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Vertical distribution of heat and momentum flux over east coast of India during Monex-79

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सार — मोनेक्स-79 के आंकड़ों का प्रयोग करते हुए भारतीय उपमहाद्वीप के पूर्वी तट पर ऊष्मा और संवेग वहन का अभिकलन किया गया है। याम्योत्तरीय परिचलन के कारण माध्य और भंवर संघटक पृथक होते हैं। ये अभिवाह विभिन्न स्तरों में अक्षांश सहित विशिष्ट परिवर्तन दर्शाते हैं।

ABSTRACT. The heat and momentum transport over east coast of Indian sub-continent have been computed using Monex-79 data. The mean and eddy components due to meridional circulation are separated. These fluxes show remarkable changes with latitude in different layers.

1. Introduction

The dynamic and thermal properties of the regional atmosphere are directly affected by the transfer of momentum, heat and water vapour from the surrounding. According to the principle of conservation of mass, the water content in the atmosphere can neither be created nor destroyed. Any local change of water content can be brought out only through the addition or subtraction. The necessity for the transport of water content in the atmosphere arises from the fact that there are areas of excess precipitation over evaporation with a reversal of them in certain other parts of the world. The excess or deficit must be made through the transport of water by atmospheric circulations. Several people in India have made an effort in studies on the sensible heat, water vapour and momentum transport including Sankar Rao (1962), Sankar Rao and Ramanadham (1963), Saha (1970), Saha and Bavadekar (1973, 1977), Ghosh *et al.* (1978), Bavadekar and Mooley (1978), Appa Rao and Ramanamurty (1977), Appa Rao (1981, 1985). Some of the studies are confined to the Arabian Sea and west coast of India, whereas others have dealt with the land stations of India. In the present study an attempt has been made to study the heat, momentum and moisture transport over the eastern coast of India for a period May through August 1979 using Monex-79 data.

2. Evaluation of parameters

The time averaged total northward flux of heat per unit time accomplished by the atmosphere at any station is given by :

$$Q=\frac{c_p}{g}\int_0^{p_0}\overline{v}\;\overline{T}\,dp+\frac{L}{g}\int_0^{p_0}\overline{v}\;\overline{x}\,dp \tag{1}$$

where the bar denotes the time average, and the deviation from time-mean is denoted by prime :

$$(\ )=\overline{(\ )}+(\ )'$$

$$Q=\frac{c_p}{g}\int_0^{p_0}\overline{v}\;\overline{T}\,dp+\frac{L}{g}\int_0^{p_0}\overline{v}\;\overline{x}\,dp+$$

$$+\frac{c_p}{g}\int_0^{p_0}\overline{v'}\,\overline{T'}\,dp+\frac{L}{g}\int_0^{p_0}\overline{v'\,x'}\,dp \tag{2}$$

The first two terms on the right of Eqn. (2) measure the effect of mean meridional circulation and the standing eddies while the last two terms measure the local eddy flux of sensible and latent heat respectively.

The flux of relative momentum at any station is given by :

$$M=\frac{1}{g}+\int_0^{p_0}\overline{v\,u}\,dp$$

$$=\frac{1}{g}\int_0^{p_0}\overline{v\,u}\,dp+\frac{1}{g}\int_0^{p_0}\overline{v'\,u'}\,dp \tag{3}$$

The first term on the right of Eqn. (3) represents the flux of relative momentum due to mean meridional circulation and the standing eddies while the second term represents the local meridional eddy flux of relative momentum at any station.

2.1. *List of symbols*

u= zonal component of wind,

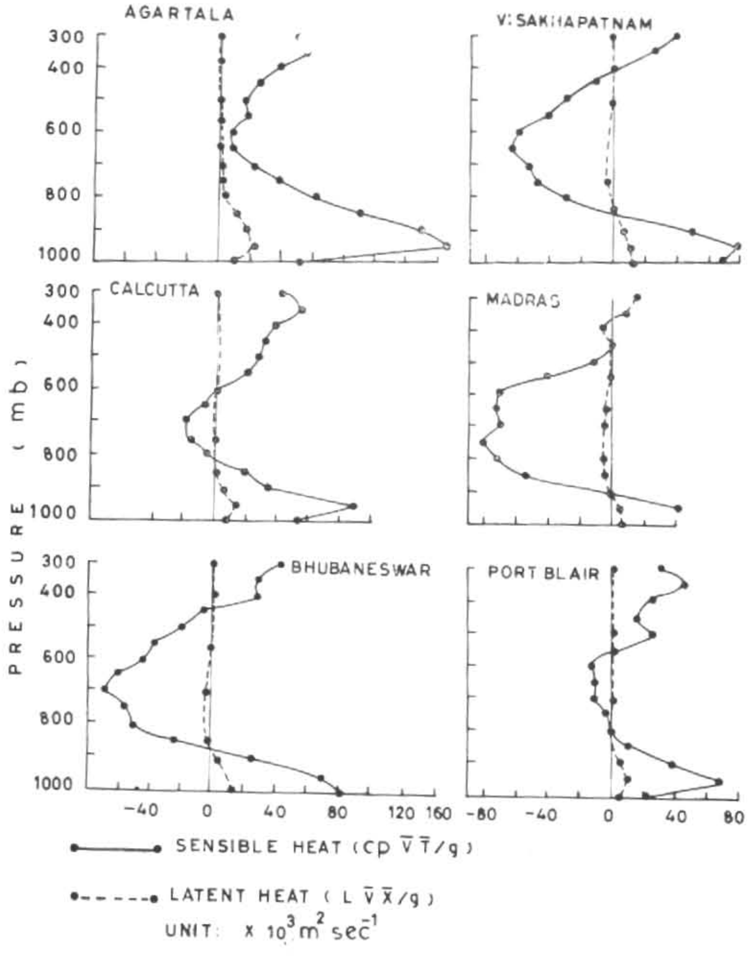

Fig. 1. Vertical variation of heat flux due to mean circulation

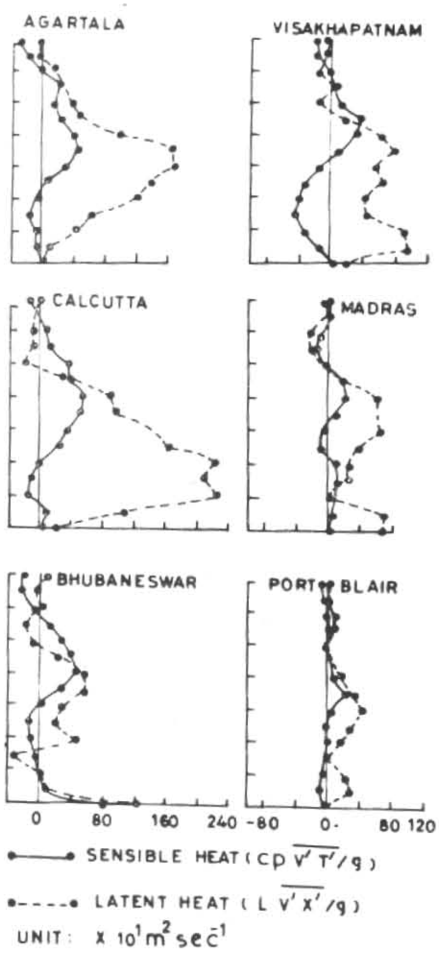

Fig. 2. Vertical variation of heat flux due to local eddies

v= meridional component of wind,

T= temperature (°K),

c_p= specific heat of air at constant pressure,

p= pressure,

p_0= pressure at the earth surface,

Q= rate of diabatic heating,

x= humidity mixing ratio and

L= latent heat of vaporization

3. Data used

Daily aerological data obtained from Monex-79 (May through August) experiment over the eastern coastal stations of India have been utilised to make the study of heat, momentum and moisture fluxes distributions in the vertical and deviation with respect to time mean at 00 GMT observation hour. The computations were performed up to 300 mb level in the vertical at the interval of 50 mb.

4. Discussion of results

(a) *Heat flux*

Fig. 1 shows the vertical distribution of sensible and latent heat flux over Agartala, Calcutta, Bhubaneswar, Visakhapatnam, Madras and Port Blair due to mean meridional circulation. On the basis of vertical distribution of sensible and latent heat fluxes and the momentum flux, it is divided into three layers for better understanding :

(*i*) Layer A : The lowest layer 1000 mb to the height up to which the sensible and the momentum flux are positive and significant.

(*ii*) Layer B : Above layer A, in which these fluxes are generally negative.

(*iii*) Layer C : Uppermost layer in which generally the latent heat flux is insignificant and sensible heat flux is positive, significant and momentum flux being negative.

It is observed that in general the sensible heat flux due to mean circulation is larger about an order of magnitude in each layer as compared with the latent heat flux. In layer A, there is a single maxima around 950 mb in both the fluxes which are northward and a minima in the middle layer B in sensible heat flux where the latent heat flux becomes insignificant except over

TABLE 1

Magnitude of peak in different fluxes due to mean circulation in layer B

Station	Sensible heat flux $\times 10^3$ (m^2 sec^{-1})	Latent heat flux $\times 10^3$ (m^2 sec^{-1})	Momentum flux $\times 10^{-1}$ (m^2 sec^{-2})
Port Blair	—14.0	0.0	—21.6
Madras	—80.0	—7.0	—162.7
Visakhapatnam	—64.2	—4.2	—77.3
Bhubaneswar	—68.4	—4.2	—80.0
Calcutta	—17.2	0.0	—16.2
Agartala	7.0	1.4	10.0

Madras, Visakhapatnam and Bhubaneswar and further in layer C, the sensible heat flux is northward with a sharp peak around 350 mb surface and the latent heat flux becomes insignificant.

The thickness of middle layer B in which the seasonal mean sensible heat flux is southward, increases from Port Blair through Madras and then gradually decreases through Calcutta and is changed to northward flux at Agartala. At Port Blair the depth of layer B is 260 mb (800-540 mb), Madras 550 mb (900-350 mb), Visakhapatnam 450 mb (850-400 mb), Bhubaneswar 440 mb (870-430 mb), Calcutta 220 mb (820-600 mb) and at Agartala there is absence of layer B, as the mean sensible heat flux is northward.

The magnitude of sharp peak in the sensible heat flux, latent heat flux and the momentum flux in layer B due to mean circulation is presented in Table 1. It is noted that the magnitude of sharp peak in these fluxes varies with latitude in accordance with the variation of thickness of middle layer with the latitude.

The mean latent heat flux is significant in the lowest layer with a sharp peak around 950 mb at all the stations over east coast of Indian subcontinent. However, from higher latitude to lower latitude along the eastern coast, the latent heat flux in layer B due to mean circulation is insignificant at Agartala and Calcutta which becomes significant over Bhubaneswar, Visakhapatnam, Madras and insignificant again at the Port Blair.

Fig. 2 shows the vertical distribution of mean eddy sensible and latent heat fluxes. It is seen that the time mean eddy latent heat flux, in general, is larger and more significant as compared with the eddy sensible heat flux. The eddy latent heat flux is positive northward throughout the whole depth of layers A and B from 1000 to 350 mb surface at Agartala with a pronounced maxima at about 650-700 mb surface. The thickness of northward eddy latent heat flux as well as its magnitude increases with the increasing latitude over the eastern coast of India. In layer C, the eddy sensible as well as eddy latent heat flux is generally southward and less pronounced over all the stations of eastern coast of India.

The eddy sensible heat flux is generally southward in layer A and the northward in layer B. The distribution of eddy sensible heat flux is more significant in lower and middle layers at Agartala, Calcutta, Bhubaneswar and Visakhapatnam. However, at Madras and Port Blair, it is not well defined.

The magnitude of the sharp peak and the thickness of the layer A in eddy sensible heat flux increases with latitude from Port Blair with a pronounced peak at Visakhapatnam and then decreases with the increasing latitude up to Agartala. However, the thickness of layer B in which northward eddy sensible heat transport prevails, increases gradually with the increasing latitude. Similar variation with latitude in layer C where southward eddy sensible heat flux prevails is observed.

(b) *Momentum flux*

Generally the momentum flux due to mean circulation is southward in layer C and northward with a pronounced peak centred around 950 mb surface in layer A over the east coast of India (Fig. 3). In the middle layer B there is a remarkable variation in thickness with latitude on the momentum transport due to mean circulation. At Port Blair the layer B shows a southward momentum transport in the lower part (820-550 mb) and northward in the upper part (550-425 mb). In order to highlight the characteristics of middle layer the momentum transport due to mean meridional circulation is illustrated in Fig. 4.

The penetration of southward flux of momentum in the middle layer B increases at first with the latitude being maximum depth of penetration at Madras (900-450 mb) and then decreases gradually with the increasing latitude up to Calcutta and is changed into northward flux at Agartala where layer A and layer B have been merged into a single layer. In the upper layer C the momentum transport due to local eddies shows a reversal of southward momentum transport over lower latitude at Port Blair and Madras to northward transport at Visakhapatnam through Agartala. This northward eddy momentum transport in the upper layer C seems to be due to passage of easterly jet stream which passes in between Calcutta and Trivandrum and south of this jet southward momentum transport in the layer C at Madras and Port Blair are observed.

A significant change in eddy momentum transport in the lower layer A has been observed at Madras which is southward. However, at all other stations of east coast of India it is northward and no significant change has been observed.

In the middle layer B the eddy momentum transport is southward at Port Blair. The depth of penetration of this eddy flux is largest starting from 950 mb with no clear upper boundary of the layer B. This shows a remarkable change at Madras where the thickness is about 400 mb (750-350 mb) and the eddy flux is changed to northward. Further, with the increasing latitude the layer B shows that the depth of penetration of northward flux decreases with increasing latitude and is changed into southward eddy momentum transport over Calcutta. Further onward the thickness of this southward transport increases to Agartala.

Except at Port Blair generally the momentum transport in the middle layer due to mean circulation is opposite to that of the eddy circulation.

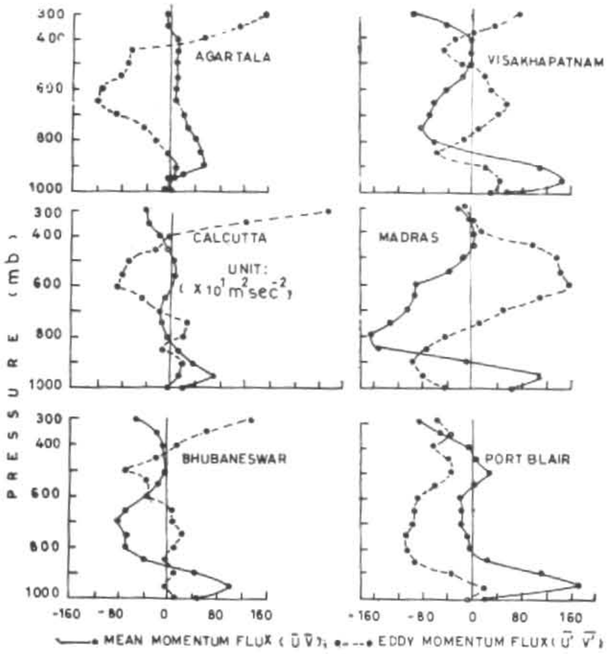

Fig. 3. Vertical variation of momentum flux

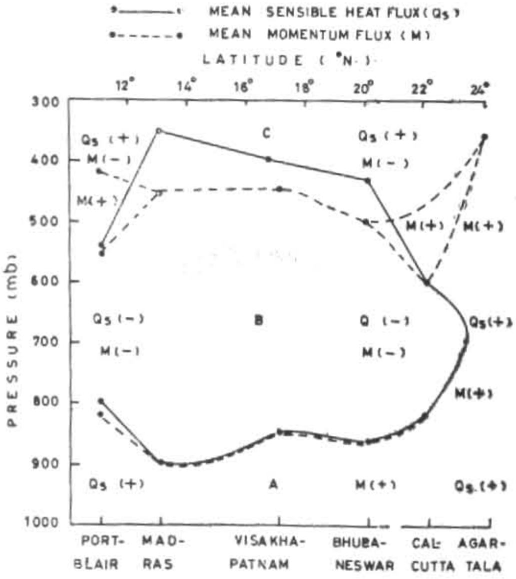

Fig. 4. Latitudinal variation of heat and momentum flux

5. Conclusions

(*i*) The magnitude of southward seasonal mean sensible and latent heat fluxes and momentum flux increases with latitude in the middle layer (layer B) over the eastern coast from Port Blair to Madras and then gradually decreases with the increasing latitude.

(*ii*) The sensible heat flux due to mean circulation is about an order of magnitude larger in each layer as compared with the latent heat flux. However, the mean eddy latent heat flux is larger and more significant as compared with the eddy sensible heat flux over east coast of India.

(*iii*) The eddy momentum flux in layer C is northward and maximum at Calcutta which decreases in its magnitude over east coast with decreasing latitude and becomes southward at Madras and Port Blair.

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