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On the planetary scale changes during the summer monsoon 1979

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सार — जून 1979 के लिए स्थापित एफ. जी. जी. ई. III-बी आंकड़ों का प्रयोग, एशिया के ग्रीष्मकालीन मानसून की प्रारंभिक अवस्था के दौरान ऊपरी और निचले क्षोभ मण्डलों में ग्रहीय मान परिवर्तनों के अध्ययन के लिए किया गया है। 850 मि. बार पर मानसून जेट के अक्षांश पर कटिबंधीय हवाओं की विविधता में तरंग संख्या एक का अधिकतम योगदान रहा है। यह प्रारंभिक अवस्था में भूमध्य हिन्द महासागर क्षेत्र में गुप्त उष्मीय क्षेत्रों के पुनर्वितरण के प्रतिक्रियास्वरूप प्रकट हुए। जबकि प्रमुख ताप स्रोत क्षेत्र 70° पू. के आसपास और उत्तरी एवं पश्चिम की ओर प्रकट होते हैं। 300 मि. बार में मध्य अक्षांश ग्रहीय मानों में महत्वपूर्ण परिवर्तन पहले आता है। तरंग संख्या एक और दो कमजोर पड़ जाती हैं और उनका उच्चिष्ठ आयाम की ओर अभिमुख होता है और पूर्व की ओर मुड़ जाता है। तरंग संख्या तीन पर्वतीय बल के कारण अधिक मात्रा में प्रकट होती है।

ABSTRACT. FGGE III-b data sets for June 1979 were used to study the planetary scale changes in the upper and lower tropospheres during the onset phase of the Asiatic summer monsoon. The largest contribution to the variance of the zonal wind at the latitude of the low level jet at 850 mb was from the wave number one. This appeared to be in response to the re-distribution] of the latent heating fields in the equatorial Indian Ocean region in the onset phase when a prominent heat source region appeared around 70°E and extended northwards and westwards. At 300 mb significant changes preceded the onset in the middle latitude planetary scales. The wave numbers one and two weakened and their amplitude maxima shifted polewards and eastwards. The wave number three appeared to be largely due to orographic forcing.

1. Introduction

During the summer months of May to August, the Asiatic monsoon (or the monsoon as referred to, hereafter) dominates the global tropics over a vast region from 30° W to 150° E. Studies by Krishnamurti (1971 a, b) and Kanamitsu and Krishnamurti (1978) show that the 200 mb monsoon flows are of planetary scales with a large proportion of the total variance of the fields in the quasi-stationary components of the long waves (wave numbers one and two). Pearce and Mohanty (1984) found the planetary waves on the subtropical jet having a controlling influence on the low level cross-equatorial flow over the western Indian Ocean during the monsoon. In 1979, the onset phase in the Arabian Sea was during 11-15 June 1979. In the pre-onset period from 22 May to 5 June 1979 persistent blocking type situations with large amplitude troughs were observed in the middle latitudes along the 50-55° N sector in the upper troposphere (Sikka 1980). The extension of such large amplitude troughs bringing in cold air into the monsoon region reduces the differential heating between the land and the ocean, and thus delays the onset as it happened in 1979. The planetary scales thus play an important role in the evolution of the monsoon characteristics. The teleconnections between the tropical heat sources and the planetary scale waves of the middle and high latitudes have been the subject of several studies. Simmons (1982) found that a tropical heat source placed at 15° N, 135° E produce the largest response in the middle and high latitudes. Hoskins and Karoly (1981) showed that the response in the lower levels was in the neighbourhood, west of the source. At upper levels the response was found poleward and east ward in the middle latitudes. Most of these studies, however, discuss steady state linear solutions to model equations for a barotropic, potential vorticity conserving atmosphere. The basic flow in the foregoing studies is either zonally symmetric or one with slowly varying zonal asymmetries. Despite these limitations, the hypothesis that the wave energy forced in one region of the atmosphere propagate and influence other regions seems to be well-founded and is able to explain various circulation features. Studies by Webster and Chou (1980), Krishnamurti and Ramanathan (1982), Ramanathan (1986) and Pearce and Mohanty (1984) show that the distributions of the latent heating undergoes significant changes during the onset and play a crucial role in the evolution of the monsoon flows. Some of the planetary scale changes during the onset may be due to this re-distribution of the thermal sources. In this study we investigate some aspects of the planetary scale changes associated with the onset of the monsoon, 1979.

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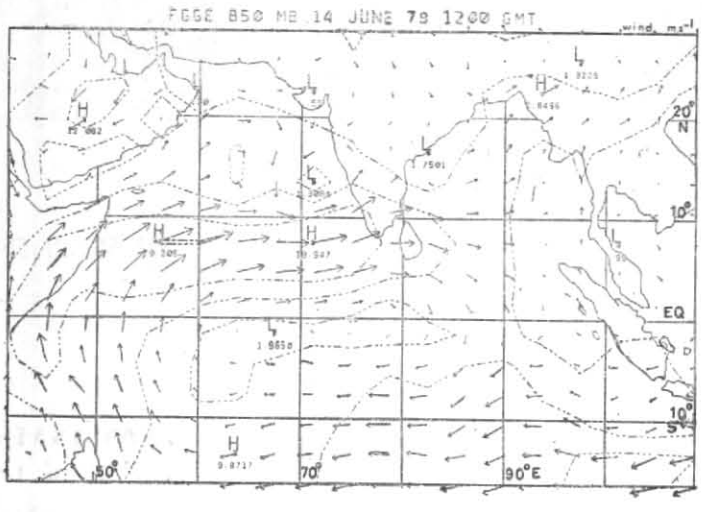


Fig. 1. 850 mb wind analysis on 14 June 1979, 1200 GMT

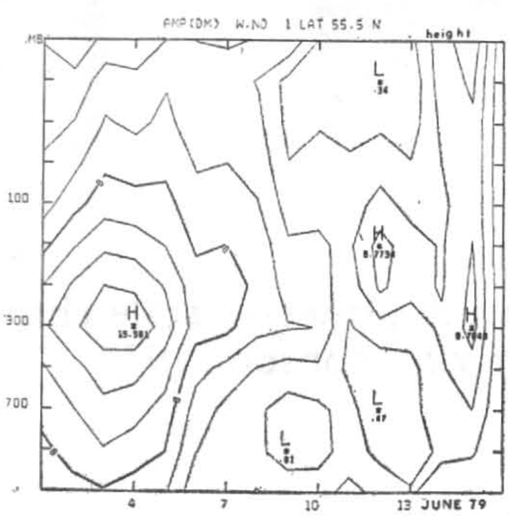
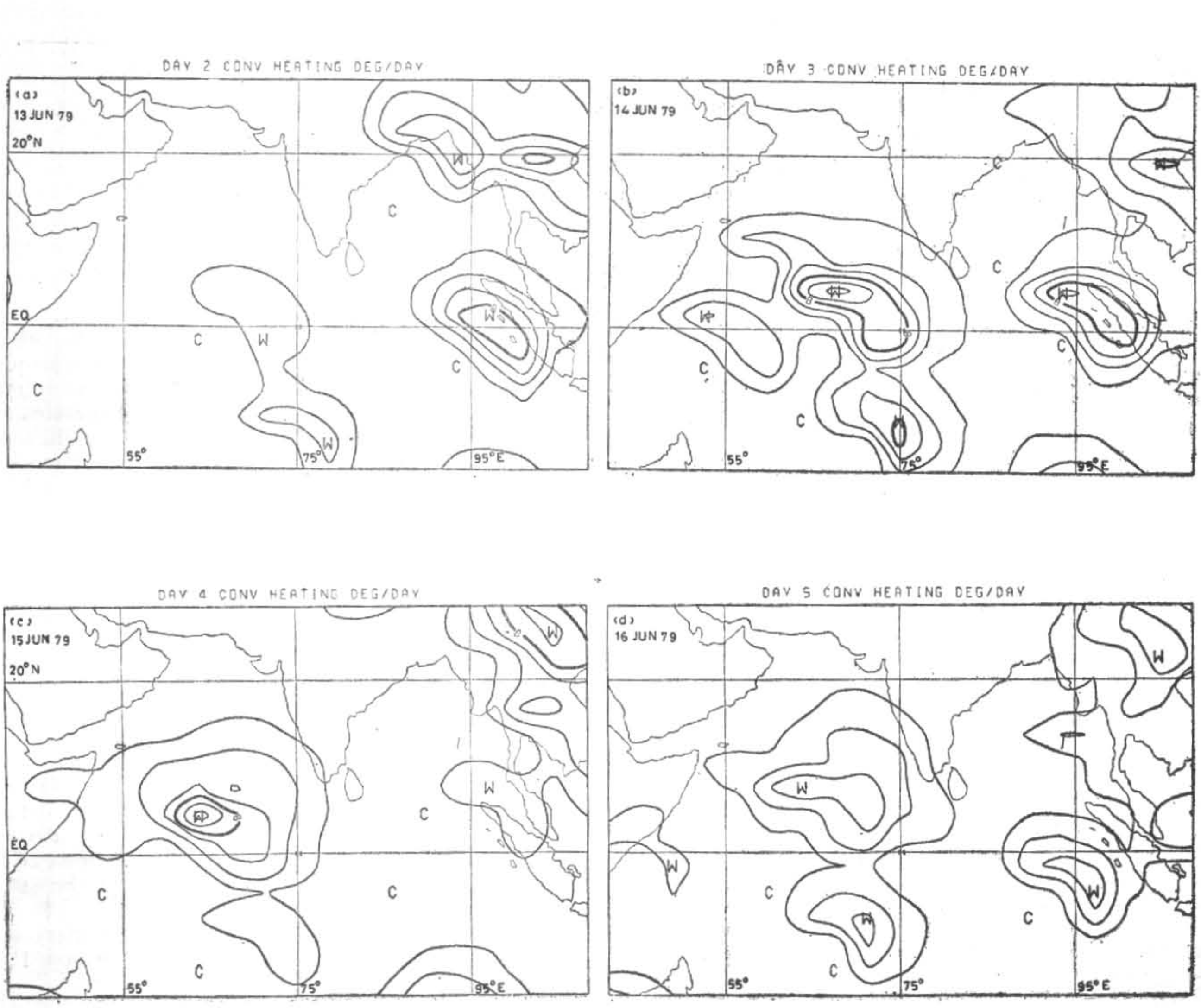


Fig. 2. Vertical profile of height field amplitudes during the period 1-15 June 1979



Figs. 3(a-d). Condensational heating fields from the forecast mode valid for (a) 13 June '79, (b) 14 June '79, (c) 15 June '79 & (d) 16 June '79

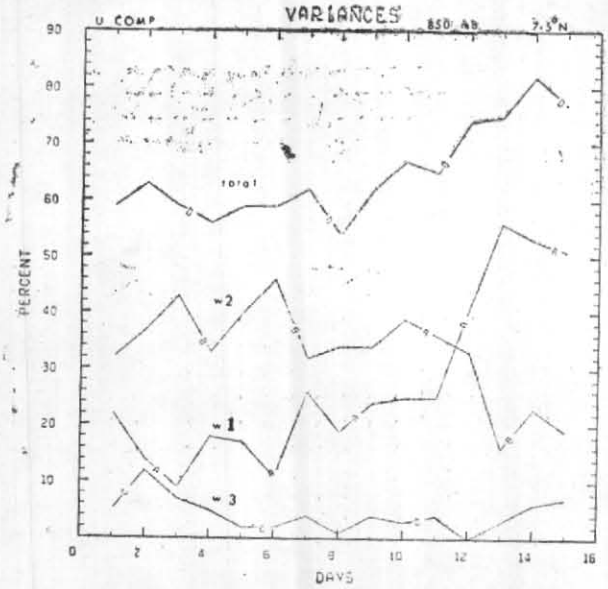


Fig. 4. Percent variance contributions from wave numbers one, two and three (A, B, C and $D = A+B+C$) of U comp. along 7.5° N during 1-15 June 1979

It is, however, well-known that at low wave numbers westward travelling waves and eastward travelling baroclinic instabilities will coexist with stationary waves forced by orography and with the quasi-stationary waves from the heat sources. No attempt has been made in this study for the separation of these waves for the data analysis. The purpose is to follow the time histories of the amplitudes and phases of the total planetary waves as they exist in the observations and examine the changes in relation to the forcing mechanisms and synoptic changes. Section 2 gives the data set details and the method of analysis. The lower and upper tropospheric changes are discussed in the next section.

2. The data sets

The data sets used in this study were the FGGE III-b wind and height analyses for the period 1-15 June 1979. The onset phase of the monsoon in the Arabian Sea was during 11-15 June 1979. The period before 5 June 1979 was marked by above normal pressure in the vicinity of the seasonal low in the Indian region, persistent blocking type situations near 50-55°N and 30-50°E and other features unfavourable for the onset. The period 1-4 June 1979 in our data sets may, therefore, represent the pre-onset phase. The period 5-11 June '79 when conditions favourable to the onset, like the development of the seasonal low and the disappearance of the blocking highs, were getting established, is referred to as the transition period in this study. The data analysis was done with reference to a few significant synoptic features characterising the monsoon onset. In the lower levels we examine the strengthening of the low level jet and at the upper levels our attention will be focussed on the history of the blocking highs which seemed to be associated with the delay of the onset in 1979. For this, the zonal wind (U) data sets at 850 mb close to the jet were examined. Initially zonal harmonic analysis was performed over the 850 mb U fields and the Z fields at 12 levels 10, 30, 50, 70, 100, 150, 200, 300, 500, 700, 850, 1000 mb for each latitude circle

$$F = \bar{F} + \sum_{k=1}^{N/2} C_k \cos K(\lambda - \theta_k) \qquad (1)$$

where F is any variable given for an even number of points N along the latitude circle, $\bar{F}$ is the zonal mean of F, $N/2$ the number of resolvable waves, C_k the amplitude and θ_k the phase angle of the kth harmonic and λ the longitude increasing from Greenwich. Fig. 1 gives the 850 mb streamline-isotach analysis on 14 June 1979 1200 GMT at the onset time. One could locate the wind maxima in the latitude belt 5°-10° N centred around 7.5° N. Planetary scale changes in this belt will therefore, be interesting and hence examined in detail. Fig. 2 gives the vertical distribution of the wave number one height amplitudes from 1000 mb to 10 mb for the period 1-15 June 1979 along 55° N. On most of the days an amplitude maximum was found at 300 mb. The wave appeared to be trapped vertically which is typical of the northern hemisphere summer. Further discussions on the upper level planetary scale changes relate mainly to 300 mb level.

Pearce and Mohanty (1984) computed the fields of heat sources as residuals of the moisture and temperature (enthalpy) budgets and found that the heating due to condensation in the regions of ascent provided an increasing heat source over the Arabian Sea accompanied by the strengthening of the low level cross-equatorial flow. This is in agreement with Ramanathan (1986) who used a global spectral model in which the convective heating was computed by the method of parameterization by Kuo. With FGGE III-b data sets as input,

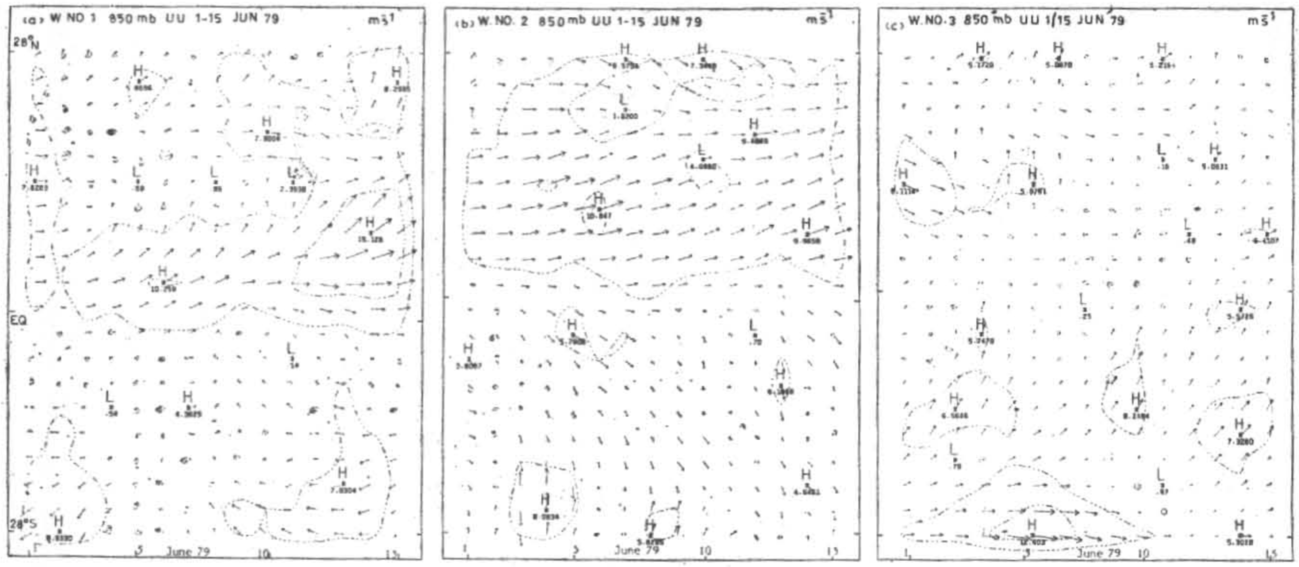


Fig. 5. Latitudinal variation (30° S to 30° N) of the amplitudes and phases for the wave numbers one, two and three of the *U* component during 1-15 June 1979. Amplitude values are proportional to the length of the arrows and contoured at 5 m s^{-1}. The directions towards which the arrows are pointed are the phase angles. For example, an arrow pointing towards the east indicates the amplitude maximum at 90°E

the model was integrated for five days from 11 June 1979 to provide the forecasts for the onset phase. The model condensational heating fields (Figs. 3 a, b, c, d) are used for discussion in the study.

3. Tropospheric planetary scale changes

(a) *Low level features*

Fig. 4 shows the percent variance of the wave numbers one, two and three (A, B, C with $D=A+B+C$ in Fig. 4) of the U component along 7.5° N during 1-15 June 1979. The planetary scales accounted for about 60% of the total variance. The wave number three was the weakest of them with contributions about 10% or less. Wave number two was the largest in the period before the onset with about 30 to 40% of the total variance. During the onset phase the wave number one showed substantial increase and could account for about 50% of the total variance. It appears that the strengthening of the low-level jet in 1979 was largely due to wave number one. Fig. 5 shows the latitudinal variation (from 30° S to 30° N) of the amplitudes and phases for the wave numbers one, two and three for the U component.

The wave number one amplitudes increased during the period 5-13 June 1979 from 10 m s^{-1} to 15 m s^{-1}. The wave number two amplitudes also showed a maximum of 10 m s^{-1} by 5 June 1979 but weakened slightly during the onset phase. The phase angles indicated that the amplitude maxima in both these waves were in the longitudinal belt in the Arabian Sea. In the southern hemisphere the waves had insignificant amplitudes throughout the fortnight and did not seem to be part of the northern hemisphere planetary scale changes. The wave number three was weak throughout in both the hemispheres and hence was not interesting for the monsoon onset.

(b) *Upper tropospheric changes*

Fig. 6 shows the 300 mb Z field amplitudes and phases for wave numbers one, two and three for the fortnight. Initially all the three waves had amplitude maxima in the 0-50° E around 50-55° N in the pre-onset phase. This was perhaps the contributing factor to the persistent blocking highs in the sector during the pre-onset phase. After 5 June in the transition period the amplitude maxima of all the three waves moved north especially those of wave numbers one and two.

The phase angles of one and three showed that the waves were propagating east as well. The wave number two which was the weakest of the three almost disappeared during the onset phase. The wave number one, on the other hand, was the largest with maxima around 65-70° N, 90-95° E and 75-80° N, 150° E. Fig. 7 shows the wave number one *amplitudes* of the 300 mb Z fields along 55° N plotted with the 850 mb U fields along 7.5° N during the fortnight. The 300 mb wave started weakening much earlier than the dramatic strengthening of the U amplitudes, suggesting that the upper tropospheric changes in wave number one preceded those in the lower levels.

4. Discussion

Pearce and Mohanty (1984) show that the mean heating for the pre-onset months is concentrated in the eastern Indian Ocean in the tropical belts of the West Pacific and Indonesian regions. During the fully-developed monsoon this heat source extends from Indonesia across Southeast Asia and India to the east coast of Africa; and its influence extends over virtually the

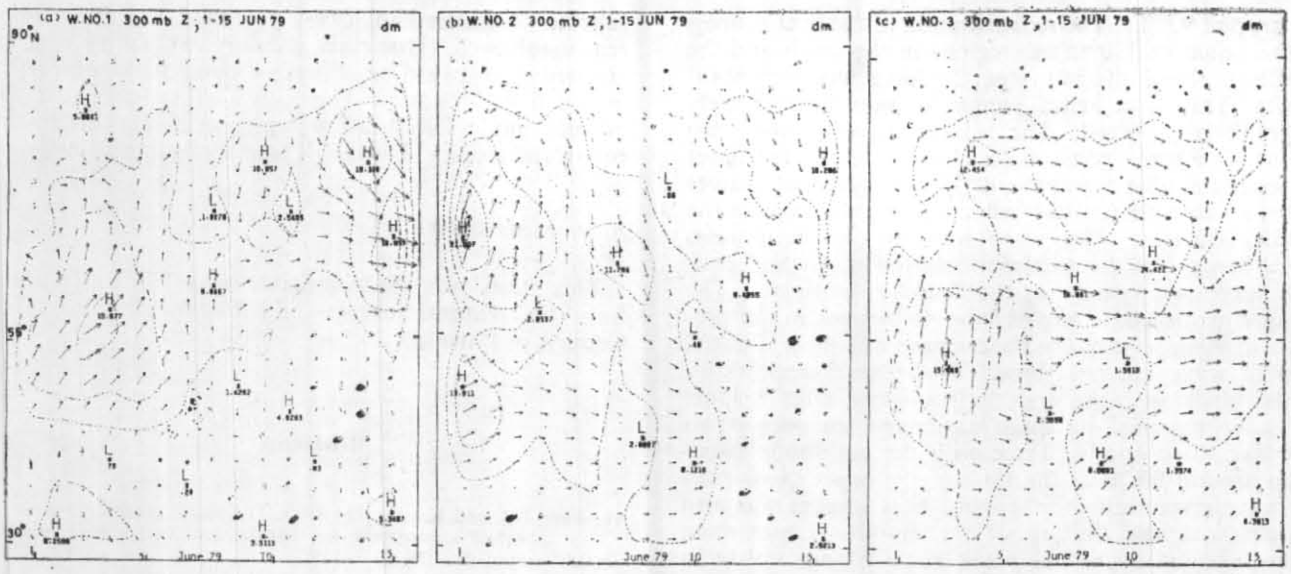


Fig. 6. Same as in Fig. 5 except for 300 mb Z field contoured at 5 dm

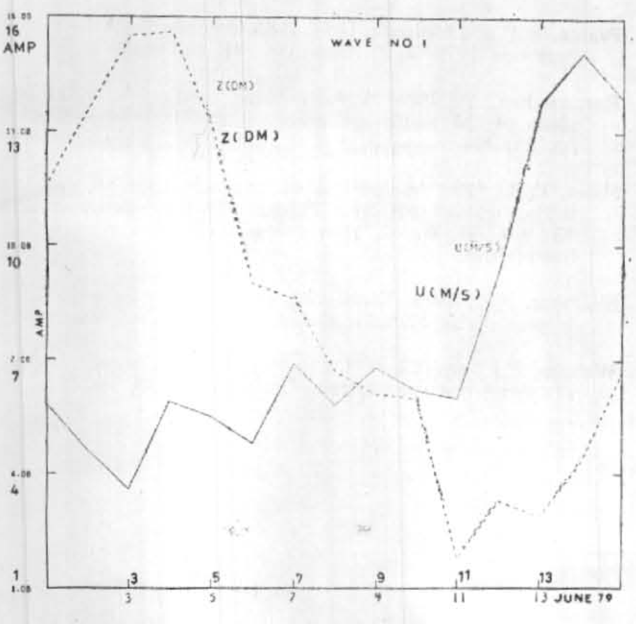


Fig. 7. Plots of the wave number one amplitudes of 300 mb Z fields along 55 N and 850 mb U fields along 7.5 N during 1-15 June 1979

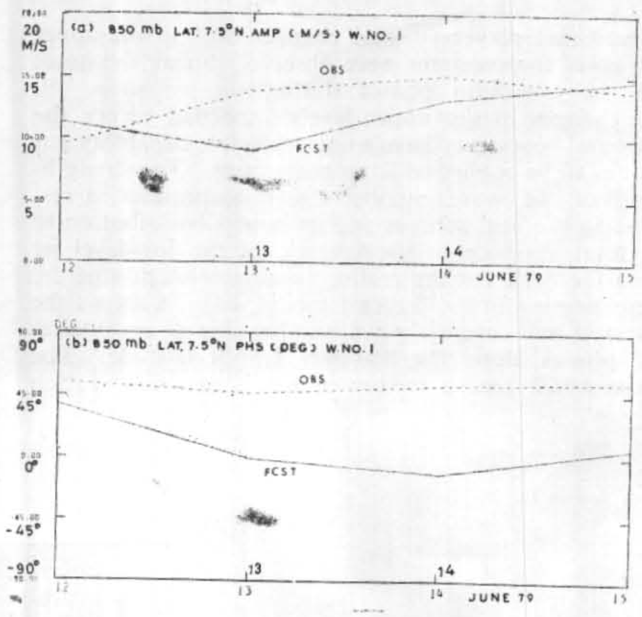


Fig. 8 Observed and forecast wave number one 850 mb U component amplitudes and phases along 7.5 N

whole of the region 0-150° E and well into the southern hemisphere. It is difficult to see such a gradual westward extension of heat sources in the (short-range) model forecast condensational heating shown at 24-hour intervals from day 2 to day 5 (Fig. 3) (12 June to 16 June 1979). These figures suggest a significant redistribution of heat sources in the Indian ocean region in which a source region around 70° E becomes gradually prominent and extends northwards and westwards. The sequence of events from the model output (Ramanathan 1986) are the development of a low pressure area around 70° E, build-up of a meridional pressure gradient, low level convergence and then the strengthening of the zonal wind in an adjustment process. More observational studies would, however, be required to establish whether the heat sources precede the strengthening of the low-level jet or *vice-versa*, in all the occurrences. At 300 mb the wave number three phases showed little changes in the transition and onset periods. The change of phase around 5 June 1979 was, however, rather abrupt. It appeared that with the disappearance of the blocking highs and the consequent transients contributing to the wave, the wave assumed its seasonal quasi-stationary structure with the amplitude maxima in the 65-70° N, belt around 90° E. The redistribution of the heat sources in the equatorial tropical regions in the onset and the transition phases did not seem to have any significant impact. This wave hence seems to have been largely orographically forced. The weaker wave number two had no significant phase angle changes during the onset phases but almost disappeared. The tropical heat sources perhaps had a destructive influence on this wave in the middle latitudes. The wave number one amplitudes strengthened but the maximum shifted north and east. The wave weakened in the middle latitudes. The changes in the phase angles from 45 degrees in the pre-onset to 90 degrees in the onset phase was more gradual than in wave number three. With the disappearance of the blocking highs and the transients after 5 June, the wave regained its quasi-stationary seasonal structure like wave number three with the amplitude maximum around 90° E at the time of the onset. However, the wave response to the tropical heat sources was also evident with the shifting of the amplitude maximum polewards and a gradual phase angle change unlike in wave number three.

5. Conclusion

Significant planetary scale changes both in the upper and lower tropospheres were observed during the onset and the transition phases during the monsoon '79. The changes in the upper levels happened before the onset and hence may have some predictive capability but this has to be confirmed from more cases. The strengthening of the wave number one U amplitudes in response to the heat sources and its largest contribution to the total variance in the latitude of the low-level jet stress the need for the realistic parameterization of the latent heating in the forecast model. Fig. 8 shows the observed and forecast wave number one U amplitudes and phases along the 850 mb 7.5° N latitude. The model which used a version of Kuo's parameterization scheme (Ramanathan 1986) predicted the amplitudes reasonably well. However, the forecast phases had an erroneous westward propagating component especially in the first 24 hours. This could also be due to the normal mode initialization which are suspect in the equatorial tropics. These will be investigated elsewhere.

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