Solar and Lunar Daily Geomagnetic Variations at Lunping from 1966 to 1989

YINN-NIEN HUANG
Telecommunication Training Institute M.O.C.
Taipei Hsien, Taiwan, R.O.C.

(Received 28 June 1990; revised 26 September 1990)

ABSTRACT

Mean hourly values of geomagnetic declination, horizontal intensity and vertical intensity observed at Lunping have been analysed by use of the Chapman-Miller method in order to determine their solar and luni-solar diurnal components. Data obtained from 1966 to 1989 have been used. First the data are analysed as a whole, then reanalysed after subdivision according to season, month and solar activity. The lunar semi-diurnal variations are separated into parts of ionospheric and oceanic dynamo origin. The results are tabulated, discussed and compared with those of other observatories.

1. INTRODUCTION

A permanent geomagnetic observatory was established at Lunping, Taiwan by the author in 1965 (Huang, 1970). Routine observations have been carried out since July 1965. A set of Ruska Variometers have been used for variation measurements. A GSI 2 nd Order Magnetometer was used for the absolute measurement of the three geomagnetic elements, D, H and Z, for the period from July 1, 1965 to March 23, 1971. Since then, a proton precession magnetometer has been used for the absolute measurements of total field intensity, F; and the GSI 1st Order Magnetometer has been used for the absolute measurements of declination, D, and inclination, I. The three geomagnetic elements D, H and Z are derived from the observed values of D, F and I. The geographical as well as geomagnetic location of Lunping is: 25°00′ N; 121°10′ E and 14.21° N; 191.28° E respectively. Fig. 1 shows the geographical location of Lunping.

The objective of the present study is to determine the daily variations of the geomagnetic field at Lunping due to the influence of the Sun and the Moon. The method of analysis is very similar to that of Leaton, Malin and Finch (1962). The analysis uses all the 24 years data obtained at Lunping from 1966 to 1989.

2. DATA AND ANALYSIS

The data used in the present analysis consist of hourly mean values of the eastward declination, horizontal intensity and vertical downward intensity, denoted by D, H and Z, respectively, for the period from January 1, 1966 to December 31, 1989. All hourly mean values have been published annually as the Report of Lunping Observatory, Geomagnetism. Each hourly value in the monthly table of the annual report represents the mean value for a period of 1 hr. For analysis, all hourly values from the monthly tables were stored on magnetic tapes after a careful check. Any date which had incomplete data was omitted from the analysis.

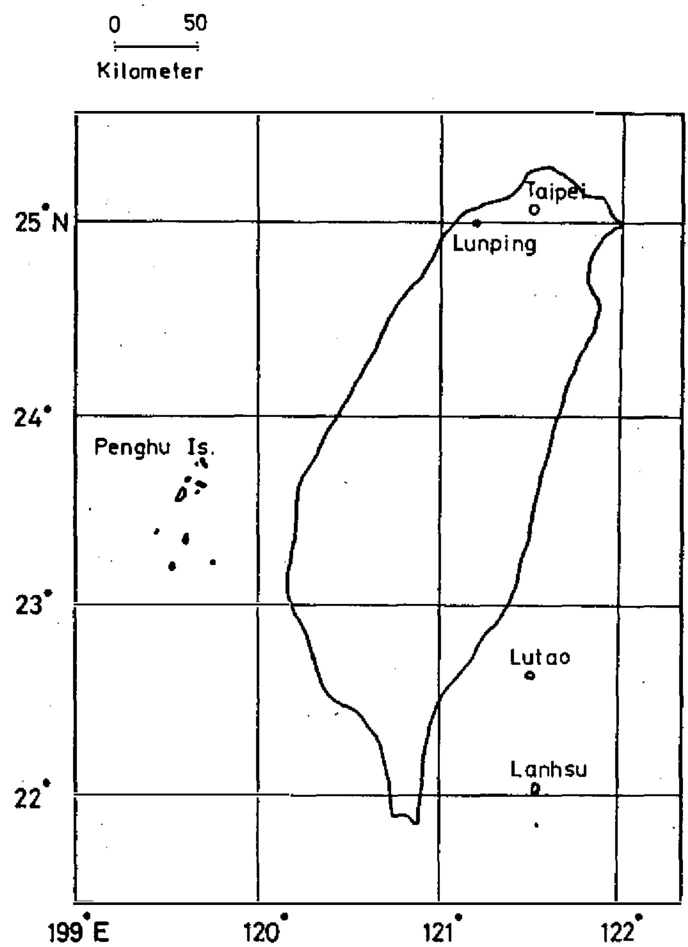

Fig. 1. A map showing the geographical location of the Lunping Observatory.

The method of analysis used to determine the solar variation, S, and the lunar variation, L, is that of Chapman and Miller (1940) as detailed by Tschu

(1949), Leaton, Malin and Finch (1962) and Malin and Chapman (1970). The vector probable errors were derived by the method detailed by Malin and Chapman (1970). The solar variations, S, are given in terms of the amplitudes, S_n, and phases, σ_n, of the four harmonics $n = 1, 2, 3$ and 4, as follows

$$S = \sum_{n=1}^{4} S_n sin(nt + \sigma_n) \tag{1}$$

The lunar variation, L, is given in terms of the amplitudes, l_n, and phases, λ_n, of the four harmonics $n = 1, 2, 3$ and 4, as follows

$$L = \sum_{n=1}^{4} l_n sin[(n-2)t + 2\tau + \lambda_n] \tag{2}$$

Here t denotes mean solar time, measured from the local midnight and τ denotes mean lunar time, measured from the mean local lower transit of the Moon. τ is related to t by

$$\tau = t - \nu \tag{3}$$

where ν is the phase of the Moon measured by the hour angle between the Sun and the Moon increasing from 00 at one new moon to 24 at the next. In terms of ν, Eq. (2) can be rewritten as

$$L = \sum_{n=1}^{4} l_n sin(nt - 2\nu + \lambda_n) \tag{4}$$

The most important component of the lunar daily variation has a period of half a lunar day and is expressed by

$$L_2 = l_2 sin(2\tau + \lambda_2) \tag{5}$$

Besides L_2, which is a purely lunar daily variation, L has a part, $(L - L_2)$, which is dependent on both lunar and solar time and is called the luni-solar component.

The data for each element were first analysed as a whole, and then reanalysed after subdivision according to season, month and solar activity. Three seasonal divisions were used: summer-May, June, July and August; winter-January, February, November and December; and equinoxes-March, April, September and October. For solar activity, two divisions were used corresponding to solar quiet and active periods. The quiet period includes all the data for the months when the monthly mean Zurich relative sunspot number, R, was less than 50, viz. from January to July 1966; from January 1973 to December 1976 and from April 1984 to November 1987. The rest of the data were classified as in the active period, viz. from August 1966 to December 1972; from November 1977 to April 1984 and from December 1987 to December 1989. The mean sunspot numbers for the quiet and the active periods are $\overline{R} = 25$ and $\overline{R} = 106$, respectively.

The results of the analysis are presented in Tables 1-6. Tables 1-3 for the D, H and Z elements, respectively, give the amplitudes, s_n, vector probable errors, E_n, and phases, σ_n, of the solar harmonics. Tables 4-6 for D, H and Z respectively, give the amplitudes, l_n, vector probable errors, E_n, and phases, λ_n, of the lunar harmonics.

3. SEASONAL VARIATIONS OF S

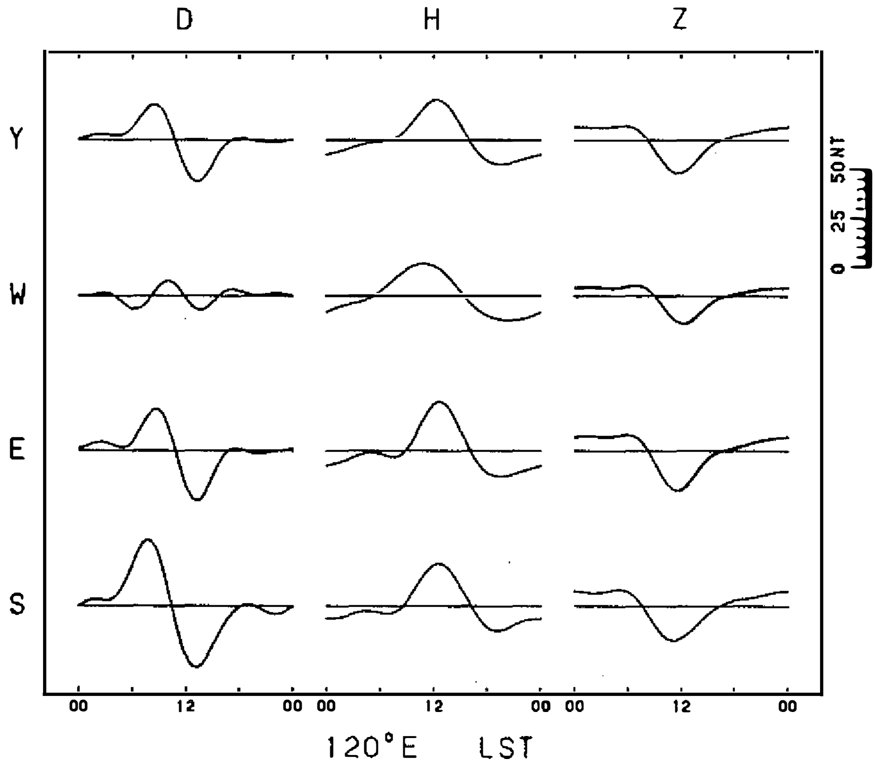

Fig. 2. Day-graphs illustrating the solar daily variations separately for year and for each season.

Fig. 2 shows the day-graphs of the solar daily variations for the D, H and Z elements synthesized from their harmonic components as listed in Tables 1-3 by use of Eq. (1). The curves Y, obtained by using all the data, represent the annual mean variations. The curves W, E and S represent the mean variations in winter, equinoxes and summer. The shape of the daily variation in D varies from winter to summer; and the range of daily variation shows a marked increase from winter to summer. However, the shapes of the daily variations in H and Z do not show marked changes; and the maximum and minimum ranges appear in equinox and winter, respectively, with the summer range in between the two.

To be more quantitative, the range of solar daily variation, denoted by $R(S)$, was obtained by taking the difference between the greatest and least of 24 values of solar daily variation, S, synthesized at hourly intervals using Eq. (1). Table 7 summarizes the results obtained for each element. The ratios of seasonal or monthly to annual mean ranges are also given in the table. The mean ratios of D and H and of D, H and Z were also calculated and are given in Table 7, denoted by $D+H$ and $D+H+Z$, respectively. Using these ratios, the seasonal changes may be examined.

For D elements, the ratios were smallest in winter and largest in summer with the summer value almost four times greater than the winter one. For H and Z the ratios were also smallest in winter but largest in the equinoxes instead of summer. These results are different from those obtained by Gupta and Malin (1972) in which they found that the ratios for S were greatest for the summer months and least for the winter months; and that all elements show essentially the same seasonal pattern. However, it should be noted that the ratios for $H + D + Z$ at Lunping, which may represent the overall characteristics of the equivalent current system, were greatest in summer and smallest in winter. This result is consistent with the findings of Shiraki for the three Japanese observatories, Memambetsu, Kakioka and Kanoya (Shiraki, 1977), except for the Z element for which their ratio is largest in summer instead of for the equinoxes.

To be more precise, Fig. 3a shows the plots of ratios for each month. An abrupt decrease in the ratio for the D element in the winter months can be observed. For H and Z the peak values appear in the equinoxes; and two minima appear in summer and in winter, with the former larger than the latter. The summer minimum almost disappears for the ratios of $H+D+Z$ and $H+D$.

Fig. 4 shows the harmonic dials of the solar daily variations, S, for each element constructed using the amplitude and phase angle data listed in Tables 1-3. The cross with a letter S_n represents the dial origin for the nth harmonics. The points with lettered W, E, S and Y represent the dial points determined for winter, equinoxes, summer and all data, respectively. For clarity, the dial point for all data, representing the annual mean value, is connected to the dial origin by a dashed line. The distance from the origin to the dial point represents the amplitude of the harmonics; and the counter-clockwise angle measured from the positive horizontal axis through the origin to the line connecting the origin and the dial point represents the phase angle of the harmonics. The probable

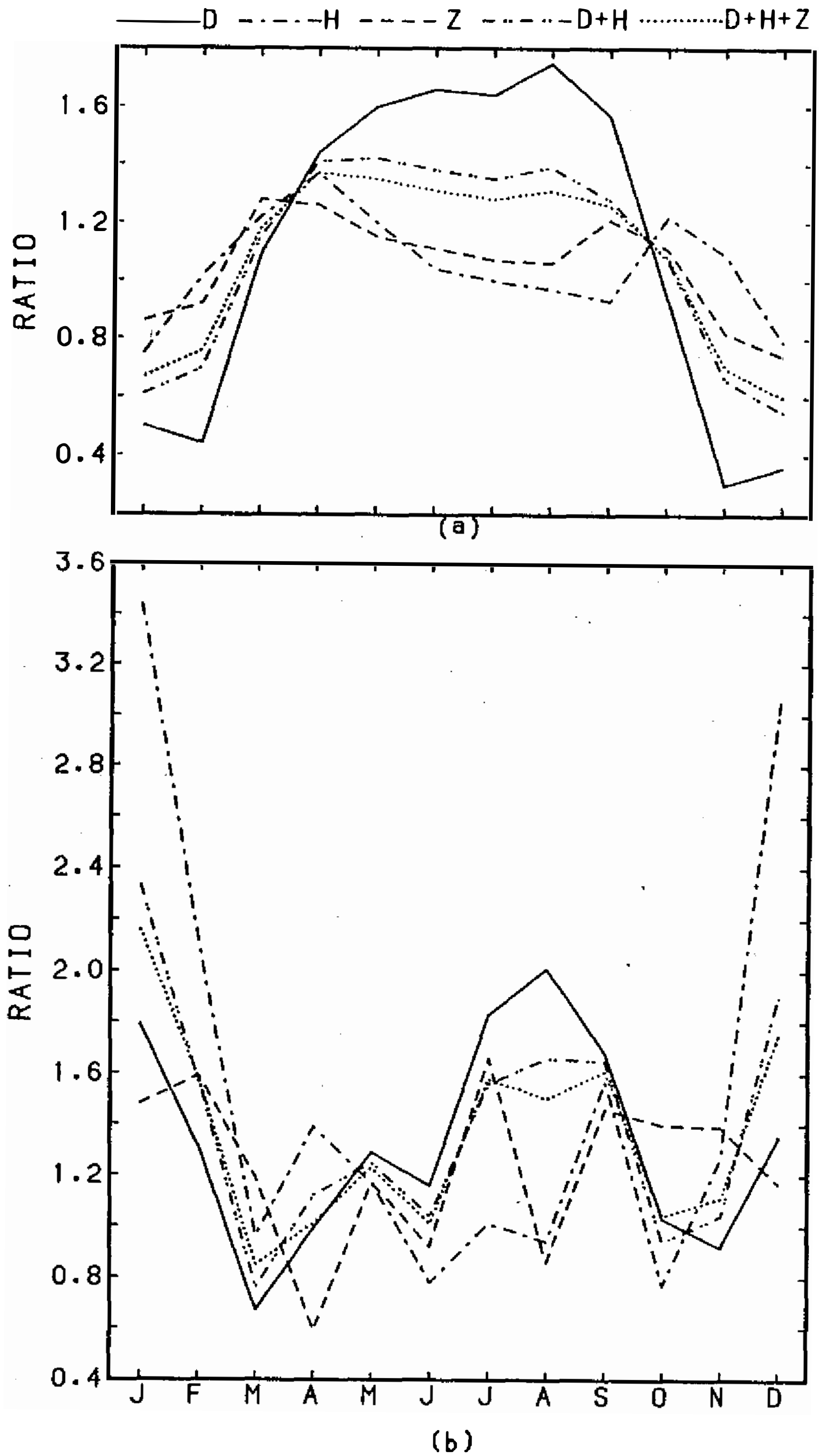

Fig. 3. Month to month variations of the ratios of the monthly to annual mean ranges for (a) solar daily variation; (b) lunar daily variation.

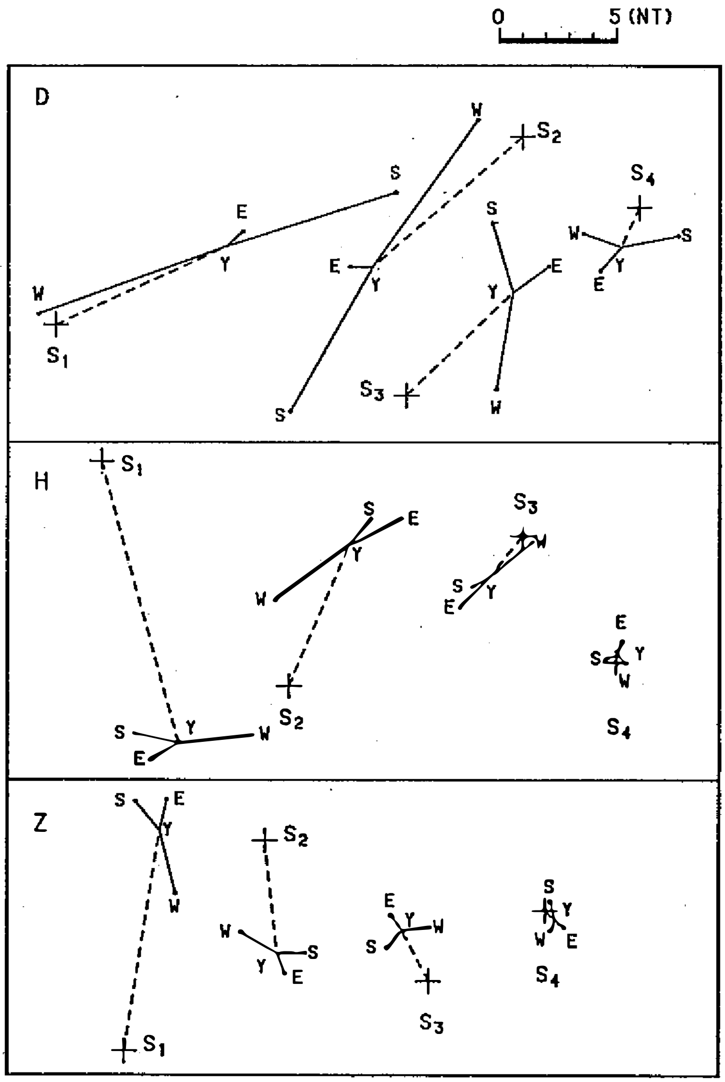

Fig. 4. Harmonic dials for the harmonic components of S for the year and the seasons. The meanings for the letters and full and dotted lines are given in the text.

error circles are too small to be drawn in the figure and are not shown.

For the D element, the amplitude increases markedly from winter to summer for all harmonics except S_4, for which the largest value appears in the equinoxes instead of summer. The amplitudes of S_1 and S_2 are comparable but the seasonal variations of the phase angle change in the opposite direction. For the H element, all harmonic components have maximum values appearing at the equinoxes except for S_1 harmonics which have a maximum value in winter. The minimum values appear in different seasons for different harmonic components. The amplitude of each harmonic component decreases with an increasing order of harmonics. The seasonal variations of the phase angle change in different ways for different harmonic components. S_4 harmonic components are very small compared with other harmonic components. Some of the monthly mean S_4 harmonics are statistically insignificant as can be seen in Table 2. For the Z element, S_1 is the dominant harmonic. The largest amplitude appears in the equinoxes for all harmonics. The smallest amplitude appears at winter for all harmonics except S_4 for which it appears in summer. The phase angles of all harmonic components have a similar seasonal change.

4. SOLAR CYCLE VARIATIONS OF S

The solar harmonic components of each element determined for the solar quiet and active periods are listed in the rows labelled as QUIET( ) and ACTIVE( ) in Tables 1-3. The letters W, E and S in parentheses singnify that the harmonics were determined by use of the winter, the equinoxes and the summer data in the prescribed solar activity period and may represent the seasonal mean harmonics of winter, equinoxes and summer, respectively. The letter Y signifies the annual mean harmonic component determined by using all the data in the prescribed solar activity period. The mean sunspot numbers for the solar quiet and active periods are 26 and 106, respectively.

Fig. 5 shows the harmonic dials for each element constructed by use of the annual mean harmonic components at different solar activity periods. The points lettered a and q represent the annual mean harmonic components determined for the solar active and quiet periods, respectively. The points lettered y represent the annual mean harmonic components detemined using all the data, regardless of solar activity.

The general increase in amplitude of the harmonics with increasing solar activity can be observed for all elements. There seems no general correlation between phase angle variation and increase in solar activity. For the D element, the significant phase drift with increasing solar activity can be observed for S_1 and S_2. For the H element, the phase drift with increasing solar activity can only be observed for S_1. S_1 of the Z element only shows a slight phase drift with increasing solar activity when compared to S_1 and S_2 of D and S_1 of H.

To be more quantitative, the dependence of the amplitude of each harmonic component on the sunspot number was analysed by assuming the following relationship

$$\text{Amplitude} = A(1 + mR) \quad (6)$$

where R represents the mean sunpot number and A and m are coefficients to be determined by the least mean square method. The coefficient m is an index for measuring the sensitivity of the amplitude of the harmonics to the solar activity. Using this index, the percentage increase in amplitude associated with

Table 1. Solar harmonic components of the D element. Unit 0.1 NT

DECLINATION EAST

	NUMBER OF DAYS	S_1	E_1	σ_1	S_2	E_2	σ_2	S_3	E_3	σ_3	S_4	E_4	σ_4
ALL	8648	80	1	25	85	0	221	63	0	44	19	0	245
WINTER	2859	9	1	146	21	1	160	39	0	4	26	0	205
EQUINOX	2871	90	1	26	92	1	217	82	1	42	32	0	238
SUMMER	2916	156	1	21	153	1	230	82	1	63	20	0	324
JANUARY	736	9	3	152	29	2	169	47	1	4	33	1	203
FEBRUARY	672	17	2	73	23	1	177	40	1	5	26	1	199
MARCH	732	67	2	18	78	2	189	81	1	19	36	1	209
APRIL	699	121	2	24	113	2	215	95	1	37	30	1	240
MAY	732	148	2	24	146	2	232	85	1	62	19	1	314
JUNE	710	166	2	17	153	2	225	77	1	59	21	1	329
JULY	735	165	2	19	153	2	227	75	1	61	19	1	333
AUGUST	735	152	3	28	165	2	236	91	1	70	23	1	323
SEPTEMBER	707	122	2	34	136	2	238	99	2	67	31	1	270
OCTOBER	730	57	2	28	62	2	213	69	1	44	38	1	239
NOVEMBER	711	4	2	86	16	2	141	31	1	8	20	1	222
DECEMBER	737	21	2	178	14	1	146	34	1	359	26	0	199
QUIET(Y)	3273	67	1	33	72	0	231	53	0	48	15	0	248
QUIET(W)	979	31	2	156	8	1	229	29	1	9	21	1	205
QUIET(E)	1110	67	2	36	71	1	226	67	1	43	26	1	235
QUIET(S)	1182	140	2	23	126	1	234	70	1	67	18	1	320
ACTIVE(Y)	5374	90	1	21	94	1	216	69	0	42	21	0	243
ACTIVE(W)	1879	5	2	16	30	1	152	44	1	2	29	0	205
ACTIVE(E)	1760	105	1	23	106	1	213	92	1	42	35	1	239
ACTIVE(S)	1733	168	2	21	173	1	227	91	1	62	22	0	326

an increase in R from 0 to 100 can be expressed by $10^4\ m$. The results are listed in Table 8. The values of $10^4\ m$ are not constant but vary for different elements and orders of harmonics.

The range of solar daily variation, $R(S)$, for each element is also detemined for the solar active and quiet periods and are listed in Table 7. Fig. 6a shows the solar activity dependence of each element for each season. The dashed and full lines represent the $R(S)$ values determined for the solar active and quiet periods respectively. The dotted lines represent the $R(S)$ values determined for all data, regardless of solar activity. The general increase in $R(S)$ with

Table 2. Solar harmonic components of the H element. Unit 0.1 NT

HORIZONTAL INTENSITY

	NUMBER OF DAYS	S_1	E_1	σ_1	S_2	E_2	σ_2	S_3	E_3	σ_3	S_4	E_4	σ_4
ALL	8645	125	1	285	65	1	67	23	0	231	4	0	78
WINTER	2858	133	3	299	37	1	99	5	1	329	4	1	359
EQUINOX	2865	129	3	279	86	2	56	41	1	229	9	1	74
SUMMER	2920	117	2	277	79	1	64	30	1	225	5	1	161
JANUARY	736	115	4	303	20	2	124	10	1	59	9	1	312
FEBRUARY	672	148	4	293	49	2	92	8	2	327	(3)	1	25
MARCH	727	157	4	283	80	3	69	29	2	241	5	1	44
APRIL	699	149	4	276	104	2	61	46	2	226	6	1	102
MAY	734	129	4	276	92	3	61	42	2	225	3	1	124
JUNE	711	117	3	278	76	2	68	32	1	216	(1)	1	289
JULY	733	117	4	278	74	2	70	24	2	232	5	1	147
AUGUST	739	106	5	276	77	3	59	25	2	231	11	1	173
SEPTEMBER	704	80	5	270	85	2	34	41	2	214	6	1	105
OCTOBER	732	132	6	285	83	2	59	49	2	234	23	1	66
NOVEMBER	711	149	5	297	58	3	94	20	2	275	9	1	75
DECEMBER	736	123	5	304	26	2	102	6	1	57	6	1	328
QUIET(Y)	3273	91	1	294	51	1	64	20	1	225	2	1	76
QUIET(W)	980	105	4	306	26	2	99	3	1	25	3	1	322
QUIET(E)	1108	88	4	290	65	2	55	33	2	226	7	1	72
QUIET(S)	1183	84	3	286	64	1	62	26	1	221	3	1	155
ACTIVE(Y)	5371	146	2	282	74	1	68	26	1	234	4	0	78
ACTIVE(W)	1877	148	3	296	43	1	99	7	1	318	5	1	8
ACTIVE(E)	1756	156	4	276	99	2	57	45	1	230	11	1	74
ACTIVE(S)	1736	140	3	274	90	2	65	33	1	227	6	1	162

increasing solar activity can be seen in this figure. The 10^4 m values were also determined, for all data, and listed in Table 8. It should be remarked that the 10^4 m values obtained by the present study are rather close to the values obtained by Chapman, Gupta and Malin (1971) for D and H. However, the present value for the Z element is larger than that obtained by Chapman *et al.* (1971). Shiraki's (1977) results for Japanese observatories also shows the largest 10^4 m value appearing in the Z element. Seasonally, the solar activity dependence is smallest in winter compared to other seasons, for all elements.

Table 3. Solar harmonic components of the Z element. Unit 0.1 NT

VERTICAL INTENSITY

	NUMBER OF DAYS	S_1	E_1	σ_1	S_2	E_2	σ_2	S_3	E_3	σ_3	S_4	E_4	σ_4
ALL	8618	95	0	81	48	0	276	25	0	118	6	0	318
WINTER	2852	71	1	72	41	0	255	23	0	89	9	0	285
EQUINOX	2856	109	1	81	57	0	279	32	0	120	11	0	318
SUMMER	2908	107	1	88	51	0	290	23	0	142	5	0	61
JANUARY	730	71	2	72	44	1	253	25	1	85	11	1	283
FEBRUARY	671	81	2	69	45	1	249	25	1	80	9	1	271
MARCH	722	115	2	74	62	1	264	35	1	100	12	1	292
APRIL	697	113	2	80	60	1	279	35	1	122	12	1	327
MAY	729	107	2	86	55	1	292	29	1	144	6	1	33
JUNE	709	107	2	86	54	1	285	23	1	137	6	1	65
JULY	733	109	2	86	51	1	284	19	1	133	5	1	81
AUGUST	729	108	2	91	48	2	298	22	1	153	4	0	70
SEPTEMBER	704	112	2	89	59	1	294	33	1	138	9	1	334
OCTOBER	727	99	2	79	52	1	279	31	1	124	12	1	325
NOVEMBER	709	76	2	75	40	1	263	21	1	104	6	1	313
DECEMBER	736	62	2	73	37	1	259	22	1	96	9	0	290
QUIET(Y)	3236	68	1	86	34	0	285	18	0	130	5	0	334
QUIET(W)	970	43	2	74	29	1	258	18	0	94	8	0	293
QUIET(E)	1090	74	1	86	39	1	287	23	1	132	8	1	332
QUIET(S)	1174	82	2	93	38	1	299	18	1	154	4	0	56
ACTIVE(Y)	5381	112	1	79	57	0	273	29	0	113	7	0	311
ACTIVE(W)	1881	85	1	72	46	1	254	26	0	87	10	0	281
ACTIVE(E)	1765	130	1	79	69	0	276	39	0	116	13	0	312
ACTIVE(S)	1733	123	1	85	60	1	286	26	1	136	5	0	64

5. SEASONAL VARIATIONS OF L

Fig. 7 shows the day-graphs of the lunar daily variations for D, H and Z at a new Moon ($\nu = 0$), synthesized from their harmonic components listed in Tables 4-6 using Eq. (4). The letter Y refers to the annual mean variation obtained from all the data and the letters W, E and S refer to the mean variations in the winter, the equinoxes and the summer, respectively. It can be seen that the shape as well as the range of daily variation for each element shows a marked change with seasons.

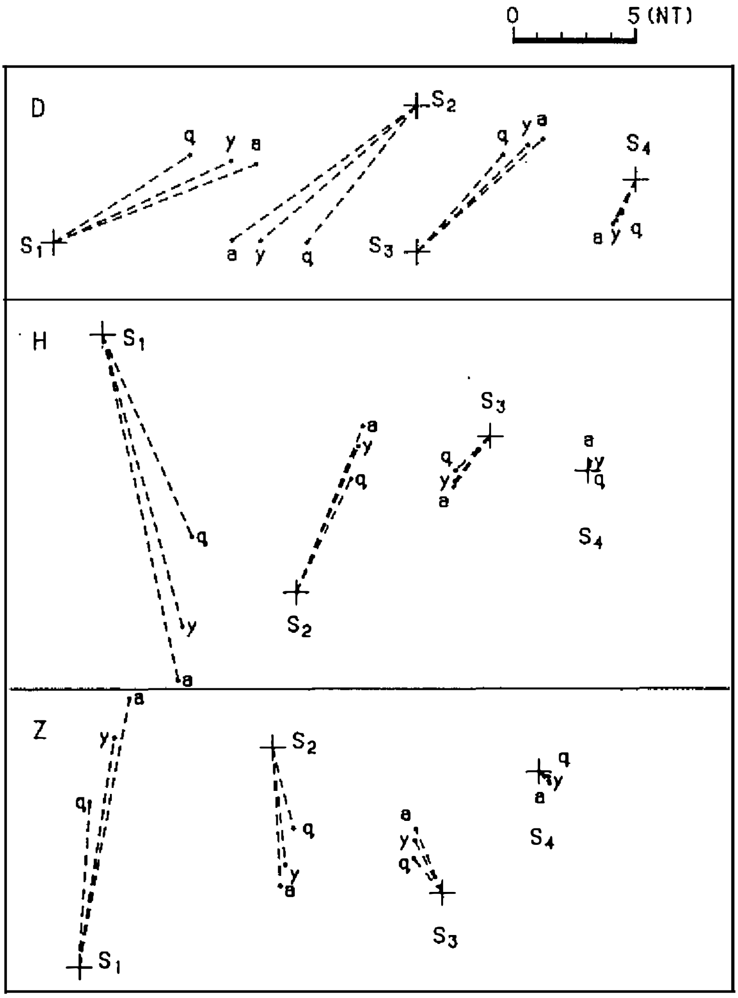

Fig. 5. Harmonic dial showing the variation of harmonic components for S with respect to solar activity. The points lettered a, q and y represent the annual mean components determined for the solar active and quiet periods and all data, respectively, as explained in the text.

To be more quantitative, the range of the lunar daily variation, denoted by $R(L)$, was obtained using the following equation, as used by Chapman *et al.* (1971).

$$R(L) = 2\sum_{n=1}^{4} l_n \tag{7}$$

This value can give the difference between the largest and smallest values that L can attain over a long period. The probable error, E, of the range $R(L)$ was

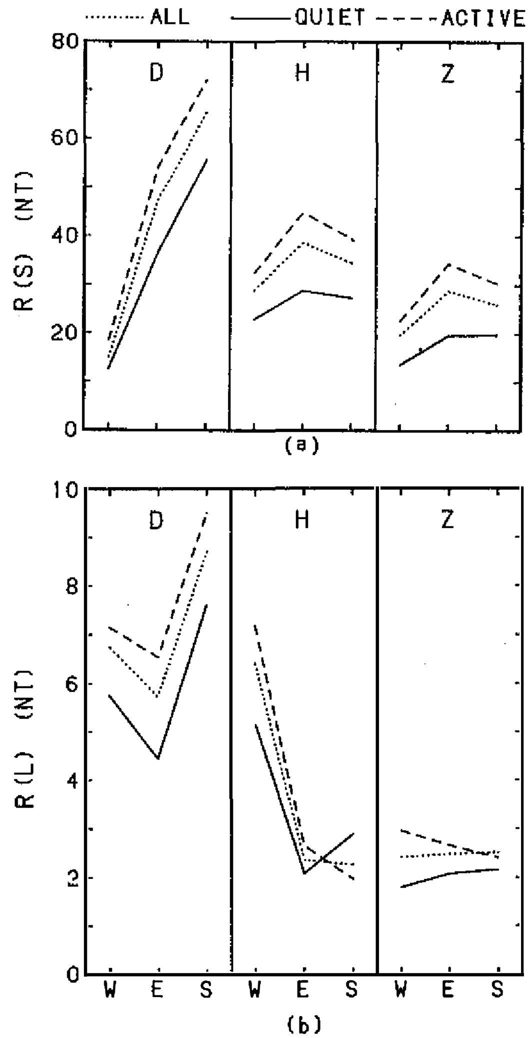

Fig. 6. Seasonal variation and solar activity dependence of (a) annual mean range of solar daily variation, $R(S)$, and (b) annual mean range of lunar daily variation, $R(L)$.

calculated using

$$E = 1.146(\sum_{n=1}^{4} E_n^2)^{\frac{1}{2}} \tag{8}$$

where E_n is the probable vector error for each harmonic component (Chapman *et al.*, 1971). Table 9 summarizes the results obtained for each element and also for the mean value of H and D, denoted by $H + D$, and that of H, D and Z as denoted by $H + D + Z$. The probable errors and the ratios of seasonal or monthly to annual mean ranges are also given in Table 9.

Seasonal plots of $R(L)$ for each element are given by dotted lines in Fig.

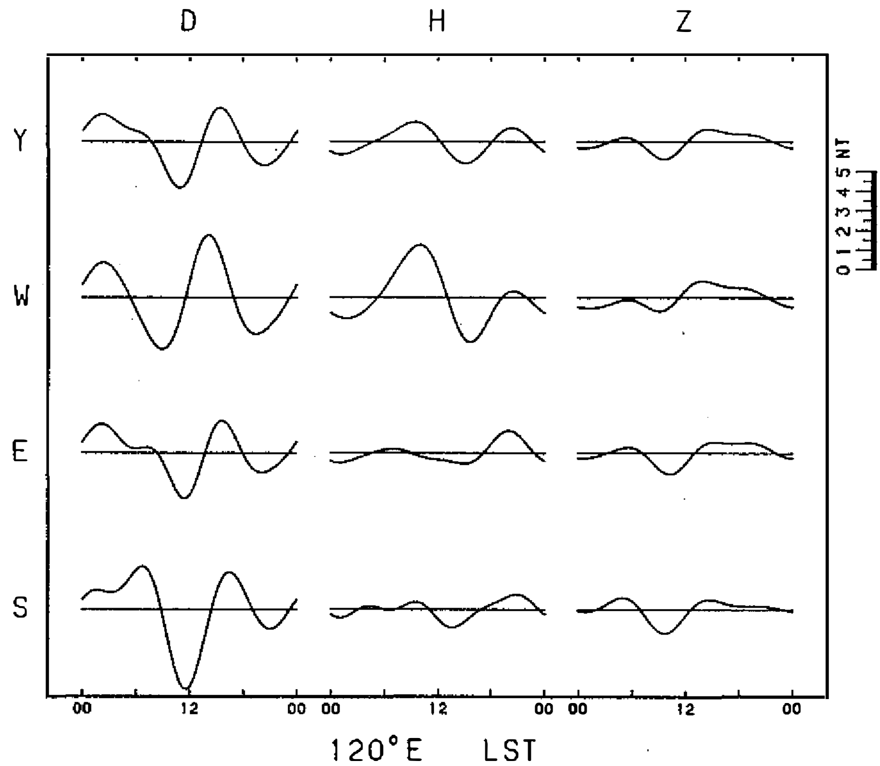

Fig. 7. Day-graphs illustrating the lunar daily variations separately for year and seasons.

6b. It can be seen that the minimum range appears in the equinoxes for all elements; whereas the maximum range appears in different seasons for different elements. The maximum range appears in summer for D and Z but in winter for H. The seasonal change of $R(L)$ is very small for Z. The ratios of seasonal to annual mean ranges also show similar results. These results are quite different from those obtained by Gupta and Malin (1972) in which they found that the greatest L ratio generally occurs in summer and the least in winter. However, it should be noted that the present results are quite similar to those obtained by Shiraki (1977, and 1981) at three Japanese observatories. Although Matsushita and Maeda (1965) have shown that the total external current intensity for the equinoxes is comparable with, or sometimes even greater than, the intensity for the local summer, present results have shown that the ratio for $H+D+Z$, which may represent the overall characteristics of the equivalent L current system, is not greatest for the equinoxes but in winter; and the summer value is greater than the equinox's value.

Fig. 3b shows the plots of the monthly ratio for each element. Abrupt increases in ratio for D, H, $D+H$ and $D+H+Z$ can be seen in January and December. Unusually small ratios were found for all the elements in June, the

Table 4. Lunar harmonic components of the D element. Unit 0.01 NT

DECLINATION EAST

	NUMBER OF DAYS	l_1	E_1	λ_1	l_2	E_2	λ_2	l_3	E_3	λ_3	l_4	E_4	λ_4
ALL	8648	52	7	81	138	5	343	69	4	110	24	2	311
WINTER	2859	(25)	15	189	233	6	22	57	3	188	22	3	334
EQUINOX	2871	60	11	79	113	7	337	78	6	91	37	5	285
SUMMER	2916	108	15	72	182	10	296	124	7	97	21	4	331
JANUARY	736	79	32	234	301	16	33	94	12	213	35	9	3
FEBRUARY	672	(46)	24	139	234	11	14	65	10	155	26	7	289
MARCH	732	(15)	21	42	67	16	13	64	15	55	43	10	255
APRIL	699	61	17	90	111	16	342	75	10	81	34	9	280
MAY	732	81	21	53	134	17	294	116	12	91	36	7	320
JUNE	710	109	26	66	122	17	297	90	11	81	(8)	7	73
JULY	735	123	21	79	232	18	299	146	13	103	19	8	343
AUGUST	735	147	28	84	249	20	296	146	13	106	27	9	329
SEPTEMBER	707	120	25	91	188	21	319	128	19	118	41	10	319
OCTOBER	730	71	23	57	117	16	343	65	9	93	38	6	290
NOVEMBER	711	(40)	22	59	161	16	12	39	6	143	22	7	305
DECEMBER	737	51	22	195	249	12	23	63	7	208	19	5	360
QUIET(Y)	3273	49	8	79	122	5	346	59	4	105	18	3	313
QUIET(W)	979	(25)	17	202	209	8	25	42	8	190	(12)	6	352
QUIET(E)	1110	41	17	80	95	10	351	55	9	87	31	6	286
QUIET(S)	1182	96	17	73	157	13	302	110	8	94	18	6	323
ACTIVE(Y)	5374	55	10	81	149	6	341	76	4	113	28	2	311
ACTIVE(W)	1879	(23)	21	200	242	9	21	64	6	186	29	4	328
ACTIVE(E)	1760	69	15	79	125	8	330	92	6	92	41	5	283
ACTIVE(S)	1733	117	21	71	201	14	292	134	8	98	23	5	336

reason for which is as yet not known. If this unusual event is disregarded, the seasonal variations of the ratios are characterized by an unusually large peak appearing in winter; a subsidiary peak appearing in summer; and two minima appearing in March and October.

The difference between the seasonal variations of S and L has been studied by some workers. Chapman and Bartels (1940) stated that the seasonal variation of L is much greater than that of S_q; whereas Matsushita and Maeda (1965) concluded that the seasonal variation of the L field is similar to that of S_q field. Gupta and Malin (1972) have shown that the results from long term

Table 5. Lunar harmonic components of the H element. Unit 0.01 NT

HORIZONTAL INTENSITY

	NUMBER OF DAYS	l_1	E_1	λ_1	l_2	E_2	λ_2	l_3	E_3	λ_3	l_4	E_4	λ_4
ALL	8645	(29)	14	339	81	9	190	25	5	295	(4)	4	238
WINTER	2858	120	35	323	149	12	171	46	7	306	(6)	5	92
EQUINOX	2865	(28)	29	134	56	17	218	24	9	259	(10)	8	341
SUMMER	2920	(25)	21	98	52	15	210	(15)	8	312	21	6	216
JANUARY	736	181	48	340	209	21	170	63	15	324	(23)	13	155
FEBRUARY	672	94	45	304	135	24	190	61	19	318	(3)	15	52
MARCH	727	(14)	44	19	95	31	215	(12)	18	20	(11)	14	236
APRIL	699	(43)	45	127	111	20	209	(29)	20	297	(9)	14	289
MAY	734	(39)	47	94	83	31	227	(21)	16	317	(18)	12	194
JUNE	711	(21)	35	223	60	17	219	(6)	11	301	22	11	256
JULY	733	(51)	44	125	45	19	206	(18)	16	310	(24)	14	217
AUGUST	739	(57)	58	55	(31)	33	165	(15)	18	296	27	10	194
SEPTEMBER	704	(79)	56	153	56	25	320	55	18	259	(27)	14	13
OCTOBER	732	(14)	63	82	(40)	23	170	(39)	20	214	(12)	15	4
NOVEMBER	711	(23)	59	316	93	30	176	(34)	16	237	(24)	13	31
DECEMBER	736	204	56	319	166	25	158	45	15	301	(4)	10	27
QUIET(Y)	3273	(16)	16	336	78	9	207	19	6	311	(8)	7	202
QUIET(W)	980	97	46	316	128	19	176	(25)	14	298	(6)	7	221
QUIET(E)	1108	(21)	41	168	70	22	229	(12)	16	299	(0)	14	330
QUIET(S)	1183	(31)	29	89	70	14	229	23	9	331	19	9	195
ACTIVE(Y)	5371	(36)	20	341	85	11	181	30	6	289	(4)	5	290
ACTIVE(W)	1877	131	37	325	160	13	169	56	8	308	(12)	7	81
ACTIVE(E)	1756	(33)	39	123	50	20	208	33	12	252	(16)	9	340
ACTIVE(S)	1736	(20)	32	93	(45)	22	190	(11)	10	278	23	9	228

data confirm the view of Chapman and Bartels (1940). Green and Malin's results also support the view of Chapman and Bartels (Green and Malin, 1971). The present results, however, are quite different from those obtained by the above-mentioned workers as can be seen in Fig. 3 by comparing the seasonal variation of the ratio for S given in Fig. 3a with that for L given in 3b. If the seasonal mean values of $R(S)$ and $R(L)$ listed in Tables 7 and 9 are used for the comparison of the seasonal variations of S and L, it is found that the seasonal variation of S is greater than that of L for the D elements; smaller than that of L for the H element; and comparable to that of L for the Z element, $D+H$

Table 6. Lunar harmonic components of the Z element. Unit 0.01 NT

VERTICAL INTENSITY

	NUMBER OF DAYS	l_1	E_1	λ_1	l_2	E_2	λ_2	l_3	E_3	λ_3	l_4	E_4	λ_4
ALL	8618	37	5	180	39	2	319	26	2	199	7	1	24
WINTER	2852	59	10	209	28	5	332	24	2	216	10	2	43
EQUINOX	2856	40	10	156	48	5	302	25	3	183	10	3	354
SUMMER	2908	32	9	132	50	5	328	36	4	199	6	3	61
JANUARY	730	105	21	241	(23)	11	40	24	9	243	(10)	6	62
FEBRUARY	671	102	25	216	36	13	357	26	9	212	(10)	6	340
MARCH	722	(34)	19	155	51	11	274	26	9	122	19	7	309
APRIL	697	(1)	21	343	33	11	270	16	7	176	14	5	346
MAY	729	(32)	18	65	47	10	301	33	7	186	16	5	34
JUNE	709	(21)	17	48	47	9	294	24	8	163	(8)	6	310
JULY	733	42	18	136	75	10	332	54	10	187	(11)	6	29
AUGUST	729	(18)	25	222	(32)	17	348	37	7	220	(7)	5	101
SEPTEMBER	704	44	21	141	65	11	318	35	10	204	15	7	48
OCTOBER	727	(43)	24	167	57	12	306	39	8	185	(13)	7	1
NOVEMBER	709	67	20	158	47	10	310	27	7	191	(10)	5	32
DECEMBER	736	75	21	199	(15)	11	6	26	7	265	12	5	118
QUIET(Y)	3236	22	8	177	29	4	300	23	3	206	6	3	22
QUIET(W)	970	(37)	19	208	19	9	299	24	5	221	9	4	58
QUIET(E)	1090	(32)	16	136	41	10	289	20	8	185	(11)	6	351
QUIET(S)	1174	(26)	19	115	40	8	319	33	6	208	9	4	61
ACTIVE(Y)	5381	46	6	178	47	3	326	30	2	197	8	2	29
ACTIVE(W)	1881	71	14	201	38	7	343	26	4	216	12	3	47
ACTIVE(E)	1765	45	10	168	51	4	307	27	4	183	10	2	354
ACTIVE(S)	1733	36	13	171	50	9	336	33	6	195	(1)	4	18

and $D+H+Z$.

Fig. 8 shows the harmonic dials for the harmonic components of the lunar daily variation, L, for each element constructed by use of the amplitude and phase angle data listed in Tables 4-6. The crosses lettered L_n represent the dial origin for the nth harmonic components. The points lettered W, E, S and Y represent the dial points determined for winter, equinoxes, summer and all data, respectively. The probable error circle is given for each dial point. The amplitude l_n may be considered to be statistically significant at the 5 per cent level, if it is larger than 2.08 times the radius of the probable error

Table 7. The monthly and seasonal mean ranges of solar daily variations, $R(S)$, and their ratios to the annual mean ranges.

	D		H		Z		D+H	D+H+Z
	R(S)	RATIO	R(S)	RATIO	R(S)	RATIO	RATIO	RATIO
ALL	396	1.00	330	1.00	242	1.00	1.00	1.00
WINTER	149	0.38	289	0.88	196	0.81	0.61	0.66
EQUINOX	473	1.20	386	1.17	288	1.19	1.19	1.19
SUMMER	653	1.65	345	1.05	261	1.08	1.38	1.31
JANUARY	194	0.50	245	0.75	206	0.86	0.61	0.67
FEBRUARY	170	0.44	336	1.02	220	0.92	0.70	0.76
MARCH	427	1.09	402	1.22	309	1.28	1.15	1.18
APRIL	569	1.44	450	1.37	304	1.26	1.41	1.37
MAY	633	1.60	396	1.20	278	1.15	1.42	1.35
JUNE	654	1.66	341	1.04	266	1.11	1.38	1.31
JULY	648	1.64	329	1.00	258	1.07	1.35	1.28
AUGUST	689	1.75	320	0.97	255	1.06	1.39	1.31
SEPTEMBER	621	1.57	304	0.93	292	1.21	1.28	1.26
OCTOBER	369	0.94	402	1.22	267	1.11	1.07	1.08
NOVEMBER	118	0.30	358	1.09	198	0.82	0.66	0.70
DECEMBER	140	0.36	259	0.79	179	0.74	0.55	0.60
QUIET(Y)	328	1.00	256	1.00	172	1.00	1.00	1.00
QUIET(W)	126	0.39	228	0.89	135	0.79	0.61	0.65
QUIET(E)	365	1.12	288	1.13	196	1.15	1.12	1.13
QUIET(S)	557	1.70	274	1.07	197	1.15	1.43	1.37
ACTIVE(Y)	439	1.00	377	1.00	285	1.00	1.00	1.00
ACTIVE(W)	185	0.43	324	0.86	226	0.80	0.63	0.67
ACTIVE(E)	542	1.24	448	1.20	344	1.21	1.22	1.22
ACTIVE(S)	720	1.64	395	1.05	304	1.07	1.37	1.29

circle (Leaton *et al.*, 1962). The statistically insignificant values in Tables 4-6 are in parentheses. The seasonal mean lunar harmonic components are all statistically significant for the D (except for winter) and Z elements. However, almost all of the seasonal mean lunar harmonic components of H are statistically insignificant except for L_2 for all seasons, L_1 and L_3 for winter and L_4 for summer. More data are required before the significant lunar harmonics can be obtained.

The seasonal variations of each harmonic component for each element can

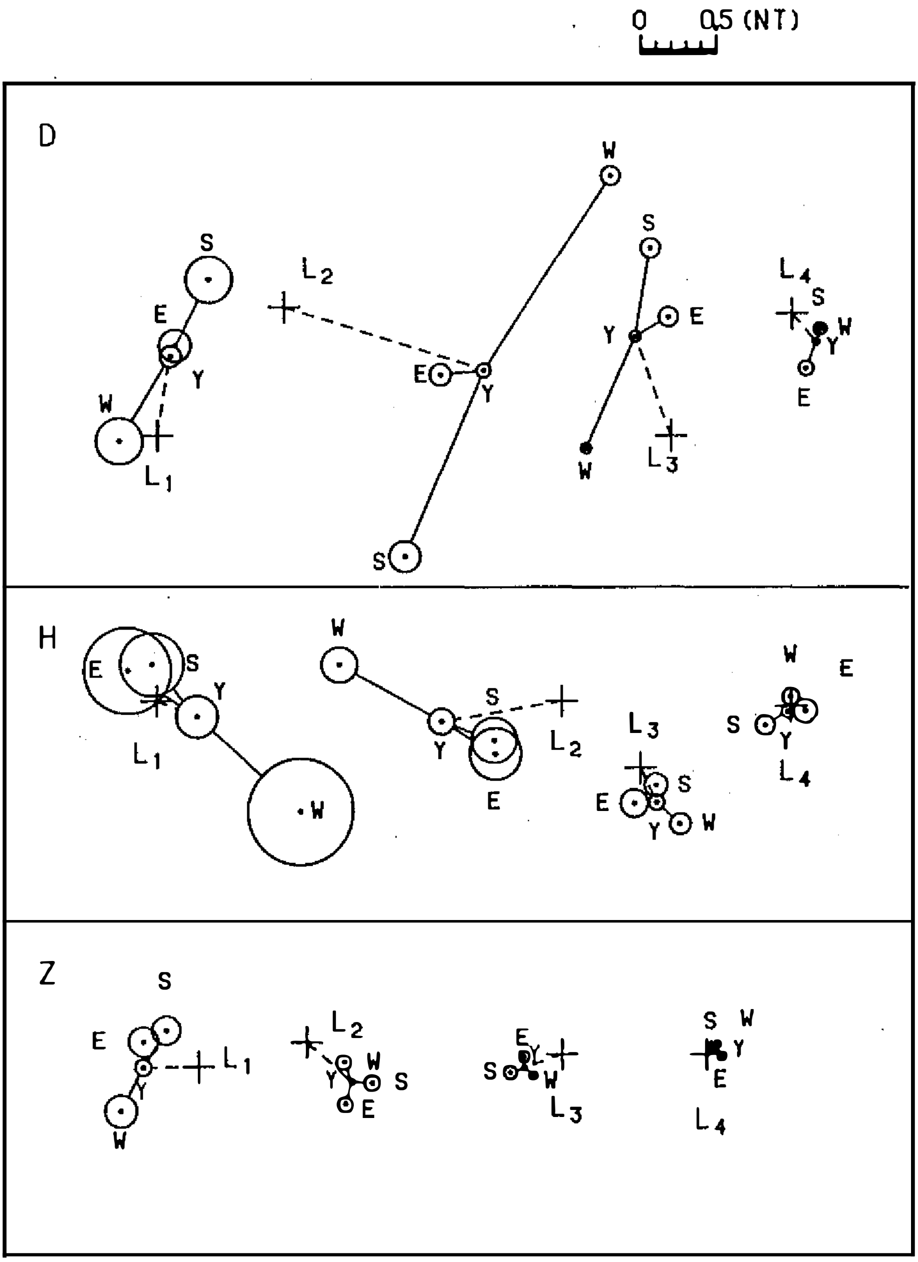

Fig. 8. Harmonic dials for harmonic components of L for the year and the seasons. The meanings of the letters and full and dotted lines are given in the text.

be seen in Fig. 9. For the D element, the seasonal variation has two maxima appearing in December and July/August with the former larger than the latter for L_1, L_2 and L_3. It should be noted that both L_2 and L_3 are larger than L_1, L_2 being the largest harmonic component of all. An abrupt increase in the

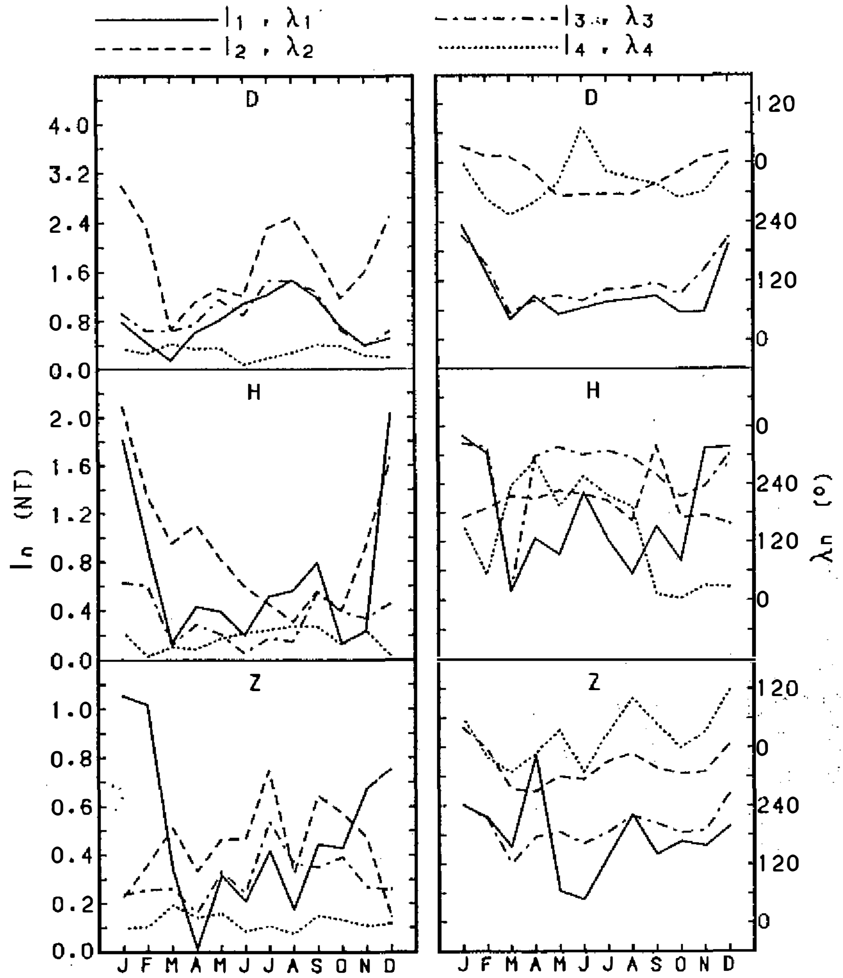

Fig. 9. Month to month variations of the amplitude (left) and the phase angle (right) of lunar harmonic components.

amplitude of the L_2 component in winter can be observed. An abrupt increase of phase angle in a counter-clockwise direction in winter can also be observed for the L_1, L_3 and L_4 harmonic components. For the H element, the seasonal variations shown in Fig. 9 are not as reliable as those for D and Z because of large probability errors. Nevertheless, the L_2 components for each month are all statistically significant except for the months of August and October; and an abrupt increase of amplitude in December/January can be observed. Similar abrupt increases of amplitude in December/January are also observed for L_1 harmonics and in winter months for L_3 harmonics. For the Z element, the seasonal variations of each harmonic component are quite irregular. However, an abrupt amplitude increase of L_1 component in winter can be seen.

6. SOLAR CYCLE VARIATIONS OF L

The lunar harmonic components of each element for the solar active and quiet periods were determined for each season and for all data. The results are listed as ACTIVE( ) and QUIET( ) in Tables 4-6. The letters W, E and S in parentheses signify that the harmonics were determined by use of the winter, the equinoxes and the summer data in the prescribed solar activity period and may represent the seasonal mean lunar harmonics of winter, the equinoxes and summer, respectively. The letter Y signifies the annual mean lunar harmonic component determined by use of all data in the prescribed solar activity period.

Fig. 10 shows the harmonic dials for each element constructed, using the annual mean harmonic components at different solar activity periods. The points with full line probability error circles represent the annual mean lunar components determined for the solar quiet periods; and those with a dashed line probability error circles for the solar active periods. For comparison, the annual mean lunar harmonic components determined by use of all the data, regardless of solar activity, are also shown in the figure with dotted line probability error circles.

The amplitudes of all harmonic components except L_4 of H and Z increase with increasing solar activity. There seems no general tendency for phase angle variation with change of solar activity. For the D element, counter-clockwise phase angle drift with increasing solar activity can be observed for L_1 and L_3. For the H element, clockwise phase angle drift with increasing solar activity can be observed for L_2 and L_3. L_1 and L_4 are not significant enough to observe their phase angle drift with a change of solar activity. For the Z element, counter-clockwise phase angle drift with increasing solar activity can be observed for L_2 The L_1, L_3 and L_4 component do not show significant phase angle drift.

To be more quantitative, 10^4 m was calculated using Eq. (6) for each annual mean harmonic component and for the range, R(L), of the annual mean lunar daily variations. The results are listed in Table 8. The doubtful values due to large probability errors are parenthesized. It can be seen that the value of 10^4 m for each harmonic component is not constant but varies with different elements and order of harmonics; for some cases it even becomes negative. However, for $R(L)$, it is always positive. It should be remarked that the value of 10^4 m determined for $R(L)$ is smallest for the D element and largest for Z. This result is quite different from that obtained by Shiraki (1977) for the three Japanese observatories and by Green and Malin (1971) for Watheroo.

The range, $R(L)$, of the seasonal mean lunar daily variation was also determined for solar active and quiet periods for each element and listed in Table 9. Fig. 6b shows the solar activity dependence of each element in each season. There seems no general tendency for $R(L)$ to vary with solar activity except for

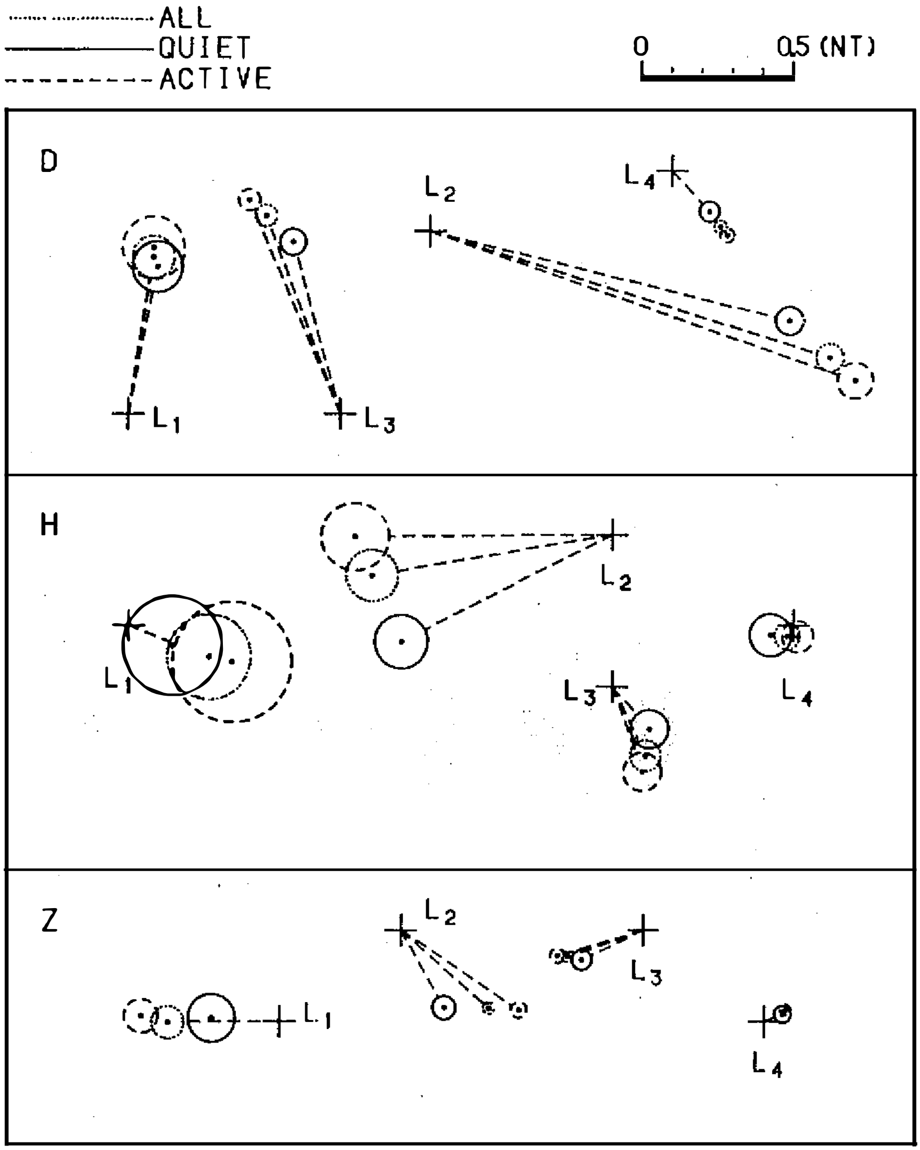

Fig. 10. Harmonic dial showing the variation of harmonic components of L with respect to solar activity.

the D and Z elements, for which $R(L)$ increases with increasing solar activity. For H, the solar activity dependence varies with different seasons. However, it should be noted that if the annual mean variations, instead of seasonal mean variations, are considered, the range of each element shows an increase with increasing solar activity as can be inferred from the positive values of $R(L)$ listed in Table 8.

The values of 10^4 m determined for L_2 (except for the Z component) are all much smaller than those determined for solar harmonic components. Also the

Table 8. The values of 10^4 m for S_n, L_n, $R(S)$, $R(L)$, L_0 and L_I

	D	H	Z	D+H	D+H+Z
S1	48	92	104	70	81
S2	42	62	104	52	69
S3	41	39	85	40	55
S4	46	133	59	90	79
L1	15	(261)	197	(138)	(158)
L2	28	10	93	19	44
L3	41	92	42	66	58
L4	80	(-57)	32	(11)	(18)
R(S)	47	69	103	58	73
R(L)	32	37	96	35	55
L_0	7	-27	5	-9	-4
L_I	16	(201)	135	(109)	(117)

values of 10^4 m determined for $R(L)$ are smaller than those determined for $R(S)$. For the solar activity dependence of S and L, Matsushita and Maeda found no particular difference between them; whereas Chapman and Bartels (1940) and more recently Chapman *et al.* (1971) concluded that the dependence of S is much greater than that of L. The present results seem to support the opinion of Chapman *et al.* (1971).

7. THE OCEAN EFFECT ON THE LUNAR SEMI-DIURNAL VARIATIONS

The lunar daily variation contains contributions from the ionospheric and oceanic dynamo (Malin, 1969). The oceanic dynamo is powered by the tidal motion of the sea across the Earth's main magnetic field. Malin (1970) has given a method for the separation of the contributions from two dynamos. According to Malin (1970), the ocean dynamo part, L_0, and the ionospheric dynamo part, L_I, may be represented by the following two equations, respectively.

$$L_0 = l_0 sin(2\tau + \lambda_0) \tag{9}$$

$$L_I = l_I sin(2\tau + \lambda_I) \tag{10}$$

where l_0, λ_0 and l_I, λ_I are the amplitudes and the phase angles of the lunar semi-diurnal variations due to oceanic and ionospheric origins, respectively; and

Table 9. The monthly and seasonal mean ranges of lunar daily variations, $R(L)$, and their ratios to the annual mean ranges.

	D			H			Z			D+H	D+H+Z
	R(L)	E	RATIO	R(L)	E	RATIO	R(L)	E	RATIO	RATIO	RATIO
ALL	569	11	1.00	277	20	1.00	219	7	1.00	1.00	1.00
WINTER	674	20	1.19	642	43	2.32	241	14	1.10	1.56	1.47
EQUINOX	574	17	1.01	235	41	0.85	247	13	1.13	0.96	1.00
SUMMER	870	23	1.53	226	32	0.82	251	13	1.15	1.30	1.27
JANUARY	1018	44	1.79	953	64	3.44	323	30	1.48	2.33	2.16
FEBRUARY	740	34	1.31	584	65	2.11	348	35	1.59	1.57	1.58
MARCH	377	36	0.67	265	68	0.96	261	28	1.19	0.76	0.85
APRIL	563	31	0.99	382	63	1.39	128	28	0.59	1.12	1.01
MAY	733	35	1.29	321	68	1.17	254	26	1.17	1.25	1.23
JUNE	658	38	1.16	216	48	0.78	201	25	0.92	1.04	1.01
JULY	1039	37	1.83	278	60	1.01	362	27	1.66	1.56	1.58
AUGUST	1139	43	2.01	260	81	0.94	188	36	0.86	1.66	1.50
SEPTEMBER	953	45	1.68	435	75	1.57	318	31	1.46	1.65	1.61
OCTOBER	583	34	1.03	211	82	0.77	305	33	1.40	0.94	1.04
NOVEMBER	522	33	0.92	349	80	1.27	303	27	1.39	1.04	1.11
DECEMBER	764	30	1.35	838	73	3.03	255	29	1.17	1.90	1.75
QUIET(Y)	497	13	1.00	243	24	1.00	161	11	1.00	1.00	1.00
QUIET(W)	575	25	1.16	513	60	2.12	179	25	1.12	1.48	1.41
QUIET(E)	445	25	0.90	208	59	0.86	207	25	1.29	0.89	0.96
QUIET(S)	761	27	1.54	288	40	1.19	216	25	1.34	1.42	1.41
ACTIVE(Y)	617	14	1.00	310	28	1.00	261	8	1.00	1.00	1.00
ACTIVE(W)	715	27	1.16	718	46	2.32	295	19	1.14	1.55	1.46
ACTIVE(E)	654	22	1.07	264	53	0.86	265	13	1.02	1.00	1.00
ACTIVE(S)	951	32	1.55	197	47	0.64	240	20	0.93	1.24	1.17

can be obtained by solving the following simultaneous equations:

$$l_0 cos\lambda_0 = \sum_{n=1}^{4} l_n cos\lambda_n \tag{11}$$

$$l_0 sin\lambda_0 = \sum_{n=1}^{4} l_n sin\lambda_n \tag{12}$$

$$l_I cos\lambda_I = -(l_1 cos\lambda_1 + l_3 cos\lambda_3 + l_4 cos\lambda_4) \tag{13}$$

$$l_I sin\lambda_I = -(l_1 sin\lambda_1 + l_3 sin\lambda_3 + l_4 sin\lambda_4) \quad (14)$$

The vector probable errors of L_0 and L_I can be calculated by use of the following equations:

$$P_0 = (P_1^2 + P_2^2 + P_3^2 + P_4^2)^{\frac{1}{2}} \quad (15)$$

$$P_I = (P_1^2 + P_3^2 + P_4^2)^{\frac{1}{2}} \quad (16)$$

Table 10. Amplitude and phase angle of L_2, L_0 and L_I. Unit 0.01 NT.

		l_2	E_2	λ_2	l_0	E_0	λ_0	l_I	E_I	λ_I
D	ALL	139	5	343	144	9	270	98	8	23
	WINTER	233	6	22	167	17	19	66	16	23
	EQUINOX	113	7	337	135	15	259	103	13	25
	SUMMER	183	10	296	129	20	260	219	17	24
	QUIET(Y)	122	5	346	140	11	266	92	10	27
	ACTIVE(Y)	149	6	341	148	13	272	104	11	22
H	ALL	81	9	190	67	18	134	51	15	229
	WINTER	149	12	171	84	38	140	160	36	253
	EQUINOX	56	17	218	(72)	35	24	(16)	31	215
	SUMMER	52	15	210	61	28	357	(10)	23	205
	QUIET(Y)	78	9	207	78	21	129	(31)	19	229
	ACTIVE(Y)	85	11	181	60	24	136	63	21	228
Z	ALL	39	2	319	41	6	6	56	6	230
	WINTER	28	5	332	63	12	30	73	11	231
	EQUINOX	48	5	302	37	12	345	53	11	225
	SUMMER	50	5	328	(14)	12	342	56	11	220
	QUIET(Y)	29	4	300	39	10	10	37	9	235
	ACTIVE(Y)	47	3	326	40	7	2	67	6	226

This method was applied to the present results to obtain l_0, λ_0 and l_I, λ_I for each season and for all data. The results are listed in Table 10. Column E of the table gives the vector probable error. The statistically insignificant harmonic components are in parentheses. For the D element, all harmonic components

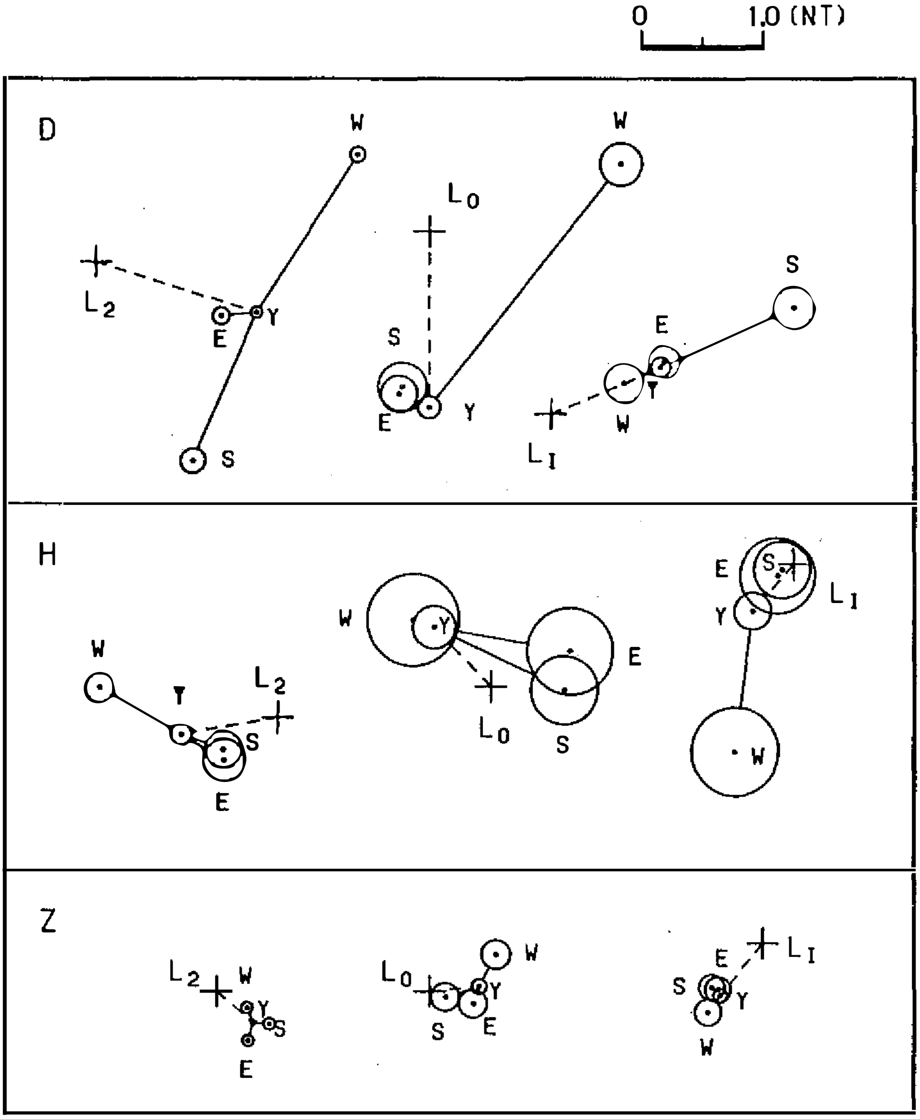

Fig. 11. Harmonic dials of L_2, L_0 and L_I separately for year and seasons.

are statistically significant, for H, L_0 for equinoxes and L_I for equinoxes and summer are not statistically significant and for Z, only L_0 for summer is not statistically significant.

Fig. 11 shows the harmonic dials of L_2, L_0 and L_I determined for each season and for all data. For the annual mean harmonic components, denoted by Y, the amplitude of the oceanic part, L_0, is slightly larger than that of ionospheric part, L_I, for D and H; and slightly smaller than that of L_I for Z. This result shows that the oceanic dynamo effect is remarkably large at

Lunping. The phase angles of L_0 and L_I for D and H are quite different from the corresponding phase angles of L_2. As for the seasonal variations of L_0 and L_I, the following findings are worthy of notice.

For the D element: the seasonal variation of L_I is quite different from that of L_2. The amplitude of L_I is maximum in summer and minimum in winter; whereas the amplitude of L_2 is maximum in winter and minimum during the equinoxes. Although the phase angle of L_2 changes remarkably from winter to the summers, the phase angle of L_I remains almost invariant with season. It should be noted that L_0 also exhibits a significant seasonal variation which may be due to the seasonal changes in lunar declination giving rise to an annual variation of oceanic tides.

For the H element: L_I's determined for the equinoxes and the summer are not significant enough for an accurate description of their seasonal variations. However, it can be noted that L_I for winter is larger than L_I for other seasons; and the phase angle of L_I is quite different from that of L_2. L_0 also shows a significant seasonal variation. For the Z element: the seasonal variation of L_I is quite different from that of L_2 both in amplitude and phase angle.

The seasonal variation of L_I for each element can be more easily recognized by referring to Table 11 in which the ratios of seasonal mean amplitude to annual mean amplitude are listed. Comparing the ratios for $D+H$ and $D+H+Z$ at different seasons, it can be seen that, even by removal of the oceanic dynamo effect, the anomalous seasonal change of amplitude still remains unchanged.

Annual mean L_0 and L_I for the solar active and quiet periods were also calculated and listed in Table 10. Fig. 12 shows their harmonic dials. For comparison, L_2 dials are also shown. For the D element, the amplitudes of L_2, L_I and L_0 all increase with increasing solar activity. The phase angle of L_2 and L_I drift in a clockwise direction with increasing solar activity while that of L_0 drifts in the opposite direction. For H, L_I determined for the solar quiet period is not statistically significant. However, the increase of amplitude with increasing solar activity can be observed. The amplitude of L_0 decreases with increasing solar activity. The phase angle of L_2 drifts in a clockwise direction with increasing solar activity, while that of L_I and L_0 remaining almost invariant. For Z, the amplitude of L_I increases with increasing solar activity. L_I and L_0 drift in a counter-clockwise direction with increasing solar activity. The values of $10^4\ m$ for L_0 and L_I are also determined and given in Table 8.

8. CONCLUSIONS

The solar and lunar daily geomagnetic variations at Lunping have been analysed by use ofthe Chapman-Miller method. The hourly mean values of

Table 11. The ratios of seasonal to annual mean amplitudes of L_2 and L_I.

	D		H		Z		D+H		D+H+Z	
	L_2	L_I	L_2	L_I	L_2	L_I	L_2	L_I	L_2	L_I
ALL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
WINTER	1.68	0.67	1.85	3.14	0.71	1.31	1.77	1.90	1.41	1.71
EQUINOX	0.81	1.04	0.70	0.31	1.23	0.96	0.76	0.68	0.91	0.77
SUMMER	1.32	2.23	0.64	0.20	1.29	1.00	0.98	1.22	1.08	1.15

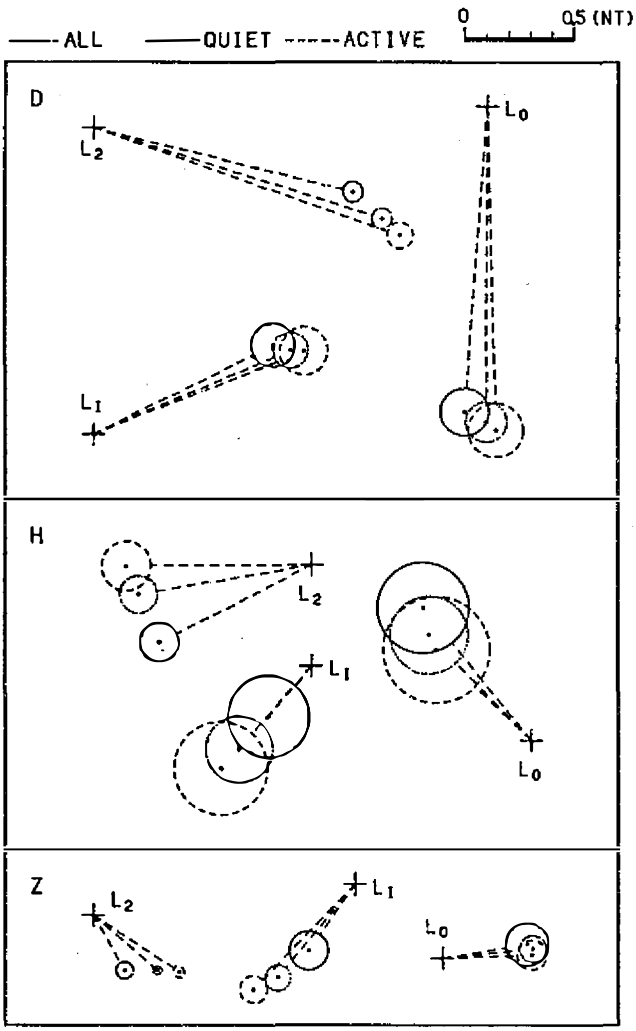

Fig. 12. Harmonic dial showing the variation of annual mean L_2, L_I and L_0 with respect to solar activity.

D, H and Z obtained for the period from 1966 to 1989 have been used for the analysis. The results were tabulated, discussed and compared with other observatories. The following are the major findings of the present study.

(1) The seasonal variations of $R(S)$ are different for different elements. D has a maximum range in summer while H and Z have a maximum range for the equinoxes. An abrupt increase of $R(S)$ in winter is found for the D element.

(2) The solar activity dependence of S_n is different for different elements and orders of harmonics. The values of 10 m determined for $R(S)$ is rather close to the values obtained by Chapman *et al.* (1970) for D and H but unusually large for Z.

(3) The seasonal variations of $R(L)$ are different for different elements. The maximum $R(L)$ appears in summer for D and Z and in winter for H. The seasonal variations of the ratio of the monthly to annual mean range shows an unually large peak appearing in December and January, a subsidiary peak in summer and two minima in March and October.

(4) The seasonal variation of $R(S)$ is greater than that of $R(L)$ for the D element; smaller than that of $R(L)$ for H; and comparable to that of $R(L)$ for Z.

(5) The solar activity dependence of L_n is different for different elements and orders of harmonics. The values of 10^4 m determined for $R(L)$ is smallest for the D element and largest for the Z element. The values of 10^4 m determined for L_2 (except for Z element) are all much smaller than those determined for the solar harmonic component. The values of 10^4 m determined for $R(L)$ are also smaller than those for $R(S)$.

(6) The oceanic dynamo effect is found to be remarkably large at Lunping. For annual mean harmonic components, the amplitude of the oceanic part is found to be larger than that of the ionospheric part for D and H. The seasonal variations of L_I are found to be quite different from those of L_2.

Acknowledgements. The author is grateful to the observers working in the Lunping Observatory. Without their many years of dedicated effort, the present study could not have been accomplished.

REFERENCES

Chapman, S. and J. Bartels, 1940: *Geomagnetism*, Clarendon, Oxford. 1049pp.

Chapman, S., J. G. Gupta and S. R. C. Malin, 1971: The sunspot cycle influence on the solar and lunar daily geomagnetic variations. *Proc. R. Soc. Lond.*, A, **324**, 1-15.

Chapman, S. and J. C. P. Miller, 1940: The statistical determination of lunar daily variations in geomagnetic and meterological elements. *Mon. Not. R. astr. Soc. Geophys. Suppl.*, **4**, 649-669.

Green, P. and S. R. C. Malin, 1971: Lunar and solar daily variations of the geomagnetic field at Watheroo, Western Australia. *J. atmos. terr. Phys.*, **33**, 305-318.

Gupta, J. C. and S. R. C. Malin, 1972: Seasonal variations in the solar and lunar daily geomagnetic variations, Geophys. *J. R. astr. Soc.*, **30**, 11-18.

Huang, Y.N., 1970: Geomagnetic variations at Lunping, Taiwan. *Bull. Inst. Geophys. Natl Central Univ.*, **8**, 1-15.

Leaton, B. R., S. R. Malin and H. F. Finch, 1962: The solar and luni-solar daily variation of the geomagnetic field at Greenwich and Abinger, 1916-1957. *R. Obs. Bull. Lond.*, No. 63, D273.

Malin, S. R. C., 1969: The effect of the sea on lunar variations of the vertical component of the geomagnetic field. *Planet. Space Sci.*, **17**, 487-490.

Malin, S. R. C., 1970: Separation of lunar daily geomagnetic variations into parts of ionospheric and oceanic origin. *Geophys. J. R. astr. Soc.*, **21**, 447-455.

Malin, S. R. C. and S. Chapman, 1970: The determination of lunar daily geophysical variations by Chapman-Miller method. *Geophys. J. R. astr. Soc.*, **19**, 15-35.

Matsushita, S. and H. Maeda, 1965: On the geomagnetic lunar daily variation field. *J. Geophys. Res.*, **70**, 2559-2578.

Shiraki, M., 1977: Solar and lunar daily geomagnetic variations at Kakioka, Memambetsu and Kanoya, Japan, 1958-1973. *Geophys. Mag.*, **38**, 37-69.

Shiraki, M., 1981: Seasonal dependence of lunar daily geomagnetic variations in different regions of the world. *J. Geomag. Geoelectr.*, **33**, 467-501, 1981

Tschu, K. K., 1949: On the practical determination of lunar and luni-solar daily variations in certain geophysical data. *Aust. J. Sci Res.*, A, **2**, 1-24.

崙坪地區自1966年至1989年之地球磁場之太陽與太陰日變化

黃胤年
交通部電信訓練所

本文使用在崙坪地磁觀測台觀測到之地磁磁場之磁偏角，水平分力和垂直分力之每小時平均值，以Chapman-Miller法分析其太陽及太陰之週日變化。本文所採用之數據始自1966年迄1989年共計23年。首先用所有數據作整體的分析，然後分別分析其季節變化、月變化、太陽週期變化等。月球之半日變化則再分爲由於電離層及海洋之電動效應所引起之兩部分。所得結果均用圖表表示，並與其他地磁觀測台所得結果相互比較及討論。