM) correction.

The amount of the COM correction varies from +1.5m to -1m with time. The variation is not uniform with time, occurring abruptly during a few minutes around at the highest elevation.

3.1.2 Asymmetrical shape (Box-wing modeling)

The ADEOS has a significantly asymmetrical figure unlike simlpe sphere-shaped geodetic satellites. Since the area of the solar panel is considerably large compared with the body, it is impossible to estimate effects of atmospheric pressure and/or solar radiation pressure precisely without taking such a figure into account.

We constructed here a Box-wing shaped model which approximates the body with a box and the solar panel with an independent rectangle (Figure 1). Area is 14 m^2 on the along-track side of the body, 20 m^2 on the radial direction side, 16m^2 on the cross-track side and 60m^2 on the plane of the solar panel. The solar panel part rotates on the side of the body so that its plane always faces to the direction of the sun.

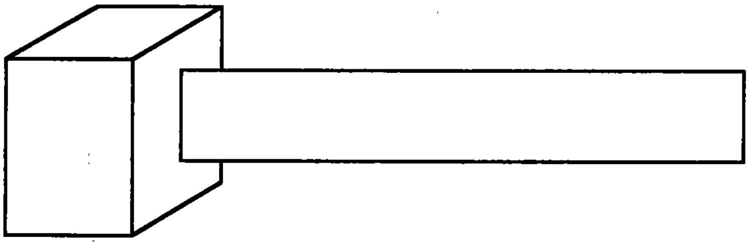

Figure 1 Box-wing model

3.2. Data acquisition

We acquired tracking data of the ADEOS by performing SLR observations at the Simosato Hydrographic Observatory during Oct.1996-Jun.1997. The reflected laser light from the RIS is very strong and the average ranging rms is 3-4cm. It should be noted, however, that the geometrical sky coverage of the data is limited, since the data acquisition is only possible when it is approaching due to the equipped direction of the RIS. Acquired data at Simosato are 48 passes with 593 normal points.

Among the global tracking stations, there are 3 stations which acquired an especially large amount of data; Greenwich (England) has 127 passes with 591 normal points, Monument Peak (USA) has 47 with 244 and Orroral (Australia) has 79 with 531.

3.3. Orbit prediction experiment using global data

3.3.3 Assessment of applications of COM and Box-wing models

Applications of the COM and Box-wing models were evaluated through the orbit prediction experiments using ADEOS global normal point data. For this purpose, two sets of 3-day arc data with the period of (a) 10/30 - 11/1 and (b) 11/8 - 11/10 are analyzed; the accuracy of the prediction is represented as the difference of predicted and determined orbits for the period (b), where the predicted orbits are obtained by extrapolation from the arc-(a) analysis.

The atmospheric density model applied is DTM 2) and the gravitational potential model is JGM-3 3). Drag coefficients are estimated once every day and the radiation pressure coefficients are fixed to 1.5.

We obtained predicted orbits for three cases: application of both COM and Box-wing model (Reference), no application of COM correction (No COM) and no application of Box-wing model (No BW). Figure 2 shows differences between predicted and determined orbits for the three cases.

As seen from the figure, an amount of deviation in the along-track component after a week is 300-400m in the reference case, while it is 800m in the No COM case and 4000-5000m in the No BW case. On the other hand, amounts of deviation in the cross-track and radial components are considerably small, though a little improvement can be seen.

In spite that the absolute amount of the deviation is considered to depend on the number of data and/or temporal and spatial data distribution, it should be concluded that both models, especially the Box-wing model significantly improve the orbit prediction.

3.3.4. Evaluation of the orbit prediction due to long period data analysis

3.3.4.1 Scheme

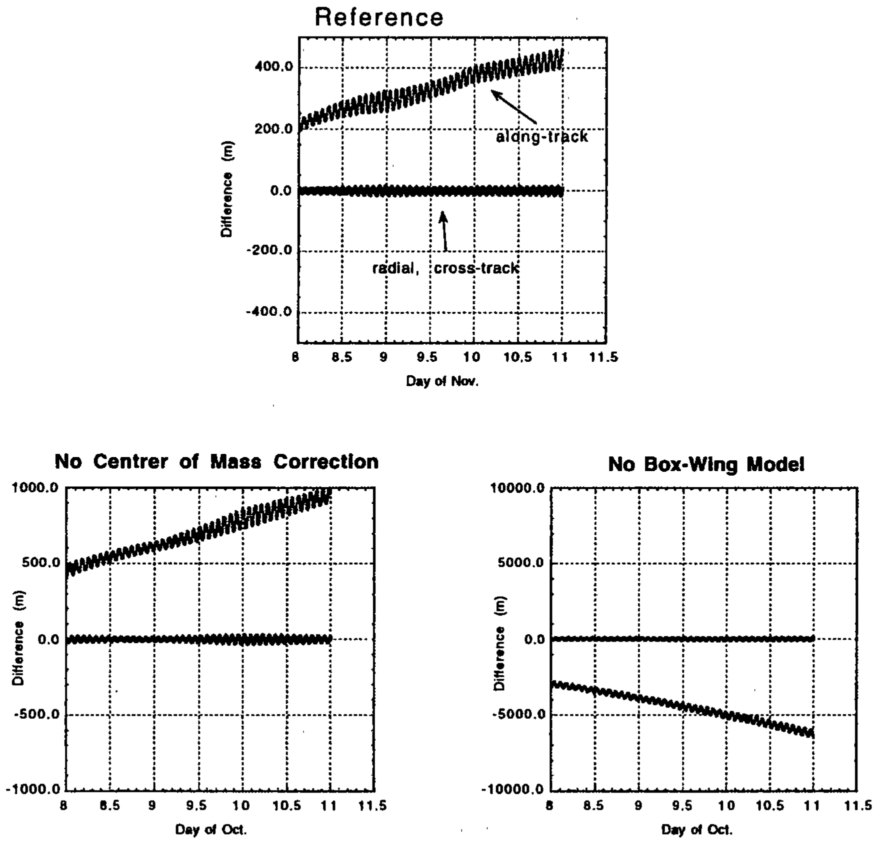

Figure 2 Evaluation of model application

We performed assessments of predicted orbits as well as evaluations of determined orbits on the basis of analyses of whole global data acquired in February and March of 1997.

The scheme of the whole analysis is as follows. First, we analyse data during this period with 10-day arc and edit the data on the basis of range residuals. Next, 3-day analyses are made using the editted data. The 3-day arc period is slided with every 1 day. The reason for applying this procedure is that the direct 3-day arc analysis usually results in failure of removing bad data because the number of data included is too small. Another reason is that we can evaluate accuracy of determined orbits by comparing results between 3-day arc and 10-day arc data.

Predicted orbits are obtained through an extrapolation from a 3-day arc orbit as is done in the previous section. We evaluate such a predicted orbit by comparing with a determined orbit within the arc period.

Figure 3 shows data numbers for February and March of 1997. It plots monthly accumulated number against the day. Thus, the steeper slope indicates dense data. A discrete block indicates a single pass. The number of passes are at most 4-5.

The range residuals after the analyses for the most arcs are less than 20 cm, which

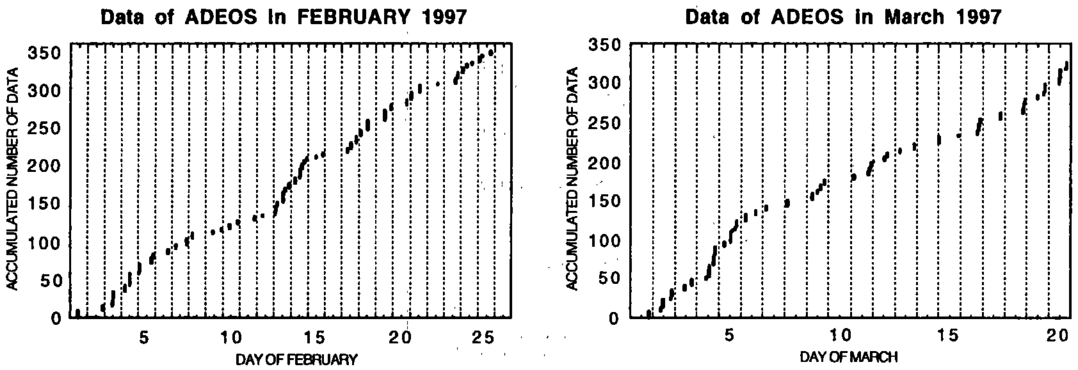

Figure 3 Accumulated number of data in February and March 1997

indicates that the estimation converges well. However, Since the data density is rather low, a relative value between those of different arcs does not reflect the accuracy of the orbit precision.

3.3.4.2 Accuracy of determined orbit

Accuracy of the determined orbits was examined by comparing those of an identical day from 4 different arcs: 10-day arc and three slided 3-day arcs.

Table 1 shows the result of comparison for February 14, which has comparatively dense data. The 3-day arcs are (a) 2/14-16, (b) 2/13-15 and (c) 2/12-14.

Considering that the agreement between orbits determined from different arcs is a measure of an accuracy of orbit determination, Table 1 indicates that the orbit of this arc is determined by 1-2 meters in the along-track component and several tens of centimeters in the cross-track and radial components.

For other days, differences between arcs gets larger in the along-track component when the data are especially sparse.

3.3.4.3 Evaluation of predicted orbits

We evaluated predicted orbits by comparing with the determined orbits. We take

Table 1 Differences in determined orbits

ARC	COMPONENT	(a)	(b)	(c)
10d-3d	ALONG	-55 ± 78	-25 ± 39	-11 ± 44
	CROSS	1 ± 52	0 ± 32	0 ± 50
	RADIAL	-1 ± 24	0 ± 15	-1 ± 14
		(b)-(a)	(c) - (a)	(c) - (b)
3d-3d	ALONG	30 ± 58	44 ± 52	14 ± 48
	CROSS	0 ± 21	0 ± 13	0 ± 17
	RADIAL	1 ± 14	0 ± 14	-1 ± 7

Table 2 Evaluation of predicted orbits in February 14

component	arc (3day)	Difference(m)
ALONG	2/ 3-5	-281. 59 ± 118. 54
	4-6	80. 99 ± 103. 60
	5-7	-200. 06 ± 90. 18
	6-8	-345. 17 ± 80. 15
	7-9	-120. 11 ± 61. 36
CROSS	2/ 3-5	-0. 07 ± 7. 76
	4-6	-0. 06 ± 6. 83
	5-7	-0. 07 ± 7. 29
	6-8	0. 03 ± 2. 47
	7-9	0. 07 ± 2. 80
RADIAL	2/ 3-5	0. 29 ± 58. 21
	4-6	-0. 07 ± 51. 24
	5-7	0. 18 ± 44. 23
	6-8	0. 36 ± 38. 45
	7-9	0. 06 ± 30. 14

February 14 again as an example; the determined orbit of this day is compared with predicted orbits extrapolated from those of previous arcs. The reference orbit used is that from the arc (b). It can be regarded as a true orbit in this discussion.

Table 2 shows averages and rms of differences between the determined and predicted orbits; the predicted orbits are calculated from five slided 3-day arcs and the time interval from the final day of the arc to February 14 is 5-9 days. We can see from this table that in the along-track component, the error amounts to several hundred kilometers; while the average does not simply depend on the elapse of time, the rms, which acturally represents an amplitude of the oscillatory variation with the period of once-per-revolution of the orbit, increases with elapsed time. Therefore, it is concluded that the deviation is also controlled by the distribution of data within the arc, whereas the oscillatory error mainly depends on the time elapse.

Errors in the other component is significantly small compared with those in the along-track component. Especially the bias error (average) amounts only to several centimeters level, which is within an accuracy of determined orbit. The oscillatory error amounts to several meters in the cross-track component and to several tens of meters in the radial component. As a whole, errors in the cross-track component is at the smallest.

Reference

1) ADEOS/RIS Tracking Support Coordination Group: ADEOS/RIS Tracking Standards, (1996).

2) Barlier, F., Berger, C., Falin, J., Kockarts, G., Thuillier, G.: Atmospheric Model Based on Satellite Drag Data, Ann. Geophys., 34, 9-24, (1978).

3) Tapley, B.D., Watkins, M.M., Ries, J.C., Davis, G.W., Eanes, R.J., Poole, S.R., Rim, H.J., Schutz, B.E., Shum, C.K., Nerem, R.S., Lerch, F.J., Pavlis, E., Klosko, S.M., Pavlis, N.K., Williamson, R.G: The JGM-3 Gravity Model, XIX General Assembly of the European Geophysical Society, Grenoble, France, April 25-29, (1994).