Spectra of different fluxes over the arid and semiarid zones of northwest India during MONEX 1979

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MS received 14 March 1988

Abstract. Fluxes of heat, momentum and the kinetic energy over the arid and semiarid regions of Indian Peninsula have been computed. Spectral analysis of these fluxes at 50 mb interval were performed at each level in the vertical up to 300 mb surface. The eddy latent heat transport is governed essentially by short- and long-range periodicities. A 5-day periodicity is generally present in the vertical mean eddy fluxes. Long-range periodic oscillations are more pronounced in the extreme north of the Indian subcontinent. Dominance of medium-range periodicity is observed in all the fluxes except latent heat.

Keywords. Atmospheric flux; periodicity; MONEX; vertical distribution; oscillations.

1. Introduction

The study of different fluxes helps in better understanding of excess and deficit in the budget analysis. Spectral analysis has been widely used to understand the dominant periodicities in meteorological parameters to study the cause of the oscillations. Several investigators (Sankar Rao 1962; Sankar Rao and Ramanadham 1963; Saha 1970; Saha and Bavadekar 1973, 1977; Rao and Ramanamurty 1977; Ghosh *et al* 1978; Bavadekar and Mooley 1978; Rao 1981) attempted to study the fluxes over the Indian region. Singh and Singh (1987) carried out the study of heat and momentum transport over the east and west coasts of India during MONEX 79. The power spectral analysis of useful meteorological variables has been attempted by many workers. Madden and Julian (1972) showed the evidence of a global 5-day pressure wave. Gupta (1972) and Gupta and Singh (1977) observed the 5-day pressure oscillation over the Siberian anticyclone and the 4–5-day pressure oscillation over the Mediterranean regions respectively.

The present study was carried out to throw some light on the significant periodicities in sensible heat fluxes, latent heat fluxes and momentum and kinetic energy fluxes over the arid and semiarid zones of northwest India during the MONEX 79 summer monsoon months May to August at each level in the vertical up to 300 mb surface.

2. Data and method of analysis

The daily aerological data obtained from the MONEX 79 set of data at Ahmedabad, Jodhpur, Gwalior, New Delhi and Patiala have been used for computation of sensible heat transport, latent heat transport, momentum transport and flux of kinetic energy. These vertically integrated fluxes, as well as fluxes at each level up to 300 mb surface,

were subjected to spectral analysis in time domain following Blackman and Tukey (1958).

The heat, momentum and kinetic energy fluxes at any station may be expressed as

$$Q = \frac{C_p}{g} \int_0^{P_0} \bar{V} \bar{T} dP + \frac{L}{g} \int_0^{P_0} \bar{V} \bar{X} dP + \frac{C_p}{g} \int_0^{P_0} \overline{V' T'} dP + \frac{L}{g} \int_0^{P_0} \overline{V' X'} dP$$

$$M = \frac{1}{g} \int_0^{P_0} \bar{U} \bar{V} dP + \frac{1}{g} \int_0^{P_0} \overline{U' V'} dP$$

$$K = \bar{K} + K'; \quad \bar{K} = \frac{1}{2}(\bar{U}^2 + \bar{V}^2); \quad K' = \frac{1}{2}(U'^2 + V'^2)$$

$$F_k = \int_0^{P_0} \bar{V} \bar{K} dP + \int_0^{P_0} \overline{V' K'} dP,$$

where Q is the time-averaged northward flux of sensible and latent heat, M the momentum flux per unit time, X the humidity mixing ratio, K the kinetic energy and F_k the flux of kinetic energy per unit mass. The other parameters have their usual meaning. $(\bar{\quad})$ denotes the time average and $(\quad')$ the deviation from the time average.

3. Discussion of the results

Of the several charts of power spectra, it has been considered adequate to present only the chart for vertical mean eddy flux in figures 1–5 for the purpose of illustration.

Tables 1 and 2 show the existing periodicities over the arid and semiarid regions of India for eddy sensible heat transport and eddy momentum transport at Ahmedabad, Jodhpur, Gwalior, New Delhi and Patiala. The vertical distribution of periodicity in eddy kinetic energy and flux of eddy kinetic energies do not show any significant changes other than those periodicities in tables 1 and 2. The computation of periodicity in eddy latent heat transport could not be performed from 700 to 300 mb because of lack of suitable number of data in the time series. Hence they are not presented here. However, the results are summarized below.

The vertical mean eddy sensible heat transport (table 1) does not show any remarkable periodicity over Ahmedabad, Jodhpur and Gwalior. However, at New Delhi and Patiala the presence of a short-range (<5-day) or medium-range (5–10-day) periodicity in the vertical mean eddy sensible heat transport is observed. The vertical mean eddy latent heat transport shows the presence of medium-range periodicity over Ahmedabad, Jodhpur and Patiala and besides that a short-range periodicity is present at Gwalior and New Delhi. The observed periodicity in vertical mean eddy momentum transport varies from 4.7 to 5.6 days over these stations (table 2). Thus, a fluctuation at an average of about 5 days can be considered to be present in the vertical mean eddy momentum transport over these regions. The vertical mean eddy kinetic energy shows the presence of medium-range periodicity over Ahmedabad, Jodhpur and New Delhi whereas the vertical mean flux of kinetic energy shows periodicity of short range at Jodhpur and of medium range over New Delhi and Patiala.

Thus, the vertically integrated eddy sensible heat transport over Ahmedabad, Jodhpur and Gwalior during MONEX 79 seems to be due to eddies of different scales

Figure 1. Spectra of vertical mean eddy sensible heat flux.

which do not show their periodic occurrence whereas the vertical mean of eddy momentum transport, eddy latent heat transport, eddy kinetic energy and eddy kinetic energy flux usually seem to be governed by atmospheric processes that have varying periodicity in short and medium ranges, more closely around 5 days. This 5-day periodicity in different meteorological parameters, studied by several investigators (Ananthakrishnan and Keshavamurty 1970; Bhalme and Parasnis 1975; Murakami 1976), is most prominent in northern India and is related to the frequency of monsoon lows travelling from the Bay of Bengal to northern India. Yanai *et al* (1968) found a westward-propagating wave with a 4–5-day period in certain regions of the tropics in the meridional component of the wind at lower tropospheric levels. Wallace and Chang (1969) found an easterly wave with a period of 4–5 days and also a 4-day period of planetary scale pressure fluctuation at the equator. Misra (1972) observed the westward-propagating planetary pressure wave of 4–5-day period in the tropics. Rao and Ramanamurty (1972) observed a 4–8-day periodicity in tropical wave disturbances over Singapore.

Figure 2. Spectra of vertical mean eddy latent heat flux.

We conclude that except in the eddy sensible heat transport over Ahmedabad, Jodhpur and Gwalior, a generally 3–7-day periodicity is present over the arid and semiarid zones of northwest India in vertical mean eddy latent heat transport, vertical mean eddy momentum transport and vertical mean eddy kinetic energy and vertical mean eddy flux of kinetic energy. Figure 6 and tables 1 and 2 show the vertical distribution of periodicities in eddy transport of heat, momentum and kinetic energy. In eddy latent heat transport short-, medium- and long-range (> 10-day) periodicity has been observed over the region. The eddy latent heat transport is dominated by short- and long-range periodic fluctuations of atmospheric processes in the layer below 800 mb surface over Ahmedabad, Jodhpur, Gwalior and New Delhi. In the layer from

Figure 3. Spectra of vertical mean eddy momentum flux.

800 mb to 950 mb surface over Gwalior and New Delhi, the eddy transport of latent heat is dominated by long-range periodicity.

The eddy sensible heat transport, eddy momentum transport, eddy kinetic energy and eddy flux of kinetic energy seem to be mainly controlled by short- and medium-range fluctuations of atmospheric processes throughout the layer up to 300 mb surface. The long-range periodicity is occasionally present below 700 mb surface in these fluxes over Ahmedabad, Jodhpur, Gwalior and New Delhi. However, at Patiala we observe the presence of long-range periodicity at 900, 850, 700 and 300 mb in eddy momentum transport; at 850 and 900 mb in eddy kinetic energy and at 900, 700, 400 and 300 mb in eddy flux of kinetic energy and at 750–650 mb surface in eddy sensible heat transport. Thus, as we move towards the north over the arid and semiarid zones of northwest Indian subcontinent, the dominance of long-range periodicity is observed in the lower

Figure 4. Spectra of vertical mean eddy kinetic energy.

troposphere around 700 mb surface at Patiala, New Delhi and sometimes at Jodhpur in some of the fluxes, and at upper troposphere around 300–400 mb surface.

At Ahmedabad and Gwalior, the long-range periodicity in eddy sensible heat transport is observed at about 300–400 mb surface and at Patiala at about 650–750 mb. This shows that with increasing latitude, the long-range periodicity, if present at upper surfaces (below 300 mb surface), shifts to higher pressure surfaces (lower heights) over these regions. This is observed more clearly in eddy sensible heat transport and less clearly in other fluxes. These shifts seem to be due to the influence of western disturbances which passed through extreme northern Indian subcontinent during MONEX 79. As 1979 was an abnormal monsoon year, these fluxes may not be very representative of average monsoon conditions but still they throw much light on this area of research. Information on absolute and relative values of these fluxes can be useful for modelling studies. The noted periodicities in the range of 5–7 days and 12–15 days are in agreement with periodicities noted in the monsoon system by many earlier studies.

4. Conclusions

(i) A periodicity of around 5 days is substantiated over arid and semiarid zones of northwest Indian subcontinent in vertical mean eddy latent heat and momentum

Figure 5. Spectra of vertical mean eddy kinetic energy flux.

transport. However, the vertical mean eddy sensible heat transport is not governed by any periodic oscillations over Ahmedabad, Jodhpur and Gwalior.

(ii) Medium-range periodicity usually dominates in eddy sensible heat, momentum, kinetic energy and flux of eddy kinetic energy in the lower troposphere. The eddy latent heat transport is essentially governed by short- and long-range periodicities over arid and semiarid zones of northwest India.

(iii) Long-range periodicity, if present at any surface, usually shifts to lower altitude pressure surface with increasing latitude over these regions of northwest India.

(iv) The dominance of medium-range periodicity in most of the fluxes in the lower troposphere as well as the shift of long-range periodicity to lower altitude with increasing latitude over northwest India seem to be associated with drought monsoon year.

Table 1. Periodicity (in days) in eddy sensible heat flux at different levels in the troposphere during MONEX 79.

Station Pressure level (mb)	Ahmedabad			Jodhpur			Gwalior			New Delhi			Patiala		
	Short	Med.	Long	Short	Med.	Long	Short	Med.	Long	Short	Med.	Long	Short	Med.	Long
Integrated surface to 300 mb)	x	x	x	x	x	x	x	x	x	3-1	5-6	x	x	7-0	x
Surface pressure	2-2	x	x	x	x	x	x	x	x	3-1	x	x	2-0	x	x
950	x	x	x	x	x	x	4-0	x	x	4-0	x	x	x	9-3	x
900	2-8	x	x	x	x	x	x	x	x	2-3 to 4-0	x	14-0	x	9-3	x
850	2-5	x	x	x	x	x	x	x	x	4-0	x	x	2-8	9-3	x
800	x	5-6	x	3-4	x	x	4-0	x	x	4-0	x	x	4-7	x	x
750	4-7	x	x	2-4	x	12-0	x	x	x	x	7-0	x	2-8	x	14-0
700	x	x	x	x	x	x	4-7	x	x	x	7-0	x	x	x	14-0
650	x	x	x	x	6-0	x	x	x	x	x	7-0	x	x	7-0	12-0
600	x	x	x	x	x	x	3-5	x	x	x	5-6	x	3-5	7-0	x
550	4-0	x	x	x	6-0	x	x	7-0	x	4-0	x	x	x	7-0	x
500	3-1	x	x	x	x	x	3-1	x	x	x	x	x	x	5-6	x
450	4-7	x	x	—	—	—	3-1	x	14-0	3-1	x	x	x	5-6	x
400	4-7	x	14-0	—	—	—	3-1	x	x	x	5-6	x	4-7	x	x
350	4-7	x	14-0	—	—	—	3-5	x	12-0	x	5-6	x	4-0	x	x
300	x	5-6	14-0	—	—	—	x	x	12-0	x	5-6	x	x	7-0	x

‘—’ not computed due to lack of data; ‘x’ no periodicity is present.

Table 2. Periodicity (in days) in eddy momentum flux at different levels in the troposphere during MONEX 79.

Station Pressure level (mb)	Ahmedabad			Jodhpur			Gwalior			New Delhi			Patiala		
	Short	Med.	Long	Short	Med.	Long	Short	Med.	Long	Short	Med.	Long	Short	Med.	Long
Integrated (surface to 300 mb)	x	5.6	x	4.8	x	x	x	5.6	x	x	5.6	x	4.7	x	x
Surface pressure	3.1	x	x	x	x	x	x	x	x	4.0	x	x	x	5.6	x
950	4.7	x	x	x	x	x	x	x	x	x	x	x	x	5.6	x
900	3.1 to 4.7	x	x	2.7	x	x	x	x	x	3.1	x	x	4.0	x	14.0
850	3.5 to 4.7	x	x	3.4	x	x	4.7	x	x	x	5.6	x	x	x	14.0
800	x	5.6	x	x	6.0	x	x	x	x	x	5.6	x	x	x	x
750	x	5.6	x	x	x	12.0	3.5	x	x	x	5.6	x	x	9.3	x
700	4.7	x	x	x	8.0	x	4.0	x	x	x	5.6	x	x	x	14.0
650	4.0	x	x	x	8.0	x	x	x	x	x	5.6	x	x	x	x
600	x	x	x	x	x	x	x	5.6	x	x	5.6	x	x	x	x
550	x	7.0	x	x	x	x	x	5.6	x	4.7	x	x	4.0	x	x
500	x	5.6	x	x	x	x	x	x	x	x	x	x	2.6	x	x
450	4.7	x	x	—	—	—	4.7	x	x	4.0	x	x	4.0	x	x
400	x	x	x	—	—	—	3.1	x	x	x	9.3	x	x	9.3	x
350	3.5	x	14.0	—	—	—	3.1	x	x	4.7	9.3	x	4.7	x	x
300	3.5	x	x	—	—	—	x	x	14.0	x	5.6	x	x	x	14.0

Figure 6. Periodicity in different fluxes at various stations in the vertical.

Acknowledgement

The financial support provided by UGC, New Delhi, is gratefully acknowledged.

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