水路部研究報告　第34号　平成10年３月10日
REPORT OF HYDROGRAPHIC RESEARCHES No.34 March, 1998

Observation of 1994 November 3 Total Solar Eclipse †

Masayuki OKUMURA*, Tsuyoshi KATO** and Masato KATAYAMA*

Abstract

Observation of the total solar eclipse on November 3, 1994, was made by the Hydrographic Department of Japan (JHD) by means of flash spectrum recording method. Analysis 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 Japanese ephemeris :

$\Delta(\lambda_S - \lambda_M) = +0.49'' \pm 0.15''$,

$\Delta(\beta_S - \beta_M) = +0.32'' \pm 0.19''$,

$\Delta(r_S - r_M) = -0.10'' \pm 0.02''$.　(4615Å)

Key words : Total solar eclipse, contact times, ephemerides of the Sun and the Moon.

1. Introduction

The Hydrographic Department of Japan (JHD) sent an observation team to South America for the total solar eclipse of November 3, 1994. The purpose of the observation is to determine the accurate position of the Sun relative to that of the Moon, for maintainance and improvement of the astronomical ephemeris accuracy.

The two members of the JHD, Masayuki Okumura (chief) and Tsuyoshi Kato, participated as constituents of the official Japanese expedition team for the eclipse sent by the Japanese Government.

The expedition team consisted of six members from National Astronomical Observatory (NAO) and the JHD with Dr. Kiyoshi Ichimoto of NAO as the leader. The observation site was set up at Putre, Tarapaca, located in the north part of Chile (Fig. 1).

After installation and adjustment of the observation instruments for about three weeks, the JHD members observed the eclipse successfully although the sky was covered by thin clouds during the solar eclipse (see photos 1 to 3).

This paper 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 team was set in the playground of the Regimiento Caballeria Blindado No-1 Granaderos de Putre of the Chilean army, reserved place for observation parties from all over the world. Electricity of 220V was supplied to the observation teams by Chilean army.

In the days preceding the eclipse, the observation team determined the position of the telescopes of both the JHD and the NAO using a GPS receiver (Furuno GN-72). Geodetic coordinates in geocentric reference frame (WGS-84) were determined by obtained data

† Received 1997 December 3rd; Accepted 1998 January 26th.
* 航法測地課　Geodesy and Geophysics Division, Hydrographic Department
** 第九管区海上保安本部　9th Regional Maritime Safety Headquarters

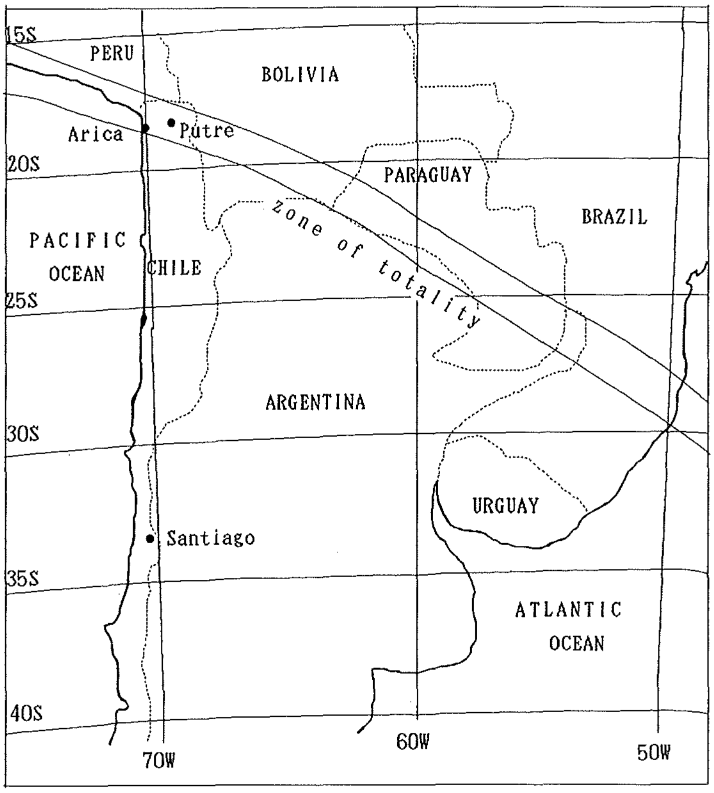

Fig. 1. Path of total phase at south america.

from October 13 to 23 as follows :

longitude : $\lambda_g = 69°\ 33'50.57''$W,

latitude : $\phi_g = 18°\ 11'51.37''$S,

height : $H = +3522$ m.

(WGS-84)

Height is from the reference ellipsoid of WGS-84.

The observation team also obtained the meteorological data from October 13 to November 4 :

mean minimum temperature	3.3℃
mean maximum 〃	26.8℃
mean minimum humidity	23%
mean maximum 〃	34%

With the progress of the eclipse on November 3, the temperature went down and a local minimum value of 14℃ was recorded at 10h 15 m local standard time about an hour after the totality, about 4℃ lower than it would have shown without the eclipse.

The observation team were suffered from mountain sickness and very low humidity.

Fig. 2 shows the variation of temperature and humidity on the day of the eclipse.

3. Observation of the eclipse

The CCD-video camera and video tape recorder were introduced for this observation of the flash spectrum recording method, instead of 16-mm movie camera and cinefilm used in the past observations of eclipses by the JHD. These new equipments enable us to obtain digital data directly and make the analysis easier. The data analysis was carried out with the same procedure in the past eclipse observations by the JHD.

A schematic diagram of the equipments used is shown in Figs. 3 (a) and 3 (b). Since a detailed description of the main equipments is given in Mori and Kubo (1971), only an outline and the differences are explained below.

A spectrotelescope and a CCD-video camera

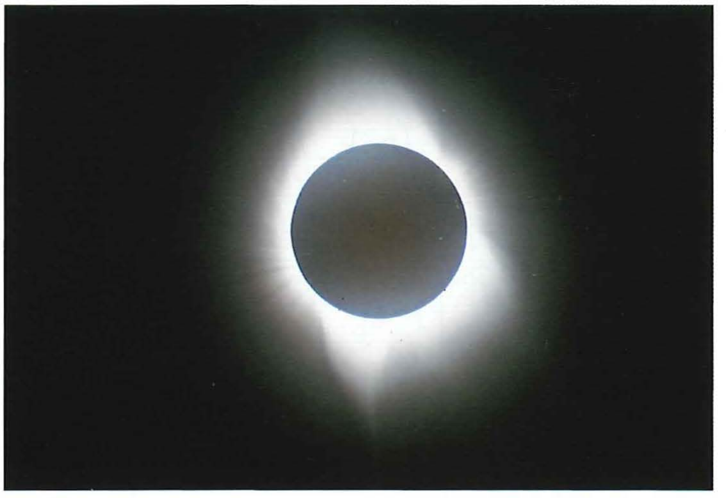

Photo 1. The solar corona at the total solar eclipce of November 3, 1994.

Photo 2. The spectrotelescope.

Photo 3. The recording equipments.

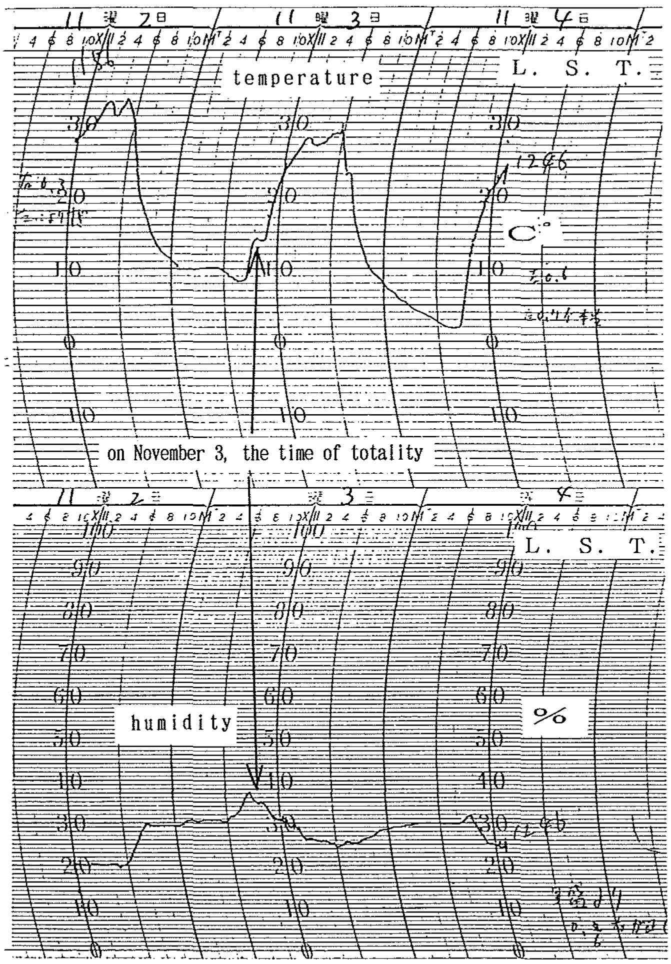

Fig. 2. Temperrature and humidity at the observation site on 1994 Nov 2 to 4.

based on an equatorial mounting constitute the main part of the equipments. Both the equatorial mounting and the CCD-video camera are driven by AC 100V which was converted from 12V DC batteries. The optics of the spectrotelescope consist of an objective lens with apperture of 80mm and focal length of 1200 mm and direct-vision prism just ahead of the objective lens. The resolution of the image at the focal point is 5.8mm/1000" and the dispersion of the prism is 77Å/mm at 4764Å.

A CCD-video camera (Hamamatsu photonics C3077-50) was used for recording of the flash spectra at the second and third contacts. The size of the CCD detector is 8.8mm× 6.6mm with the direction of dispersion parallel to the longer side and that of position angle to the shorter side. Time signal was recorded in lower left of each frame.

Digital image was recorded about 30 times a second on a Hi8 8mm VTR tape. Examples of the images are shown in Photos 4 and 5.

The time signal from a video timer (Hoei VTG-33) was calibrated to UTC by using GPS with an accuracy better than 10ms. The recorded time signal was corrected due to delay of 20 ms.

The flash spectra were recorded for 60 seconds each around the second and the third contacts.

After the eclipse observation, spectral images of the Sun's disk through a slit were recorded with various densities of ND filters inserted in front of the CCD-video camera and

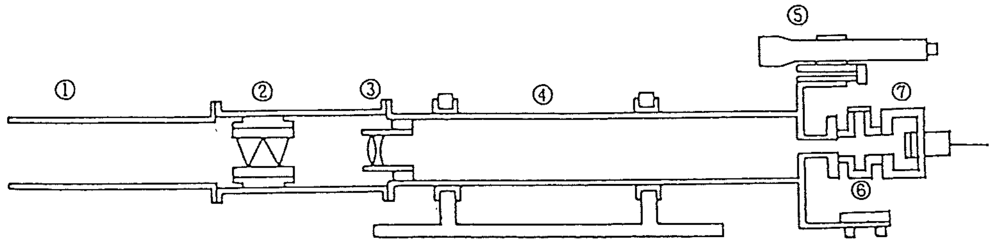

Fig. 3 (a). Schematic of the spectrotelescope.

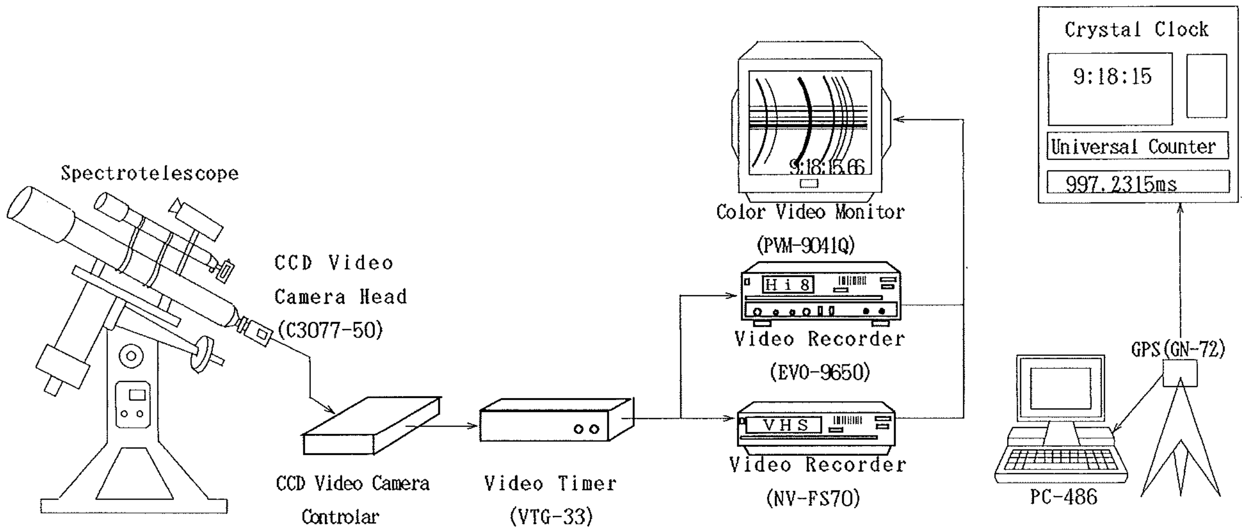

Fig. 3 (b). Diagram of recording equipments.

with several widths of the slit in order to obtain the relation between light intensity and brightness of the image.

4. Analysis

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 1. (Japanese Ephemeris for 1994, 1993) They are calculated consistently with the Japanese Ephemeris for 1994 which is accordant with the IAU (1976) System of Astronomical Constants.

The difference between the center of mass, which is given in the Ephemeris, and the figure center was taken into consideration. The lunar limb profile was estimated from Watts' (1963) lunar charts which is based on the figure center. The difference was estimated from observations of lunar occultation of stars by the JHD (Japanese Ephemeris for 1998, 1997) :

$\Delta\lambda_M = +0.38''$ and $\Delta\beta_M = -0.21''$.

where λ_M and β_M are the ecliptic coordinates of the Moon's longitude and latitude. As for the semidiameter of the Sun s_0 and the Moon k, the following values are adopted :

$s_0 = 959.63''$, (at the distance of 1 A.U.)

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

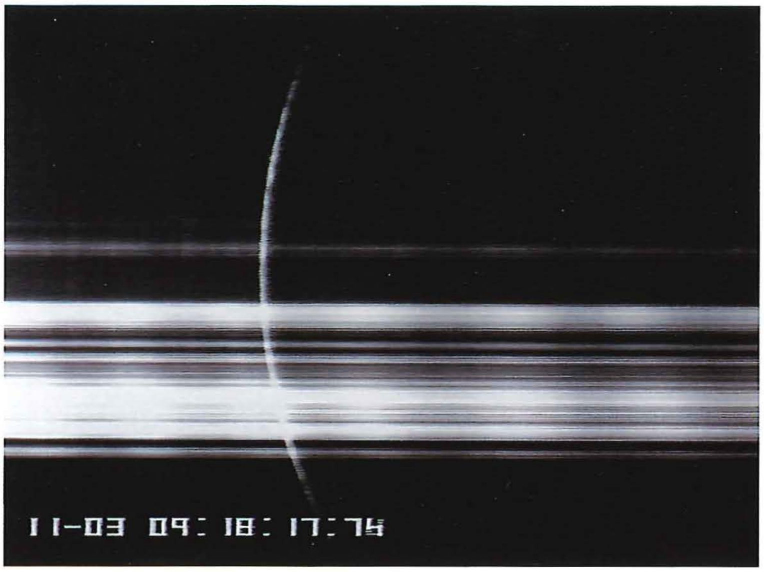

Photo 4. Exmple of the image of flash spectra near Second contact.

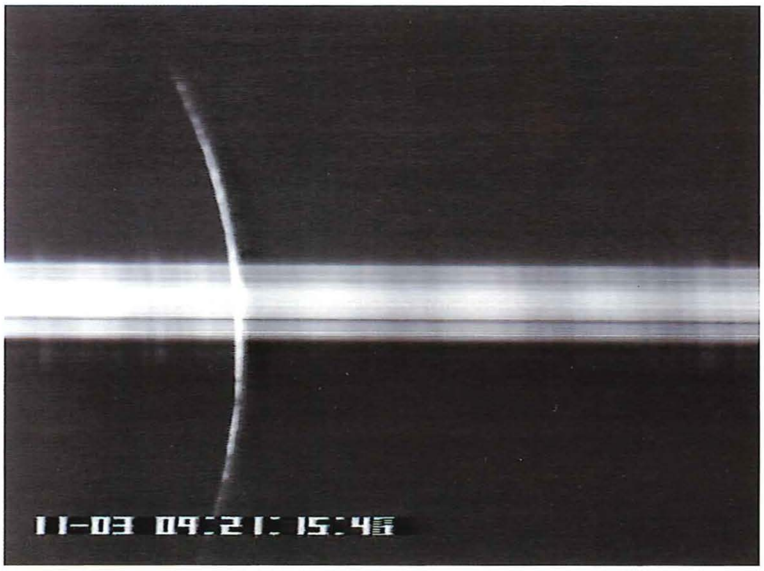

Photo 5. Exmple of the image of flash spectra near third contact.

Table 1. The coordinates of the Sun and the Moon and the local prediction for the observation site.

			Second contact	Third contact
Contact Time(UTC) (t_0)			12h 18m 17.73s	12h 21m 19.77s
Position Angle of Contact Point (P_0-180°)			115.17°	289.37°
Distance between the Centers of the Sun and the Moon			45.14"	45.33"
Geocentric	R.A.	of the Sun	14h 33m 42.544s	14h 33m 43.043s
〃	Dec.	〃	-15° 04' 48.13"	-15° 04' 50.50"
〃	R.A.	of the Moon	14h 30m 08.986s	14h 30m 16.772s
〃	Dec.	〃	-15° 15' 21.63"	-15° 15' 47.85"
Topocentric	R.A.	of the Sun	14h 33m 43.052s	14h 33m 43.547s
〃	Dec.	〃	-15° .04' 46.54"	-15° 04' 48.93"
〃	R.A.	of the Moon	14h 33m 40.232s	14h 33m 46.500s
〃	Dec.	〃	-15° 04' 27.34"	-15° 05' 03.97"
〃	S.D.	〃	1012.58"	1012.77"
Relative Velocity of the Moon to the Sun		(Magnitude)	0.4964"/s	
〃		(Position angle)	112.27°	

UT1−UTC was taken from IERS Annual Report for 1994 (1995) and is used in the local prediction :

UT1−UTC=+0.545s.

Since TAI−UTC=29s at that time and TDT−TAI=32.184s, we have TDT−UT1=60.639s.

Correction for the polar motion is not taken into consideration, because the value is so small that it does not affect the analysis. (IERS Annual Report for 1994, 1995).

The brightness values of spectra of the crescent Sun on the frame were measured by a Hamamatsu photonics DVS-3000.

The brightness values were measured for each frame of the VTR tape along the direction of position angle, which is parallel to the edges of the image, at three wave length. The adopted wave lengths were 5960 Å, 4740 Å and 4615 Å which are less affected by the emission lines from the chromosphere. We measured only the brightness value of the continuum from the photosphere.

The DVS-3000 has 640 pixels for the direction of dispersion and 485 pixels for that of position angle. Each one pixel corresponds to 0.97 Å of wave length for the former and to 0.13° of position angle for the latter.

The brightness data were obtained digitally with an interval of one pixel on the frame along position angle for each wave length and recorded on a MO disk.

We used the prominent features of the spectra to find the relation between the position angle and the position of the images. The outline of the process is as follows. A graph is made for any frame to show the relation between the position on the frame along the direction of position angle and the brightness, 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 the position angle and y-axis for the 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 frame position along the direction of position angle.

From the brightness data for any position angle for all the frames, we can draw the so-called eclipse curve, a curve showing how the intensity changes with respect to time, since we have already the relation between the image brightness and the intensity of light. 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. Therefore eclipse curve reveals the relation between the intensity and the height of the solar edge above the lunar limb (from Figs. 4 (a) to 4 (d)). The eclipse curves in Fig. 4 and the following reduction as far as Section 5 are for 4615 Å, We have similar results for the other two wave lengths.

Every eclipse curve shows a similar feature, i. e., rapid change between the slow curves.

We define the solar edge by the point with the inflection point of the eclipse curve, in the analysis. In practice, we obtain the inflection points of conspicuous hills and valleys on the lunar limb. Then we can obtain the time for every position angle when the brightness is equal to the mean value thus determined. It should be called the contact time for that position angle. We can get such contact times for each pixel of data for the both contacts. These contact times consutitute the basic data in the following analysis for the relative position of the Sun to the Moon. The second to fourth columns of the Tables 2 and 3 give contact times for each pixel which is about 0.13° of position angle for the three wave lengths for the second and third contacts, respectively.

The fundamental equation for the reduction for the relative position of the Sun and the Moon is given in Kubo et al. (1993) :

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

with

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

where i=2, 3 represent that the values are those of the second and the third contacts repectively, α, δ and r are right ascension, declination, and semidiameter, and subscripts S and M mean the valuse for the Sun and the Moon. The meanings of the notations are as follows :

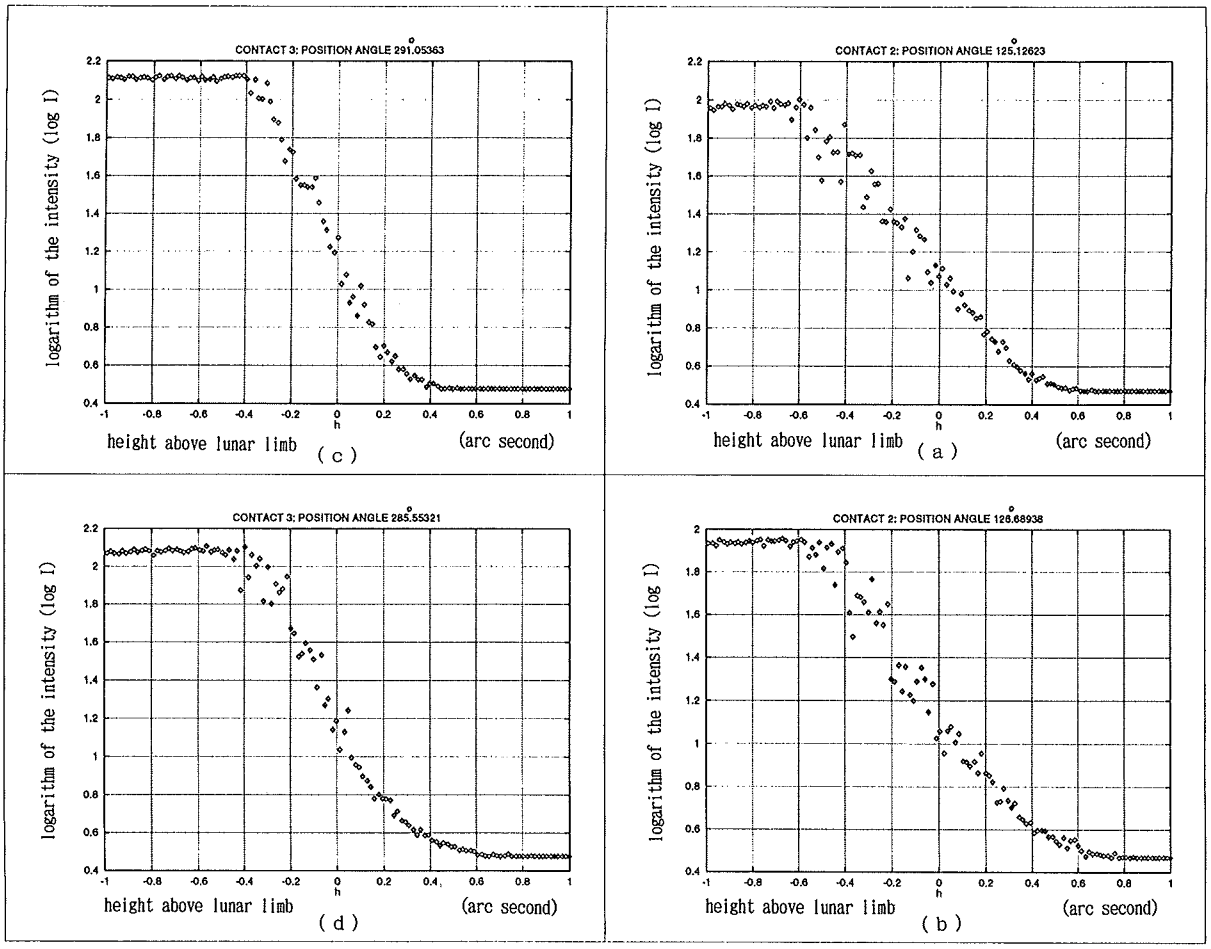

Fig. 4. Eclipse curves at 4615 Å (a, b : second contact, c, d : third contact).

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

t_C : contact time for the point,

h : height of lunar limb above the datum of the Moon,

t_0 : predicted contact time given in Table 1,

p_0 : position angle 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 are also shown in Table 1. It should be noticed that the predicted topocentric values for all those quantities are used in the analysis. The applied topocentric lunar libration parameters are $l=-0.14°$, $b=+0.12°$ and $C=+19.67°$. A correction of 0.2° to the position angle of lunar profile 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 equations for all the points of both contacts we have the equation for the least squares solution. The equation is

Table 2. Position angle (p), contact times (tc), height by Watts (hw) and observed heights (h) ((1): 4960 Å, (2): 4740 Å, (3): 4615 Å). Second contact.

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
		12h 18m					
°	s	s	s	"	"	"	"
107.11		15.87		0.13		0.57	
107.24		16.14		0.20		0.44	
107.49		16.17	16.24	0.21		0.45	0.37
107.62		16.27	16.21	0.14		0.42	0.40
107.75			16.39	0.06			0.32
108.13		16.35	16.54	-0.00		0.42	0.28
108.26		16.02		0.00		0.60	
108.38			15.95	0.06			0.60
108.51	16.21			0.13	0.64		
109.02		16.31		0.29		0.52	
109.27	17.00	16.63	16.66	0.31	0.31	0.38	0.32
109.53		16.83	16.71	0.12		0.30	0.31
109.65		16.98	16.92	-0.06		0.23	0.22
109.78		17.12	17.13	-0.07		0.17	0.12
109.91		17.12		0.03		0.18	
110.03	17.53	17.23	17.28	0.09	0.10	0.13	0.06
110.16		17.22	17.28	0.02		0.14	0.07
110.29			17.34	-0.11			0.05
110.41	17.36	17.12	17.25	-0.13	0.21	0.21	0.10
110.54		17.05	17.19	0.01		0.25	0.14
110.67		17.03	17.12	0.18		0.26	0.18
110.79			17.11	0.18			0.19
111.17			16.39	-0.03			0.57
115.72		17.60	17.52	0.32		0.06	0.07
115.84		17.81	17.77	0.05		-0.05	-0.06
115.97			17.89	-0.09			-0.11
116.10	18.38	18.04	18.04	-0.07	-0.21	-0.17	-0.20
116.22		18.03	18.10	0.05		-0.17	-0.23
116.35		18.09	18.16	-0.01		-0.20	-0.26
116.47		18.02	18.14	-0.18		-0.17	-0.25
116.60		17.99	18.09	-0.16		-0.16	-0.23
116.73		18.06	18.10	-0.14		-0.20	-0.24
116.85		18.11	18.16	-0.20		-0.23	-0.28
116.98		18.16	18.21	-0.22		-0.26	-0.31
117.10		18.14	18.28	-0.21		-0.26	-0.35
117.23		18.01	18.17	-0.22		-0.20	-0.30
117.36		17.85	18.06	-0.32		-0.12	-0.25
117.48		17.72	17.88	-0.42		-0.06	-0.16
117.61		17.70	17.77	-0.38		-0.06	-0.11
117.74			17.74	-0.29			-0.11
117.86		17.63	17.75	-0.22		-0.04	-0.12
117.99		17.50		-0.15		0.02	
118.12		17.38	17.54	-0.09		0.07	-0.02
118.24		17.22	17.36	-0.01		0.14	0.06
118.37			17.24	0.10			0.11
118.49		17.03		0.25		0.22	
118.62		16.97	17.05	0.39		0.24	0.19
118.75			17.02	0.43			0.20
118.87			16.86	0.48			0.27
119.00	16.90			0.71	0.39		
119.63		17.30		0.15		0.01	
119.76			17.31	-0.02			-0.02
120.65		17.20		0.82		-0.03	
120.77		17.48		0.09		-0.18	
120.90		17.62	17.57	-0.39		-0.26	-0.24
121.03		17.67	17.63	-0.08		-0.30	-0.29
121.15		17.79	17.76	0.14		-0.37	-0.36
121.28		17.73	17.79	0.11		-0.35	-0.39
121.41		17.58		0.04		-0.29	
121.53		17.28	17.48	-0.08		-0.16	-0.26
121.66		17.24	17.27	-0.18		-0.16	-0.17
121.79		17.27		-0.11		-0.18	
121.92		17.32	17.32	0.04		-0.22	-0.22
122.04	17.75	17.32	17.29	0.09	-0.30	-0.23	-0.22
122.17		17.39	17.36	0.06		-0.28	-0.27
122.30		17.39	17.36	0.00		-0.30	-0.28
122.42		17.49	17.42	0.00		-0.36	-0.33
122.55		17.48	17.43	-0.09		-0.37	-0.35
122.68		17.55	17.55	-0.21		-0.42	-0.42
122.81	17.87	17.46	17.47	-0.23	-0.45	-0.40	-0.40
122.93		17.54	17.47	-0.21		-0.45	-0.41
123.06			17.55	-0.24			-0.47
123.32		17.89	17.82	-0.58		-0.67	-0.63
123.57		17.81	17.85	-0.71		-0.66	-0.68
123.70			17.79	-0.78			-0.67
123.83			17.84	-0.85			-0.71
124.08			18.19	-1.00			-0.91
124.21		18.55	18.46	-1.13		-1.11	-1.06
124.34		18.60		-1.24		-1.15	
124.46			18.60	-1.32			-1.17
124.59		18.75	18.66	-1.39		-1.26	-1.21
124.72	19.16			-1.39	-1.33		
124.85		18.72	18.71	-1.34		-1.28	-1.27
124.98	19.12	18.74	18.71	-1.36	-1.35	-1.32	-1.29
125.10		18.67	18.67	-1.43		-1.30	-1.29
125.23	18.97	18.64		-1.43	-1.31	-1.30	
125.36			18.58	-1.39			-1.29
125.49		18.31	18.47	-1.27		-1.19	-1.26
125.62		18.08		-1.07		-1.10	
125.75		18.00	18.04	-1.01		-1.08	-1.09
125.87		17.96	17.97	-1.09		-1.08	-1.08
126.00		17.93		-1.17		-1.09	
126.65		18.09	18.09	-1.49		-1.28	-1.27
126.90		17.98		-1.42		-1.27	
127.03		17.93	17.93	-1.42		-1.27	-1.26
127.29		17.75	17.76	-1.37		-1.23	-1.22
127.42		17.80		-1.18		-1.28	
127.55		18.01	17.78	-1.16		-1.40	-1.28
127.68		18.15		-1.32		-1.50	
127.94		18.39	18.15	-1.50		-1.66	-1.53
128.33		18.40	18.28	-1.60		-1.74	-1.67
128.59		18.21	18.18	-1.76		-1.70	-1.67
128.85		17.90	17.86	-1.74		-1.61	-1.57
128.98		17.73	17.70	-1.64		-1.56	-1.52

Table 3. Position angle (p), contact times (tc), height by Watts (hw) and observed heights (h) ((1) : 4960 Å, (2) : 4740 Å, (3) : 4615 Å). Third contact.

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
°	s	12h 21m s	s	″	″	″	″
280.13	22.97			0.87	0.87		
281.13	23.90			1.85	1.47		
283.89	19.27			-0.78	-0.49		
284.01		19.15	19.03	-0.93		-0.85	-0.87
284.14			18.80	-1.06			-0.97
284.26		18.77	18.65	-1.15		-1.02	-1.04
284.39			18.39	-1.23			-1.15
284.51		18.33	18.16	-1.36		-1.21	-1.25
284.64		18.04		-1.47		-1.34	
284.89		17.46		-1.54		-1.61	
285.14	17.00	17.07		-1.53	-1.51	-1.78	
285.39			16.95	-1.77			-1.79
285.51		16.96		-1.85		-1.81	
285.64	16.74	16.82		-1.76	-1.60	-1.87	
285.76			16.66	-1.56			-1.91
286.01			16.94	-1.45			-1.76
286.14		17.00	17.07	-1.50		-1.75	-1.68
286.26		17.16	17.25	-1.38		-1.67	-1.59
286.38		17.30	17.42	-1.23		-1.59	-1.50
286.51		17.54	17.62	-1.32		-1.47	-1.39
286.63		17.63	17.47	-1.53		-1.42	-1.46
286.76		17.50		-1.72		-1.47	
286.88		17.06		-1.82		-1.69	
287.01		16.71		-1.89		-1.85	
287.13			16.25	-2.04			-2.04
287.26		16.29		-2.23		-2.05	
287.51		15.91	15.79	-2.42		-2.23	-2.26
287.63			15.70	-2.44			-2.29
287.75		15.75	15.64	-2.50		-2.30	-2.32
287.88		15.65		-2.52		-2.34	
288.00		15.60	15.56	-2.52		-2.36	-2.35
288.25		15.71	15.70	-2.47	-2.30	-2.28	
288.38	15.43	15.75	15.66	-2.41	-2.13	-2.28	-2.30
288.50			15.63	-2.40			-2.31
288.63		15.67		-2.42		-2.31	
288.75	15.43		15.51	-2.39	-2.12		-2.36
288.87			15.50	-2.24			-2.37
289.12			15.65	-1.98	-2.29		
289.25		15.79	15.76	-2.22		-2.24	-2.23
289.37		15.80	15.60	-2.59		-2.23	-2.31
289.62		15.47		-2.74		-2.40	
289.75		15.44	15.35	-2.73		-2.41	-2.43
290.37	15.20	15.42	15.28	-2.57	-2.23	-2.42	-2.47
290.49	15.18			-2.62	-2.24		
290.74		15.29	15.18	-2.92		-2.48	-2.52
290.87	15.24	15.15			-2.91	-2.51	-2.54
291.12		15.21	15.12	-2.83		-2.53	-2.56
291.24		15.22	15.12	-2.92		-2.53	-2.56
291.37		15.19	15.10	-3.04		-2.54	-2.57
291.49		15.22	15.14	-3.08		-2.53	-2.55
291.61	14.99	15.20		-3.05	-2.34	-2.54	
291.74		15.25	15.16	-2.96		-2.52	-2.55
291.86		15.24	15.17	-2.78		-2.53	-2.54
291.99		15.31	15.23	-2.67		-2.50	-2.52
292.11	15.08	15.32	15.27	-2.84	-2.31	-2.49	-2.50
292.24		15.39	15.30	-2.97		-2.46	-2.49
292.36		15.40	15.34	-2.96		-2.46	-2.47
292.49	15.22	15.45	15.36	-2.90	-2.25	-2.44	-2.47
292.61		15.44	15.37	-2.79		-2.44	-2.47
292.74		15.47	15.40	-2.67		-2.43	-2.46
292.86		15.49	15.44	-2.62		-2.43	-2.44
292.99	15.30	15.57	15.52	-2.61	-2.23	-2.40	-2.41
293.11		15.59	15.52	-2.55		-2.39	-2.41
293.24		15.65	15.57	-2.56		-2.37	-2.40
293.36		15.59	15.49	-2.59		-2.40	-2.44
293.49		15.59		-2.49		-2.41	
293.61		15.57	15.51	-2.44		-2.42	-2.44
293.73			15.52	-2.57			-2.44
293.86		15.57	15.47	-2.63		-2.44	-2.47
294.23		15.58		-2.79		-2.45	
294.48	15.40			-2.43	-2.26		
294.61		15.73	15.80	-2.25		-2.40	-2.35
294.73		15.94	16.01	-2.11		-2.30	-2.26
294.86	15.66	16.10	16.12	-1.97	-2.15	-2.23	-2.21
294.99		16.21	16.19	-1.86		-2.18	-2.19
295.11	15.99	16.26	16.23	-1.78	-2.01	-2.16	-2.18
295.24		16.30	16.31	-1.67		-2.15	-2.14
295.36		16.42	16.56	-1.55		-2.10	-2.03
295.49		16.69	16.79	-1.52		-1.98	-1.92
295.61	16.39	16.86	16.87	-1.54	-1.85	-1.90	-1.89
295.74		16.94	16.97	-1.53		-1.87	-1.86
295.86	16.69	17.06	17.20	-1.44	-1.72	-1.82	-1.75
295.99	16.80	17.30	17.48	-1.29	-1.67	-1.71	-1.62
296.11	17.00	17.57	17.71	-1.15	-1.59	-1.59	-1.52
296.24		17.76	17.85	-1.07		-1.50	-1.46
296.36	17.47	17.86	17.92	-1.13	-1.37	-1.47	-1.44
296.49	17.64	17.95	17.99	-1.36	-1.30	-1.43	-1.42
296.61	17.71	17.95	17.93	-1.52	-1.28	-1.45	-1.45
296.74	17.77	17.91		-1.47	-1.26	-1.48	
296.87	17.92	17.99		-1.50		-1.48	-1.45
296.99	17.75	17.97	18.04	-1.45	-1.29	-1.47	-1.43
297.12	17.81	18.06	18.10	-1.14	-1.27	-1.44	-1.42
297.24		18.06	18.08	-1.01		-1.45	-1.44
297.37	17.87	18.06	18.17	-1.06	-1.27	-1.46	-1.41
297.50		18.20	18.44	-0.98		-1.41	-1.29
297.62	18.00	18.48	18.76	-0.79	-1.23	-1.28	-1.15
297.75	18.19	18.73		-0.59	-1.15	-1.17	
297.87	18.38	18.96		-0.46	-1.07	-1.07	
298.00	18.59			-0.47	-0.98		
298.12	18.77			-0.60	-0.91		
298.25	18.92			-0.67	-0.85		
298.38	18.96			-0.65	-0.84		
298.50	18.94			-0.58	-0.86		
298.63	18.97			-0.54	-0.87		
298.76	19.04			-0.55	-0.85		
298.88	19.09			-0.60	-0.84		
299.01	19.10			-0.71	-0.85		
299.13	19.02	19.14		-0.83	-0.91	-1.13	
299.26	18.91	19.00	19.14	-0.84	-0.97	-1.21	-1.15
299.39	18.84	19.05		-0.75	-1.02	-1.20	

Table 3. (continued). Third contact.

p	tc(1)	tc(2)	tc(3)	hw	h(1)	h(2)	h(3)
	12h 21m						
°	s	s	s	"	"	"	"
299.51	18.84			-0.68	-1.04		
299.64	18.95			-0.75	-1.01		
299.77	19.05			-0.82	-0.97		
299.89	19.15			-0.67	-0.94		
300.02	19.26			-0.59	-0.91		
300.78	19.32			-1.20	-0.99		
300.91	19.12	19.16	19.19	-1.29	-1.10	-1.36	-1.36
301.04	19.02		19.12	-1.35	-1.17		-1.42
301.17	18.95	19.01	19.11	-1.42	-1.23	-1.47	-1.44
301.29	18.93		19.16	-1.50	-1.26		-1.43
301.42	18.92	19.11		-1.54	-1.28	-1.47	
301.55	18.97			-1.53	-1.28		
301.67	19.06			-1.53	-1.26		
301.80	19.14			-1.55	-1.23		
302.44	19.28			-1.64	-1.28		
302.57	19.29			-1.65	-1.30		
302.83	19.38			-1.73	-1.30		
302.95	19.45			-1.65	-1.29		
303.08	19.53			-1.52	-1.27		

constructed with the condition that $(h-h_W)^2$ should be the 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 lengths after the best fit with respect to x, y and z are given in the 5th and the 6th to 8th columns of Tables 2 and 3, respectively.

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

$$\Delta(\delta_S-\delta_M)=+0.53''\pm0.18'',$$
$$\Delta(\alpha_S-\alpha_M)\cos\delta_S=+0.33''\pm0.09'',$$
$$\Delta(r_S-r_M)=-0.10''\pm0.02''.$$

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

$$\Delta(\lambda_S-\lambda_M)=+0.49''\pm0.15'',$$
$$\Delta(\beta_S-\beta_M)=+0.32''\pm0.19'',$$
$$\Delta(r_S-r_M)=-0.10''\pm0.02''.$$

All the above results are for the wave length 4615 Å as stated before. Results of the other wave-lengths are,

$$\Delta(\lambda_S-\lambda_M)=+0.48''\pm0.29'',$$
$$\Delta(\beta_S-\beta_M)=+0.40''\pm0.37'',$$
$$\Delta(r_S-r_M)=+0.12''\pm0.05'', \text{ (for 4960 Å)}$$

and

$$\Delta(\lambda_S-\lambda_M)=+0.63''\pm0.16'',$$
$$\Delta(\beta_S-\beta_M)=+0.43''\pm0.21'',$$
$$\Delta(r_S-r_M)=-0.09''\pm0.03'', \text{ (for 4740 Å)}$$

5. Discussion

We compare above results to those of the past eclipses reported in this series of the Report of Hydrographic Researches. They are : for 1970 March 7 : (Mori and Kubo, 1971)

$$\Delta(\lambda_S-\lambda_M)=+0.17''\pm0.02'',$$
$$\Delta(\beta_S-\beta_M)=-0.43''\pm0.07'',$$
$$\Delta(r_S-r_M)=+0.29''\pm0.02'', \text{ (for 4615 Å)}$$

for 1973 June 30 : (Mori and Ganeko, 1976)

$$\Delta(\lambda_S-\lambda_M)=-0.26''\pm0.02'',$$
$$\Delta(\beta_S-\beta_M)=-0.32''\pm0.14'',$$
$$\Delta(r_S-r_M)=+0.44''\pm0.04'', \text{ (for 4615 Å)}$$

for 1991 July 11 : (Kubo et al.1993)

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

As seen from Fig. 5, the obtained lunar limb h and those from Watts' charts h_W show a very good coincidence with each other. This fact means that our observation was made with sufficiently good precision. However, comparison of the reported ecliptic longitude and latitude differences shows larger correction values for the 1994 solar eclipse. We can not discuss the changing rate of the solar radius in this paper. (Gilliand, 1981, Kubo, 1993, and Pasachoff and Nelson, 1986) We assume that causes

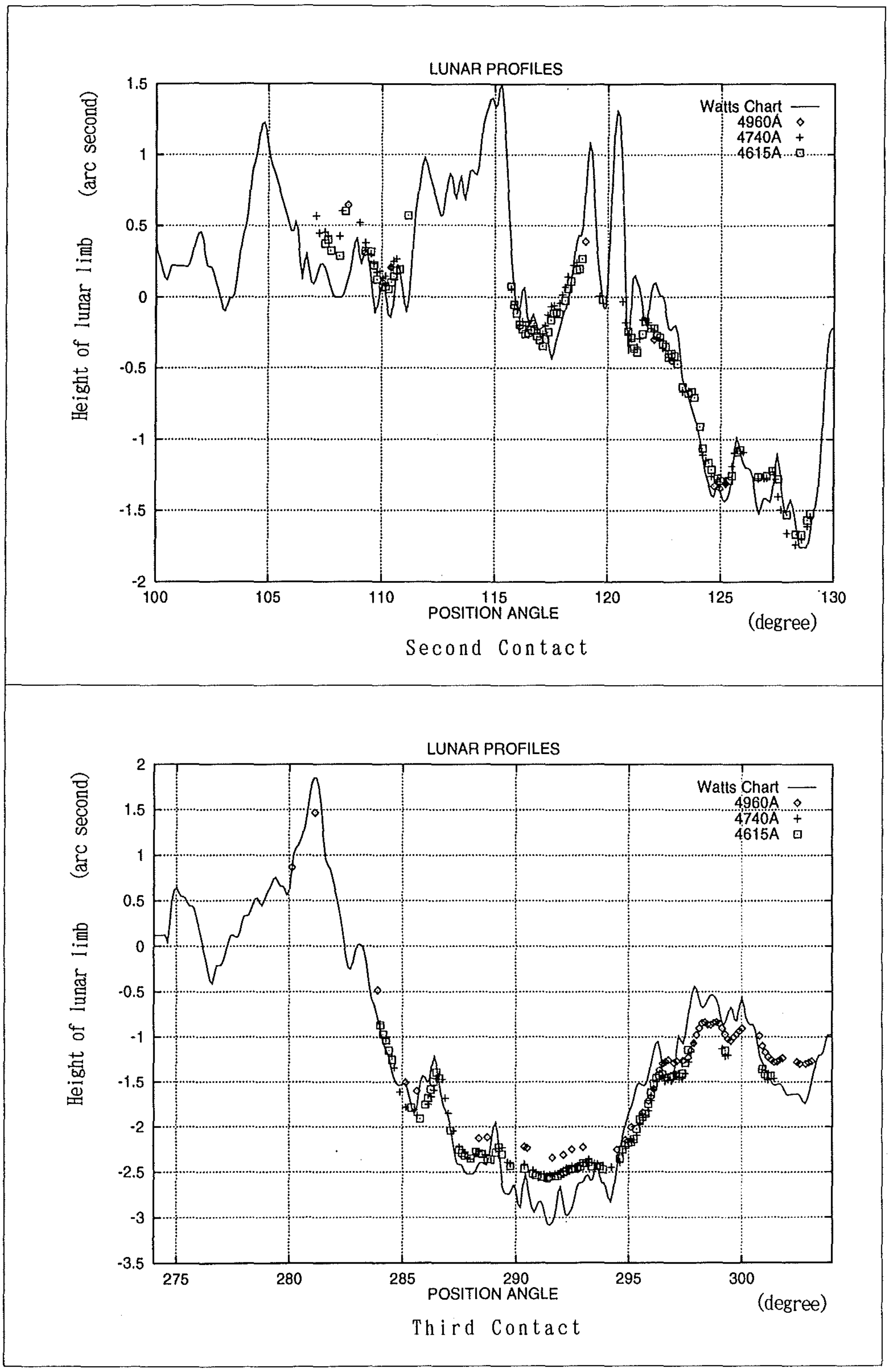

Fig. 5. Observed lunar profiles (caracters) and those by Watts' charts (solid lines).

are as follows.

(i) The final results are limited by the corrections of lunar limb which depend on Watts' charts. Poor quality of the lunar limb profile calculated from the Watts' charts may contaminate our results.

(ii) There are deep valley and high mountain at the third contact. The strong light emerged from the deep valley affected eclipse curves.

(iii) Thin cloud affected the results to some extent.

(iv) Characteristics of the new observation equipments differs from the past ones.

For exmple, the resolution is lower than the past one.

We have to continue to discuss the reason of larger corrections and to improve these results in order to accumulate the data of the total solar eclipse with these new equipments in the future.

If observations may give more precise results, efforts to improve ephemerides should be done to keep pace with the advancement of observation.

Acknowledgements

The members of the JHD observation team were greatly helped and supported by Dr. Ichimoto, the leader of the Japanese expedition team, and other members from National Astronomical Observatory throughout the expedition. The authers wish to thank for support and cooperation by Chilean army in Putre. Mr. Michihiro Suzuki of Geodesy and Geophysics Division, JHD, helped them by providing a very detailed local prediction.

And we thank Dr. Yoshio Kubo, Deputy Commander of 9th Regional Maritime Safety Headquarters, for helpful comments.

The authors express their sincere thanks for all of those supports.

References

Appleby, G. M. and Morrison, L. V. : *Mon. Not. R. Astr. Soc.*, **205**, 57, (1983).

Gilliand, R. L. : *Ap. J.*, **248**, 1144, (1981).

IERS Annual Report for 1994 : IERS Central Bureau, Paris, II-58, (1995).

Japanese Ephemeris for 1994 and 1998 : Hydrogr. Dept., Tokyo, (1993 and 1997).

Kawada, M. and Kubo, Y. : Rep. *Hydrogr. Res.*, CORRECTION TO THE ARGUMENT OF WATTS' MOON LIMB CHARTS OBTAINED FROM THE LUNAR OCCULTATION OF MARS IN 1986, **26**, 261-264, (1990).

Kubo, Y., Koyama, K., Okumura, M. and Kato, T. : OBSERVATION OF 1991 JULY 11 TOTAL SOLAR ECLIPSE, ibid., **29**, 99-117, (1993).

Kubo, Y. : Position and Radius of the Sun Determined by Solar Eclipses in Combination with Lunar Occultations, *Publ. Astron. Soc. Japan*, **45**, 819-829, (1993).

Mori, T. and Kubo. Y. : OBSERVATION OF THE 1970 MEXICO SOLAR ECLIPSE, Rep. *Hydrogr. Res.*, **7**, 39-62, (1971).

Mori, T. and Ganeko, Y. : OBSERVATION OF THE 1973 SOLAR ECLIPSE IN MOURITANIA, ibid., **11**, 43-52, (1976).

Pasachoff, J. M. and Nelson, B. O. : TIMING OF THE 1984 TOTAL SOLAR ECLIPSE AND THE SIZE OF THE SUN, *Solar Physics*, **108**, 191-194, (1986).

Watts, C. B. : *Astr. Pap. Amer. Eph.*, **17**, (1963).

1994年11月３日の皆既日食の観測（要旨）

奥村　雅之，加藤　剛，片山　真人

1994年11月３日の皆既日食において，記録装置をこれまでの16㎜映画用カメラ及びフィルムからCCDビデオカメラ及びハイエイト８㎜ビデオテープに変更した閃光分光器を使用し，スペクトル連続撮影法による接触時刻観測を行った．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下記の改正量を得た：

$\Delta(\lambda_S-\lambda_M)=+0.49''\pm0.15''$,

$\Delta(\beta_S-\beta_M)=+0.32''\pm0.19''$,

$\Delta(r_S-r_M)=-0.10''\pm0.02''$.