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551.466.2 : 551.577.38 : 551.553.21 (267)

Wave disturbances over Indian Ocean area during drought and normal summer monsoons

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सार — ग्रीष्म मानसून की दो विपरीत अवधियों के दौरान हिन्द महासागर क्षेत्र के क्षोभमंडलीय तरंग विक्षोभ कर अध्ययन करने के लिए यह विश्लेषण किया गया है । इस अध्ययन से योभ्योन्तरीय पवन घटक में 2 से 3 एवं 4 से 6 दिनों की दो महत्वपूर्ण आवर्तिताओं का पता चला है । ये तरंगे 20° से 32° के तरंग दैर्ध्य सहित पश्चिम की ओर चलती हैं । सामान्य सूखे के वर्ष की तुलना में मानसून वष में तरंग क्रियाशीलता सामान्यतया प्रबल होती हैं ।

ABSTRACT. Analysis has been carried out to study the tropospheric wave disturbances over the Indian Ocean area during two contrasting summer monsoon periods. The study reveals two significant waves with periodicity of 2 to 3 and 4 to 6 days in meridional wind component. These waves move westward with a wave length of about 20° and 32° respectively. The wave activity, in general, is stronger during the normal monsoon year than the drought year.

1. Introduction

It has been observed that the cross equatorial flow over the Indian Ocean area has an important role in the Indian monsoons (Rao and Desai 1973). The studies of the Indian Ocean area are limited due to lack of data. Some work has been reported as case studies to identify waves associated with the synoptic scale disturbances over the Indian Ocean area. To obtain a consistent model of the disturbances, a large number of case studies are required. It has been shown that the spectrum analysis technique can be an alternative to the case study approach (Maruyama 1967, 1979; Yanai *et al.* 1968 etc).

Selective studies to identify the tropospheric wave disturbances over the Indian sub-continent have been reported (Keshavamurthy 1973; Subbaramayya and Bhaskar Rao 1974; Murakami 1976). Existence of large scale wave disturbances over east of the Indian Ocean area have been identified (Appa Rao and Ramanamurty 1972, 1976). Waves in the lower stratosphere based on two stations of the Indian Ocean have been studied by Maruyama (1979). An attempt has been made in this paper to study the important tropospheric wave disturbances over the Indian Ocean area during two contrasting summer monsoons. 1966 and 1967 are selected as the contrasting years of drought and normal monsoons for the analysis (Appa Rao 1981).

2. Data used

Daily 00 GMT upper air data reported by six stations (Fig. 1) over the Indian Ocean area, situated about 10 deg. on both sides of equator have been used in the study. Data of Gan pertain to 12 GMT during 1966 and for the other 00 GMT. The analysis has been carried out for 850 mb and above, at the standard isobaric levels during the monsoon seasons (June to September) of 1966 and 1967.

3. Method of analysis

The power spectral analysis has been mainly based on the method suggested by Blackman and Tukey (1958), Munk *et al.* (1959) and WMO-79 (1966). The same procedure has been adopted earlier by Appa Rao and Ramana Murthy (1972, 1976) and also in the present study. Daily data of zonal and meridional winds and temperatures are subiected to spectrum and cross-spectrum technique with a maximum lag of 40. The reliability and statistical significance of the spectral peaks have been tested and normalised spectral values are presented for discussion (WMO-79; Panofsky and Brier 1958).

4. Results

4.1. *Mean tropospheric flow patterns in zonal wind and temperature*

The latitude height cross sections of zonal wind pattern for the two years are shown in Figs. 2 and 3. Low level westerlies prevail from surface to about 300 mb in both the years. Easterlies exist above the westerlies, with a strong pocket at about 100 mb (12 deg. N). The lower tropospheric westerlies extend more southwards during 1967 than 1966. The zonal winds are stronger in 1967 (850 mb) near 12 deg. N than 1966. The upper tropospheric easterlies are

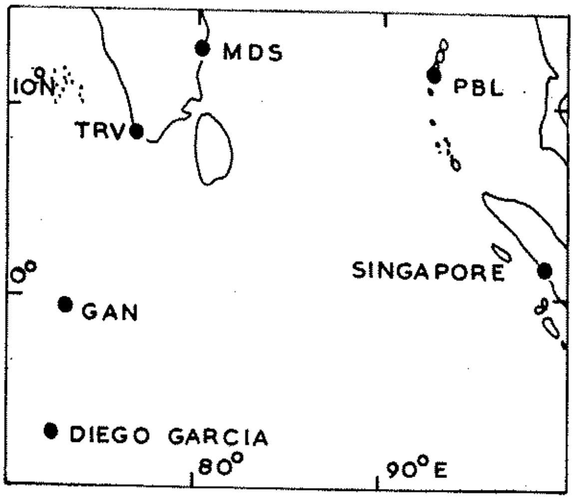

Fig. 1. Observation stations over Indian Ocean area during 1966 and 1967 used in the study

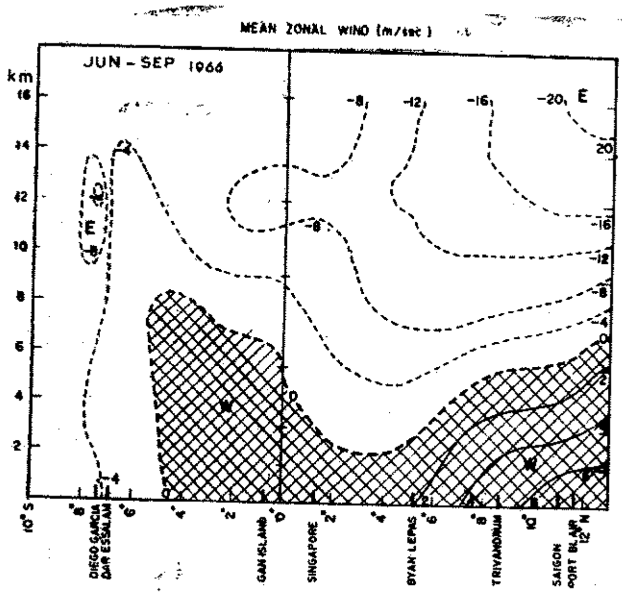

Fig. 2

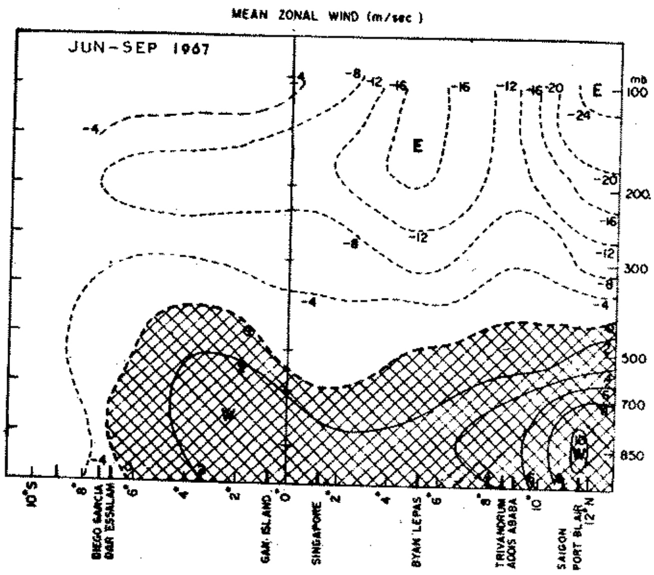

Fig. 3

Figs. 2 & 3. Latitude-height cross section roughly along 80° E (W=Westerlies, E=Easterlies)

stronger (100 mb) at 5 deg. N and 12 deg. N in the normal year. In general, winds are stronger in normal monsoon year (1967) than the drought year (1966) over the northern hemisphere. Temperature patterns do not show any major differences and the diagrams are not given.

4.2. *Spectral results*

The spectral results of zonal (U), and meridional winds (V) and temperature (T) have been worked out. The results of Gan are only illustrated in Figs. 4 to 7 and of other stations are given in Tables 1 and 2, for brevity. Statistically significant peaks are marked by arrows in the diagrams. In general, it is observed that a large portion of kinetic energy is associated with zonal wind component at low frequencies. Meridional wind component contains neither trend nor concentration of energy at low frequencies.

It is observed from Table 1 that at Port Blair, waves with periods of 2 to 3 days exist in V, U and T spectra throughout the troposphere. They are more prominent in the normal monsoon year than the drought year. Madras has shown periods of 2 to 3, 4 to 6 and 10 days. These peaks are mainly noticed in V spectra. Periods of 2 to 3 days are seen in U and T spectra also. Trivandrum indicates periods of 2 to 3 and 4 to 7 days.

TABLE 1

Significant spectral peaks with period in days during summer monsoon periods over Indian Ocean area

Height (mb)	1967									1966								
	Port Blair			Madras			Trivandrum			Port Blair			Madras			Trivandrum		
	U	*V*	*T*	*U*	*V*	*T*	*U*	*V*	*T*	*U*	*V*	*T*	*U*	*V*	*T*	*U*	*V*	*T*
850	2.6	2.3	2.2 4.7	2.5	4.0	—	4.0 2.4	3.5	3.3 3.0	—	—	—	—	—	3.8	—	—	8.9 4.4
700	—	—	2.2 7.3	2.2 2.5	10.0	—	—	—	40.0	—	—	—	—	2.5	6.2	6.7	4.7	2.9
600	2.2	—	—	—	2.3 10.0	—	—	7.3	26.7	2.2 2.5	—	—	— 3.1	6.7	—	10.0	—	—
500	2.6	2.1	—	2.2	2.1	—	6.7	—	40.0 3.3	2.2 6.7	8.0	—	7.3 2.3	—	2.7	10.0	4.0	6.7
300	5.0	2.3	2.0	4.4	3.0 3.5 4.4	2.1	4.2 2.4	2.4	40.0 3.3	—	2.2	10.0	2.7	2.9	—	—	—	—
200	—	2.2	—	—	—	2.1	11.4	—	40.0	2.9	—	—	—	2.9	—	—	—	—
100	3.1	—	4.4	2.7 16.0	8.9	2.6	4.7	—	—	—	—	—	10.0	2.3	2.5	—	—	—

TABLE 2

Significant spectral peaks with period in days during summer monsoon periods over Indian Ocean area

Height (mb)	1967									1966								
	Singapore			Gan			D. Garcia			Singapore			Gan			D. Garcia		
	U	*V*	*T*	*U*	*V*	*T*	*U*	*V*	*T*	*U*	*V*	*T*	*U*	*V*	*T*	*U*	*V*	*T*
850	—	—	4.0 2.8	3.0	7.3	4.0	4.0	3.3	2.7 5.0 16.0	—	6.7 5.3	—	—	—	—	16.0	6.7	—
700	8.0	5.3 2.9	4.7	—	—	—	5.3 2.7	3.6	3.0	—	5.7	—	—	—	—	—	4.7	—
600	8.9 5.7	5.3 4.4	3.6	—	—	—	5.3 2.6	8.9	3.3	11.4	6.7	—	—	—	—	—	—	—
500	5.7	5.7 4.2	3.3	—	5.7	3.1	—	8.9	3.0	11.4	8.9	26.7	—	6.7 5.0	—	6.7 3.1	—	—
300	—	5.7	—	3.1	10.0	—	3.3 2.8	5.7 2.6	2.6	6.7	6.7 3.5	26.7	—	5.3 4.2	4.4	8.9 6.7	3.1	—
200	3.3 2.7	4.0	7.3	6.2 2.6	6.2	3.1 6.2	—	2.9	3.2	—	5.0	3.6	—	—	—	2.3	2.8	—
100	10.0	4.0	—	40.0	6.2	—	3.2 2.7	4.4	—	—	5.0	4.4	13.3	—	—	—	—	—

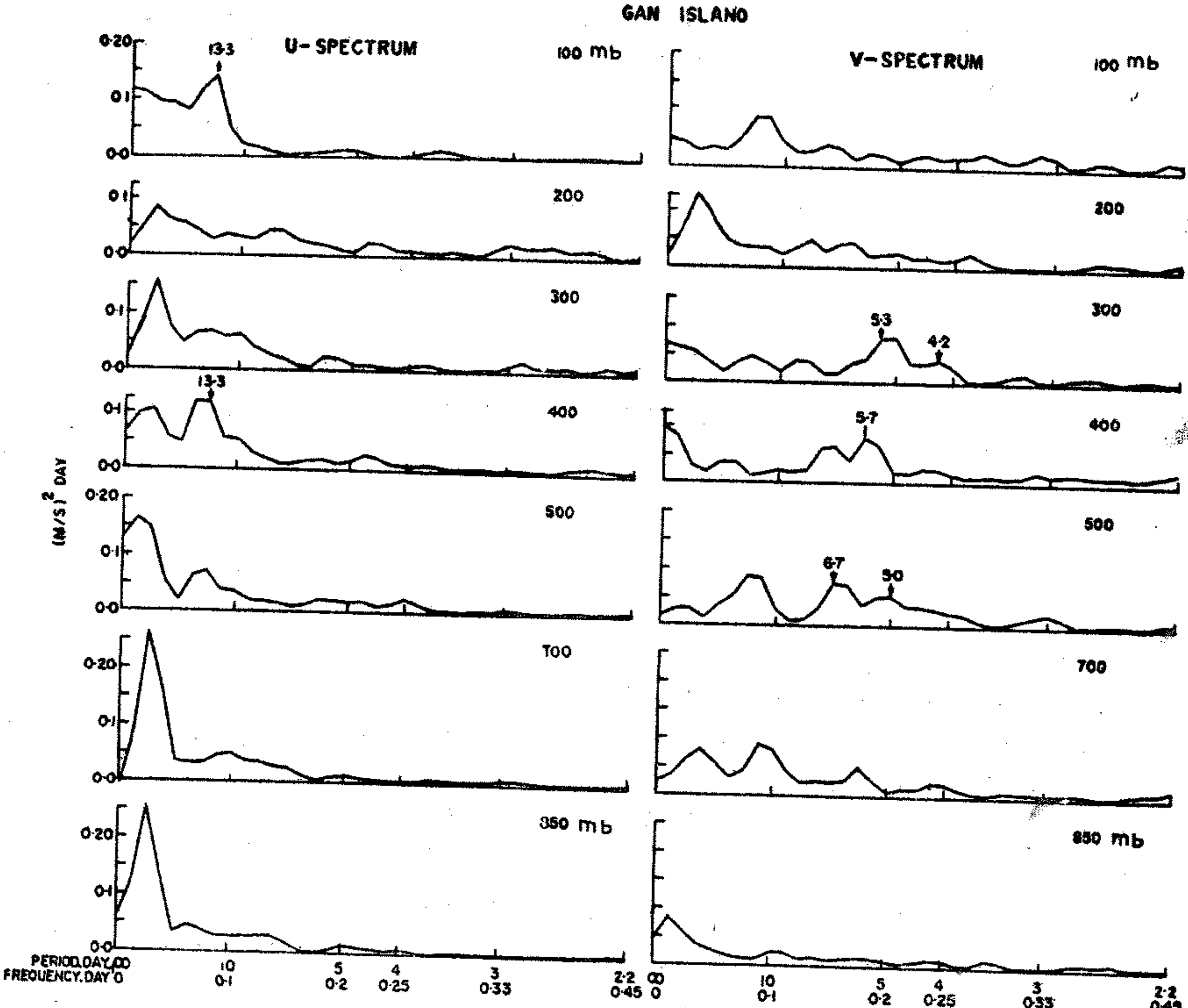

Fig. 4. Vertical distribution during June to September 1966

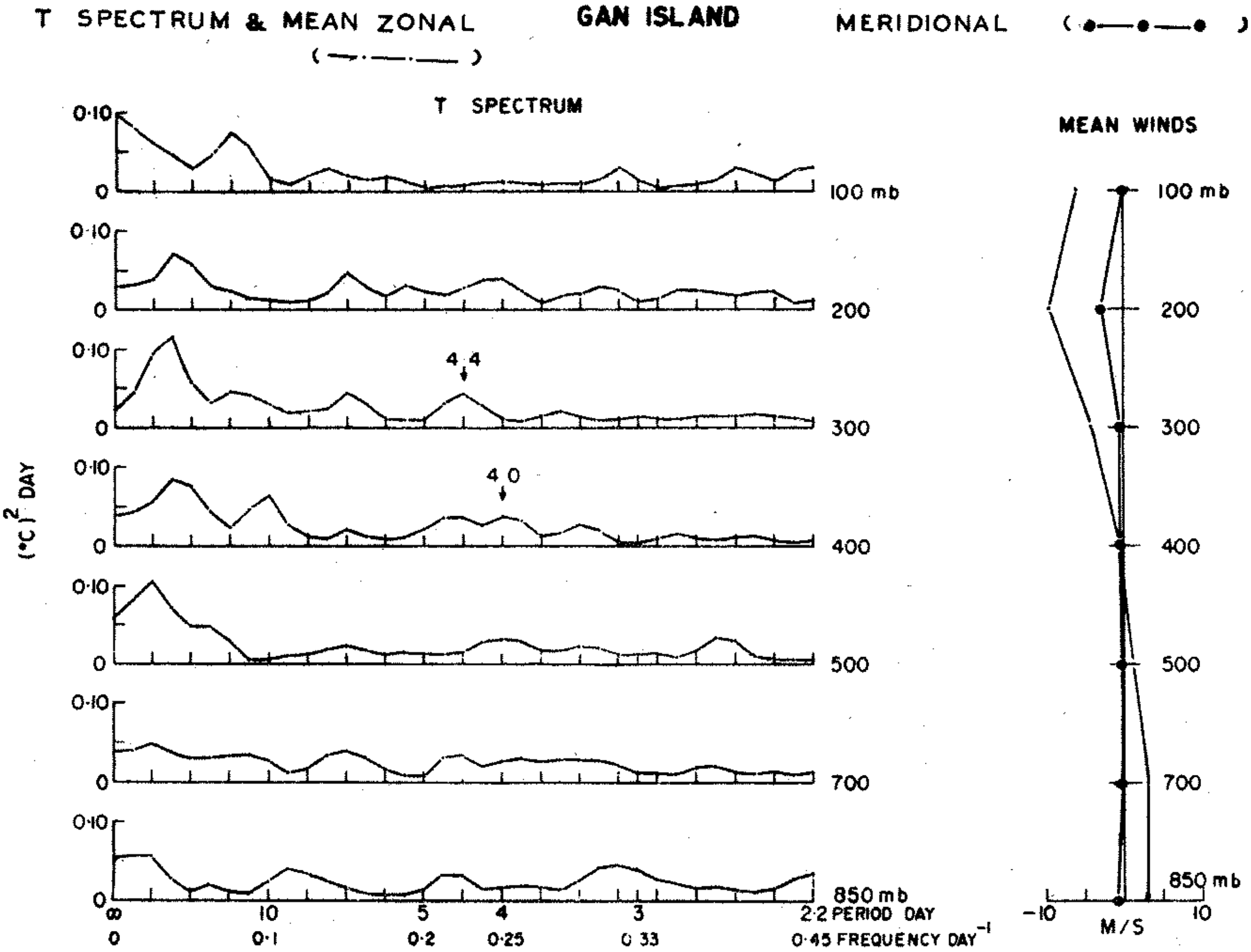

Fig. 5. Vertical distribution during June-September 1966

The wave activity is quite different for the stations (Table 2) along the equator. Singapore has shown prominent peaks with periods of 4 to 6 days in *V*, *U* and *T* spectra during both the years. Another significant peak of 7 to 9 days is noticeable during 1966 in *V* spectra. Gan assumes special importance due to its central location in the area under consideration and closeness to the equator. At this station (Figs. 4 to 7) peaks with periods of 4 to 6, 7 to 10 days are seen in *V* spectra during 1967. The same peaks are noticeable in the middle troposphere during 1966. Deigo Garcia shows peaks of 3 to 7 days in *V*, *U* and *T* spectra.

From the above results, it is inferred that two types of wave disturbances with periods of 4 to 6 and 2 to 3 days prevail over the Indian Ocean area. The former is seen prominently at equatorial stations and the latter at about 10 deg. N. The first type can be identified as Yanai-Maruyama waves (Y-M waves). Similar type of waves have been observed over the Pacific and east of the Indian Ocean area (Yanai *et al.* 1968 & Appa Rao and Ramanamurty 1972, 1976). Generally the wave activity is stronger and greater in depth during the normal monsoon year, compared to the drought year as seen from the tables at many stations. Maruyama (1979) observed wave disturbances with the periodicity of 4 to 5 and 10 to 20 days in the lower stratosphere over Indian Ocean area. It is, therefore, suggested that wave disturbances with periods of 4 to 6 days presently observed in the upper troposphere and those in the lower stratosphere, observed earlier by Maruyama may indicate important coupling between troposphere and stratosphere over the Indian Ocean area.

Wave disturbances of 4 to 5 days in other meteorological elements over Indian sub-continent have also

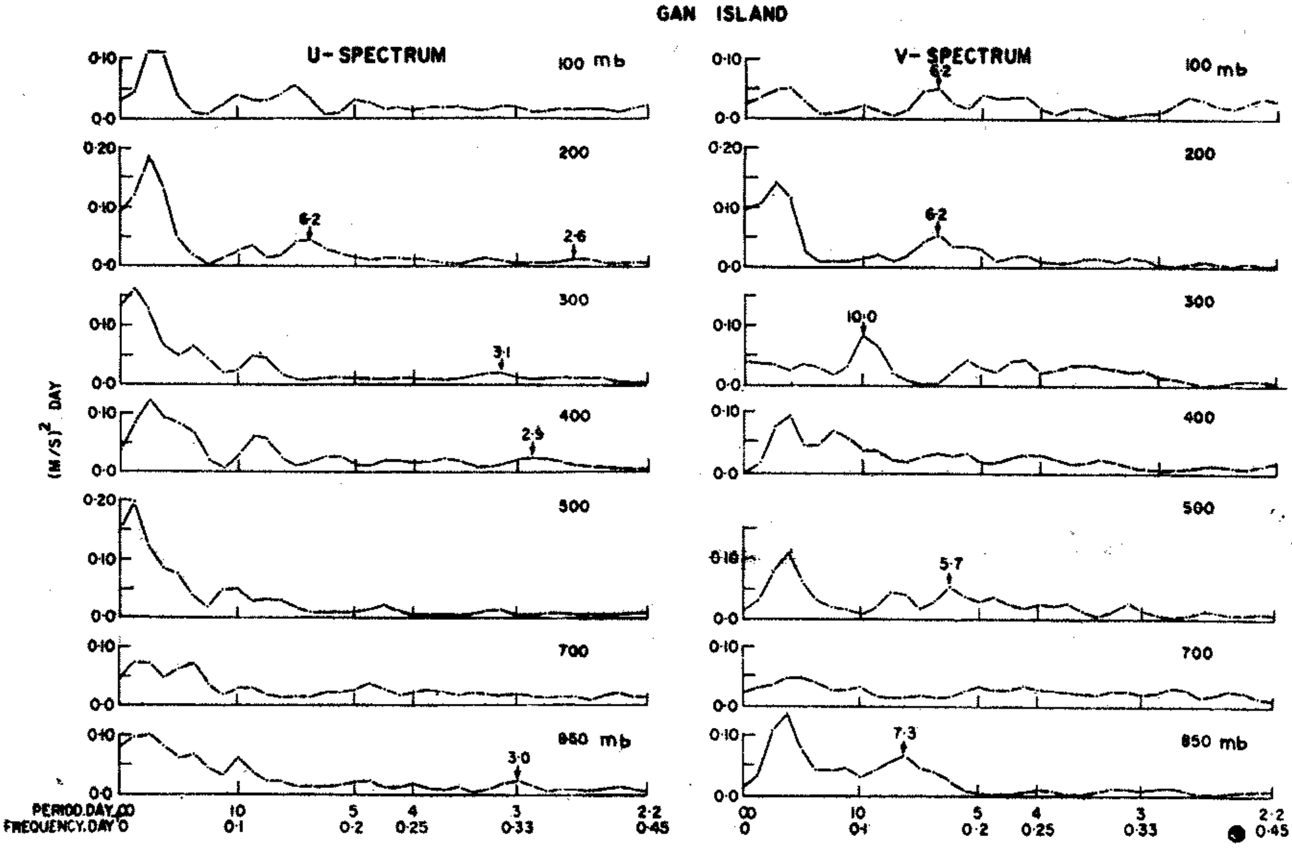

Fig. 6. Vertical distribution during June to September 1967

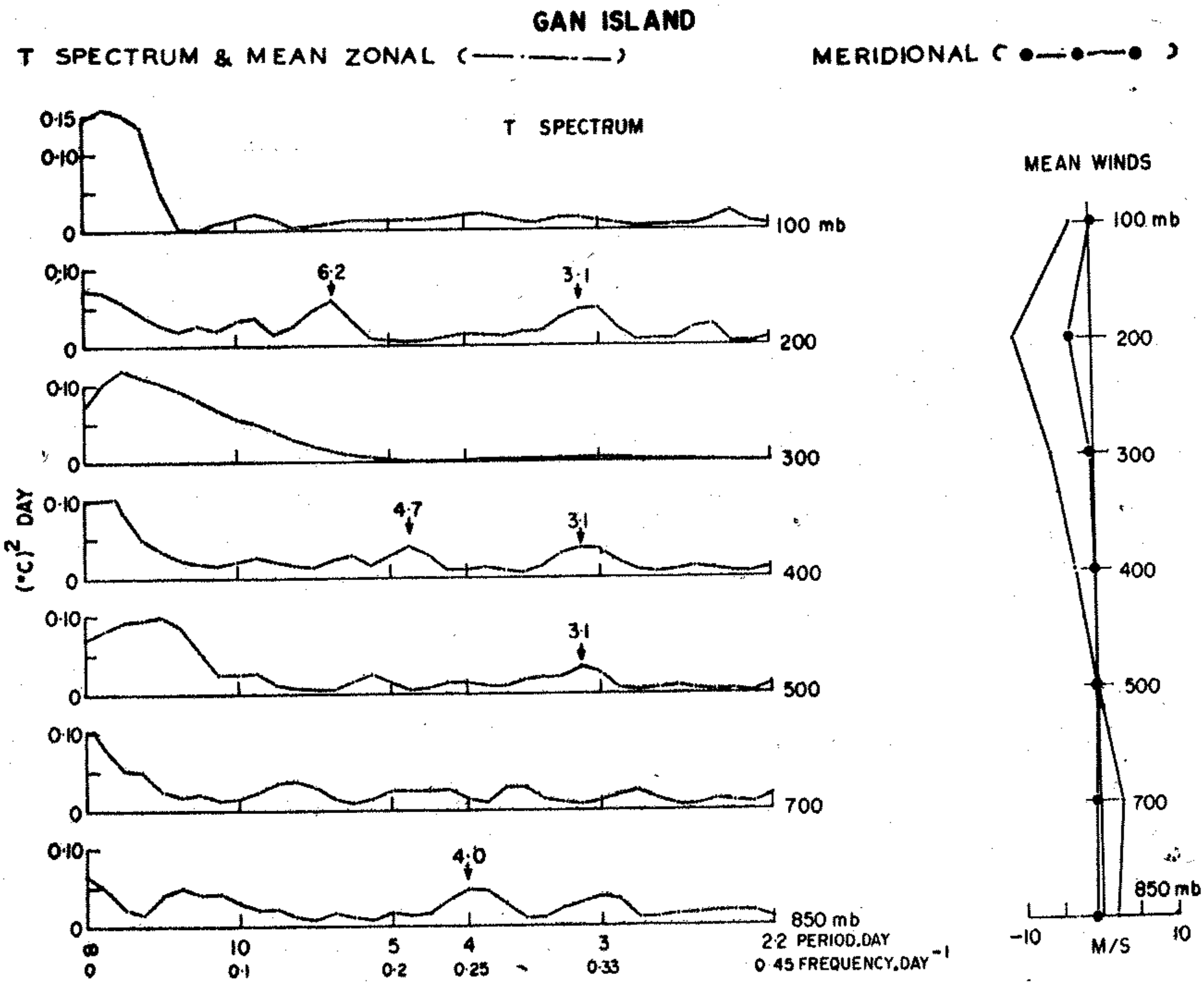

Fig. 7. Vertical distribution during June to September 1967

been reported. Murakami (1976, 1977) observed disturbances with periods of 5 and 15 days in meridional wind component over monsoon trough area, whereas Keshavamurthy (1973) noticed periods of 5 to 6, 7 to 9 and 15 to 20 days in the same component. Quasi-periodic waves around 5 days period in pressure and wind fields have been noticed by Ananthakrishnan and Keshavamurthy (1970). Similar features in sea level pressure have been reported by Bhalme and Parasanis (1975), Krishnamurthy and Bhalme (1976).

4.3. *Horizontal scale of the disturbances in the meridional wind component*

Horizontal structure of these disturbances is studied by computing the cross spectra between meridional wind component of station pairs along the same longitudinal belt. Two disturbances with a periodicity of 2.3 and 5.7 days at 850 mb level are considered for this. The phase differences ($\Delta\theta$) between station pairs and their longitudinal separation ($\Delta\lambda$) are plotted. It is seen from the diagram (Fig. 8) that points are scattered very much with coherence from 0.2 to 0.8. A regression line has been fitted to this data giving weightage to the points with high coherence. It is seen that the phase difference increases with longitude indicating that the disturbances are propagating westwards. The horizontal wave length of the disturbances are about 20 degrees and 32 degrees longitude in case of 2.3 and 5.7 days periods respectively. The phase speed worked out to be 9 and 6 degrees per day for these two waves respectively. Keshavamurthy (1973) obtained a wave length of 20 degrees longitude for the disturbances of 5.5 days period at 850 mb level based on stations with longitudinal separation of about 15 degrees. Murakami's (1976) computation show the wave length to be about 25 to 30 degrees longitude based on integrated values for the periods between 4 & 6 days in the lower tropospheric levels from 0.3 to 5.4 km. The wave length obtained by us agree reasonably well with the results of Murakami, in case of 5.7 days period.

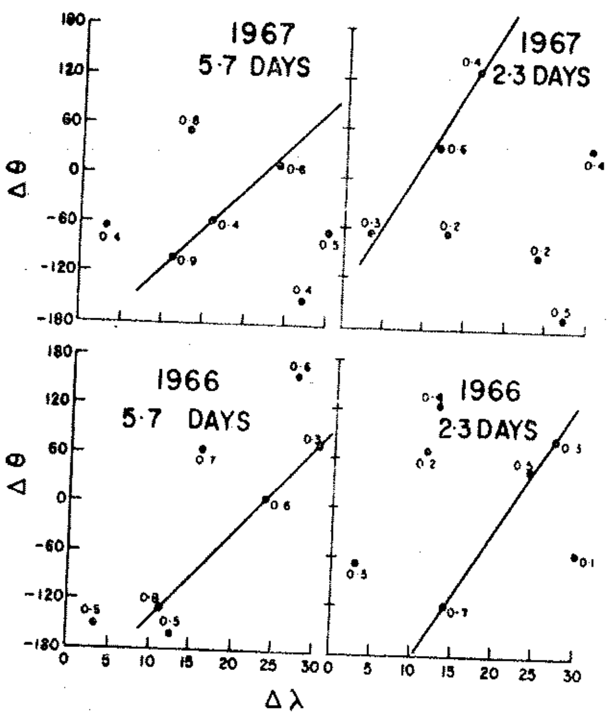

Fig. 8. Relationship between the phase difference of the V-component (Δθ) and the longitudinal difference (Δλ) at 850 mb with coherence

5. Conclusion

The study of the wave disturbances during drought and normal summer monsoon periods over the Indian Ocean area lead to the following conclusions :

In both the years, two prominent wave disturbances exist with periods of 2 to 3 and 4 to 6 days. The former one is mainly seen over the stations situated about 10 deg. N and the latter in equatorial stations. The wave activity is more prominent during the normal monsoon year. Cross spectrum analysis reveals that the disturbances move westward with a phase speed of about 9 and 6 degrees per day. The existence of the 4 to 6 days period. Yanai-Maruyama waves in the upper troposphere and lower stratosphere suggests a direct coupling between troposphere and stratosphere. Kelvin wave activity is absent in the two years under consideration.

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