MAUSAM, 48, 3 (July 1997), 367-374

551.511.62:551.515.2

Analysis of different tropospheric energies in the surroundings of the Bay of Bengal during different cyclonic periods

M.D. MAHBUB ALAM* and SULTANA SHAFEE

Department of Physics, Dhaka University

Dhaka - 1000, Bangladesh

(Received 19 June 1995, Modified 6 May 1996)

सार — इस अध्ययन के लिए, पिछले दशक की विभिन्न चक्रवातीय अवधियों के लिए धरातल, 850, 700, 500, 400, 300, 200, 150, और 100 है.पा. के मानक समदाब तलों के लिए 0000 यू. टी. सी. के उपरितन वायु आँकड़ों पर विचार किया गया है। चक्रवातों की गति और इनके प्रभावित अंतिम क्षेत्रों के संदर्भ में बंगाल की खाड़ी के समीपवर्ती क्षेत्रों की शुष्क स्थैतिक ऊर्जा, गुप्त ऊष्मा ऊर्जा, नम स्थैतिक ऊर्जा और सकल ऊर्जा तथा इनके ऊर्ध्वाधर वितरण का अध्ययन किया गया है। दाब को ऊर्ध्वाधर निर्देशांक मानकर ग्राफों की सहायता से विभिन्न क्षोभ मंडलीय ऊर्जाओं के प्रभावों पर चर्चा की गई है।

ABSTRACT. Upper-air data of 0000 UTC for standard isobaric surfaces at surface, 850, 700, 500, 400, 300, 200, 150 and 100 hPa levels for the different cyclonic periods in the last decade were considered for study. The dry static energy, the latent heat energy, the moist static energy and the total energy and their vertical distribution were studied in the surroundings of the Bay of Bengal in relation to the movement of the cyclone and their ultimate landfall. The effects of different tropospheric energies considering the pressure as a vertical coordinate are discussed with the help of graphs.

Key words — Cyclone, Dry static energy, Latent heat energy, Moist static energy, Total energy, Specific humidity, Bay of Bengal.

1. Introduction

Because of the special geographical location, Bangladesh is devastated by different natural disasters like tropical cyclones, nor'westers, tornado, floods etc. One of these, tropical cyclone is the most devastating and may cause huge damage and loss to lives and properties in Bangladesh. Cyclones forming in the Bay of Bengal move initially towards west or northwest; at times they recurve and move to north and northeast. As a result, the countries bordering the Bay of Bengal, specially west and north, are so much victimized.

It is generally accepted that the track and the intensity of the cyclone in the tropics depends mostly on the sea surface temperature (SST). Once formed, the cyclone is found to move over middle latitude oceans where the ocean is colder (Krishnamurti 1979).

The role of energy fluxes is to govern the atmospheric circulation as well as the physical processes

**Present affiliation* : On leave of absence from Department of Physics, BIT Khulna, Khulna - 9203, Bangladesh

responsible for the formation of tropical cyclones. Therefore, it is essential to study the role of tropospheric energy and their vertical distribution in prediction of formation and movement of tropical cyclones in respect of their intensity, track and landfall.

In the present study we have examined the behaviour of different tropospheric energies, such as, the dry static energy, the latent heat energy, the moist static energy and the total energy and their vertical distribution in the surroundings of the Bay of Bengal during the cyclonic periods. We have considered several severe cyclonic storms with a core of hurricane winds and one cyclonic storm formed in the Bay of Bengal and crossed the Bangladesh coast in the last decade. The severe cyclonic storms with a core of hurricane winds occurring in 1994, 1992, 1991, 1988 & 1985 and the cyclonic storm of 1992 have been considered for the study. We have tried to form a clear idea about the vertical distribution of energies in the surroundings of the Bay of Bengal.

2. Method of analysis

We computed the different tropospheric energies, such as, the dry static energy, the latent heat energy, the moist static energy and the total energy by using the following relations:

Dry static energy

$$s = C_p T + gZ \quad (1)$$

Moist static energy

$$h = C_p T + gZ + Lq \quad (2)$$

$$\text{Total energy} = C_p T + gZ + Lq + \frac{1}{2} V^2 \quad (3)$$

where,

C_p = the specific heat of air at constant pressure

T = the basic state absolute temperature

g = the acceleration due to gravity

Z = the geopotential height in meter

L = the latent heat of evaporation of water

V = the wind speed

$C_p T$ = the specific enthalpy

gZ = the potential energy per unit mass

Lq = the latent heat energy per unit mass

$\frac{1}{2} V^2$ = the kinetic energy per unit mass

q = the specific humidity.

The empirical formula for specific humidity is given by:

$$q = \frac{r q_s}{100} = \frac{0.622 * E_s(T_d)}{P - 0.38 * E_s(T_T)} \quad (4)$$

q_s = specific humidity at saturation

P = the basic state of pressure

T_d = the dew point temperature

T_T = the dry bulb temperature

$E_s(T_d)$ = the saturation vapour pressure at dew point temperature

$E_s(T_T)$ = the saturation vapour pressure at dry bulb temperature

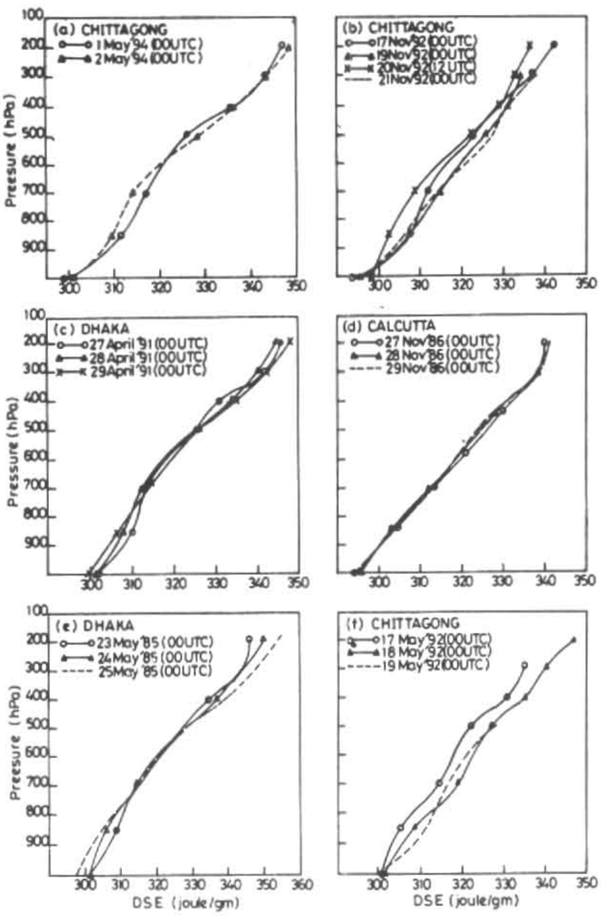
r = the relative humidity (Roger and Richard 1982).

$$r = \frac{\text{sat. vapour pressure at dew point} * 100}{\text{sat. vapour pressure at air temperature}} \quad (5)$$

We use the value of specific heat at constant pressure C_p = 1004 JK^{-1} kg^{-1}. The latent heat of evaporation and saturation vapour pressure over water at different temperatures were used from Byers (1974). The latent heat of evaporation L over water were extrapolated at 1°C intervals from Byers (1974) and q requires separate computation.

3. Data sources

Upper-air data of 0000 UTC and in some cases at 1200 UTC for the standard isobaric surfaces at surface, 850, 700, 500, 400, 300, 200, 150 and 100 hPa levels of different cyclonic periods in the last decade have been considered for this study. The data were collected from the Storm Warning Center (SWC) of Bangladesh



Figs. 1 (a-f). Dry static energy (joule/g) over Chittagong, Dhaka and Calcutta

Meteorological Department (BMD). The different cyclonic periods are:

(*i*) 29 April to 2 May 1994

(*ii*) 17 November to 21 November 1992

(*iii*) 27 April to 29 April 1991

(*iv*) 24 November to 29 November 1988

(*v*) 23 May to 25 May 1985

(*vi*) 17 May to 19 May 1992

The data were analysed for the stations Dhaka, Chittagong, Calcutta, Cuttack and Port Blair. It may be noted that the data were not available for some cases for all stations in the synoptic chart and constant pressure chart. We have collected data from synoptic chart and constant pressure chart, where the data plotted are in round figures. There is virtually no weather station over the Bay of Bengal, so we could not collect any data over this region.

4. Results and discussions

4.1. *Dry static energy*

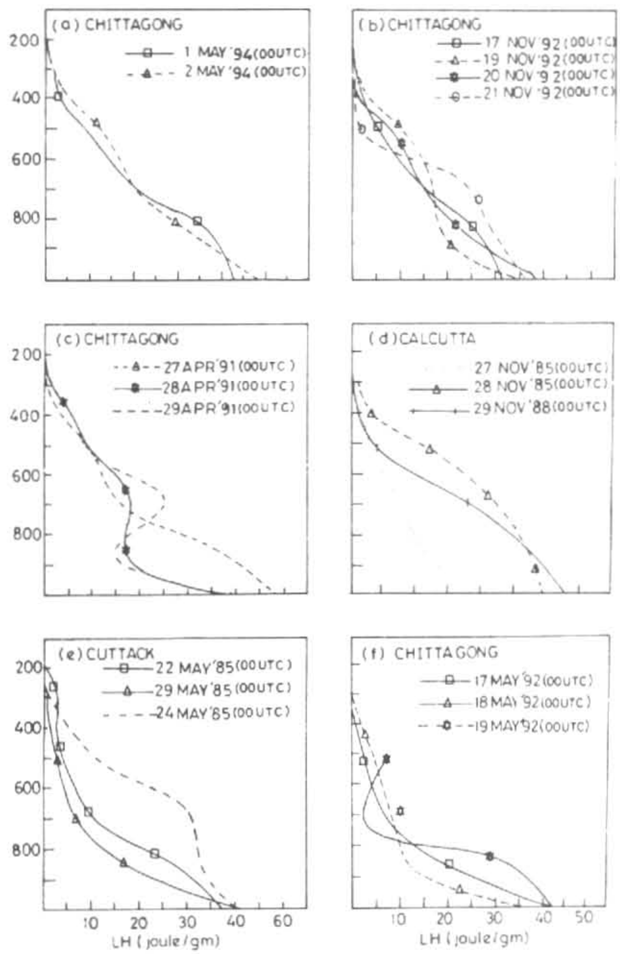
The dry static energy of the troposphere over different stations surrounding the Bay of Bengal on different dates during the formation and landfall of tropical cyclones has been computed for different isobaric levels. The day-to-day variation of dry static energy has been discussed. It has been found that the dry static energy increases with height in general. But if a day-to-day variation of dry static energy with height for cyclones of different intensities is considered, the nature of variation is found to be different. The changes observed for different cyclones are discussed below :

(a) *Cyclone of 29 April-2 May 1994*

The dry static energy decreases from surface to 475 hPa level and increases from 475 to 200 hPa over Dhaka on 1 May with respect to that of 30 April. The dry static energy decreases from 600 to 475 hPa and increases from 850 to 600 hPa and 475 to 200 hPa over Calcutta on 1 May with respect to that of 30 April. The dry static energy increases at all levels over Dhaka and Calcutta on 2 May with respect to that of 1 May. The dry static energy decreases (Fig. 1a) from, 950 to 575 hPa level and increases from 575 to 200 hPa over Chittagong on 2 May with respect to that of 1 May. It is clear from the above discussions that the dry static energy of the troposphere decreases at all levels in the far away stations, such as, Dhaka and Calcutta, whereas there exists a decreases and an increases of dry static energy in the lower and upper troposphere respectively at the nearby station, such as, Chittagong on the day of landfall with respect to that of the previous day.

(b) *Cyclone of 17-21 November 1992*

The dry static energy is almost constant from surface to 500 hPa level and it increases from 500 to 200 hPa over Dhaka on 18 November with respect to that of 17 November. The dry static energy increases gradually from surface to 400 hPa with little anomalies over Dhaka during 18-20 November. The dry static energy decreases at all levels on 21st with respect to that of 20 November over Dhaka. The dry static energy increases (Fig. 1b) on 19th with respect to that of 17th, decreases on 20th with respect to that of 19th



Figs. 2 (a-f). Latent heat energy (joule/g) over Chittagong, Calcutta and Cuttack

and increases on 21st with respect to that of 20 November at all levels with little anomalies over Chittagong. The dry static energy increases gradually at all levels over Cuttack during the period. The dry static energy increases at all levels on 18th with respect to that of 17th and decreases gradually with little anomalies during 18-20 November over Port Blair.

(c) *Cyclone of 27-29 April 1991*

The dry static energy decreases at all levels (Fig. 1c) over Dhaka on 28 April with respect to that of 27 April and decreases from surface to 800 hPa level and increases from 800 to 200 hPa on 29th with respect to that of 28th. The dry static energy has no regular trend on 27 and 28 April but almost constant from surface to 600 hPa and increases from 600 to 200 hPa over Chittagong on 29th with respect to that of 28 April. The dry static energy decreases at all levels over Calcutta on 28th with respect to that of 27th and increases at all levels on 29th with respect to that of 28th. The dry static energy decreases at all levels over Cuttack on 27th with respect to that of 26th April and decreases from surface to 700 hPa and increases from 700 to 400 hPa on 29th with respect to that if 27th April. The dry static energy decreases at all levels over Port Blair on 26th with respect to that of 25th and increases at all levels on 28th with respect to that of 26 April.

(d) *Cyclone of 24-29 November 1988*

The dry static energy increases at all levels over Dhaka and decreases at all levels over Chittagong and Calcutta with little anomalies on 28 November with respect to that of 27th. The dry static energy decreases from 850 to 450 hPa level and increases from 450 to 200 hPa over Dhaka on 29th with respect to that of 28. The dry static energy is almost constant over Chittagong from 850 to 500 hPa and increases from 500 to 200 hPa on 29th with respect to that of 28 November. The dry static energy decreases (Fig. 1d) from 850 to 600 hPa and increases from 600 to 400 hPa level and constant above this level over Calcutta on 29th with respect to that of 28 November. The dry static energy increases at all levels over Dhaka and Chittagong after the landfall.

(e) *Cyclone of 23-25 May 1985*

The dry static energy decreases gradually (Fig. 1e) from surface to 725 hPa level and increases gradually from 725 to 200 hPa over Dhaka during 23 - 25 May. Little amount of dry static energy increases at all levels over Calcutta on 23rd with respect to that of 22nd. The dry static energy decreases significantly at all levels with little anomalies around surface over Cuttack on 23rd with respect to that of 22nd and increases significantly at all levels on 24h with respect to that of 23rd. It may be mentioned that the data at Chittagong is not available during 23-25 May.

(f) *Cyclonic storm of 17-19 May 1992*

The dry static energy decreases from surface to 600 hPa level over Dhaka, increases at all levels (Fig. 1f) over Chittagong, irregular over Calcutta and increases from surface to 850 hPa level and decreases from 850 to 200 hPa over Cuttack on 18 May with respect to that of 17th. The dry static energy is almost constant over Dhaka and has no regular trend over Chittagong on 18th and 19th. The dry static energy decreases at all levels over Cuttack and increases from 850 to 200 hPa and decreases from surface to 850 hPa level over Calcutta on 19th with respect to that of 18 May.

4.2. *Latent heat energy*

(a) *Cyclone of 29 April-2 May 1994*

The latent heat energy decreases from surface to 600 hPa level and increases from 600 to 450 hPa level over Dhaka on 1 May with respect to that of 30 April. The latent heat energy decreases from surface to 400 hPa with little anomalies over Calcutta on 1 May with respect to that of 30 April. The latent heat energy decreases (Fig. 2a) from surface to 800 hPa, 850 hPa and 925 to 700 hPa on 2 May with respect to that of 1 May over Dhaka, Calcutta and Chittagong respectively. The analysis also indicates that the latent heat energy increases from 700 to 300 hPa and 850 to 400 hPa level over Chittagong and Calcutta respectively on the same day. The latent heat energy increases on 3 May, that is, after the landfall over Dhaka and has no regular trend over Calcutta.

(b) *Cyclone of 17-21 November 1992*

The latent heat energy decreases at all levels over Dhaka on 18 November with respect to that of 17th. The latent heat energy decreases (Fig. 2b) from surface to 725 hPa level and increases from 725 to 350 hPa over Chittagong on 19th with respect to that of 17th. The latent heat energy increases from surface to 725 hPa and decreases from 700 to 300 hPa gradually with little anomalies on 18th to 21st over Dhaka and Chittagong. The latent heat energy decreases at all levels on 19th with respect to that of 18th and increases from surface to 750 hPa and decreases from 750 to 300 hPa on 20th with respect to that of 19th over Cuttack. The latent heat energy increases at all levels on 18 with respect to that of 17th over Port Blair. The latent heat energy decreases gradually from surface to 300 hPa level during 18-20 November over Port Blair with little anomalies in the lower surface on 19th.

(c) *Cyclone of 27-29 April 1991*

The latent heat energy decreases significantly (Fig. 2c) from surface to 750 hPa level and increases from 725 to 600 hPa over Chittagong on 28 and 29 April with respect to that of 27th. The latent heat energy increases significantly from surface to 750 or 700 hPa over Dhaka, Calcutta, Cuttack and Port Blair as the cyclone moves towards the landfall and little amount of latent heat decreases on 29th around surface over Dhaka and Cuttack. The latent heat energy is irregular above 700 hPa level over Chittagong and Port Blair and increases over Dhaka, Calcutta and Cuttack on 29 April with respect to that of 28th.

(d) *Cyclone of 24-29 November 1988*

The latent heat energy increases significantly over all stations on 28 November with respect to that of 27th. The latent heat energy increases from surface to 850 hPa level and decreases significantly (Fig. 2d) from 850 to 300 hPa over Calcutta, almost constant over Dhaka and irregular over Chittagong on 29th with respect to that of 28th. This indicates that the latent heat energy decreases in the region where the cyclone moves and all other regions have little or no changed.

(e) *Cyclone of 23-25 May 1985*

The latent heat energy increases gradually at all levels over Dhaka during 23 - 25 May except little anomalies around surface where the latent heat energy decreases gradually. The latent heat energy decreases (Fig. 2e) over Cuttack on 23rd with respect to that of 22nd and increases significantly on 24th May with respect to that of 23rd. The latent heat energy decreases from surface to 750 hPa and increases from 750 to 300 hPa level over Calcutta on 23rd with respect to that of 22 May.

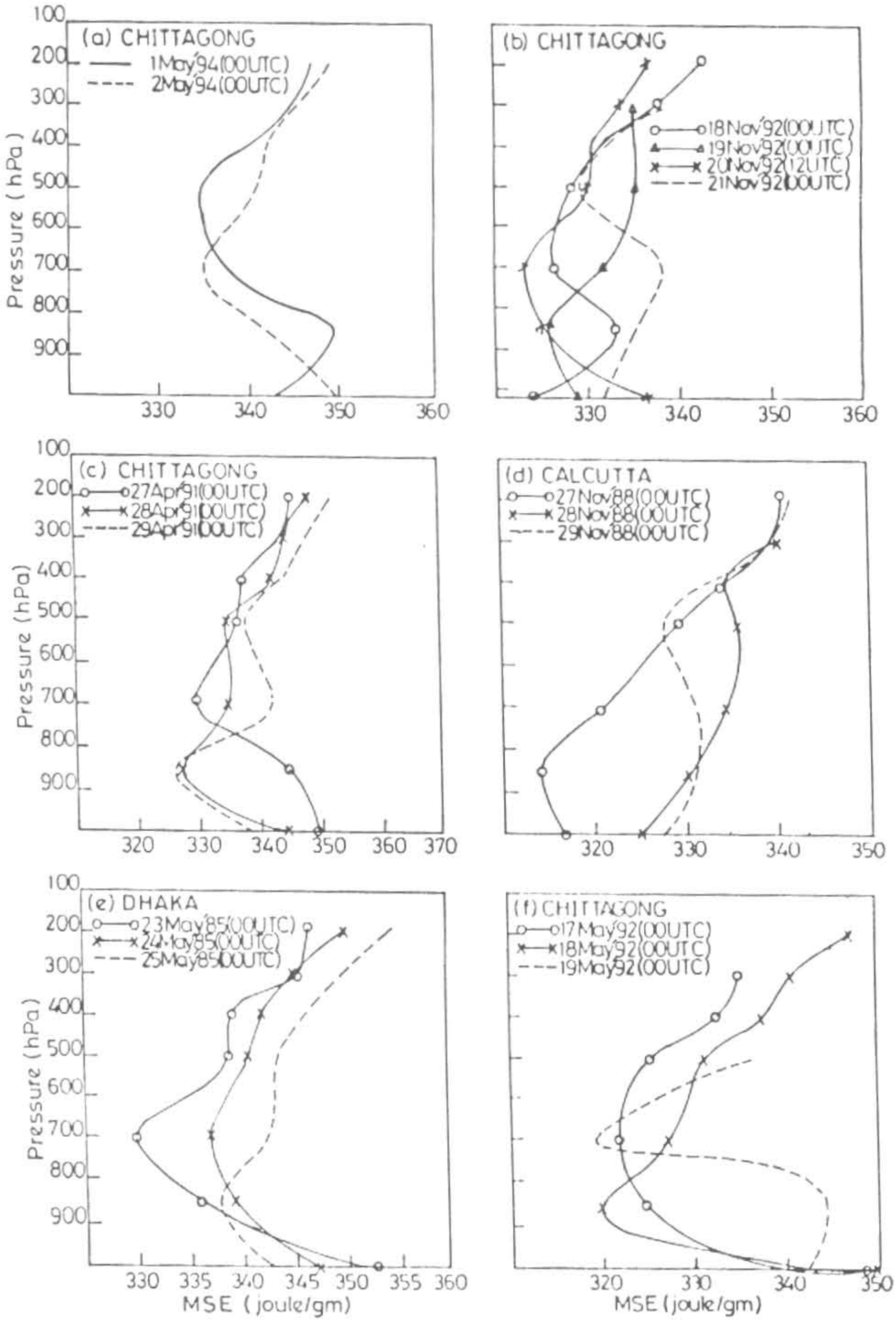
(f) *Cyclonic storm of 17-19 May 1992*

The latent heat energy decreases (Fig. 2f) from surface to 700 hPa level over Chittagong and increases at the same level over Dhaka and Calcutta on 18 May with respect to that of 17th. The latent heat energy decreases at all levels over Dhaka and Calcutta and increases significantly from surface to 775 hPa level over Chittagong on 19th with respect to that of 18th. The latent heat energy decreases gradually at all levels over Cuttack during 17-19 May.

4.3. *Moist static energy*

(a) *Cyclone of 29 April - 2 May 1994*

The moist static energy decreases from surface to 525 hPa level and increases from 525 to 200



Figs. 3 (a-f). Moist static energy (joule/g) over Chittagong, Dhaka and Calcutta

hPa over Dhaka on 1 May with respect to that of 30 April. The moist static energy decreases from surface to 425 level and increases from 425 to 200 hPa with little anomalies over Calcutta on 1 May with respect to that of 30 April. The moist static energy decreases from surface to 775 and 900 hPa and increases from these levels to 200 hPa over Dhaka and Calcutta respectively on 2 May with respect to that of 1 May. The moist static energy increases from surface to 950 hPa and 650 to 200 hPa and decreases (Fig. 3a) from 950 to 650 hPa over Chittagong on 2 May with respect to that of 1 May. It is also found that the magnitude of moist static energy decreases in the lower troposphere (from

950 to 650 hPa) and increases in the upper troposphere during the cyclonic period. This decrease of moist static energy in the lower troposphere is significant in the nearby station such as Chittagong and increase in moist static energy is also significant in the far away station, such as, Calcutta.

(b) *Cyclone of 17-21 November 1992*

The moist static energy decreases from surface to 450 hPa level over Dhaka on 18 November with respect to that of 17th. The moist static energy increases gradually from surface to 725 hPa during 18 - 21 November over Dhaka and decreases significantly from 625 to 200 hPa level on 21st with respect to that of 20th. The moist static energy decreases from surface to 750 hPa and increases from 750 to 350 hPa on 19th with respect to that of 17th over Chittagong. The moist static energy increases from surface to 850 hPa and decreases from 850 to 200 hPa on 20th with respect to that of 19th over Chittagong. The moist static energy increases at all levels (Fig. 3b) over Chittagong on 21st with respect to that of 20th . The moist static energy decreases from surface to 500 hPa and increases from 500 to 200 hPa level over Cuttack on 19th with respect to that of 18th. The moist static energy increases from surface to 650 hPa and decreases above this level on 20th with respect to that of 19th over Cuttack. Except 17 November the moist static energy decreases gradually over Port Blair during the cyclonic period.

(c) *Cyclone of 27-29 April 1991*

The moist static energy increases gradually over Dhaka during 27- 29 April except little anomalies from surface to 900 hPa level on 29th. The moist static energy decreases significantly (Fig. 3c) from surface to 800 hPa over Chittagong on 28th and 29th with respect to that of 27th and increases from 800 to 200 hPa on 29th with respect to that of 28th. The moist static energy increases over Calcutta from surface to 750 hPa and decreases from 750 to 200 hPa level on 28th with respect to that of 27th and increases at all levels on 29th with respect to that of 27th and 28th. The moist static energy increases from surface to 850 hPa level and decreases from 800 to 200 hPa level over Cuttack on 27th with respect to that of 26th. Again the moist static energy decreases from surface to 800 hPa level and increases from 800 to 200 hPa level on 29th with respect to that of 27th over the station. The moist static energy increases over Port Blair from surface to 800 hPa and decreases from 800 to 200 hPa level on 26th with respect to that of 25th and increases at all levels on 28th with respect to that of 27 April.

(d) *Cyclone of 24-29 November 1988*

The moist static energy increases significantly over all stations on 28 November with respect to that of 27th except little anomalies in the upper troposphere. The moist static energy decreases from surface to 450 hPa on 29th with respect to that of 28th over Dhaka. The moist static energy increases (Fig. 3d) from surface to 825 hPa and decreases from 825 to 375 hPa on 29th with respect to that of 28th over Calcutta. The moist static energy increases at all levels over Chittagong on 29th with respect to that of 28 November.

(e) *Cyclone of 23-25 May 1985*

The moist static energy increases gradually (Fig. 3e) over Dhaka from 800 to 200 hPa level and decreases gradually from surface to 900 hPa during 23-25th May. The moist static energy decreases from surface to 775 hPa and increases from 775 to 300 hPa over Calcutta on 23rd with respect to that of 22nd. The moist static energy decreases over Cuttack at all levels on 23rd with respect to that of 22nd and increases at all levels on 24th with respect to that of 23 May.

(f) *Cyclonic storm of 7-19 May 1992*

The moist static energy increases gradually (Fig. 3f) over Chittagong and decreases gradually over Cuttack with few exceptions during 17-19 May. The moist static energy increases from surface to 700 hPa level over Dhaka on 18th with respect to that of 17th. The moist static energy increases from surface to 700 hPa, 450 to 200 hPa and decreases from 700 to 450 hPa over Calcutta on 18th with respect to that of 17th. The moist static energy is almost constant over Dhaka from 700 to 200 hPa level on 17th and 18th. The moist static energy decreases from surface to 500 hPa and 800 hPa and increases from these levels to 200 hPa level over Dhaka and Calcutta respectively on 19th with respect to that of 18 May. The moist static energy increases near the landfall station, such as, Chittagong and decreases far away stations, such as, Dhaka, Calcutta and Cuttack during the period.

4.4. *Total energy*

The changing pattern of variation of total energy is the same as mentioned in case of moist static energy. In addition to the kinetic energy with the moist static energy there is only fractional variation of the magnitude of total energy.

5. Conclusions

(*i*) The dry static energy decreases or remains almost constant in the lower troposphere and increases in the upper troposphere on the day of landfall with respect to that of the previous day in the nearby stations. The dry static energy increases in case of the weakened cyclone and in case of the cyclonic storm on the day of landfall with respect to that of the previous day.

(*ii*) The latent heat energy decreases with little anomalies in case of all the severe cyclonic storms with a core of hurricane winds from surface to 750 hPa or 700 hPa level in the nearby stations and increases in the far away stations on the day of landfall with respect to that of the previous day. The latent heat energy increases in the nearby stations and decreases in the far away stations in case of the weakened cyclone and in case of the cyclonic storm on the day of landfall with respect to that of the previous day.

(*iii*) The moist static energy decreases with little anomalies in case of all the severe cyclonic storms with a core of hurricane winds from surface to 800 hPa or 700 hPa level and increases from these levels to 200 hPa in the nearby stations and increases significantly in the far away stations on the day of landfall with respect to that of the previous day. The moist static energy increases at all levels in the nearby stations and decreases in the far away stations in case of the weakened cyclone and in case of the cyclonic storm on the day of landfall with respect to that of previous day.

(*iv*) It is also found that the dry static energy, the latent heat energy and the moist static energy decreases towards the region where the cyclone moves.

Acknowledgements

The authors are indebted to Mr. M.H. Khan Chowdhury, Director, Bangladesh Meteorological Department (BMD) for giving many valuable suggestions. The authors also like to thank Mr. S. Karmakar, Assistant Director, BMD, Mr. Sujit Kumar Deb Sharma, Meteorologist and System Manager and Mr. Shah Alam, Meteorologist, Storm Warning Center (SWC), BMD, for supplying the data and helping in various ways. The authors wish to express their gratitude to the University Grants Commission (UGC), Bangladesh, for financial support to one of the authors (Md. Mahbub Alam).

References

Byers, H.R., 1974, General Meteorology, Fourth edition, 106- 116.

Krishnamurti, T.N., 1979, Compendium of Meteorology, WMO No. 364, Vol. 2, Part 4, 186p.

Roger, G.B. and Richard, J.C. 1982, Atmosphere, Weather and Climate, 4th edition 62-63.