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Letters to the Editor

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KINETIC ENERGY OF EXTRA TROPICAL WAVES AND THEIR EFFECT ON THE INDIAN MONSOON RAINFALL

1. The effects of mid-latitudinal circulations on the activity of the monsoon have been studied by many workers. Malurkar (1950) showed that southward extension of extra-tropical westerly trough into northern India leads to break in the Indian monsoon. Pisharoty and Desai (1956) and Mooley (1957) concluded that passage of western disturbances (which are the remnants of mid-latitude systems) in quick succession lead to break in monsoon. Chakravarthy and Basu (1957) compared the number of western disturbance days and eastern disturbance days and found that greater the number of western disturbance days lesser the number of eastern disturbance days. Changraney (1966) showed that 31 out of 52 cases of heavy rainfall in the northern river catchments occurred during the presence and movement of westerly waves. Bedi *et al*. (1981) observed that systems in the westerlies are more active in the weak monsoon situations. Ramaswamy (1958 and 1962) used global data and showed that during active monsoon period middle latitude systems are confined to northern middle latitudes only and in the break monsoon, they penetrate into the northern Indian latitudes and thereby replace easterlies over the north Indian plains by westerlies. Unninayar and Murakami (1978) found that during weak monsoon situation anticyclonic circulation (at 200 hPa) over Himalaya bifurcates into two cells due to penetration of the mid latitude trough into sub-tropics. At 700 hPa they found that easterlies around 20° N and 30° N over India are replaced by westerlies and north-westerlies intensified in the Arabian Sea. Sikka and Grossman (1981) found that a large amplitude trough in the regime of subtropical westerlies was present during the break period of monsoon 1979. Raman and Rao (1981) are of the views that mid latitude trough have effect of pulling the monsoon trough further north. Unninayar and Murakami (1978) studied wave number domain and found that during abnormal period strong mid latitude trough penetrates deep into the monsoon area. Bawiskar *et al.* (2002) showed that short waves over extra tropics are significantly active during onset and withdrawal phases and weak during established phase.

All the above studies present qualitative effect of mid-latitude systems on Indian monsoon. These studies show that the migration of the mid latitude systems into the tropics leads to weakening of monsoon conditions over India. The purpose of the present study is to quantify the effect of the mid latitude systems on Indian monsoon rainfall through kinetic energy of waves. For this purpose, Fourier technique is used to decompose the wind field into independent wave components. Intra-seasonal variation of kinetic energy of these waves over extra-tropics are studied in relation to the monsoon rainfall over India.

2. Daily zonal (u) and meridional (v) wind data at 500 hPa for the period from 1 June to 30 September of 1994, 1995 and 1996 are considered. The data are provided by the National Center for Medium Range Weather Forecasting (NCMRWF), New Delhi. The data are at 1.5° × 1.5° latitude/longitude interval. The area considered for this study is between 12° S and 51° N and all longitudes in E-W direction. Bawiskar *et al*. (1995, 2000 and 2002) showed that NCMRWF data is the most suitable data set for the study of tropical and extra-tropical regions. Method of decomposition of the observed wind field into the spectrum of waves and the computation of their kinetic energy is given in detail by Bawiskar and Singh (1992).

3. The area between 10° S and 50° N is divided into three broad belts as Equatorial Belt (10° S - 10° N), Monsoon Belt (10° N - 30° N) and Extra-Tropical Belt (30° N - 50° N). These belts will be referred to as EB, MB and XB respectively. There are 240 grid points along each latitude circle. The data can be decomposed into maximum 120 waves. Percentage variances of all the 120 waves are computed. Larger the variance, more intense is the wave. Bawiskar (2001) showed that a signal given by a wave having large variance is dependable but a significant signal given by a wave with less variance is not worth depending. Instead of presenting contribution of individual wave, these waves are grouped into three categories. The percentage variances of the different categories of waves of u-field over the three belts are presented in Table 1. The table clearly shows that the variance explained by first ten waves is around 95% or more. As such we have considered only first ten waves.

(*i*) Kinetic energy of Standing Waves (SW) and Transient Waves (TW) over the belts EB, MB and XB are given in Table 2. The XB is dominated by standing wave 0 (*i.e.*, zonal flow) and transient short waves 3-10.

TABLE 1

Percentage variance explained by various wave categories for zonal wind (*u*) at 500 hPa

Latitudinal belts	Wave categories	Percentage variance explained		
		1994	1995	1996
XB	Long waves (1-2)	43.0	47.9	38.3
(30° N - 50° N)	Short waves (3-10)	53.0	48.9	56.8
	Remaining waves(11-120)	4.0	3.2	4.9
MB	Long waves (1-2)	42.9	39.3	46.5
(10° N - 30° N)	Short waves (6-10)	50.6	52.9	47.5
	Remaining waves(11-120)	6.3	8.1	6.6
EB	Long waves (1-2)	67.3	70.9	63.5
(10° S - 10° N)	Short waves (6-10)	31.4	27.7	35.4
	Remaining waves(11-120)	1.3	1.4	1.7

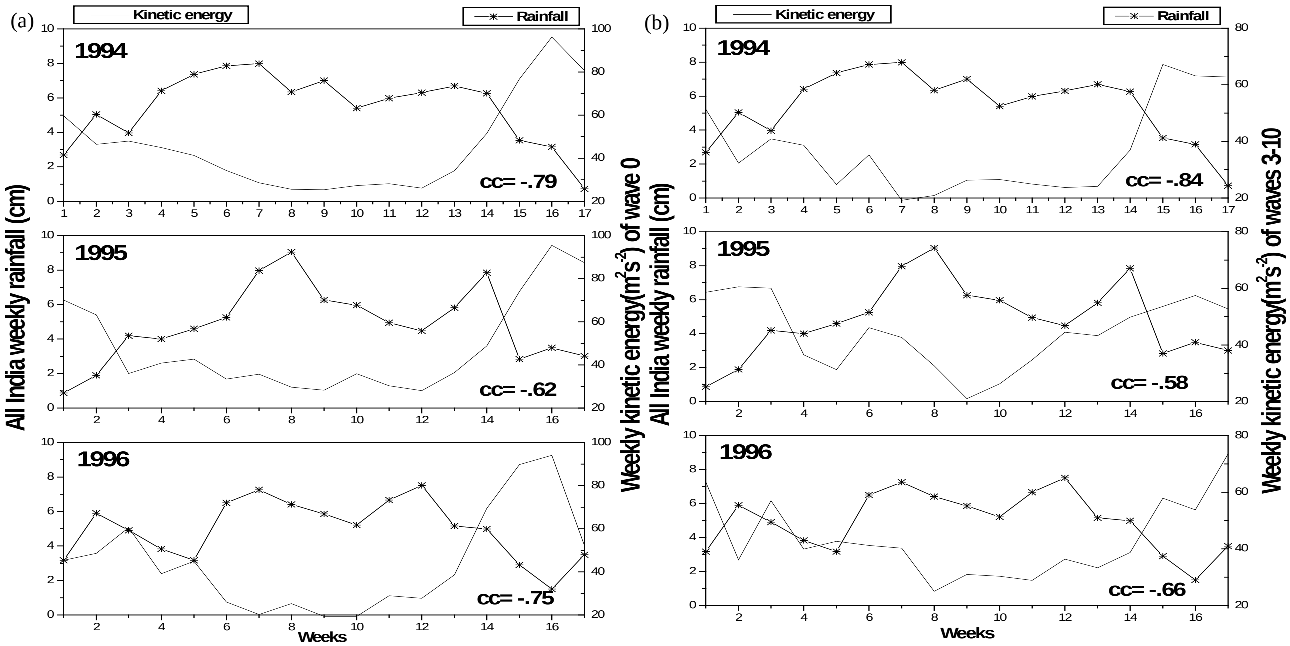
XB = Extra tropical Belt, MB = Monsoon Belt & EB = Equatorial Belt

TABLE 2

Kinetic energy of Standing Waves (SW) and Transient Waves (TW) at 500 hPa over EB, MB and XB (Unit : m^2s^{-2})

Latitudinal belts	Waves	1994		1995		1996	
		SW	TW	SW	TW	SW	TW
XB	0	31.0	2.0	31.3	3.7	30.6	2.1
(30° N - 50° N)	1	1.4	2.0	1.9	3.2	1.2	3.6
	2	0.5	2.0	1.2	3.8	0.4	3.5
	3-10	4.7	21.6	4.2	32.1	3.9	30.8
MB	0	5.1	1.5	5.5	2.5	4.6	1.2
(10° N - 30° N)	1	1.1	1.1	1.0	1.4	1.1	2.1
	2	0.7	0.9	0.9	1.4	0.7	1.5
	3-10	1.9	5.6	1.6	8.3	1.8	8.2
EB	0	13.7	.4	15.3	0.6	12.0	0.5
(10° S - 10° N)	1	1.6	1.1	1.9	1.6	1.4	2.3
	2	2.1	.9	2.0	1.3	2.5	1.8
	3-10	1.7	4.6	1.5	6.8	1.9	7.3

(*ii*) Many meteorological elements have weekly and quasi-bi-weekly periodicity (Krishnamurti and Bhalme, 1976). The precipitation over India and east Asia have dominant quasi bi-weekly periodicity (Unninayar and Murakami, 1978). Bawiskar *et al*. (1998) showed that kinetic energy of wave 1 has dominant 30-40 day as well as weekly and bi-weekly periodicity whereas short waves have dominant weekly and bi-weekly periodicity. Therefore, to investigate the relationship, weekly series for the period from 1 June to 30 September of all India rainfall and kinetic energy of zonal waves over XB are prepared and correlated. Each series contains seventeen data points. The correlations are computed for waves 0 to 10. It is found that wave number 0 and



Figs. 1(a&b). Comparison between All India weekly rainfall (cm) and weekly kinetic energy (m^2 s^{-2}) of (a) wave 0 over the belt from 36° N – 42° N and (b) wave 3-10 over the belt from 42° N – 45° N

effective kinetic energy of waves 3-10 over extra-tropics have significant negative correlation with all India weekly rainfall.

Comparison between weekly all India rainfall and weekly kinetic energy of wave 0 averaged over latitudes (36° N to 42° N) is shown in Fig. 1(a). Kinetic energy decreases during first four weeks (June) and then remains minimum during week No. 4 to 12 (July and August) and afterwards starts increasing upto week No.16. The similar features are also shown by KE of waves 3-10 [Fig. 1(b)]. All the variations show significant negative correlation. It is therefore, worthwhile to look into the daily variations of kinetic energy of wave 0 and waves 3-10 during active and weak monsoon rainfall. We have selected two contrasting cases; (a) active phase of monsoon 1995 and (b) break phase of monsoon 1996.

(*iii*) The most active week of the three years was week ending of 26 July 1995. All India weekly rainfall was around 9 cm during week No. 8 which is 126% of the long term normal of that week. As per the Weekly Weather Report (WWR) of IMD, 24 out of 35 sub-divisions received either excess or normal rainfall. The sub-divisions close to foot hills of Himalaya were either deficient or scanty. During this week a low pressure area over northwest Bay moved in west northwesterly direction and gave widespread rainfall over central India. The monsoon trough was in its normal/south of normal position.

Fig. 2 gives latitudinal and daily variation of kinetic energy of wave 0 and waves 3-10 from 10 July 1995 to 19 August 1995. The meridional oscillation of kinetic energy of waves 3-10 is very large as compared to that of wave 0. This is because, wave 0 is dominated by standing component while waves 3-10 are dominated by transient component (Table 2). The isoline of 30 m^2s^{-2} of kinetic energy of waves 3-10 moved gradually from 30° N to 40° N. It then remained stationary around 37° N for about three days and then again moved northward upto 50° N. This northward retrogression of kinetic energy is followed by a very good rainfall activity during the week ending of 26 July 1995. Fig. 2 further shows that the isoline of 30 m^2s^{-2} of kinetic energy of waves 3-10 propagates southwards from 50° N to 37° N during 5 to 11 August 1995. This event is immediately followed by a break situation during 12-15 August 1995 (De *et al.*, 1998).

(*iv*) There was a break from 1 to 5 July 1996 (De *et al.*, 1998). As per WWR the monsoon covered the whole

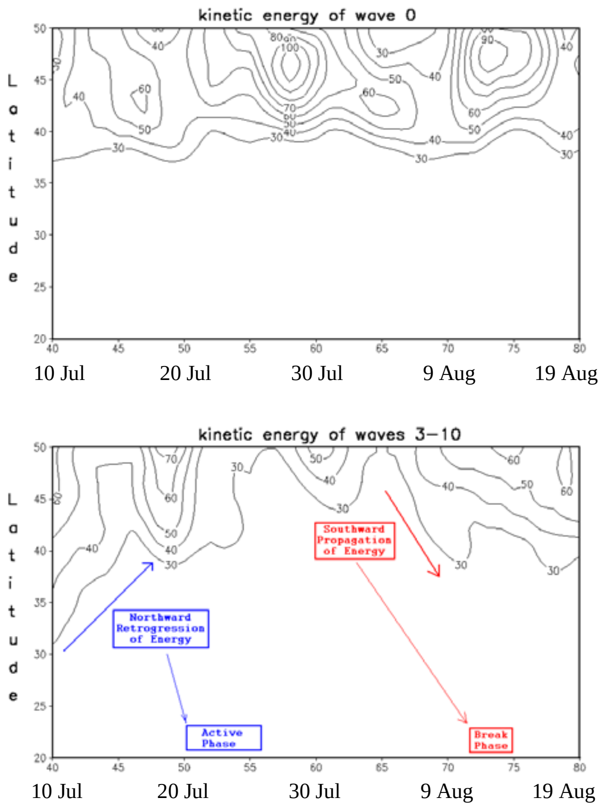


Fig. 2. Latitudinal and daily variation of kinetic energy ($m^2 s^{-2}$) of wave 0 and waves 3-10 at 500 hPa from 10 July 1995 to 19 August 1995

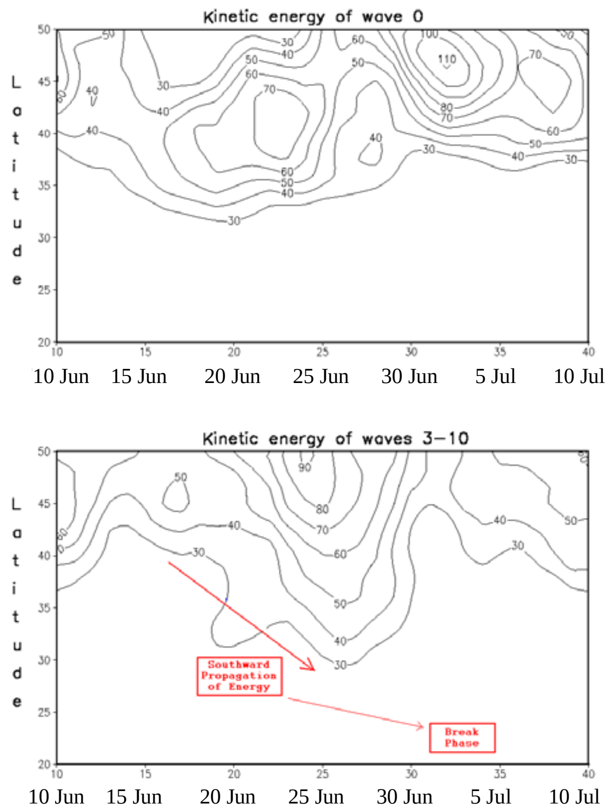


Fig. 3. Latitudinal and daily variation of kinetic energy ($m^2 s^{-2}$) of wave 0 and waves 3-10 at 500 hPa from 10 June 1996 to 10 July 1996

country on 30 June. A western disturbance as an upper air system lay over Pakistan and moved northwestward across Jammu and Kashmir on 2 July 1996. The axis of monsoon trough was close to foot hills of Himalaya from 1 to 3 July 1996 and remained their upto 5 July 1996. Nearly 26 out 35 sub-divisions were either deficient or scanty. Sub-divisions close to foot hills of Himalaya received either normal or excess rainfall. The weekly rainfall was 56% of the long term normal of that week.

Fig. 3 gives latitudinal and daily variation of kinetic energy of wave 0 and waves 3-10 for the period from 10 June 1996 to 10 July 1996. The meridional oscillation in the kinetic energy of waves 3-10 is more significant as compared to that of wave 0. The isoline of 30 m^2s^{-2} of kinetic energy of waves 3-10 gradually moves southwards from 40° N to 28° N during 12 June to 27 June 1996. This event was immediately followed by a break like situation which led to subdued rainfall activity during week ending 3 July 1996.

4. The above cases clearly indicate that intensification (weakening) of waves 3-10 over XB causes southward (northward) propagation (retrogression) of their kinetic energy and leads to weak (active) rainfall spell over India.

Strengthening of the wind causes an intensification as well as an increase in the amplitude of a wave. Increase in the amplitude results into southward penetration of westerlies. Southward penetration of westerlies either weaken or replace the easterlies over north India. Replacement of easterlies by the westerlies leads to the disappearance of monsoon trough. The disappearance of monsoon trough weakens the monsoon and rainfall activity. This situation is generally known as a break in monsoon activity. The reverse happens when the wave weakens.

5. The major findings of this study are as follows – Kinetic energy of wave 0 and effective kinetic energy of waves 3-10 have significant negative correlation with weekly all India rainfall. Kinetic energy of wave 0 is dominated by standing component while kinetic energy of waves 3-10 is dominated by transient component. The fluctuations in the kinetic energy of waves 3-10 are very

large as compared to the fluctuations in the kinetic energy of wave 0. Intensification (weakening) of waves 3-10 causes southward (northward) propagation (retrogression) of their kinetic energy and leads to weak (active) rainfall spell over India.

Some more cases of active and weak spells are required to be considered for the confirmation, nevertheless the results have practical utility and are useful in getting prior signal about subdued or good rainfall activity over India.

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