CHAPTER - III

HEAT CONTENT VARIATIONS

3.1. Introduction

This chapter deals with the seasonal variations of heat content upto a depth of 200m in different layers of 50m thickness in the northern Indian Ocean during the period 1977-1986. Daily variations of heat content of different layers for different polygon areas (Ref. fig.1.1) and variations of cyclone heat potential (CHP28) before and after three storm events were analysed over Arabian Sea and Bay of Bengal during June 1977 and May-June 1979.

Heat storage in the Indian Ocean is greatly influenced by the forcing signals of semi-annual monsoons. Various investigators have pointed out that the local heat exchange with the atmosphere can hardly account for the large amounts of heat stored seasonally in the upper ocean at low latitudes. Duing and Leetma (1980), suggested that the Arabian Sea coastal upwelling is a major cause of heat storage variability. In the western equatorial Atlantic, Merle (1980) observed that the annual cycle of heat content appeared to be the result of vertical movement of thermocline associated with the dynamic response of the ocean to the seasonally varying winds. In fact, he showed that the rate of heat storage could be up to ten times larger than the net input through the sea surface.
Vertical and horizontal advections are of significant importance over the Indian Ocean, because of the intensity of eddy circulation during the monsoon. Bruce and Beatty (1985) and Molinari et al. (1986) are of the opinion that SST and heat storage of the surface layer control the amplitude of air-sea interaction to a great extent. Heat received from the atmosphere by the ocean at low latitudes has to be exported meridionally to higher latitudes. In the case of Arabian Sea and Somali basin, most of this heat must leave southward across the equator (Bruce, 1987). According to him, the energy of eddy field plays a significant role in the heat storage and vertical and horizontal transfer, in the western Indian Ocean during southwest monsoon.

Studies on the heat content of the upper ocean layer have received considerable attention in recent years because of its importance in Ocean-atmosphere energy exchanges. Long period weather fluctuations are related to the larger thermal memory of the ocean. According to Rao (1987,b), the heat content of top 100-200m layer is strongly influenced by the surface mixed layer cooling and the associated vertical advective processes in the upper thermocline.

The conventional method of monitoring heat content variations requires observations of vertical temperature profiles of the ocean either from ships or bouys. Attempts have also been made to estimate the heat content of the ocean from satellite data. Miller (1978) developed an algorithm to predict changes in the surface heat content using the satellite derived SST and
surface wind stress. Christenson and Mascarenhas (1979) computed heat storage of the ocean mixed layer by relating the density anomaly to temperature. Ali and Desai (1989) noticed a decrease in content of the upper 250m layer from west to east in the equatorial Indian Ocean during the onset of monsoon 1979. Dhoulath et al, (1990) estimated cyclone heat potential utilising the satellite derived SST and cloud motion vector winds extrapolated to the surface and examined the role of ocean heat potential on atmospheric disturbances.

3.2 Seasonal variations of heat content

The average heat content computed for the different seasons for different layer of 50m thickness over the northern Indian Ocean during the period 1977-1986 are presented in the following sections. During pre-monsoon the study is limited for the Arabian Sea due to the paucity of data.

3.2.1 Pre-monsoon season

Distribution of average heat content in the 0-50m layer in the Arabian Sea is shown in fig (3.1). The heat content of this layer increases from west to east reaching a maximum of $62 \times 10^8$ J/M$^2$ near the south west coast of India, where the mixed layer extends to about 50m. Similar increasing trend is also noticed for the MLD in this season (discussed in chapter-II). The maximum heat content area coincides with the area of warmer SST (>31$^\circ$C) and the area of minimum heat content of $54 \times 10^8$ J/M$^2$ coincides with cooler SST (26$^\circ$C) region. In the eastern Arabian Sea, heat
content decreases towards north along the west coast of India due to the increase in SST in the same direction. Maximum variations in heat content is observed around 12° N, 62° E. Heat content of 50-100m layer (fig.3.2) shows a decreasing trend from west to east south of 10° N. In the central Arabian Sea, the heat content increases from west to east reaching a maximum of $56 \times 10^8$ J/m² around 10° N, 59° E. The minimum heat content is observed around 13° N, 63° E. The decrease in heat content between this layer and the surface (0-50m) layer is minimum in the western Arabian Sea while, in the central Arabian Sea and near the Kerala coast, it is maximum. Maximum variations in heat content of this layer are found on the western side of the Arabian Sea.

Fig (3.3) shows the distribution of heat content for the 100-150m layer. It can be seen that, in this layer heat content varies between $42 \times 10^8$ and $50 \times 10^8$ J/m². The maximum heat content is observed around 8° N, 60° E from where it decreases in a northeasterly direction and attains the minimum value in the central Arabian Sea. Low heat content of $44 \times 10^8$ J/m² is also observed near the Kerala coast. In the western region, a decrease of about $15 \times 10^8$ J/m² is seen between this layer and the 1st layer (0-50m) while, it is about $13 \times 10^8$ J/m² in the eastern region. In the northern Arabian Sea where the heat content is minimum for the 1st layer, a decrease in heat content of $17 \times 10^8$ J/m² is noticed between 100-150m and the next upper layer.

The 150-200m layer shows minimum heat content of $38 \times 10^8$ J/m² along 8-10° N, 66-69° E (fig.3.4). The maximum is found in
the same region (around 13° N, 63° E) as in the case of 100-150m layer with a decrease of $10^8 J/M^2$. The minimum heat content near the Kerala coast is seen shifted slightly towards west. Generally the heat content decreases in all direction from the south central Arabian Sea. The decrease in heat content is maximum between the upper 100m layer and the lower layers in the southeastern Arabian Sea. On the an average decrease of $20*10^8 J/M^2$ in heat content is observed during this season between the 1st and last layer (150-200m).

3.2.2 Monsoon season

During this season, maximum heat content for the surface layer is observed in the western Equatorial region and in the central Bay of Bengal (fig.3.5). Heat content decreases towards east reaching a minimum of $50*10^8 J/M^2$ near the Kerala coast. Maximum variations are observed in the Arabian Sea compared to Bay of Bengal where a comparatively high heat content values are seen. In this season MLD extends to 120m in the central Arabian Sea (fig.2.10) showing a similar decreasing trend towards east as that of heat content variations. The minimum heat content area coincides with almost cooler SST of 27° C (Fig. 2.14). The low heat content near the southeastern Arabian Sea could be attributed to the upwelling phenomena prevailing during the monsoon period.

In the 50-100m layer, maximum heat content is found around 8° N, 59° E and in the western parts of Bay of Bengal
The maximum heat content area observed for the surface (0-50m) layer in the western equatorial region has been changed to a low heat content area in the 2nd layer. In this region though the MLD extends to about 100m, considerable decrease of about 19*10^8 J/M in heat content is noticed between the upper two layers. In Bay of Bengal, the maximum heat content area corresponds to warmer SST and vice versa. The decrease in heat content between the upper two layers is more in the northern Bay while it is less in the southern parts.

Fig(3.7) shows the distribution of heat content in the third (100-150m) layer. Minimum heat content is encountered in the north equatorial region and near northern Bay of Bengal. The heat content increases towards northwest reaching a maximum of 50*10^8 J/M^2 in the southwest Arabian Sea. In the Bay of Bengal, heat content increased towards the central Bay with maximum value of 52*10^8 J/M^2 concentrated around 13° N, 86° E. The decrease in heat content between 2nd and third layer is maximum in the northeastern Arabian Sea and northern Bay of Bengal while it is minimum in the central Bay of Bengal. Maximum variations are observed in the northern Bay and near the eastern parts of north equatorial region. The heat content of the 4th layer varies between 32*10^8 and 42*10^8 J/M^2 during this season (fig.3.8). This layer shows an increasing trend in heat content towards west in the central Arabian Sea with maximum around 13° N, 59° E. Almost uniform heat content of 36*10^8 J/M^2 is noticed in the western parts of north equatorial Indian Ocean. Southern Bay Bengal
experiences minimum heat content for this layer where the heat loss between the 3rd and 4th layer is maximum about $18 \times 10^8$ J/M$^2$. Along the western coast of India, the variations in heat content are more compared to other areas.

3.2.3 Post-monsoon Season

During this season, maximum heat content of $59 \times 10^8$ J/M$^2$ is observed in the south central Arabian Sea and eastern coast of Bay of Bengal for the surface (0-50m) layer (fig.3.9). Heat content decreases in all directions in the Central Arabian Sea and towards west in the Bay of Bengal. Low heat content area observed in the previous season has now been changed into a high heat content area in the Arabian Sea. Along the western Bay of Bengal, variations in heat content are less while, it is more on the eastern side. Maximum heat content area corresponds to an SST of 28° C and the MLD extends to about 70m. Minimum heat content is observed south of 10° N which corresponds to moderately high SST and deep MLD. In the northwestern Arabian Sea, the maximum heat content corresponds to low MLD and almost high SST. The Maximum heat content in the central Bay coincides with high SST and low MLD.

Fig (3.10) illustrates the heat content distribution for the 50-100m layer in the northern Indian Ocean. In this layer, horizontal variations in heat content shows similar trend that of the 1st layer in the Arabian Sea. The maximum heat content area for the 1st layer observed in the central Arabian Sea remains at the same region with a slight decrease. Small pockets of
alternate high and low heat content are observed in the eastern Bay of Bengal. Maximum heat content variations in the eastern Bay of Bengal are found in the same region as in the surface layer.

The heat content distribution in the 3rd layer are more or less similar to that in the upper (50-100m) layer along most parts of the eastern Arabian Sea (fig.3.11). In the southwestern Arabian Sea, the decrease in heat content between this layer and 2nd layer is maximum about $12 \times 10^8 \text{ J/M}^2$. Compared to Arabian Sea, Bay of Bengal shows in general, lower heat content values.

In the 4th layer, the maximum heat content area of the next upper layer has been disappeared and it is found near the southwestern Arabian Sea (fig.3.12). In Bay of Bengal, maximum heat content in this layer is of about $38 \times 10^8 \text{ J/M}^2$ recorded around $8^\circ \text{ N}, 93^\circ \text{ E}$. The difference in heat content between 3rd and 4th layer is maximum near north eastern Arabian Sea and minimum on the western Arabian Sea while, there is no such marked difference in Bay of Bengal.

3.2.4 Winter season

In this season, southcentral Arabian Sea registers maximum heat content of $59 \times 10^8 \text{ J/M}^2$ (fig.3.13). The area of maximum heat content remains in the same region as during the previous season. Lower heat content of $54 \times 10^8 \text{ J/M}^2$ is noticed in the central Bay of Bengal. The maximum heat content both in Arabian Sea and Bay of Bengal corresponds to warmer SST of $29^\circ \text{ C}$ (Ref. fig.2.16). Compared to previous season, Bay of Bengal shows lower heat
content while Arabian Sea recorded higher heat content. The heat content variations in the 2nd layer shows an increasing trend from west to east in the Arabian Sea with maximum occurring around 10°N, 60-64°E (fig. 3.14). Rate of heat content variations is more near the southwest coast of India and in the western parts of Bay of Bengal. A decreasing trend is seen from west to east in the central Bay of Bengal while the trend is reversed in the northern Bay of Bengal.

In the Arabian Sea, variations in heat content in the 3rd layer are similar to those in the next upper layer (fig 3.15). Minimum heat content of 34\times10^8 J/M^2 is noticed around 14°N, 85°E, from where, it increases in all directions. The heat content of lower layer (4th) shows maximum of 39\times10^8 J/M^2 in the same region as in the case of upper (100-150m) layer. In the central Arabian Sea heat content increases towards west while, it increases towards east in the southern Arabian Sea (fig 3.16).

The decrease in heat content between the surface (0-50m) layer and the next layer is minimum (about 2\times10^8 J/M^2) in the southwestern Arabian Sea and central Bay of Bengal but, it is maximum (about 8\times10^8 J/M^2) along the western coast of India and in the northeastern Bay. Almost similar decrease is seen in the layers between 2nd and 3rd. The reduction in heat content between the lower two layers is about 3\times10^8 J/M^2 near the western coast of India and about 9\times10^8 J/M^2 in the Central Arabian Sea. The heat loss between these two layers is almost uniform in most parts of Bay of Bengal.
3.3 Daily variations of heat content

In order to study the daily variations, average heat content of the polygon areas (Ref.fig.1.1) for different layers during 1977 and 1979 have been considered.

3.3.1 Area-I Phase I

During MONSOON-77, the first phase of observation was carried out during 6-20th June and the second phase during 30th June to 15th July. Fig(3.17,a) shows the daily variations in heat content of the different layers during the 1st phase. It is seen that, the heat content slightly decreases from 6th to 7th June in the surface layer (0-50m) and then decreases sharply to a maximum of $63 \times 10^8$ J/M$^2$ on 9th. Subsequently, it decreases gradually reaching a minimum of $57 \times 10^8$ J/M$^2$ on 18th June. The corresponding SST shows more or less a similar variation as that of the heat content of 0-50m layer. The 2nd layer shows more or less opposite variations compared to the above layer. From 6-13th June, heat content fluctuates by $3.5 \times 10^8$ J/M$^2$ and afterwards remains steady up to 20th June. The lowering of heat content between the 1st and 2nd layers varies from $7.5 \times 10^8$ J/M$^2$ to $13 \times 10^8$ J/M$^2$. The corresponding values between 2nd and 3rd layers are $2 \times 10^8$ J/M$^2$ and $8.5 \times 10^8$ J/M$^2$ and those between the lower two layers are $8 \times 10^8$ J/M$^2$ and $11.5 \times 10^8$ J/M$^2$. The lower two layers show in general, an increasing trend contrast to the upper two layers. The daily fluctuations in heat content are not very prominent in this period probably because of the low variations in MLD.
3.3.2 Area-I Phase-II

The day to day variations of heat content during 30th June to 15th July are presented in fig(3.17,b). The heat content in all the four layers show gradual decrease up to 7th July thereafter it increases up to 13th July. Subsequently, the heat content decreases beyond 13th July, thus exhibiting a wavy pattern. The variations of heat content in the surface layer somewhat follows the daily variations of SST. The heat loss between successive 50m layers increases downwards. It varies between $4 \times 10^8$ to $9 \times 10^8$ J/M$^2$ between the 1st and 2nd layers. The corresponding values between the 2nd and 3rd layers are $5 \times 10^8$ J/M$^2$ and $9 \times 10^8$ J/M$^2$ and that between the next pair of layers are $5 \times 10^8$ J/M$^2$ and $14.5 \times 10^8$ J/M$^2$.

During MONEX 79, heat content variations of different layers were analysed in three polygon areas viz. 1. Area-II (16-23rd May) 2. Area-III (2-10th June) 3. Area-IV (10-23rd July).

3.3.3 Area-II (16-23rd May 1979)

Fig (3.18,a) shows the daily variations in heat content during May 1979. The heat content in the upper layer decreases from $60.5 \times 10^8$ J/M$^2$ on 16th to $58 \times 10^8$ J/M$^2$ on 19th May. Subsequently, the heat content shows an increase reaching $60.5 \times 10^8$ J/M$^2$ on 21st, thereafter it shows slight decrease. The 2nd and 3rd layers however show more or less constant heat content. The variations of SST shows a trend similar to the variations in heat content of the top layer up to 18th May.
Subsequently, the SST gradually increases up to 21st May and decreases afterwards. The magnitude of heat loss between successive layers is more or less the same except during 16-18th May when the heat loss is slightly higher between the 3rd and 4th layers.

3.3.4 Area-III (2-10th June 1979)

In this area, the heat content in the upper two layers show more or less uniform value during the period of observations except for minor fluctuations amounting to $2 \times 10^8$ J/M$^2$ (fig.3.18,b). The 3rd and 4th layers show an increasing trend with slight daily fluctuations not exceeding $3 \times 10^8$ J/M$^2$. Heat content in the upper layer and the SST show more or less similar variations during this period also. The lowering of heat content between 1st and 2nd layer and 3rd and 4th layer exhibits equal magnitudes. However, the heat loss between the 2nd and 3rd layers seems to be slightly higher magnitude than the layers both above and below.

3.3.5 Area-IV (10-23rd July 1979)

In the Bay of Bengal polygon, the surface layer shows more or less constant heat content with minor fluctuations amounting to $3 \times 10^8$ J/M$^2$ (fig.3.19). The fluctuations in SST are also small for this period. Thus the surface layer heat content is mainly controlled by the SST. All the layers show a minimum heat content on 12th July and maximum on 21st July. On 12th July, heat content of 50-100m layer in particular and all the other lower layers in general, is less while, the MLD of the same day is more
This could be possible if the heat from this region gets transported to the other region on this day. In contrast to the surface layer, the lower three layers exhibit much variations. The variations in MLD are also large in this period. In the 2nd layer heat content decreases sharply from a value of $51.5 \times 10^8 \, \text{J/M}^2$ on 10th to $42 \times 10^8 \, \text{J/M}^2$ on 12th July, after which heat content increases up to 17th July, thereafter fluctuate considerably from day to day. The lower two layers also show similar trend in heat content variations as the 50-100m layer. The variations in SST also exhibit more or less similar trend as the heat content variations in the surface layer. The reduction in heat content between the first two layers varies between $7 \times 10^8$ and $16 \times 10^8 \, \text{J/M}^2$. The corresponding values between the 2nd and 3rd layers are $8.5 \times 10^8$ and $16 \times 10^8 \, \text{J/M}^2$ and those between the lower two layers are $7.5 \times 10^8$ and $12.5 \times 10^8 \, \text{J/M}^2$.

3.4 Cyclone heat potential (CHP$_{28}$)

The role of heat potential in atmospheric disturbances is examined using information from Indian Daily Weather Reports on the cyclonic storm formed in the eastern Arabian Sea and in southwestern Bay of Bengal. The track of three storms formed in the Arabian Sea and Bay of Bengal during June 1977, May and June 1979 are presented in fig (3.20). The variations of CHP$_{28}$ has been studied in relation to surface wind speed.

Cyclone heat potential is estimated by two methods which were explained in chapter-1. Daily variations of CHP$_{28}$ were analysed during June 6-20th 1977 and June 2-14th 1979 in the
Arabian Sea. For this, CHP28 has been estimated as the heat content over 28°C isotherm.

Utilizing the satellite derived wind speed and SST, CHP28 has been estimated in the Bay of Bengal and Arabian Sea before and after two storms (fig.2.20 b & c) during both May and June 1979. The CHP28 estimated from satellite parameters were compared with the values estimated from temperature profiles. The correlation coefficient is equal to 0.968. Table 3.1 gives the comparison of CHP28 obtained from satellite and ship. The values obtained from ship and satellite parameters are comparable (±8% for a range of 5.8 to 6.7*10^8 J/M^2). At three points the variations in CHP28 are wider, this can be expected considering that wind speed have been obtained by extrapolating cloud motion vector winds to the surface.

3.4.1. CHP28 during 8-12th June 1977

A low pressure area formed at 15° N, 70° E on 8th June, deepened to depression in the next day and intensifying into a cyclonic storm and moved northwestward during 10-12th June (fig.3.20,a).

The temporal evolution of daily average temperature profile for the polygon area I before and after the above storm is shown in fig (3.21). It is clear that from 8-13th June, MLD deepened by 20m. Significant cooling up to 75m is noticed after the storm. This cooling and deepening of mixed layer is probably because of enhanced mixing caused by upwelling due to strong winds.
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The daily variations of CHP$_{28}$ and surface wind speed during 6-20th June 1977 are presented in fig (3.22,a). CHP$_{28}$ increases from 5.8$\times 10^8$ to 6.8$\times 10^8$ J/M$^2$ during 6-9th June. A sharp decrease of about 1.4$\times 10^8$ J/M$^2$ is noticed from 9-12th June after which a gradual increase is seen on 13th June.

The surface wind speed shows a maximum on 10th June after which, it decreases sharply to a minimum on 14th June. The increase in CHP$_{28}$ and wind speed during 6-9th June indicates a favorable condition for the formation of a depression. The sudden decrease in CHP$_{28}$ from 9th to 12th June implies a net oceanic heat loss during the storm event. Similar fall in ocean heat potential has been observed during the onset of a cyclonic storm in the south western Bay of Bengal (Rao,1987,b). Low CHP$_{28}$ observed during 12-15th June may be caused by mixing due to upwelling resulted by the passage of storm. The decrease in CHP$_{28}$ due to upwelling at the center of the storm has been reported earlier in the Arabian Sea by Ramesh Babu and Sastry (1984) and Rao et al,(1983). Seetharamayya and Mullen (1987) found a fall of 3$\times 10^8$ J/M$^2$ in cyclone heat potential during 9-18th June and the corresponding fall in SST is about 0.5$^{\circ}$ C after the passage of onset vortex. This lowering of SST may be due to the entrainment of cold sub-surface water into the surface and the subsequent mixing between cold deep waters and warm waters results downward transfer of heat (Ramesh Babu and Sastry,1984).
3.4.2 CHP\textsubscript{28} during 5-13th May 1979

The well marked low pressure, which intensified into a depression on the evening of 5th May, lay around 7° N, 90° E. Moving slowly westwards, the depression developed into a storm by the morning of 7th May near 7° N, 88° E (fig. 3.20, b). The storm took a southwesterly track and developed into a cyclonic storm by the morning of 11th May and developed into a hurricane with maximum intensity on 11th and 12th May. It crossed the Andhra coast between Nellore and Ongole by the evening of 12th May and gradually dissipated by the morning of 14th May.

The vertical temperature profile on 5th and 14th May at a fixed position around 7.5° N, 87° E is presented in (fig. 3.21) shows a deepening of 25m in MLD after the storm.

Due to the scarcity of ship observations during this storm event in Bay of Bengal, CHP\textsubscript{28} only from satellite parameters have been analysed. Fig (3.23) shows the distribution of CHP\textsubscript{28} on 1st and 17th May 1979 (4 days before and 4 days after the storm). On 1st May, the heat potential increases in the southwesterly direction reaching a maximum of $6.6 \times 10^8$ J/M$^2$ around 13.5° N, 83° E (fig. 3.23, a). This increase in CHP\textsubscript{28} also confirm the indication for the formation of depression as discussed in the earlier sections. Rao and Rao (1986) observed a gradual increase in heat potential before the formation of a depression in the northern Bay of Bengal. The low heat potential observed on 17th May, around 15° N, 81° E could be because of heat taken away by
the storm in the form of latent heat as this area is along the track of cyclone (fig.3.23,b).

The distribution of surface wind speed on 1st and 17th May (fig.3.24) shows very low values near the central Bay on 1st May. Wind speed increases rapidly towards west, reaching a maximum of 7.5 m/s at 14° N 83° E. Comparing this with fig (3.24,a) it is seen that for both wind speed and CHP28 the trends of gradient are same on 1st May. On 17th May wind speed increases in the direction of passage of the storm (fig.3.24,b).

3.4.3 CHP28 during 16-19th June 1979

A cyclonic cell, the monsoon onset vortex, which was noticed on 14th June intensified into a depression around 14° N, 70° E (fig.3.20,c). Between 16-18th June, a core of strong winds of 60-70 knots was seen along 8-10° N. On moving northwesterly, the depression intensified into a storm and crossed the Arabian coast by 20th June 1979.

From the temperature profile on 14th and 21st June 1979 (fig.3.21), mixed layer deepening of 18m is observed after the storm in the polygon area III.

Fig(3.22,b) shows the daily variations of CHP28 and wind speed during 2-14th June immediately before the commencement of a cyclonic storm. CHP28 shows a decrease of $2.1 \times 10^8$ J/M$^2$ from 2-4 June afterwards, it increases to a maximum heat potential on 14th June with small fluctuations in between. This increase in CHP28
favours the intensification of low pressure which persisted near Lakshadweep during 8-13th June. The corresponding surface wind speed shows an increasing trend throughout the period.

The distribution of CHP$_{28}$ and wind speed before and after this storm derived from satellite data can be seen in fig (3.25 and 3.26). Before the onset of storm, i.e., on 10th June, maximum CHP$_{28}$ is recorded near the southwest coast of India (fig.3.25,a). This also indicates a favorable response for the monsoon vortex, which deepened into a depression on 16th June around 13° N, 71° E. The surface wind speed shows a maximum of 7 m/s in the same area of maximum CHP$_{28}$ (fig.3.26,a). After the monsoon vortex, CHP$_{28}$ showed a fall of about $10^8$ J/M$^2$ in the southeastern Arabian Sea (fig.2.25,b). On this day the CHP$_{28}$ shows a decrease towards northwest. This may imply that heat has been taken away by the storm along its track. The corresponding wind speed shows an increasing trend towards northwest in the direction of passage of the storm (fig.3.26,b).

3.5 Discussion

In the preceding sections we have looked into the distribution of heat content in four different layers of 50 m thickness analysed on a seasonal basis for the period 1977-1986 in the northern Indian Ocean. Daily variations in heat content of these layers in four different polygon areas and the variations in CHP$_{28}$ during three storm events during MONSOON-77 and MONEX-79 were also studied. In the following section, the results obtained are discussed in detail in the light of earlier investigations.
The heat content of the surface layer (0-50m) shows maximum of $62 \times 10^8$ J/M$^2$ during pre-monsoon season and a minimum of $50 \times 10^8$ J/M$^2$ during monsoon season in the south centriole Arabian Sea. During the post-monsoon and winter seasons, the heat content values in this region are $58 \times 10^8$ J/M$^2$ and $53 \times 10^8$ J/M$^2$ respectively. Bruce (1987) reported a minimum heat content in the surface layer (0-100m) at the end of south west monsoon in the western Indian Ocean. He has noticed intense warming below 100m with the progress of southwest monsoon which was almost equal to the heat loss in the upper 100m layer. Varma (1989) observed a minimum heat content of about $52 \times 10^8$ J/M$^2$ during July in the 0-50m layer both near the eastern central Arabian Sea and northern Somali coast. While analyzing the heat budget of the equatorial Atlantic, Merle (1980) also observed minimum heat content in the surface (0-50m) layer during monsoon season. The zonal variations of heat content in all the lower three layers more or less follow the variations in the surface layer during monsoon. This could be because of vertical turbulent mixing caused by strong winds during monsoon season. During pre and post-monsoon seasons, the variations in heat content in the lower layers do not follow the variations in the surface layer may be due to relatively less mixing because of low surface winds.

Bay of Bengal exhibits higher heat content in the surface layer during monsoon compared to Arabian Sea. This could be due to comparatively high SST observed in this region during this season. But during the post-monsoon and winter seasons, when Bay
of Bengal and Arabian Sea shows similar magnitudes in SST. Lower heat content values are seen in the surface layer in Bay of Bengal. This low heat content is caused by mixing provided by upwelling above 100m. Rao (1987,b) noticed a gradual fall in heat content in the top 100m layer near southwestern Bay of Bengal which he attributed to vertical advective processes controlled by Ekman and probably geostrophic transports.

The decrease in heat content from west to east in the 1st layer in the north Equatorial region during monsoon season is mostly controlled by similar variations in the SST. Ali and Desai (1989) also observed similar variations in the equatorial Indian Ocean and suggested that the water below thermocline plays a greater role in determining the heat content variations. Rao (1987,a) reported a decrease in heat content from west to east in the central Arabian Sea during 7-13th June 1977. The decrease in heat content between the surface layer and the next layer (50-100m) is about $9 \times 10^8$ J/M$^2$ in the eastern Arabian Sea which shows a continuous fall towards west. Varma (1989) observed a fall of $5 \times 10^8$ J/M$^2$ in the eastern central Arabian Sea and near the Somali basin.

During monsoon, the reduction in heat content between the first and second layers is minimum in the eastern Arabian Sea (about $2 \times 10^8$ J/M$^2$) and maximum (about $18 \times 10^8$ J/M$^2$) in the western north equatorial Indian Ocean while the trend is different in Bay of Bengal. This maximum heat content variability in the western parts may be due to less mixing below 50m. A reduction of $8 \times 10^8$ J/M$^2$ has been reported earlier (Varma,1989).
for the eastern central Arabian Sea and about $4 \times 10^8 \, \text{J/m}^2$ for the northern part of Somali basin. Rao (1987,a) attempted to explain the heat content variations in the top 100m in terms of near surface mixed layer cooling and vertical advective processes in the upper thermocline.

During post-monsoon period, the lowering of heat content between the 1st and 2nd layers is comparatively less on the western side than the eastern region both in the Arabian Sea and Bay of Bengal. This is associated with the mixed layer cooling and deepening noticed on the western side and shallow MLD on the eastern side as discussed in the previous chapter.

In winter season, the decrease in heat content between the surface (0-50m) and the second layer is more in the southeastern Arabian Sea (about $10 \times 10^8 \, \text{J/m}^2$) and less (about $2 \times 10^8 \, \text{J/m}^2$) in its western side. Whereas in Bay of Bengal conspicuous variations are not present. This is probably due to a large temperature gradient associated with a shallow thermocline in the east and comparatively deep MLD in the west. Merle (1980) related the seasonal heat content variability to the shallowness of thermocline in the equatorial Atlantic region. Considerable reduction in heat content between the upper 100m and 100-200m layer has been noticed earlier along the Somali basin also (Bruce, 1987).

The heat loss between successive layers beyond 100m exhibits higher values in the east and lower value in the west during both monsoon and winter seasons. During pre and post-
monsoon seasons, this trend ia more or less reversed in the Arabian Sea. Larger difference in heat content between successive layers encountered during the seasons when the temperature gradient is larger. Similar situation has been encountered while analyzing the heat content along the Somali region (Bruce,1987).

In Bay of Bengal, the lowering of heat content between successive layers beyond 100m shows higher values on the west and lower values on the east during pre and post-monsoon seasons. During monsoon season, larger heat loss between the 2nd and 3rd layers has been observed in the northwestern Bay of Bengal. This is because of shallow thermocline observed in this region. In winter season, the heat loss beyond 100m exhibits comparatively higher values on the west and lower values on the east.

Results of studies on daily variation of heat content during different periods have been presented in section 3.3. It is seen that in most of the cases, heat content variations in the surface layer coincides almost with SST variations. In Area- I, during 6-20th June 1977, the decrease in content between the upper and lower most layers is more compared to the middle layers (50-100m and 100-150m ). This implies that downward advective transfer of heat decreases from the surface to deeper layers.

The variations in heat content during May 16-22nd and June 2-10th 1979 (Area II and III) are not significant compared to the variations during July 1979 in Bay of Bengal. The heat content in the surface layer is almost constant in the northern Bay of Bengal in July. The fluctuations of heat content observed
in the lower layers could be due to the vertical oscillations of thermocline.

Analyses of CHP28 during three storm events show in general, an increase in heat potential just before the storm and considerable decrease after the storm. Such lowering of heat potential due to passing storm has been observed earlier by few authors (Leipper, 1967; Rao, et al, 1983; Rao, 1987(a); Ramesh Babu and Sastry, 1984). Cooling and deepening of mixed layer is also noticed due to the passage of storms. Camp and Elsberry (1978) suggested that mixed layer cooling and deepening is mostly caused by vertical mixing during the passage of storm.
Fig. 3.1 Distribution of heat content in 0-50m during pre-monsoon season ($10^8 \text{J/m}^2$)

Fig. 3.2 Distribution of heat content in 50-100m during pre-monsoon season ($10^9 \text{J/m}^2$)
Fig. 3.3 Distribution of heat content in 100-150m during pre-monsoon season \((10^8 \, \text{J/m}^2)\)

Fig. 3.4 Distribution of heat content in 150-200m during pre-monsoon season \((10^8 \, \text{J/m}^2)\)
Fig. 3.5 Distribution of heat content in 0-50 m during monsoon season (10^9 J/m^2)
Fig. 3.6: Distribution of heat content in 50-100m during monsoon season (10^9 J/m^2).
Fig. 3.7 Distribution of heat content in 100-150m during monsoon season ($10^4$ J/m$^2$).
Fig. 3.8 Distribution of heat content in 150-200m during monsoon season ($10^9$ J/M$^2$)
Fig. 3.9 Distribution of heat content in 0.50m during post-monsoon season (10^8 J/m^2).
Fig. 3.10 Distribution of heat content in 50-100m during post-monsoon season ($10^8 \text{ J/M}^2$)
Fig. 3.11 Distribution of heat content in 100-150m during post-monsoon season (10^8 J/m^2).
Fig. 3.13 Distribution of heat content in 0-50m during winter season (10^8 J/m^2)
Fig. 3.14 Distribution of heat content in 50-100m during winter season (10^8 J/m^2).
Fig. 3.15 Distribution of heat content in 100-150m during winter season (10^8 J/m^2)

[Diagram showing distribution of heat content with latitude and longitude axes, highlighting regions with different heat content values.]
Fig. 3.16 Distribution of heat content in 150-200m during winter season (10^8 J/M^2)
Fig. 3.17 Daily variation of heat content in different layers in Area-I (a) Phase-I (b) Phase-II
Fig. 3.18 Daily variation of heat content in different layers in (a) Area-II (b) Area-III
Fig. 3.19 Daily variation of heat content in different layers in Area-IV.
Fig. 3.20 Track of cyclonic storms studied in Arabian Sea and Bay of Bengal
(a) during 8-12 June, 1975 (b) during 5-14 May, 1979 (c) during 16-19 June, 1979.
Fig. 3.21 Temperature profiles before and after the three storms.
Fig. 3.22 Daily variation of \( CHP_{2a} \) and wind speed in
(a) Area-I, storm-a (b) Area-III, storm-C
Fig. 3.23 Distribution of CHP$_{28}$ on (a) 1st May (b) 17th May 1979 ($10^8 \text{ J/m}^2$)
Fig. 3.24 Distribution of surface wind speed on
(a) 1st May (b) 17th May 1979 M/s
Fig. 3.25 Distribution of CHP\textsubscript{28} on (a) 10th June 1979 (b) 30th June-1979 \((10^8 \text{ J/m}^2)\)
Fig. 3.26 Distribution of surface wind speed on (a) 10th June (b) 30th June 1979  M/s