The O_1 Component of the Geomagnetic Lunar Daily Variation in the Indian Equatorial Region

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(Received January 9, 1974; Revised March 26, 1974)

The O_1 component of the geomagnetic lunar daily variation is examined at 4 Indian equatorial stations for the active sun years from 1958 to 1961 following the Chapman-Miller method generalized by Winch. Clear geomagnetic O_1 tides are found at every station and are favourably considered as due to an ionospheric current like the equatorial electrojet.

1. Introduction

The lunar gravitational tide has declinational components because the equatorial plane of the Earth and the plane of the moon's orbit do not coincide. The O_1 tide is the largest of the declinational components, which vary during the course of a lunar month. Its phase angle increases by 13.9431 degrees per mean solar hour. The geomagnetic lunar daily variation which is considered to be driven by the combined effects of the lunar O_1 tide and the ionospheric electric conductivity is denoted by $L(O_1)$ and is expressed as follows (WINCH, 1970 a and b) if the first two harmonics of the time variation in the conductivity are taken into account:

$$L(O_1) = \sum_{n=-1}^3 l_n \sin(nt - 2\nu - h + \lambda_n),$$

where l_n is the amplitude of the n th harmonic, t is the mean solar time increasing by 2π per solar day, ν is the difference in the rates of increase of solar time (t) and lunar time (τ) increasing by 2π in a mean synodic month of 29.5306 mean solar days, h is the mean longitude of the Sun and λ_n is the phase angle.

Additional terms arise from higher harmonics in the ionospheric electrical conductivity. For the numerical analysis of data the range of summation is taken to be from $n = -4$ to $n = 4$. Summands $n = 1, 2, 3, 4$ are referred to as phase law tides and the summand $n = 0$ as the long period tide. The summands $n = -1, -2, -3, -4$ are denoted as partial tides.

WINCH (1970 a) has generalized the CHAPMAN-MILLER (1940) method, permitting the determination of partial tides and the long period tide in addition to the phase law tides. He determines the O_1 component of the lunar geomagnetic tides at Toolangi by this method and finds that $L(O_1)$ partial tides are

more pronounced in the D component than in the H or Z component (WINCH, 1970 b), a result similar to his earlier ones for $L(M_2)$ partial tides (WINCH, 1970 a).

TARPLEY (1971) has analyzed geomagnetic data from 12 stations for the O_1 component by the Chapman-Miller method. He finds well determined O_1 tides in the Z component at several stations but detects in most cases little or no solar modulation, thus ruling out an ionospheric source for the $O_1(Z)$. He considers that its most probable cause is electric currents induced in the oceans by O_1 tidal currents.

In this paper the Chapman-Miller method generalized by WINCH (1970 a and b) is applied to geomagnetic data from 4 Indian equatorial stations to detect the O_1 component of the geomagnetic lunar tides.

2. Data Analysis

The hourly mean values of the geomagnetic elements, D , H and Z at 4 stations (whose locations are shown in Table 1) are analyzed for the active sun years from 1958 to 1961. The days on which three consecutive hourly values were missing have been excluded. Blanks due to loss of data are filled in by linear interpolation.

Although the analysis has been carried out separately for each of the three seasons (northern summer, equinoxes and northern winter) as well as for the whole year, only the yearly averaged values of the $L(O_1)$ are presented here for discussion to avoid as much as possible the seasonal effect originating from the lunar semi-diurnal tide (M_2) (WINCH, 1970 b).

The amplitudes are corrected for the use of hourly mean values (to compensate for the effect of summing days of slightly different lunar phase in each group), but this correction is slight and about 0.3, 1, 3 and 5% for the first, second, third and fourth harmonics, respectively, of both the phase law and partial tides.

Table 1. Latitude and dip of the 4 Indian Equatorial Observatories.

Station	Latitude		Dip
	Geographic	Geomagnetic	
Alibag	18°38'N	9°.5N	24°36'N
Annamalainagar	11°22'N	1°.4N	5°23'N
Kodaikanal	10°14'N	0°.6N	3°22'N
Trivandrum	8°29'N	1°.2S	0°41'S

3. Results and Discussion

The yearly averaged amplitudes and phase angles of the long period tide

and the first four harmonics of the phase law tide as well as the partial tide are given in Table 2 for all the stations for the three elements D , H and Z . The probable errors (p.e.) for each of the harmonics are also given. The amplitudes are considered significant at 5% level if they are 2.08 times the corresponding probable errors. Phase angles are given at epoch local midnight when $t=0$ and also when O_1 characteristic $2s-h=0$, where s is the mean longitude of the Moon (WINCH, 1970 b).

The noteworthy points in Table 2 are as follows. As regards the D component, the amplitudes of the four harmonics of the phase law tide at the 4 stations are all significant with the exception of one and they are of about the same magnitude for the respective harmonics, the second harmonic being the most prominent; the partial tides are significant at all the stations only for the third harmonic. As regards the H component, the third harmonic of the phase law tide has a large and significant amplitude and a phase angle close to 0° at the equatorial stations (Annamalainagar, Kodaikanal and Trivandrum) whereas it has an insignificant amplitude and a phase angle of about 180° at Alibag. For both the phase law and partial tides, the amplitudes for the H component are generally small or insignificant at Alibag (the station outside the equatorial electrojet) while those for the Z component are generally small or insignificant at Trivandrum (just under the electrojet). These facts indicate that the geomagnetic $L(O_1)$ in the equatorial region is ascribable in quality to an ionospheric current like the equatorial electrojet.

Phase law tides and partial tides are graphically represented in Figs. 1, 2 and 3 for D , H and Z respectively, against local time (t) as abscissa and characteristic $2s-h$ at $t=0$ as ordinate (WINCH, 1970 b).

The D component contours are almost equal and similar at all the 4 stations especially for the phase law tide. The H component contours show stronger tides at the stations near the dip equator (Kodaikanal and Trivandrum) whereas the Z component contours show the strongest tides at Annamalainagar at which the Z component from the equatorial electrojet, with the width of a few degrees, is expected to be the largest. It is also evident in Fig. 2 that the H component contours are far dense during daytime hours (from 6h to 18h). The above features also suggest the existence of an electrojet-like current overhead near the dip equator.

WINCH (1970 b) suggests that partial tides may play a greater part in $L(O_1)$ than they do in $L(M_2)$ because a partial tide term, $n=-1$, has arisen in the expression for $L(O_1)$ mentioned at the beginning of this paper. He finds that, in the D component at Toolangi, $L(O_1)$ partial tides are greater than those of $L(M_2)$. Comparison of the results of the present analysis with the corresponding results of $L(M_2)$, for the same period, from an earlier analysis (RAO and SASTRI, 1972), however, does not seem to bear this out.

TARPLEY (1971) states that stringent criteria should be used in judging

Table 2. O_1 Component in the Indian equatorial region, 1958-61 (Amplitude and probable error in gammas and phase in degrees).

Station	Har- monic n	D				H				Z			
		Phase law		Partial		Phase law		Partial		Phase law		Partial	
		Ampl.	Phase	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase
Alibag	0	0.35	181	0.19	27	0.21	1.93	0.53	266	0.76	1.91	221	1.40
	1	0.35	196	0.19	27	0.14	0.23	0.41	266	0.41	0.51	278	0.18
	2	0.61	351	0.29	242	0.11	0.36	0.19	48	0.19	0.34	55	0.11
	3	0.25	178	0.23	76	0.08	0.09	0.13	278	0.13	0.38	200	0.09
Annamalainagar	4	0.15	260	0.07	313	0.04	0.14	0.07	110	0.07	0.22	334	0.04
	0	0.82	110	0.15	324	0.51	1.12	0.86	2.37	0.86	2.37	155	3.81
	1	0.41	177	0.15	324	0.12	0.43	0.41	1.46	0.41	1.46	100	0.39
	2	0.65	6	0.17	217	0.10	0.36	0.23	212	0.23	1.20	358	0.23
Kodaikanal	3	0.37	196	0.17	65	0.06	0.65	0.16	329	0.20	0.30	221	0.17
	4	0.14	319	0.15	253	0.05	0.33	0.17	83	0.12	0.32	250	0.13
	0	0.57	127	0.17	8	0.38	2.24	0.94	0.76	0.94	0.76	314	0.25
	1	0.56	196	0.17	8	0.16	0.95	0.43	0.32	0.43	0.32	184	0.13
Trivandrum	2	0.72	9	0.19	257	0.12	0.78	0.25	183	0.23	0.43	3	0.10
	3	0.39	188	0.19	78	0.08	0.90	0.26	334	0.23	0.37	172	0.07
	4	0.15	303	0.10	266	0.06	0.46	0.14	110	0.11	0.10	305	0.06
	0	0.68	355	0.08	307	0.61	1.87	0.88	0.54	0.88	0.54	296	0.89
Trivandrum	1	0.36	185	0.08	307	0.12	0.62	0.52	324	0.38	0.57	326	0.29
	2	0.52	8	0.22	241	0.10	0.72	0.65	167	0.21	0.34	138	0.20
	3	0.29	188	0.15	60	0.05	0.94	0.30	338	0.20	0.24	320	0.14
	4	0.09	305	0.04	148	0.05	0.46	0.15	102	0.10	0.17	176	0.08

Fig. 1. O_1 Component of geomagnetic lunar tides in declination (Westerly) in the Indian Equatorial Region during the period 1958-61. Extrema are shown in units of gamma.

whether or not the deduced magnetic variation is a genuine O_1 tide because of the possibility of M_2 seasonal variation contaminating the O_1 analysis. The criterion applied is that $l_1 \geq 1.5l_2$ for a well determined O_1 tide in addition to the

Fig. 3. O_1 Component of geomagnetic lunar tides in vertical intensity in the Indian Equatorial Region during the period 1958-61. Extrema are shown in units of gamma.

The horizontal part of the geomagnetic $L(O_1)$ is shown for two stations, Alibag and Trivandrum, in Fig. 4. Other two stations, Annamalainagar and Kodaikanal, also show similar vector changes characterized by clockwise rota-

Fig. 4. The O_1 variation vector in the horizontal magnetic field (at Alibag and Trivandrum) when $2s-h=0$. The scale is in gammas. The numbers along the curve give local time.

tion. This clearly shows that clockwise vector rotation is a feature not only at geographic latitudes higher than about 20°N as pointed out by TARPLEY (1971) but also in the equatorial region. However, after 18 hours a change to an anti-clockwise direction is seen at the equatorial stations and the same tendency may be traced even at Alibag.

Lastly it is worthy of notice that we do not find any noteworthy prominence of the first harmonic over others in the Z component of the geomagnetic $L(O_1)$ obtained at the 4 Indian equatorial stations (of which three are coastal stations). This is unfavourable for ascribing the Z component of the $L(O_1)$ to the electric current induced in the ocean as TARPLEY (1971) suggested. SASTRI and RAO (1971) found that, in this region, the ocean dynamo contribution was smaller than the ionospheric part even in the M_2 geomagnetic lunar component.

In summary, it is tentatively concluded that the geomagnetic $L(O_1)$ is clearly observed in the Indian equatorial region, whose various features are favourably explained by an ionospheric current like the equatorial electrojet.

The authors gratefully thank Prof. B.N. Bhargava, Director, Indian Institute of Geomagnetism, for going through the paper and for his valuable suggestions.

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