Lunar occultation observations in 1996

Summary - In 1996, timing data of 969 lunar occultations of reliable quality, including 589 photoelectric observations, were obtained at four astronomical stations of JHD. Reduction and analysis give the following results for the moon's longitude and latitude:

$$\Delta L = +0''.33 \pm 0''.02(m.e.)$$
$$\Delta B = -0''.24 \pm 0''.02(m.e.)$$

for the epoch 1996.5 on the FK5 system.

Key words : occultation - moon's coordinates

This is a continuation of the report series of occultation observations made by the Hydrographic Department of Japan (JHD) and contains the data for 1996.

The constants and data adopted in this reduction for the lunar occultation data in 1996 are accordant with the IAU (1976) system.

1. Observations

Observations of occultations of stars by the moon were continued in 1996 at four astronomical stations of JHD. One staff member of the Sirahama Hydrographic Observatory, and three of the Simosato Hydrographic Observatory were changed in April, 1996. JHD also made lunar grazing occultation at Maebaru and Naze in 1996.

In total, 969 timing data were acquired through the year, including 589 photoelectric data. Among them, 969 data are adopted in the present report.

The H92 Catalogue was compiled by the stars in the ACRS (Corbin and Urban, 1991), PPM (Roser and Bastian, 1989, 1992), FK5 (Friche et al., 1988), etc.

Table A gives the individual numbers of lunar occnltation observations accepted in this report. Parenthesized figures in the third column are the numbers of observations which are accompanied by simultaneous photoelectric timing.

Table 1 shows the geodetic coordinates (Tokyo Datum) and geocentric rectangular coordinates (world geodetic system) of the stations, the instruments and observers.

Records of observations are listed on the left hand pages of Table 2 excepting the last column.

Explanations of each column are given on pages 9―11.

Table A. Number of lunar occultation data acquisitions

Station	Photoelectric	Visual	Total
Head Office, Tokyo	6	13(2)	19
Sirahama Hydrogr. Obs.	30	134(21)	164
Simosato Hydrogr. Obs.	204	119(73)	323
Bisei Hydrogr. Obs.	349	87(57)	436
Maebaru(grazing)		12	12
Naze(grazing)		15	15

2. Reduction

According to the recommendations of the International Astronomical Union (IAU) in 1976, new methods and theories have been adopted for the Japanese Ephemeris since the edition for 1985. (See Japanese Ephemeris 1986.)

The reduction for occultations of stars by the moon was made using the Japanese Ephemeris (IAU 1976 system) for lunar position and a corresponding star coordinate system, FK5. For the geocentric coordinates of the observatories a coordinate system, Marine Geodetic Control Network, was used. Marine Geodetic Control Network was derived by the satellite laser ranging (SLR) at the Simosato Hydrographic Observatory and other laser sites in the world (T. Tatsuno and M. Fujita, 1994).

The detailed scheme of the reduction is in No.12 of this series.

A. Constants and basic data

a. Ephemeris	the Japanese Ephemeris, 1996.
b. Star place	H92 and H92sup Catalogue.
c. Moon	Independent argument: TDT (TAI＋32.184),
	radius: $\kappa = \frac{\sin(\sigma_0)}{\sin(\pi_0)} = 0.2725076$(IAU,1984),
	limb correction: Watts' charts (1963).
d. Earth	Equatorial radius: a_e ＝ 6378140m (IAU,1976),
	rotation axis (x_p,y_p) and UT1-UTC : IERS Annual Report for 1996.
e. Station	Earth centered coordinates (*u,v,w*): *Marine Geodetic Control Network.*
	Tranformation parameters from the Tokyo Datum to this system:
	$\Delta u = -146.23$, $\Delta v = +507.57$, $\Delta w = +681.86$m
	(T. Tatsuno and M. Fujita, 1994).
	Refraction height h_r for the standard atmosphere (Uniwa, unpublished):
	$h_r = 2.3 + 2.20 \cot^2 a - 0.0045 \cot^4 a$ *(m),*
	a : altitude of the star.

B. Computations

Computations are made with a work station EWS 4800 using the following programs.

A3941: arrangement of relevant data (Y. Ganeko, 1973 and M. Kawada, 1978),
A3942: main calculation (Y. Ganeko, 1973, M. Kawada, 1978 and A. Senda, 1985),
A3927, A3943, A3945, A3946: preparation and rearrangement for limb correction
(T. Kanazawa and M. Kawada, 1975, 1976),
A3944: Watts' charts reading (T. Kanazawa, 1975),
A4126: inter-and extrapolations of the vertical profiles (M. Kawada, 1976),
A3947: least-squares calculations to be described in the nextsection
(Y. Ganeko and M. Sasaki, 1973 and M. Kawada, 1978).

Results of the reductions are tabulated in the last column of the left hand pages and in the columns of the right hand pages of Table 2.

3. Preliminary analysis

The corrections to the moon's longitude (ΔL) and latitude (ΔB) for the Japanese lunar ephemeris 1996 are derived by the following equation,

$$\frac{\partial \sigma}{\partial L}\Delta L + \frac{\partial \sigma}{\partial B} = \Delta \sigma$$

$\Delta \sigma$ is a observational residual of angular distance between the Moon's center and the star.

The least-squares calculations are made for every synodic month from lunation 903 to 915 applying the weight w_a^2 whose square root w_a is given in the column 23 of Table 2.

When two or more timings have been obtained for a single event at a station, the following visual data are excluded from the analysis: (i) those obtained simultaneously with photoelectric timing, and (ii) those obtained later than another visual timing. The results for synodic months are listed in Table B.

Table B. Solutions for lunations

Lunation	No. of eq.	Sum w_a^2	ΔL	m. e.	ΔB	m. e.	Epoch
903	61	159.6	+0".50	±0".05	-0".32	±0".10	1996.03
904	106	264.8	+0.22	.05	-0.30	.08	.09
905	95	232.1	+0.36	.05	-0.09	.07	.17
906	25	113.1	+0.20	.13	-0.46	.18	.26
907	70	239.6	+0.27	.04	-0.14	.06	.32
908	29	104.3	+0.05	.10	-0.07	.13	.42
909	11	35.2	+0.46	.12	-0.57	.20	.51
910	53	149.6	+0.38	.07	-0.27	.09	.58
911	40	108.2	+0.24	.07	-0.34	.12	.67
912	51	127.8	+0.31	.06	-0.51	.09	.76
913	52	202.5	+0.34	.07	-0.25	.09	.82
914	122	325.0	+0.42	.04	-0.24	.05	.90
915	89	241.0	+0.37	.04	+0.02	.07	.97

Mean values of ΔL and ΔB through the year are also calculated using the same formula. The solution is given in Table C.

Table C. Solution for the year

No. of eq.	Sum w_a^2	ΔL	m. e.	ΔB	m. e.	Epoch
804	2302.9	+0".33	±0".02	-0".24	±0".02	1996.51

A solution of ΔL and ΔB for photoelectric observations is:

ΔL = +0".33 ±0".02 (m. e.) and

ΔB = −0".26 ±0".03 (m. e.) for 1996.51, n = 580.

In Figure 1, **Δ *L*** and **Δ *B*** for the lunar ephemeris based on IAU 1976 system from 1972 to 1997 are exhibited.

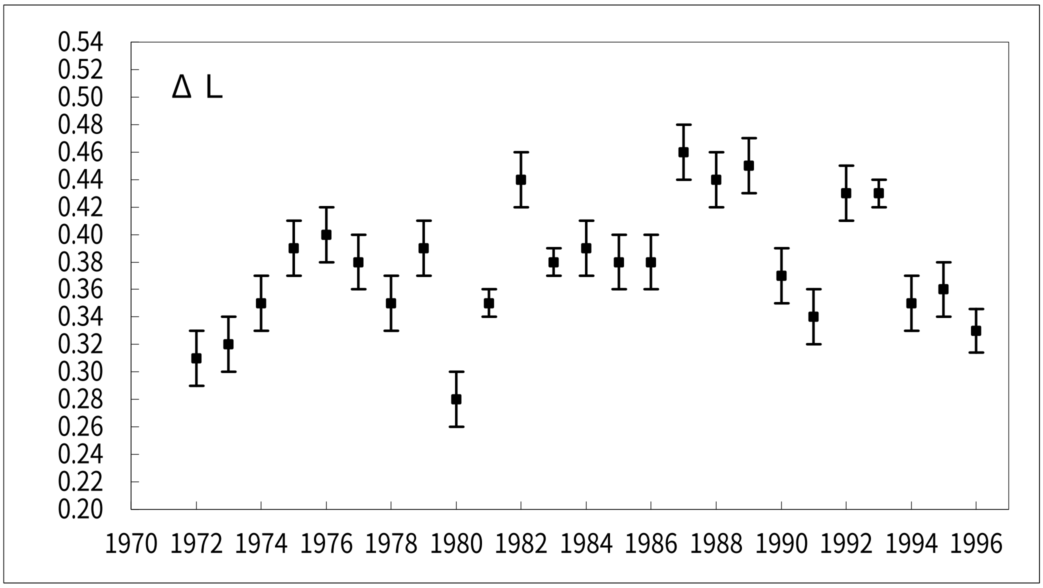

Figure 1a. Δ *L* **in arc second** (**vertical bar denotes mean error**),

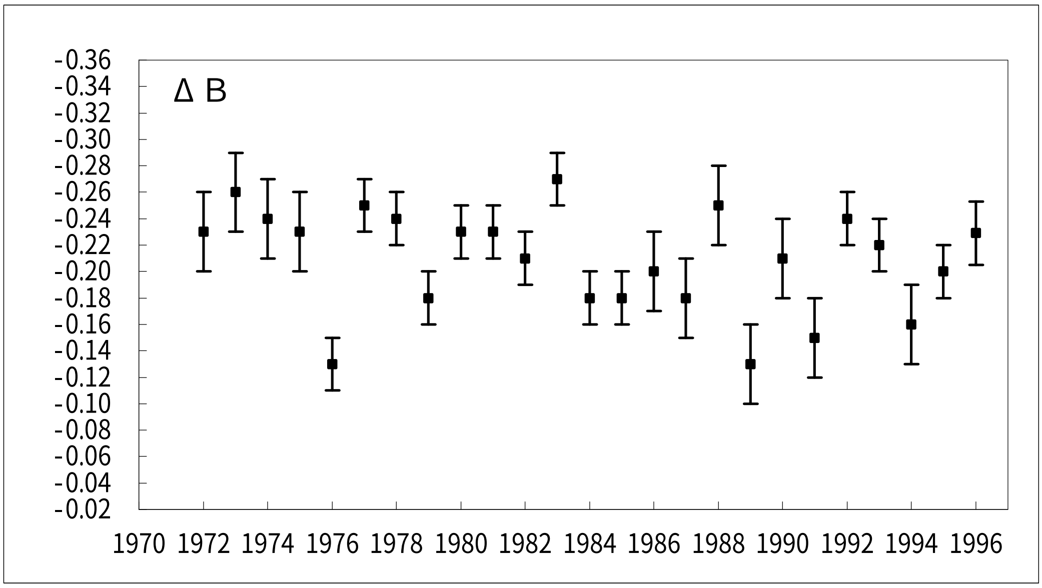

Figure 1b. Δ *B* **in arc second (vertical bar denotes mean error**).

This reduction based on IAU 1976 system was made for the all occultation data obtained from 1972 to 1996. The solutions are given in Table D.

Table D. Solution based on IAU 1976 system for 1972-1996

Year	No. of eq.	Sum w_a^2	ΔL	m. e.	ΔB	m. e.	Epoch
1972	708	3013.3	+0".31	±0".02	-0".23	±0".03	1972.53
1973	655	3239.1	+0.32	0.02	-0.26	0.03	1973.59
1974	647	3224.9	+0.35	0.02	-0.24	0.03	1974.53
1975	767	3549.4	+0.39	0.02	-0.23	0.03	1975.55
1976	809	3451.3	+0.40	0.02	-0.13	0.02	1976.51
1977	867	3686.7	+0.38	0.02	-0.25	0.02	1977.53
1978	815	3799.9	+0.35	0.02	-0.24	0.02	1978.52
1979	770	3289.3	+0.39	0.02	-0.18	0.02	1979.47
1980	807	2985.0	+0.28	0.02	-0.23	0.02	1980.56
1981	899	3368.6	+0.35	0.01	-0.23	0.02	1981.48
1982	861	3207.9	+0.44	0.02	-0.21	0.02	1982.50
1983	957	3565.7	+0.38	0.01	-0.27	0.02	1983.55
1984	852	3307.9	+0.39	0.02	-0.18	0.02	1984.61
1985	800	3386.0	+0.38	0.02	-0.18	0.02	1985.51
1986	650	2675.5	+0.38	0.02	-0.20	0.03	1986.49
1987	574	2359.9	+0.46	0.02	-0.18	0.03	1987.54
1988	576	2274.7	+0.44	0.02	-0.25	0.03	1988.49
1989	648	2059.5	+0.45	0.02	-0.13	0.03	1989.47
1990	627	2151.8	+0.37	0.02	-0.21	0.03	1990.48
1991	688	2354.8	+0.34	0.02	-0.15	0.03	1991.48
1992	956	3045.7	+0.43	0.02	-0.24	0.02	1992.53
1993	1027	2989.3	+0.43	0.01	-0.22	0.02	1993.54
1994	753	2512.9	+0.35	0.02	-0.16	0.03	1994.51
1995	1026	3276.8	+0.36	0.02	-0.20	0.02	1995.58
1996	804	2302.9	+0.33	0.02	-0.23	0.02	1996.51

Calculations and compilation of this report have been made by M. Kawada, M. Suzuki and A. Sengoku of the Geodesy and Geophysics Division, JHD.

TABLE 1. GEODETIC POSITIONS AND INSTRUMENTS OF OBSERVATION STATIONS

Explanation

Column

1, 2 Name and code of station.

3 Geodetic latitude and longitude of the main telescope, referred to the Tokyo Datum, height from the mean sea level and height from the reference ellipsoid taken from the geoid contour by Ganeko (1976).

4 Geocentric rectangular coordinates (*u, v, w) in the Marine Geodetic Control Network. Its origin* is the geocenter; *w-axis goes through the Conventional International Origin; u-axis is in the* conventional zero meridian; *v-axis is taken so that the coordinate system is right-handed.*

5 Characteristics of telescopes: aperture in cm; type (Refractor, Cassegrain-reflector or Newtonian -reflector); focal length in m; mounting (equatorial, alt-azimuthal). The symbol P denotes the telescope with photoelectric device; the symbol g means the guiding telescope attached to the main telescope.

6 Name and code of observer.

TABLE 1. GEODETIC POSITIONS AND INSTRUMENTS OF OBSERVATION STATIONS

Station Name	Station Code	Geodetic Coordinates (Tokyo Datum)	Geocentric Coordinates	Telescope	Observer Name	Observer Code
水路部（東京） Head Office, JHD Tokyo	3	35°39′41.″42N 139 46 10.53E 40.6m, 40.6m	-3960483m 3350856 3698080	30C 5.0P eq 10R 1.1 g	M.Okumura K.Tomii M.Suzuki M.Katayama K.Masui T.Uchikawa M.Ushijima H.Fukura H.Matushita Y.Sumiya H.watanabe	OKUM TOMK SUZM KATM MASK UCTU USIM FUKH MATH SUMY WATH
白浜水路観測所 Sirahama Hydrogra- phic Observatory	16	34°42′46.″65N 138 59 20.39E 172.1m,177.1m	-3960311m 3444362 3612161	40C 6.6P eq 11R 1.6 g	S.Kanagawa Y.Ishiguro T.Sonoda T.Ishiyama	KAGS ISIY SONT ISTU
白浜水路観測所 Sirahama Hydrogra- phic Observatory	17	34°42′41.″83N 138 59 18.87E 91.0m, 96.0m	-3960299m 3444403 3507560	28C 2.8 eq	S.Kanagawa T.Sonoda T.Ishiyama	KAGS SONT ISTU
下里水路観測所 Simosato Hydrogra- phic Observatory	24	33°34′26.″97N 135 56 22.69E 63.1m, 63.1m	-3822380m 3699386 3507560	62C 10.0P eq 15R 2.3 g 8R 1.2 g	K.Muneta M.Suzuki Y.Takanashi Y.Narita N.Koshin H.Fukura M.Takahashi M.Kurihara H.Matushita* Y.Sumiya*	MUNK SUZM TAKY NARY INON FUKH TAKM KURM MATH SUMY
美星水路観測所 Bisei Hydrographic Observatory	42	34°40′35.″98N 133 34 27.16E 516.0m,498.0m	-3619421m 3804547 3609033	60C 9.4P eq 15R 2.3 g 8R 1.2 g	A.Suzuki S.Yoshida Y.Yamada	SUZA YOSS YADY
前原，福岡 Maebaru,Fukuoka	105	33°34′01.″30N 130 12 14.10E 4.0m, 33.6m	-3433814m 4063141 3506854	20C 2.0 eq	S.Yoshida	YOSS
前原，福岡 Maebaru,Fukuoka	106	33°33′42.″30N 130 11 38.10E 4.0m, 33.6m	-3433314m 4063988 3506366	20C 2.0 eq	T.Tsugawa	TUGT
前原，福岡 Maebaru,Fukuoka	107	33°33′11.″20N 130 10 56.50E 4.0m, 33.6m	-3432836m 4065085 3505568	20C 2.0 eq	M.Okumura	OKUM
名瀬，鹿児島 Naze,Kagoshima	108	28°19′20.″40N 129 30 41.90E 3.0m, 3.0m	-3574641m 4334922 3008386	20C 2.0 eq	M.katayama	KATM
名瀬，鹿児島 Naze,Kagoshima	109	28°19′25.″00N 129 31 26.00E 3.0m, 3.0m	-3575525m 4334106 3008511	20C 2.0 eq	K.Tomii	TOMK
名瀬，鹿児島 Naze,Kagoshima	110	28°19′06.″01N 129 32 01.20E 3.0m, 3.0m	-3576440m 4333709 3007999	20C 2.0 eq	M.Suzuki	SUZM

* temporary support from Tokyo.

TABLE 2. OBSERVATIONS AND REDUCTIONS

Explanation

Column

1, 13 Serial number in sequence of observation time.

2 DM reference number.

3 Magnitude of star.

4 Lunation number.

5 Moon's age.

6 Phenomenon: D for disappearance and R for reappearance. Prefix G stands for grazing event, B for bright limb event and L for event during an eclipse of the moon.

7 Observation time in UTC. It is given down to two decimal places for the photoelectric observations and to one place for the visual data which have been already corrected for the personal equation given in column 8. D denotes that the occultation was observed as multiple events, and all the events are listed in the successive lines.

8 Personal equation (negative quantity) applied to the visual data. For eye-ear timing, the personal equation is always reckoned to be zero, and the column is vacant. For JHD's key-tappings with the quality classification (A, B or C), the delay time τ given in the Table E is applied (Mori *et al*., 1975), and for those without the classification, $-0^{s}.5$ is adopted.

Table E.

Class	Vis. Mag	τ	σ_τ
A	～6.0	$0.^{s}40$	$0.^{s}10$
	6.1～8.0	0.45	0.10
	8.1～	0.50	0.15
B	～6.0	0.50	0.15
	6.1～8.0	0.55	0.20
	8.1～	0.60	0.20
C	～6.0	0.70	0.20
	6.1～8.0	0.90	0.35
	8.1～	1.10	0.50

9 Accuracy of the observation timing. For photoelectric observations a net value of the maximum estimated error is given. For visual observations made at JHD stations, a quality class A, B or C is given. This classification is assigned by the observer himself immediately after each timing.

10 Observer code.

11 Station code.

12,14 Right ascension and declination of the star, referred to the mean equinox and the mean equator of J2000.0.

15 Reference number in the source catalogue. The following abbreviations are used:
C1 : ACRS Part1, M : PPM, F : FK5, E : FK5ext., K : USNO.

16,17 Hour angle and altitude of the star.

Column

18 Position angle of the event referred to the moon's orbit. χ is the position angle of the star on the Besselian plane and ρ is the position angle of the moon's motion, both measured at the moon's tabulated center counterclockwise from the north as seen from the observer.

19 Position angle of the star measured at the moon's center on the celestial sphere.
The relation of χ_m to χ is

$$\chi_m = \chi - \sigma \sin\chi \tan\delta_*.$$

20 Ratio of the apparent horizontal parallax (π) of the moon to its mean horizontal parallax (π_0) .

21 Limb profile at the mean distance of the moon. The reading accuracy is within ±0".05 except for the following two cases:

a. Interpolation is doubtful due to the inferior patterns of the charts (Maximum error is within ±0".2).

b. Extrapolation is needed. When the expolation error seems to exceed ±0".5, Z is put in the column.

In both cases, P, Q, R or S is attached to the tabular value, according as the estimated error of ±0".1, ±0".2, ±0".3, ±0".4.

22 O-C of σ, including the limb correction.

23 Square roots (w_0 and w_a) of weight of observation and weight of the observation equation for finding the Moon's position.

$$w_0 = \frac{0''.05}{S_0}, \quad w_a = k w_t,$$

where

$$S_0^2 = \left(\frac{\partial\sigma}{\partial t}\right)^2 \sigma_t^{\,2} + \delta^2(\varphi, \lambda, h),$$

σ_τ : accuracy of timing (column. 9), taken from Table E for the visual observations of JHD stations.

$\delta(\varphi, \lambda, h)$: effect of error in station coordinates: ±0".005 for the JHD stations and ±0".03 for the other stations,

$$w_t^2 = \frac{0''.1^2}{S_0^2 + \delta_{hw}^2},$$

$$k^2 = \frac{0''.3^2}{0''.1^2 + \sum w_t^2 \left\{\left(\frac{\partial\sigma}{\partial\alpha}\right)^2 \sigma_\alpha^{\,2} + \left(\frac{\partial\alpha}{\partial\alpha}\right)^2 \sigma_\delta^{\,2}\right\}},$$

Σ in the denominator indicates the summation for every observation of the same event of one star.

σ_α and σ_δ are mean errors of the star position. They are calculated by the following formulae:

$$\sigma_\alpha^2 = \sigma_{\alpha 0}^2 + \sigma_{\mu\alpha}^2 (T - T_0)^2,$$

$$\sigma_\delta^2 = \sigma_{\delta 0}^2 + \sigma_{\mu\delta}^2 (T - T_0)^2.$$

Column

23 $\sigma_{\alpha 0}$ and $\sigma_{\delta 0}$ are mean errors of the places at the observation epoch of the catalogue, and $\sigma_{\mu\alpha}$ and $\sigma_{\mu\delta}$ are those of the proper motions. They are taken from the source catalogue except for FK4sup and AGK3, for which the following values are provisionally assigned.

T_0 is observation epoch of catalogue and T is the date of the occultation, δ_{hw} is sum of the intrinsic error of the Watts' charts and the error of chart reading. The adopted value of this term is ± 0".07, except for special cases (See the explanation on column 21).

In the case of double stars whose difference in $\Delta\sigma$'s is less than 1", the following value is assigned to each observation:

$$w_t^2 = \frac{1}{2} \bullet \frac{0\overset{''}{.}1^2}{S_0^2 + \delta_{hw}^2 \frac{3}{8}\left(\text{diff.in}\,\Delta s\right)^2},$$

W_t = 0 is assigned for the other double stars' event and visual observation obtained at the same time with photoelectric observation, or preceded by another visual observation.

W_t = 0 is also assigned for one which seems inappropriate to adopt in the preliminary analysis in this report because of its possible error in observation, in star place or in lunar profile.

24 SAOC reference number.

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