Proc. Indian Acad. Sci. (Earth Planet. Sci.), Vol. 98, No. 4, December 1989, pp. 365–373.

Harmonic analysis of summer mean wind at 200 mbar level during contrasting monsoon years over India

S M BAWISKAR, S T AWADE and S S SINGH
Indian Institute of Tropical Meteorology, Pune 411 005, India

MS received 7 October 1989

Abstract. Summer (June–August) mean zonal and meridional wind components at 200 mbar level are subjected to harmonic analysis for the years 1970, 1971, 1972 and 1979. It is found that the small scale disturbances are intense during normal monsoon years. The westerlies in the belt 10°S to 30°S are stronger during drought years. During normal monsoon years (1970, 1971) the northward transport of westerly momentum by wave number 1 at 19·6°N is large as compared to drought years (1972, 1979). The transport of westerly momentum by standing eddies is northward for all the years between 5°S and 28·7°N but large during the normal monsoon years.

Keywords. Harmonic analysis; summer mean wind; meridional transport.

1. Introduction

Indian summer monsoon is the largest local perturbation in the general circulation of the atmosphere and is the most important among the seasonal standing eddies. During the monsoon period over India and neighbourhood angular momentum source is disturbed due to large scale cloudiness. Thus the study of angular momentum becomes important. The wave-like character of disturbances suggest that the use of Fourier analysis is the natural method to study the different scales of eddies.

There are a number of studies in wave number domain (Kanamitsu and Krishnamurti 1978; Murakami 1981; Awade *et al* 1984). Awade *et al* (1986) studied the large scale features of the summer monsoon of 1979 by using monthly data for the period June through August at 700 mb and 300 mb levels and computed momentum flux in wave number domain and wave to wave and wave to zonal interactions.

In the present paper we have extended the above work by considering four years of data. The computation of transport of westerly momentum in wave number domain has been done for two normal monsoon years (1970, 1971) and two drought years (1972, 1979) in order to understand anomalies in the monsoon activity in terms of global circulation of the atmosphere.

2. Data

Monthly mean grid point data of zonal and meridional winds at 200 mbar level were picked up over thirteen latitude circles, as given in table 1, at 5° longitude interval for the months June, July and August. The data were obtained from the US National Meteorological Centre (NMC).

Murakami (1978) showed that the NMC data are adequate (at least qualitatively) in describing some characteristic features at 200 mbar level circulation during 1970–72 summer. Therefore we have considered 200 mbar level for our study.

Since only monthly data were available it was not possible to compute the corresponding transient terms. Murakami (1963, 1981) showed that the standing part is the source of energy to the transient part. Kanamitsu and Krishnamurti (1978) also showed that a large portion of variance of eddy kinetic energy of long waves is due to the standing eddies. Therefore the study of the standing part is considered important.

3. Meridional transport of westerly momentum

From monthly zonal $U(\lambda)$ and meridional $V(\lambda)$ winds the three-monthly mean values $\bar{U}(\lambda)$ and $\bar{V}(\lambda)$ were calculated at 72 grid points along each latitude circle.

Averages of the three-monthly wind components along latitude circles are given by

$$[\bar{U}] = \frac{1}{N}\sum_{\lambda=1}^{N} \bar{U}(\lambda), \quad [\bar{V}] = \frac{1}{N}\sum_{\lambda=1}^{N} \bar{V}(\lambda) \tag{1}$$

where $N = 72$, overbar denotes time average and [ ] denotes the zonal average.

These averages are given in table 1 and depicted graphically in figure 1. We see that westerlies in the belt 14·7°S to 28·7°S are stronger by 3 to 5 m s^{-1} during the drought years (1972, 1979) as compared to the normal monsoon years (1970, 1971). The northerly component during 1979 is stronger as compared to all other years.

Following the usual method we write

$$\bar{U}(\lambda) = [\bar{U}] + \bar{U}^*(\lambda), \quad \bar{V}(\lambda) = [\bar{V}] + \bar{V}^*(\lambda) \tag{2}$$

the asterisk indicates departure from zonal average.

Table 1. Zonal averages of zonal and meridional wind at 200 mbar level for the period June through August (Unit: m s^{-1}).

	$[\bar{U}]$				$[\bar{V}]$			
Lat.	1970	1971	1972	1979	1970	1971	1972	1979
28·7°N	6·2	3·3	7·3	6·6	0·1	−0·0	−0·0	0·3
24·2°N	2·3	0·9	4·9	3·2	0·0	0·0	0·0	0·0
19·6°N	0·5	0·6	3·9	0·0	0·2	0·3	0·3	0·3
14·7°N	−0·1	0·6	2·1	−3·2	0·1	0·3	0·3	0·0
9·9°N	−3·6	−2·9	−2·4	−5·9	−0·2	−0·0	−0·1	−0·6
5·0°N	−6·0	−5·1	−5·1	−7·7	−0·7	−0·5	−0·7	−1·4
0·0°	−4·4	−4·1	−4·4	−6·3	−0·7	−0·7	−0·9	−1·7
5·0°S	−0·3	−0·1	−0·2	−2·2	−0·6	−0·6	−0·6	−1·4
9·9°S	4·1	5·3	5·7	4·3	−0·5	−0·5	−0·3	−1·2
14·7°S	8·9	10·9	13·0	14·1	−0·5	−0·3	−0·2	−0·9
19·6°S	18·0	20·4	23·7	25·2	−0·3	−0·3	−0·3	−0·7
24·2°S	27·9	28·1	32·8	35·0	−0·3	−0·2	−0·3	−0·3
28·7°S	32·7	32·1	34·7	38·4	−0·3	−0·3	−0·2	−0·0

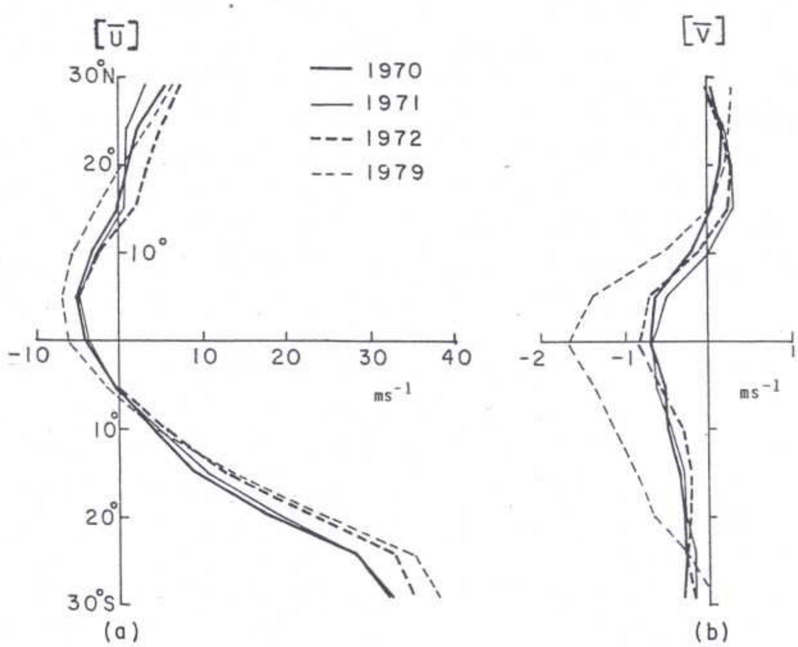

Figure 1. Latitudinal variation of zonally averaged (**a**) zonal wind (**b**) meridional wind at 200 mbar level for the period June through August. Unit: $m\,s^{-1}$.

From (1) and (2) the meridional transport of westerly momentum is given by

$$[\bar{U}\,\bar{V}] = [\bar{U}][\bar{V}] + [\bar{U}^*\,\bar{V}^*]. \tag{3}$$

The first term on the right side of (3) represents the meridional transport of westerly momentum by mean meridional circulation (MMC) and the second term the momentum transport by standing eddies (SE). The values of these quantities are given in table 2. Figure 2 gives a graphical representation.

3.1 *Transport by MMC*

The momentum transport is southward between 28·7°S and 9·9°S and northward between 5°S and 28·7°S for all the years. The northward transport of momentum is maximum between equator and 5°N. During 1979 there is a large convergence of momentum between 5°N and 10°N.

3.2 *Transport of momentum by SE*

The momentum transport by SE is northward almost throughout the region under consideration for all the years. During the normal monsoon years (1970, 1971) the northward transport is large in the belt 5°S to 19·6°N as compared to transport during the drought years (1972, 1979).

3.3 *Total transport of momentum*

Total transport is almost dominated by SE in the region 9·9°N to 28·7°N for all the

Table 2. Transport of westerly momentum by mean meridional circulation (MMC) and standing eddies (SE) at 200 mbar level for the period June through August. (Unit: $m^2 s^{-2}$).

	MMC				SE			
Lat.	1970	1971	1972	1979	1970	1971	1972	1979
28·7°N	0·4	0·0	−0·3	1·8	18·3	18·6	15·9	15·1
24·2°N	0·5	0·2	0·8	0·7	18·2	19·0	13·5	15·9
19·6°N	0·1	0·2	1·1	0·0	17·3	16·9	8·5	8·8
14·7°N	0·0	0·2	0·5	−0·2	14·1	11·7	4·1	3·6
9·9°N	0·8	0·0	0·3	3·5	15·2	11·3	3·9	1·4
5·0°N	3·9	2·7	3·6	10·6	17·2	13·3	3·0	2·6
0·0°	3·0	2·7	3·7	10·8	15·7	12·4	2·0	3·0
5·0°S	0·2	0·1	0·2	3·1	16·6	13·5	0·5	4·0
9·9°S	−2·0	−2·5	−1·8	−5·0	8·0	5·8	−1·9	5·0
14·7°S	−4·2	−3·6	−2·9	−13·2	8·8	5·8	−0·4	3·1
19·6°S	−5·5	−5·8	−6·0	−17·4	10·2	7·1	1·6	1·7
24·2°S	−7·8	−5·4	−9·1	−10·4	14·6	10·8	4·3	0·2
28·7°S	−11·2	−8·0	−7·0	1·6	12·1	6·9	8·4	−1·3

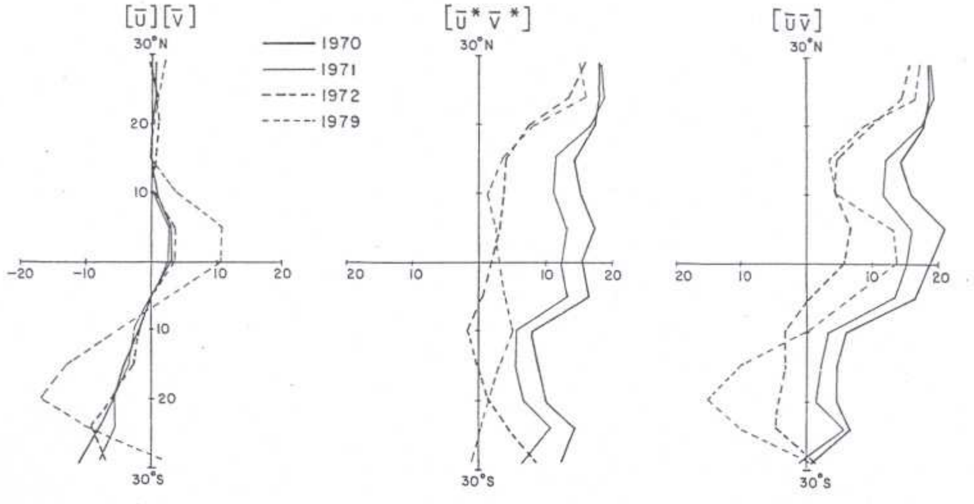

Figure 2. Latitudinal variation of meridional transport of westerly momentum (**a**) by mean meridional circulation (**b**) by standing eddies (**c**) by total at 200 mbar level for the period June through August. Unit: $m^2 s^{-2}$.

years. The transport during the normal years (1970, 1971) is northward whereas the transport is southward during the drought years (1972, 1979) in the region 9·9°S to 24·2°S.

4. Harmonic analysis

The three-monthly mean values $\bar{U}(\lambda)$ and $\bar{V}(\lambda)$ were subjected to harmonic analysis. As we have 72 grid points we need 36 waves for the exact representation of observed values.

The harmonic components are calculated as follows

$$\bar{U}(\lambda) = [\bar{U}] + \sum_{m=1}^{N/2} \left(a_m \cos\left(\frac{2\pi m\lambda}{N}\right) + b_m \sin\left(\frac{2\pi m\lambda}{N}\right)\right), \tag{4}$$

$$\bar{V}(\lambda) = [\bar{V}] + \sum_{m=1}^{N/2} \left(c_m \cos\left(\frac{2\pi m\lambda}{N}\right) + d_m \sin\left(\frac{2\pi m\lambda}{N}\right)\right), \tag{5}$$

where m is the wave number. The first term on the right side of (4) and (5) is wave number zero. a_m, b_m, c_m and d_m are given by

$$a_m = \frac{2}{N} \sum_{\lambda=1}^{N} \bar{U}(\lambda) \cos\left(\frac{2\pi m\lambda}{N}\right); \quad b_m = \frac{2}{N} \sum_{\lambda=1}^{N} \bar{U}(\lambda) \sin\left(\frac{2\pi m\lambda}{N}\right), \tag{6}$$

$$c_m = \frac{2}{N} \sum_{\lambda=1}^{N} \bar{V}(\lambda) \cos\left(\frac{2\pi m\lambda}{N}\right), \quad d_m = \frac{2}{N} \sum_{\lambda=1}^{N} \bar{V}(\lambda) \sin\left(\frac{2\pi m\lambda}{N}\right). \tag{7}$$

The transport of westerly momentum by SE in wave number domain is given by

$$[\bar{U}^* \bar{V}^*] = \frac{1}{2} \sum_{m=1}^{N/2} (a_m c_m + b_m d_m) \tag{8}$$

where the term $1/2\,(a_m c_m + b_m d_m)$ gives the transport by wave number m.

4.1 *Percentage variance of harmonics of zonal wind*

The percentage variance explained by long waves, (waves 1 to 4), medium waves (waves 5 to 16) and short waves (waves 17 to 36) are given in table 3. We find that during the drought years (1972, 1979) the percentage variance explained by long waves is greater as compared to the percentage variance explained during the normal years (1970, 1971). The percentage variance explained by long waves during 1979 is

Table 3. Percentage variance of harmonics of zonal wind at 200 mbar level for the period June through August.

	Long waves (1 to 4)				Medium waves (5 to 16)				Short waves (17 to 36)			
Lat.	1970	1971	1972	1979	1970	1971	1972	1979	1970	1971	1972	1979
28·7°N	64·6	66·3	84·3	89·8	24·3	21·3	12·4	9·8	11·0	11·4	3·2	0·3
24·2°N	61·5	65·1	86·6	97·2	25·8	23·0	10·6	2·4	12·5	11·8	3·0	0·3
19·6°N	65·0	68·0	85·2	98·3	23·1	21·6	10·9	1·4	11·7	10·3	3·8	0·2
14·7°N	55·9	63·2	76·4	97·6	30·0	25·7	18·3	1·8	13·4	11·0	5·2	0·5
9·9°N	45·3	47·4	62·1	93·4	38·4	37·1	27·6	5·5	16·2	15·5	10·2	1·0
5·0°N	39·4	44·8	56·7	93·7	41·6	37·6	30·7	5·3	18·9	17·5	12·4	0·9
0·0°	33·9	41·5	65·8	93·7	47·5	40·5	24·9	5·2	18·2	17·9	9·3	1·0
5·0°S	61·1	61·8	78·5	98·0	27·3	26·6	15·2	1·6	11·5	11·5	6·2	0·4
9·9°S	39·9	45·4	77·6	97·9	42·6	41·1	15·0	1·8	17·4	13·3	7·3	0·2
14·7°S	44·6	54·0	40·1	94·8	39·7	34·8	48·2	4·6	15·6	11·1	11·5	0·5
19·6°S	48·2	58·9	75·4	90·7	37·7	31·7	21·9	8·4	13·8	9·4	2·5	0·7
24·2°S	87·2	87·6	95·2	94·7	9·4	9·0	4·5	4·8	3·3	3·3	0·2	0·4
28·7°S	89·1	88·2	97·7	93·4	8·4	9·7	1·9	5·7	2·4	2·1	0·2	0·4

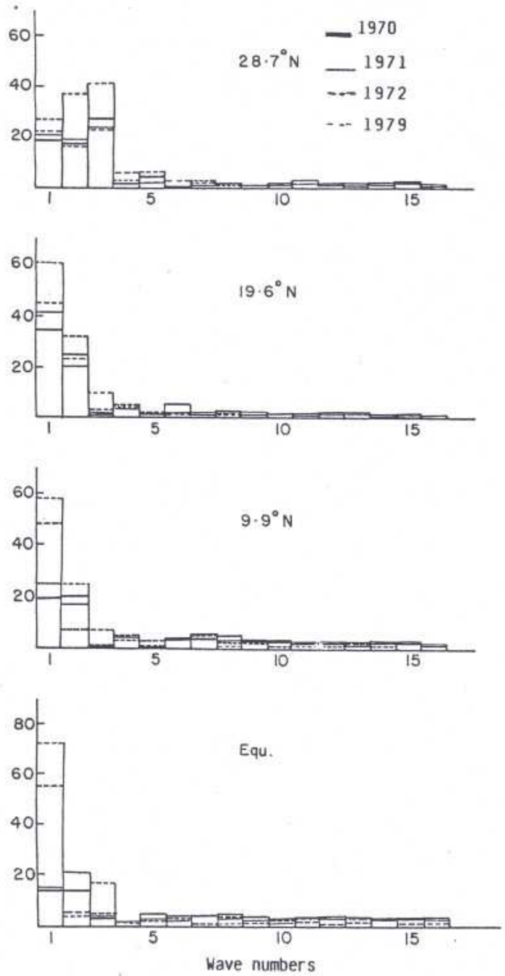

Figure 3. Percentage variance of harmonics of zonal wind at 200 mbar level for the period June through August.

greater than 90% throughout the region. Figure 3 gives the pictorial representation of individual waves (up to wave No. 16) for some latitude circles.

4.2 *Percentage variance of harmonics of meridional wind*

Table 4 and figure 4 give the percentage variance of the harmonics of the v-component. The percentage variance explained by the long waves increases from equator to north. In the equatorial region the contribution to variance by long waves and medium waves are comparable for all the years.

5. Momentum transport

The transport of momentum by the three categories of waves is given in table 5. It may be noted that the meridional transport of momentum by all the three categories of waves is more pronounced in the years of good monsoon activity. We find that

Table 4. Percentage variance of harmonics of meridional wind at 200 mb level for the period June through August.

	Long waves (1 to 4)				Medium waves (5 to 16)				Short waves (17 to 36)			
Lat.	1970	1971	1972	1979	1970	1971	1972	1979	1970	1971	1972	1979
28·7°N	74·2	80·5	75·5	80·6	21·8	15·5	22·2	17·7	4·0	4·1	2·2	1·6
24·2°N	74·4	81·5	73·8	80·6	20·6	12·8	22·5	17·7	5·0	5·7	3·6	1·6
19·6°N	71·4	75·8	63·5	73·5	18·2	14·6	31·3	23·0	10·4	9·7	5·2	3·5
14·7°N	62·2	65·7	59·5	69·6	18·4	17·8	34·6	24·0	19·3	16·9	6·0	6·3
9·9°N	49·4	47·9	48·5	60·5	26·4	25·7	42·3	31·3	24·3	26·7	9·5	8·1
5·0°N	37·2	33·2	44·5	43·7	38·1	35·4	38·6	49·8	24·8	32·0	17·2	6·4
0·0°	31·7	26·1	35·8	43·9	47·3	45·0	40·6	47·5	21·2	29·1	14·1	8·4
5·0°S	34·4	29·4	33·9	49·4	44·5	42·7	52·4	40·7	21·8	28·3	13·8	9·8
9·9°S	40·7	38·0	46·7	48·2	38·6	35·7	38·7	44·4	20·7	26·8	15·0	7·0
14·7°S	40·6	44·1	48·7	49·6	40·5	24·3	38·1	44·2	19·0	21·8	13·6	6·1
19·6°S	36·7	32·7	31·5	39·5	42·6	45·0	52·7	52·2	21·3	22·4	15·6	8·3
24·2°S	30·1	20·4	10·1	20·8	46·0	54·6	69·3	70·7	23·4	27·0	20·6	8·4
28·7°S	34·5	39·9	14·4	50·0	47·8	45·4	67·9	42·6	17·7	14·1	17·8	7·5

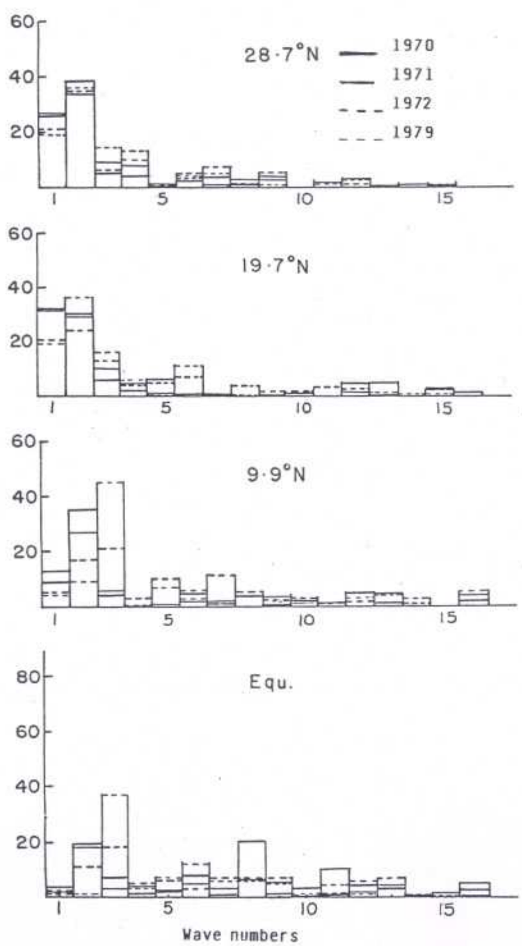

Figure 4. Percentage variance of harmonics of meridional wind at 200 mbar level for the period June through August.

Table 5. Meridional transport of momentum at 200 mbar level for the period June through August ($m^2 s^{-2}$).

Lat.	Long waves (1 to 4)				Medium waves (5 to 16)				Short waves (17 to 36)			
	1970	1971	1972	1979	1970	1971	1972	1979	1970	1971	1972	1979
28·7°N	15·6	16·4	15·7	14·2	1·5	1·7	0·2	0·8	1·2	0·4	−0·1	0·1
24·2°N	14·7	16·7	13·0	15·3	2·0	1·5	0·3	0·3	1·5	0·7	−0·1	0·0
19·6°N	12·1	13·1	8·7	8·4	3·2	2·6	−0·1	0·1	1·9	1·0	−0·1	0·1
14·7°N	7·5	6·7	6·0	3·7	4·2	3·6	−1·6	−0·3	2·4	1·2	−0·3	0·2
9·9°N	6·9	5·0	4·1	1·1	5·5	4·3	0·0	0·1	2·7	1·9	−0·2	0·1
5·0°N	6·9	5·4	2·6	2·3	7·0	5·2	0·1	0·1	3·2	2·6	0·3	0·1
0·0°	5·4	4·9	0·9	2·7	7·4	5·3	0·9	0·4	2·7	2·4	0·2	0·1
5·0°S	7·5	6·2	−1·0	3·6	6·6	4·9	1·4	0·3	2·5	2·2	0·0	0·0
9·9°S	0·3	0·8	−3·0	5·2	5·4	3·1	1·0	−0·2	2·1	1·8	0·0	0·0
14·7°S	1·7	0·9	−1·5	3·3	4·8	3·1	1·1	−0·1	2·2	1·7	0·1	−0·1
19·6°S	4·1	3·1	2·2	2·2	4·2	2·5	−0·9	−0·5	1·8	1·4	0·3	0·0
24·2°S	11·2	8·4	5·9	0·6	1·8	0·8	−1·5	−0·5	1·5	1·5	−0·2	0·1
28·7°S	10·2	6·8	6·9	−1·0	1·0	−0·6	1·3	−0·3	1·0	0·7	−0·1	0·1

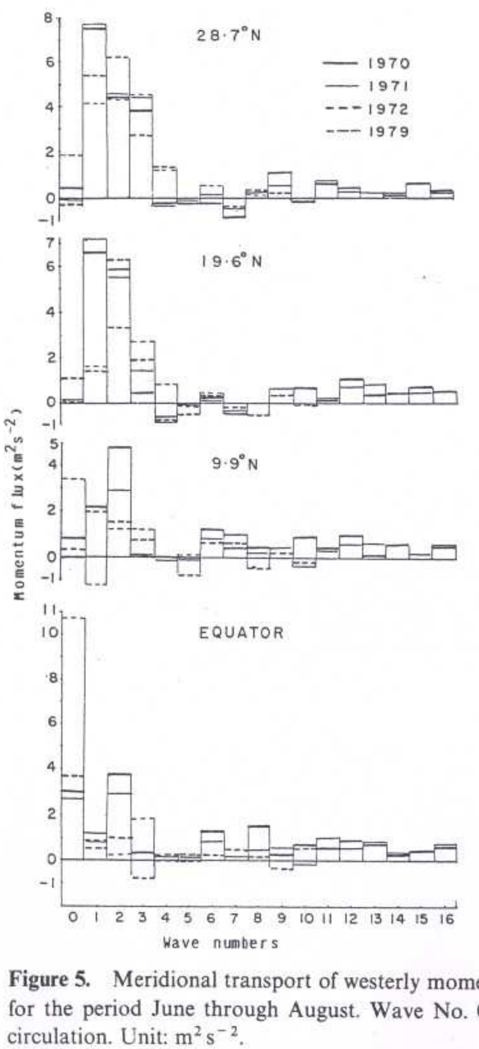

Figure 5. Meridional transport of westerly momentum by various scales at 200 mbar level for the period June through August. Wave No. 0 denotes transport by mean meridional circulation. Unit: $m^2 s^{-2}$.

medium and short waves (i.e. small scales) are intense during the normal monsoon years. Figure 5 gives the pictorial representation at some latitude circles.

At 19·6°N (figure 5) the transport of westerly momentum by wave number 1 during 1970 and 1971 is $6{\cdot}6\,m^2\,s^{-2}$ and $7{\cdot}2\,m^2\,s^{-2}$ and during 1972 and 1979 is $1{\cdot}4\,m^2\,s^{-2}$ and $1{\cdot}6\,m^2\,s^{-2}$ respectively. The long waves are the source of energy to tropical easterly jet. Krishnamurti and Kanamitsu (1981) showed that the long waves (waves 1 and 2) have very large southwest to northeast tilt between 5°N and 30°N. A consequence of this tilt is the removal of westerly momentum poleward and away from the latitude of tropical easterly jet. This implies that greater the removal of westerly momentum, stronger is the tropical easterly jet.

6. Conclusions

During the normal monsoon years, the northward transport of momentum by standing eddies in the belt 5°S to 28·7°N is large. At 19·6°N the transport of momentum by wave number 1 during normal monsoon years is considerably large. Furthermore, the small scale disturbances are intense during the normal monsoon years.

During the drought monsoon years the westerlies are stronger in the belt 10°S to 30°S.

Acknowledgements

The authors are thankful to Shri D R Sikka, for his interest in the study. The authors are grateful to Prof. R Ananthakrishnan, Dr S Rajamani and Shri D K Paul for critically going through the manuscript and for constructive suggestions. They are also grateful to Shri R K Verma for providing the NMC wind data.

References

Awade S T, Totagi M Y and Bawiskar S M 1986 Large scale features of summer monsoon during 1979; *Mausam* **37** 441–450

Awade S T, Totagi M Y, Bawiskar S M and Sikka D R 1984 Dynamics of the large scale tropical circulations summer monsoon and tropical drought; *Mausam* **35** 115–322

Kanamitsu M and Krishnamurti T N 1978 Northern summer tropical circulation during drought and normal monsoon months; *Mon. Weather Rev.* **106** 331–347

Krishnamurti T N and Kanamitsu M 1981 Northern summer planetary scale monsoon during drought and normal rainfall months: in *Monsoon dynamics* (ed) Sir James Lighthill and R P Pearce (Cambridge: University Press) pp. 19–48

Murakami T 1963 Maintenance of the kinetic energy of the disturbances appearing on the monthly mean weather charts; *J. Meteorol. Soc. Jpn.* **41** 15–28

Murakami T 1978 Regional energetics of 200 mb summer circulations; *Mon. Weather Rev.* **106** 514–628

Murakami T 1981 Summer mean energetics for standing eddies in wave number domain: in *Monsoon dynamics* (ed) Sir James Lighthill and R P Pearce (Cambridge: University Press) pp. 65–80