

## On the tropospheric zonal and meridional fluxes of moisture in relation to nor'westers in Bangladesh during the pre-monsoon season

SAMARENDRA KARMAKAR and MD. MAHBUB ALAM\*

Bangladesh Meteorological Department, Agargaon, Sher - E - Bangla Nagar, Dhaka - 1207, Bangladesh

\*Khulna University of Engineering & Technology, Khulna - 9203, Bangladesh

(Received 15 April 2005, Modified 4 July 2006)

e mails : malam@phy.kuet.ac.bd; malam60@hotmail.com

**सार** – इस-शोध पत्र में मानसून – पूर्व ऋतु के दौरान बंगलादेश में काल बैसाखियों की घटना से पूर्व क्षोभमंडल में आर्द्रता के क्षेत्रीय और याम्योत्तरीय फ्लक्सों का अध्ययन करने का प्रयास किया गया है। इस अध्ययन से यह पता चला है कि 925 से लगभग 300 हैक्टापास्कल स्तर तक की परत में 61.68 से 96.26% तक डब्ल्यू एफ. एम. की अधिकतम आवृत्ति वाले 925 से 200 हैक्टापास्कल के स्तर तक 0000 यू. टी. सी. पर ढाका के क्षोभमंडल में आर्द्रता के पश्चिमी फ्लक्सों (सकारात्मक) (डब्ल्यू एफ. एम.) का प्रभाव रहता है। काल बैसाखियों की घटना की तारीखों को 0000 यू. टी. सी. पर ढाका में अधिकतम डब्ल्यू एफ. एम. निचले क्षोभमंडल में  $200 \text{ gm kg}^{-1} \times \text{ms}^{-1}$  से भी अधिक हो सकते हैं और 0000 यू. टी. सी. पर ढाका में आर्द्रता के अधिकतम पूर्वी (नकारात्मक) फ्लक्स 1000 हैक्टापास्कल पर  $-128.3 \text{ gm kg}^{-1} \times \text{ms}^{-1}$  हो सकते हैं। बहुत सी घटनाओं में ऊपरी क्षोभमंडल में आर्द्रता के क्षेत्रीय फ्लक्स (जेड. एफ. एम.) विद्यमान नहीं होते हैं। 0000 यू. टी. सी. पर ढाका में जेड. एफ. एम. मुख्य रूप से पश्चिमीभिमुखी होते हैं और काल बैसाखियों की घटना न होने की तारीखों को फ्लक्सों की अपेक्षा काल बैसाखियों की घटना की तारीखों को निम्न और मध्य क्षोभमंडल में और अधिक पश्चिमाभिमुखी होते हैं। 1000 से 300 हैक्टापास्कल स्तर तक 0000 यू. टी. सी. पर ढाका के क्षोभमंडल में आर्द्रता के दक्षिण फ्लक्स (सकारात्मक) (एस. एफ. एम.) का प्रभाव रहता है। आर्द्रता के याम्योत्तरीय फ्लक्स (एम. एफ. एम.) मुख्य रूप से दक्षिणाभिमुखी होते हैं और काल बैसाखियों की घटना न होने की तारीखों की अपेक्षा काल बैसाखियों की घटना की तारीखों को निम्न ओर मध्य क्षोभमंडल में और अधिक दक्षिणाभिमुखी होते हैं। अधिकांश घटनाओं में ऊपरी क्षोभमंडल में एम. एफ. एम. विद्यमान नहीं होते हैं।

बंगलादेश में काल बैसाखियों की घटना की तारीखों को 0000 यू. टी. सी. पर ढाका में 1000 से 100 हैक्टापास्कल तक उर्ध्वाधर रूप से समेकित जेड. एफ. एम. और एम. एफ. एम. आकलित किए गए, इनकी तुलना की गई और निष्कर्ष प्रस्तुत किया गया है। इस अध्ययन में बंगलादेश और इसके निकटवर्ती क्षेत्रों में 925 से 400 हैक्टापास्कल तक उर्ध्वाधर रूप से समेकित जेड. एफ. एम. और एम. एफ. एम. के स्थानिक वितरण पर भी विचार किया गया है। काल बैसाखियों की अधिकांश घटनाओं में बंगलादेश में परत के लिए उर्ध्वाधर रूप से समेकित जेड. एफ. एम. और एम. एफ. एम. की दूरी क्रमशः लगभग  $(2-12) \times 10^5$  और  $(3-14) \times 10^5 \text{ kg} \times \text{ms}^{-1}$  होती है।

**ABSTRACT.** Attempts have been made to study the zonal and meridional fluxes of moisture of the troposphere prior to the occurrence of nor'westers in Bangladesh during the pre-monsoon season. The study reveals that the westerly fluxes (positive) of moisture (WFM) dominate in the troposphere over Dhaka at 0000 UTC from 925 to 200 hPa level having maximum frequency of WFM from 61.68 to 96.26% in the layer from 925 to about 300 hPa level. The maximum WFM over Dhaka at 0000 UTC on the dates of occurrence of nor'westers may be more than  $200 \text{ gm kg}^{-1} \times \text{ms}^{-1}$  in the lower troposphere and the maximum easterly (negative) fluxes of moisture (EFM) over Dhaka at 0000 UTC may be  $-128.3 \text{ gm kg}^{-1} \times \text{ms}^{-1}$  at 1000 hPa. In the upper troposphere the zonal fluxes of moisture (ZFM) become nil in most of the cases. The ZFM over Dhaka at 0000 UTC are mainly westerly and more westerly in the lower and middle troposphere on the dates of occurrence of nor'westers as compared to the fluxes on the dates of non-occurrence. The southerly fluxes (positive) of moisture (SFM) dominate in the troposphere over Dhaka at 0000 UTC from 1000 to 300 hPa level. The meridional fluxes of moisture (MFM) are mainly southerly and more southerly in the lower and middle troposphere on the dates of occurrence of nor'westers as compared to the dates of non-occurrence. In the upper troposphere the MFM become nil in most of the cases.

The vertically integrated ZFM and MFM from 1000 to 100 hPa over Dhaka at 0000 UTC on the dates of occurrence of nor'westers in Bangladesh have been computed, compared and inference has been drawn. The present study also deals with the spatial distribution of the vertically integrated ZFM and MFM from 925 to 400 hPa level over

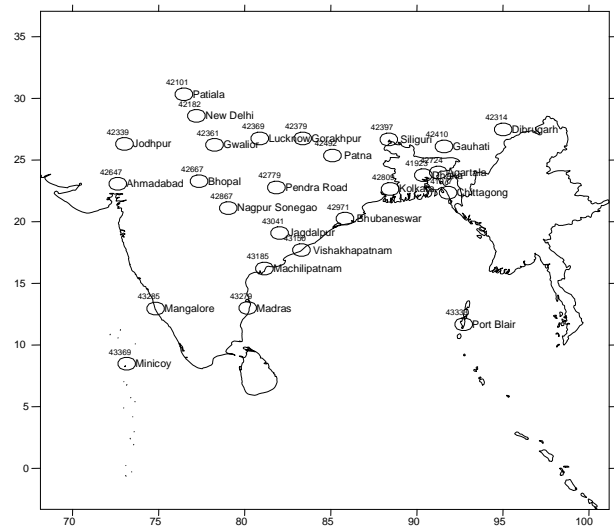
Bangladesh and its surrounding areas. The range of the vertically integrated ZFM and MFM for the layer is about  $(2-12) \times 10^5$  and  $(3-14) \times 10^5 \text{ kg} \times \text{ms}^{-1}$  respectively over Bangladesh in most of the cases.

**Key words** – Zonal flux of moisture, Meridional flux of moisture, Westerly flux of moisture, Easterly flux of moisture, Southerly flux of moisture, Northerly flux of moisture, Pre-monsoon, Nor'westers.

## 1. Introduction

Because of the peculiar geographical location of Bangladesh, a number of nor'westers affect the country every year during the pre-monsoon season and become a cause of loss of lives and properties in Bangladesh. These nor'westers are the manifestations of convective activity in the troposphere. This convective activity is a mechanism by which thermodynamic changes take place over Bangladesh and India during the pre-monsoon season. The thermodynamic changes take place due to the build up of energy, moisture, their fluxes and different dynamical parameters.

Different authors have made computation of energy, moisture and their fluxes. Palmen *et al.* (1958) calculated the kinetic energy released by meridional circulation between the equator and  $30^\circ \text{ N}$ . They computed the heat transfer and the eddy moisture flow and found that the northward eddy moisture flow is  $0.2 \times 10^{15}$  cal per sec. Henry and Hess (1958) developed methods for determining the contribution of each harmonic wave component to the geostrophic kinetic energy of meridional and zonal motion, and to the geostrophic fluxes of angular momentum and enthalpy. Hastenrath (1966) established the budgets of mechanical energy, latent heat, geopotential energy and sensible heat for the layers 1000-850, 850-700, 700-500 and 500-300 hPa, for both the Caribbean Sea and the Gulf of Mexico. He found that the terms of the mechanical energy are one or two orders of magnitude smaller than those of the other energy forms. According to him there is strong divergence of latent heat, concentrated in the layers 1000-850 hPa and 850-700 hPa over the Caribbean Sea during the winter half-year. Grubber (1970) studied the mean structure and energy budget over Florida Peninsula in order to assess the role played by convective processes in the vertical transfer of heat. He found the net export of energy mainly in the 300-100 hPa layer. Alestalo and Holopainen (1980) computed the horizontal fluxes of energy at European aerological stations between the surface and 150 hPa level. All these studies of energy fluxes are of different regions and not of Bangladesh-India region and the studies are not related to thunderstorms. Over the Bangladesh-India region, there are some studies related to the onset and withdrawal of southwest monsoon (Anjaneyulu, 1971; Keshavamurthy, 1968; Krishnamurthy, 1971; Chowdhury and Karmakar, 1980(a,b), 1981 and 1983; Karmakar, 1984). But no study



**Fig. 1.** Location of the Rawinsonde Stations

has been made on the tropospheric fluxes of moisture related to nor'westers over this region.

This present study is an attempt to study the fluxes of moisture of the troposphere over Dhaka as well as its surrounding areas of India before the occurrence of several nor'westers in Bangladesh with a view to find out some criteria for their occurrence.

## 2. Data used

Real time rawinsonde data of 0000 UTC at different isobaric heights from 1000 to 100 hPa at Dhaka, Chittagong and different Indian stations have been collected from the Storm Warning Centre (SWC) of Bangladesh Meteorological Department. SWC received these data on real time basis through GTS-Link. For frequency analysis of different fluxes of moisture only the data at Dhaka has been considered and for spatial distribution all the available data of 26 stations have been considered. The stations under study are shown in Fig. 1. It may be mentioned that data of all the 26 stations were not available on the dates of occurrence of nor'westers.

In some cases, rawinsonde data were not available at one/two levels. In those cases, number of data is less than 107. The nor'westers under study occurred over different

TABLE 1

%Frequency of zonal and meridional fluxes of moisture over Dhaka at 0000 UTC on the dates of occurrence of nor'westers in Bangladesh

Pressure (hPa)	Total frequency	% Frequency of positive fluxes	% Frequency of negative fluxes	% Frequency of zero fluxes	% Frequency of positive fluxes	% Frequency of negative fluxes	% Frequency of zero fluxes
1000	107	41.12	48.60	10.28	92.52	4.67	2.80
925	107	85.05	13.08	1.87	98.13	1.87	0.00
850	107	94.39	2.80	2.80	71.96	19.63	8.41
700	107	97.20	0.00	2.80	24.30	67.29	8.41
500	107	70.09	0.00	29.91	19.63	43.93	36.45
400	107	65.42	0.93	33.64	28.97	33.64	37.38
300	107	61.68	0.93	37.38	34.58	27.10	38.32
200	107	10.28	0.00	89.72	6.54	2.80	90.65
100	107	0.00	0.00	100.00	0.00	0.00	100.00

parts of Bangladesh during the pre-monsoon season of 1990-1995. For spatial distribution of the instability indices, 26 cases of nor'westers have been considered for the study. Rawinsonde data at Dhaka on the dates of non-occurrence of nor'westers (especially 1 day before the date of occurrence of nor'westers) have also been collected from Bangladesh Meteorological Department for the comparative study.

### 3. Methodology

#### 3.1. Water vapour fluxes in the atmosphere

For a given level in the atmosphere, the magnitude of the instantaneous zonal and meridional fluxes of water vapour are given by :

$$Q_{\lambda_L} = qu \quad (1)$$

$$Q_{\phi_L} = qv \quad (2)$$

Where

$Q_{\lambda_L}, Q_{\phi_L}$  = Zonal and meridional water vapour flux for a given level ( $\text{gm kg}^{-1} \times \text{ms}^{-1}$ )

$q$  = Specific humidity ( $\text{gm kg}^{-1}$ )

$u, v$  = Zonal and meridional wind component ( $\text{ms}^{-1}$ )

#### 3.2. Vertically integrated fluxes of moisture

The vertically integrated zonal and meridional components of the moisture flux are given by

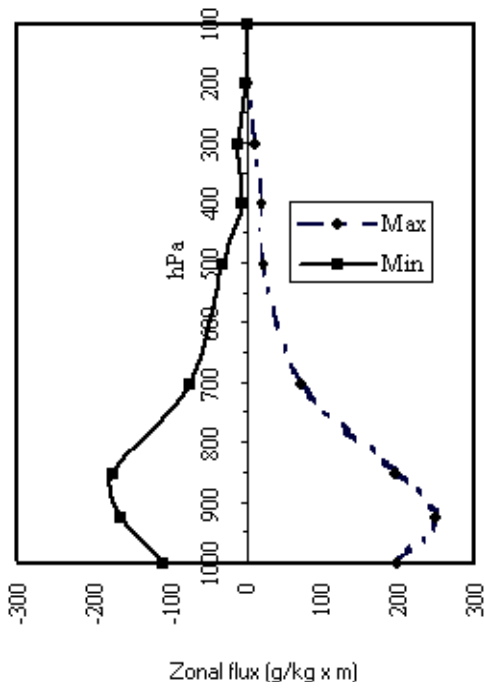
$$Q_{\lambda_L} = g^{-1} \int_{1000}^{500} qu dp$$

$$Q_{\phi_L} = g^{-1} \int_{1000}^{500} qv dp$$

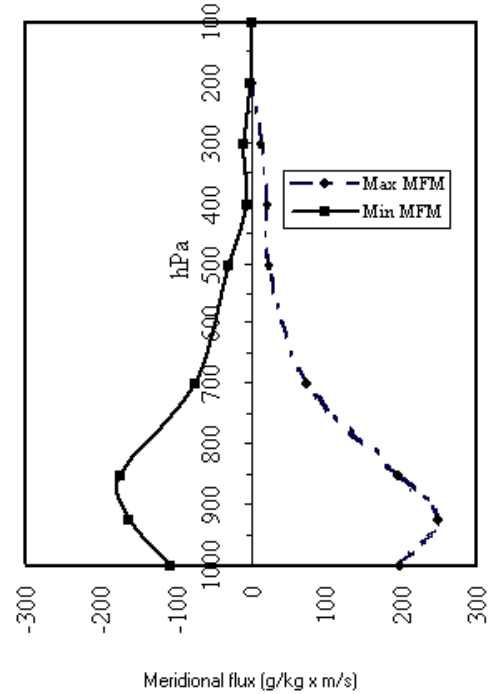
The integration has been done by taking the layer mean values of the fluxes of moisture from 1000 to 400 hPa level over Dhaka and for spatial distribution from 925 to 100 hPa level. Here 925 hPa has been taken because the surface pressure becomes less than 1000 hPa level in most of the stations during the pre-monsoon season. The unit of  $Q_{\lambda_L}$  and  $Q_{\phi_L}$  is  $\text{kg} \times \text{ms}^{-1}$ .

### 4. Results and discussion

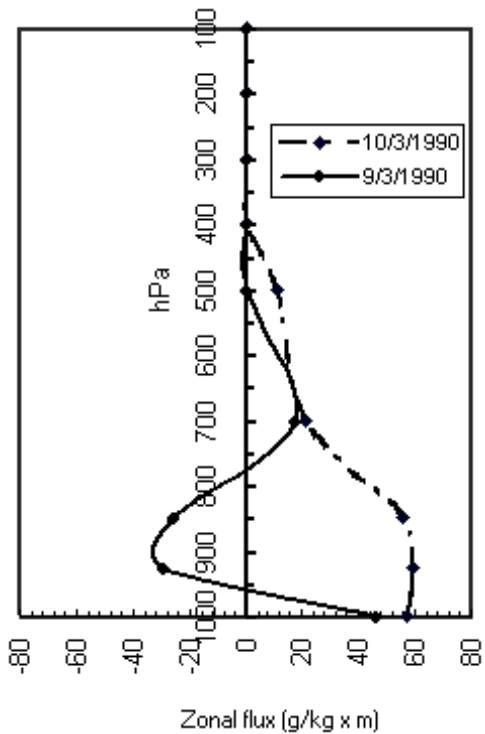
The zonal fluxes of moisture (ZFM) and meridional fluxes of moisture (MFM) over Dhaka at 0000 UTC have been computed at different isobaric levels on the dates of occurrence of about 107 nor'westers over Bangladesh during pre-monsoon season of 1990-1995. The fluxes over Dhaka have also been computed for the dates of non-occurrence of nor'westers. A comparative study of the frequency of westerly (positive) and easterly (negative) and southerly (positive) and northerly (negative) fluxes of moisture have been made and are given in Table 1.



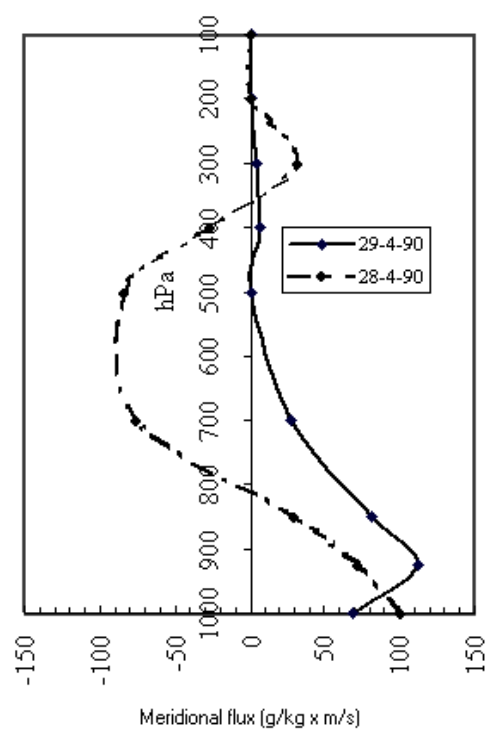
**Fig. 2.** Vertical variation of the maximum and minimum zonal fluxes of moisture ( $\text{g kg}^{-1} \times \text{ms}^{-1}$ ) over Dhaka at 0000 UTC on the dates of occurrence of nor'westers over Bangladesh



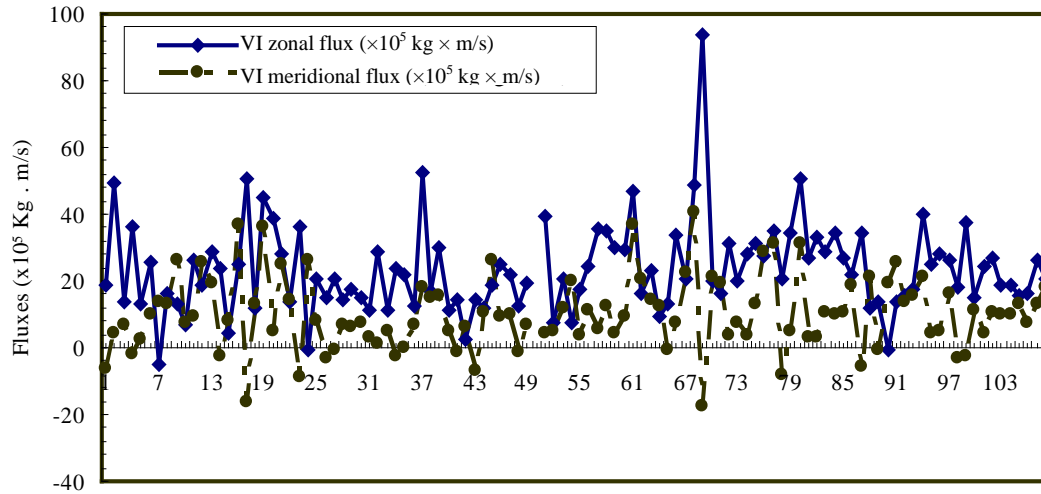
**Fig. 4.** Vertical variation of the maximum and minimum meridional fluxes of moisture ( $\text{g kg}^{-1} \times \text{ms}^{-1}$ ) over Dhaka at 0000 UTC on the date of occurrence of nor'westers over Bangladesh



**Fig. 3.** Vertical profiles of the zonal fluxes of moisture ( $\text{g kg}^{-1} \times \text{ms}^{-1}$ ) over Dhaka at 0000 UTC on the date of occurrence (10 March 1990) and the date of non-occurrence (9 March 1990)



**Fig. 5.** Vertical profiles of the meridional fluxes of moisture ( $\text{g kg}^{-1} \times \text{ms}^{-1}$ ) over Dhaka at 0000 UTC on the date of occurrence (29 April 1990) and the date of non-occurrence (28 April 1990)



**Fig. 6.** Vertically integrated zonal and meridional fluxes of moisture over Dhaka at 0000 UTC on the dates of occurrence of nor'westers in Bangladesh

#### 4.1. Zonal fluxes of moisture (ZFM) over Dhaka

Table 1 shows that the EFM dominates at 1000 hPa in many cases over Dhaka on the dates of occurrence of nor'westers over Bangladesh and the EFM decrease with height. The WFM dominate in the troposphere from 925 to 300 hPa level having maximum frequency of WFM from 61.68 to 97.20% in the layer from 925 to about 300 hPa level. In the upper troposphere the ZFM become nil in most of the cases.

The maximum WFM over Dhaka at 0000 UTC on the dates of occurrence of nor'westers may be 223.6, 203.8, 315.6, 174.1, 88.2, 38.7 and 19.1  $\text{gm kg}^{-1} \times \text{ms}^{-1}$  at 1000, 925, 850, 700, 500, 400 and 300 hPa levels respectively and then the fluxes become unimportant above. The maximum EFM over Dhaka at 0000 UTC may be -128.3, -59.7, -12.6 and -50.2  $\text{gm kg}^{-1} \times \text{ms}^{-1}$  at 1000, 925, 850 and 700 hPa levels respectively and then the fluxes become unimportant above. Fig. 2, as an example, shows the variation of maximum and minimum ZFM with height. The maximum ZFM are always westerly on the dates of occurrence of nor'westers.

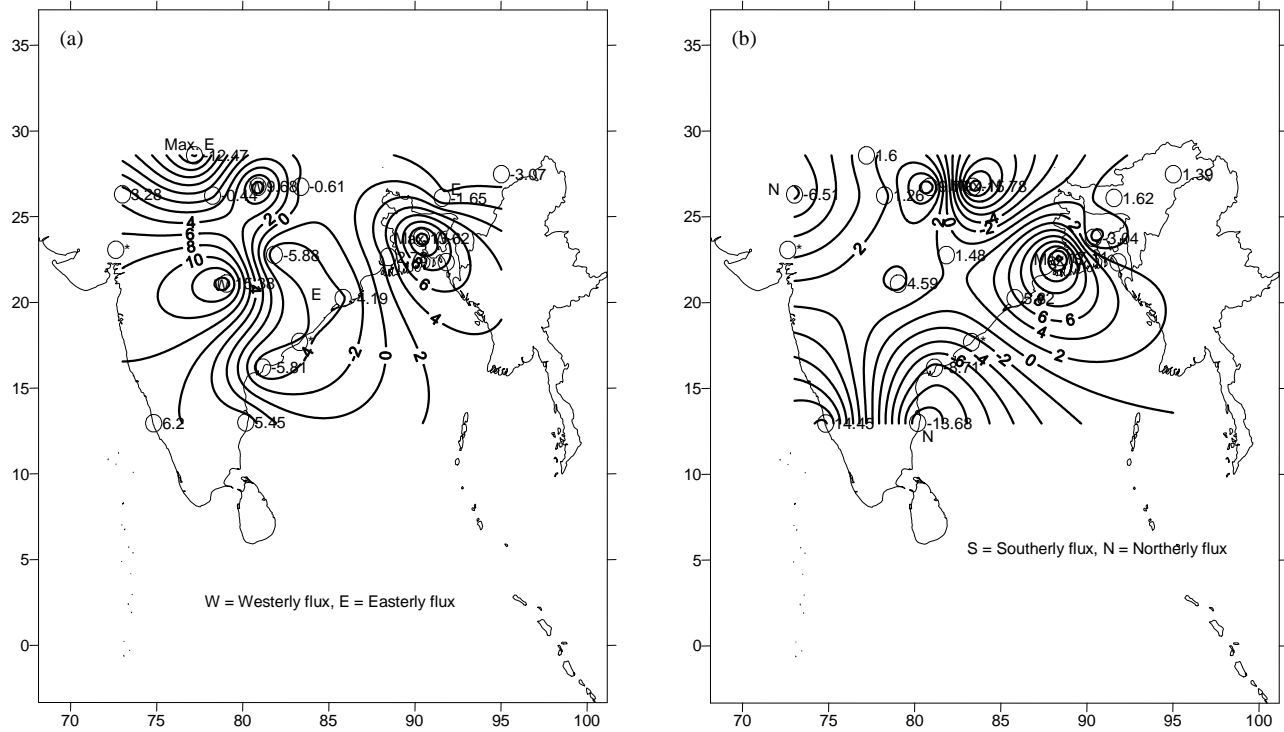
The vertical profiles of the ZFM over Dhaka at 0000 UTC on the dates of occurrence and non-occurrence of nor'westers in Bangladesh are studied and the variation is shown in Fig. 3 as an example. It has been found that the fluxes are mainly westerly and more westerly in the lower and middle troposphere on the dates of occurrence of nor'westers as compared to the fluxes on the dates of non-occurrence. The fluxes become nil in the upper troposphere.

#### 4.2. Meridional fluxes of moisture (MFM) over Dhaka

Table 1 shows that the southerly flux of moisture (SFM) dominate from 1000 to about 300 hPa level in most of the cases over Dhaka on the dates of occurrence of nor'westers over Bangladesh, having maximum frequency of SFM in the lower troposphere and the frequency of SFM decreases with height. The frequency of SFM is 92.52% at 1000 and 98.13% at 925 hPa levels. The frequency of northerly flux of moisture (NFM) is less in the lower troposphere having maximum frequency of NFM from 67.29 to 27.10% in the layer from 700 to about 300 hPa level. In the upper troposphere the MFM become nil in most of the cases.

The maximum SFM over Dhaka at 0000 UTC on the dates of occurrence of nor'westers may be 199.4, 250.2, 196.9, 74.9, 23.6, 21.6 and 12.3  $\text{gm kg}^{-1} \times \text{ms}^{-1}$  at 1000, 925, 850, 700, 500, 400 and 300 hPa levels respectively and then the fluxes become unimportant above. The maximum NFM over Dhaka at 0000 UTC may be -109.1, -163.5, -174.1, -74.4 and -31.0  $\text{gm kg}^{-1} \times \text{ms}^{-1}$  at 1000, 925, 850, 700 and 500 hPa levels respectively and then the fluxes become unimportant above on the dates of occurrence of nor'westers in Bangladesh. Fig. 4 shows, as an example, the variation of maximum and minimum ZFM with height. The maximum MFM are always southerly on the dates of occurrence of nor'westers.

The vertical profiles of the MFM over Dhaka at 0000 UTC on the dates of occurrence and non-occurrence of nor'westers in Bangladesh are studied and the variation is



**Figs. 7(a&b).** Spatial distribution of vertically integrated zonal and meridional fluxes of moisture at 0000 UTC on 14 May 1992 (date of occurrence) from 925 to 400 hPa ( $\times 10^5$  kg  $\times$  m/s)

shown in Fig. 5 as an example. It has been found that the fluxes are mainly southerly and more southerly in the lower and middle troposphere on the dates of occurrence of nor'westers as compared to the fluxes on the dates of non-occurrence. The fluxes become nil in the upper troposphere.

#### 4.3. Vertically integrated zonal and meridional fluxes of moisture over Dhaka

The ZFM and MFM computed at different isobaric levels over Dhaka at 0000 UTC on the dates of occurrence of nor'westers, have been integrated from 1000 to 400 hPa level by taking the layer mean moisture flux. The vertically integrated ZFM and MFM for 107 nor'westers are shown in Fig. 6. Fig. 6 shows that the vertically integrated ZFM are much higher than that of the MFM.

The frequency of vertically integrated ZFM and MFM over Dhaka at 0000 UTC on the dates of occurrence of nor'westers in Bangladesh is given in Table 2. The table shows that only 3 nor'westers out of 106 (2.83%) the fluxes are easterly and the fluxes are westerly in 97.17%

cases. About 83.96% WFM are in the range of  $(10-40) \times 10^5$  kg  $\times$  ms<sup>-1</sup> and 7.55% WFM are in the range of  $(40-60) \times 10^5$  kg  $\times$  ms<sup>-1</sup> on the dates of occurrence of nor'westers in Bangladesh. The vertically integrated MFM are northerly in 19.63% cases of nor'westers. The MFM are southerly in 80.37% cases and about 39.25% MFM are in the range of  $(10-30) \times 10^5$  kg  $\times$  ms<sup>-1</sup> and 4.67% SFM are in the range of  $(30-50) \times 10^5$  kg  $\times$  ms<sup>-1</sup>.

The vertically integrated ZFM may vary from  $-4.84 \times 10^5$  to  $93.78 \times 10^5$  kg  $\times$  ms<sup>-1</sup> and the vertically integrated MFM may vary from  $-17.63 \times 10^5$  to  $40.85 \times 10^5$  kg  $\times$  ms<sup>-1</sup> over Dhaka at 0000 UTC on the dates of occurrence of nor'westers in Bangladesh.

#### 4.4. Spatial distribution of the vertically integrated ZFM and MFM

The spatial distribution of the vertically integrated ZFM from 925 to 400 hPa level over Bangladesh and its surrounding areas has been analyzed for several cases of nor'westers and one distribution is shown in Fig. 7(a) as an example. It has been found that vertically integrated

TABLE 2

Frequency of vertically integrated zonal and meridional fluxes of moisture over Dhaka at 0000 UTC on the dates of occurrence of nor'westers in Bangladesh

Range of fluxes ( $\times 10^5 \text{ kg} \times \text{ms}^{-1}$ )	Frequency of vertically integrated zonal fluxes of moisture	Frequency of vertically integrated meridional fluxes of moisture
-20 to -10	0	2
-10 to 0	3	19
0 to 10	6	39
10 to 20	39	29
20 to 30	35	13
30 to 40	16	4
40 to 50	5	1
50 to 60	3	0
Total	107	107

WFM dominate over Bangladesh on most of the dates of occurrence of nor'westers and the gradient of fluxes is steep over the country. The range of the vertically integrated ZFM for the layer is about  $(2-12) \times 10^5 \text{ kg} \times \text{ms}^{-1}$  over Bangladesh in most of the cases. A trough of WFM exists over Bihar, sub-Himalayan West Bengal and north-western Bangladesh extending to south-eastern Bangladesh as can be seen from Fig. 7(a).

The spatial distribution of the vertically integrated MFM from 925 to 400 hPa level over Bangladesh and its surrounding areas has been analyzed for several cases of nor'westers and one distribution is shown in Fig. 7(b) as an example. It has been found that vertically integrated SFM dominate over south-southwestern and adjoining central parts of Bangladesh on the dates of occurrence of nor'westers and the gradient of fluxes is steep over the region. There exist NFM in the northwestern and northeastern parts of the country in many cases. The range of the vertically integrated MFM for the layer is about  $(3-14) \times 10^5 \text{ kg} \times \text{ms}^{-1}$  in most of the cases. A trough of WFM exists over Bihar, sub-Himalayan West Bengal and north-western Bangladesh extending to south-eastern Bangladesh as can be seen from Fig. 7(b).

## 5. Conclusions

On the basis of the present study, the following conclusions can be drawn:

(i) The westerly fluxes (positive) of moisture dominate in the troposphere over Dhaka at 0000 UTC from 925 to

200 hPa level having maximum frequency of westerly fluxes from 61.68 to 96.26% in the layer from 925 to about 300 hPa level. In the upper troposphere the zonal fluxes of moisture become nil in most of the cases.

(ii) The maximum westerly fluxes of moisture over Dhaka at 0000 UTC on the dates of occurrence of nor'westers may be more than  $200 \text{ gm kg}^{-1} \times \text{ms}^{-1}$  in the lower troposphere and the maximum easterly fluxes of moisture may be  $-128.3 \text{ gm kg}^{-1} \times \text{ms}^{-1}$  at 1000 hPa.

(iii) The zonal fluxes of moisture over Dhaka at 0000 UTC are mainly westerly and more westerly in the lower and middle troposphere on the dates of occurrence of nor'westers as compared to the fluxes on the dates of non-occurrence.

(iv) The southerly fluxes (positive) of moisture dominate in the troposphere over Dhaka at 0000 UTC from 1000 to 300 hPa level. The frequency of southerly is 92.52% at 1000 hPa and 98.13% at 925 hPa level. The frequency of northerly fluxes of moisture is less in the lower troposphere having maximum frequency of northerly fluxes from 67.29 to 27.10% in the layer from 700 to about 300 hPa level. In the upper troposphere the meridional fluxes of moisture become nil in most of the cases.

(v) The meridional fluxes of moisture are mainly southerly and more southerly in the lower and middle troposphere on the dates of occurrence of nor'westers as compared to the dates of non-occurrence.

(vi) The frequency of vertically integrated fluxes of moisture over Dhaka at 0000 UTC from 1000 to 100 hPa on the dates of occurrence of nor'westers in Bangladesh are westerly in 97.17% cases and southerly in 80.37% cases. There exist vertically integrated northerly fluxes in the northwestern and northeastern parts of the country in many cases. The range of the vertically integrated meridional fluxes of moisture at 0000 UTC for the layer is about  $(3-14) \times 10^5 \text{ kg} \times \text{ms}^{-1}$  in most of the cases.

(vii) The spatial distribution of the vertically integrated ZFM from 925 to 400 hPa level over Bangladesh and its surrounding areas at 0000 UTC indicates that vertically integrated WFM dominate over Bangladesh and/or eastern Uttar Pradesh, Bihar and Sub-Himalayan West Bengal of India on the dates of occurrence of nor'westers and the gradient of fluxes is steep over the country. The vertically integrated southerly fluxes of moisture dominate over south southwestern and adjoining central parts of Bangladesh on the dates of occurrence of nor'westers and the gradient of fluxes is steep over the region.

#### Acknowledgements

The authors are thankful to the Director of Bangladesh Meteorological Department (BMD) for providing the relevant data for the study. Thanks are also due to Mr. Abdul Mannan, Assistant Meteorologist, Mr. S. M. Quamrul Hassan, Assistant Meteorologist and Mrs. Masuda Mohi, Teleprinter Operator of BMD for their help in scanning the diagram and in the preliminary compilation of data.

#### References

- Alestalo, M. and Holopainen, E., 1980, "Atmospheric energy fluxes over Europe", *Tellus*, **32**, 6, 500-510.
- Anjaneyulu, T. S. S., 1971, "On the estimates of heat and moisture over the Indian monsoon trough zone", *Tellus*, **21**, 64-74.
- Chowdhury, M. H. K. and Karmakar, S., 1980(a), "Some aspects of energetics of the troposphere over the Arabian Sea with advancement of south-west monsoon", *FGGE Operations Report: Results of Summer Monex Field Phase Research*, **9**, Part-A, 81-91.
- Chowdhury, M. H. K. and Karmakar, S., 1980(b), "Diagnostic study on some aspects of energetics and structural features of the troposphere over the Arabian Sea with the advancement of SW-Monsoon", *FGGE Operations Report: Results of Summer Monex Field Phase Research*, **9**, Part-B, 212-240.
- Chowdhury, M. H. K. and Karmakar, S., 1981, "On the meridional and zonal fluxes of energy components in the troposphere over the Arabian Sea with the advancement of SW-Monsoon", *Mausam*, **32**, 4, 375-380.
- Chowdhury, M. H. K. and Karmakar, S., 1983, "On the zonal and meridional eddy fluxes of energy components of the troposphere over the Arabian Sea during the onset phase of SW-Monsoon", *Mausam*, **34**, 2, 161-166.
- Grubber, A., 1970, "The energy budget over the Florida Peninsula when a convective regime dominates", *J. Appl. Met.*, **9**, 1-6, 401-416.
- Hastenrath, S. L., 1966, "On general circulation and energy budget in the area of Central American Seas", *J. Atm. Sci.*, **23**, 6, 694-711.
- Henry, R.M. and Hess, S.L., 1958, "A study of the large-scale spectra of some meteorological parameters", *J. Met.*, **16**, 397-403.
- Karmakar, S., 1984, "Some aspects of tropospheric energy and its fluxes over Bangladesh and neighborhood during the withdrawal phase of southwest monsoon", M. S. Thesis, Department of Meteorology and Oceanography, University of the Philippines.
- Keshavamurthy, R. N., 1968, "On the maintenance of the mean zonal motion in the Indian Summer monsoon", *Mon. Wea. Rev.*, **96**, 23-31.
- Krishnamurthy, T. N., 1971, "Observational study of the tropical upper tropospheric motion field during the northern hemisphere summer", *J. Appl. Met.*, **10**, 1066-1096.
- Palmen, E., Riehl, H. and Vuorela, L. A., 1958, "On the meridional circulation and release of kinetic energy in the tropics", *J. Met.*, **15**, 271-277.