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STRUCTURE OF MONSOON PERTURBATIONS*

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ABSTRACT

Applying the technique of power and cross-spectrum analysis to wind and other data over the Indian region, the periodicity and horizontal and vertical structure of monsoon disturbances are studied.

INTRODUCTION

THE DISTURBANCES of the monsoon like monsoon lows and depressions have been studied extensively by synoptic methods. The structure of monsoon depressions was studied by Desai (1948), Pramanik and Rao (1948) and Koteswaram and George (1958, 1960). The frequency of occurrence and tracks of these depressions were studied by Ananthakrishnan (1964).

More recently the technique of power and cross-spectrum analysis is being applied increasingly to study the structure of tropical disturbances. A preliminary study of the periodicities of the *v* and *u* components of the wind at some Pacific stations was made by Rosenthal (1960). Yanai *et al.* (1968) made an extensive study of the power and cross-spectra of the *v* component of wind at Pacific stations. They found a peak around 4 days in the lower troposphere corresponding to the easterly waves whose scale was found to be about 6000 km. They also found large spectral density around 4-5 days in the upper troposphere and lower stratosphere corresponding to westward moving waves of scale 10,000 km. Wallace and Chang (1969) studied the spectra of *v* and *u* components, surface pressure, temperature and relative humidity of tropical stations (in the lower troposphere). They found easterly waves with periods of 4-5 days and horizontal wave-lengths of 3000 km, planetary scale pressure fluctuations with periods around 4 days and low frequency oscillations with periods greater than 10 days in the *u* component with wavelengths of the order of 10,000 km. Ananthakrishnan and Keshavamurty (1970) found large spectral density in periods longer than 10 days in the *u* component and surface pressure and one week period in *v*, *u* and surface pressure at Indian stations during the south-west monsoon period.

In this paper, the periodicity and horizontal and vertical structure of monsoon perturbations by applying power and cross spectrum analysis techniques to wind and other data of Indian stations during the south-west monsoon season are studied.

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Data and Computations

We have analysed mainly the *v* component of wind at the stations Nagpur, Calcutta, Lucknow, New Delhi, Vishakhapatnam, Port Blair and Trivandrum for the standard levels 900, 850, 700, 500, 300 and 200 mb during the monsoon season June-September of 1967. This was a normal monsoon season. For Calcutta we have used greater vertical resolution *i.e.* we have analysed data at 0.3, 0.6, 0.9, 1.5, 2.1, 3.0, 3.6, 4.5, 5.4, 6.0, 7.2, 9.0, 10.5 and 12.0 km. It was desirable to use data of a recent year as the quality of the data has been improving in recent years. The height of the ascent is increasing and also the missing data are fewer. We have analysed the wind data of 1965, 66 and 68 of Nagpur, New Delhi and Trivandrum. We have also studied the surface pressure departure data of Trivandrum, Nagpur and New Delhi for the monsoon seasons of the above years.

The method of power spectrum analysis has been dealt with extensively by Blackmann and Tukey. The method followed by us is mainly based on the formulation in WMO Technical Note on Climatic Change. For cross spectrum analysis we have essentially followed the method of Munk *et al.* (1959) and Maruyama (1968). As no ready made computer programme was available one was written by the author.

The length of the record (N) in our case was 120 observations (one observation daily so that $\triangle t = 1$ day). The maximum lag used is $M = 30$ (sometimes 15) so that the frequency (k) refers to cycles in 60 days and the period $p = \frac{60}{k}$ days.

As we have used the deviations from the mean (x'_i and y'_i) as our initial data the zero mean has been removed. No attempt, however, has been made to remove the longer cycles by weighted averaging as the length of the record would be considerably reduced; and there is no point in taking a longer period as the character of the disturbances would be different if we extended the period beyond the monsoon season.

Missing data in all cases have been filled by linear interpolation. The number of missing data was large in the higher levels of some stations and so they have not been analysed: for instance 200 mb data of Vishakhapatnam, Lucknow and Port Blair.

Results

v Component :

We shall first consider the power spectra of the *v* component of wind at Nagpur, Calcutta and Lucknow. Fig. 1 shows the *v* component spectra of Nagpur at standard levels. The most prominent peaks are those corresponding to (i) $p = 20$ days at 850, 900 and 700 mb (ii) $p = 5.5$ and 6 days at 900, 850, 700 mb (iii) $p = 7.5$ and 8.6 days at 500 and 300 mb. Calcutta (Fig. 2) shows peaks around (i) $p = 15$ days at 0.3, 0.6, 0.9 and 1.5 km, (ii) $p = 7.5$ and 8.6 days at 6.0, 7.3, 9.0, 10.5 and 12.0 km. Lucknow (Fig. 3) shows spectral peaks around (i) 5.5 and 6 days at 0.3, 0.6,

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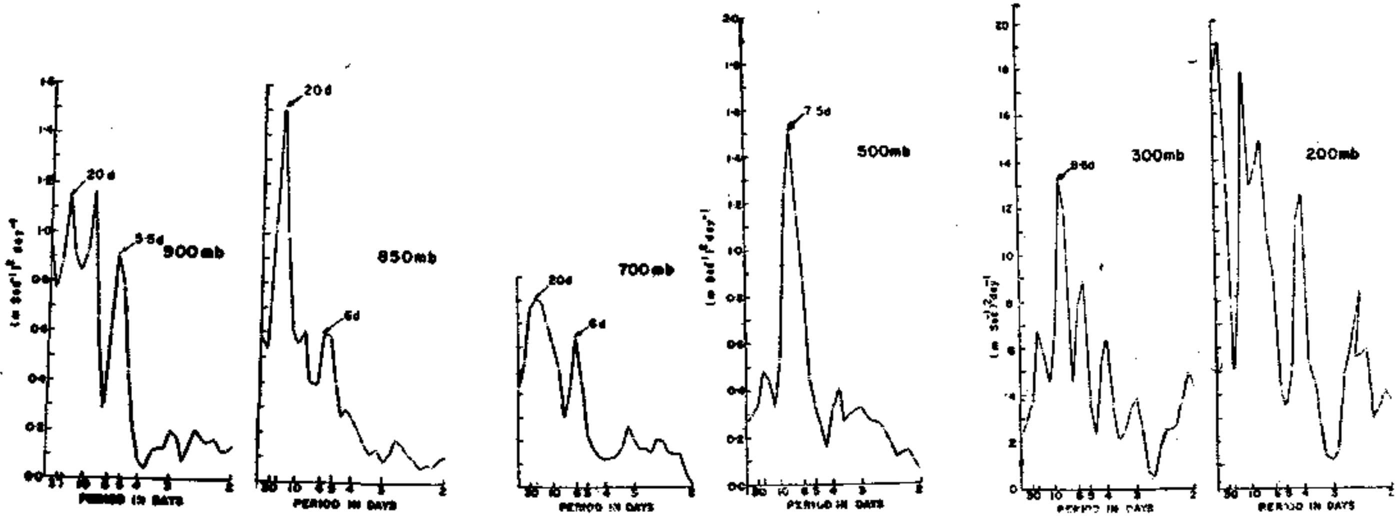


Fig. 1. NAGPUR *v* Component June-September, 1967 at 200, 300, 500, 700, 850 and 900 mb.

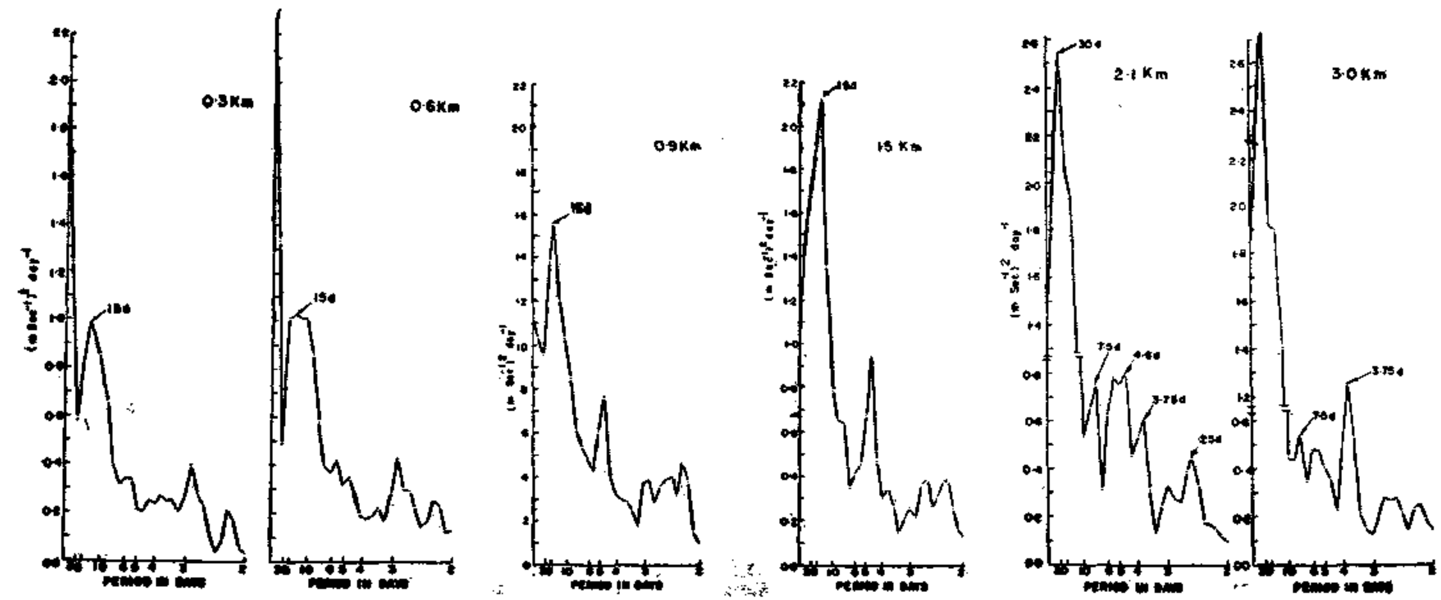


Fig. 2a. CALCUTTA *v* Component June-September 1967 at 0.3, 0.6, 0.9, 1.5, 2.0 and 3.0 km.

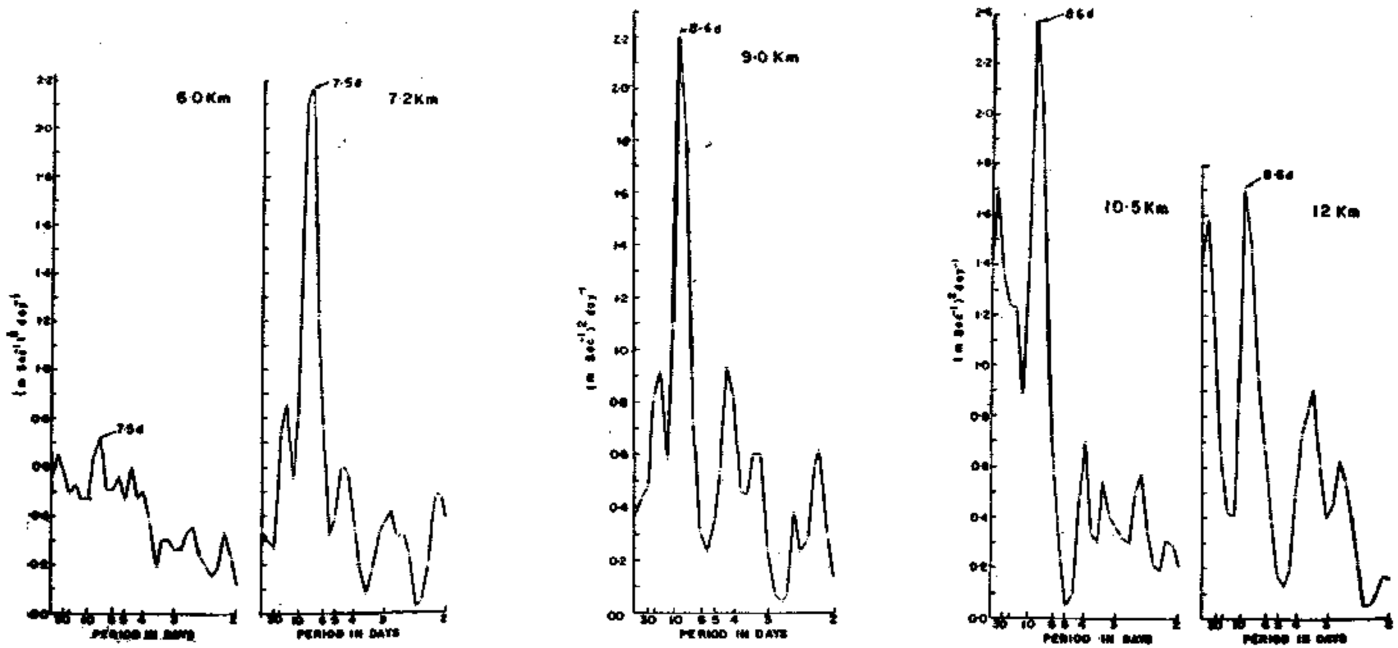


Fig. 2b. CALCUTTA v Component June-September 1967 at 6.0, 7.2, 9.0, 10.5 and 12.0 km.

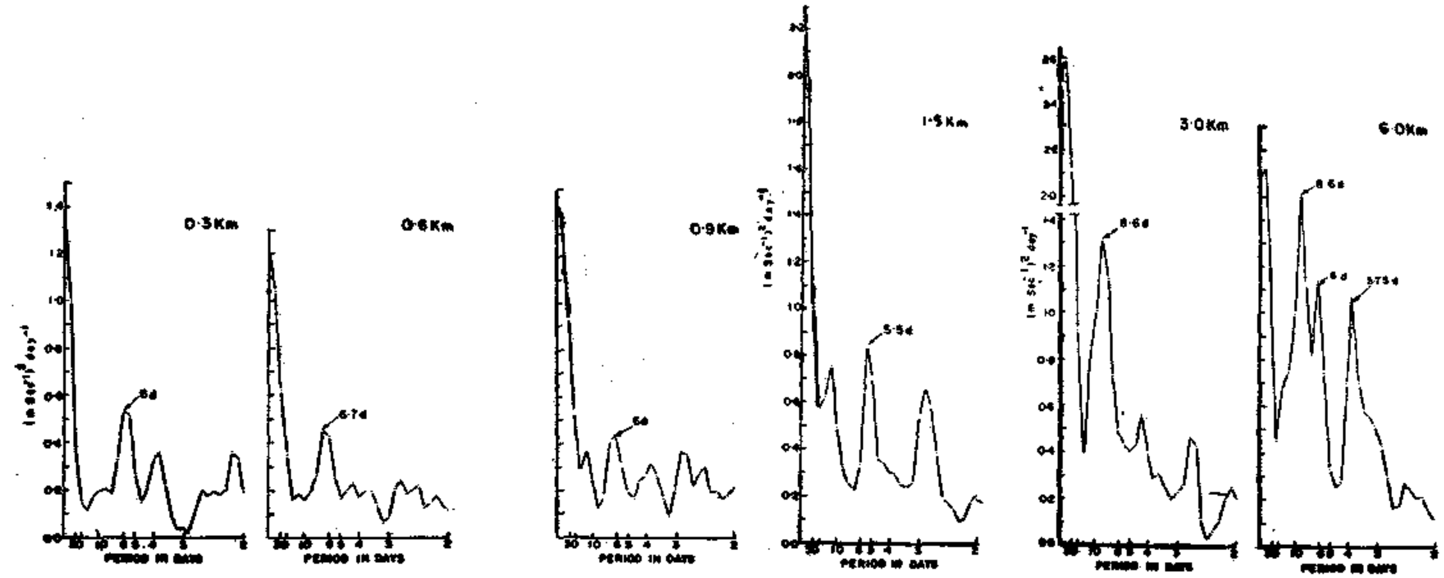


Fig. 3. LUCKNOW *v* Component June-September 1967 at 0.3, 0.6, 0.9, 1.5, 3.0 and 6.0 km.

0.9 and 1.5 km and (ii) around $p = 8.6$ days at 3.0, 6.0 km. Fig. 4 shows the vertical profile of power spectral density in these periods. Corresponding to the period $p = 20$ days we see that both Nagpur and Calcutta show maximum power in the lower troposphere *i.e.* around 1.5 to 2.0 km. The power falls off

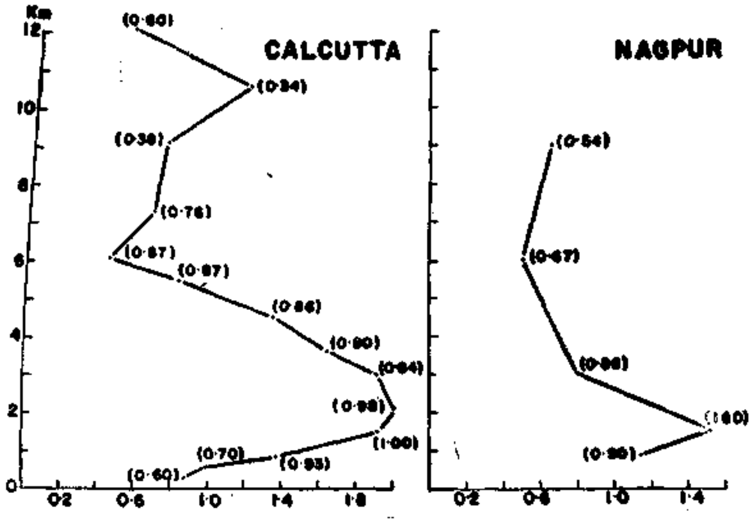
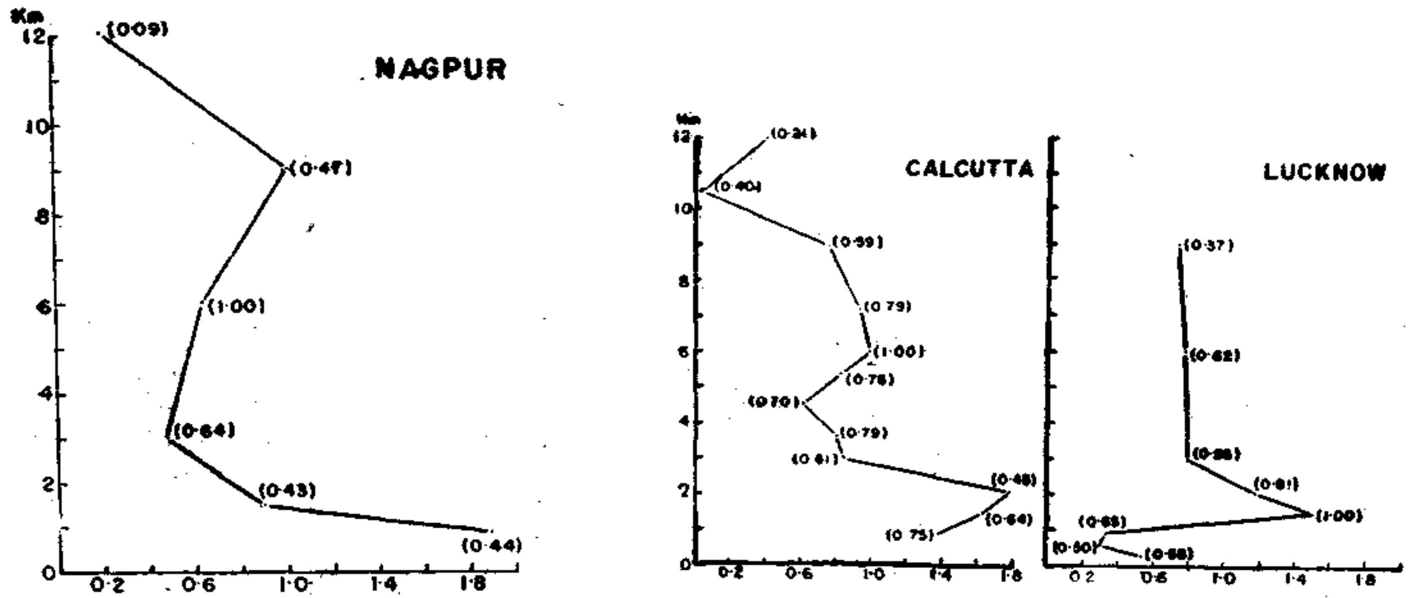


Fig. 4a. Power Spectral Density, v—Component, (m Sec.$^{-1}$)^2 Day^{-1}
P = 20 Days.

with height *i.e.* these disturbances are most marked in the lower troposphere. The coherence of the disturbance at different levels compared with that at 850 mb is calculated and shown in brackets. The coherence values decrease to 0.5 only above 400 mb at Calcutta and above 300 mb at Nagpur showing that these disturbances extend from the surface to 400-300 mb.

The vertical profiles of power spectral density in the period $p = 5$ days show similar feature *i.e.* maximum power in the lower levels which falls off with height. These were calculated with the maximum lag $M = 15$. The coherence values with 500 mb as reference level show that the depth of the disturbance at Calcutta is from surface to above 300 mb, at Nagpur from surface to below 300 mb. At Lucknow the coherence values have been calculated with 850 mb as the base. The disturbance extends from surface to above 500 mb. It is seen that in this period also the disturbances extend from the surface to about 400-300 mb.

Let us now see the vertical structure of the disturbance in the period $p = 7.5$ days. A marked contrast is seen. At Nagpur the maximum power in this period is found at 500 mb and above and very small power in the lower levels. Similarly at Calcutta the maximum power is found in the upper troposphere (at 7.2 km) and very small power in the lower levels. At Lucknow the maximum power is seen at 700 mb and above. The coherence values at Calcutta and Nagpur show that these disturbances extend from about 2-3 km to just around 200 mb though they have maximum power in the middle and upper tropospheres.



4b. Power Spectral Density *v*—Component, (m Sec—1)² Day—1 P = 5.0 Days at Nagpur, Calcutta and Lucknow.

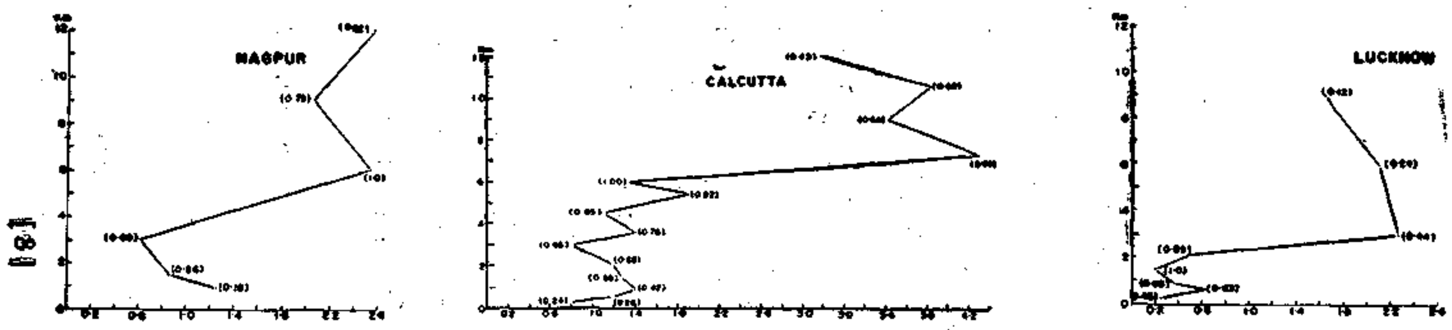


Fig. 4c. Power Spectral Density *v*—Component, (m Sec—1)² Day—1. P = 7.5 Days at Nagpur, Calcutta and Lucknow.

Thus we have two types of disturbances. (i) Corresponding to the period $p = 20$ days and $p = 5$ to 6 days. These disturbances extend from the surface to 400-300 mb. These have maximum power around 850 mb which falls off with height. (ii) Disturbances corresponding to period $p = 7$ to 8 days. These have maximum power around 6-7 km but extend from 2-3 km to nearly 12 km.

HORIZONTAL SCALE OF THE DISTURBANCE

We shall examine the horizontal structure of these disturbances by computing cross-spectra between v components of different stations. We evaluate the phase difference between the spectra of station pairs Nagpur—Calcutta, Nagpur—Vishakhapatnam, Nagpur—Port Blair, Lucknow—Calcutta, Vishakhapatnam—Port Blair, at different levels. Following Yanai *et al.*, the phase difference between the station pairs is plotted against their longitudinal separation (in degrees). Then a straightline is fitted and the wavelength is calculated. Of course the stations have latitudinal separation also but if we reject the station pairs on this account very few will be left. While drawing the straight line less weight is given to station pairs having large latitudinal separation. The coherence values are shown in bracket. Figs. 5 shows the $\Delta\theta - \Delta\lambda$ diagrams at 850 mb corresponding to the periods $p = 20$ days and $p = 5.5$ days. Disturbances in these periods are most marked at this level. The straight line fit for $p = 20$ days is excellent; but the coherence values are rather poor. In this case we get the wavelength $\lambda = 34$ degrees longitude. The movement is from east to west as stations to the east always lead. The speed of movement is $C = \frac{34}{20} = 1.7°/\text{day}$. For disturbances in the period range $p = 5.5$ days the straight line fit is not bad; the coherence values are somewhat larger than for $p = 20$ days. By extrapolation the wavelength is obtained as $\lambda = 20°$. The direction of movement is from east to west and the speed of movement is $C = \frac{20°}{5.5}$ day $= 3.6$ degree/day.

The disturbances in the period range around $p = 7.5$ days are most marked around 500 mb. Therefore we have prepared the $\Delta\theta - \Delta\lambda$ diagram at this level (Fig. 5c). Here we find that the scatter of points is much more; but coherence values are larger. Neglecting the farthest point which corresponds to Nagpur—Port Blair (coh. = 0.64) which has very large latitudinal separation and drawing a straight line we get the wavelength $\lambda = 35°$. The movement is from east to west and the speed of movement $C = \frac{35 \text{ degree}}{7.5 \text{ days}} = 4.7$ degree/day.

TABLE 1. *Wavelengths and phase velocities of disturbances*

Level	Period in days	Wavelength in degrees of longitude	Phase velocity east to west
850	20	34	1.7
850	5.5	20	3.6
500	7.5	35	4.7

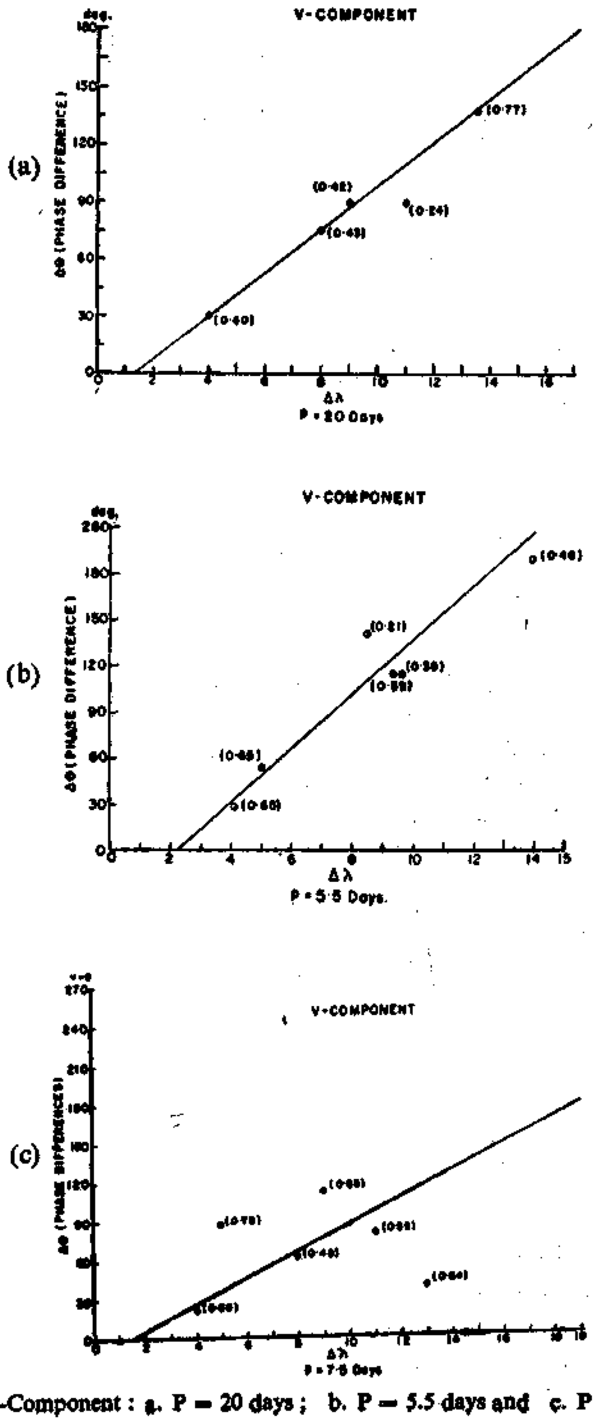


Fig. 5. ν—Component : a. P = 20 days ; b. P = 5.5 days and c. P = 7.5 days.

So we have three types of disturbances. The one corresponding to a period of 20 days and having a scale of 34° longitude corresponds to monsoon depressions. This moves slowly westwards with a speed of 1.7 degree long. per day. This disturbance as we have seen earlier is most marked in the lower levels around 850 mb. The other lower tropospheric disturbance of period 5.5 days is of a smaller scale around 20 degree longitude. These correspond to the weaker monsoon lows. These move (westwards) a little faster with a speed $C = 3.6$ degree long./day.

The disturbance with a period 7.5 days which is most marked in the middle and upper tropospheres has a scale of 35°. This corresponds to the middle and upper tropospheric lows or troughs. These move faster than the lower tropospheric disturbances. The slowest moving are the monsoon depressions. Because of the slightly different speeds of the disturbances of the lower and upper tropospheres superposition and favourable location with respect to each other is possible.

The scales of the disturbances we have estimated by the above method correspond to complete wavelengths. On synoptic charts we generally concentrate on cyclonic circulations only, which would correspond more to half-wavelength. Therefore considering only the cyclonic portions the scale of the monsoon depressions and middle and upper tropospheric lows and waves would be about 17 degrees of longitude and that of the monsoon lows would be about 10 degrees.

Conclusion

There are three types of disturbances in the Indian South-west monsoon.

(i) Monsoon depressions of period 20 days, horizontal scale about 35 deg. long. and extending from surface to 400-300 mb, they are most marked around 850 mb ;

(ii) monsoon lows of period 5.5 days, horizontal scale 20 deg. long., being most marked in the lower levels; and

(iii) middle and upper trophospheric lows and waves of scale 35 deg. long.

All these disturbances move westwards.

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DISCUSSION

P. K. DAS : What was the total variance of the '*v*' component ? Could you tell us what fraction of the total variance resides in the periodicities described by you ? I do not know what smoothening procedure was adopted by you ; but, it is important to see that the smoothening procedure for raw data does not create ficticious periodicities.

R. N. KESHAVAMURTY : Fig. 1, 2, 3 show the power spectral density plotted against frequency (period). It can be seen that the power residing in the 20-day period in the lower levels and in the 7-8 day period in the upper levels is quite a considerable percentage of the total variance (at the level). The raw spectra have been smoothened by the formula

$$HSPF(K) = 0.54\ SPF(K) + 0.23\ \{ SPF\ (K-1) + SPF\ (K + 1) \}$$

This is known to improve the spectra.

V. SRINIVASAN : Synoptic experience indicates that low pressure areas move less fast than depression. Very often low pressure areas stagnate. The results presented appear to be different from our synoptic experience. Can you explain the discrepancy ?

R. N. KESHAVAMURTY : On synoptic charts the systems we see are superpositions of transient disturbances on stationary disturbances ; this gives an impression of stagnation. In the technique of power spectrum analysis, however, we sort out and analyse the transcient disturbances ; hence the discrepancy.