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Separation of Lunar Daily Geomagnetic Variations into Parts of Oceanic and Ionospheric Origin in the Indian Region

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Summary

Seasonal changes and variation in the equatorial region of the lunar semi-diurnal component in H and Z, separated into parts of oceanic and ionospheric origin by Malin's method, are examined for four Indian observatories, three in the equatorial electrojet region and one outside it. The results suggest that the amplitudes of both the oceanic and ionospheric parts in H and Z are in general smallest in the j-season. The ionospheric part in H shows equatorial enhancement. The ocean dynamo contribution is smaller than that of the ionospheric part. At Kodaikanal, an inland station about 130 km from the nearest coast, the magnitude of the oceanic part is still considerable.

Introduction

Malin (1970) has proposed a method for separation of the lunar daily geomagnetic variations, L, into parts of oceanic and ionospheric origin, based on certain assumptions. He considers the effect of the ocean dynamo, which operates equally well by day and by night, to be purely of internal origin, relative to the surface of the Earth, and lunar semi-diurnal in period. The contribution of the ionospheric dynamo to L is assumed to be zero at local midnight because the ionospheric conductivity is reduced to one-thirtieth of its midday value. With these assumptions, he formulated equations to compute the oceanic and ionospheric contributions and applied them to the lunar daily harmonics of the six observatories in British Isles. In this note a similar analysis has been carried out separately for d, e and j seasons and the year (for the period 1958–61) for the four observatories in India, three of which are in the equatorial electrojet region and the fourth outside the electrojet belt.

Method

L variations are considered to be lunar semi-diurnal, with amplitude, $l(t)$, and phase, $\lambda(t)$, functions of solar time.

$$L = l(t) \sin [2\tau + \lambda(t)] \tag{1}$$

which is equivalent to the Chapman's phase law

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

where l_n is the amplitude of the nth harmonic, λ_n its phase, t the mean solar time measured from local midnight and τ the mean lunar time measured from the local lower transit of mean Moon. By equating the coefficients of $\sin 2\tau$ and $\cos 2\tau$ in the two equations, the following formulae are obtained.

$$l(t) \cos \lambda(t) = \sum_n l_n \cos [(n-2)t + \lambda_n] \quad (2)$$

and

$$l(t) \sin \lambda(t) = \sum_n l_n \sin [(n-2)t + \lambda_n]. \quad (3)$$

The vector probable error, ρ, of L is $\rho = [\Sigma \rho_n^2]^{\frac{1}{2}}$.

The first four harmonics ($n = 1, 2, 3$ and 4), determined by the Chapman–Miller method (1940), are considered in the analysis. At local midnight, when $t = 0$ in equation (1), L represents the ocean dynamo variation, L_0,

$$L_0 = l_0 \sin (2\tau + \lambda_0)$$

where l_0 and λ_0 are midnight values of $l(t)$ and $\lambda(t)$. From equations (2) and (3)

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

and

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

ρ_0, the vector probable error of L_0 is

$$\left[\sum_{n=1}^{4} \rho_n^2\right]^{\frac{1}{2}}.$$

The ocean dynamo variation contributes only to the second harmonic. Therefore the ionospheric dynamo part, L_I, of L_2 is then obtained by subtracting L_0 from L_2

$$L_I = l_I \sin (2\tau + \lambda_I)$$

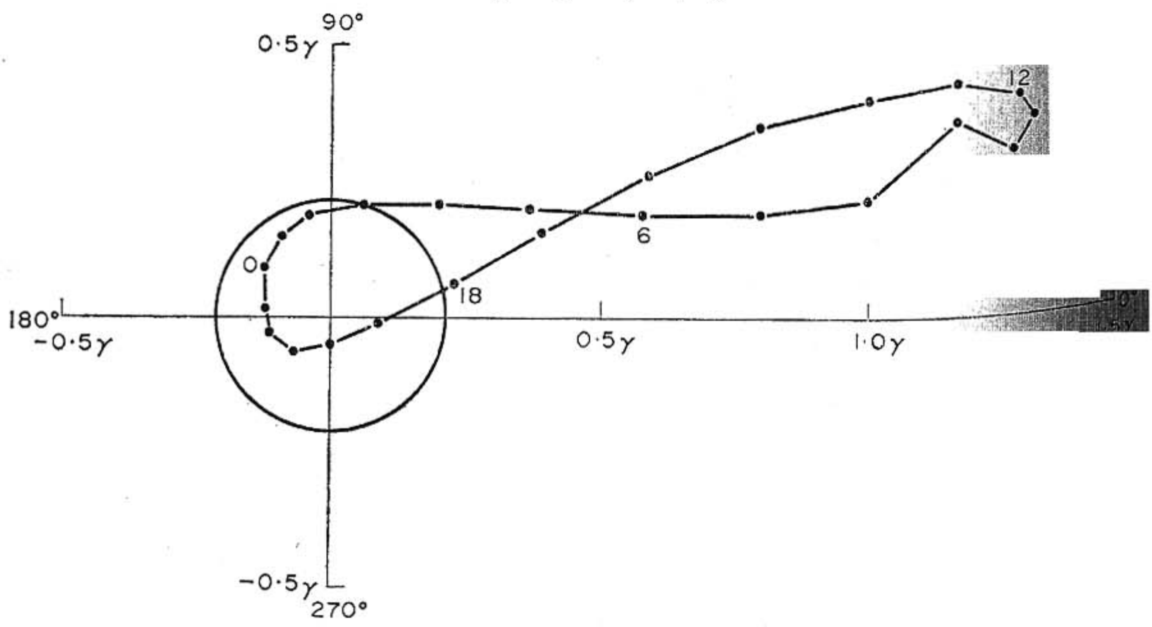

Fig. 1. Harmonic dial for the lunar semi-diurnal variation of vertical intensity at Hyderabad for the period 1966–69. The 24 dial points represent the values of $l(t)$ and $\lambda(t)$ for each hour of mean solar time.

where

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

and

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

The vector probable error, ρ_I, of L_I is given by

$$\rho_I = [\rho_1^2 + \rho_3^2 + \rho_4^2]^{\frac{1}{2}}.$$

These formulae (due to Malin) are applied to the lunar daily variations at the four Indian observatories; Alibag (dip 24·6°) and the three equatorial observatories, Annamalainagar (dip 5·4°), Kodaikanal (dip 3·3°) and Trivandrum (dip −0·7°). The analysis is done for the two elements H and Z, with the lunar harmonics computed from the hourly mean values of the elements by the Chapman–Miller method by one of us (D. R. K. Rao) for the period 1958-61.

The validity of the assumption, that the contribution of the ionospheric dynamo to L is zero at local midnight, is tested for the lunar daily variation in the vertical intensity, Z, during the period 1966–69, at Hyderabad (Geog. lat. 17·4°N), an inland observatory far from the sea coast. Using equations (2) and (3) and the observed values of l_n and λ_n, values of $l(t)$ and $\lambda(t)$ are calculated for the 24 hourly values of t and are shown in Fig. 1. The circle with the origin as centre has a radius 2·08 times the probable error, representing a 5 per cent level of significance. Though the minimum value does not occur at local midnight, the midnight value and the values on either side of it do not differ significantly from zero.

Table 1

Separation of oceanic and ionospheric parts in L_2.

Season	Alibag ·01γ	°	Annamalainagar ·01γ	°	Kodaikanal ·01γ	°	Trivandrum ·01γ	°
			H					
			oceanic part					
d	99±66	47	195±94	40	144±92	49	139±90	23
e	251±91	40	235±103	356	301±95	11	207±92	322
j	76±66	329	81±100	342	50±89	290	66±92	281
Year	113±41	41	144±48	12	142±51	17	110±52	338
			ionospheric part					
d	226±58	188	465±84	220	526±87	228	566±81	213
e	204±83	203	431±76	170	558±73	173	546±75	155
j	164±58	155	254±81	172	313±73	158	300±74	161
Year	166±37	188	333±39	192	403±42	190	418±42	181
l_2, λ_2	94±18	147	189±28	191	263±28	186	319±31	188
			Z					
			oceanic part					
d	72±38	176	293±113	148	37±27	130	203±75	92
e	99±53	191	172±73	114	126±32	95	167±63	79
j	93±40	213	40±39	51	41±32	110	87±54	186
Year	83±23	197	149±55	129	68±20	103	127±35	114
			ionospheric part					
d	164±33	78	325±105	26	115±21	77	270±66	232
e	129±47	7	247±63	309	171±28	291	149±54	230
j	155±31	10	113±36	293	106±29	294	57±47	173
Year	118±20	35	169±48	342	67±18	310	143±31	222
l_2, λ_2	46±12	67	92±27	43	31±8	19	160±17	165

Results

The oceanic and ionospheric parts in different seasons and the year for both the elements *H* and *Z* are given in Table 1, together with the lunar semi-diurnal harmonic for the year. The following features are evident.

Oceanic part

The amplitudes for the year in both *H* and *Z* are significant at all the observatories. In *H*, the amplitudes at all the observatories are the largest and most significant in the e-season and least in the j-season. In *Z*, the amplitudes at the equatorial stations are significantly large in the e-season. In addition, in the d-season, they are largest at Annamalainagar and at Trivandrum.

Ionospheric part

The amplitudes in both *H* and *Z* are significant in all the seasons and for the year at all the observatories, except for *Z* at Trivandrum in the j-season. In *H*, the ionospheric part is in phase with the semi-diurnal harmonic at all the three equatorial observatories and the phase angles are close to 180°. Malin's (1970) computations for the British stations show that the phase angles are close to zero for all the elements. The amplitudes show equatorial enhancement, indicating the electrojet effect on the ionospheric part of the lunar variations. At the equatorial observatories the amplitudes in both *H* and *Z* are the least in the j-season.

Though Kodaikanal is an inland station, the oceanic effect for *H* and *Z* is still large. For *Z*, both effects are of equal amplitude, similar to that found for Eskdalemuir (Malin 1970). The amplitudes of the oceanic part are generally smaller than those of the ionospheric part, and the seasonal variation in the amplitudes, especially smaller values for the j-season at equatorial observatories, correspond to similar variation in the ionospheric effect. Thus, the induced ionospheric dynamo part (contribution 2 of Table 1, Malin 1970) predominates over the direct ocean dynamo effect in the low latitudes and in the equatorial region. Apparently the ocean dynamo effect is weak because of the very small vertical component of the geomagnetic field in the equatorial region.

Conclusion

In the Indian equatorial region, separation of the oceanic and ionospheric effects in the lunar semi-diurnal harmonic indicates an equatorial enhancement of the ionospheric part, which is the dominant part of the variation.

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