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Diurnal and spatial variation of convective parameters over Bay of Bengal during BOBMEX 1999

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सार – इस शोध–पत्र में, बॉब मेक्स 1999 की अवधि के दौरान बंगाल की खाड़ी में तापगतिकीय प्राचलों के दैनिक और स्थानिक परिवर्तन जैसे कि सवंहनी उपलब्ध स्थितिज ऊर्जा (सी.ए.पी.ई.), संवहनी अवरूद्ध ऊर्जा (सी.आई.एन.ई.), आर्द्र स्थैतिक ऊर्जा (एम.एस.ई), संवहनी रूप से उत्पन्न अधिकतम ऊर्ध्ववाह गति (डब्ल्यू.$_{\text{मैक्स}}$) और अविमीय गतिज प्राचल (एल.) का अध्ययन करने का प्रयास किया गया है। इस अध्ययन से यह ज्ञात होता है कि बंगाल की खाड़ी में इन तापगतिकीय प्राचलों में विशिष्ट प्रकार का दैनिक परिवर्तन होता है। सी.ए.पी.ई. का औसत मान दिन की अपेक्षा रात के समय अधिक पाया गया है और सी.आई.एन.ई. एवं एम.एस.ई. का ऋणात्मक मान रात की अपेक्षा दिन के समय अधिक पाया गया। इस अध्ययन से यह भी पता चलता है कि प्रयोग की अवधि के अधिकांश दिनों में निम्न क्षोभमंडल संवहनी रूप से अस्थिर (आर्द्र) था। सी.ए.पी.ई. के संयुक्त विश्लेषण से यह पता चलता है कि श्रीलंका–तमिलनाडु तट के समीप, दक्षिण–पश्चिम और समीपवर्ती पश्चिम मध्य खाडी, संवहनी रूप से अधिक अस्थिर है तथा बारी–बारी से आने वाले उतार चढाव, उसमें निष्क्रिय गुरूत्व तरंगों की उपस्थिति की ओर भी संकेत करता है।

ABSTRACT. An attempt has been made to study the diurnal and spatial variation of thermo-dynamical parameters *viz.*, Convective Available Potential Energy (CAPE), Convective Inhibition Energy (CINE), Moist Static Energy (MSE), convectively generated maximum updraft speed (W_{max}) and non-dimensional kinetic parameter (L) over Bay of Bengal during BOBMEX-1999 period. The study reveals that there is a marked diurnal variation in these thermodynamic parameters over Bay of Bengal. The average value of the CAPE was found to be more during the night than in the day and the negative value of CINE and MSE are found to be more during the day than in the night. The study also shows that during the period of experiment on most of the days, lower troposphere was convectively unstable (moist). The composite analysis of CAPE shows that southwest & adjoining west-central Bay near Sri Lanka - Tamil Nadu coast is more convectively unstable and an alternate rise and fall in it also indicates the presence of inertia gravity waves.

Key words – Convective available potential energy, Convective inhibition energy, Moist static energy.

1. Introduction

It is well known that in the southwest monsoon (SWM) season, meso-scale weather phenomena are embedded into the synoptic scale SWM circulation. These meso-scale weather phenomena include the development of strong convections such as convectively generated inertia gravity waves (IGW). These meso-scale weather phenomena are reflected by the occurrence of isolated heavy rainfall on individual days, succeeding and preceding the days with comparatively less rainfall due to availability of sufficient moisture. To identify isolated heavy rainfall events, which are due to meso-scale weather phenomena, embedded in synoptic scale SWM circulation, it is required to examine the station data on contrasting rainfall days. Based on studies over tropical oceanic and land regions of the Caribbean and over the Pacific regions of the tropics Reihl (1954), Reihl *et al.*, (1973) have shown that the days associated with less or no precipitation activity did contain less moisture than that on the days with good rainfall. Mukherjee and Ramana Murthy (1978) in their studies related to contrasting rainfall features and associated thermodynamic behavior over Mumbai found that the difference in static stability and precipitable water content (PWC) between consecutive days of contrasting rainfall was not significant. Further, Williams and Renno (1993) have shown that isolated heavy rainfall on any isolated day results not only from a higher value of CAPE, rather it results from the combined effect of a high positive value of CAPE and low negative value of CINE. In a recent study (Dutta and De, 1999) related to behaviour of thermo-dynamical parameters *viz*., CAPE, MSE and Scorer parameter, and low-level instability it is found that in most cases CAPE was more on the day of heavy rainfall.

Now it is well known that the thermo-dynamical and dynamical structure of atmosphere over Bay of Bengal plays important role in determining the behaviour of monsoon dynamics over the Indian continent because of convectively generated instabilities. To understand the behaviour of these instabilities and their contribution in monsoon dynamics over Indian continent it is necessary to understand the spatial as well as temporal variation of thermo-dynamical and dynamical structure of atmosphere over this region. For this purpose under the Indian Climate Research Program (ICRP), an experiment called Bay of Bengal Monsoon Experiment (BOBMEX) 1999 was designed. Dutta & Rao (2001) have studied the diurnal and spatial variation of thermodynamic parameters over land along the east coast of India during BOBMEX 1999. Their study revealed that the maximum value of CAPE occurred in the early morning or night & that of CINE was found to be in the afternoon over Kolkata. The study also showed that the value of the CINE was sensitive to the location of level of free convection (LFC) and value of CAPE was sensitive to the upper level buoyancy force and the location of level of neutral buoyancy (LNB). Objective of present study is to understand the diurnal and spatial variation of the above-mentioned convective parameters over Bay of Bengal during BOBMEX 1999.

2. Data

Upper air radiosonde (RS) data at different locations over Bay of Bengal on all the BOBMEX (1999) days, *viz*., 19^{th} to 29^{th} June, 1^{st}, 3^{rd} to 8^{th}, 10^{th}, 11^{th}, 17^{th} and 23^{rd} July for 0600 UTC, 0700 UTC, 1800 UTC and 1900 UTC have been used for the present study. Area of present study is the oceanic part of the latitude and longitude box extending from 0° N to 17° N and 72° E to 88° E. RS data at different locations over this area has been obtained from the National Data Centre, India Meteorological Department, Pune.

3. Methodology

3.1. In the present study CAPE has been calculated using the formula

$$\mathrm{CAPE} = \int_{Z_{LFC}}^{Z_{LNB}} \frac{g(T_{VP} - T_{VE})}{T_{VE}} dz = \int_{P_{LFC}}^{P_{LNB}} \frac{-R(T_{VP} - T_{VE})}{P} dp \qquad (1)$$

Where,

T_{VE} = Virtual temperature of the environment at pressure level p.

T_{VP} = Virtual temperature at pressure level p of an air parcel following pseudo adiabat through surface wet bulb temperature.

P_{LFC} = Pressure at the level of free convection (LFC)

P_{LNB} = Pressure at the level of neutral buoyancy (LNB)

Z_{LFC} = Height of the LFC and

Z_{LNB} = Height of the LNB.

Physically CAPE may be interpreted as the maximum amount of potential energy, possessed by air parcel, solely due to convection, convertible to vertical kinetic energy. In T - ϕ diagram it represents the positive area.

In some soundings LNB is not found and then the integral representing CAPE is evaluated numerically between the pressure level P_{LFC} and 200 hPa.

3.2. The convectively generated maximum updraft (W_{max}) is calculated using CAPE given by the formula

$$W_{max} = \sqrt{2 \times \mathrm{CAPE}} \qquad (2)$$

(Williams and Reno, 1993)

3.3. CINE is computed using the formula following William and Renno (1993) as :

$$\mathrm{CINE} = \int_{Z_{SFC}}^{Z_{LFC}} \frac{g(T_{VP} - T_{VE})}{T_{VE}} dz = \int_{P_{SFC}}^{P_{LFC}} \frac{-R(T_{VP} - T_{VE})}{P} dp \qquad (3)$$

Where, Z_{SFC}, Z_{LFC} are the height of the surface and LFC respectively above mean sea level and P_{SFC}, P_{LFC} are the pressures at the surface and at LFC respectively.

Physically, CINE may be interpreted as the amount of energy that must be supplied to an air parcel up to LFC following pseudo adiabat through the surface wet bulb temperature, to overcome the resistance inhibiting convection, owing to the low level stability of the atmosphere.

TABLE 1

Temporal and spatial distribution of computed thermodynamic parameters

Date	Lat. (°)	Long. (°)	Time (hrs)	CAPE (J kg^{-1})	CINE (J kg^{-1})	Height weighted averaged MSE, σ (J kg^{-1})	W_{max} (ms^{-1})	L
5 Jul	2	83	600	1.37E-01	–31.93312	346688.4	0.52345	-0.99571
7 Jul	6	84	600	2853.294	–69.86478	346141.8	75.54196	39.84023
11 Jul	12	81	600	2436.95	–190.3088	354481.8	69.81332	11.80524
23 Jul	17	88	600	0	0	422102.5	0	
20 Jun	10	72	700	1691.054	–206.1712	354548	58.15589	7.202183
22 Jun	10	72	700	1564.814	–163.1225	354898.2	55.94308	8.592877
24 Jun	10	72	700	1668.108	–14.72427	348266.3	57.75999	112.2897
26 Jun	10	72	700	1761.594	–149.127	350177.9	59.35645	10.81271
28 Jun	5	73	700	1370.761	–131.6472	350225.1	52.35955	9.412382
29 Jun	3	75	700	5.86E-01	–54.68124	342482.3	1.082589	-0.98928
1 Jul	0	77	700	1910.317	–128.4272	339853.1	61.81128	13.87471
17 Jul	13	82	700	1961.127	–14.72427	353314.4	62.6279	132.1901
19 Jun	10	72	1800	3415.662	–41.65617	346331.3	82.65182	80.99654
10 Jul	12	82	1800	3131.193	–172.0146	352493.8	79.13524	17.20307
20 Jul	17	88	1800	7.51E-01	–7.37136	361105.7	1.225561	-0.89812
21 Jun	10	72	1900	672.1144	–176.3821	354901.1	36.66373	2.810559
23 Jun	10	72	1900	1885.251	–17.0812	346126.7	61.40441	109.3699
25 Jun	10	72	1900	3656.969	–11.61306	343383	85.52156	313.9014
27 Jun	7	73	1900	1022.375	–29.20906	344079.3	45.21891	34.00198
29 Jun	2	76	1900	3015.008	–36.00405	338247.7	77.65318	82.7408
1 Jul	1	78	1900	1.34E-01	–55.54868	341731.2	0.517687	-0.99759
3 Jul	0	80	1900	1309.083	–31.24037	337985.3	51.16802	40.90357
4 Jul	1	82	1900	3822.004	–16.62754	333063.8	87.43002	228.8599
6 Jul	5	84	1900	2120.861	–2.019499	343011.2	65.1285	1049.192
8 Jul	9	83	1900	3092.234	–113.7335	346454.9	78.64139	26.18842

3.4. By using CAPE and CINE, computed earlier, following Basu and Mandal (2002) here also we have computed a non-dimensional kinetic parameter (L) by using the formula

$$\mathrm{L} = \frac{|\mathrm{CAPE}| - |\mathrm{CINE}|}{|\mathrm{CINE}|} \tag{4}$$

Clearly L is large, when CAPE is large and CINE is small. Atmospheric state is favourable for convective activity when the value of L is large and moisture is available up to considerable depth in the atmosphere.

3.5. Moist static energy (MSE) of the atmosphere at any level is computed using the formula

$$\mathrm{MSE} = \mathrm{C_p}T + \mathrm{g}Z + \mathrm{Lq} \tag{5}$$

where Cp is the specific heat of gas at constant pressure, L is the latent heat of evaporation and q is the specific humidity. Then weighted average of MSE (σ) is defined as

$$\sigma = \frac{\sum Z_i \times \mathrm{MSE}_i}{\sum Z_i} \tag{6}$$

Where MSE_i is the MSE at the ith level, the height of which is Z_i.

Both the integrals in (1) and (2) are evaluated numerically using Trapezoidal rule. CAPE, W_{max}, CINE, L & σ obtained at different points, over the area of the study at different times have been plotted and then contour analysis have been done to obtain their composite diagram.

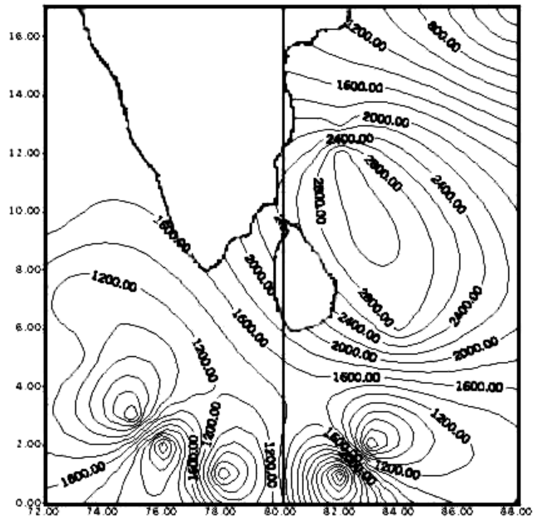

Fig. 1. CAPE (J kg^{-1}), Composite Chart for BOBMEX period over North Indian Ocean

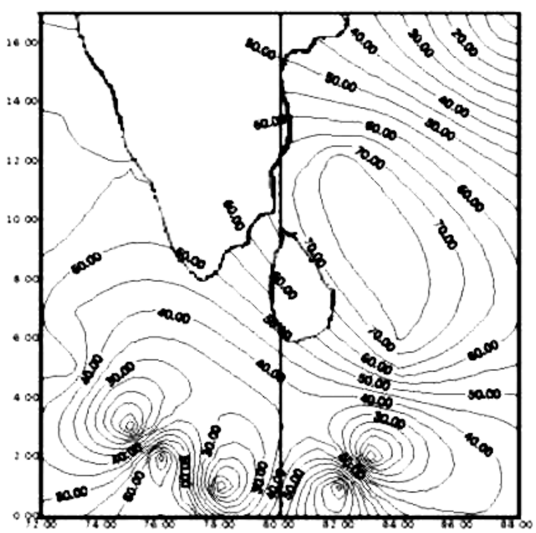

Fig. 2. W_{max} (ms^{-1}) Composite Chart for BOBMEX period over North Indian Ocean

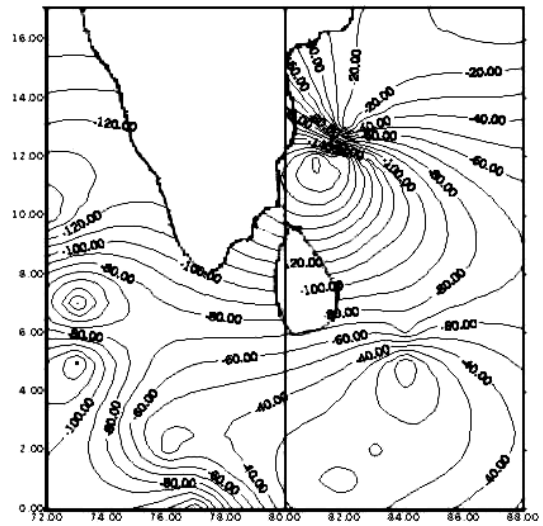

Fig. 3. CINE (J kg^{-1}) Composite Chart for BOBMEX period over North Indian Ocean

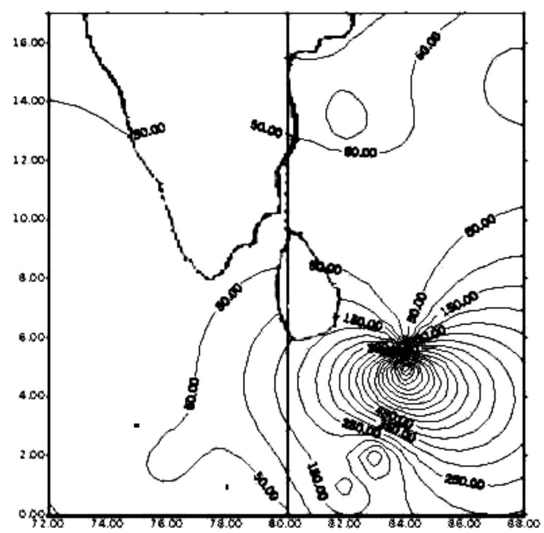

Fig. 4. Non-Dimensional Kinetic Parameter (L) Composite Chart for BOBMEX period over North Indian Ocean

4. Discussion

4.1. *Convective available potential energy (CAPE)*

The CAPE values computed using RS data, reported by ships at different locations and at different times, during BOBMEX 1999 period, have been given in Table 1. From the table it is clear that the time of observation may broadly be divided into two groups, *viz*., daytime (0600 UTC or 0700 UTC) and night time (1800 UTC or 1900 UTC).

From the table it is seen that at night CAPE value exceeds 2000 J/kg on seven occasions whereas in the day it exceeds that only on two occasions. Maximum value of CAPE was attained during night and it was 3822 J/kg.

Based on the different values of CAPE, given in the Table 1, we have found out the mean, standard deviation (SD) and coefficient of variation (CV) of CAPE for daytime as well as for night time. The mean, SD and CV for daytime are found to be 1434.89 J/kg, 910.19 J/kg and

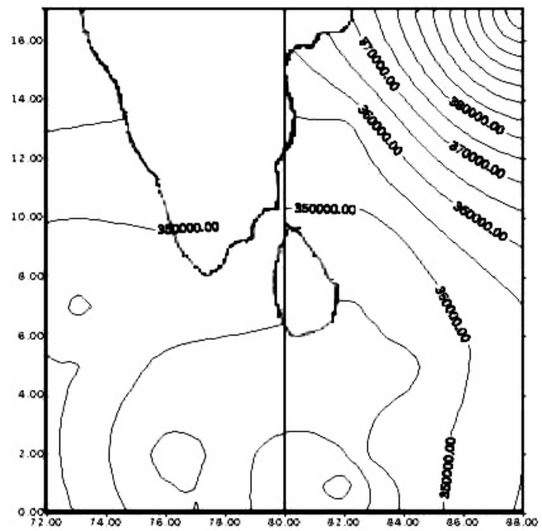

Fig. 5. MSE (J kg^{-1}): Composite Chart for BOBMEX period over North Indian Ocean

0.63 respectively. Those for night time are found to be 2087.97 J/kg, 1321.19 J/kg and 0.63 respectively.

To get an insight about the spatial variation of CAPE over Bay of Bengal, a composite diagram of CAPE has been prepared and shown in Fig. 1. From this Composite diagram it is seen that during BOBMEX 1999, highest CAPE value has been found over Southwest & adjoining West Central Bay. Also there is an alternate rise and fall of CAPE value over Bay of Bengal and Arabian Sea near the equator. This may be attributed to the westward propagating Inertia Gravity Waves.

4.2. *Convectively generated maximum updraft (W_{max})*

Convectively generated maximum updraft have been computed from CAPE values for each case and given in Table 1. From the table it is seen that during night it exceeds the value 60 ms^{-1} on eight occasions whereas in the day it exceeds that only 4 times. At night W_{max} attains its highest value of 87.4 ms^{-1}.

Based on the different values of W_{max}, given in the Table 1, we have found out the mean, standard deviation (SD) and coefficient of variation (CV) of W_{max} for day time as well as for night time. The mean, SD and CV for daytime are found to be 46.25 m/s, 27.04 m/s and 0.58 respectively. Those for night time are found to be 57.87 m/s, 28.75 m/s and 0.50 respectively.

Composite diagram for W_{max} (Fig. 2) shows similar pattern as that of CAPE.

4.3. *Convective inhibition energy (CINE)*

Similar to CAPE, the values of CINE are computed and have been given in the Table 1. From the table it is clear that negative value of CINE exceeds -100 J/kg on six occasions during the day, whereas it exceeds the same value only on three occasions at night. In the night, negative maximum value of CINE was -176 J/kg, whereas that in the day it was -206 J/kg.

Based on the different values of CINE, given in the Table 1, we have found out the mean, standard deviation (SD) and coefficient of variation (CV) of CINE for day time as well as for night time. The mean, SD and CV for day time are found to be –96.23 J/kg, -70.48 J/kg and 0.73 respectively. Those for night time are found to be –54.65 J/kg, -55.75 J/kg and 1.02 respectively.

It is clear from the composite diagram of CINE (Fig. 3), that minimum negative value of CINE (more than -50 J/kg) was available near the equator, which shows that low-level convective inhibition was less near the equator.

4.4. *Non-dimensional kinetic parameter (L)*

The value of L at different locations over Bay of Bengal at different timings during BOBMEX, 1999 has been given in Table 1. From the table, it is clear that L exceeds the value 50 on six occasions at night whereas it exceeds 50 only on two occasions in the day.

Based on the different values of L, given in the Table 1, we have found out the mean, standard deviation (SD) and coefficient of variation (CV) of L for day time as well as for night time. The mean, SD and CV for day time are found to be 31.28, 44.29 and 1.42 respectively. Those for night time are found to be 152.64, 274.3 and 1.8 respectively.

To have an insight about the spatial variation of L, we may look at the composite diagram of L (Fig. 4). From this diagram, it is clear that L is maximum over South Bay. So, this region is prone to have more convective activity.

4.5. *Weighted average of MSE (σ) over Bay of Bengal*

The weighted average of MSE values as computed at different locations and at different times, during BOBMEX 1999 period, has been given in Table 1. From

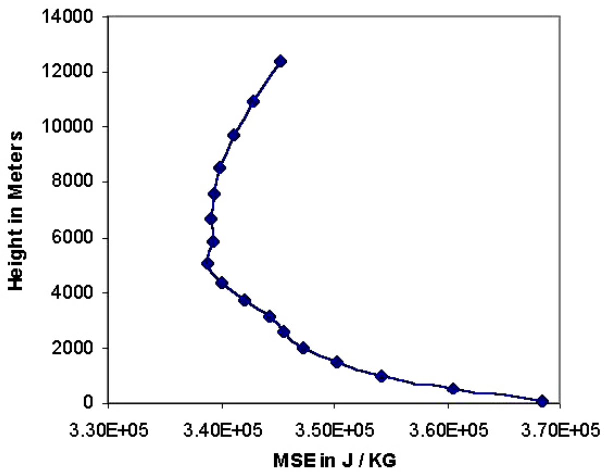

Fig. 6. Vertical Profile of MSE: Composite Chart for BOBMEX period over North Indian Ocean

the table it is clear that the maximum value of MSE (422102.5 J/kg) was attained at 0600 UTC and the minimum value of MSE (333063.8 J/kg) was attained at 1900 UTC.

Based on the different values of σ, given in the Table 1, we have found out the mean, standard deviation (SD) and coefficient of variation (CV) of σ for day time as well as for night time. The mean, SD and CV for day time are found to be 355264.983 J/kg, 20676.66 J/kg and 0.58 respectively. Those for night time are found to be –345301.15 J/kg, 7194.75 J/kg and 0.021 respectively.

The composite diagram of MSE (Fig. 5) shows that the value of weighted average of MSE is increasing in the northeasterly direction from the southwest Bay.

Since the vertical profiles of MSE on each of the 25 BOBMEX 1999 days show similar pattern, hence instead of showing each of these 25 vertical profiles, a composite vertical profile has been prepared and shown in Fig. 6. The composite profile shows that, MSE decreases with height in the lower level, which indicates that over Bay of Bengal the atmosphere is moist convectively unstable in the lower troposphere.

5. Conclusions

From the above study, following conclusions may be made :

During the period of study (BOBMEX 1999) with available data over different parts of Bay of Bengal (BOB).

(*i*) The mean value of CAPE was found to be more during night time than in the day time.

(*ii*) Mean value of CINE and σ was found to be more in the day time than in the night time.

(*iii*) Atmosphere in the lower tropospheric levels over Bay of Bengal was highly convectively unstable (moist).

(*iv*) Southwest and adjoining west central Bay was comparatively more convectively unstable.

(*v*) Alternate rise and fall in the value of CAPE near the equator indicates the presence of Inertia Gravity Waves.

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