OBSERVATION OF 1991 JULY 11 TOTAL SOLAR ECLIPSE†

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Abstract

Observation of contact times at the 1991 July 11 total solar eclipse was made by the Hydrographic Department of Japan (JHD) by means of flash spectrum cinematography method. Reduction of the observation gives the following correction to the relative position and semidiameter of the Sun and the Moon to be applied to the tabular values in the ephemeris:

$\Delta\ (\lambda_S-\lambda_M)=-0.20''\pm0.02''$,
$\Delta\ (\beta_S-\beta_M)=-0.50''\pm0.07''$,
$\Delta\ (r_S-r_M)\ =+0.51''\pm0.02''$.　　(4615Å)

Comparing this result with those for the past eclipses observed by JHD by the same method, a significant change in the radius of the Sun is perceived. The effect of errors in the lunar profile charts on the result is also discussed.

Key words: Total solar eclipse, Contact times, Ephemerides of the Sun and the Moon, Radius of the Sun.

1. Introduction

The Hydrographic Department of Japan (JHD) despatched an observation team to the total solar eclipse of 1991 July 11 which was seen in Hawaii and countries in Central and South Americas. The purpose of the observation is to determine the accurate position of the Sun relative to that of the Moon, of which the latter is assumed to have been determined accurately enough by lunar occultation observations, in order to maintain and improve the accuracy of the tabular values in the astronomical ephemeris.

The two members of the JHD observation team, Kaoru Koyama (chief) and Masayuki Okumura, acted as constituents of the official Japanese expedition to the eclipse sent by the Japanese Government throughout the period from the departure from Japan to the return.

The expedition consisted of eleven members from three institutes, i.e., National Astronomical Observatory (NAO), Kyoto University and JHD with Dr. Hiroki Kurokawa of Kyoto University as the leader. The main group of eight members including those from JHD settled the observation site in La

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Paz, Baja California Sur, Mexico. Meanwhile, the other three members from NAO made an observation at a site near the top of Mt. Popocatepetl near Mexico City.

The members to La Paz left Japan on June 11, 1991 and went first to Ensenada on Pacific coast of Mexico, where they received the containers of the equipments which had been shipped from Japan beforehand. Then most members proceeded to La Paz by rental cars accompanying the trucks which carried the containers from Ensenada to La Paz, and arrived in La Paz on June 17. Meanwhile, Dr. Kurokawa and a few members flied to Mexico City for various business jobs and then to La Paz and arrived there before the arrival of the members who followed the trucks.

After the work of installing and adjusting the observation instruments for about three weeks, the JHD members observed the eclipse successfuly. This article describes first how the observation was made and then the result of the analysis of the obtained data.

2. Observation Site

The observation site of the Japanese expedition was set in the playground of Universidad Automona de Baja California Sur (UABCS), where official parties from countries in all over the world were appointed to settle their observation sites by Comite Universitario Para la Observation del Eclipse (CUPOE). Electricity of 120 V was arranged to be supplied to the observation teams by CUPOE.

In the days preceding the eclipse, observation of both the geographical and astronomical coordinates of the JHD telescope was made. The geographical coordinates were determined by observing NNSS satellites, which were operated under the WGS-84 system at that time. A Magnavox receiver was used for the observation and 337 data for three-dimensional analysis were obtained in the period from June 22 to July 10. The result of the analysis is as follows:

geographical longitude: $\lambda_g = 110°\ 18'\ 50.83''\mathrm{W} \pm 0.03''$,

〃 latitude: $\phi_g = 24°\ 06'\ 02.33''\mathrm{N} \pm 0.01''$,

height from reference ellipsoid: $H = +0.4\mathrm{m} \pm 0.3\mathrm{m}$. (WGS-84)

The figures following "±" marks are mean errors throughout this article.

On the other hand, the astronomical longitude and latitude of the same point were determined by equal altitude observation of stars using an Ni-2 type astrolabe of Carl Zeiss. The result is:

astronomical longitude: $\lambda_a = 110°\ 18'\ 59.2''\mathrm{W} \pm 1.1''$,

〃 latitude: $\phi_a = 24°\ 06'\ 07.6''\mathrm{N} \pm 1.5''$.

The difference astronomical minus geographycal coordinates is the so-called deflection of the vertical for that place. That is:

$$\xi = \phi_a - \phi_g \qquad = +5.3'' \pm 1.5'',$$

$$\eta = (\lambda_a - \lambda_g)\ \cos\phi \qquad = -7.5'' \pm 1.0''.$$

This means that there exists either a surplus of mass under the ground in the direction of nearly south-east or a lack of mass in the opposite direction.

It should be noticed that the geographical coordinates of the telescope should be used in the reduction in the following.

Meteorological observation was also made during the period from June 24 to July 11. Main features about temperature in this period are as follows:

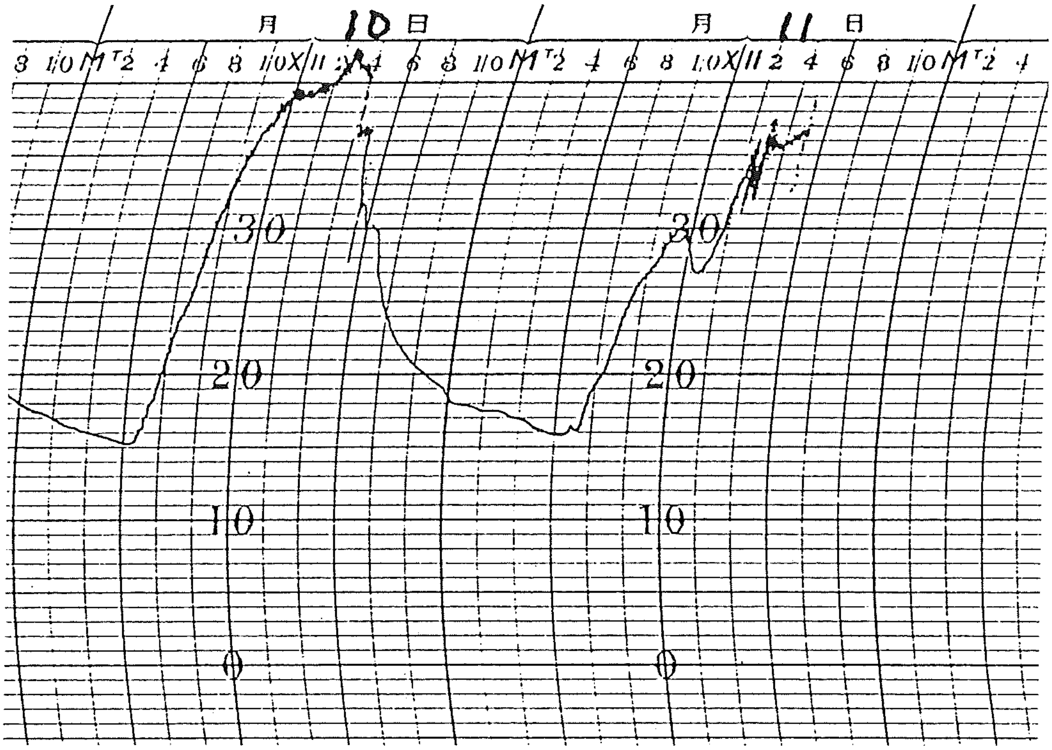

Figure 1. Temperature at the observation site on 1991 July 10 and 11.

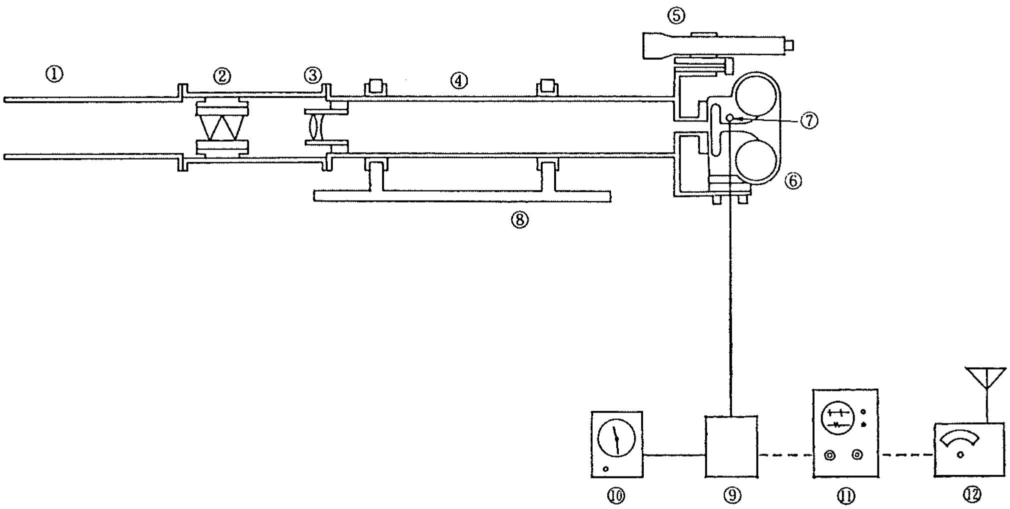

Figure 2. Schematic diagram of the spectrophotographic equipments.
①hood ②prisms ③lens ④telescope tube
⑤guiding telescope ⑥16-mm movie camera ⑦LED
⑧bearings ⑨electronic circuits ⑩quartz clock
⑪time difference monitor ⑫Loran C receiver

mean minimum temperature : 15.9℃,
mean maximum 〃 : 38.1℃,
mean temperature at 9^h local standard time : 28.3℃.

With the progress of the eclipse on July 11, the temperature went down and recorded a local minimum value 27.0℃ about half an hour after the totality, about 5.5℃ lower than it would have shown if it were not for the eclipse. In Figure 1 is shown the variation of temperature on the days before and of the eclipse.

3. Observation of the eclipse

The observation of the eclipse on 1991 July 11 was made by flash spectrum cinematography method, which is the same as adopted in the past observations of eclipses by JHD.

A schematic diagram of the equipments used is shown in Figure 2. Since a detailed description of the equipments is given in Mori and Kubo (1971), only an outline of them is explained below.

A spectrotelscope and a 16-mm movie camera boaded on an equatorial mounting constitute the main part of the equipments. Both the equatorial and the movie camera are driven by DC batteries. The optics of the spectrotelescope cansists of an objective lens with apperture of 80 mm and focal length of 1200 mm and a direct vision type prism just ahead of the lens. The size of the image at the focal point is 5.8mm/1000″ and the dispersion of the prism is 87 Å/mm at 5000 Å.

A Bolex H16 type camera is used for cinematographing of the flash spectra at the 2nd and 3rd contacts. The size of each frame of the film is about 10.5 mm×7.5 mm with the direction of dispersion parallel to the longer side and that of position angle to the shorter side. Time marks of 10 Hz synchronized with UTC were printed along an edge of the film to make enable a precise determination of time for each shot of photographs.

Around the 2nd and the 3rd contacts of the eclipse, photographing was made with a rate of about 22 shots per second. The film used was Kodak Plus X. An example of the photographs is shown in Figure 3.

UTC for the time marks was provided by a quartz clock which was regulated by time aignals of Loran C radio wave emitted from the master station of West Coast U.S. Chain (118°50′ W and 42°43′ N). The correction for propagation time of 6.315 ms was applied. Thus the UTC for each time mark on the film was determined with an accuracy better than 0.1 ms.

The photographs of the flash spectra were taken for 60 seconds each around the 2nd and the 3rd contacts, but those for 5.5 seconds at each contact were used in the reduction described below.

After the observation of the eclipse, spectral images of a slit were photographed with ND filters of various densities inserted in front of the movie camera for several widths of the slit in order to obtain the relation between light intensity and density on the film.

The developement of the film was made by a commercial company after the observation team having returned to Japan.

4. Reduction

The density of the images of spectra of the crescent Sun on the film was measured by a Perkin-Elmer PDS microdensitometer belonging to the Institute of Astronomy, the University of Tokyo. The density

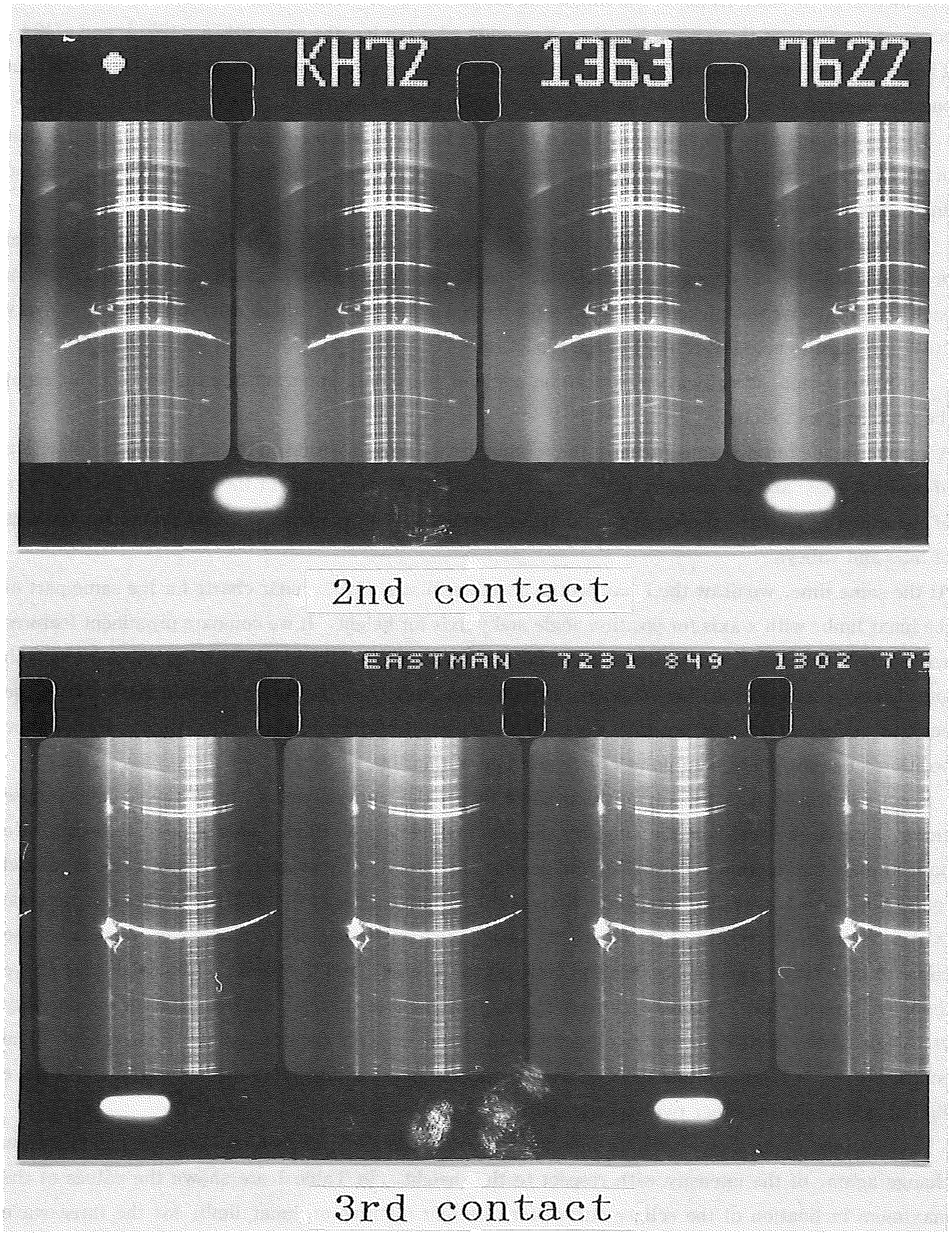

Figure 3. Example of the photographs of flash spectra near 2nd (upper) and 3rd (lower) contacts.

was measured for each frame of the film along the direction of position angle, which is parallel to the edges of the film, at three wave lengths. The adopted wave lengths were 5047Å, 4960Å and 4740Å. They were selected so that the effect of the emisson lines from the chromosphere might be avoided but only the density of the continuum from the photosphere be measured.

The dimension of the diaphragm of PDS was 75 μm for the direction of dispersion and 10 μm for that of position angle, the former corresponding to 6.5Å of wave length and the latter to 0.096° of position angle, respectively.

The density data were obtained for points along position angle with an interval of 1 μm on the film or about 0.01° of position angle for each wave length and recorded on a magnetic tape, but one from each 15 data points was picked up and used for the reduction, that is, the density data about for every 0.144° of position angle were used in the reduction.

As the next step, identification of position angle of every data point must be made. The ouline of the process is as follows:

A graph is made for any frame to show the relation between the position on the film along the direction of position angle and the density, with x-axis for the former and y-axis for the latter. Then the curve of the graph reflects the profile of the lunar limb near the contact point, showing prominent features of hills and valleys.

At the same time, we draw the lunar profile based on Watts' (1963) lunar charts for the same part of the lunar limb, with x-axis for position angle and y-axis for height. If we compare prominent features seen in the both curves, we recognize a similarity between them. By a least squares fitting of the both arguments (x-axis values) for common prominent features, we can obtain the relation between the position angle and the film position along the direction of position angle. Thus we can identify the position angle for every data point of every frame of the film.

From the density data for any position angle for all the frames, we can draw the so-calld eclipse curve, a curve showing how the intensity changes with respect to time. This is possible because we have already the relation between the film density and the intensity of light and every frame is related to the time when it was photographed. Knowing the relative velocity of the Moon to the Sun, the time is also related to the height of the solar edge above the lunar limb easily. So we can consider eclipse curve to be a curve showing the relation between the intensity and the height of the solar edge above the lunar limb as well. Figures 4(a) to 4(d) show such eclipse curves, i.e., logarithm of the intensity vs. height above lunar limb, for two points on the lunar limb for each of 2nd and 3rd contacts. The eclipse curves in Figures 4 and the following reduction as far as Section 5 are for 5047Å. We have similar results for the other two wave lengths.

Every eclipse curve shows a similar feature, i.e., slow change first, then rapid change and then slow change again, of the intensity with respect to the height. In Table 1 are shown the values of the maximum inclination of the eclipse curves for different features on lunar limb, for the three wave lengths and at each contact. They are accordant with the result for 1970 and 1973 eclipses, $d \log (I/I_0)/dh = 2.8/1''$ (for 4615Å).

We define the solar edge by the point with the maximum inclination, or the inflection point of the eclipse curve, in the analysis below. In practice, we obtain the density for this inflection point for points of various features on the lunar limb and then their mean values. They may be different for each

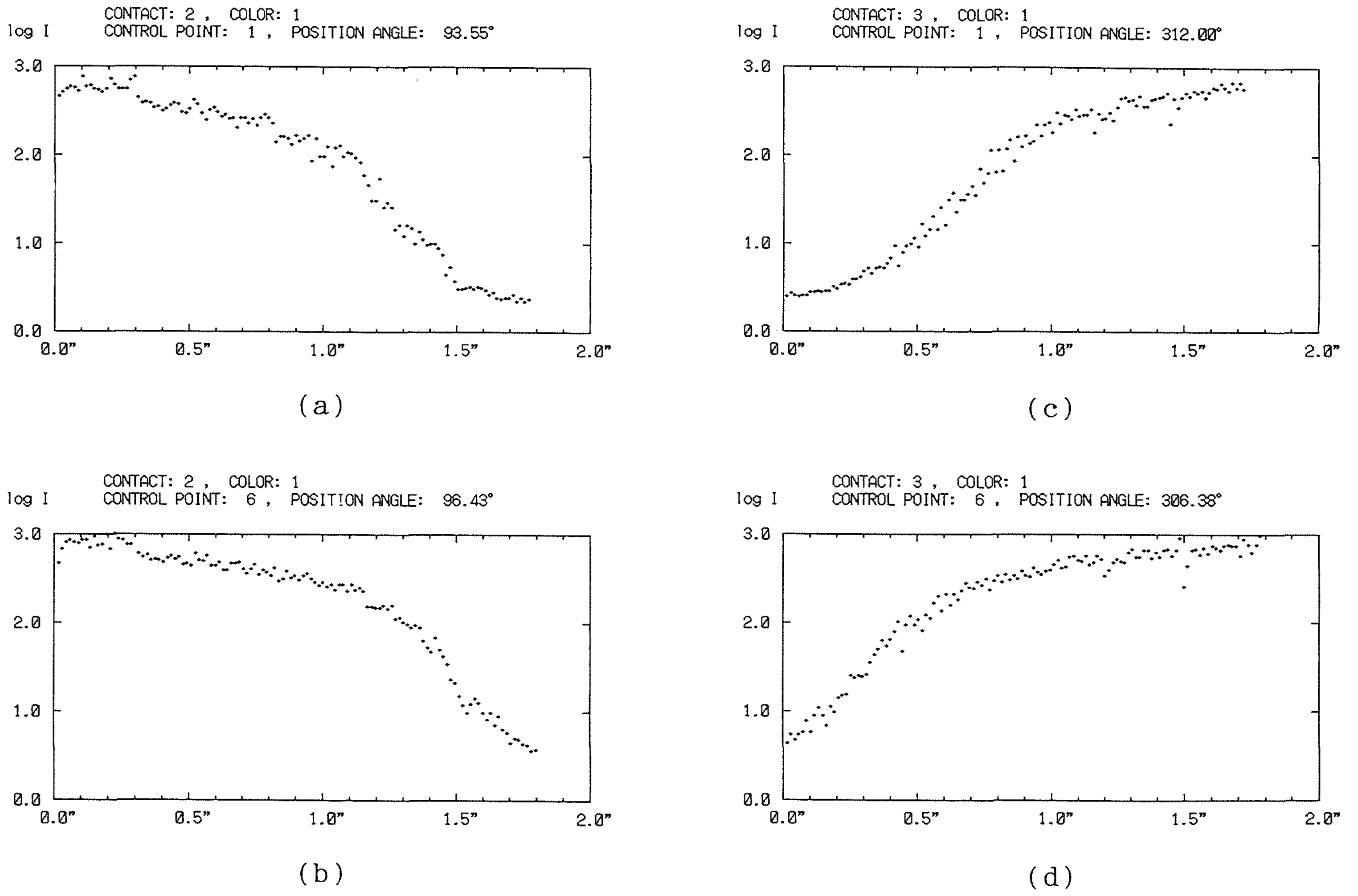

Figure 4. Example of the eclipse curves ((a) and (b) at 2nd contact and (c) and (d) at 3rd contact).

Table 1. Maximum values of d log $(I/I_0)/dh$. (Unit : $(1'')^{-1}$)
Values for each feature are the means of several points.

	5047 Å	4960 Å	4740 Å
2nd contact			
Hills	3.14	3.15	2.54
Valleys	3.62	3.47	2.93
Others	3.10	2.98	2.59
Mean	3.27	3.18	2.68
3rd contact			
Hills	2.66	2.64	2.57
Valleys	3.15	3.37	3.21
Others	2.99	3.20	2.92
Mean	2.94	3.08	2.90
Mean of both contacts			
Hills	2.90	2.89	2.56
Valleys	3.39	3.42	3.07
Others	3.04	3.09	2.75
Mean	3.11	3.13	2.79

wave length and for each contact. Then we can obtain for every position angle the time when the density is equal to the mean value thus determined. It should be called the contact time for that position angle. We can get such cotact times for many points with some interval of position angle for the both contacts. These contact times constitute the basic data in the following analysis for the relative position of the Sun to the Moon. The 2nd to 4th columns of Table 3 give contact times for points every 0.1° of position angle for the three wave lengths. It should be noticed that they are values for the interval of 0.1° calculated by linear interpolation from the original data which have been obtained for about every 0.144°.

5. Relative Position of the Sun to the Moon and the Radius of the Sun

The data of the coordinates of the Sun and the Moon and the local predicion of the eclipse for the observation site are given in Table 2. They are used as the basis in the following reduction. They are all calculated consistently with the Japanese Ephemeris for 1991. It is completely accordant with IAU (1976) System of Astronomical Constants. The tabular values in the Japanese Ephemeris for the Sun and the Moon are also coincident with those in DE200/LE200 ephemeris within the accuracy of 0.01″.

However, in the values in Table 2, the following correction to the coordinates of the Moon is applied. This is a correction to reduce the center of mass of the Moon which are given in the Ephemeris to the center of figure which is assumed to be coincident with the center of the Watts' lunar charts. The amount of correction is obtained from observation of lunar occultations of stars by JHD and it is as follows (Japanese Ephemeris for 1993):

$\Delta\lambda_M = +0.38''$ and $\Delta\beta_M = -0.19''$.

As for the semidiameter of the Sun s_0 and the radius of the Moon k, the following values are adopted: respecitively.

$s_0 = 959.63''$, (at the distance of 1 a.u.)

$k = 0.2725076$. (in unit of the equatorial radius of the Earth)

Also the following value for UT1−UTC taken from IERS Annual Report for 1991 is used in the local prediction:

$\mathrm{UT1-UTC} = +0.213^s$.

Since $\mathrm{TAI-UTC} = 26^s$ at that time and $\mathrm{TDT-TAI} = 32.184^s$, we also have

$\mathrm{TDT-UT1} = 57.971^s$.

Correction for the polar motion is not taken into consideration.

Also the following values for the topocentric lunar libration is used:

$l = +1.00°$, $b = +0.01°$, $C = +6.51°$.

The fundamental equation for the reduction for the relative positon of the Sun and the Moon is given in Mori and Kubo (1971) and Mori and Ganeko (1976), although the both expressions are a little different from each other. We adopt in the present calculation the one in Mori and Ganeko, which is written as follows:

$$h = x\cos p + y\sin p + z + H_i - v(t_C - t_{0i})\cos(p-\phi) - (r_S - r_M)_i{}^2\sin^2(p - p_{0i})/2r_S, \quad (i = 2, 3)$$

with

$x = \Delta(\delta_S - \delta_M)$,

$y = \Delta(\alpha_S - \alpha_M)\cos\delta_S$,

Table 2. The coordinates of the Sun and the Moon and the local prediction for the observation site.

		2nd contact	3rd contact
Contact Time (UTC) (t_0)		$18^h\ 47^m\ 33.66^s$	$18^h\ 54^m\ 09.56^s$
Posision Angle of Contact Point ($p_0-180°$)		92.84°	308.23°
Distance of Centers of Sun and Moon		76.16″	76.22″
Geocentric	R.A. of Sun	$7^h\ 22^m\ 09.635^s$	7° $22^m\ 10.756^s$
〃	Dec. 〃	22° 05′ 54.68″	22° 05′ 52.49″
〃	R.A. of Moon	$7^h\ 21^m\ 23.272^s$	7° $21^m\ 40.867^s$
〃	Dec. 〃	22° 08′ 15.28″	22° 07′ 17.66″
Topocentric	R.A. of Sun	7° $22^m\ 09.732^s$	$7^h\ 22^m\ 10.837^s$
〃	Dec. 〃	22° 05′ 54.36″	22° 05′ 52.18″
〃	S.D. 〃	943.97″	943.97″
〃	R.A. of Moon	$7^h\ 22^m\ 04.258^s$	$7^h\ 22^m\ 15.144^s$
〃	Dec. 〃	22° 05′ 58.13″	22° 05′ 05.01″
〃	S.D. 〃	1020.13″	1020.19″
Relative Velocity of Moon to Sun	(Mag.)	0.3667″/s	
	(P.A.)	110.54°	

$z = \Delta\ (r_S - r_M)$,

$H_i = (\delta_S - \delta_M)_i \cos p + (\alpha_S - \alpha_M)_i \cos\delta_{Si} \sin p + (r_S - r_M)_i = (r_S - r_M)_i\ \{1 + \cos(p - p_{0i})\}$,

where i = 2,3 mean that the values are those at the time of the 2nd and the 3rd contacts, and S and M for the Sun and the Moon, respectively.

The meanings of the notations are as follows:

p : position angle of a point on the lunar limb,

t_C : contact time for the point,

h : observed height of lunar limb above mean level at the point,

t_0 : predicted contact time given in Table 2,

p_0 : position angle of the center of the Moon with respect to that of the Sun at t_0, $p_0 - 180°$ appearing in the prediction,

v : magnitude of the velocity of the Moon relative to the Sun,

ϕ : position angle of the direction of the above velocity,

v and ϕ being also shown in Table 2.

It should be noticed that the predicted topocentric values for all those quantities are used in the reduction. Also, in consulting Watts' lunar charts a correction of 0.2° to the argument for the position angle is applied (Appleby and Morrison, 1983 and Kawada and Kubo, 1990).

We have one equation for one point on the lunar limb, and from the equaions for all the points for the both contacts we have the equation for the least equares solution. The equation is constructed with the condition that $(h - h_W)^2$ should be minimum, where h_W is the height for the point on the lunar limb read from Watts' charts and reduced to the topocentric distance of the Moon. h_W and h's for the three wave lenghts after the best fit with respect to x, y and z are given in the 5th and the 6th to 8th columns of Table 3, respectively. Those for wave length 5047 Å are also shown in Figure 5.

Solving the equation, we have corrections to the computed values for the relative position and semidiameter of the Sun and the Moon:

$\Delta\ (\delta_S - \delta_M) = -0.52'' \pm 0.07''$,

$\Delta\ (\alpha_S - \alpha_M)\ \cos\ \delta_S = -0.28'' \pm 0.03''$,

$\Delta\ (r_S - r_M) = +0.55'' \pm 0.02''$.

We can also solve the equation for the longitude and latitude if we make the following transformation of the unknowns:

$x' = \Delta\ (\lambda_S - \lambda_M) = \cos\alpha\ \sin\varepsilon\ x + (\cos\delta\ \cos\varepsilon + \sin\delta\ \sin\alpha\ \sin\varepsilon) y$,

$y' = \Delta\ (\beta_S - \beta_M) = (\cos\delta\ \cos\varepsilon + \sin\delta\ \sin\alpha \sin\varepsilon) x - \cos\alpha\ \sin\varepsilon\ y$.

Then we have

$\Delta\ (\lambda_S - \lambda_M) = -0.21'' \pm 0.02''$,

$\Delta\ (\beta_S - \beta_M) = -0.55'' \pm 0.07''$,

$\Delta\ (r_S - r_M) = +0.55'' \pm 0.02''$.

All the above result is for the wave length 5047 Å as stated before. Reductions have been made also for the other two wave lenghts.

They are

$\Delta\ (\lambda_S - \lambda_M) = -0.21'' \pm 0.02''$,

$\Delta\ (\beta_S - \beta_M) = -0.57'' \pm 0.07''$,

Table 3. Position angle (p), contact times (tc), height by Watts (hw) and observed heights (h) ((1) : 5047 Å, (2): 4960 Å, (3): 4740 Å). 2nd contact.

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
	18h 47m						
°	s	s	s	"	"	"	"
80.1				-0.79			
80.2				-0.82			
80.3		30.19		-0.87		-0.75	
80.4		30.26		-0.97		-0.74	
80.5	30.33	30.38		-1.08	-0.72	-0.74	
80.6	30.48	30.47	30.31	-1.23	-0.73	-0.74	-0.70
80.7	30.63	30.63	30.45	-1.31	-0.75	-0.75	-0.71
80.8	30.88	30.93	30.75	-1.18	-0.80	-0.82	-0.77
80.9	31.19	31.24	31.10	-1.01	-0.86	-0.89	-0.85
81.0	31.48	31.53	31.38	-1.01	-0.92	-0.94	-0.91
81.1	31.61	31.64	31.51	-1.04	-0.93	-0.95	-0.92
81.2	31.59	31.63	31.50	-0.97	-0.89	-0.92	-0.89
81.3	31.52	31.57	31.44	-0.89	-0.84	-0.87	-0.84
81.4	31.43	31.47	31.32	-0.83	-0.78	-0.80	-0.77
81.5	31.32	31.37	31.20	-0.79	-0.72	-0.74	-0.70
81.6	31.34	31.40	31.24	-0.76	-0.69	-0.72	-0.68
81.7	31.50	31.55	31.40	-0.73	-0.71	-0.74	-0.71
81.8	31.66	31.69	31.59	-0.71	-0.74	-0.75	-0.74
81.9	31.75	31.76	31.69	-0.67	-0.73	-0.75	-0.74
82.0	31.76	31.79	31.72	-0.57	-0.71	-0.73	-0.72
82.1	31.71	31.75	31.65	-0.44	-0.66	-0.69	-0.67
82.2	31.48	31.52	31.41	-0.32	-0.56	-0.58	-0.56
82.3	31.15	31.19	31.04	-0.23	-0.43	-0.45	-0.42
82.4	30.87	30.88	30.78	-0.21	-0.31	-0.32	-0.31
82.5	30.71	30.72	30.66	-0.20	-0.23	-0.24	-0.24
82.6	30.60	30.58	30.55	-0.11	-0.17	-0.17	-0.17
82.7	30.45	30.42	30.43	-0.01	-0.09	-0.09	-0.11
82.8	30.27	30.23	30.25	0.06	-0.01	0.00	-0.02
82.9	30.15			0.09	0.06		
83.0	30.19			0.06	0.08		
83.1	30.25	30.20		0.04	0.08	0.09	
83.2	30.36	30.38		0.08	0.07	0.06	
83.3	30.53	30.58	30.29	0.14	0.04	0.02	0.10
83.4	30.70	30.69	30.55	0.15	0.02	0.01	0.04
83.5	30.87	30.94	30.80	0.14	-0.01	-0.05	-0.02
83.6	31.02	31.10	30.97	0.08	-0.04	-0.07	-0.04
83.7	31.11	31.19	31.05	0.01	-0.04	-0.08	-0.05
83.8	31.20	31.27	31.12	-0.03	-0.05	-0.08	-0.04
83.9	31.34	31.38	31.27	-0.06	-0.07	-0.09	-0.07
84.0	31.51	31.54	31.46	-0.14	-0.10	-0.12	-0.11
84.1	31.71	31.71	31.65	-0.22	-0.14	-0.15	-0.15
84.2	31.89	31.87	31.82	-0.25	-0.18	-0.18	-0.18
84.3	32.02	31.99	31.95	-0.25	-0.20	-0.19	-0.20
84.4	32.08	32.05	32.02	-0.26	-0.19	-0.19	-0.20
84.5	32.08	32.04	32.02	-0.26	-0.17	-0.17	-0.17
84.6	32.06	32.03	32.00	-0.24	-0.14	-0.14	-0.15
84.7	32.10	32.07	32.03	-0.22	-0.13	-0.13	-0.13
84.8	32.22	32.16	32.13	-0.21	-0.15	-0.14	-0.15
84.9	32.38	32.32	32.30	-0.22	-0.18	-0.17	-0.18
85.0	32.56	32.48	32.48	-0.26	-0.22	-0.20	-0.22
85.1	32.73	32.63	32.64	-0.31	-0.25	-0.23	-0.25
85.2	32.84	32.76	32.75	-0.38	-0.27	-0.25	-0.27
85.3	32.85	32.79	32.79	-0.43	-0.25	-0.24	-0.26
85.4	32.82	32.77	32.78	-0.46	-0.22	-0.21	-0.23
85.5	32.83	32.77	32.76	-0.44	-0.20	-0.19	-0.21
85.6	32.85	32.79	32.79	-0.35	-0.19	-0.18	-0.20
85.7	32.90	32.84	32.85	-0.28	-0.19	-0.18	-0.20
85.8	32.92	32.88	32.87	-0.35	-0.18	-0.17	-0.19
85.9	32.84	32.84	32.82	-0.43	-0.13	-0.14	-0.15
86.0	32.66	32.68	32.66	-0.36	-0.05	-0.07	-0.08

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
	18h 47m						
°	s	s	s	"	"	"	"
86.1	32.50	32.50	32.49	-0.25	0.02	0.01	0.00
86.2	32.45	32.42	32.41	-0.23	0.05	0.06	0.04
86.3	32.48	32.44	32.42	-0.22	0.06	0.07	0.06
86.4	32.57	32.51	32.50	-0.16	0.05	0.06	0.05
86.5	32.67	32.59	32.59	-0.08	0.04	0.06	0.04
86.6	32.69	32.64	32.62	-0.07	0.05	0.06	0.04
86.7	32.67	32.64	32.62	-0.06	0.07	0.07	0.06
86.8	32.61	32.61	32.56	0.02	0.11	0.10	0.10
86.9	32.33	32.35	32.28	0.11	0.22	0.20	0.21
87.0	32.03	32.04	31.95	0.18	0.33	0.32	0.33
87.1	31.81	31.80	31.74	0.22	0.42	0.42	0.42
87.2	31.73	31.72	31.67	0.21	0.47	0.46	0.46
87.3	31.73	31.72	31.68	0.22	0.48	0.48	0.47
87.4	31.75	31.75	31.70	0.32	0.49	0.48	0.48
87.5	31.75	31.76	31.71	0.43	0.51	0.50	0.49
87.6	31.80	31.80	31.75	0.47	0.50	0.50	0.49
87.7	31.87	31.87	31.81	0.44	0.50	0.49	0.49
87.8	32.00	31.98	31.93	0.34	0.47	0.47	0.46
87.9	32.23	32.18	32.14	0.23	0.41	0.41	0.41
88.0	32.47	32.42	32.39	0.19	0.34	0.35	0.34
88.1	32.68	32.62	32.59	0.21	0.28	0.29	0.28
88.2	32.69	32.68	32.64	0.32	0.29	0.29	0.28
88.3	32.48	32.52	32.44	0.43	0.37	0.35	0.36
88.4	32.21	32.24	32.16	0.45	0.48	0.46	0.47
88.5	32.04	32.05	31.99	0.44	0.55	0.54	0.54
88.6	31.94	31.95	31.88	0.44	0.60	0.59	0.59
88.7	31.92	31.91	31.84	0.44	0.62	0.61	0.61
88.8	31.96	31.94	31.89	0.44	0.61	0.61	0.61
88.9	32.04	32.03	31.97	0.44	0.60	0.60	0.59
89.0	32.09	32.08	32.04	0.44	0.59	0.59	0.58
89.1	32.13	32.13	32.08	0.44	0.59	0.58	0.58
89.2	32.25	32.22	32.18	0.45	0.56	0.56	0.56
89.3	32.43	32.39	32.35	0.44	0.51	0.52	0.51
89.4	32.65	32.57	32.54	0.34	0.44	0.46	0.45
89.5	32.89	32.79	32.75	0.23	0.37	0.40	0.39
89.6	33.16	33.03	33.01	0.20	0.29	0.33	0.31
89.7	33.44	33.31	33.33	0.18	0.20	0.24	0.21
89.8	33.87	33.80	33.74	0.09	0.07	0.08	0.08
89.9	34.19	34.17	34.06	0.01	-0.04	-0.04	-0.02
90.0	34.23	34.26	34.20	-0.02	-0.04	-0.06	-0.06
90.1	34.05	34.06	34.04	-0.01	0.03	0.02	0.00
90.2	33.80	33.82	33.78	0.09	0.12	0.11	0.10
90.3	33.66	33.66	33.61	0.21	0.18	0.17	0.17
90.4	33.69	33.67	33.62	0.33	0.18	0.18	0.17
90.5	33.70	33.71	33.64	0.43	0.18	0.17	0.17
90.6	33.53	33.58	33.50	0.44	0.25	0.22	0.23
90.7	33.24	33.35	33.20	0.44	0.35	0.31	0.34
90.8	32.88	32.99	32.90	0.49	0.48	0.44	0.45
90.9	32.56	32.63	32.49	0.58	0.60	0.57	0.60
91.0	32.24	32.26	32.15	0.73	0.72	0.70	0.72
91.1	31.99	32.00	31.85	0.86	0.81	0.80	0.83
91.2	31.77	31.75	31.58	0.88	0.89	0.89	0.93
91.3	31.66	31.63	31.50	0.88	0.94	0.94	0.96
91.4	31.67	31.62	31.51	0.97	0.94	0.95	0.96
91.5	31.76	31.71	31.61	1.06	0.91	0.92	0.94
91.6	31.93	31.88	31.80	1.07	0.86	0.87	0.87
91.7	32.18	32.11	32.04	1.02	0.78	0.80	0.79
91.8	32.44	32.38	32.36	0.91	0.69	0.71	0.69
91.9	32.71	32.59	32.57	0.77	0.60	0.64	0.62
92.0	32.94	32.82	32.81	0.62	0.53	0.56	0.54

Table 3 (continued). 2nd contact.

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
	18h 47m						
o	s	s	s	"	"	"	"
92.1	33.15	33.04	33.04	0.47	0.46	0.49	0.46
92.2	33.36	33.26	33.29	0.35	0.38	0.42	0.38
92.3	33.59	33.51	33.51	0.24	0.31	0.33	0.30
92.4	33.75	33.70	33.68	0.16	0.26	0.27	0.25
92.5	33.85	33.80	33.78	0.12	0.22	0.23	0.22
92.6	33.87	33.85	33.82	0.15	0.22	0.22	0.20
92.7	33.84	33.82	33.80	0.19	0.23	0.23	0.21
92.8	33.81	33.79	33.76	0.19	0.24	0.24	0.23
92.9	33.83	33.80	33.78	0.18	0.24	0.24	0.22
93.0	33.95	33.90	33.88	0.21	0.20	0.21	0.19
93.1	34.12	34.07	34.03	0.22	0.14	0.15	0.14
93.2	34.27	34.23	34.18	0.11	0.09	0.10	0.09
93.3	34.33	34.32	34.29	0.01	0.06	0.06	0.05
93.4	34.22	34.20	34.22	0.11	0.11	0.11	0.07
93.5	33.97	33.96	33.96	0.26	0.19	0.19	0.16
93.6	33.70	33.70	33.64	0.27	0.29	0.28	0.27
93.7	33.51	33.51	33.45	0.23	0.35	0.35	0.34
93.8	33.42	33.39	33.35	0.20	0.38	0.39	0.38
93.9	33.45	33.39	33.38	0.19	0.37	0.39	0.36
94.0	33.55	33.48	33.48	0.20	0.33	0.35	0.33
94.1	33.68	33.61	33.61	0.22	0.29	0.31	0.28
94.2	33.76	33.71	33.68	0.22	0.26	0.27	0.25
94.3	33.70	33.68	33.65	0.22	0.28	0.28	0.26
94.4	33.51	33.53	33.45	0.27	0.34	0.33	0.33
94.5	33.25	33.31	33.19	0.31	0.43	0.40	0.42
94.6	33.12	33.09	33.02	0.30	0.47	0.48	0.48
94.7	33.19	33.10	33.04	0.27	0.45	0.47	0.47
94.8	33.40	33.29	33.27	0.22	0.37	0.40	0.38
94.9	33.73	33.61	33.58	0.18	0.25	0.28	0.27
95.0	33.94	33.89	33.87	0.14	0.17	0.18	0.16
95.1	33.94	33.90	33.88	0.11	0.17	0.18	0.15
95.2	33.75	33.74	33.72	0.13	0.23	0.23	0.21
95.3	33.59	33.57	33.54	0.16	0.28	0.28	0.26
95.4	33.49	33.47	33.45	0.20	0.31	0.31	0.29
95.5	33.43	33.40	33.40	0.22	0.33	0.33	0.31
95.6	33.43	33.38	33.39	0.19	0.32	0.34	0.30
95.7	33.54	33.46	33.49	0.14	0.28	0.30	0.26
95.8	33.78	33.70	33.70	0.04	0.19	0.21	0.18
95.9	34.07	34.01	33.97	-0.05	0.08	0.09	0.08
96.0	34.25	34.20	34.16	-0.08	0.01	0.02	0.01
96.1	34.35	34.31	34.26	-0.09	-0.03	-0.02	-0.04
96.2	34.48	34.43	34.37	-0.15	-0.09	-0.07	-0.08
96.3	34.61	34.58	34.53	-0.17	-0.14	-0.13	-0.15
96.4	34.63	34.58	34.59	-0.05	-0.15	-0.14	-0.18
96.5	34.48	34.44	34.48	0.08	-0.11	-0.10	-0.15
96.6	34.29	34.25	34.28	0.08	-0.05	-0.04	-0.08
96.7	34.21	34.17	34.17	0.01	-0.03	-0.02	-0.05
96.8	34.19	34.15	34.14	-0.09	-0.03	-0.02	-0.05
96.9	34.13	34.10	34.10	-0.13	-0.02	-0.01	-0.04
97.0	33.99	33.97	33.98	0.01	0.02	0.02	-0.01
97.1	33.84	33.82	33.82	0.18	0.07	0.07	0.04
97.2	33.78	33.74	33.74	0.21	0.08	0.09	0.06
97.3	33.83	33.78	33.78	0.19	0.05	0.07	0.03
97.4	33.89	33.84	33.84	0.20	0.02	0.03	0.00
97.5	33.92	33.87	33.87	0.22	0.00	0.01	-0.02
97.6	33.91	33.88	33.88	0.22	-0.01	0.00	-0.03
97.7	33.90	33.87	33.85	0.22	-0.02	-0.01	-0.03
97.8	33.96	33.92	33.90	0.22	-0.05	-0.04	-0.06
97.9	33.99	33.98	33.96	0.22	-0.07	-0.07	-0.09
98.0	33.88	33.88	33.87	0.21	-0.04	-0.04	-0.07

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
	18h 47m						
o	s	s	s	"	"	"	"
98.1	33.67	33.69	33.65	0.22	0.02	0.01	-0.01
98.2	33.43	33.48	33.41	0.28	0.10	0.08	0.07
98.3	33.18	33.24	33.15	0.33	0.18	0.15	0.15
98.4	33.01	33.05	32.97	0.29	0.22	0.20	0.20
98.5	32.96	32.99	32.93	0.23	0.23	0.21	0.20
98.6	32.87	32.95	32.88	0.20	0.25	0.21	0.21
98.7	32.67	32.81	32.70	0.22	0.31	0.25	0.26
98.8	32.44	32.55	32.42	0.30	0.37	0.33	0.35
98.9	32.19	32.26	32.12	0.42	0.45	0.42	0.44
99.0	31.93	31.97	31.74	0.54	0.53	0.51	0.56
99.1	31.68	31.70	31.47	0.65	0.61	0.60	0.65
99.2	31.47	31.48	31.24	0.77	0.67	0.66	0.72
99.3	31.27	31.25	31.06	0.87	0.73	0.73	0.77
99.4	31.11	31.09	30.92	0.89	0.77	0.77	0.80
99.5	31.08	31.06	30.87	0.88	0.76	0.77	0.80
99.6	31.17	31.13	30.95	0.89	0.72	0.73	0.76
99.7	31.26	31.21	31.04	0.88	0.67	0.68	0.71
99.8	31.35	31.32	31.13	0.76	0.62	0.63	0.67
99.9	31.48	31.46	31.26	0.62	0.56	0.56	0.60
100.0	31.57	31.54	31.37	0.56	0.51	0.52	0.55
100.1	31.60	31.57	31.41	0.56	0.48	0.49	0.52
100.2	31.59	31.55	31.38	0.61	0.47	0.48	0.51
100.3	31.58	31.55	31.37	0.65	0.46	0.47	0.50
100.4	31.61	31.58	31.40	0.58	0.43	0.44	0.47
100.5	31.68	31.65	31.48	0.48	0.39	0.40	0.42
100.6	31.71	31.69	31.50	0.48	0.36	0.36	0.40
100.7	31.70	31.68	31.49	0.52	0.35	0.35	0.39
100.8	31.73	31.71	31.51	0.55	0.31	0.32	0.36
100.9	31.76	31.76	31.56	0.58	0.29	0.28	0.32
101.0	31.68	31.64	31.46	0.59	0.30	0.31	0.34
101.1	31.43	31.37	31.21	0.63	0.37	0.39	0.41
101.2	31.06	31.00	30.90	0.79	0.48	0.50	0.50
101.3	30.62	30.59	30.59	0.96	0.62	0.63	0.60
101.4	30.25	30.16	30.25	1.02	0.74	0.77	0.70
101.5				1.04			
102.1				1.38			
102.2				1.30			
102.3				1.12			
102.4	30.36	30.43		0.90	0.49	0.46	
102.5	30.62	30.71	30.44	0.68	0.37	0.34	0.40
102.6	30.75	30.80	30.63	0.50	0.31	0.28	0.31
102.7	30.72	30.76	30.63	0.39	0.29	0.28	0.29
102.8	30.60	30.64	30.53	0.40	0.31	0.29	0.30
102.9	30.46	30.57	30.39	0.47	0.34	0.30	0.33
103.0	30.38	30.51	30.33	0.56	0.35	0.30	0.33
103.1	30.42	30.54	30.30	0.60	0.31	0.26	0.31
103.2	30.59	30.67	30.34	0.49	0.22	0.19	0.27
103.3	30.84	30.86	30.56	0.32	0.11	0.10	0.17
103.4	31.11	31.09	30.88	0.20	-0.02	-0.01	0.03
103.5	31.43	31.34	31.17	0.10	-0.16	-0.13	-0.10
103.6	31.59	31.51	31.37	-0.06	-0.24	-0.21	-0.20
103.7	31.61	31.52	31.40	-0.21	-0.27	-0.24	-0.23
103.8	31.55	31.47	31.34	-0.24	-0.28	-0.25	-0.24
103.9	31.47	31.37	31.24	-0.22	-0.27	-0.24	-0.23
104.0	31.34	31.25	31.14	-0.22	-0.25	-0.22	-0.22
104.1	31.15	31.10	30.98	-0.22	-0.21	-0.19	-0.19
104.2	30.93	30.86	30.76	-0.22	-0.15	-0.13	-0.13
104.3	30.63	30.59	30.48	-0.22	-0.07	-0.06	-0.06
104.4	30.33	30.30	30.16	-0.23	0.01	0.02	0.03
104.5	30.13			-0.22	0.06		

Table 3 (continued). 3rd contact.

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
	18h 54m						
o	s	s	s	"	"	"	"
295.1				0.00			
295.2				0.01			
295.3				0.00			
295.4				-0.09			
295.5	12.98			-0.21	-0.25		
295.6	12.91	13.02	13.06	-0.30	-0.25	-0.20	-0.22
295.7	12.86	12.92	12.99	-0.37	-0.24	-0.21	-0.21
295.8	12.77	12.87	12.92	-0.37	-0.24	-0.20	-0.21
295.9	12.65	12.76	12.82	-0.34	-0.25	-0.21	-0.22
296.0	12.48	12.60	12.66	-0.31	-0.28	-0.24	-0.25
296.1	12.27	12.36	12.39	-0.30	-0.33	-0.30	-0.31
296.2	12.03	12.11	12.13	-0.33	-0.39	-0.36	-0.38
296.3	11.81	11.88	11.90	-0.39	-0.44	-0.41	-0.44
296.4	11.75	11.83	11.84	-0.43	-0.43	-0.40	-0.43
296.5	11.85	11.90	11.95	-0.44	-0.37	-0.35	-0.36
296.6	12.05	12.09	12.19	-0.35	-0.27	-0.25	-0.25
296.7	12.35	12.36	12.45	-0.25	-0.13	-0.12	-0.12
296.8	12.50	12.51	12.61	-0.22	-0.05	-0.04	-0.04
296.9	12.48	12.54	12.60	-0.21	-0.03	0.00	-0.01
297.0	12.40	12.44	12.49	-0.17	-0.03	-0.01	-0.02
297.1	12.30	12.33	12.37	-0.13	-0.04	-0.02	-0.04
297.2	12.19	12.25	12.27	-0.16	-0.05	-0.03	-0.05
297.3	12.15	12.19	12.24	-0.19	-0.04	-0.02	-0.03
297.4	12.20	12.24	12.29	-0.17	0.01	0.02	0.01
297.5	12.28	12.31	12.37	-0.11	0.06	0.07	0.07
297.6	12.35	12.36	12.42	-0.01	0.11	0.12	0.11
297.7	12.44	12.43	12.48	0.10	0.17	0.17	0.16
297.8	12.57	12.53	12.58	0.17	0.25	0.23	0.22
297.9	12.75	12.68	12.73	0.21	0.33	0.31	0.30
298.0	12.82	12.80	12.84	0.21	0.38	0.38	0.36
298.1	12.83	12.81	12.88	0.20	0.41	0.41	0.40
298.2	12.78	12.78	12.86	0.21	0.42	0.42	0.42
298.3	12.68	12.70	12.77	0.22	0.41	0.42	0.41
298.4	12.58	12.58	12.66	0.22	0.39	0.40	0.40
298.5	12.45	12.45	12.53	0.22	0.37	0.37	0.37
298.6	12.32	12.31	12.38	0.21	0.35	0.35	0.34
298.7	12.21	12.22	12.25	0.22	0.33	0.33	0.32
298.8	12.16	12.15	12.22	0.32	0.34	0.33	0.33
298.9	12.15	12.14	12.22	0.41	0.35	0.35	0.35
299.0	12.15	12.14	12.21	0.33	0.38	0.37	0.37
299.1	12.17	12.15	12.20	0.23	0.41	0.40	0.39
299.2	12.26	12.21	12.28	0.23	0.46	0.45	0.44
299.3	12.42	12.33	12.41	0.30	0.54	0.51	0.51
299.4	12.50	12.42	12.48	0.40	0.59	0.56	0.56
299.5	12.55	12.46	12.53	0.50	0.63	0.60	0.60
299.6	12.60	12.51	12.59	0.48	0.67	0.64	0.64
299.7	12.65	12.56	12.66	0.45	0.71	0.68	0.69
299.8	12.62	12.58	12.66	0.50	0.72	0.70	0.70
299.9	12.53	12.49	12.57	0.55	0.70	0.69	0.69
300.0	12.39	12.34	12.41	0.56	0.67	0.66	0.66
300.1	12.22	12.17	12.23	0.56	0.63	0.62	0.61
300.2	12.09	12.06	12.12	0.58	0.60	0.59	0.59
300.3	12.18	12.11	12.18	0.60	0.66	0.63	0.63
300.4	12.27	12.21	12.27	0.58	0.71	0.69	0.68
300.5	12.36	12.28	12.35	0.57	0.76	0.73	0.73
300.6	12.46	12.36	12.44	0.59	0.81	0.78	0.78
300.7	12.58	12.46	12.54	0.65	0.87	0.83	0.84
300.8	12.67	12.56	12.64	0.76	0.92	0.89	0.89
300.9	12.66	12.60	12.67	0.87	0.94	0.92	0.92
301.0	12.55	12.51	12.61	0.89	0.92	0.90	0.91

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
	18h 54m						
o	s	s	s	"	"	"	"
301.1	12.35	12.36	12.41	0.88	0.86	0.87	0.86
301.2	12.17	12.13	12.18	0.86	0.81	0.80	0.79
301.3	11.99	11.97	11.99	0.83	0.77	0.76	0.74
301.4	11.92	11.85	11.90	0.74	0.75	0.73	0.72
301.5	11.89	11.82	11.87	0.66	0.76	0.74	0.73
301.6	11.90	11.84	11.89	0.65	0.78	0.76	0.75
301.7	11.99	11.91	11.97	0.65	0.83	0.80	0.80
301.8	12.12	12.02	12.09	0.65	0.89	0.86	0.86
301.9	12.16	12.08	12.14	0.65	0.92	0.89	0.89
302.0	12.13	12.07	12.11	0.74	0.93	0.90	0.89
302.1	12.06	11.99	12.05	0.83	0.91	0.89	0.89
302.2	11.92	11.86	11.92	0.89	0.88	0.86	0.85
302.3	11.74	11.70	11.76	0.88	0.83	0.82	0.81
302.4	11.50	11.51	11.56	0.76	0.76	0.76	0.75
302.5	11.24	11.31	11.32	0.61	0.67	0.70	0.68
302.6	10.98	11.11	11.10	0.51	0.60	0.64	0.61
302.7	10.78	10.91	10.87	0.44	0.54	0.58	0.55
302.8	10.64	10.71	10.69	0.41	0.50	0.53	0.50
302.9	10.55	10.58	10.58	0.39	0.48	0.49	0.47
303.0	10.49	10.49	10.52	0.40	0.47	0.47	0.46
303.1	10.51	10.48	10.55	0.43	0.49	0.48	0.48
303.2	10.66	10.58	10.70	0.54	0.56	0.53	0.55
303.3	10.88	10.76	10.94	0.65	0.65	0.61	0.65
303.4	11.19	11.08	11.21	0.66	0.77	0.73	0.75
303.5	11.40	11.33	11.43	0.66	0.86	0.83	0.84
303.6	11.63	11.51	11.63	0.74	0.95	0.91	0.93
303.7	11.78	11.68	11.78	0.86	1.01	0.98	0.99
303.8	11.89	11.78	11.89	1.00	1.07	1.02	1.04
303.9	11.87	11.76	11.88	1.09	1.07	1.03	1.05
304.0	11.68	11.62	11.72	1.07	1.01	0.99	1.00
304.1	11.40	11.40	11.47	0.99	0.92	0.92	0.92
304.2	11.11	11.19	11.20	0.94	0.82	0.85	0.84
304.3	10.88	11.00	10.99	0.88	0.75	0.80	0.77
304.4	10.79	10.84	10.85	0.76	0.73	0.75	0.73
304.5	10.79	10.78	10.85	0.66	0.74	0.73	0.73
304.6	10.84	10.81	10.88	0.76	0.76	0.75	0.76
304.7	10.79	10.81	10.83	0.87	0.75	0.76	0.75
304.8	10.61	10.68	10.67	0.79	0.70	0.72	0.70
304.9	10.42	10.46	10.46	0.67	0.64	0.65	0.63
305.0	10.25	10.27	10.26	0.62	0.59	0.59	0.57
305.1	10.12	10.10	10.12	0.60	0.55	0.54	0.53
305.2	10.09	10.05	10.10	0.59	0.54	0.53	0.52
305.3	10.09	10.05	10.10	0.59	0.55	0.54	0.53
305.4	10.07	10.03	10.07	0.62	0.55	0.54	0.53
305.5	9.97	9.94	9.97	0.62	0.52	0.51	0.50
305.6	9.76	9.72	9.74	0.54	0.45	0.44	0.42
305.7	9.48	9.47	9.48	0.45	0.36	0.35	0.34
305.8	9.35	9.32	9.36	0.41	0.32	0.31	0.30
305.9	9.31	9.29	9.33	0.40	0.31	0.30	0.30
306.0	9.30	9.28	9.31	0.43	0.31	0.30	0.29
306.1	9.20	9.14	9.18	0.44	0.28	0.26	0.25
306.2	8.99	8.88	8.94	0.34	0.21	0.17	0.17
306.3	8.74	8.66	8.71	0.23	0.13	0.10	0.10
306.4	8.62	8.60	8.64	0.18	0.09	0.08	0.08
306.5	8.67	8.70	8.75	0.17	0.11	0.12	0.12
306.6	8.83	8.85	8.88	0.19	0.17	0.18	0.17
306.7	8.94	8.94	8.97	0.22	0.21	0.21	0.20
306.8	8.98	8.98	9.00	0.21	0.23	0.23	0.22
306.9	8.99	8.99	9.02	0.19	0.24	0.24	0.23
307.0	9.00	9.00	9.02	0.21	0.25	0.24	0.23

Table 3 (continued). 3rd contact.

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
	18h 54m						
o	s	s	s	"	"	"	"
307.1	8.99	8.96	8.99	0.22	0.24	0.23	0.22
307.2	8.91	8.85	8.89	0.11	0.22	0.20	0.19
307.3	8.76	8.71	8.75	0.01	0.17	0.15	0.14
307.4	8.65	8.62	8.67	0.09	0.13	0.12	0.12
307.5	8.61	8.61	8.65	0.21	0.12	0.12	0.11
307.6	8.63	8.64	8.68	0.23	0.13	0.13	0.12
307.7	8.69	8.70	8.75	0.22	0.15	0.15	0.15
307.8	8.75	8.77	8.81	0.22	0.17	0.18	0.17
307.9	8.80	8.80	8.83	0.22	0.19	0.19	0.18
308.0	8.78	8.77	8.80	0.23	0.18	0.18	0.17
308.1	8.71	8.67	8.71	0.22	0.16	0.14	0.14
308.2	8.56	8.51	8.56	0.12	0.10	0.09	0.09
308.3	8.42	8.44	8.47	0.01	0.06	0.06	0.05
308.4	8.42	8.46	8.47	-0.02	0.05	0.07	0.05
308.5	8.46	8.49	8.51	0.00	0.07	0.08	0.06
308.6	8.52	8.57	8.60	0.03	0.09	0.11	0.10
308.7	8.63	8.69	8.72	0.07	0.13	0.15	0.14
308.8	8.79	8.85	8.87	0.13	0.18	0.20	0.19
308.9	8.96	9.04	9.06	0.21	0.24	0.26	0.25
309.0	9.14	9.19	9.22	0.32	0.30	0.31	0.30
309.1	9.30	9.35	9.40	0.43	0.35	0.37	0.36
309.2	9.49	9.53	9.59	0.53	0.41	0.43	0.43
309.3	9.72	9.73	9.83	0.62	0.49	0.49	0.51
309.4	9.93	9.92	9.99	0.65	0.56	0.55	0.56
309.5	10.03	10.03	10.08	0.66	0.59	0.59	0.59
309.6	9.99	10.01	10.02	0.67	0.57	0.58	0.57
309.7	9.82	9.86	9.87	0.66	0.51	0.52	0.51
309.8	9.65	9.69	9.70	0.56	0.45	0.46	0.45
309.9	9.60	9.66	9.69	0.45	0.43	0.45	0.44
310.0	9.67	9.72	9.77	0.42	0.44	0.46	0.46
310.1	9.76	9.80	9.86	0.44	0.47	0.48	0.49
310.2	9.80	9.83	9.87	0.44	0.48	0.49	0.48
310.3	9.72	9.74	9.76	0.44	0.45	0.45	0.44
310.4	9.53	9.56	9.57	0.43	0.37	0.38	0.37
310.5	9.32	9.33	9.34	0.41	0.30	0.30	0.29
310.6	9.14	9.18	9.20	0.31	0.23	0.24	0.23
310.7	9.09	9.16	9.18	0.23	0.20	0.23	0.21
310.8	9.17	9.26	9.30	0.26	0.22	0.25	0.25
310.9	9.35	9.43	9.48	0.33	0.28	0.31	0.31
311.0	9.57	9.63	9.72	0.38	0.35	0.37	0.38
311.1	9.82	9.84	9.94	0.43	0.43	0.43	0.45
311.2	10.07	10.07	10.18	0.54	0.50	0.50	0.53
311.3	10.24	10.25	10.34	0.65	0.56	0.56	0.57
311.4	10.29	10.33	10.36	0.68	0.56	0.58	0.57
311.5	10.20	10.27	10.28	0.66	0.52	0.55	0.53
311.6	10.08	10.16	10.18	0.56	0.47	0.50	0.49
311.7	10.01	10.09	10.10	0.45	0.44	0.47	0.46
311.8	9.95	10.03	10.05	0.42	0.41	0.44	0.43
311.9	9.87	9.93	9.94	0.44	0.37	0.39	0.38
312.0	9.72	9.80	9.78	0.46	0.31	0.34	0.31
312.1	9.55	9.63	9.61	0.44	0.24	0.27	0.25
312.2	9.41	9.48	9.48	0.29	0.19	0.21	0.19
312.3	9.31	9.38	9.40	0.12	0.14	0.17	0.16
312.4	9.26	9.33	9.36	0.09	0.11	0.14	0.13
312.5	9.24	9.31	9.33	0.13	0.10	0.12	0.11

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
	18h 54m						
o	s	s	s	"	"	"	"
312.6	9.22	9.30	9.32	0.22	0.08	0.10	0.09
312.7	9.23	9.31	9.33	0.30	0.07	0.10	0.09
312.8	9.26	9.32	9.35	0.29	0.07	0.09	0.08
312.9	9.28	9.35	9.40	0.26	0.06	0.08	0.09
313.0	9.34	9.43	9.48	0.29	0.07	0.10	0.10
313.1	9.49	9.56	9.65	0.33	0.11	0.13	0.15
313.2	9.71	9.75	9.83	0.37	0.17	0.18	0.20
313.3	9.88	9.92	10.00	0.38	0.21	0.23	0.24
313.4	10.01	10.04	10.11	0.35	0.25	0.25	0.26
313.5	10.11	10.13	10.20	0.33	0.27	0.27	0.28
313.6	10.21	10.22	10.31	0.37	0.29	0.29	0.30
313.7	10.36	10.36	10.47	0.43	0.32	0.32	0.34
313.8	10.53	10.51	10.63	0.49	0.37	0.36	0.38
313.9	10.68	10.66	10.77	0.54	0.40	0.39	0.41
314.0	10.77	10.76	10.86	0.60	0.42	0.41	0.43
314.1	10.86	10.83	10.97	0.65	0.43	0.42	0.45
314.2	10.98	10.93	11.05	0.68	0.46	0.44	0.46
314.3	10.96	10.98	11.05	0.66	0.43	0.44	0.45
314.4	10.84	10.92	10.95	0.54	0.38	0.40	0.40
314.5	10.82	10.82	10.96	0.45	0.35	0.35	0.38
314.6	11.09	10.94	11.21	0.51	0.43	0.38	0.45
314.7	11.54	11.38	11.68	0.64	0.56	0.50	0.59
314.8	11.96	11.97	12.11	0.77	0.69	0.69	0.72
314.9	12.38	12.39	12.49	0.87	0.81	0.81	0.83
315.0	12.53	12.58	12.67	0.89	0.84	0.86	0.87
315.1	12.56	12.61	12.69	0.88	0.83	0.85	0.86
315.2	12.54	12.61	12.67	0.89	0.81	0.83	0.83
315.3	12.55	12.61	12.69	0.88	0.79	0.81	0.82
315.4	12.53	12.59	12.67	0.78	0.77	0.78	0.80
315.5	12.52	12.56	12.61	0.67	0.74	0.75	0.76
315.6	12.62	12.59	12.65	0.63	0.75	0.74	0.75
315.7	12.88	12.75	12.83	0.65	0.82	0.78	0.79
315.8		12.98	13.08	0.76		0.83	0.85
315.9				0.87			
316.0				0.89			
316.1				0.88			
316.2				0.88			
316.3				0.88			
316.4	13.10			0.88	0.75		
316.5	12.94	13.06		0.88	0.68	0.71	
316.6	12.83	12.89	12.96	0.89	0.62	0.63	0.64
316.7	12.74	12.77	12.83	0.88	0.56	0.57	0.58
316.8	12.68	12.66	12.74	0.78	0.52	0.51	0.53
316.9	12.66	12.61	12.69	0.67	0.49	0.47	0.49
317.0	12.68	12.64	12.69	0.64	0.48	0.46	0.46
317.1	12.74	12.66	12.73	0.65	0.47	0.44	0.45
317.2	12.81	12.70	12.79	0.66	0.47	0.43	0.45
317.3	12.92	12.82	12.90	0.66	0.48	0.45	0.46
317.4	13.05	12.94	13.01	0.65	0.50	0.46	0.48
317.5		13.03		0.65		0.47	
317.6		13.10		0.66		0.46	
317.7				0.66			
317.8				0.54			
317.9				0.45			
318.0				0.52			

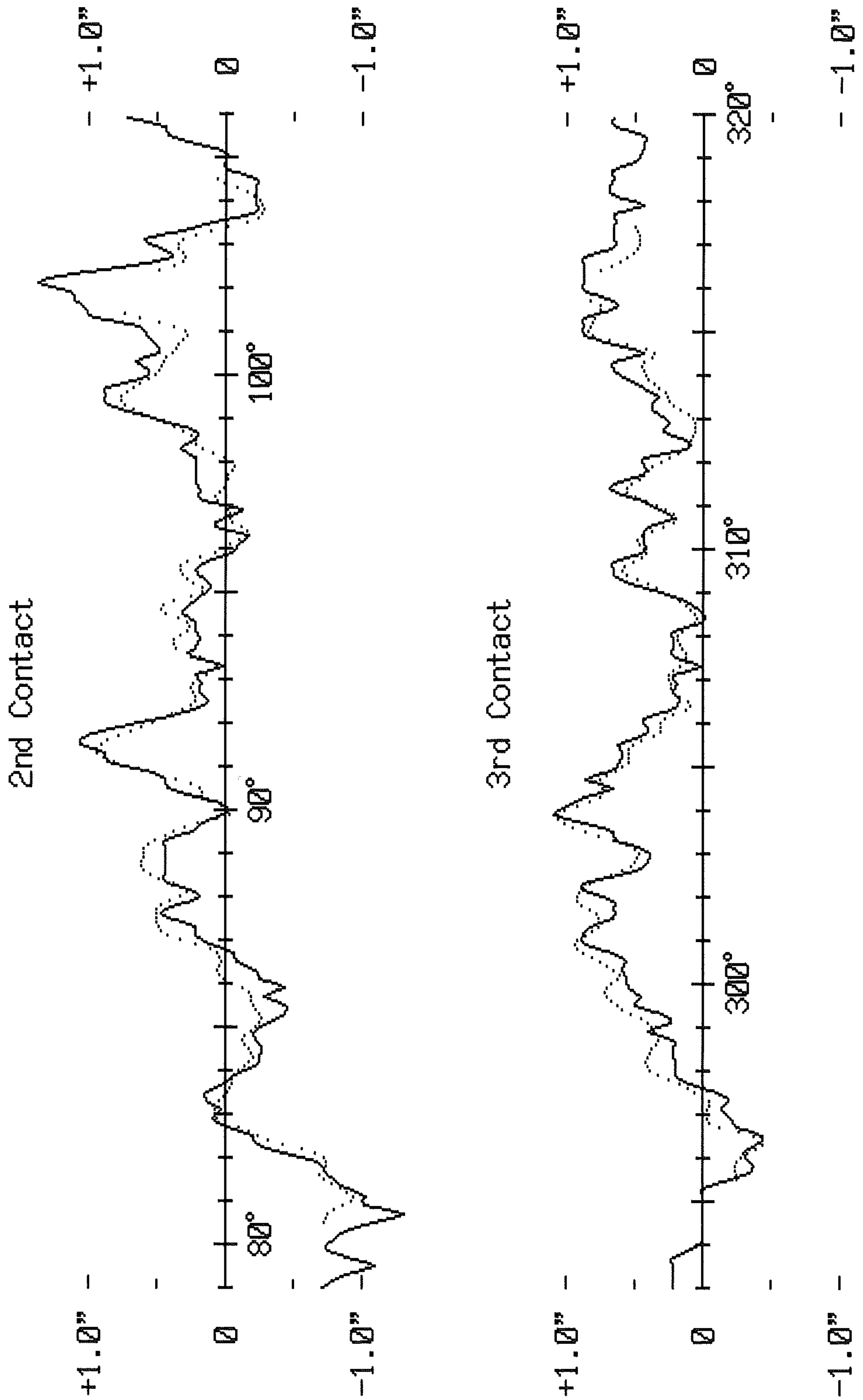

Figure 5. Observed lunar profiles (dotted lines) and those by Watts' charts (solid lines).

$\Delta\ (r_S - r_M) = +0.56'' \pm 0.02''$, (for 4960 Å)

and

$\Delta\ (\lambda_S - \lambda_M) = -0.20'' \pm 0.02''$,

$\Delta\ (\beta_S - \beta_M) = -0.51'' \pm 0.07''$,

$\Delta\ (r_S - r_M) = +0.52'' \pm 0.02''$. (for 4740 Å)

6. Discussion

As seen in Figure 5, the observed lunar limb h and that calculated from Watts' charts h_W show a very good coincidence with each other. This fact means that our observation was made with a sufficiently good accuracy as well as that Watts' charts are correct enough at least for the regions considered. The mean errors of 0.02″ for longitude and semidiameter and 0.07″ for latitude, for example, seem to be reasonable in this respect.

Now we compare the present result with those which were obtained at the eclipses in 1970 and 1973 and published in this series of the Report of Hydrographic Researches. It should be noticed, however, that in the past results the ephemerides were different from the current one.
Further, the solar edge defined in the 1970 eclipse analysis is 0.04″ larger than that defined by the inflection point (Mori and Kubo, 1971).

So we have recomputed the reductions for the 1970 and 1973 eclipses adopting the completely same standard and formula as the present reduction. The result is as follows:

For 1970 March 7:

$\Delta\ (\lambda_S - \lambda_M) = -0.17'' \pm 0.02''$,

$\Delta\ (\beta_S - \beta_M) = -0.43'' \pm 0.07''$,

$\Delta\ (r_S - r_M) = +0.29'' \pm 0.02''$.

For 1973 June 30:

$\Delta\ (\lambda_S - \lambda_M) = -0.26'' \pm 0.02''$,

$\Delta\ (\beta_S - \beta_M) = -0.32'' \pm 0.14''$,

$\Delta\ (r_S - r_M) = +0.44'' \pm 0.05''$.

The result for 1970 and 1973 is for wave length 4615 Å. So we need for a rigorous comparison to reduce our present result for 1991 to the same wave lenght by extrapolation. After the reduction to the wave length 4615 Å, we have

For 1991 July 11:

$\Delta\ (\lambda_S - \lambda_M) = -0.20'' \pm 0.02''$,

$\Delta\ (\beta_S - \beta_M) = -0.50'' \pm 0.07''$,

$\Delta\ (r_S - r_M) = +0.51'' \pm 0.02''$.

By comparison, we notice that the differences of the coordinates as well as of the semidiameter vary fairly largely. The variation in the coordinates, which seems too large, may be partly due to the incompleteness of the ephemeris. On the other hand, the change in the semidiameter is not affected by the ephemeris and seems to be physically significant. Assuming that the radius of the Moon is constant, the change in the radius of the Sun is well accordant with Gillliland (1981).

Throughout the reductions above, however, we have assumed that Watts' charts are perfectly correct. Figure 5 and the corresponding figures in Mori and Kubo (1971) and Mori and Ganeko (1976) show that this is true at least relatively or locally in small regions of the lunar limb.

However, there exists a possibiity that the mean levels of Watts' charts differ from region to region. We can show a proof for that from the result of an analysis of lunar occultations of stars extending for many years (unpublished yet). If we apply this correction to the mean levels of Watts' charts, the result is affected considerably. Though preliminary, it becomes:

For 1970 March 7:

$\Delta\ (\lambda_S - \lambda_M) = +0.10'' \pm 0.02''$,

$\Delta\ (\beta_S - \beta_M) = -0.50'' \pm 0.07''$,

$\Delta\ (r_S - r_M) = +0.32'' \pm 0.02''$.

For 1973 June 30:

$\Delta\ (\lambda_S - \lambda_M) = -0.24'' \pm 0.02''$,

$\Delta\ (\beta_S - \beta_M) = -0.28'' \pm 0.14''$,

$\Delta\ (r_S - r_M) = +0.40'' \pm 0.05''$.

For 1991 July 11:

$\Delta\ (\lambda_S - \lambda_M) = -0.17'' \pm 0.02''$,

$\Delta\ (\beta_S - \beta_M) = -0.54'' \pm 0.07''$,

$\Delta\ (r_S - r_M) = +0.47'' \pm 0.02''$.

A detailed discussion on the correction to Watts' charts and the final result will be published elsewhere.

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1991年７月11日の皆既日食の観測（要旨）

1991年７月11日の皆既日食において，水路部では閃光スペクトル連続撮影法による接触時刻の観測を行っ

た。観測の整約の結果，太陽と月の位置及び視半径の相対値について，天体暦の表値に施すべき次の改正量を得た：

$\Delta\ (\lambda_S-\lambda_M)=-0.20''\pm0.02''$,

$\Delta\ (\beta_S-\beta_M)=-0.50''\pm0.07''$,

$\Delta\ (r_S-r_M)=+0.51''\pm0.02''$. (4615Å)

また，この結果を過去に水路部が同一の方法で行った日食観測の結果と比較したところ，太陽の半径について有意な時間変化が認められた。以上の結果において，月縁図の誤差は少なからぬ影響を及ぼすが，それについても考察した。