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Solar and Lunar Daily Geomagnetic Variations at Kakioka, Memambetsu and Kanoya, Japan, 1958-1973

By

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Abstract: Hourly mean values of the magnetic declination, horizontal intensity and vertical intensity at three Japanese observatories, Kakioka, Memambetsu and Kanoya, for the 16 years 1958–1973 have been analysed to determine their solar and lunar daily geomagnetic variations. The results of the annual mean variations, the seasonal mean variations and the solar cycle influence on the variations are tabulated by the first four harmonic components. These results for solar and lunar daily variations are compared and discussed.

1. Introduction

This paper describes a study on the solar and lunar daily variations of the geomagnetic field at three Japanese observatories, Kakioka, Memambetsu and Kanoya, for the period 1958 to 1973.

The solar daily geomagnetic variation S and the lunar daily geomagnetic variation L have long been studied by many research workers. Morphologies of S and L are now fairly well known. And the ionospheric dynamo theory alone can reasonably explain the phenomena of S and L. The present situation of S and L was recently reviewed by Matsushita (1967), Maeda (1968) and others.

L is more useful for investigating the ionospheric dynamo theory than S, since the period of lunar tides is incommensurable with that of the ionospheric conductivity. However, as the amplitude of L is smaller than that of S (about a tenth) and the periods of these two variations differ so little (51 minutes of time), reliable determination of L requires a large series of data. Analyses of L on the global scale using such data have gradually been carried out (see Gupta 1973, p. 86). But the distribution of latitude and longitude of the observatories for which data have been analysed is not good enough. Further analyses are very desirable. The present analysis of L at Kakioka, Memambetsu and Kanoya may make a large contribution to filling up the gap in the distribution.

For the study of L, it is certainly desirable to analyse a large series of data not only at one observatory but at many observatories for the same period. And the same method of analysis should be applied to all the data. Though at present such an analysis on a global scale is difficult, the present study is directed to such an analysis, in which only three observatories are used even now. Using such an analysis various differences obtained for different periods or different observatories are considered to be real one, otherwise they are attributed to some errors.

Three observatories used in the present analysis are distributed 13 degrees wide in latitude near the focus position of S equivalent current system in the western North Pacific region (Shiraki, 1974). It is possible to examine whether the location of L focus coincides with that of S focus, comparing the variations at three observatories, especially horizontal geomagnetic intensity variations. This problem was discussed by Chapman and Fogle (1968) for the European sector of longitude by comparing the result from analysis at San Fernando with that from analysis at Greenwich. They estimated that the focus position of L equivalent current system is located in a lower latitude than that of S equivalent current system. It is very interesting to examine this problem for the western North Pacific region.

For the study of dynamo theory, it is necessary to examine not only the global distribution of S and L but also their more detailed features such as seasonal change or sunspot cycle influence. Up to the present time contradicted results have been obtained for these features by comparing S with L. Chapman and Bartels (1940) showed that the seasonal change of S is much less than that of L. But Matsushita and Maeda (1965 b) concluded that no difference is found between them. The recent result presented by Gupta and Malin (1972) is more complicated in that the result from the short-term data is similar to the conclusion of Matsushita and Maeda and the result from long-term data appears to confirm the view of Chapman and Bartels. On the other hand for the sunspot cycle influence on S and L, Matsushita and Maeda (1965 b) found no particular difference between them, but Chapman and Bartels (1940) and recently Chapman, Gupta and Malin (1971) concluded that its influence on S is much greater than that on L. These contradicted results for both seasonal change and sunspot cycle influence may be caused by the insufficient distribution of observatories used, especially for L. The present results from analysis of data subdivided into seasons and sunspot numbers may make a contribution to the goal of these problems, too.

2. Data

Memambetsu and Kanoya are permanent observatories (Fig. 1, Table 1) maintained by Kakioka Magnetic Observatory which belongs to Japan Meteorological Agency.

Continuous magnetic observations were started at Kakioka, Memambetsu and Kanoya in 1913, 1952 and 1958, respectively. The interval of the present analysis is from 1958, when the observation at Kanoya was started, to 1973 (16 years). The data used are hourly mean values of magnetic west declination *D*, horizontal intensity *H* and vertical downward intensity *Z* of the geomagnetic field at the three observatories. All hourly mean values used have been published in the yearbooks, the Report of the Kakioka Magnetic Observatory. The published tables list 24 hourly values per day, each value being the mean for the interval between two consecutive hours of Universal Time (UT). The first entry for each day corresponds to the epoch 00h 30m UT.

For the interval from 1963 to 1973, the hourly mean values have been routinely

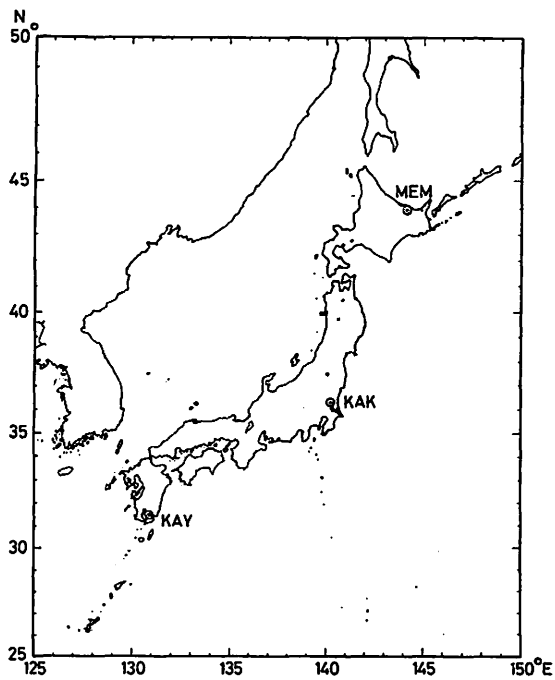


Fig. 1. Location of the three Japanese observatories, Kakioka (KAK), Memambetsu (MEM) and Kanoya (KAY).

Table 1. Location and mean geomagnetic field.

	Memambetsu	Kakioka	Kanoya
Geographic latitude	43° 55′N	36° 14′N	31° 25′N
Geographic longitude	144° 12′E	140° 11′E	130° 53′E
Geomagnetic latitude	34.0°N	26.0°N	20.5°N
Geomagnetic longitude	208.4°	206.0°	198.1°
Dip latitude*	37.4°N	30.1°N	26.0°N
16-yr. mean magnetic declination	8° 13.0′ W**	6° 26.7′ W	5° 06.4′ W
16-yr. mean horizontal intensity	26538γ**	30159γ	32957γ
16-yr. mean vertical intensity	41495γ**	34770γ	32043γ

* See Matsushita and Maeda (1965 a).

** As a gap in hourly published values exists between 1962 and 1963, the hourly values before 1962 are adjusted to those after 1963.

stored in magnetic tapes. These tapes were used for the present analysis. The hourly mean values for the years from 1958 to 1962 were punched into cards from the published tables. The punched data were checked by comparing the daily sums or daily means with the corresponding published values.

For some days data are incomplete. Such days have been omitted from the analysis. The largest number of omitted days is 19 for Z at Memambetsu. It is only 0.34 percent of the total number of days used. No days are omitted for H at Kakioka. The magnetic coordinates and mean geomagnetic fields of 16 years at Kakioka, Memambetsu and Kanoya are given in Table 1 together with the geographic coordinates.

3. Analysis

Periodic variations such as S and L are adequately represented in the form of Fourier coefficients determined by harmonic analysis. If s_n and σ_n denote the amplitude and phase of the n-th harmonic of S, one may write

$$S=\sum S_n=\sum s_n \sin(nt+\sigma_n) \qquad (1)$$

Here t denotes local mean solar time reckoned from local mean midnight; S is customarily represented by first four harmonics for $n=1$, 2, 3 and 4.

On the other hand, if l_n and λ_n denote the amplitude and phase of the n-th harmonic of L, one may write

$$L=\sum L_n=\sum l_n \sin[(n-2)t+2\tau+\lambda_n] \qquad (2)$$

Here τ denotes local mean lunar time reckoned from lower transit of the mean moon; τ is related to t by

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

where ν is the age of the mean moon. It increases by 360° in one lunation (or synodic month), i. e., in 29.5306 mean solar days. From the relation of Eq. (3), Eq. (2) is rewritten as follows.

$$L = \sum L_n = \sum l_n \sin(nt - 2\nu + \lambda_n) \tag{4}$$

The harmonic for $n=2$ has the period of the M_2 tide which is a main term of the lunar gravitational potential. And other harmonics are the results of the combined effects of the M_2 tide and ionospheric conductivity. Eq. (4) is the well-known Chapman's phase law. The most important harmonic terms are those for which n is close to 2. Only the harmonics for $n=1$, 2, 3 and 4 are usually determined from the observatory data.

The method of analysis used to determine S_n and L_n is of Chapman and Miller (1940). This method has mostly been used in the recent analyses of S and L with a large amount of data of the world. The Chapman-Miller method was primarily developed to determine L_n from observatory data, but it is such a convenient method that S_n can also be determined as a byproduct. Details of this method were discussed by Tschu (1949), Leaton, Malin and Finch (1962), and Malin and Chapman (1970).

Vector probable errors should not be omitted from the results of analysis for L. In the present paper they were determined by the method described by Malin and Chapman (1970).

4. Results of Analysis

The data for each element at each observatory were first analysed as a whole, and re-analysed after subdivision according to the season and the sunspot number.

Three seasonal subdivisions, which were introduced by Lloyd and are now customarily used in dealing with S and L, are as follows:

winter: January, February, November and December

equinoxes: March, April, September and October

summer: May, June, July and August

The analysis from a whole data is given as "all" in Tables 2-4, and corresponds to the annual mean.

Sixteen years are classified by the annual mean sunspot number into two categories:

quiet: 1961-1966, 1971, 1973

active: 1958-1960, 1967-1970, 1972

Table 2 S. Solar harmonic components at Kakioka. Unit 0.1 γ.

	Number of days	s_1	σ_1	s_2	σ_2	s_3	σ_3	s_4	σ_4
Declination east									
all	5840	122	27°	98	214°	63	33°	20	226°
winter	1923	42	27	41	195	49	18	29	206
equinox	1951	132	28	99	209	79	30	32	224
summer	1966	189	25	158	222	65	48	10	316
quiet	2920	102	33	85	221	55	37	18	227
active	2920	142	22	113	208	71	30	21	224
Horizontal intensity									
all	5843	12	84	52	340	36	153	9	355
winter	1923	31	343	31	303	25	113	11	319
equinox	1952	26	98	71	337	50	153	17	347
summer	1968	29	140	63	0	40	176	9	78
quiet	2920	6	60	44	347	30	155	8	356
active	2923	19	91	61	335	41	152	10	354
Vertical intensity									
all	5839	76	87	41	317	33	160	11	351
winter	1923	61	74	34	300	29	136	15	325
equinox	1949	79	87	43	318	41	157	19	346
summer	1967	92	97	47	329	35	184	9	67
quiet	2919	62	89	33	324	30	163	10	350
active	2920	91	87	49	312	37	157	12	351

Table 2 L. Lunar harmonic components at Kakioka. Unit 0.01 γ.

	Number of days	l_1	$p.e.$	λ_1	l_2	$p.e.$	λ_2	l_3	$p.e.$	λ_3	l_4	$p.e.$	λ_4
Declination east													
all	5840	33	8	107°	94	4	303°	40	4	114°	12	2	307°
winter	1923	39	10	257	131	6	20	62	4	218	19	3	39
equinox	1951	57	19	124	96	8	297	54	6	98	31	4	268
summer	1966	83	12	81	194	8	266	94	8	86	12	5	310
quiet	2920	22	11	116	88	6	300	35	3	114	13	2	310
active	2920	44	8	104	100	7	305	46	6	115	11	4	304
Horizontal intensity													
all	5843	49	15	242	89	6	75	55	4	241	13	5	104
winter	1923	129	25	284	129	13	106	61	7	268	20	5	106
equinox	1952	37	25	158	52	13	57	49	11	217	8	5	50
summer	1968	69	32	196	119	15	50	67	7	234	15	8	124
quiet	2920	38	19	230	81	8	83	45	6	240	11	5	139
active	2923	62	28	249	99	13	69	65	6	242	17	7	82
Vertical intensity													
all	5839	24	7	194	33	4	284	36	2	253	9	3	93
winter	1923	55	9	42	88	7	221	42	4	327	16	4	140
equinox	1949	42	10	205	41	6	307	45	6	233	14	4	29
summer	1967	79	9	207	64	7	355	61	5	229	10	5	98
quiet	2919	29	9	195	37	5	277	31	3	248	6	3	106
active	2920	19	9	191	29	7	292	42	4	256	13	5	88

Table 3 S. Solar harmonic components at Memambetsu. Unit 0.1 γ.

	Number of days	s_1	σ_1	s_2	σ_2	s_3	σ_3	s_4	σ_4
Declination east									
all	5827	140	31°	96	214°	53	30°	14	221°
winter	1919	57	43	33	203	40	21	23	205
equinox	1947	153	33	94	207	68	25	22	220
summer	1961	210	27	162	221	53	44	8	338
quiet	2915	119	37	83	222	46	35	13	224
active	2912	162	27	110	209	60	27	15	218
Horizontal intensity									
all	5826	67	96	70	323	48	146	14	348
winter	1921	33	48	50	306	36	123	15	320
equinox	1944	82	96	88	322	63	143	24	340
summer	1961	99	110	76	336	50	166	12	49
quiet	2915	48	96	57	331	41	149	13	349
active	2911	86	96	83	318	55	144	15	346
Vertical intensity									
all	5824	43	96	22	302	15	142	5	333
winter	1919	18	81	12	313	13	142	7	317
equinox	1945	43	93	21	295	16	131	6	327
summer	1960	69	102	33	303	15	152	3	32
quiet	2912	35	98	18	309	13	146	5	334
active	2912	52	95	26	298	16	138	5	333

Table 3 L. Lunar harmonic components at Memambetsu. Unit 0.01 γ.

	Number of days	l_1	p.e.	λ_1	l_2	p.e.	λ_2	l_3	p.e.	λ_3	l_4	p.e.	λ_4
Declination east													
all	5827	40	11	126°	74	6	319°	29	4	120°	6	3	326°
winter	1919	32	13	257	125	7	32	54	6	231	22	4	65
equinox	1947	78	22	137	76	9	316	41	8	109	24	5	267
summer	1961	73	15	92	157	9	271	79	7	88	9	6	319
quiet	2915	30	13	146	67	7	319	24	3	117	6	3	319
active	2912	52	11	114	80	8	318	35	7	122	5	5	335
Horizontal intensity													
all	5826	56	17	222	77	6	67	62	5	233	16	5	84
winter	1921	110	21	294	101	12	123	48	8	272	18	7	112
equinox	1944	60	26	182	58	12	54	63	11	219	14	6	47
summer	1961	108	32	186	135	14	36	89	8	222	22	9	82
quiet	2915	49	17	212	70	9	78	52	5	232	12	5	118
active	2911	65	30	230	85	11	59	72	6	233	23	9	66
Vertical intensity													
all	5824	8	3	144	37	3	302	10	1	225	2	1	77
winter	1919	50	4	30	55	3	249	21	2	359	10	2	181
equinox	1945	23	7	219	34	4	322	20	3	225	7	2	21
summer	1960	43	6	173	57	4	336	29	3	195	5	2	35
quiet	2912	11	5	176	39	3	304	10	2	214	2	2	66
active	2912	9	5	99	36	3	301	11	2	235	2	2	87

Table 4 S. Solar harmonic components at Kanoya. Unit 0.1 γ.

	Number of days	s_1	σ_1	s_2	σ_2	s_3	σ_3	s_4	σ_4
Declination east									
all	5833	111	23°	101	217°	74	42°	24	237°
winter	1919	28	16	38	188	52	22	34	213
equinox	1950	119	25	103	211	92	38	38	232
summer	1964	184	23	169	226	84	59	18	313
quiet	2916	93	30	88	225	65	46	22	238
active	2917	130	18	116	211	83	39	27	237
Horizontal intensity									
all	5835	35	274	49	11	30	173	6	6
winter	1922	59	309	13	336	17	118	10	329
equinox	1949	26	254	70	5	46	175	12	5
summer	1964	39	237	68	23	37	191	6	113
quiet	2920	31	280	42	16	25	174	5	8
active	2915	38	270	56	7	36	171	8	4
Vertical intensity									
all	5835	98	76	46	281	32	124	11	315
winter	1920	75	67	36	261	31	98	16	290
equinox	1950	104	75	47	279	39	121	18	311
summer	1965	116	83	57	294	32	151	8	53
quiet	2918	79	79	37	287	28	128	10	316
active	2917	117	74	55	276	36	120	11	315

Table 4 L. Lunar harmonic components at Kanoya. Unit 0.01 γ.

	Number of days	l_1	p.e.	λ_1	l_2	p.e.	λ_2	l_3	p.e.	λ_3	l_4	p.e.	λ_4
Declination east													
all	5833	42	7	91°	85	5	303°	56	4	119°	19	3	318°
winter	1919	26	10	245	149	7	33	77	5	215	23	3	19
equinox	1950	58	18	106	87	7	290	69	6	96	38	5	275
summer	1964	97	14	74	212	10	266	122	7	96	20	6	336
quiet	2916	35	10	78	76	6	297	49	4	115	20	3	320
active	2917	50	7	99	94	8	308	63	6	121	19	4	315
Horizontal intensity													
all	5835	37	14	281	69	8	111	47	5	260	7	5	141
winter	1922	127	29	298	131	13	127	62	8	284	12	5	132
equinox	1949	22	26	114	22	13	119	39	11	231	4	5	25
summer	1964	34	34	209	71	17	78	50	8	253	12	8	167
quiet	2920	20	21	278	64	8	124	38	6	255	8	5	191
active	2915	53	27	282	77	15	100	56	7	263	11	8	107
Vertical intensity													
all	5835	33	8	183	18	4	135	27	3	225	6	3	30
winter	1920	26	15	96	73	9	162	37	5	301	12	4	104
equinox	1950	45	11	187	6	5	98	33	6	199	18	3	342
summer	1965	55	10	206	32	6	16	47	6	199	3	5	79
quiet	2918	31	10	186	19	5	155	26	4	221	6	3	11
active	2917	34	9	180	19	7	116	28	4	229	6	5	47

The mean sunspot numbers of the two categories are 37.0 for quiet years and 117.5 for active years. Overall mean is 77.3.

The results of analysis are presented in Tables 2, 3 and 4. Tables 2 S, 3 S and 4 S give the amplitude s_n and phase σ_n of S harmonics of each element for Kakioka, Memambetsu and Kanoya, respectively. Tables 2 L, 3 L and 4 L give the amplitude l_n, vector probable error $p.e.$ and phase λ_n of L harmonics corresponding to Tables 2 S, 3 S and 4 S, respectively. In these tables the unit of s_n is 0.1γ ($1\gamma=1$ nT in the new terminology) and that of l_n and $p.e.$ is 0.01γ. Phases are given in degrees.

No probable errors are given for S harmonics, because their probable errors are very small compared with the amplitudes and are very close to the probable errors for the corresponding L harmonics. The amplitude s_n or l_n is considered to be significant when it exceeds 2.08 times its vector probable error (Leaton, Malin and Finch, 1962). From this viewpoint all S harmonics in Tables 2 S, 3 S and 4 S are significant, and all but 30 of the 216 harmonics of L in Tables 2 L, 3 L and 4 L are significant. Total number of days used in the analysis for each category is also given in the tables.

The published data for element D are expressed in angular measure west. All phase angles for D have therefore been corrected by 180° and all amplitudes at a station have been multiplied by a factor so that the results for D may be expressed in γ east. The factors used for Kakioka, Memambetsu and Kanoya are 8.773γ, 7.720γ and 9.587γ per minute of arc, respectively. These factors were calculated from the mean values of H at the respective observatory for the period from 1958 to 1973 (see Table 1).

5. Discussions

5.1 The annual mean variations of S and L

Figs. 2 S and 2 L illustrate the annual mean variations of D, H and Z at Kakioka, Memambetsu and Kanoya for S and L, respectively (hereafter called daygraph). The daygraphs for S are drawn from synthetic 24-hourly values derived from Eq. (1), with the coefficients given in the "all" rows in Tables 2 S, 3 S and 4 S. These synthetic hourly values represent slight smoothing of the actual mean daily sequences of hourly values taken from the published data. The daygraphs for L refer to the epoch of new moon ($\nu=0$ in Eq. (3)). The 24-hourly values were synthesized as if the sun and the moon remained on the same meridian during the lunar day centered at new moon.

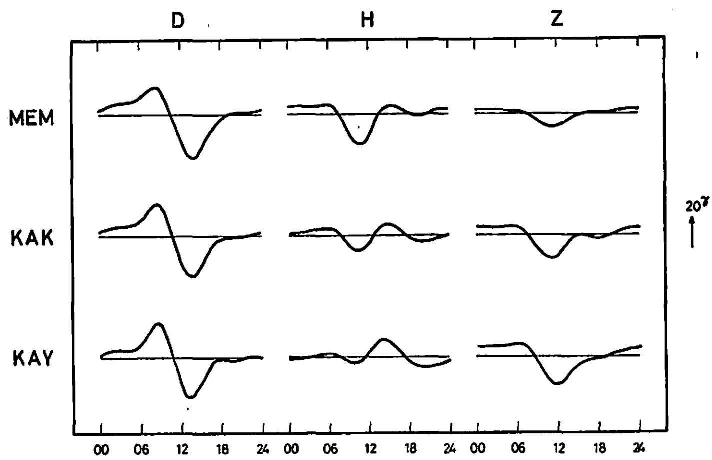


Fig. 2 S. Daygraphs of the annual mean solar daily variation at Kakioka, Memambetsu and Kanoya for magnetic declination D, horizontal intensity H and vertical intensity Z.

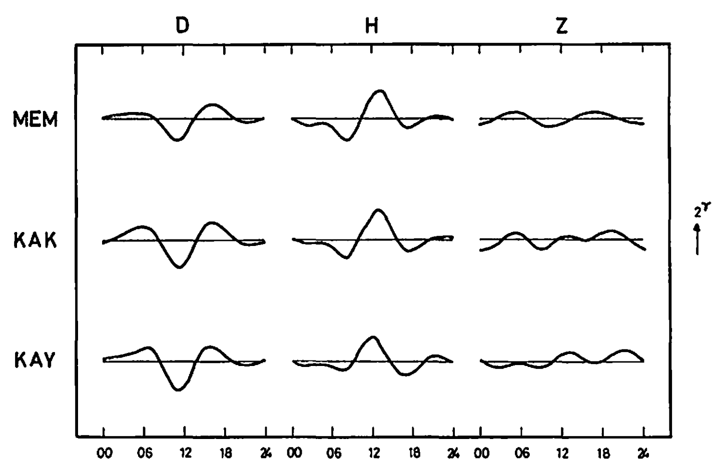
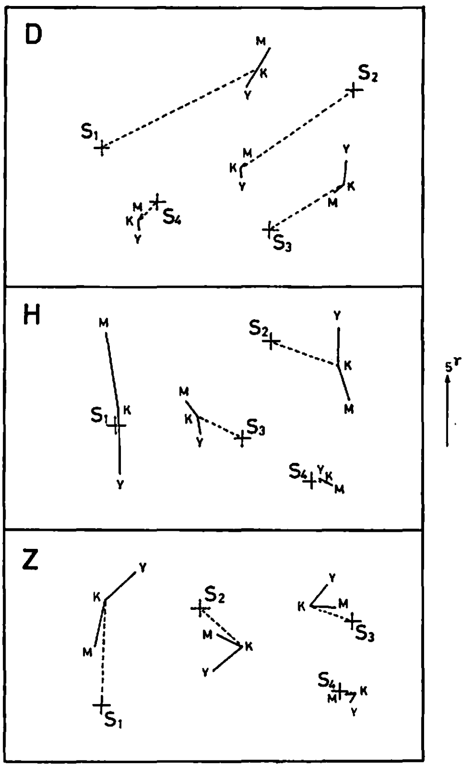


Fig. 2 L. The same as Fig. 2 S, for lunar variation. The curves refer to the epoch of new moon, and are drawn as if during the lunar day centered at new moon, the sun and moon remained on the same meridian.

The variation of geomagnetic field shown as daygraphs may also be expressed by the amplitudes and phases of annual mean harmonics for S and L as illustrated by harmonic dials in Figs. 3 S and 3 L, respectively. The vectors (drawn only for Kakioka) from the origin to the marked points have the length s_n or l_n on the scales shown, and they make the counterclockwise angle σ_n or λ_n from the righthanded positive direction along the horizontal axis. In the figures for



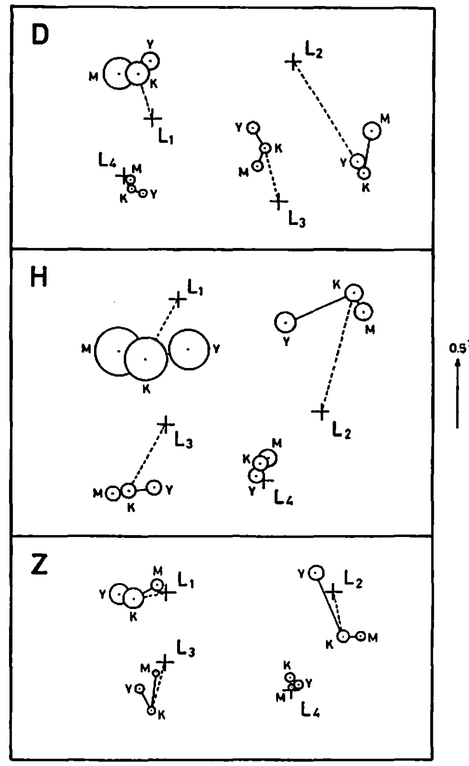


Fig 3 S.   Fig. 3 L.

Fig. 3 S. Harmonic dials for the annual mean solar daily variation at Kakioka (K), Memambetsu (M) and Kanoya (Y) for *D*, *H* and *Z*. The dial vector is drawn only for Kakioka. Vectors for Memambetsu and Kanoya are indicated by their end points. Numerical subscripts indicate the order of the harmonic component.

Fig. 3 L. The same as Fig. 3 S, for lunar variation. The vector probable error circles are drawn at the end points of vectors.

L, the vector probable error circles are also shown.

In Fig. 2 S the shapes of the solar daily variation of *D* are very similar among Kakioka, Memambetsu and Kanoya and the ranges of variation are almost the same. For *Z* the shapes are similar but the ranges decrease with increasing latitude. Of the three elements, *H* shows the largest difference in shape and range among three observatories. Each range for three elements and three observatories is given in Table 5 S.

These features for *S* show fairly good agreement with the results obtained in the middle latitudes so far (Chapman and Bartels, 1940; Matsushita, 1967), and they are understandable in the light of the relative relationship of an observatory

Table 5 S. The range of the annual mean variation for S. Unit is 1γ.

	D	H	Z
Memambetsu	45	26	12
Kakioka	45	17	22
Kanoya	47	17	25

to the focus position of S equivalent current system. The information of the focus latitude is mainly given by the latitudinal change in shape of H variation. At an observatory located to the north of the focus position in the northern hemisphere, the daily variation of H shows a pronounced minimum around noon or a little earlier, while that at an observatory to the south of the focus position shows a pronounced maximum in the daytime. The type of variation changes at the focus latitude. In Fig. 2 S the H variation at Memambetsu indicates the type peculiar to the north of the focus. Contrary to this, the H variation at Kanoya shows a maximum in the daytime, though the time of occurrence is not the same as that of a minimum at Memambetsu; Kanoya may be located to the south of the focus. The type of the variation at Kakioka is of a mixed nature, but is rather close to the type to the north of the focus. Consequently the focus position of S equivalent current system may be between Kakioka and Kanoya.

Also, the focus latitude of equivalent current system may be approximated by the latitude where S_1 component of H changes its sign (Hasegawa, 1960). It is clear from the harmonic dial of H in Fig. 3 S that the sign of S_1 component changes between Kakioka and Kanoya.

In Fig. 2 L the shapes of the lunar daily variation of D are very similar among three observatories, and ranges increase slightly from Memambetsu to Kanoya. This statement about the shape is true for H, but the range decreases from Memambetsu to Kanoya. For Z the shape is very different from each other, and the range at each observatory is less than that of D and H. The range of

Table 5 L. The range of the annual mean variation for L. The epoch is new moon. Unit is 0.1γ.

	D	H	Z
Memambetsu	30	42	12
Kakioka	36	41	20
Kanoya	40	32	17

all the elements at the three observatories is given in Table 5 L.

The above features of D and H for L may be explained in the light of the current system of L for the epoch of new moon presented by Chapman and Bartels (1940, p. 263, Fig. 6). Their figure is of the equinoxial season, but may be applied to the annual mean variation without large errors. Considering the current direction around the two foci in the daytime, the expected variations of D and H to the north of the foci in the northern hemisphere are similar to the observed variations of D and H at Kakioka, Memambetsu and Kanoya. Therefore the focus positions of L current system may be located in the latitudes lower than those of the three observatories. This is supported by the latitudinal changes of range for D and H given in Table 5 L.

As the focus latitude of S current system is estimated at somewhat north of Kanoya and that of L current system at south of Kanoya, the latter is of course lower than that of the former. This result is the same as that obtained by Chapman and Fogle (1968) for the European sector of longitude. They estimated the relative relationship of S and L focus positions by comparing the result from the analysis at San Fernando (36.5°N, 6.2°W) with that from the analysis at Greenwich (51.5°N, 0°W). Theirs and the present results are consistent with the S and L current diagrams drawn by Chapman and Bartels (1940) and Matsushita and Maeda (1965 a, b). According to Chapman and Bartels the focus latitude of S current system (p. 229, Fig. 15) and that of L current system (p. 263, Fig. 6) are estimated at 40° and 35° in geographic latitude, respectively. Though the current diagram for L is based on so few observatories that it does not give accurate values, the relative relationship of S and L focus positions is the same as that of the present author's. Matsushita and Maeda's current diagrams also indicate that the focus latitude of L current system is lower than that of S current system—much lower than that of the present result—even though their values are of a mean lunation, not restricted to new moon like the present study.

In Fig. 2 S the time of maximum or minimum of S variation at an observatory is not coincident with those at the other observatories. However, those of D and H at Kakioka generally lie between those at Memambetsu and Kanoya. This is clearly seen from the harmonic dials in Fig. 3 S.

The same statement is, however, not true for Z. In Fig. 2 S the minimum time at Kakioka is about one hour earlier than that at Kanoya. This fact is also clear in Fig. 3 S except S_1 component. This phenomenon was first pointed out by Rikitake, Yokoyama and Sato (1956) and it is explained by the anomalous electrical conductivity distribution beneath central Japan. For S_1 component the effect is not clear, perhaps the latitudinal dependency of Z is largest for S_1 and it conceals the above effect.

Though it is not so clear as S, L variation of Z shows similar effect. In Fig. 3 L, the phase of L_1 and L_3 components of Z at Kakioka leads those at Memambetsu or Kanoya. The difference is small but significant when considering the vector probable errors and the fact that the data at the three observatories during the same period of 16 years have been analysed by the same method in the present analysis. In Fig. 3 L the above phenomenon is, however, not seen for L_2 component, though it is the main harmonic of L. This may be due to the ocean effect on L variation, which will be discussed in the following.

The principal mechanism for the production of L variation is an ionospheric dynamo. However, the oceanic dynamo is also a fairly large source of L (Malin, 1969). The oceanic dynamo generates electric currents by the tidal movements of the sea across the lines of force of the Earth's main magnetic field. As the conductivity of the ocean does not exhibit appreciable time variation, the geomagnetic variation resulting from the oceanic dynamo may contribute to L_2 component only (Malin, 1970).

In Fig. 3 L, the differences among the three observatories of L_2 component for H and Z are more notable than those of L_1 or L_3 component. Considering the vector probable errors, such a difference may be significant. The latitudinal change of L variation resulting from the ionospheric dynamo is expected to be more or less systematic as seen for S variation, but that resulting from the oceanic dynamo does not necessarily show systematic changes, because the distribution of sea is not uniform. Different contributions from the oceanic dynamo may bring much different values of L_2 harmonic for each observatory.

When the source of L variation is considered to be in the ionosphere alone, the main harmonic component is expected to be L_2. That the main harmonic component is L_2 is generally true for D and H. But the main harmonic components of Z at Kakioka and Kanoya are L_3 and L_1, respectively. This fact may be explained by the oceanic dynamo effect. The ionospheric part and oceanic part of L_2 variation are out of phase and the amplitude of L_2 becomes smaller than that of L_3 or L_1. It is also explained by the oceanic dynamo effect that the phase lead of Z at Kakioka in comparison with Memambetsu and Kanoya, is absent in L_2 component.

5.2 The seasonal mean variations of S and L

Figs. 4 S and 4 L illustrate by daygraphs the seasonal mean variations of D,

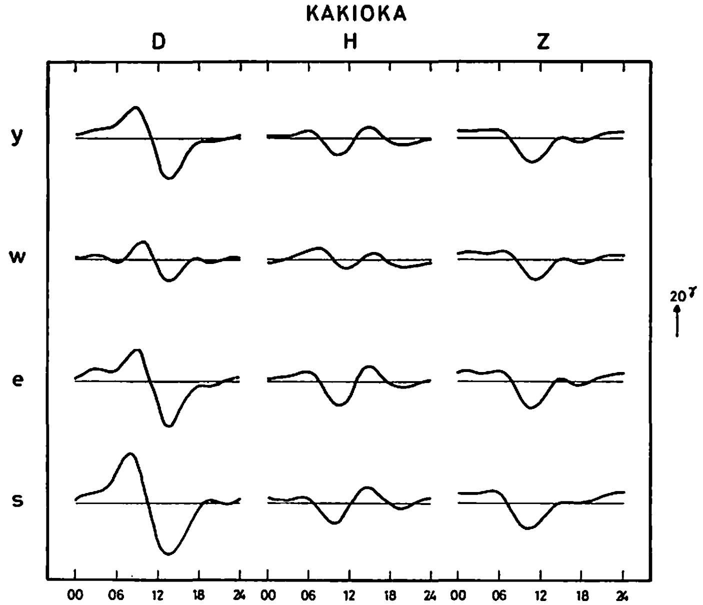


Fig. 4 S. Daygraphs of the annual mean and seasonal mean solar daily variations at Kakioka for *D*, *H* and *Z*. The letter y refers to the annual mean, those of w, e and s to the winter, equinox and summer variations.

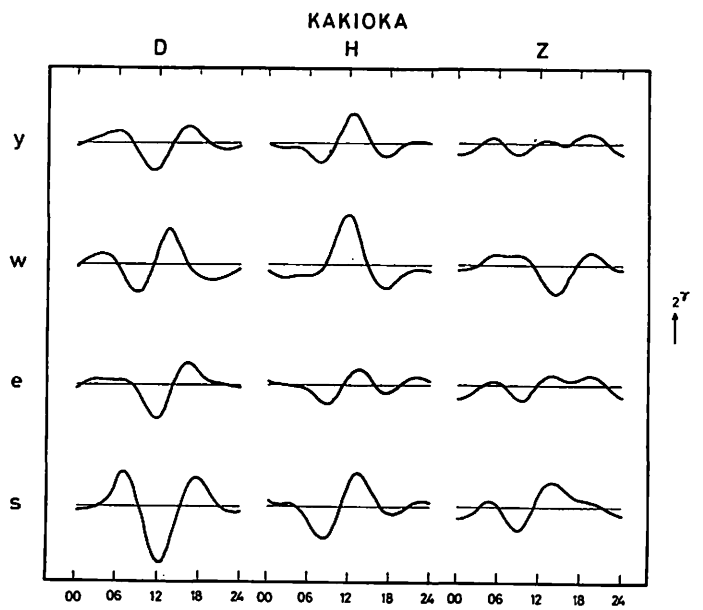


Fig. 4 L. The same as Fig. 4 S, for lunar variations. The curves refer to the epoch of new moon, and are drawn as if during the lunar day centered at new moon, the sun and moon remained on the same meridian.

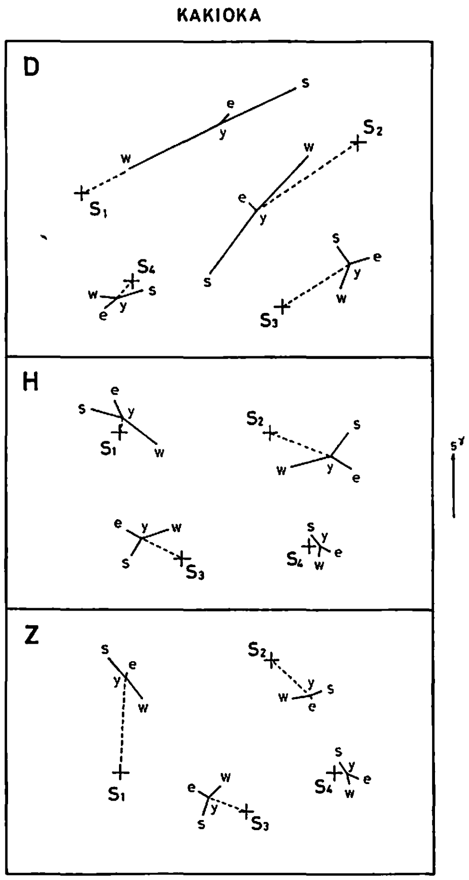


Fig. 5 S.

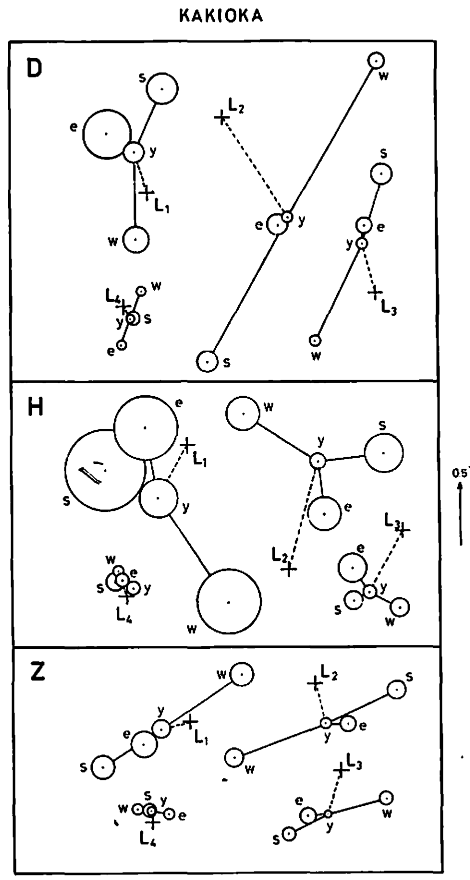


Fig. 5 L.

Fig. 5 S. Harmonic dials for the annual mean and seasonal mean solar daily variations at Kakioka for *D*, *H* and *Z*. The dial vector is drawn only for the annual mean variation, but not drawn for the seasonal mean variations; they are indicated only by their end points. The dial points y refer to the annual mean, those marked w, e, s to the winter, equinox and summer values of *S*. Numerical subscript indicates the order of the harmonic component.

Fig. 5 L. The same as Fig. 5 S, for lunar variations. The vector probable error circles are drawn at the end points of the vectors.

H and *Z* at Kakioka for *S* and *L*, respectively. In Fig. 4 L the daygraphs refer to the epoch of new moon like those in Fig. 2 L. Figs. 5 S and 5 L illustrate by harmonic dials the annual and seasonal mean harmonics at Kakioka for *S* and *L*, respectively.

In Fig. 4 S the shape of the variations of *D* and *Z* changes little with seasons, but their ranges increase from winter to summer. The shape of H variation changes somewhat with season and the range for equinoxes is greater than that for summer. This feature of H variation is explained by the seasonal change of focus latitude of S equivalent current system (Shiraki, 1974). As regard to the phase, summer leads winter for all the elements. The maximum or minimum time for summer is about 1.8 hours earlier than that for winter. These features of seasonal changes of S generally agree with Chapman and Bartels (1940) or Matsushita (1967).

On the other hand, in Fig. 4 L, the shapes and ranges of L variation show remarkable change with seasons. The first remarkable point is that the range of each element for equinoxes is smaller than that for winter. And ranges of D or Z for winter and summer are nearly equal and the range of H is greatest for winter. Such seasonal change of L is notably different from that of S. Numerical comparison of S and L will be given later together with the results at Memambetsu and Kanoya.

Another peculiarity seen from Fig. 4 L is that the shape of the variation also shows a remarkable difference between winter and summer, and the shape for equinoxes is rather close to that for summer; these are true for all elements. Assuming that the change of shape is simply caused by the phase change, the phase of winter precedes that of summer by about 4 hours for D and about 2 hours for H, and it succeeds that of summer by about 6 hours for Z.

In Figs. 5 S and 5 L the amplitude of each harmonic component does not necessarily show the same feature of seasonal change as the range of the daygraph. This case is found in S_3 and S_4 of D and Z, and L_1 of H. Moreover the largest term changes from one harmonic to another with season for some cases; S_3 is the largest term of D for winter, but not for other seasons. The amplitude of L_2 for H is less than that of L_1 for winter, though the amplitude of L_2 is larger than that of L_1 for equinoxes and summer. The largest term of Z for L varies with seasons.

Seasonal changes of S and L at Memambetsu and Kanoya are not appreciably different from those at Kakioka. Therefore the figures corresponding to Figs. 4 and 5 are not shown for Memambetsu and Kanoya. The large latitudinal dependency of shapes and ranges is seen in a seasonal mean variation for S similarly as the annual mean variation, but the characteristics of the seasonal change described for Kakioka are generally common to Memambetsu and Kanoya. For L variation the latitudinal dependency is small in each season similarly as the annual mean case, though the seasonal change itself is very remarkable.

If examined in detail, however, the seasonal changes are slightly different among three observatories, especially for L. There are some factors for the complexity of seasonal change of L. First, the number of days in the seasonal subdivision is one third of the whole data. Therefore all harmonics for each season are determined less accurately than those for the annual mean ones. Generally the vector probable errors for each season are about twice the annual case.

Another source of complexity is the effect related to the O_1 tide in the lunar gravitational potential. The L variation in the present analysis is restricted to the M_2 tide, but when the data are divided into seasons, the pure M_2 tide is not isolated in the analysis. The O_1 tide has the same frequency as the seasonal modulation of L_1 harmonic in Eq. (4). Therefore the O_1 tidal effect is included in the seasonal change of L variation. As the O_1 tide has an amplitude about half as large as the M_2 tide in the potential, it cannot be neglected from the lunar geomagnetic fields. Similarly as the M_2 tide, the O_1 tidal effect is not only of ionospheric origin but of oceanic origin. The apparently large L_1 component of H for winter may partly be due to the influence of the O_1 tidal effect.

Remarkable difference in seasonal change between S and L at Kakioka was already noted. Seasonal changes of S and L are compared here by a numerical expression. The amplitudes of the harmonics are not necessarily a good basis of the measure of seasonal variation, because harmonics of different phases can produce a combined curve whose range needs not vary like amplitude. This is noted before. It is better to consider a range of the daygraph.

The range of S, $r(S)$, is the difference between the largest and smallest of the 24 hourly values synthesized from Eq. (1). Such ranges for the annual mean variation are already given in Table 5S.

The range of L, $r(L)$, is similarly obtained from the synthesized hourly values of L, but it changes from day to day with the phase of the moon. For simplicity the range for the new moon may be taken to be representative, and is given in Table 5L for the annual mean variation. In another way Chapman, Gupta and Malin (1971) used a simpler range obtained as follows:

$$R(L)=2\sum_{n=1}^{4} l_n \tag{5}$$

This gives the difference between the largest and smallest values that L can attain over a long period. Both ranges for L are considered in the present paper. The probable error ρ of the range $r(L)$ or $R(L)$ is calculated by

$$\rho=1.146\left[\sum_{n=1}^{4}\rho_n^2\right]^{1/2} \tag{6}$$

where ρ_n is a vector probable error of each harmonic component (Chapman, Gupta and Malin, 1971).

Using the ranges of S and L, the seasonal changes may be examined. For convenience, however, the ratio of the range for a season to that for the annual mean is used similarly as Gupta and Malin (1972). The ranges themselves are not convenient for averaging them over elements or over observatories. Moreover they are not convenient for the final comparison of S and L.

The ratios of S are given in Table 6 S for each of the three elements and three observatories. As the ratios show considerable scatter among elements and observatories, the mean values from all elements at each observatory and grand means for all observatories are also included in Table 6 S. The probable errors of the S ratios are negligibly small, so they are not given in the table.

In Table 6 S the mean ratio from all elements, which may represent the overall characteristics of the equivalent current system, is largest for summer and smallest for winter as expected. Those of D and Z behave similarly, but those of H are largest for equinoxes.

On the other hand, the ratios of seasonal to annual mean ranges for L are calculated for both $r(L)$ and $R(L)$. However, since the ratio from $r(L)$ is nearly

Table 6 S. The ratio of seasonal range to annual mean range for S.

	D	H	Z	$D+H+Z$	$D+H$
winter/annual					
Memambetsu	0.48	0.74	0.57	0.60	0.61
Kakioka	0.53	0.68	0.86	0.69	0.61
Kanoya	0.51	0.82	0.86	0.73	0.67
mean	0.51	0.75	0.76	0.67	0.63
equinox/annual					
Memambetsu	1.09	1.29	1.03	1.14	1.19
Kakioka	1.13	1.45	1.10	1.23	1.29
Kanoya	1.15	1.39	1.09	1.21	1.27
mean	1.12	1.38	1.07	1.19	1.25
summer/annual					
Memambetsu	1.51	1.20	1.44	1.38	1.36
Kakioka	1.47	1.24	1.17	1.29	1.36
Kanoya	1.51	1.31	1.21	1.34	1.41
mean	1.50	1.25	1.27	1.34	1.38

Table 6 L. The ratio of seasonal range to annual mean range for L. The ratio is calculated from range $R(L)$. The ratio from range $r(L)$ is included only for the mean values.

	D	H	Z	$D+H+Z$	$D+H$
winter/annual					
Memambetsu	1.57±0.10	1.31±0.10	2.36±0.11	1.70±0.06	1.44±0.07
Kakioka	1.40±0.06	1.65±0.12	1.98±0.12	1.54±0.05	1.47±0.05
Kanoya	1.37±0.05	2.09±0.18	1.79±0.18	1.44±0.05	1.42±0.05
weighted mean	1.41±0.04	1.54±0.07	2.09±0.07	1.55±0.03	1.44±0.04
weighted mean from $r(L)$	1.47±0.06	1.44±0.09	2.12±0.11	1.55±0.04	1.46±0.04
equinox/annual					
Memambetsu	1.47±0.12	0.92±0.10	1.46±0.11	1.24±0.06	1.13±0.07
Kakioka	1.33±0.08	0.71±0.10	1.39±0.10	1.16±0.05	1.06±0.06
Kanoya	1.25±0.07	0.55±0.12	1.23±0.13	1.09±0.06	1.06±0.06
weighted mean	1.32±0.05	0.75±0.06	1.38±0.06	1.18±0.04	1.08±0.04
weighted mean from $r(L)$	1.31±0.06	0.73±0.08	1.21±0.09	1.13±0.04	1.10±0.05
summer/annual					
Memambetsu	2.13±0.13	1.68±0.13	2.33±0.13	2.05±0.07	1.91±0.10
Kakioka	2.15±0.08	1.31±0.12	2.10±0.12	1.93±0.06	1.87±0.07
Kanoya	2.24±0.08	1.05±0.16	1.64±0.14	1.90±0.06	1.97±0.07
weighted mean	2.18±0.05	1.37±0.07	2.05±0.07	1.96±0.04	1.92±0.05
weighted mean from $r(L)$	2.23±0.07	1.43±0.10	2.28±0.12	2.02±0.05	1.98±0.06

equal to that from $R(L)$, the ratio from $R(L)$ is given in Table 6 L. Only the mean ratios from $r(L)$ for all observatories are included in the table for comparison. The ratios for L are determined less accurately than those for S, so the probable errors are shown in Table 6 L. And the mean values shown in the table are weighted means with weight w_i which is the inverse of the square of each probable error. The probable errors of the means are $1/(\sum w_i)^{1/2}$ (Chapman, Gupta and Malin, 1971). As discussed in the previous section, L variation includes a fairly large part due to the oceanic dynamo effect, especially for Z. Therefore the mean from D and H excluding Z, which may be less affected by the oceanic dynamo than the mean from all elements, is also calculated and given in Table 6 L. For the convenience of comparison of S and L, the mean from D and H for S is also given in Table 6 S.

In Table 6 L the ratios of all elements at all observatories are smallest for equinoxes and the ratios H and Z are largest for winter. The mean ratios from all elements or from D and H are largest for summer and smallest for equinoxes.

It may be interesting to examine whether such a feature of seasonal change

Table 7. The weighted mean ratios from Kakioka, Memambetsu and Kanoya of seasonal to annual mean amplitude of L_2 component.

	D	H	Z	$D+H+Z$	$D+H$
winter/annual	1.55±0.07	1.48±0.12	1.63±0.11	1.56±0.05	1.52±0.06
equinox/annual	1.02±0.07	0.57±0.10	0.91±0.10	0.90±0.05	0.90±0.05
summer/annual	2.19±0.10	1.40±0.13	1.62±0.12	1.86±0.06	1.94±0.08

of L is seen or not for L_2 component, which represents the L variation for the mean lunation. The ratios of L_2 amplitude for a season to the annual mean L_2 amplitude were calculated for each of three elements and three observatories. The weighted means from three observatories are given in Table 7. It is clear from Tables 6 L and 7 that the seasonal ratios only from L_2 component are nearly equal to the corresponding ratios from ranges.

Comparing the result for S in Table 6 S with that for L in Table 6 L, remarkable differences are clearly seen. The main difference is in the ratio for winter. The ratio of L for winter is greater than unity and is twice or more as large as that of S.

The present result does not agree with those hitherto presented. Chapman and Bartels (1940) found that the seasonal change of L is much greater than that of S, while Matsushita and Maeda (1965 b) concluded that the seasonal changes of S and L are similar. Recently, Gupta and Malin (1972) presented more complicated result that the seasonal changes of S and L are similar for the short term data of the IGY/C period but the seasonal change of L is much greater than that of S for longer term data. Though their results are different from each other, a point of agreement is that the current intensity for both S and L is largest for summer and smallest for winter. And their contradictory point is percentage change of the seasonal ratios between S and L being different.

For the purpose of comparison the results obtained by Gupta and Malin from long term data are given in Table 8 S for S and in Table 8 L for L together with the present result. The present ratio for S is in good agreement with their ratios, but the present ratio for L in winter is very different from theirs.

The local effect may be considerable as the origin of this discrepancy for L. Though the sources of the L variation are both ionospheric and oceanic dynamos, the latter may be more effective as the local effect since Japan is surrounded by sea. The ocean effect is included in L_2 component and the anomalous large ratio for winter is noticed not only in range but also in L_2 component. Therefore

Table 8 S. Comparison of the ratios of seasonal range to annual mean range for S between the result obtained from long term data by Gupta and Malin (1972) and the present result.

	D	H	Z	$D+H+Z$	$D+H$
winter/annual					
Gupta and Malin	0.64	0.92	0.71	0.76	0.78
present result	0.51	0.75	0.76	0.67	0.63
all mean	0.60	0.87	0.73	0.73	0.74
equinox/annual					
Gupta and Malin	1.13	1.17	1.14	1.15	1.15
present result	1.12	1.38	1.07	1.19	1.25
all mean	1.13	1.23	1.12	1.16	1.18
summer/annual					
Gupta and Malin	1.37	1.25	1.21	1.28	1.31
present result	1.50	1.25	1.27	1.34	1.38
all mean	1.41	1.25	1.23	1.30	1.33

Table 8 L. Comparison of the ratios of seasonal range to annual mean range for L between the result obtained from long term data by Gupta and Malin (1972) and the present result.

	D	H	Z	$D+H+Z$	$D+H$
winter/annual					
Gupta and Malin	0.55±0.01	0.69±0.02	0.57±0.01	0.57±0.01	0.58±0.01
present result	1.41±0.04	1.54±0.07	2.09±0.07	1.55±0.03	1.44±0.04
all weighted mean	0.67±0.01	0.77±0.02	0.59±0.01	0.62±0.01	0.71±0.01
equinox/annual					
Gupta and Malin	0.95±0.02	1.29±0.03	0.88±0.02	0.98±0.01	1.05±0.02
present result	1.32±0.05	0.75±0.06	1.38±0.06	1.18±0.04	1.08±0.04
all weighted mean	1.00±0.02	1.20±0.03	0.91±0.02	0.95±0.01	1.09±0.01
summer/annual					
Gupta and Malin	1.71±0.02	1.51±0.03	1.65±0.02	1.65±0.01	1.65±0.02
present result	2.18±0.05	1.37±0.07	2.05±0.07	1.96±0.04	1.92±0.05
all weighted mean	1.79±0.02	1.50±0.03	1.68±0.02	1.82±0.01	1.59±0.01

the large oceanic dynamo effect may be included in the L variation in winter.

The O_1 tidal effect may also be the origin of large excess for winter. It was noted before that the seasonal mean variation of L includes the geomagnetic variation due to the O_1 tide. This is clearly seen for H in winter, which may be a local feature.

On the other hand, the latitudinal effect too could be the cause of the large winter ratio of L for the present observatories. All observatories but Helwan used in the analysis of Gupta and Malin are located in higher geomagnetic latitudes than the present ones. The ratio for winter to year at Helwan given in their paper is also greater than unity similarly as those at the present three observatories. This gives us an idea that the ratio of the winter range to annual range for L is less than unity in higher latitudes and is greater than unity in lower latitudes. However, the number of observatories used is only ten in total, and the observatories for the lower latitude group are too local to conclude it. The more analyses at various latitudes are very desirable for further discussions.

5.3 Solar cycle changes of S and L

Figs. 6 S and 6 L illustrate by harmonic dials the solar cycle changes of the annual mean harmonics of D, H and Z at Kakioka for S and L, respectively. The two divisions of quiet and active are indicated in the figures by the initials q and a, respectively. The result from whole data is also included and is indicated by m.

In Fig. 6 S each amplitude of all components and all elements increases with increasing sunspot numbers. In Fig. 6 L all but three harmonics (L_4 of D, L_1 and L_2 of Z) also show the increase of amplitude from quiet to active. As regard to the phase of S, the quiet group generally leads the active group, but their difference is very small. For the phase of L, no systematic change is seen.

These statements for Kakioka are generally true for Memambetsu and Kanoya. So the figures corresponding to Fig. 6 are not shown. Moreover, the daygraphs are also not shown for all observatories. The shapes of the variation for both groups are very similar to those for Figs. 2 S and 2 L, and the ranges of quiet group are less than those of active group for all cases of S and all but two cases of L.

It is very important for the investigation of the ionospheric dynamo theory to compare the changes of S and L with the sunspot cycle. On the assumption that the increase of the solar activity brings the increase of electric conductivity in the dynamo layer, it is expected that the solar cycle influence on S and L

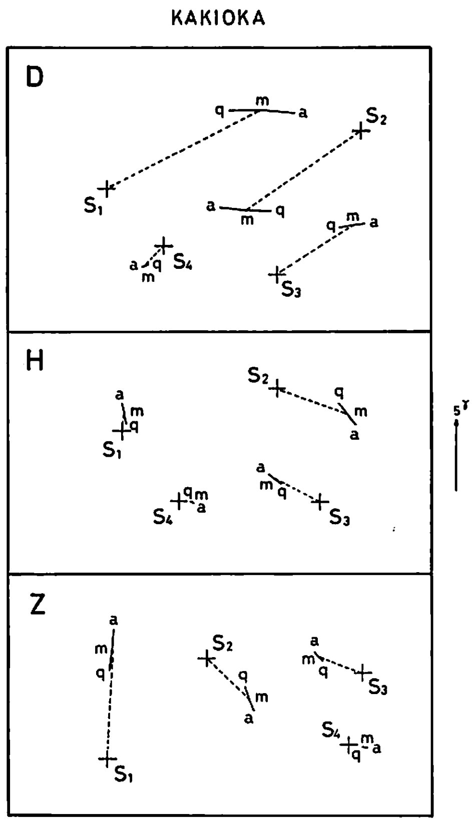


Fig. 6 S.

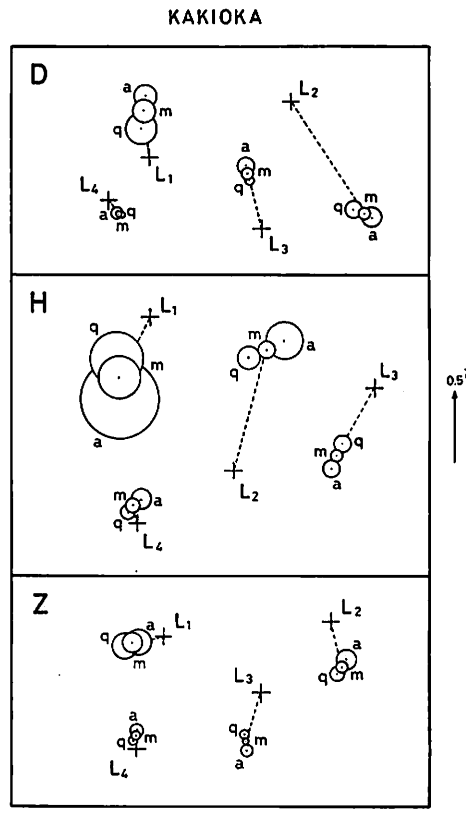


Fig. 6 L.

Fig. 6 S. Harmonic dials for the annual mean solar daily variations at Kakioka with respect to the solar activity for *D*, *H* and *Z*. The points marked q and a represent results derived from groups of solar quiet years and of solar active years, respectively. The point marked m represents result derived from whole data. The dial vector is drawn only for whole data, not for quiet or active group. They are indicated only by their end points. Numerical subscript indicates the order of the harmonic component.

Fig. 6 L. The same as Fig. 6 S, for lunar variations. The vector probable error circles are drawn at the end points of the vectors.

are similar. Therefore using numerical expression, it is examined here whether the solar cycle influences on *S* and *L* are similar or not.

The influence of the solar activity on *S* and *L* has been customarily studied by Wolf's formula, that is, the linear relationship between the sunspot number *R* and the daily range of *S* or *L*. The relationship is expressed as follows:

$$\text{range}=A+BR=A(1+m\cdot R) \qquad (7)$$

Table 9 S. The values of 10^4m for the range of S.

	D	H	Z	$D+H+Z$	$D+H$
Memambetsu	55	83	65	68	69
Kakioka	55	64	73	64	60
Kanoya	47	39	77	54	43
mean	52	62	72	55	57

Table 9 L. The values of 10^4m for the range of L.

	D	H	Z	$D+H+Z$	$D+H$
Memambetsu	53±17	51±19	−7±11	19±8	52±13
Kakioka	38±10	59±22	−1±11	26±7	42±8
Kanoya	36±8	84±34	10±16	32±7	38±8
weighted mean	39±6	59±13	−1±7	26±5	42±6
weighted mean from $r(L)$	35±7	63±18	2±11	28±6	39±7

where $m=B/A$. The ratio m is a good index of the solar cycle changes of S and L; 10^4m represents the percentage change in range associated with an increase in R from 0 to 100.

The ranges of S and L for the two sunspot divisions are obtained similarly as the case of the discussion on the seasonal changes. Applying the ranges to the equation, the values of 10^4m of S and L for all elements and observatories are given in Tables 9 S and 9 L, respectively. The values for L are those from the range $R(L)$. The difference of the values obtained from $r(L)$ and $R(L)$ is not significant. For comparison, only the mean values for $r(L)$ from all observatories are included in Table 9 L. The probable errors for S are negligibly small, but those for L are significantly large and are included in the table. The mean values from all elements or from D and H at each observatory and the grand means for the three observatories are straight means for S and weighted means for L.

In Table 9 S the values of 10^4m for S show considerable scatter for elements and for observatories also. This nonuniformity in values indicates that the distribution of S current system changes in form as well as in intensity with the change of solar activity. The large increase of m value for H with increasing latitude is explained by the solar cycle change of focus position of S equivalent current system (Shiraki, 1973). It is located at lower latitudes during solar active years than that during solar quiet years.

In Table 9 L the values of m for L show considerable scatter as well as those for S. Of the three elements, Z is very different from the others. The values for Z are much less than those for D or H and they are negative at Kakioka and Memambetsu. This may be due to the ocean effect, which is largest for Z as noted before. Therefore the mean values from D and H are more suitable for the comparison of the solar cycle changes of S and L, though the ocean effect may still remain in them.

Comparing the results in Tables 9 S and 9 L, the values of 10^4m for S are greater than those for L. But the difference is not so large. This result would appear to confirm the conclusion of Matsushita and Maeda (1965 b). But their result for L restricted to only L_2 component and the present one is obtained from the range. For strict comparison, the solar cycle dependency of each harmonic component of S and L is also examined. Using an equation similar to that for the range, the values of m are calculated for the amplitude of each harmonic component of three elements of three observatories. The mean values of 10^4m from three observatories are given in Tables 10 S and 10 L for S and L, respectively.

In these tables the mean values for S are not constant but linearly decrease with increasing harmonics. The value of S_2 component is nearly equal to that

Table 10 S. The mean values of 10^4m from Kakioka, Memambetsu and Kanoya for the amplitude of S harmonics.

Component	D	H	Z	$D+H+Z$	$D+H$
S_1	58	90	79	76	74
S_2	47	57	75	60	52
S_3	40	57	35	44	49
S_4	27	59	20	35	43

Table 10 L. The weighted mean values of 10^4m from Kakioka, Memambetsu and Kanoya for the amplitude of L harmonics.

Component	D	H	Z	$D+H+Z$	$D+H$
L_1	79 ± 61	61 ± 96	-18 ± 34	9 ± 28	74 ± 52
L_2	23 ± 10	30 ± 17	-11 ± 12	13 ± 7	25 ± 8
L_3	46 ± 18	65 ± 18	28 ± 17	45 ± 10	55 ± 12
L_4	-11 ± 24	96 ± 113	21 ± 101	-5 ± 23	-6 ± 24

of range. On the other hand, the values for L do not show such a linear change as those for S. Those of L_1 and L_3 from D and H are nearly equal to the corresponding values of S. The value of L_2 is much smaller and that of L_4 is negative.

The small value of L_2 component may be due to the oceanic dynamo effect. Since the oceanic dynamo may not vary with the sunspot cycle, the presence of constant oceanic dynamo effect could reduce the value of m. If the oceanic part of L_2 is assumed to be about one fourth of the ionospheric one, the value for L_2 could be reduced to the measured one, even if the ionospheric part of L_2 had the same value of S_2 or the median value between L_1 and L_3. Such an amount of oceanic part of L_2 may be possible. The cause of the negative value of L_4 is not known. It may be due to the relatively small amplitude of L_4 and consequently less accurate determination of values.

The measured value of m for L_2 is much smaller than that for S_2 or the range of S. Therefore, strictly speaking, the present result for the solar cycle influence on S and L is not consistent with that of Matsushita and Maeda. However, considering the oceanic dynamo part of L_2, it is possible to conclude that the solar cycle change of L is very similar to that of S. This supports the conclusion of Matsushita and Maeda.

The values of m in Table 9 S or 10 S should be compared with the sunspot cycle dependency of electrical conductivity in the dynamo layer, which may be inferred from the electron density at the E layer. The solar cycle dependency of the E layer has been well studied. According to the recent result by Maeda and Fukao (1972), electron density at the E layer increases by about 1.4 times with increasing sunspot number from 0 to 100; this means $10^4 m$ is about 40. The value of m obtained from the range or from each harmonic amplitude for n less than 3 is larger than the one obtained from electron density at the E layer.

Therefore the solar cycle change of S cannot be explained only by the change of the electrical conductivity at the E layer. Matsushita (1967) also noted such a feature and presented a probable explanation of the enhancement of the tidal wind in the dynamo layer due to the temperature increase caused by solar activity. Though it is usually considered that the origin of the ionospheric dynamo is mainly in the E layer, the dynamo action in the F layer cannot be neglected (Rishbeth, 1971; Matuura, 1974). The solar cycle dependency of the F layer is not well known as yet, but it may be possible to explain the discrepant part between the solar cycle dependency of S and that of the E layer. Since the magnetospheric phenomena also contribute to S and they are indisputably dependent on the solar activity, a part of the m value may be explained as of magnetospheric origin.

On the other hand, taking the oceanic dynamo effect on L_2 component into consideration, it was noted already that the values of m for L are nearly equal to that for S. However, from simple consideration of dynamo theory, the values of m for all harmonic components are expected to be constant and equal to the corresponding value of the dynamo layer. As regard to the L variation, the thermal tide or magnetospheric phenomena cannot be considered as the origin of such an excess in the m value. As the probable origin, the dynamo action in the F layer is a possibility like as S. Another possible origin is the modulation effect of S. The periods of the L variation in Eq. (4) can be, in another way, considered as the modulation of S by half-monthly variation. The period of the solar activity is about 27 days, but is not definite. If its second harmonic shows half-monthly variation, the L variation may be contaminated by the modulation of S by the solar activity. Therefore, this may explain at least a part of the measured value of m for L.

However, there is another possibility that the measured values in Table 10 L are practically constant and nearly equal to the value of the E layer, when probable errors are strictly taken into consideration. In this case the L variation may be explained by the ionospheric dynamo in the E layer, if the oceanic dynamo effect is excluded.

The present result of the solar cycle influence on S and L is contrary to the view of Chapman and Bartels (1940) and Chapman, Gupta and Malin (1971). Chapman, Gupta and Malin recently discussed the solar cycle influence on S and L using the results from analyses of data during the IGY/C and the preceding sunspot minimum years as well as the results from analyses of long series of data, and they confirmed the conclusion of Chapman and Bartels. They showed that the sunspot cycle influence on L, measured by the Wolf ratio, is significant, but is only about one third of the sunspot cycle influence on S. They suggested that the oceanic dynamo effect on L may be a cause of the difference in the ratio. Their results from analysis of long series of data are given in Tables 11 S and 11 L for S and L, respectively, together with the present results. For the convenience of comparison, the means from D and H for their result are calculated and are given in the tables. Moreover the overall mean of their and the present results is calculated, including the result at Toolangi obtained by Green (1972).

Table 11 S. Comparison of the values of 10^4m for S obtained from long term data by Chapman, Gupta and Malin (1971) with the present ones.

	D	H	Z	$D+H+Z$	$D+H$
Chapman et al.	56	49	56	52	53
present result	52	62	72	55	57
all mean*	55	55	59	55	54

* includes the result at Toolangi (Green, 1972).

Table 11 L. Comparison of the values of 10^4m for L obtained from long term data by Chapman, Gupta and Malin (1971) with the present ones.

	D	H	Z	$D+H+Z$	$D+H$
Chapman et al.	20 ± 5	25 ± 7	13 ± 4	18 ± 3	22 ± 4
present result	39 ± 6	59 ± 13	-1 ± 7	26 ± 5	42 ± 6
all weighted mean*	29 ± 4	31 ± 6	10 ± 4	21 ± 2	29 ± 3

* includes the result at Toolangi (Green, 1972).

The present result for S shows a fairly good agreement with theirs, but that for L is very different from their result, especially for the mean from D and H. The present value of 10^4m for L is about twice that of Chapman, Gupta and Malin.

The cause of this discrepancy for L is also probably due to the oceanic dynamo effect. In Table 11 L the effect of oceanic dynamo is not excluded from both their results and the present one. While the solar cycle dependency of the ionospheric part of L_2 is the same all over the world, the effect of oceanic dynamo is different for individual stations. Hence, the reduction of the m value due to the presence of oceanic dynamo may be different from station to station. Much greater ocean effect may be included in their result than the present one. It is very desirable for the comparison of solar cycle influence of S and L to exclude the oceanic dynamo part from the L variation.

5.4 Other discussions

In Figs. 2–6, the force scale for L is ten times larger than that for S. As the daygraphs and harmonic dials for S and L are rather similar in size, it follows that S at Kakioka, Memambetsu and Kanoya is about ten times as large as L. However the ratio of S to L shows remarkable differences with elements, seasons and observatories. Using the ranges $r(S)$ and $r(L)$ as the measures of

Table 12. The ratio of the range for S to the range for L.

	D	H	Z
annual			
Memambetsu	18.8	8.0	12.5
Kakioka	15.8	5.6	16.9
Kanoya	16.0	7.0	25.7
winter			
Memambetsu	5.7	4.9	3.4
Kakioka	6.2	2.5	6.7
Kanoya	5.3	2.9	9.8
equinox			
Memambetsu	14.7	11.3	11.4
Kakioka	13.8	11.5	14.7
Kanoya	14.3	18.7	20.2
summer			
Memambetsu	14.1	5.7	8.1
Kakioka	10.9	4.8	8.2
Kanoya	9.8	8.7	14.2

S and L, the ratio of S to L is calculated for each of all elements, all seasons, and all observatories. They are given in Table 12.

The ratio is smaller for H and larger for Z, and smaller in winter and larger at equinoxes. The maximum value is for annual Z at Kanoya ($S/L \sim 26$) and the minimum one is for H in winter at Kakioka ($S/L \sim 2.5$). The straight mean of all values is 10.8 and is not so different from the values obtained in the world up to the present.

Each ratio in the table reflects the various features of the variation of S and L at the respective observatory. The smaller ratio for H than D or Z is explained by the different focus positions of the S and L equivalent current systems. The largest ratio for Z may be due to the oceanic dynamo effect on L variation. The smallest ratio in winter and the largest ratio at equinoxes are explained by the different seasonal changes of S and L.

The smallest ratio for H in winter is very remarkable and important. On the study of S in winter, attention to the lunar variation is desirable, especially in using the records for individual days.

Table 13. Comparison of the result of L for D at Kakioka obtained by Yamaguchi (1957) with the corresponding present result. Unit is minute of arc west.

	Yamaguchi		present	
	l_2	λ_2	l_2	λ_2
annual	0.11	114°	0.107±0.005	123°
winter	0.14	199	0.149±0.007	200
equinox	0.12	99	0.109±0.010	117
summer	0.24	100	0.221±0.010	86

Yamaguchi (1957) has previously obtained L at Kakioka from a long series of data. He calculated the L variation only for D using the data for the period from 1925 to 1945 (21 years). He used the method described by Chapman and Bartels (1940) and gave the result of L_2 component only. Table 13 shows a comparison of his result and the corresponding present result. As his result was given in the unit of the minute of arc west, the present result is also given in the same unit. It is clear from the table that the present result and that of Yamaguchi is in fairly good agreement.

6. Conclusions

In this paper the solar and lunar daily geomagnetic variations at three Japanese observatories, Kakioka, Memambetsu and Kanoya, are determined using the hourly mean values of the magnetic declination, horizontal intensity and vertical intensity for the period 1958 to 1973. The method of analysis is that of Chapman and Miller, and the first four harmonic components are tabulated for the results of the annual mean variations, the seasonal mean variations and the solar cycle influence on the variations. These results for solar and lunar daily variations are compared and discussed.

Examining the latitudinal changes of the annual mean variations at three observatories, it is shown that the focus latitude of S equivalent current system is located in higher latitude than those of L equivalent current system. Moreover, the oceanic dynamo effect on the lunar daily variation is qualitatively discussed and it is pointed out that its effect is largest for the vertical intensity.

From the analysis of seasonal subdivision, it is found that the intensity of the lunar daily variation for winter is larger than that for equinoxes. This result is very different from those obtained up to the present. Its origin may be local and probably due to the oceanic dynamo effect.

As regard to the solar cycle influence on the solar and lunar daily variations, it is concluded that they are very similar if the oceanic dynamo effect for the lunar daily variation is taken into consideration. This result confirms that of Matsushita and Maeda (1965 b).

Though so many interesting results have been obtained in the present study, the distribution of observatories is too local. Further analyses for many observatories using long series of data of the same period are very desirable for definite conclusions on the present problems.

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1958–1973年の柿岡，女満別および鹿屋の地磁気太陽・太陰日変化

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われわれの三つの観測所，柿岡，女満別および鹿屋の地磁気太陽・太陰日変化の解析を行った．用いた資料は，1958–1973年の16年間の偏角，水平成分および鉛直成分の毎時平均値である．Chapman-Miller (1940) の方法で，年平均，季節平均および太陽活動の影響について解析し，その結果が示されている．これらの結果から，太陽日変化と太陰日変化を比較し，いくつかの問題点を議論した．

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