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Upper tropospheric energetics of standing eddies in wave number domain during contrasting monsoon activity over India

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सार–भारत पर विपर्यासी मानसून सक्रियता के दौरान तरंग संख्या प्रक्षेत्र में स्थायी भँवरों के ऊपरी क्षोभमण्डलीय ऊर्जाविकियों की जांच की गई है। दो सामान्य वर्षा के वर्ष (1970, 1971) और दो अनावृष्टि मानसून के वर्ष (1972, 1979) को तुलनात्मक अध्ययन के लिए विचारार्थ चुना गया। तरंग–तरंग अन्योन्यक्रिया और तरंग को क्षेत्रीय माध्य प्रवाह अन्योन्यक्रिया को संगणित करने के लिए सॉलट्जमैन (1957) के ऊर्जा समीकरणो का उपयोग किया गया है। परिणामों के विश्लेषण से पता चलता है कि उष्णकटिबन्धीय पुरवा हवा के क्षेत्र में (5°द–24.2°उ) स्थायी भँवर, दक्षिणी गोलार्धीय पछुवा हवाओं (24.2°द–5°द) के क्षेत्र के स्थायी भँवरों से विशालतर गतिक ऊर्जा रखते हैं। सभी तरंगों (अर्थात् तरंग 1 से 15) की तरंग से पुरवा हवा के क्षेत्र में क्षेत्रीय माध्य प्रवाह परस्पर क्रिया गतिक ऊर्जा का एक स्रोत है और पछुआ हवाओं के क्षेत्र में क्षेत्रीय माध्य प्रवाह को गतिक ऊर्जा का वे निमज्जन होते हैं। पुरवा हवा ग्रहीय स्थायी तरंग (तरंग 1–2) के क्षेत्र में अन्य स्थायी तरंगों के लिए प्रमुख गतिक ऊर्जा स्रोत हैं और सभी तरंगों की तरंग–तरंग परस्पर क्रिया सामान्य मानसून वर्ष (1970, 1971) के दौरान अन्य स्थायी तरंगों को मुख्य गतिक ऊर्जा के धनात्मक असन्तुलन की ओर उन्मुख होते हैं और अनावृष्टि मानसून वर्षों (1972, 1979) के दौरान गतिक ऊर्जा के ऋणात्मक असन्तुलन के होते हैं। पश्चिमी पवनों के क्षेत्र में सामान्य मानसून वर्षों के दौरान गतिक ऊर्जा का असन्तुलन ऋणात्मक है और अनावृष्टि मानसून वर्षों के दौरान धनात्मक है।

ABSTRACT. The upper tropospheric energetics of the standing eddies in wave number domain during contrasting monsoon activity over India have been investigated. Two normal monsoon years (1970, 1971) and two drought monsoon years (1972, 1979) are considered for a comparative study. Energy equations of Saltzman (1957) are used to compute wave-wave interaction and wave to zonal mean flow interaction. Analysis of the results show that the standing eddies in the region of tropical easterlies (5°S-24.2°N) have larger kinetic energy than those in the region of southern hemispheric westerlies (24.2°S-5°S). Wave to zonal mean flow interaction of all waves (waves 1-15) indicate that the standing eddies are a source of kinetic energy to zonal mean flow in the region of easterlies and they are sink of kinetic energy to zonal mean flow in the region of westerlies. In the region of easterlies planetary standing waves (waves 1-2) are the major kinetic energy source to other standing waves and wave-wave interaction of all waves leads to positive imbalance of kinetic energy during normal monsoon years (1970, 1971) and negative imbalance of kinetic energy during drought monsoon years (1972, 1979). In the region of westerlies the imbalance of kinetic energy is negative during normal monsoon years and positive during drought monsoon years.

Key words — Contrasting monsoons, Wave number domain, Energetics of standing eddies, Interactions, and Imbalance of kinetic energy.

1. Introduction

Large-scale atmospheric circulations have wave like character and hence characteristic features of large-scale atmospheric circulations can be well investigated by subjecting the observed field to Fourier analysis. It will help in analysing large-scale as well as small-scale eddies. The term eddy represents any disturbance in the zonal mean flow. There are two types of eddies. The eddies having life period of a few days are called transient eddies and the eddies which persist for a longer period of time are called standing eddies. Southwest monsoon, tropical easterly jet, mid-Pacific and mid-Atlantic troughs are some examples of standing eddies. Murakami (1981) has shown that the Fourier representation of atmospheric circulations has shed much light upon the processes of generation, dissipation and transfer of kinetic energy in and among the waves of the atmosphere. A number of investigators have applied Fourier technique to study energetics of eddies. Kanamitsu *et al.* (1972) measured wave to wave and wave to zonal mean flow interaction at 200 hPa over tropical belt (15°S-15°N) for 1967 and showed that wave number one is a major energy source for tropics. Murakami (1981) proposed a computational model to partition kinetic energy exchanges into standing (summer-mean) and transient motion and showed that the character of energy processes in wave number domain varies considerably with latitudinal region during northern summer. Krishnamurti and Kanamitsu (1981) studied energy exchanges for two contrasting monsoon years and found that wave number 3 showed a contrasting behaviour

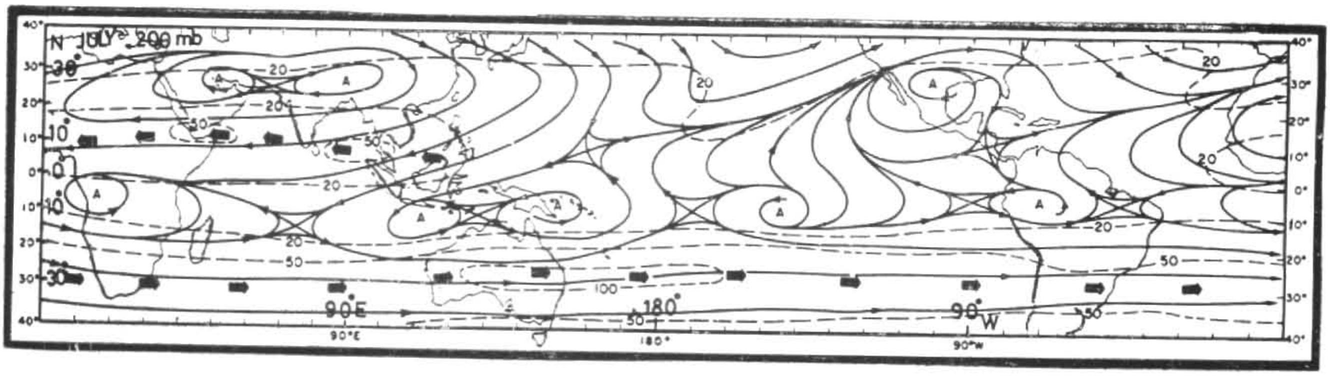

Fig. 1. Resultant wind for the month of July at 200 hPa (*after* T. N. Krishnamurti, adapted from climatological data base).

during drought and normal monsoon activity. Bawiskar *et al.* (1989) have computed transport of momentum for contrasting monsoon years, *viz.*, two normal monsoon years (1970, 1971) and two drought monsoon years (1972, 1979) in wave number domain by using Fourier technique and found that small-scale eddies are intense during normal monsoon years. In our earlier studies, *viz.,* Awade *et al.* (1982), Awade *et al.* (1984) and Awade *et al.* (1985), we have used geopotential height data and geostrophic winds to compute energetics of standing eddies. Because of geostrophic approximation the analysis of equatorial region and the terms involving zonal averages of meridional wind in $M(n)$ and $L(n)$ could not be incorporated. In the present study we have used NMC wind data. Murakami's study confirmed that NMC data was adequate in describing characteristic features of 200 hPa circulation. We have used Fourier technique to investigate energy aspect of the standing eddies in wave number domain. The kinetic energy of standing eddies, kinetic energy transfer between eddies and zonal mean flow (wave to zonal mean flow interaction) and kinetic energy transfer among eddies (wave to wave interaction) have been computed and analysed. Such an analysis could answer questions as to whether a given eddy is source or sink of kinetic energy to other eddies and whether the zonal mean flow supplies kinetic energy to eddies or *vice versa.*

2. Data

Two normal monsoon years (1970, 1971) and two drought monsoon years (1972, 1979) are considered for a comparative study. As the upper tropospheric circulations are well marked at 200 hPa the same pressure level is selected. Monthly mean grid point data of zonal wind (u) and meridional wind (v) along a complete latitude circle at 5° longitude interval for the months of June, July and August are taken from global grid point data provided by National Meteorological Centre (NMC), USA. The thirteen latitude circles considered are 28.7°S, 24.2°S, 19.6°S, 14.7°S, 9.9°S, 5.0°S, 0.0°, 5.0°N, 9.9°N, 14.7°N, 19.6°N, 24.2°N and 28.7°N. In the present study we have used monthly mean data and as such it is not possible to compute corresponding transformation terms involving transient part. The comparison for contrasting years is restricted to terms representing standing eddies only. It is, however, not suggested that the transient terms are negligible, the transient part plays an important role. As the standing part is the source of energy to transient part (Murakami 1981) the variation in the standing part in the energy transfer will give some indication of the activity of monsoon.

3. Method of computation

The monthly mean u and v for the months June through August are used to compute seasonal mean values, $\bar{u}$ and $\bar{v}$. The seasonal mean values are expressed by:

$$\bar{u} = [\bar{u}] + \sum_{m=1}^{n/2} \left[a_m \cos\left(\frac{2\pi m\lambda}{N}\right) + b_m \sin\left(\frac{2\pi m\lambda}{N}\right) \right] \quad (1)$$

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

The Fourier coefficients a_m, b_m, c_m and d_m are computed as follows :

$$a_m = \frac{2}{N} \sum_{\lambda=1}^{N} u \cos\left(\frac{2\pi m\lambda}{N}\right)$$

$$b_m = \frac{2}{N} \sum_{\lambda=1}^{N} \bar{u} \sin\left(\frac{2\pi m\lambda}{N}\right)$$

$$c_m = \frac{2}{N} \sum_{\lambda=1}^{N} \bar{v} \cos\left(\frac{2\pi m\lambda}{N}\right)$$

$$d_m = \frac{2}{N} \sum_{\lambda=1}^{N} \bar{v} \sin\left(\frac{2\pi m\lambda}{N}\right) \quad (3)$$

TABLE 1

Kinetic energy of standing eddies at 200 hPa for the period June through August

(Unit : $m^2 s^{-2}$)

Wave No.	Region of easterlies (5° S – 24.2° N)				Region of westerlies (24.2° S – 5° S)			
	1970	1971	1972	1979	1970	1971	1972	1979
0	6.8	4.4.	8.6	13.5	76.3	90.7	122.6	140.3
1	14.8	14.8	16.3	13.8	12.3	10.3	14.6	12.1
2	10.9	10.4	6.9	5.1	5.0	6.2	1.1	1.0
3	1.8	2.1	2.2	3.4	2.0	1.5	1.5	0.7
4	1.9	2.0	1.4	1.0	1.7	0.8	0.3	0.1
5	1.5	1.0	1.1	0.2	2.0	1.9	0.7	0.2
6	2.1	1.3	1.2	0.4	1.2	1.0	0.9	0.2
7	1.5	1.8	0.8	0.1	1.2	0.9	0.2	0.3
8	2.1	1.5	0.8	0.1	1.1	0.7	0.6	0.2
9	1.5	1.4	0.5	0.1	1.1	0.9	0.6	0.0
10	1.5	1.2	0.5	0.1	1.1	0.8	0.4	0.1
Long waves (Waves 1 to 4)	29.4	29.3	26.9	23.3	21.0	18.9	17.5	13.9
Short waves (Waves 5 to 15)	17.4	14.2	7.3	1.3	12.7	9.8	4.6	1.3
All waves (Waves 1 to 15)	46.8	43.5	34.2	24.7	33.7	28.7	22.1	15.2

The energy equation for the eddy kinetic energy in wave number domain is given by :

$$\frac{\partial K(n)}{\partial t} = -M(n) + L(n) + C(n) - D(n) \quad (4)$$

$K(n)$ gives the total kinetic energy in eddies of wave number n. $M(n)$ indicates the rate of transfer of kinetic energy between zonally-averaged flow and eddies of wave number n. $L(n)$ indicates the flow of kinetic energy transfer to eddies of wave number n from eddies of all other wave numbers.

The $C(n)$ term represents the conversion of eddy available potential energy to eddy kinetic energy for wave number n. Since data for vertical velocity was not available, no attempt has been made to measure $C(n)$. $D(n)$ is dissipation term for wave number n. Since the $D(n)$ term is a residual term and is not based on direct measurement, it is not computed. Studies in the northern hemisphere and scale consideration indicate that the term $\int [uw]\, dm$ is much smaller than the term $\int [uv]\, dm$. For this reason the term containing w in $M(n)$ and $L(n)$ are not computed.

The Fourier coefficients in expression 3 are used to compute kinetic energy of zonal mean flow $K(o)$, kinetic energy of standing eddies $K(n)$, wave to zonal mean flow interaction $M(n)$ and wave to wave interaction $L(n)$. Here the subscript n represents zonal wave number. It is worth pointing out that the wave number considered usually do not exceed $n=15$, which corresponds to the smallest scale resolvable on hemispheric chart. As pointed out by Saltzman (1970), the nature of energy transfer spectrum is highly dependent on the truncation wave number. Consequently, we cannot expect agreement between a value of $L(n)$ based on a truncation

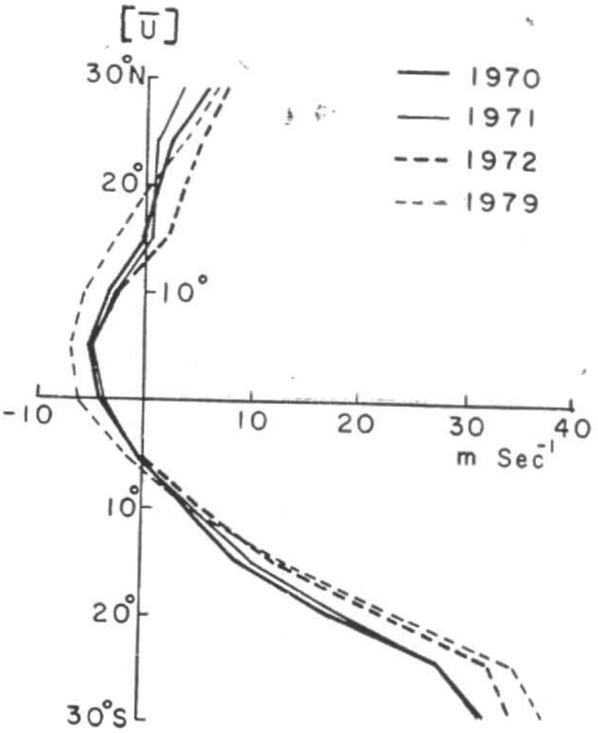

Fig. 2. Zonally averaged zonal wind at 200 hPa for the period June through August

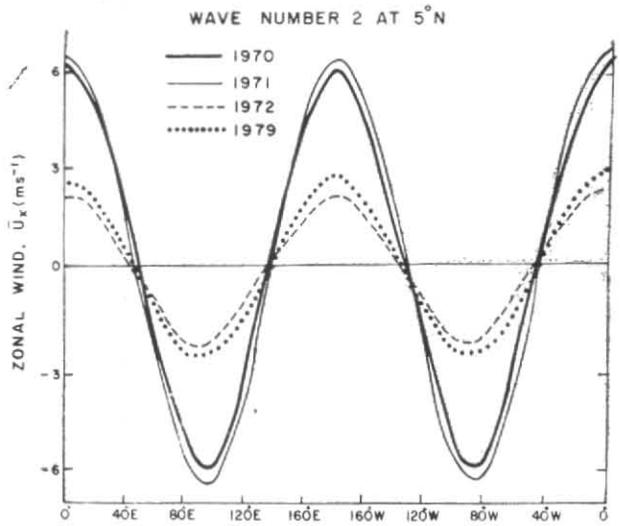

Fig. 3. Wave number 2 of zonal wind at 200 hPa for the period June through August

point of $n=10$ and one based on $n=15$, for example. In the extreme case, if we were able to extend the calculations towards $n=\infty$, thereby encompassing all the dissipative processes, a markedly different value would be obtained for $L(n)$ than if the interactions only among synoptic weather disturbances were included in the calculations. Secondly as we have considered monthly mean values the computation of error estimates ($\epsilon=2\sigma/\sqrt{N/2}$, σ is standard deviation and N number of days) is out of question.

3.1. *List of symbols used* :

a — Radius of the earth,

a_m, b_m — Cos and sin coefficient of u-Fourier series for mth wave,

c_m, d_m — Cos and sin coefficient of v-Fourier series for mth wave,

u — Zonal component of wind,

v — Meridional component of wind,

w — Vertical component of wind,

N — Number of grid points along a latitude circle ($N=72$),

λ — Longitude,

ϕ — Latitude,

g — Acceleration due to gravity,

l, m, n — Zonal wave number,

$K(n)$ — Kinetic energy of wave number n,

$M(n)$ — Wave to zonal interactions,

$L(n)$ — Wave to wave interactions,

— — Time average, $\bar{x} = \frac{1}{T}\int_0^T x\, dT$

[ ] — Zonal average, $[x] = \frac{1}{2\pi}\int_0^{2\pi} x\, d\lambda$

4. Results and discussion

As we are interested in upper tropospheric energetics of the standing eddies, it would be desirable to have some gross idea of the standing eddies at 200 hPa. Fig. 1 presents July mean streamline isotach analysis at 200 hPa for northern summer. The prominent eddies seen in northern hemisphere are anticyclones over Tibet and Mexico, tropical easterly jet around 10°N, mid-Pacific and mid-Atlantic troughs having southwest-northeast tilt, and in the southern hemisphere, anticyclones appear over Australia, central south Pacific, northern parts of South America, South Africa and the southern hemispheric tropical jet is located around 30°S. These eddies could be seen on seasonal as well as on daily maps during northern summer. Fig. 2 gives the latitudinal variation of zonally average flow (zonal mean flow). Positive values represent the westerly flow and the negative values are easterly flow. The total region between 30°S and 30°N is divided into two sub-regions according to flow pattern. The first region between 5°S and 24.2°N will be called as the region of easterlies as this region is dominated by easterly flow and monsoon circulation. The second region between 24.2°S and 5°S will be called the region of westerlies.

TABLE 2

Wave to zonal interaction at 200 hPa for the period June through August
(Unit : 10^{-6} m^2 s^{-3})

Wave No.	Region of easterlies (5° S – 24.2° N) 1970	1971	1972	1979	Region of westerlies (24.2° S – 5° S) 1970	1971	1972	1979
1	9.0	5.2	5.9	0.8	–23.4	–9.3	–4.2	–47.7
2	7.0	0.4	8.9	9.3	–30.0	–32.5	–6.7	–1.4
3	1.7	1.9	5.5	7.0	–1.6	3.2	10.4	–0.9
4	–0.8	–0.9	–0.8	2.7	2.6	–0.2	–1.4	0.6
5	–0.8	–0.4	–2.4	–0.1	0.2	–2.2	0.4	0.1
6	0.0	0.1	1.1	0.7	–10.9	–8.0	4.8	1.4
7	–0.4	0.7	0.2	–0.1	–7.1	3.3	0.2	0.3
8	–1.1	–0.1	–1.0	–0.3	–3.9	–0.2	3.1	–0.3
9	–0.7	–0.2	–0.2	0.1	–4.7	–5.5	–6.1	–0.2
10	0.8	–0.3	–0.6	–0.2	–6.2	–3.8	–2.1	0.6
Long waves (Waves 1 to 4)	16.9	6.5	19.5	19.8	–52.4	–38.8	–1.9	–49.4
Short waves (Waves 5 to 15)	0.1	–0.1	–2.5	0.8	–51.7	–33.6	–4.3	2.5
All waves (Waves 1 to 15)	17.0	6.4	17.0	20.6	–104.1	–72.4	–6.2	–46.9

The zonal mean flow in the region of easterlies is weaker than that of the region of westerlies. From Figs. 1 and 2 it can be seen that around 30°S no closed circulations are seen and this is the region of strong zonal mean flow. Around equator and north of equator there are a number of closed circulations and this is the region of weak zonal mean flow. It may be inferred from the above observations that in the region of the week zonal mean flow the standing eddies predominate the flow patterns.

4.1. *Kinetic energy of zonal mean flow (wave number zero) and standing eddies*

The kinetic energy of an eddy of wave number n is given by :

$$K(n) = \frac{1}{4}\left(a_n^2 + b_n^2 + c_n^2 + d_n^2\right) \quad (5)$$

Table 1 gives the kinetic energy of zonal mean flow (wave number zero) and first ten waves. In order to understand the broad features we have grouped the waves as long waves (waves 1 to 4), short waves (waves 5 to 15) and all waves (waves 1 to 15). The integrated effect of all these groups are also presented at the bottom of Table 1. Kinetic energy of wave number zero in the region of westerlies is very high compared to the kinetic energy of wave number zero in the region of easterlies whereas the kinetic energy of the long waves (waves 1 to 4) in the region of easterlies is higher than the kinetic energy of the long waves in the region of westerlies. As the long waves dominate the total contribution of all the waves the same thing is reflected when we compare the kinetic energy due to all waves.

Kinetic energy of wave number two in the region of easterlies is very important. From Fig. 1 it could be seen that Tibetan and Mexican anticyclones and mid-Pacific and mid-Atlantic troughs together represents wave number two. We find from Table 1 that the kinetic energy of wave number two during normal monsoon years (1970, 1971) is larger as compared to the kinetic energy of wave number two during drought monsoon years (1972, 1979). Fig. 3 presents wave number two at 5° N for all the years. It is clearly seen that the amplitude of wave number two is very high during normal monsoon years (1970, 1971). The kinetic energy of small eddies (waves 5 to 15) is much higher for normal monsoon years in the both the regions. Awade *et al.* (1978) have also found that higher wave numbers are prominent in a good monsoon year.

TABLE 3

Wave-wave interaction at 200 hPa for the period June through August

(Unit : 10^{-6} m^2 s^{-3})

Wave No.	Region of easterlies (5°S – 24.2°N)				Region of westerlies (24.2°S – 5°S)			
	1970	1971	1972	1979	1970	1971	1972	1979
1	−7.3	−6.8	−1.0	2.3	−1.6	−3.4	1.5	1.7
2	−16.1	−13.3	−10.7	−8.9	3.3	1.0	3.6	2.1
3	6.0	4.4	3.3	2.0	2.7	2.5	−1.3	−0.6
4	2.7	3.8	−1.2	1.8	−2.1	−3.6	−0.6	−0.2
5	3.0	2.9	1.5	−0.2	−2.7	2.1	−1.1	−0.5
6	6.3	1.8	1.1	0.1	3.4	2.0	0.3	0.7
7	3.0	−1.1	3.4	−0.4	−1.8	−2.9	−0.6	−0.5
8	−2.4	−0.1	1.0	0.3	−5.1	−2.1	−1.8	−0.2
9	3.4	2.3	−0.2	0.1	−0.2	−0.7	1.0	0.0
10	0.7	1.6	0.5	−0.1	−0.9	2.7	0.6	0.2
Long waves (Waves 1 to 4)	−14.7	−11.7	−9.6	−2.8	2.3	−3.5	3.2	3.0
Short waves (Waves 5 to 15)	16.0	12.0	7.3	0.4	−5.9	2.5	0.7	−0.3
All waves (Waves 1 to 15)	1.3	0.3	−2.3	−2.4	−3.6	−1.1	3.9	2.7

4.2. *Wave zonal mean flow interaction*

The exchange of kinetic energy between eddies and the zonal mean flow is given by :

$$M(n) = \frac{1}{2}\left\{\left(a_n c_n + b_n d_n\right) \cdot \left(\frac{[\bar{u}]\tan\phi}{a} + \frac{\partial[\bar{u}]}{a\partial\phi}\right) + \left(c_n c_n + d_n d_n\right) \cdot \frac{\partial[\bar{v}]}{a\partial\phi} - \left(a_n a_n + b_n b_n\right) \cdot \frac{\tan\phi}{a}\left[\bar{v}\right]\right\} \quad (6)$$

The negative sign of $M(n)$ indicates that there is a gain of kinetic energy in wave number n from the zonal mean flow and positive sign indicates that wave number n loses kinetic energy to zonal mean flow. Our units of $M(n)$ and $L(n)$ are similar to the units of Unninayar and Murakami (1978). From Table 2, we find that in the region of easterlies, waves 1, 2 and 3 are source of kinetic energy to zonal mean flow during all the years under consideration. $M(n)$ for all waves shows that eddies are source of kinetic energy to zonal mean flow in the region of easterlies and they are sink of kinetic energy in the region of westerlies. Murakami (1981) has also found that all waves over the zone (44.6° N to 0°) behaves as source of kinetic energy to zonal mean flow. Energy received by all waves in the region of westerlies is very high for normal monsoon years.

4.3. *Wave to wave interaction*

The wave to wave interaction is given by :

$$L(n) = \left\{\begin{array}{l} +\sum\limits_{l=n-m} \\[2ex] +\sum\limits_{l=n+m} \\[2ex] +\sum\limits_{l=m-n}\end{array}\right\}\left\{\begin{array}{l} a_l\left(m\,(a_n b_m + c_n d_m)\Big/ a\cos\phi \right. \\[2ex] \left. +(c_n a_m - a_n c_m)\dfrac{\tan\phi}{a}\right) \\[2ex] +c_l\left(a_n \dfrac{\partial a_m}{a\partial\phi} + c_n\dfrac{\partial c_n}{a\partial\phi}\right)\end{array}\right\}$$

$$+\left\{\begin{array}{l} +\sum\limits_{l=n-m} \\[2ex] -\sum\limits_{l=m+n} \\[2ex] -\sum\limits_{l=m-n}\end{array}\right\}\left\{\begin{array}{l} b_l\left(m\,(a_n a_m + c_n c_m)\Big/ a\cos\phi \right. \\[2ex] \left. +(a_n d_m - c_n b_m)\dfrac{\tan\phi}{a}\right) \\[2ex] -d_n\left(a_n \dfrac{\partial b_m}{a\partial\phi} + c_n\dfrac{\partial d_m}{a\partial\phi}\right)\end{array}\right\}$$

$$+\left\{\begin{array}{l} -\sum\limits_{l=n-m} \\[2ex] +\sum\limits_{l=m+n} \\[2ex] -\sum\limits_{l=m-n}\end{array}\right\}\left\{\begin{array}{l} a_l\left(m\,(b_n a_m + d_n c_m)\Big/ a\cos\phi \right. \\[2ex] \left. +(b_n d_m - d_n b_m)\dfrac{\tan\phi}{a}\right) \\[2ex] -c_l\left(b_n \dfrac{\partial b_m}{a\partial\phi} + d_n\dfrac{\partial d_m}{a\partial\phi}\right.\end{array}\right\}$$

$$+\left\{\begin{array}{l} +\sum\limits_{l=n-m} \\[2ex] +\sum\limits_{l=n+m} \\[2ex] -\sum\limits_{l=m-n}\end{array}\right\}\left\{\begin{array}{l} b_l\left(m\,(b_n b_m + d_n d_m)\Big/ a\cos\phi \right. \\[2ex] \left. +(d_n a_m - b_n c_m)\dfrac{\tan\phi}{a}\right) \\[2ex] +d_l\left(b_n \dfrac{\partial a_m}{a\partial\phi} + d_n\dfrac{\partial c_m}{a\partial\phi}\right)\end{array}\right\} \qquad (7)$$

A positive sign of $L(n)$ means that there is a gain of kinetic energy to wave number n due to wave-wave interaction of all other waves and negative sign means that wave number n is source of kinetic energy to other waves. The process of the exchange of kinetic energy among waves is independent of transfer of kinetic energy between eddies and zonal motion, viscous dissipation and conversion to and from potential and internal energy. Theoretically $L(n)$ summed over all the eddies should vanish. This is possible when all types of wave-wave interaction (that is exchange of kinetic energy among transient eddies, standing eddies and between standing and transient eddies) are considered. When exchange of kinetic energy among standing eddies for a limited area and period is considered, as in the present study, the sum need not necessarily be zero. Non-zero sum of $L(n)$ over all eddies is called imbalance. Murakami (1981) has shown that in the region between equator and 14.8° N (region of easterlies) there is a large imbalance in the exchange of kinetic energy among standing eddies. Table 3 gives the results of wave-wave interaction. Note that the region of easterlies in the present study, there is positive imbalance [that is sum of $L(n)$ for standing waves 1 to 15] during normal monsoon years (1970, 1971) and negative imbalance during drought monsoon years (1972, 1979). The factor responsible for positive and negative imbalance is the gain in short waves (waves 5 to 15), they are the greater sink of kinetic energy during normal monsoon years as compared to drought monsoon years. Planetary standing waves (waves 1 to 2) are the major energy source for other standing waves.

5. Conclusions

The salient features that emerged from this study are :

(*i*) The standing eddies are source of kinetic energy to zonal mean flow in the region of easterlies and are sink of kinetic energy to zonal mean flow in the region of westerlies.

(*ii*) In the region of easterlies planetary standing wave (waves 1 to 2) are the major energy source for other standing waves.

(*iii*) During drought monsoon years (1972, 1979) the zonal mean flow is strong, small eddies are weak and there is a negative (positive) imbalance of kinetic energy in the region of easterlies (westerlies) due to wave to wave interactions of all standing eddies.

(*iv*) During normal monsoon years (1970, 1971) the zonal mean flow is weak, small-scale eddies are intense and there is a positive (negative) imbalance of the kinetic energy in the region of easterlies (westerlies) due to wave to wave interactions of all standing eddies.

(*v*) Wave number 2 is much stronger during normal monsoon years as compared to drought monsoon years,

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