Communications

Long Period Waves in the Upper Troposphere & Lower Stratosphere over the Indian Region*

K. S. RAJA RAO, V. THAPLIYAL & S. R. PATIL

India Meteorological Office, Poona 5

Received 30 *April* 1975; *revised received* 1 *September* 1975

Long period waves in the upper troposphere and lower stratosphere in the Indian region have been identified using monthly mean data on the zonal and meridional winds and temperature over seven stations in the latitude range of 8-28°N. Four members of the wave family, viz. 2 month, 6 month, 12 month and 20-40 month periodicities, have been identified. The 2 month wave is masked by the more dominant Kelvin wave. The 6 month wave is confined to the equatorial stratosphere. The tilt of the line of maximum amplitude suggests transport of energy from the upper troposphere to lower stratosphere. The amplitude of the annual wave is a maximum below the tropopause. The prominent maximum near 200 mb, between 20 and 25°N is associated with the subtropical westerly jet. The quasi-biennial oscillation (QBO) present in the zonal wind and temperature is confined to 30-month period. From the downward tilt from the equator to the sub-tropics in the line of maximum amplitude, it is inferred that the QBO originates in the equatorial stratosphere and travels to the upper troposphere over the sub-tropical latitudes.

YANAI and Maruyama[1] found in their analysis of winds in the lower stratosphere over the Pacific, planetary scale waves of about 4 day period, and horizontal wave lengths of 10,000 km. Wallace and Kousky[2], had presented observational evidence of eastward propagating waves with periods of about 15 days and wavelengths of 20,000 km or longer, in the same region. The distinguishing characteristic of the latter type is the marked absence of fluctuations in the meridional wind component and, therefore, they gave it the name "Kelvin Wave". But the Yanai-Maruyama waves have strong meridional wind near the equator. It has been pointed out by many authors that wave disturbances in the stratosphere must be responsible for the large zonal accelerations associated with the quasi-biennial oscillation.

In the present study significant waves with long periods present in the upper troposphere and lower stratosphere in the Indian region, for the stations between latitudes 8°N and 28°N (listed in Table 1), have been identified by power spectral analysis of the monthly mean values of zonal and meridional winds and temperatures in the height ranges of 300-50 mb, using the radiosonde data.

The data used in the present analysis are based on the observations of winds and temperatures for the stations listed in Table 1 during the ten year period 1964-73.

The study covers a latitudinal extent of 20°, from 8°N to 28°N, representing the equatorial and sub-tropical conditions. The monthly mean values of the three elements have been subjected to power spectral analysis. Following Blackman and Tukey[3], the raw

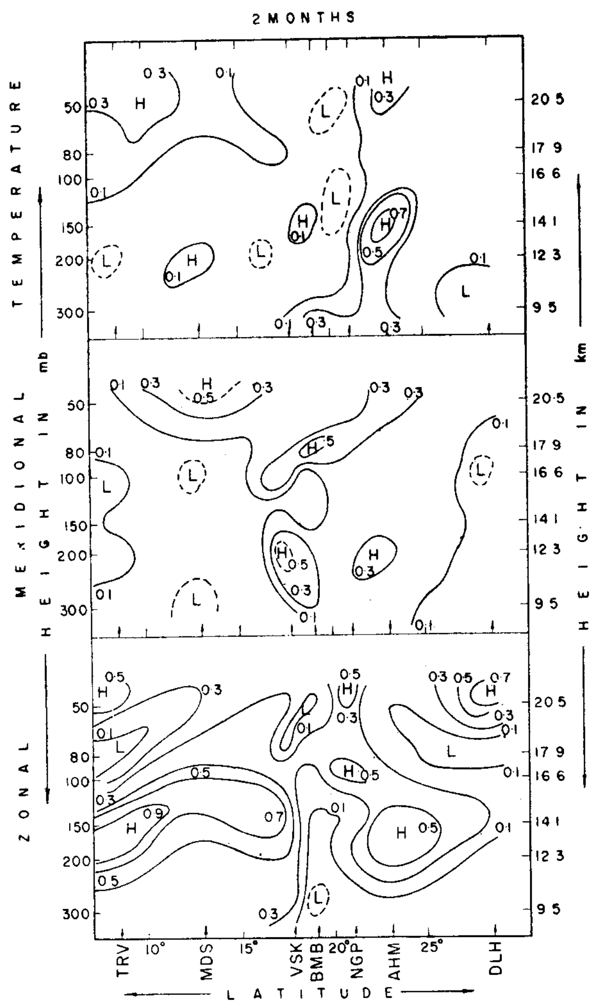

Fig. 1 – Height-latitude distribution of amplitude of long period waves (2 months) (H and L indicate high and low values of amplitude)

* Paper presented at the Symposium on Earth's Near Space Environment, 18-21 February 1975, held at the National Physical Laboratory, New Delhi 110 012.

Table 1—List of Stations Used for the Power Spectral Analysis and Their Geographical Bearings

Station	Latitute	Longitude	Abbreviation used in the figures
Trivandrum	8°29′N	76°57′E	TRV
Madras	13°0′N	80°11′E	MDS
Visakha-patnam	17°43′N	83°14′E	VSK
Bombay	19°7′N	72°51′E	BMB
Nagpur	21°6′N	79°3 ′E	NGP
Ahmedabad	23°4′N	72°38′E	AHM
Delhi	28°35′N	77°12′E	DLH

spectral estimates have been obtained and the final spectral estimates have then been computed from them, by using the 'Hamming' smoothening method. From these final spectral estimates some of the significant oscillations, viz. 2 month, 6 month, 12 month and 20-40 month periods, have been identified. By harmonic analysis, the amplitudes and phases of the oscillations with these periodicities have been determined. Tables 2-4 give the power in each of the four spectral lines over the seven stations.

Figs. 1-3 represent the amplitude of the oscillations in zonal and meridional winds, and in temperatures, as functions of height and latitude.

Table 2 —Power Spectra of Monthly Mean Zonal Winds in (m/sec)^2 Over Seven Indian Stations

Period in months	Levels in mb	TRV (8°29′)	MDS (13°0′)	VSK (17°43′)	BMB (19°7′)	NGP (21°6′)	AHM (23°4′)	DLH (28°35′)
2	300	0·3	0·3	0·2	0·0	0·1	0·1	0·0
	200	1·0	0·2	0·4	0.0	0·0	0·5	0·0
	150	0·8	0·4	0·5	0·0	0·0	0·4	0·1
	100	0·0	0·4	0·3	0·1	0·4	0·1	0·0
	80	0·0	0·2	0·1	0·1	0·2	0·0	0·0
	50	0·5	0·1	0·1	0·0	0·3	0·0	0·6
6	300	1·7	1·4	0.0	0·6	1·2	6·8	16·8
	200	10·2	13·7	6·3	18·5	15·2	20·3	28·1
	150	17·6	18·5	12·3	37·2	23·0	28·1	21·2
	100	8·4	15·2	23·0	19·4	16·8	33·6	13·0
	80	4·8	3·2	10·2	11·6	8·4	6·2	7·3
	50	7·8	9·0	0·6	2·9	4·0	0·5	11·6
12	300	23·0	72·3	240·3	316·8	353·4	432·6	380·3
	200	156·3	265·7	470·9	505·2	552·3	729·0	635·0
	150	265·7	424·4	552·3	723·6	620·0	718·2	538·2
	100	156·3	302·8	436·8	510·8	449·4	519·8	346·0
	80	81·0	136·9	259·2	331·2	275·6	361·0	265·7
	50	39·7	86·5	132·3	146·4	125·4	265·7	207·4
20	300	0·1	0·1	0·1	0·3	0·4	0·8	1·4
	200	1·4	0·0	0·1	1·4	0·6	1·4	0·8
	150	0·6	0·4	0·3	1·7	0·0	1·0	1·7
	100	1·2	0·1	2·3	0·0	1·2	0·5	1·2
	80	1·7	0·1	0·2	0·5	0·0	0·4	2·9
	50	17·6	9·0	1·2	0·1	4·4	0·2	1·0
30	300	0·1	0·1	0·6	1·0	1·2	1·2	1·2
	200	0·5	0·0	0·2	0·8	0·5	5·8	1·2
	150	2·9	0·8	0·1	1·7	2·0	4·8	1·7
	100	4·0	2·9	2·0	2·9	1·2	1·7	0·8
	80	9·0	10·9	1·2	2·3	2·9	3·6	0·3
	50	50·4	22·1	2·9	3·6	0·1	0·8	4·4
40	300	1·0	1·0	0·6	2·9	0·4	0·4	0·6
	200	1·4	1·7	5·8	5·3	2·3	0·3	1·4
	150	1·2	3·6	6·8	3·6	2·0	4·0	1·7
	100	5·8	3·6	2·0	1·7	2·3	2·3	0·6
	80	0·2	1·4	0·6	0·5	0·8	4·8	0·8
	50	24·0	1·2	2·9	0·6	0·0	0·4	2·0

Table 3—Power Spectra of Monthly Meridional Winds in (m/sec)^2 over Seven Indian Stations

Period in months	Levels in mb	TRV (8°29′)	MDS (13°0′)	VSK (17°43′)	BMB (19°7′)	NGP (21°6′)	AHM (23°4′)	DLH (28°35′)
2	300	0·0	0·0	0·0	0·1	0·1	0·0	0·0
	200	0·0	0·0	0·3	0·1	0·1	0·1	0·0
	150	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	100	0·0	0·0	0·2	0·0	0·0	0·5	0·0
	80	0·0	0·0	0·1	0·3	0·1	0·0	0·0
	50	0·0	0·3	0·0	0·0	0·0	0·3	0·0
6	300	0·1	0·0	0·3	1·2	0·2	0·6	0·5
	200	0·8	2·0	5·3	7·3	3·6	4·0	0·6
	150	2·9	3·2	4·4	6·3	3·2	3·6	0·8
	100	0·4	1·2	2·6	2·0	0·0	1·7	0·4
	80	1·0	0·2	0·2	1·2	0·1	0·1	0·0
	50	0·3	0·1	1·7	0·0	0·5	0·8	0·5
12	300	2·0	1·2	1·4	2·9	1·7	2·3	1·4
	200	21·2	19·4	21·2	13·0	10·9	4·8	2·0
	150	21·2	23·0	30·3	10·9	11·6	6 8	2·3
	100	1·7	1·2	5·8	0·6	0·6	2·3	4·0
	80	1·4	0·4	2·0	2·3	0·3	4·0	4·0
	50	0·8	0·6	0·8	1·7	1·0	3·2	0·0
20	300	0·0	0·2	0·0	0·8	0·6	0·2	0·0
	200	0·1	0·0	0·3	0·4	1·0	0·0	0·3
	150	0·6	0·0	0·6	0·3	0·2	0·8	0·2
	100	0·4	0·1	0·2	0·0	0·3	0·4	0·2
	80	0·3	0·3	0·0	0·0	0·2	0·5	0·0
	50	0·6	0·0	0·5	0·1	0·5	0·4	0·0
30	300	0·0	0·0	0·4	0·5	0·3	0·5	0·3
	200	0·3	0·4	1·0	0·1	0·1	0·1	0·3
	150	0·0	0·1	1·2	0·3	0·0	0·6	0·8
	100	0·0	0·0	0·0	0·3	0·3	0·6	0·4
	80	0·6	0·1	0·3	0·6	0·3	0·2	0·3
	50	0·3	0·0	0·5	0·0	0·2	1·2	0·0
40	300	0·2	0·2	0·0	0·2	0·5	2·0	1·2
	200	0·0	0·1	0·2	0·6	1·0	1·7	2·3
	150	0·2	0·2	0·6	0·3	0·1	0·3	2·3
	100	0·3	0·3	0·8	0·4	0·5	0·4	0·8
	80	0·1	0·5	0·6	0·1	0·3	0·3	0·4
	50	0·2	1·7	0·0	0·0	0·2	0·1	0·2

From Fig. 1, it is clear that the 2 month wave is present in the zonal wind just below the tropopause and in the lower stratosphere, amplitude decreasing with increase of latitude. It is extremely weak in the meridional wind and in temperature. Observations with IRLS (Interrogation, Recording and Location System) on board the Nimbus D satellite, of constant level balloons released between June and November 1970, indicated the existence of a 2 month-wave at 50 mbar level in meridional winds in the northern hemisphere winter (Angell[4]). These observations did not indicate the 2 month wave in the zonal wind, but they did indicate the presence of the Kelvin waves (whose periodicity is of the order of 15-20 days). It is, therefore, inferred that the 2 month wave in the zonal wind is much less dominant than the Kelvin wave and, therefore, escaped detection by the IRLS observation.

Fig. 2 indicates that the semi-annual wave is absent in all the three elements in the equatorial troposphere. It is present in zonal wind and temperature near the tropopause, above 20°N lat. It is extremely weak in meridional wind. In the lower stratosphere, it begins to strengthen from 50 mb level, apparently, with increase in height.

Table 4—Power Spectra of Monthly Mean Temperatures in (°K)² over Seven Indian Stations

Period in months	Levels in mb	TRV (8°29′)	MDS (13°0′)	VSR (17°43)	BMB (19°7′)	NGP (21°6′)	AHM (23°4′)	DLH (28°35′)
2	300	0·0	0·0	0·0	0·1	0·0	0·2	0·0
	200	0·0	0·0	0·0	0·0	0·0	0·3	0·0
	150	0·0	0·0	0·0	0·0	0·0	0·5	0·0
	100	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	80	0·0	0·0	0·0	0·0	0·0	0·0	0·0
	50	0·1	0·1	0·0	0·0	0·0	0·1	0·0
6	300	0·2	0·0	0·0	1·4	0·4	2·3	3·6
	200	0·0	0·0	0·0	0·2	0·3	2·9	0·8
	150	0·0	0·0	0·0	0·0	0·0	4·0	0·0
	100	0·8	0·5	0·4	0·1	0·2	0·4	0·6
	80	1·2	0·8	1·2	0·6	0·5	0·6	0·2
	50	0·2	0·5	0·5	0·3	1·2	1·2	0·2
12	300	0·3	1·7	7·3	6·8	16·0	34·8	72·3
	200	0·5	2·0	5·3	4·0	8·4	7·3	15·2
	150	0·4	1·4	2·9	0·5	2·0	7·3	2·9
	100	4·0	1·7	0·5	0·0	0·3	3·6	15·2
	80	13·7	11·6	2·6	5·8	2·9	0·3	6·3
	50	7·3	13·7	3·2	4·0	4·4	4·0	2·0
20	300	0·0	0·0	0·0	0·3	0·2	0·5	0·1
	200	0·0	0·0	0·1	0·2	0·3	0·4	0·1
	150	0·1	0·0	0·3	0·4	0·2	2·3	0·4
	100	0·3	0·0	0·4	0·0	0·0	0·8	0·5
	80	0·8	0·1	0·1	0·0	0·2	1·2	0·1
	50	0·6	0·0	0·4	0·5	0·1	0·0	0·0
30	300	0·0	0·1	0·0	0·2	0·5	2·0	0·0
	200	0·0	0·4	0·3	0·2	0·6	0·0	0·0
	150	0·0	0·0	0·1	0·1	0·6	5·3	0·1
	100	0·5	0·4	0·0	0·0	0·0	0·0	0·1
	80	0·8	0·8	0·1	0·6	0·8	1·4	0·1
	50	0·5	0·0	0·0	0·4	0·6	1·2	0·4
40	300	0·5	0·5	0·2	2·9	0·3	1·4	0·8
	200	0·5	0·4	0·0	1·4	0·3	0·8	1·0
	150	0·4	0·8	0·0	0·8	0·5	0·3	0·6
	100	0·0	0·8	0·3	0·0	0·1	0·1	0·5
	80	0·0	0·6	0·0	0·8	0·8	0·8	1·0
	50	0·3	1·7	0·1	0·6	2·0	0·5	1·0

The amplitude of the annual wave (Fig. 2) is a maximum in the zonal and meridional winds near the 150 mb level (close to the tropopause) in the region between 8 and 28°N latitude and it decreases on either side of the tropopause. In the zonal wind, there is a prominent maximum near 200 mb between 20 and 28°N latitude. This is associated with the sub-tropical westerly jet. The line of maximum amplitude tilts downwards from 8 to 25°N. The annual wave in temperature is much weaker than in zonal wind. It is confined to the stratosphere in the equatorial region, while in the sub-tropics it is present in the upper tropopause.

While the maximum amplitude in the zonal wind annual wave is highest over 25°N latitude and in the 200 and 150 mb height range, in meridional wind, the maximum is over 15°N latitude. But, in temperature, maximum amplitude is over 28°N latitude and at the level of 300 mb.

The six monthly wave in zonal wind shows the maximum amplitude over 18°N latitude and between 150 and 100 mb; in meridional wind, it is between 200

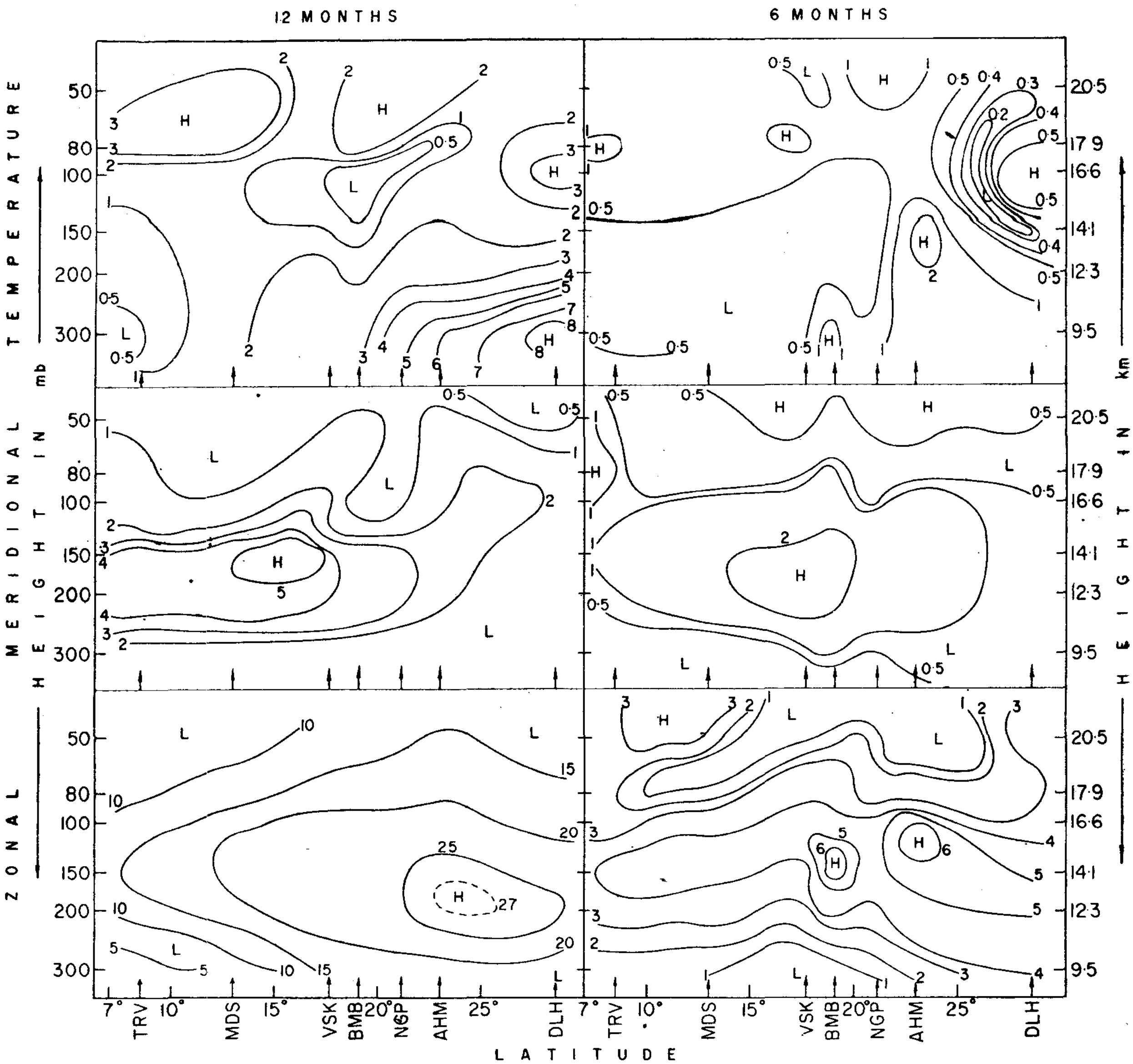

Fig. 2—Height-latitude distribution of long period waves) 6 and 12 months)
(H and L indicate high and low values of amplitude)

and 150 mb over the same latitude. But, in temperature, the maximum amplitude is over 23°N latitude and at a height of 200-150 mb. We infer that the maximum semi-annual variation is not only closer to the equator, but also at a higher level than the maximum annual variation. We, therefore, speculate that the origin of the semi-annual waves may be over the equator above the tropopause region, while that of the annual wave may be in the low latitude region below the tropopause.

In Fig. 3, height latitude variations of the 20 month, 30 month and 40 month waves are depicted. The quasi-biennial oscillation (QBO) may have any periodicity in the range 20-40 months. From Fig. 3 we infer that the 30 month periodicity is the most prominent one. This oscillation is present in the zonal wind in the lower stratosphere over the equatorial region. In meridional wind the QBO is very insignificant. It is present in temperature in the lower stratosphere above 100 mb level in the equatorial region and comes down to 150 mb level over latitude 20-25°N. We, therefore, suggest that the downward tilt of the line of maximum amplitude from the equator of sub-tropical latitude, indicates that the QBO originates in the equatorial stratosphere and travels to the upper troposphere over the subtropical latitudes.

The authors wish to express their thanks to the Director-General of Observatories, New Delhi, for providing facilities to do the work and for the permission to publish the paper.

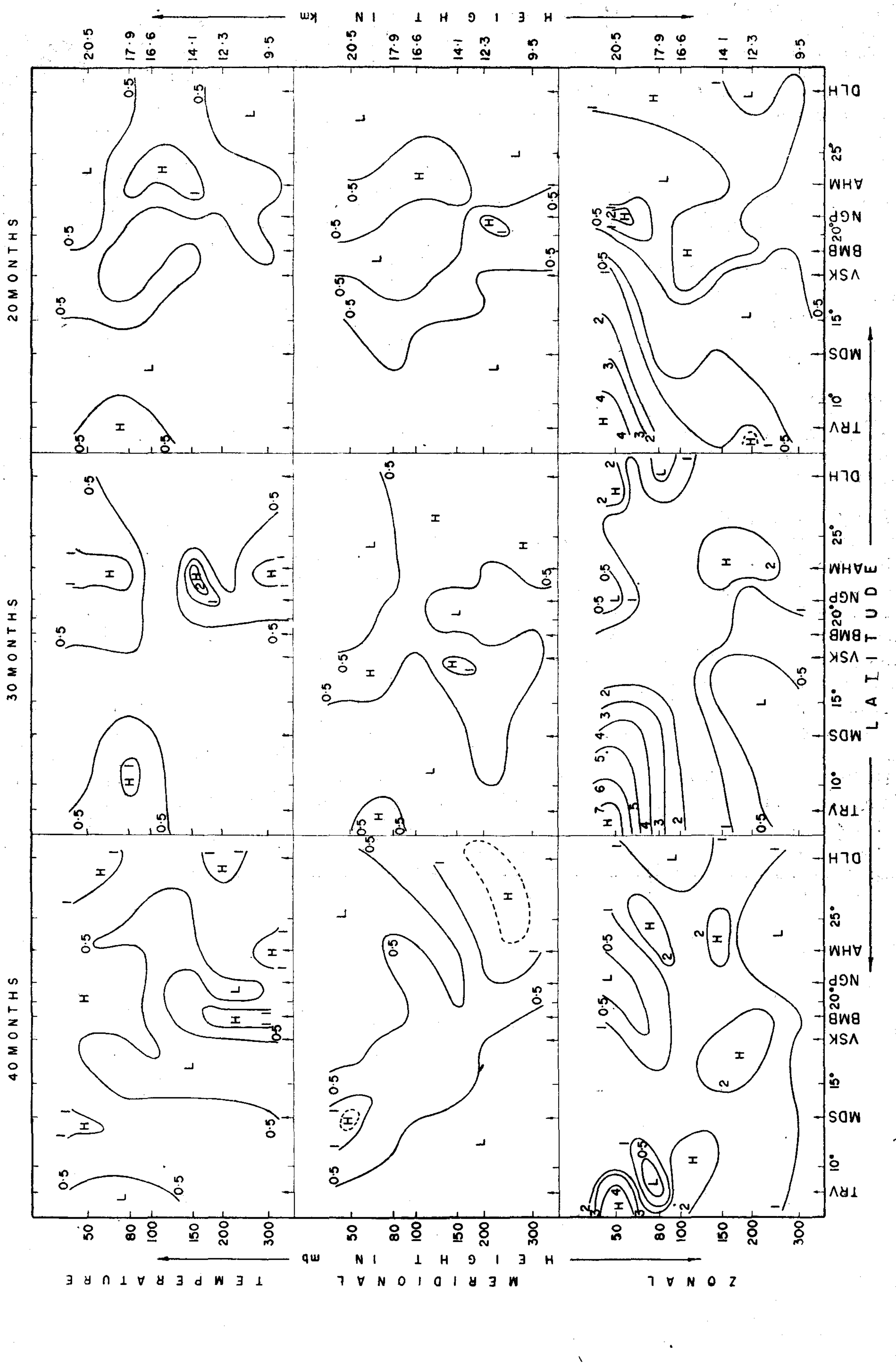

Fig. 3—Height-latitude distribution of amplitude of long period waves (20, 30 and 40 months) (H and L indicate high and low values of amplitudes)

References

1. YAMAI, M. & MARUYAMA, T., *J. met. Soc., Japan*, 44 (1966), 291.
2. WALLACE, J. M. & KOUSKY, V. E., *J. atmos Sci.*, 25 (1968), 900.
3. BLACKMAN, R. W. & TUKEY, J. W., *Measurement of Power Spectra* (Dover Publications Inc., New York), 1958.
4. ANGELL, J. K., *Space Sci. Rev.*, 13 (1972), 274.

Propagation Characteristics of hf Signal over a Transequatorial Path

A.K. SEN & S.K. TREHAN

Centre of Advanced Study in Radio Physics & Electronics University of Calcutta, Calcutta 700 009

Received 12 *September* 1975

The propagation characteristics of an hf radio signal (21.485 MHz, Radio Australia) over a transequatorial path viz. from Melbourne (37.5°S; 144.59°S) to Calcutta have been studied experimentally. A morning maximum is seen to occur in many cases.

Transequatorial propagation of an hf radio signal in different zones in relation to equatorial anomaly has been a subject of great interest in recent years. It has been observed that propagation characteristics are most stable in eastern zone while these are markedly variable in the Afro-Asian zone. We were prompted to examine the daily records of signal strength of Radio Australia transmitting on 21.485 MHz in the 13 m band from Melbourne (37.5°S; 144.59°E) received in Calcutta (22.34°N, 88.24°E) during the morning hours.

The records, in a great majority of cases, show a morning maximum followed by a period when the signal strength does not undergo much changes. Fig. 1 shows the typical records of the signal strength as had been observed by us. The morning maxima in Figs. 1(a), 1(b), 1(c) and 1(d) are seen to occur at 0828, 0840, 1000 and 0945 hrs IST, respectively. Figs. 1(e) and 1(f) show the records exhibiting the occurrence of long period fading on certain days; the morning maxima in these records are, however, not discernible.

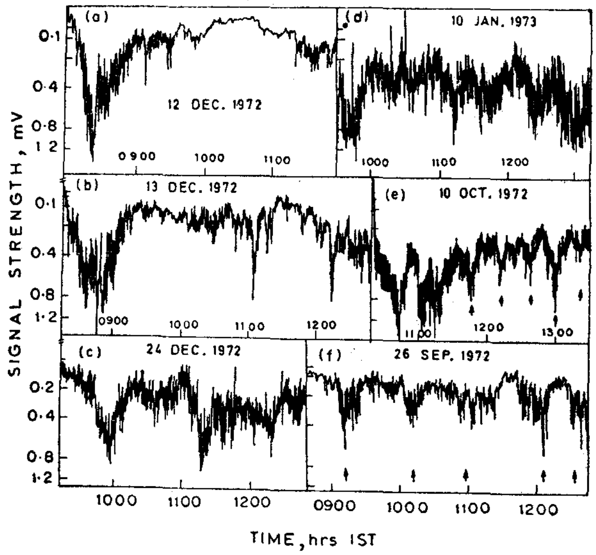

Fig. 1—Typical records of hf radio transmission from Melbourne to Calcutta on 21.485 MHz (Radio Australia) being observed at the Institute of Radio Physics & Electronics, Calcutta

During the winter season when the observations were made, the morning maximum could be noticed on a great majority of the days, tending to occur between 0820 and 1000 hrs, while the days on which long period fading occurred, the quasi-period of the fading varied from about 20 min to 75 min.

The authors are grateful to Prof. J.N. Bhar for constant encouragement and to Prof. M. K. Das Gupta for his valuable suggestions.