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Braulio V. Sanchez

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Braulio V. Sanchez
Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, MD

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Abstract

The Japanese Experimental Geodetic Satellite "Ajisai" was launched on August 12, 1986. In response to the TOPEX-POSEIDON mission requirements, the Goddard Space Flight Center Space Geodesy Branch and its associates are producing improved models of the Earth's gravitational field. With the launch of Ajisai, we now have precise laser data which can be used to test many current gravity models.

The testing of the various gravity field models show improvements of more than 70% in the orbital fits when using GEM-T1 and GEM-T2 relative to results obtained with the earlier GEM-10B model. The GEM-T2 orbital fits are at the 13-cm level (RMS).

The results of the tests with the various versions of the GEM-T1 model indicate that the addition of satellite altimetry and surface gravity anomalies as additional data types should improve future gravity field models.

Introduction

The Japanese Experimental Geodetic Satellite "AJISAI" was launched on August 12, 1986. With the launch of Ajisai, we now have precise laser data which can be used to test many current gravity models. The satellite is spherical in shape, covered with 1436 uniformly distributed laser reflectors and 318 solar reflectors. It has a diameter of 2.15 meters and a mass of 685 kg. Its orbit is almost circular, the difference between the radii at perigee and apogee being of the order of 10 km. Table 1 shows the main orbital characteristics for Ajisai. The main purpose of the satellite is to provide positioning data to the Hydrographic Department of Japan. Laser range and photographic data are acquired by tracking Ajisai. The data are used to determine the location of isolated islands, to adjust the geodetic network and to determine the relation between the Tokyo Datum and those of other parts of the world. Other applications include the determination of plate motion and crustal movements. More information on Ajisai is given by Sasaki and Hashimoto (1987).

An estimate of the magnitude of the gravitational perturbation on the Ajisai orbit is displayed in Table 2. This table shows the perturbations for a given degree (L) and order (M) harmonic in a spherical decomposition of the field. These results were obtained using a harmonic analysis based on linear perturbation theory (Kaula, 1966) assuming Kaula's Rule for the size of the coefficients. The numbers represent the RMS of total perturbation from the along-track, cross-track and radial directions. The units are centimeters. An asterisk entry signifies a value greater than 10 m. The largest perturbations are clustered at the lower degree and order end of the spectrum. The largest entry is due to the (2,0) terms with a value greater than 1.2 (10^6 cm). Other large values are (3,0) $\approx$ 4.7 (10^5 cm), (4,0) $\approx$ 5.5 (10^5 cm), (5,0) $\approx$ 1.9 (10^5 cm). The 3 asterisks in the 12th order column correspond to (13,12)=2531 cm, (15,12)=3350 cm and (17,12)=1675 cm. There is a primary resonance of order 12 with an associated periodicity of 3.3 days.

The TOPEX-POSEIDON mission was derived from requirements for a satellite altimetric system established by the TOPEX Science Working Group (NASA, 1981) and by the POSEIDON report to the French Centre National d'Etudes Spatiales (CNES, 1983). In order to fulfill the accuracy requirements of the mission, the radial component of the satellite position must be determined continuously to within ±13 cm. This accuracy requirement was at least a factor of three beyond the capability of Earth's gravity models existing in 1985.

In response to the TOPEX-POSEIDON requirements, the GSFC Space Geodesy Branch and its associates are producing improved models of the Earth's gravitational field. One of these models, designated GEM-T1 (Marsh et al., 1988) was derived exclusively from satellite tracking data acquired on 17 different satellites which ranged in inclination from 15 degree to polar. Almost 800,000 observations were used, half of which were from third generation laser systems. GEM-T1 includes spherical harmonic coefficients complete to degree 36.

This "satellite-only" model, referred to as GEM-T1, did not include data from the Japanese satellite "AJISAI", which was not available when developing this model. The analysis of these data should then provide a good test for the accuracy of the new gravity field. It will also test the accuracy of the laser data, the geodetic models and the software system used in the procedure.

Ajisai data has been included in the development of GEM-T2 (Marsh et al., 1989B), the latest of the Goddard Space Flight Center gravity field models. Just as GEM-T1, this model was produced entirely from satellite tracking data. However, it was derived from a more extensive data set: a total of 2.4 million observations obtained from 31 different satellites. It includes more than 600 coefficients above degree 36, which was the limit for GEM-T1.

Orbit Determination

The laser-range data reduction was performed using the GEODYN least squares parameter estimation and orbit determination system (Putney, 1977). The GEODYN system has the capability of estimating the state vector (position and velocity of the satellite) as well as many other kinematic and dynamic parameters including those appearing in the force models such as atmospheric drag coefficients (C_D) and solar radiation pressure coefficients (C_R).

The force models included earth and ocean tides as well as atmospheric drag and solar radiation pressure effects. The earth tides consisted of the frequency dependent Love number k_2 computed by Wahr (1979), based upon the Earth Model 1066A of Gilbert and Dziewonski (1975). The GEM-T1 ocean tides were modeled with 600 coefficients among which a subset of 66 long wavelength terms from 12 major tidal constituents were adjusted (Christodoulidis et al., 1986). The GEM-T2 tidal model includes adjustment for 90 coefficients. The tidal deformations are modeled by the Love and Shida numbers h_2 and l_2. The atmospheric model used is the 1971 Jacchia (Jacchia, 1971).

An arc length of 5 days was chosen for the reduction of the data. Past experience indicates that a 5 to 7 day arc length is optimum for this type of geodetic satellite orbit. This time span provides strong dynamic content without incurring excessive nonconservative force effects.

Dynamic editing of observations was performed in GEODYN based upon a 3.5-sigma criterion and a 10-degree minimum elevation angle cutoff. Additional editing was done in a post-GEODYN residual analysis program. In this residual analysis procedure, individual passes were edited on the basis of a maximum allowable RMS, a maximum timing bias, a minimum number of observations, and a maximum elevation angle.

The full rate laser range data was obtained from the National Space Science Data Center at the Goddard Space Flight Center, it includes data from stations in many parts of the world.

Results

The results of Ajisai orbit determination using GEM-T1 were incorporated into the solution for the GEM-T2 gravity field model. Matrices containing the partial derivatives of the observations with respect to the variables in the solution were created for 36 arcs. The observations were subjected to a station dependent sampling rate which produced a more balanced distribution in the number of observations from each of the different tracking stations. The position of the rotation pole was not included as an estimated parameter in these arcs, which were used to generate the normal equations. The results are shown in Table 3. The average RMS of fit for the 36 arcs is 22.2 cm.

The results shown in Table 4 through 10 were obtained from normal points. The normal points are created from the original laser range observations. They have several advantages:

a) The noise is reduced without losing any significant dynamical content of the data.

b) Less voluminous data sets are produced which makes orbit solutions more efficient.

c) The contributions from the different tracking stations is more balanced, avoiding dominance by one particular station due to higher data acquisition rates.

A more detailed explanation and validation of the construction of normal points can be found in Torrence et al. (1984).

Table 4 shows the results of the orbit determination when using GEM-T2, which included Ajisai data in its development. The set of estimated parameters included the epoch state vector, daily C_D's, one 5-day C_R and an adjustment for the average Earth's polar motion and change in length of day over the arc. Twelve 5-day arcs covering the months of March and April 1987 have been processed plus one 5-day arc in February. The data consisted of normal points. The average RMS of fit for the 13 arcs is 13.0 cm.

Table 5 displays the results for the 13 arcs mentioned above with a further breakdown according to tracking station; the average RMS values per station vary from 7.2 cm (Grasse, France) to 18.1 cm (Yaragadee, Australia). Individual arc RMS values also show variation with a minimum of 1.8 cm (Hollas, Hawaii) and a maximum of 31.8 cm (Yaragadee, Australia).

Table 6 displays the estimated values of the daily drag parameters, C_D's, and 5-day solar radiation pressure coefficients, C_R's, obtained for each of these arcs. These values were obtained from a largely free adjustment where the nominal uncertainty was set equal to ± 10 in both cases. Table 6 also gives the estimated values for the uncertainty (σ) associated with each of the estimated C_D's and C_R's.

We observe that in some cases a negative value for C_D was obtained, usually this result occurs when a data set is especially weak and poorly distributed. In particular, the last 2 days of the March 11 arc and the last day of the March 21 arc provide examples of this situation. These results can be compared to those obtained when estimating the orbits using only one C_D for every 5-day arc, which are given in Table 7. There are no negative values for C_D and the associated uncertainties are much smaller than the values obtained when solving for daily C_D's. The average RMS has increased by 1.7 cm to a value of 14.7 cm. Table 8 exhibits the results obtained when processing the arcs as described above with the polar motion adjustment eliminated. These results can be compared to those given in Table 4. The average RMS has increased by 4.3 cm to a value of 17.3 cm.

The changes in the pole position with respect to the results of Table 4 are displayed in Table 9. The changes in the x and y components are given in centimeters at the surface of the Earth and the change in the length of day is given in terms of (A1-UT1) in milliseconds.

Finally Table 10 presents the results obtained when processing one 5-day arc using several different gravity field models. The data consisted of 900 normal points generated using the GEM-T1 gravity field model except for the GEM-T2 case where the set of 888 normal points was created using GEM-T2.

The GEM-L2 and GEM-10B models represent the state-of-the-art in the early 1980's. The GEM-L2 model is complete to degree 20, it has 549 coefficients. The GEM-10B model is complete to degree 36, with 1366 coefficients. GEM-L2 was developed from satellite tracking data only, GEM-10B incorporated satellite tracking data, information from surface gravity anomaly blocks and GEOS-3 altimetry data. The "GEM-T1 + altimetry" gravity model is a solution obtained using the tracking data of GEM-T1 with altimetry data obtained from the SEASAT oceanographic satellite. The "GEM-T1 + surface gravity" (PGS3226, Marsh et al., 1989A) gravity field model is a solution obtained using the satellite tracking data plus 1°x1° surface gravity anomalies obtained from Ohio

State University. The "GEM-T1 + surface gravity + altimetry" (PGS3337, Marsh et al., 1989A) incorporates the 3 types of data. The percentage improvement in RMS relative to the GEM-10B results ranges from 73% to 78%.

Evaluation of Results

The results of the orbit determination tests indicate that the polar motion adjustment has a greater effect on the RMS of fit than the fivefold increase in the number of estimated drag coefficients. All things being equal, there is still a wide variation in the accuracy of the orbital fits obtained for the different tracking stations.

The results of the tests with the various versions of the GEM-T1 model indicate that the addition of satellite altimetry and surface gravity anomalies as additional data types should improve future gravity field models. Projected orbit errors due to commission errors in the gravitational field have been computed for Ajisai (Marsh et al., 1989B). Those computations indicate that the radial component of the orbit error for the GEM-T2 gravity model equals 6 cm for a 5-day arc. A similar calculation using a GEM-T2 model extended to complete degree and order 50 (PGS-3520) and making use of surface gravity data and SEASAT altimetry yields a 4 cm radial component for the orbit error. To improve the orbit determination accuracy for Ajisai to a greater extent than indicated above, it might be necessary to develop better models of the non-conservative forces acting on the satellite such as atmospheric drag and solar radiation pressure. The Center for Space Research at the University of Texas at Austin and the Space Geodesy Branch at the Goddard Space Flight Center are pursuing lines of research in this direction.

Conclusions

The testing of the various gravity field models show improvements of more than 70% when using GEM-T1 and GEM-T2 relative to results obtained with the earlier GEM-10B model. The results of the normal point data reduction using GEM-T2 show orbital fits at the 13 cm level (RMS). The results for the GEM-T1 models indicate an improvement in accuracy as the gravity model incorporates more data of different types and as the size of the gravity field increases.

In summary, the Japanese satellite Ajisai has proven to be a valuable calibration tool for geodynamic applications in addition to its other geodetic and geophysical applications. The GEM-T1 and GEM-T2 gravity field models constitute significant improvements upon the previous models.

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mean altitude:	1500 km
eccentricity:	0.0006
inclination:	50°
orbital period:	1.930 hours
rotation period of perigee:	142.53 days
nodal period:	117.53 days
primary resonance:	order 12 (3.3 days beat period)

TABLE 1. Orbital characteristics for Ajisai

L \ M	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
2	*	0	*																																		
3	*	*	*	*																																	
4	*	*	*	*	*																																
5	*	*	*	*	*	*																															
6	*	*	*	*	*	*	823																														
7	*	*	700	996	817	961	837	504																													
8	*	*	*	*	623	971	802	513	296																												
9	*	385	643	276	392	341	428	488	370	205																											
10	*	*	619	437	441	207	353	385	321	231	137																										
11	*	602	113	235	143	179	172	191	281	272	180	107																									
12	*	623	318	255	131	194	112	135	187	204	199	175	214																								
13	*	57	166	66	99	79	88	103	88	156	190	163	*	259																							
14	*	306	190	90	114	52	85	69	60	94	137	207	578	121	26																						
15	*	163	38	61	40	46	47	44	66	52	84	112	*	794	85	19																					
16	*	206	68	76	31	52	29	37	42	34	53	112	500	179	49	19	11																				
17	*	39	44	23	26	24	23	30	23	42	42	54	*	822	156	45	14	8																			
18	*	68	61	21	33	15	23	19	17	26	25	41	233	127	51	26	14	7	5																		
19	*	43	17	15	14	11	15	11	19	15	26	31	130	311	124	59	26	11	5	3																	
20	774	68	17	24	9	15	9	10	11	9	17	25	93	46	28	22	15	10	5	3	2																
21	883	20	10	9	6	8	5	9	6	13	13	18	353	96	29	35	26	15	8	3	1	0															
22	886	19	19	6	10	5	6	5	4	7	6	14	65	24	10	9	9	9	7	4	2	0	0														
23	552	10	7	3	5	2	5	3	6	5	8	11	47	99	24	5	11	11	8	5	3	1	0	0													
24	259	22	6	7	3	4	3	2	3	2	5	6	30	17	6	4	3	4	5	5	4	2	1	0	0												
25	183	8	2	3	1	2	1	3	1	4	4	6	83	18	12	9	2	3	5	5	4	3	1	1	0	0											
26	275	7	6	2	2	2	1	2	0	2	1	4	20	7	3	2	2	1	1	2	3	3	2	1	4	6	0										
27	226	1	2	0	1	0	1	0	1	1	2	4	15	30	6	2	3	2	0	2	2	2	2	2	3	1	0	0									
28	115	6	2	2	1	1	1	0	0	0	1	2	10	5	1	1	1	0	1	0	1	2	2	2	8	23	1	0	0								
29	16	3	0	0	0	0	0	0	0	1	1	2	21	5	4	2	0	1	1	0	0	1	2	2	5	4	0	0	0	0							
30	81	3	1	1	0	0	0	0	0	0	0	1	6	2	1	0	0	0	0	0	0	0	1	1	10	40	2	0	0	0	0						
31	83	0	0	0	0	0	0	0	0	0	0	1	5	9	1	1	1	0	0	0	0	0	0	1	4	6	0	0	0	0	0	0					
32	50	1	1	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	6	40	4	1	0	0	0	0	0				
33	11	0	0	0	0	0	0	0	0	0	0	0	5	2	1	0	0	0	0	0	0	0	0	0	2	4	0	0	0	0	0	0	0	0			
34	22	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	20	3	1	0	0	0	0	0	0	0		
35	27	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
36	20	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
M	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36

TABLE 2. Spectrum of the orbital perturbations for Ajisai for a gravity field with spherical harmonic coefficients of degree "L" and order "M" following Kaula's Rule. The perturbations are the square root of the sum of the squares of the along-track, cross-track and radial components (in cm). An asterisk means a value greater than 1000.

Epoch (YYMMDD)	No. Obs.	RMS (cm)	No. Stations
860818	5859	31.2	10
860823	3416	29.4	12
860828	2197	18.8	10
860901	5305	34.4	12
860906	3803	22.8	12
860911	3281	22.6	12
860916	3471	21.2	11
860921	3663	27.7	9
860926	3003	24.9	9
861001	3053	26.2	9
861006	5480	21.6	10
861011	3543	21.6	10
861016	3503	29.7	13
861021	3514	23.5	10
861026	3039	24.4	10
861101	3280	26.4	11
861106	3584	22.4	11
861111	4306	21.0	12
861116	2538	18.7	11
861121	4319	22.4	11
861126	5425	23.1	11
861201	5605	25.5	11
861206	2854	24.0	9
861211	1678	21.8	6
861216	2876	24.4	8
861221	1208	23.9	7
861226	898	13.8	5
870106	6495	20.8	7
870111	7059	18.2	7
870116	4743	10.4	7
870121	4831	20.0	9
870126	9173	23.5	11
870201	7522	18.7	7
870206	6414	15.5	10
870211	2705	10.4	8
870216	12558	17.8	9

RMS AVERAGE = 22.2 CM

TABLE 3. Ajisai Orbit Determination Results. GEM-T1 gravity field model. The set of estimated parameters included the following:

(a) epoch state vector (position and velocity)
(b) one atmospheric drag scaling coefficient (C_D) per day
(c) one solar radiation pressure scaling coefficient (C_R) per arc

EPOCH (YYMMDD)	OBS	RMS (CM)
870216	888	14.2
870301	474	17.3
870306	209	6.2
870311	251	11.8
870316	578	15.9
870321	201	15.0
870326	457	11.4
870401	390	11.9
870406	302	13.3
870411	369	13.7
870416	479	11.7
870421	938	13.7
870426	725	13.4

RMS AVERAGE = 13.0 CM

TABLE 4. Ajisai Orbit Determination Results. GEM-T2 gravity field model. Normal points. Solving for the epoch state vector, daily C_D, 5-day C_R, and the position of the rotation pole.

EPOCH		SIMOSATO (JAPAN)	RGOLAS (U.K.)	YARAG1 (AUSTRALIA)	MAZATL1 (MEXICO)	GRAZ (AUSTRIA)	QUIN1092 (CALIF.)	GRASSE (FRANCE)	AREQUIPA (PERU)	LAGU1102 (CALIF.)	GORF1052 (MD.)	HOLLAS (HAWAII)	MATERA (ITALY)	ZIMRWALD (SWITZERLAND)	TOTAL (PER ARC)
870216	OBS		97	14	59		152	11	159	176	112		108		888
	RMS		14.8	31.8	5.7		8.9	10.9	19.0	11.7	12.9		16.0		14.2
870301	OBS	17				84		136	166		56		15		474
	RMS	22.7				18.3		10.8	19.0		20.2		14.9		17.2
870306	OBS	25			8	49			59	6	38	24			209
	RMS	8.5			2.5	3.0			7.0	13.1	4.5	6.3			6.2
870311	OBS	56				26		24	106		39				251
	RMS	7.7				18.3		3.6	12.1		12.1				11.8
870316	OBS	136		67	21		58		216	34			46		578
	RMS	17.0		13.9	26.9		14.5		15.4	10.7			14.1		15.9
870321	OBS	49							127				25		201
	RMS	21.4							12.1				7.6		15.0
870326	OBS	111			62				263				21		457
	RMS	5.8			13.2				12.8				4.4		11.4
870401	OBS	43		79					251			17			390
	RMS	11.3		10.6					12.1			13.2			11.9
870406	OBS	12		29	39				196		11	15			302
	RMS	11.4		11.6	11.3				13.6		22.1	1.8			13.3
870411	OBS	48		16				33	194	19			42	17	369
	RMS	9.0		22.7				4.5	14.7	24.3			6.3	5.0	13.7
870416	OBS	68				31	20	90	193	25			33	19	479
	RMS	11.9				15.4	10.4	7.8	13.0	11.8			5.1	11.1	11.7
870421	OBS	55				106	151	100	149	121	4		221	31	938
	RMS	18.2				9.8	11.6	10.0	16.6	12.6	9.0		15.2	10.8	13.7
870426	OBS	18				172	87	32	115	34	51	25	154	37	725
	RMS	26.2				8.9	10.1	2.9	16.7	12.3	19.4	19.4	12.5	10.9	13.4
AVERAGES	OBS	53	97	41	37	78	93	60	168	59	44	20	73	26	481
	RMS	14.3	14.8	18.1	11.9	12.3	11.1	7.2	14.2	13.8	14.3	10.2	10.7	9.4	13.0
TOTAL	OBS	638	97	205	189	468	468	426	2194	415	311	81	665	104	6261

TABLE 5. Ajisai Orbit Determination Results. GEM-T2 gravity field. Normal points. RMS results in centimeters. Results given for individual tracking stations.

EPOCH (YYMMDD)								
870216	C_D	2.7	3.4	5.4	3.6	0.4	C_R	1.03
	σC_D	9.9	2.5	1.7	1.4	2.3	σC_R	0.01
870301	C_D	6.5	2.1	5.3	2.5	2.8	C_R	1.03
	σC_D	6.2	3.0	2.3	2.0	6.5	σC_R	0.03
870306	C_D	2.0	4.7	1.7	4.0	2.1	C_R	0.99
	σC_D	5.6	4.8	3.8	4.5	8.6	σC_R	0.03
870311	C_D	3.5	3.0	5.5	-0.4	-1.7	C_R	1.02
	σC_D	4.0	3.5	4.3	4.7	9.2	σC_R	0.03
870316	C_D	4.5	1.9	5.1	2.8	4.6	C_R	1.00
	σC_D	3.6	1.9	1.6	1.9	3.8	σC_R	0.01
870321	C_D	4.2	4.2	4.0	1.8	-0.8	C_R	0.99
	σC_D	8.2	6.7	4.7	2.9	6.3	σC_R	0.06
870326	C_D	1.5	3.7	3.5	2.6	1.0	C_R	1.03
	σC_D	4.2	1.9	2.1	2.0	2.7	σC_R	0.02
870401	C_D	5.6	2.5	1.5	4.9	2.2	C_R	0.96
	σC_D	6.0	1.9	1.6	1.9	9.9	σC_R	0.03
870406	C_D	3.0	5.6	1.1	5.9	1.8	C_R	1.01
	σC_D	7.5	4.7	3.2	1.9	9.7	σC_R	0.03
870411	C_D	3.5	4.4	3.0	5.2	3.3	C_R	0.92
	σC_D	8.1	3.7	2.2	2.1	4.5	σC_R	0.03
870416	C_D	4.5	5.2	2.9	8.3	6.1	C_R	0.99
	σC_D	3.4	2.2	2.2	2.4	4.1	σC_R	0.01
870421	C_D	6.6	4.7	4.8	7.4	3.6	C_R	1.00
	σC_D	3.3	1.7	1.2	1.5	3.4	σC_R	0.01
870426	C_D	6.1	5.3	5.7	6.3	5.2	C_R	1.00
	σC_D	3.3	2.0	1.5	1.5	2.2	σC_R	0.01

TABLE 6. Estimated values of the daily C_D's and 5-day C_R's and the associated uncertainties (σC_D, σC_R).

EPOCH (YYMMDD)	OBS	RMS (CM)	C_D	σC_D	C_R	σC_R
870216	895	17.1	4.0	0.17	1.04	0.01
870301	470	17.5	3.7	0.23	1.03	0.02
870306	216	7.6	3.2	0.33	1.00	0.02
870311	245	10.9	3.6	0.27	0.97	0.04
870316	578	16.4	3.6	0.13	1.00	0.01
870321	201	18.6	3.1	0.31	0.97	0.06
870326	462	13.3	3.1	0.15	1.03	0.02
870401	393	14.3	2.8	0.20	0.96	0.03
870406	300	16.0	3.6	0.24	1.02	0.03
870411	368	14.0	4.0	0.20	0.92	0.02
870416	491	17.7	5.0	0.13	0.99	0.01
870421	941	14.8	5.5	0.09	1.01	0.01
870426	726	13.6	5.8	0.13	1.00	0.01

AVERAGE RMS = 14.7

TABLE 7. Ajisai Orbit Determination Results. GEM-T2 gravity field model. Normal points. Estimating the epoch state vector, one 5-day C_D, one 5-day C_R and the position of the rotation pole.

EPOCH (YYMMDD)	OBS	RMS (CM)
870216	898	16.5
870301	474	18.1
870306	210	17.7
870311	250	18.1
870316	579	19.5
870321	201	15.1
870326	458	15.5
870401	389	16.8
870406	303	21.9
870411	369	15.7
870416	481	17.9
870421	931	17.0
870426	728	15.7

RMS AVERAGE = 17.3 CM

TABLE 8. Ajisai Orbit Determination Results. GEM-T2 gravity field model. Normal Points. Solving for the epoch state vector, daily C_D, 5-day C_R.

EPOCH (YYMMDD)	Δx (CM)	Δy (CM)	A1-UT1 (MILLISECONDS)
870216	13.3	22.8	0.81
870301	16.5	61.5	0.43
870306	-0.6	56.5	-1.70
870311	7.6	53.9	-0.30
870316	7.6	39.3	-0.40
870321	3.8	5.0	-0.34
870326	-2.5	3.2	0.009
870401	15.2	38.7	-1.14
870406	12.0	46.3	-1.37
870411	-12.6	39.3	0.006
870416	20.3	38.0	-0.93
870421	3.1	43.8	-1.36
870426	5.0	36.8	0.22

TABLE 9. Changes in the position of the pole at the Earth's surface. Δx and Δy in centimeters, A1-UT1 in milliseconds. Results correspond to RMS results given in Table 4.

GRAVITY FIELD	RMS FIT
GEM-L2 [20,20]	78.5 CM
GEM-10B [36,36]	67.0
GEM-T1 [36,36]	18.0
GEM-T1 [50,50]	17.0
GEM-T1 + SURF GRAV [36,36]	16.6
GEM-T1 + SURF GRAV [50,50]	16.0
GEM-T1 + SURF GRAV + ALT [36,36]	15.2
GEM-T1 + SURF GRAV + ALT [50,50]	14.4
GEM-T2 (888 Normal Points)	14.2

TABLE 10

GRAVITY FIELD TESTING

SATELLITE: AJISAI
TIME PERIOD: 5 DAY ARC, EPOCH FEB. 16, 1987
PARAMETERS ADJUSTED: DRAG PER DAY, SOLAR RADIATION PRESSURE, POLAR MOTION
OBSERVATIONS: 900 LASER NORMAL POINTS

[A, B]: SPHERICAL HARMONIC EXPANSION TO DEGREE A AND ORDER B

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15. Supplementary Notes

16. Abstract

The Japanese Experimental Geodetic Satellite "Ajisai" was launched on August 12, 1986. In response to the TOPEX-POSEIDON mission requirements, the GSFC Space Geodesy Branch and its associates are producing improved models of the Earth's gravitational field. With the launch of Ajisai, we now have precise laser data which can be used to test many current gravity models.

The testing of the various gravity field models show improvements of more than 70 percent in the orbital fits when using GEM-T1 and GEM-T2 relative to results obtained with the earlier GEM-10B model. The GEM-T2 orbital fits are at the 13-cm level (RMS).

The results of the tests with the various versions of the GEM-T1 model indicate that the addition of satellite altimetry and surface gravity anomalies as additional data types should improve future gravity field models.

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