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Lunar and solar atmospheric tides in surface winds and rainfall

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ABSTRACT. Lunar and solar atmospheric tides in surface winds and rainfall data at 4 stations have been determined following Chapman-Miller method as detailed by Malin and Chapman. Using the similar results obtained by Rao and Reddy (1972) for other stations a synthesis of the lunar and solar tides in surface winds and rainfall data for Indian stations have been made.

1. Introduction

Rao and Reddy (1972) have studied earlier the lunar and solar tides in rainfall data and surface winds. In the present paper the study has been extended to the analysis of rainfall and surface winds at four more stations, to cover all climatic regions in India. Details of the method of analysis have already been explained in earlier papers and rainfall data pertaining to stations under the southwest monsoon (June to September) only, were used. In the present paper, the study has been made to the post monsoon season (October to January).

The conclusions arrived at earlier for Poona are tried in this paper to establish in the light of these four stations (Table 1) and work of Brier (1965). Corrections for thermal and frictional effects for the $S_2(p)$ amplitudes (1.16 mb) and phase angle (158°), of the observed pressure oscillation are made from the results of Harris *et al.* (1966). The corrected values agree with those estimated by Seibert (1961).

The equation of motion on a rotating earth (neglecting the friction) are given as :

$$\frac{u}{\partial t} - 2\,\omega v \cos\theta = -\,\frac{1}{\rho}\,\frac{\partial p}{\partial\theta}$$

$$\frac{\partial v}{\partial t} + 2\,\omega v \cos\theta = \frac{1}{\rho}\,\frac{\partial p}{a \sin\theta\,\partial\phi}$$

where a is the radius of the earth, and ω its angular velocity.

If we consider only the main term in $S_2(p)$, namely,

$$P_s \sin^3\theta \sin\left(4\,\pi\,\frac{t_u}{T_s} + 2\phi + \sigma\right),$$

$$P_s \approx 0.35 \text{ mb}, \sigma \approx 180°.$$

Here t_u is taken to be expressed in seconds.

Thus, in connection with S_2

$$\frac{\partial}{\partial t} = \frac{2\pi}{T_s}\,\frac{\partial}{\partial\phi}$$

It is readily verified that the solution of the equation for $S_2(V)$ is :

$$S_2(u) = 2.5\, C_s \cos\theta.\, \sin(2t + \sigma + 90°)$$

$$S_2(v) = C_s\,(1 + 1.5\cos^2\theta).\, \sin(2t + \sigma + 180°)$$

where,

$$C_s = \frac{P_s}{\rho a \omega} \quad \text{in which}$$

$$P_s \approx 0.35 \times 10^3 \text{ gm. cm. sec}^{-2},$$

$$\rho = 1.29 \times 10^{-3} \text{ gm/cm}^3,$$

$$a = 6371 \times 10^5 \text{ cm, and}$$

$$\omega = 7.292 \times 10^{-5} \text{ radians/sec.}$$

(For details, *see* Lindzen and Chapman 1969 Chapman and Bartels 1940). Therefore, the final equations for S_2 $(-u)$ and S_2 (v) are written as :

$$S_2(-u) = 2.5\, C_s \cos\theta \sin(2t + 270°) \qquad (1)$$

$$S_2(v) = C_s\,(1+1.5\cos^2\theta).\, \sin(2t + 360°) \qquad (2)$$

where, $C_s \approx 6.0$ cm/sec, θ is the latitude of the place and t is the mean solar time. These equations are tested against the results of the solar semi-diurnal oscillations of the surface winds.

2. Discussion

2.1. *Solar and lunar oscillations in rainfall data*

It is seen from Table 2 that the phase angles of L_2 are decreasing with increase of latitude with the mean phase being 150°. East coast stations are showing higher amplitudes in post monsoon months and those over west coast stations in southwest monsoon months These amplitudes do not show any systematic

TABLE 1

List of stations

Rainfall data Station	Location		Period	Surface wind data Station	Location		Period
	Lat. (°N)	Long.(°E)			Lat. (°N)	Long. (°E)	
Bangalore	12°58′	77°35′	1949-60	Hyderabad	17°27′	78°28′	1951-58
Madras	13 00	80 11	1949-60	Bombay	18 54	72 49	1951-58
Bombay	18 54	72 49	1949-60	Nagpur	21 06	79 03	1951-58
Nagpur	21 06	79 03	1949-60	New Delhi	28 35	77 12	1951-58

TABLE 2

Lunar and solar semi-diurnal tide in rainfall data

Station	Southwest monsoon season			Post monsoon season		
	Amplitude (0·01 cm)	P.E. (0·01 cm)	Phase (degrees)	Amplitude (0·01 cm)	P.E. (0·01 cm)	Phase (degrees)
	Lunar semi-diurnal oscillation L_2					
Bangalore	067	43	210	201	33	160
Madras	101	40	190	221	20	190
Bombay	197	31	160	102	25	130
Nagpur	179	43	140	080	33	160
Poona*	162	41	150	050	32	170
	Solar semi-diurnal oscillation S_2					
Bangalore	077	47	210	085	31	140
Madras	122	45	230	092	22	120
Bombay	167	33	270	053	32	210
Nagpur	171	49	300	052	31	220
Poona*	139	36	240	050	31	190

*Rao and Reddy (1972)

variation with latitude or season; but they appear to be dependent on general circulation pattern of the region. Brier (1965) and Viswanathan (1966) suggested a possible mode of interaction of the tidal forces on atmospheric process to explain how the tidal forces which are small may induce detectable effects on atmospheric circulation. It is also seen from the recent studies on rainfall in India, that the general circulation pattern which helps the monsoon pattern over India modified due to localised factors like deforestation, orographic changes etc. And also the effects of sunspot cycle observed in rainfall data at many stations are not showing any regular variation with latitude or station to station.

Unlike in any other geophysical phenomenon, L_2 in rainfall is greater than S_2. This is explained in the following way Rainfall originate, in the neutral atmosphere and the solar effects are negligible in comparison with the gravitational attraction by the moon, similar to ocean tides, *i. e.*, the tidal motion due to the lunar gravitation field is greater than that due to sun. The difference of $L_2 - S_2$ is larger in case of post monsoon months than in case of southwest monsoon months.

It is also seen from Table 2 that in S_2, no regular variation in phase angles and the amplitudes with the latitude are observed. The mean phase angle in the case of southwest monsoon months is of the order of 250° and for the

TABLE 3

Variation of lunar tidal amplitude with phases of the moon

Phase of the moon	Season*	Amplitude (0·01 cm)				
		Madras	Bangalore	Poona	Bombay	Nagpur
0	I	100	020	040	080	121
	II	203	131	051	122	020
1	I	060	060	036	069	010
	II	031	111	052	111	032
2	I	333	721	448	776	1141
	II	921	323	321	321	641
3	I	321	411	1053	1543	671
	II	1311	913	743	1112	831
4	I	873	115	080	671	341
	II	521	513	321	415	211
5	I	071	210	010	047	210
	II	011	031	020	100	010
6	I	020	005	010	121	040
	II	031	060	030	011	060
7	I	011	010	050	116	021
	II	070	030	015	031	011
8	I	071	030	020	241	031
	II	121	311	081	101	033
9	I	111	421	040	182	081
	II	233	201	095	073	211
10	I	322	071	130	1021	621
	II	731	561	331	515	321
11	I	030	070	030	091	101
	II	143	113	118	179	081

*NOTE: I—Southwest monsoon season
II—Post monsoon season

posc monsoon months, it is about 175°; but in case of L_2 this wide difference is not seen and where they are of the order of 170° and 160° respectively. Similarly, the amplitudes in post monsoon season are very low compared to southwest monsoon season and where their respective mean amplitudes are 0.66 and 1.35 cm, but in the case of L_2 they are 1.31 and 1.47 respectively, which show a considerable seasonal variation both in amplitude and phase angles in the case of solar semi-diurnal oscillation, but in lunar semi-diurnal variation it is very small.

Even though the S_1 amplitudes are larger than S_2, they are not statistically significant (not shown in Table 2).

Table 3 shows the amplitude variation with phases of the moon. At all the stations, the lunar semi-monthly wave is observed but *the phase* where the maximum amplitude s seen are varying with station to station and this variation is not showing dependence either on latitude or on season. The primary maximum amplitudes are observed generally in 2-4 phases of the moon and the secondary maximum near 9-10 phases of the moon.

2.2. *Solar and lunar oscillations in surface winds*

It is seen from Table 4(a) that the amplitudes of L_2 in $-u$ and v components respectively lie in the ranges 0.4 to 1.1 cm/sec and 1.0 to 1.5 cm/sec. The difference in amplitudes of $-u$ and v, are larger for coastal stations than for inland stations. The amplitudes of both $-u$ and v are found generally increasing with increasing latitude. Phase constant for v is greater than for $-u$ with a mean value of $70° \pm 23°$. The amplitudes in J-season are greater than those in D-season at all the ten stations both for $-u$ and v components.

It is seen from Table 4(b) that the amplitudes of S_2 in $-u$ and v components respectively lie in the ranges 3.71 to 5.25 cm/sec and 5.26 to 7.21 cm/sec. Here also, as that in case of L_2, the differences in amplitudes between $-u$ and v components are larger near coastal stations than over inland stations. It may be attributed to the sea breeze at coastal station. The observed amplitudes agree with value estimated from equations (1) and (2). But the phase angles are differing by 90°, *i. e.*, according to equations (1) and (2) the phase angles for $-u$ and v components are respectively 270°and 360° but the mean observed results are 360 and 050°. Even after taking into account the frictional and other effects as suggested by Harris, the discrepancy persist. We are, therefore, led to beleive that in addition to the frictional and other effects considered by Harris and others there is some other physical phenomenon coming to play.

Table 5 shows the S_2/L_2 both for $-u$ and v components and (λ-u-λv) both for S_2 and L_2 at the ten stations (including the stations in earlier paper). From this table it is seen that the ratio (L_2/S_2) is increasing with latitude and is more for $-u$ than v, which is obviously seen from equations (1) and (2.) It is also seen that the ratio is more for coastal stations than for inland stations. Except at Calcutta for S_2, the phase angles of v component are higher than those of $-u$ component both for S_2 and L_2 which is in accordance with theory.

3. Conclusions

Rainfall data—The first harmonic of solar tide is not significant, only the second harmonic of solar and lunar tides are significant;

TABLE 4

(a) Lunar semi-diurnal (L_2) tidal variations in surface winds — (b) Solar semi-diurnal (S_2) tidal oscillations in surface winds

Season	(a) Southward component ($-u$) Amplitude (0·01 cm/sec)	P.E. (0·01 cm/sec)	Phase (Deg.)	(a) Eastward component (v) Amplitude (0·01 cm/sec)	P.E. (0·01 cm/sec)	Phase (Deg.)	(b) Southward component ($-u$) Amplitude (0·01 cm/sec)	Phase (Deg.)	(b) Eastward component (v) Amplitude (0·01 cm/sec)	Phase (Deg.)
HYDERABAD										
D	071	20	170	111	25	300	362	300	572	280
E	040	19	220	102	33	270	355	270	523	320
J	102	31	270	147	34	310	322	300	440	040
Y	089	26	230	127	31	320	371	300	526	020
BOMBAY										
D	057	18	250	101	31	320	402	270	621	120
E	059	27	240	127	25	330	346	300	574	360
J	092	22	280	136	30	310	422	330	321	360
Y	073	21	280	125	29	320	372	320	526	040
NAGPUR										
D	065	31	140	098	32	300	372	240	592	310
E	041	33	270	101	31	010	422	240	763	320
J	081	31	260	129	34	350	544	260	787	350
Y	078	31	270	118	33	340	488	260	696	340
NEW DELHI										
D	082	27	260	121	33	010	421	320	622	260
E	045	24	300	139	27	300	447	300	733	280
J	109	33	270	142	35	320	591	300	843	060
Y	094	26	280	133	30	340	525	320	721	040

TABLE 5

The variation of S/L_2 and (λ-u—λ-v) over ten Indian stations

Station	S_2/L_2		(λ-u—λ v) in deg.	
	$-u$	v	S_2	L_2
Bangalore	5·5	4·6	—60	—50
Madras	5·0	4·5	—20	—40
Hyderabad	4·2	4·1	—80	—90
Poona	4·6	4·7	—50	—60
Bombay	5·1	5·6	—80	—40
Nagpur	6·3	5·9	—80	—70
Calcutta	6·2	5·5	+20	—50
Jodhpur	5·8	6·2	—50	—90
Jaipur	6·9	4·5	—20	—110
New Delhi	5·6	5·4	—80	—60

unlike in any other geophysical phenomenon, L_2 here obtained is greater than S_2. The amplitude of L_2 does not vary with latitude but the phase angles are generally decreasing, with latitude. It is possible that the lunar tidal winds super-imposed on the prevailing winds modify the general circulation pattern of which the Indian southwest monsoon is a part. This modification may be in some way manifesting in the form of lunar semi-diurinal variation in the rainfall as first suggested by Brier (1965). Maximum amplitude is observed near 2—4 phases of the moon.

Surface winds—The amplitudes in the eastward component (v) are greater than those in the southward component ($-u$) both for S_2 and L_2. These show an increase with latitude. The differences between the amplitudes of $-u$ and v are greater over a coastal station than over an inland station. The amplitudes in J-season are larger than those in D-season but generally the E-season values are the minimum. The amplitudes are in agreement with the theoretically expected values both for S_2 and L_2 but not phase angles. The estimated phase angles are out of phase by 90° with theoretical values both for S_2 and L_2. An examination of the present results in the light of suggestions of Harris and others (1966) suggests that there may be some other physical forces which may be responsible for the lag between the computed and theoretical phase angles.

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