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Estimation of the Positions of the First Order Control Points from Global Analysis of Ajisai and LAGEOS SLR Data †

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Abstract

The positions of 13 first order control points occupied by the HTLRS were estimated from global analysis of Ajisai and LAGEOS SLR data by using the University of Texas orbit analysis system, UTOPIA. The multi-arc strategy was applied in the analysis to reduce orbit error. The station coordinates except for the HTLRS were fixed to the SSC (CSR) 94 L 01 r 02. Comparison between Ajisai and LAGEOS SLR results suggests that accuracy of estimated station coordinates of the HTLRS in a global geocentric terrestrial reference frame be about 3-4 cm. The accuracy of the baseline length between the HTLRS and Simosato is about 2 cm. The results can be utilized for other geodetic studies, such as GPS local campaign or geoidal height estimation.
Key words : SLR, Ajisai, LAGEOS, first order control points, UTOPIA.

1. Introduction

The Hydrographic Department of Japan completed a transportable satellite laser ranging (SLR) station, the HTLRS, in 1987 (Sasaki, 1988a). The primary purpose of the HTLRS is to determine the positions of selected islands, called the first order control points (Fig. 1), for the national geodetic control. The first observation of the HTLRS was carried out at Titi Sima from January to March 1988. Until the end of 1996, the HTLRS occupied fourteen sites. In 1996, the second occupation by the HTLRS started at Titi Sima, which is expected to detect variation of baseline vectors due to regional plate motion or local crustal deformation.

The positions of the first order control points have been determined by Ajisai and LAGEOS SLR data by using a software, called HYDRANGEA, developed by the Hydrographic Department (Sasaki, 1984, Sengoku, 1986, Sasaki, 1988b). The HYDRANGEA estimates dynamical parameters such as a satellite state vector at an epoch as well as station coordinates. A batch estimation procedure based on the algorithm is used in the software. One of the major limitations of HYDRANGEA is that all the parameters are global and can be estimated only once in the whole arc. Hence, it is not a satisfactory tool for low orbiting satellites, such as Ajisai or Starlette, whose orbits have to be adjusted in shorter time intervals because of changes in forces which can not be simply modeled.

A very short arc analysis method, called SPORT (Successive Passes Orbit Revising Technique), was developed to improve the positioning accuracy of SLR geodetic results (Sengoku and Kubo, 1986). In SPORT, only two successive passes simultaneously observed by both the HTLRS and Simosato are used to determine the baselines. The estimated parameters are the initial satellite position and veloc-

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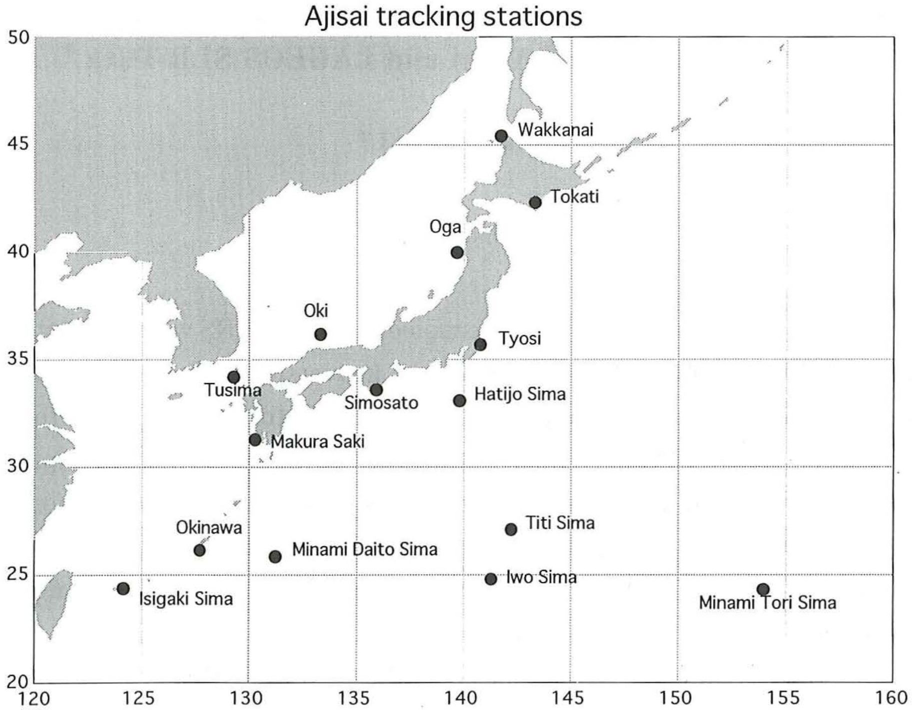

Fig. 1 SLR stations around Japan. Stations except for Simosato were occupied by the HTLRS.

ity at the epoch and the coordinates of the HTLRS. A relative positioning strategy is used and the estimated baseline length is known to be less affected by errors in the applied force models. The positioning results of the HTLRS from Ajisai SLR data obtained by SPORT are found in Sasaki (1990), Sengoku (1991), Fukushima et al. (1991), Sengoku et al. (1992), Sengoku et al. (1993), Sengoku et al. (1994), Suzuki and Fujita (1995), and Fujita (1995). Global LAGEOS data were also analyzed in five-day arcs and the mean positions of the first order control points were estimated by a statistical procedure. Comparison between these two results, computed from Ajisai and LAGEOS SLR data, shows good agreement of baseline length within a few cm, but more than 10 cm discrepancies exist in the absolute rectangular coordinates (Sengoku, 1991). This discrepancy might be caused by inaccuracy in the Ajisai SPORT analysis rather than LAGEOS five-day arcs because of the small amount of Ajisai SLR data utilized in the SPORT analysis. Consequently, geodetic results using global Ajisai data are required since LAGEOS data are not available at some HTLRS sites.

2. UTOPIA analysis

The positions of the HTLRS were determined by the University of Texas orbit analysis system, UTOPIA (McMillan, 1973, Tapley et al., 1985). This data analysis system implements a weighted least square batch procedure. The integration step size for Ajisai was 30 seconds. The UTOPIA used in this study was implemented on a CRAY supercomputer at the University of Texas Center for High Performance Computing.

Models and reference frames

The force and measurement models adopted in the analysis are shown in Table 1.

Adopted terrestrial reference frame was SSC (CSR) 94 L 01 r 02, which was determined by

Table 1. Adopted force models and measurement models for Ajisai orbit analysis

item	model and value	reference
geopotential	JGM-3 (70x70)	Tapley et al., 1994
solid Earth tide (dynamic effect)	IERS Standards, expanded to third and fourth degree	Eanes and Watkins, 1994
ocean tide model (dynamic effect)	Cheng et al. (1993)	Cheng et al., 1993
GM	398600.4415 km^3/s^2	IERS standards, 1992*
relativistic effect (dynamical effect)	IERS Standards, one body	Ries et al., 1988
atmospheric density	DTM	Barlier et al., 1978
radiation pressure of the Sun	Anisotropic reflection model	Sengoku et al., 1995
Earth's albedo	UTOPIA model	Knocke et al., 1987
infrared radiation of the Earth	UTOPIA model	Knocke et al., 1987
tropospheric delay	IERS Standards	Marini and Murray, 1980
center of mass	1.01m	Sasaki and Hashimoto, 1987
solid Earth and ocean loading (kinematic effect)	IERS Standards	IERS standards, 1992*
relativistic effect (propagation delay)	IERS Standards	Holdridge, 1967

* IERS standards (1992) was edited by McCarthy.

UTOPIA from LAGEOS SLR data (Eanes, private communication, 1994). The applied values of the position and velocity of Simosato at the epoch (MJD=47161) in a geocentric reference frame were,

(Simosato)

X=-3822388.341(m),

Y=3699363.588,

Z=3507573.175,

v_X=0.0023(m/yr),

v_Y=0.0057,

v_Z=-0.0036.

Permanent tide corrections to the station coordinates were not applied in the solution, that is, the estimated positions are not the true mean.

The EOP's were also fixed to the values of EOP (CSR) 94 L 01 r 02 (Eanes, private communication, 1994), which are consistent with the station coordinate set.

Analysis strategy for Ajisai

Generally, the quality of lower satellites' orbits, like Ajisai's, usually suffers from errors in the geopotential and atmospheric density models. Therefore, appropriate solution strategies are required to obtain an Ajisai solution that has accuracy comparable to LAGEOS.

The multi-arc strategy was applied in the analysis: the whole arc of Ajisai for a first order control point, typically a few months, was divided into 3-day arcs to improve orbit accuracy. The global parameters, which were estimated once for the entire arc, were the position of the HTLRS, the radiation pressure coefficient, and ocean tide coefficients for M_M, M_F, O_1, M_2, S_2, and K_2. From the comparison with LAGEOS results, it was found that tide parameters can accommodate some portion of errors in the applied force models. It should be notes that all the stations, except for the HTLRS, were fixed to SSC (CSR) 94 L 01 r 02. Other parameters were estimated in every 3-day arc. Empirical periodic accelerations in the radial and normal directions were introduced whose periods correspond to the orbital period of Ajisai. This type of empirical acceleration is very effective in removing orbit errors. The initial state vector of the satellite, the radial and normal components of once per revolution accelerations, and the Earth orientation parameters (EOP), x_p and y_p, were estimated every three days. The author estimated the atmospheric drag coefficient, *Cd*, once a day.

Analysis strategy for LAGEOS

The integration step size for LAGEOS was 300 seconds. The length of data arc for LAGEOS was 5days. The estimated parameters were also the same except for an along-track empirical acceleration instead of *Cd*.

3. Data description

Table 2 summarizes the used SLR data of the HTLRS. Both Ajisai and LAGEOS SLR data were analyzed though LAGEOS data were not always available in the HTLRS sites. The UTOPIA analysis was carried out for the

Table 2. Data summary of the HTLRS

site	Ajisai		LAGEOS	
	pass	NP*	pass	NP*
Titi Sima	34	420	11	234
Isigaki Sima	27	320	20	521
Marcus	43	438	29	602
Okinawa	44	740	8	139
Tusima	50	694	7	127
Oki	27	220		
Minamidaito	12	144		
Tokati	22	263		
Iwo Sima	25	375	8	104
Wakkanai	24	386		
Hatijo Sima	19	200		
Makura Saki	11	107		
Oga	12	131		

* NP: normal point

Table 3. The positions of the HTLRS by the UTOPIA multi-arc analysis of Ajisai SLR data

site	epoch (MJD)	duration (day)	*X* (m)	*Y* (m)	*Z* (m)
Titi Sima	47202	42	-4491072.430	3481527.879	2887391.822
Isigaki Sima	47383	42	-3265753.817	4810000.887	2614265.484
Marcus	47566	57	-5227190.038	2551882.420	2607609.819
Okinawa	47742	50	-3505323.671	4532740.995	2792253.144
Tusima	47825	42	-3344473.902	4087076.260	3564512.471
Oki	48169	33	-3536204.454	3749974.199	3744418.399
Minamidaito	48278	21	-3786331.491	4320316.234	2761963.938
Tokati	48524	60	-3788457.853	2820917.933	4271798.293
Iwo Sima	48676	51	-4522801.792	3622640.333	2656232.066
Wakkanai	48883	48	-3522929.074	2779243.452	4517637.387
Hatijo Sima	49041	36	-4087880.274	3451764.270	3460902.388
Makura Saki	49402	42	-3528449.709	4162495.194	3291166.921
Oga	49588	21	-3731492.582	3164405.358	4078228.577

period when the HTLRS was operational at the first order control points, which was a few months for a site.

4. Estimation of the positions of the first order control points

Table 3 shows the estimated coordinates of thirteen first order control points from Ajisai SLR data.

Table 4 gives the LAGEOS results obtained by using the same force/measurement models and reference frames as the Ajisai analysis except for surface force models and degree/order of the geopotential field which were truncated at 20 in LAGEOS analysis.

5. Accuracy of the positions of the HTLRS estimated by UTOPIA multi-arc analysis

Table 5 shows the difference between the Ajisai and LAGEOS UTOPIA results for the sites where LAGEOS tracking data were available, which implies the accuracy of Ajisai, or

Table 4. The positions of the HTLRS by the UTOPIA multi-arc analysis of LAGEOS SLR data

site	epoch (MJD)	duration (day)	X (m)	Y (m)	Z (m)
Titi Sima	47202	50	-4491072.458	3481527.892	2887391.817
Isigaki Sima	47383	50	-3265753.804	4810000.907	2614265.510
Marcus	47566	60	-5227190.049	2551882.424	2607609.813
Okinawa	47742	50	-3505323.678	4532741.002	2792253.105
Tusima	47825	35	-3344473.901	4087076.249	3564512.430
Iwo Sima	48676	45	-4522801.761	3622640.492	2656231.997

Table 5. Differences between the Ajisai and LAGEOS UTOPIA results
(baseline length and rectangular coordinates)

site	baseline length (m)	ΔX (m)	ΔY (m)	ΔZ (m)	D* (m)
Titi Sima	0.020	-0.028	0.013	-0.005	0.031
Isigaki Sima	0.005	0.013	0.020	0.026	0.035
Marcus	0.008	-0.011	0.003	-0.005	0.013
Okinawa	0.028	-0.008	0.007	-0.039	0.040
Tusima	-0.011	0.000	-0.011	-0.041	0.042
Iwo Sima	0.023	0.031	0.159	-0.069	0.176

* $D=\sqrt{\Delta X^2+\Delta Y^2+\Delta Z^2}$

(geodetic coordinates)

site	latitude (")	longitude (")	horizontal (m)	height (m)
Titi Sima	-0.0006	0.0003	0.019	0.024
Isigaki Sima	0.0006	-0.0008	0.029	0.018
Marcus	-0.0004	0.0001	0.011	0.007
Okinawa	-0.0013	0.0001	0.040	-0.009
Tusima	-0.0009	0.0003	0.030	-0.030
Iwo Sima	-0.0031	-0.0051	0.172	0.039

LAGEOS, SLR analysis, though the difference depends on analysis softwares and on the parameters estimated in the analysis. The baseline length is the straight line distance between the HTLRS and Simosato.

From Table 5, the accuracy of the estimated positions of the HTLRS in global geocentric terrestrial reference frame is inferred to be about 3-4 cm except for Iwo Sima. The accuracy of the HTLRS horizontal position is about 3cm and smaller for the vertical component. The accuracy of the baseline length between the HTLRS and Simosato is 2 cm, which is better than the other components.

6. Conclusion

It should be noted that LAGEOS SLR data obtained by the HTLRS is not abundant due to its low system size and the difference may be caused by the insufficient LAGEOS data. At Iwo Sima, the difference in horizontal position is large though differences in height and baseline length are comparable to other sites. It might be due to insufficient sky coverage of the LAGEOS satellite or problems in LAGEOS data quality of the HTLRS.

Table 5 suggests that the range bias of the HTLRS is stable and independent of satellite, if any, which means the height determined by the HTLRS is reliable. The range bias of Simosato SLR station is assumed 7 cm in the analysis. Analysis of colocation observation between the HTLRS and other SLR station is required.

The positions of the sites where the HTLRS was deployed are precisely determined by using Ajisai SLR data in a geocentric reference frame. These sites can be utilized as fiducial points for other geodetic studies, such as GPS local campaign or geoidal height estimation. The HTLRS will occupy several sites from 1996 in order to detect velocities of the sites, which will reveal tectonic motion in Japanese territory.

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あじさいとラジオスのSLRグローバル解析による一次基準点位置決定（要旨）

仙石　新

水路部が可搬式レーザー測距装置（HTLRS）によって観測を行った13の一次基準点について，測地衛星「あじさい」と「ラジオス」のレーザー測距（SLR）データをテキサス大学の軌道解析ソフトウエア「UTOPIA」を用いて解析し，一次基準点の位置をグローバルな地球基準座標系に準拠して決定した。多アーク法を用い，軌道誤差の低減を図った。HTLRS-1以外の観測点の座標は，ラジオスのSLR解析により推定されたSSC（CSR）94L01r02に固定した。あじさいとラジオスの成果の比較から，HTLRS-1の地心位置の決定確度は3-4cmであることが示された。下里とHTLRS-1の基線長の決定確度は約2cmであった。本成果を用いることにより，GPSによる測量やジオイド決定などの精度向上が図れる。