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# *HEAT STORAGE IN THE GULF OF AQABA*

*By*

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**Key Words : Physical Oceanography, Gulf of Aqaba.**

## *ABSTRACT*

*Results of the seasonal and zonal fields of heat storage (HS) for the Gulf of Aqaba are presented. The zonal annual trend of seasonal mean HS in the northern, central northern, central and southern ports of the Gulf of Aqaba, besides the NE Red Sea, are shown, as well as, the zonal fields of the amplitude of the annual signal. These distributions are presented for the upper 100-, 200-, 300-, 400- and 500m layers to describe the geographic characteristics of the annual cycle of HS for the Gulf of Aqaba and its vicinity.*

*The hydrographic data used to estimate the HS are the CTD station data files collected within the framework of the trilateral collaborative research cruises in the Gulf of Aqaba, on bard the R/B's Gadran and Sue- Ellen in the period from November 1992 to July 1994.*

*For all the mentioned layers, the minimum HS is observed in Winter season, whereas, the maximum occurs in Autumn except for the northern half of the Gulf, in the upper 100-m layer where, the maximum HS is in Summer season.*

*Generally the HS in the Gulf of Aqaba is lower than that of the NE Red Sea. The single exception is that, the HS in the central northern part for the upper 200-m is the highest.*

*The HS amplitude of the annual signal is high in the extreme north of the Gulf, for the upper 100-m layer, whereas for the rest of the layers, the maximum values are observed in the central northern part of the Gulf. The amplitude of the annual signal is generally low in the upper 100-m layer.*

*The results reveals that, the northern central part seems to be the source of formation of the deep water of the Gulf of Aqaba.*

## *INTRODUCTION*

The Gulf of Aqaba is a finger-like extension, projected about N 14.6$^{\circ}$ E, from the Red Sea (Fig. 1). The climate are arid and hot, with a yearly average net evaporation of 1 cm/day (Assaf and Kessler, 1976). Wind blow along the main axis predominantly from the north, switching abruptly to southerly in short gales of a few days duration ( Aziab). The rather uniformly highly saline water are warm through out the year, the seasonal and vertical variations does not exceed 6-7 $^{\circ}$C. Oxygen content is high, while nutrient levels and primary production are very low. Illumination is strong and light penetration is deep (Klinker *et al*, 1976).

Since the Pola expedition (1895-1896), there has been no major cruises in the Gulf of Aqaba. Some minor field work, carried out in the present century, was briefly reviewed by Morcos (1970) and Anati (1974).

The water temperature in the Gulf reveals a strong thermocline below 200 m depth. The bottom water of the Gulf of Aqaba is colder, more saline and better oxygenated than in the Red Sea proper (Morcos, 1970). He presumed that, the deep Gulf water is formed at the head of the Gulf, where the Pola expedition found lower temperature and higher salinity at the surface. He pointed out that, the bottom water of the Gulf of Aqaba is not involve in the water exchange through the strait of Tiran.

Anati (1974) and Assaf & Anti (1974) analyze the stress distribution and water transport. Assaf & Kessler (1976) have calculated energy exchange in

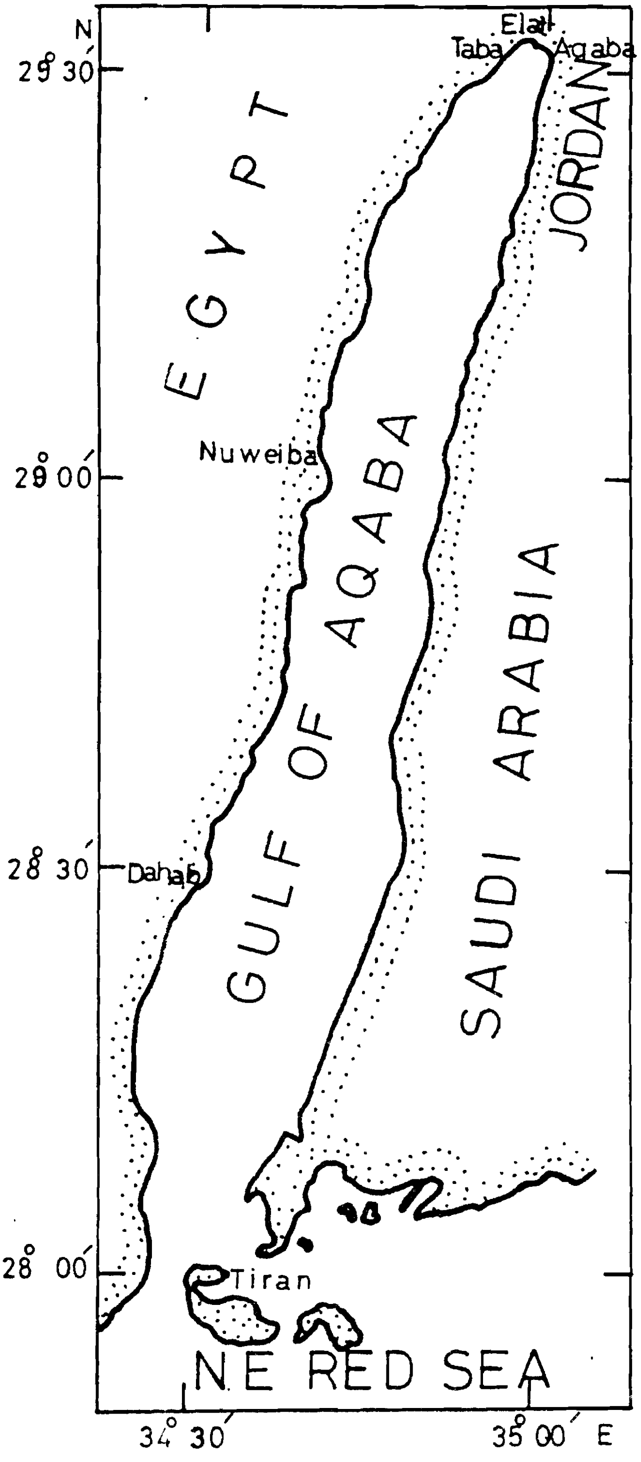


Fig. 1a, Gulf of Aqaba.

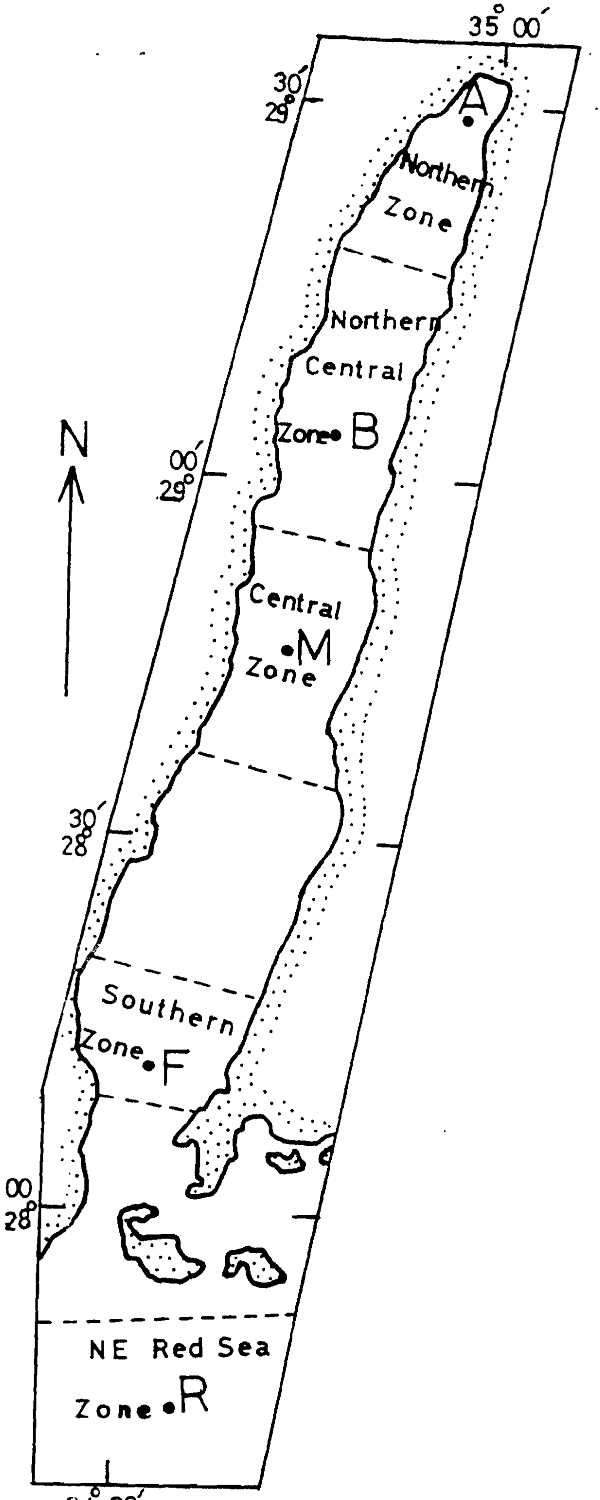


**Fig. 1b; Location map of the representative zones of the Gulf of Aqaba and NE Red Sea.**

the Gulf. Anati (1977) studied the general balances and transports in the Red Sea and the Gulf of Aqaba.

Paldor and Anati (1979) studied the seasonal variations of temperature and salinity in the Gulf of Aqaba in the upper 300-m for the period 1974-1977. They concluded that, the surface water temperature and salinity are high in Summer (about 26 $^{o}$C & 41.0 psu) and low in Winter (about 21 $^{o}$C & 40.5 psu). The water column is stratified through out the year, but much less in Winter and in the north. The Winter stratification is mainly due to salt, While the Summer stratification is mainly temperature.

Hecht & Anati (1983) investigated the hydrography of the strait of Tiran in Winter 1978. They found two typical water masses; an upper one (T1=22.0 $^{o}$C & S1= 40.65 psu) and lower one (T2=21.1 $^{o}$C & 40.80 psu ) with a thin transition layer interface between them.

In 1974 an interdisciplinary and comprehensive data collecting program in the Gulf (DCPE) was initiated and carried out until 1977. The hydrographic part of this work is to cover a longitudinal section along the axis of the Gulf extending outside the Gulf (Klinker *et al*, 1976).

The HS in the oceanic surface layers may be subjected to a considerable variability in space and time. In spite of the fact that, HS plays an essential role in the dynamics of the ocean, there are, almost, no works have been addressed this subject in the Gulf of Aqaba.

The present work shows the seasonal and geographic distribution of HS and the distribution of the amplitude of annual signal in the upper 100-, 200-, 300-, 400- and 500-m layers of the Gulf of Aqaba and its vicinity.

Verification of the ability of sea or sea- atmosphere circulation modeling to simulate the real condition should, in part, be based on a comparison of the geographic distribution of the HS (or the rate of its variability). Diagnostic studies on regional scales may require the geographic distribution of the storage. The purpose of the present work is to provide a quantitative description of the HS, based on CTD station data files.

## DATA AND METHOD OF ANALYSIS

The hydrographic data were collected, in the period 1992-1994, within the framework of the multi-disciplinary trilateral collaborative research cruises seems to continue the DCPE program (Klinker *et al*, 1976) in the Gulf of Aqaba, on board the R/B's Gadran and Sue-Ellen. The observations were made using the high resolution CTD system of sea-Bird Electronics (SBE model 19 ) with sample rate of about one meter vertical resolution. The water temperature and salinity were calibrated against Niskin samples for the standard hydrographic levels.

31 CTD tested stations were chosen to cover the seasons of the year (Table 1 & Fig.1b) and five zones along the axis of the Gulf of Aqaba. These zones represents: northern, central northern, central and southern parts of the Gulf of Aqaba. The fifth zone represents NE Red Sea, outside the straits of Tiran (Fig. 1). The seasons of the year were chosen to be Winter (January - March), Spring (April - June ), Summer (July -September ) and Autumn (October - December).

Every one of the CTD station data files (37 Stations) were tested as follows:

- For the purpose of comparison, of less than 500m were eliminated.

- Stations containing more than 2 density inversion in excess of 0.02 kg $m^{-3}$ were eliminated.

- In case of one or two density inversion, both temperature and salinity at the level of inversion were eliminated.

The remaining, after such preliminary objective analysis (the range check was not necessary since the water temperature and salinity were in order), was 31 tested CTD stations. These stations were used to estimate the HS in the Gulf of Aqaba.

The HS in the upper 100-, 200-, 300-, 400-, and 500- m layers of the Gulf of Aqaba and its vicinity (NE Red Sea).

The HS at any point (unit area) is defined as :

$$HS = \int_0^Z p\, Cp\, T\, dZ$$

Seasonal HS (J $m^{-2}$) has been estimated using the following finite-difference approximation :

$$HS = 1/8 \sum (Cp_i + Cp_{i+1})(p_i + p_{i+1})(T_i + T_{i+1})(Z_{i+1} - Z_i)$$

**Where:**

Cpi Specific heat capacity (J $kg^{-1}$ $°C^{-1}$)
pi Water density (kg $m^{-3}$)
Ti Water temperature (°C)
Zi Level depth (m) and subscript i refer to the $i^{th}$ level.

The specific heat capacity (Cp) has been calculated using the specific heat formula (UNESCO Technical Report No. 44, 1983).

Annual signal is defined as the difference between the maximum and minimum monthly heat storage for each zone and as being represented in the center of that particular zone.

## *RESULTS*

### HEAT STORAGE IN THE UPPER 100- M LAYER

The HS is higher in the NE Red Sea than in the Gulf of Aqaba. It is, in the 0-100 m layer, ranged between $8.55 \times 10^9$ and $10.21 \times 10^9$ J $m^{-2}$ inside the Gulf of Aqaba, whereas it varies from 9.29 x 109 to $10.45 \times 10^9$ J $m^{-2}$ outside.

The HS is low in Winter season whereas it is high is Summer inside the Gulf and Autumn outside. On the other hand, it is higher in the extreme northern (zone A) and southern (zone F) parts of the Gulf (Fig. 2).

**Table (1): Dates of The Chosen CTD Station Data Files to represent the Seasons and Zones (Fig. 1) of The Gulf of Aqaba.**

| Season Zones | Winter | Spring | Summer | Autumn |
|---|---|---|---|---|
| A | 11/02/93<br>14/02/94 | 25/05/94<br>02/06/94 | 22/08/92<br>19/07/94<br>24/07-94 | 22/11/92 |
| B | 12/02/93<br>12/02/93<br>19/02/93<br>14/02/94 | 26/05/94 | 19/07/94 | 22/11/92<br>27/11/92 |
| M | 12/02/93<br>15/02/94 | 26/05/94 | 14/07/93<br>19/07/94 | 27/11/92 |
| F | | 26/05/94 | 22/09/93<br>19/07/94 | 24/11/92 |
| R | 15/02/94 | 27/05/94 | 20/09/93<br>19/07/94 | 23/11/92 |

## HEAT STORAGE IN THE UPPER 200- M LAYER

The HS is ranged between 17.08 x $10^9$ J $m^{-2}$ in Winter and 10.35 x $10^9$ J $m^{-2}$ in Autumn inside the Gulf. Outside, it varies from 18.04 x $10^9$ to 19.21 x $10^9$ J $m^{-2}$ respectively.

The HS in the northern central (zone B) and central (zone M) parts of the Gulf is higher and reaches to maximum value in zone B. Except for zone B in Autumn, the HS is still higher in the NE Red Sea (Fig. 3).

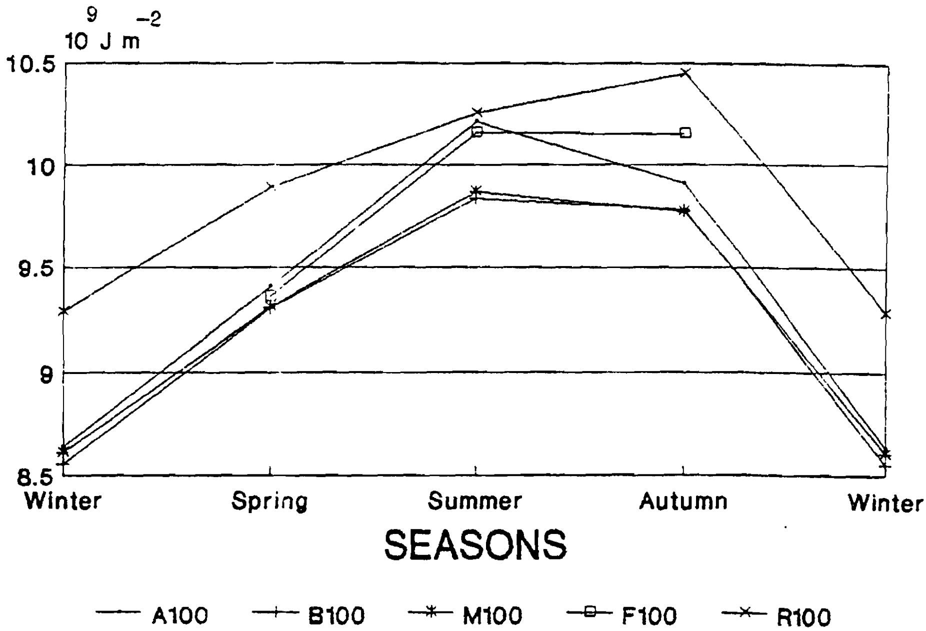


**Fig. 2; Seasonal trend of heat storage (HS), in the upper 100-m layer, for different Gulf of Aqaba zones.**

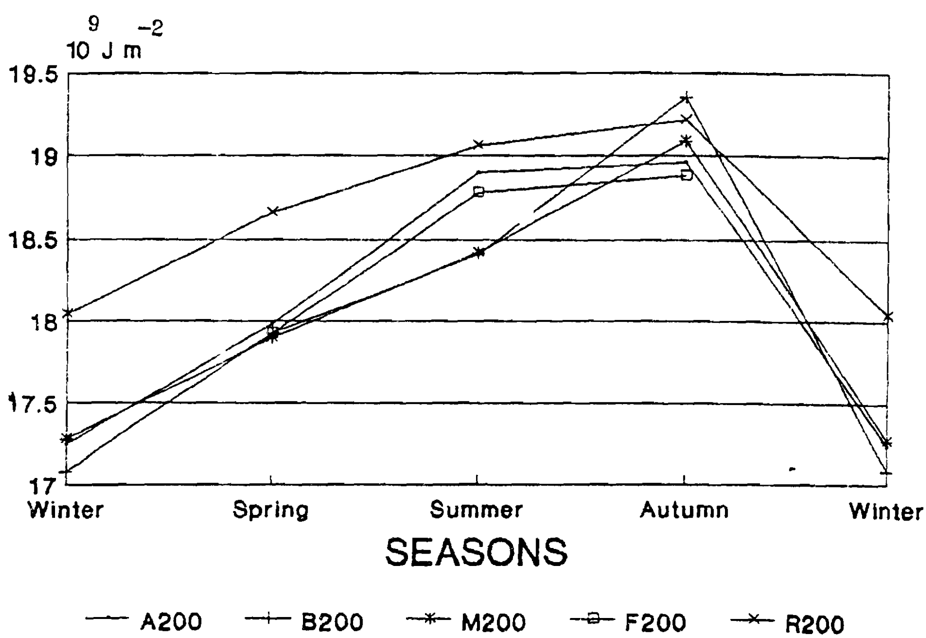


**Fig. 3; Seasonal trend of heat storage (HS), in the upper 200-m layer, for different Gulf of Aqaba zones.**

## HEAT STORAGE IN THE UPPER 300- M LAYER

The HS is the NE Red Sea is generally higher than that inside the Gulf ($25.45 \times 10^9$ - $27.57 \times 10^9$ J $m^{-2}$) and is ranged between $26.77 \times 10^9$ and $27.89 \times 10^9$ J $m^{-2}$ in Winter and Autumn seasons respectively.

In the central northern (zone B) and southern (zone F) parts of the Gulf, the HS is higher in Autumn. The northern part of the Gulf (zone A) has a higher values of HS all over the year round, except in Autumn season (Fig. 4).

## HEAT STORAGE IN THE UPPER 400- M LAYER

The HS inside the Gulf is generally lower than outside. It is ranged between $35. \times 10^9$ J $m^{-2}$ in Winter and $36.66 \times 10^9$ J $m^{-2}$ in Autumn in zone R. Inside the Gulf ,it is varied from $34.08 \times 10^9$ J $m^{-2}$ in Winter to about $36.02 \times 10^9$ J $m^{-2}$ in Autumn. Zone A is generally higher, while zones B and F has nearly the same value in Autumn (Fig. 5).

## HEAT STORAGE IN THE UPPER 500- M LAYER

It has the same trend of previous layer (0-400m) but is different in magnitude. The HS outside the Gulf is extremely higher and changes between 44.26 and $45.40 \times 10^9$ and $45.40 \times 10^9$ J $m^{-2}$ in Winter and Autumn seasons respectively. Inside the Gulf, it changes from $42. \times 10^9$ J $m^{-2}$ in Winter and $44.50 \times 10^9$ J $m^{-2}$ in Autumn. The central northern part (zone B), still has the highest HS in Autumn ($44.51 \times 10^9$ J $m^{-2}$), (Fig. 6).

## THE AMPLITUDE OF ANNUAL SIGNAL

The amplitude of annual signal of the upper 100-m layer is generally low inside the Gulf of Aqaba decreasing from $1.6 \times 10^9$ J $m^{-2}$ in the extreme northern part to $1.28 \times 10^9$ J $m^{-2}$ in the central northern part and then decreases slightly southward (Fig. 7).

In the upper 200-m layer, the amplitude of annual signal is the maximum all over the Gulf. It increases from about $1.72 \times 10^9$ J $m^{-2}$ in the northern tip

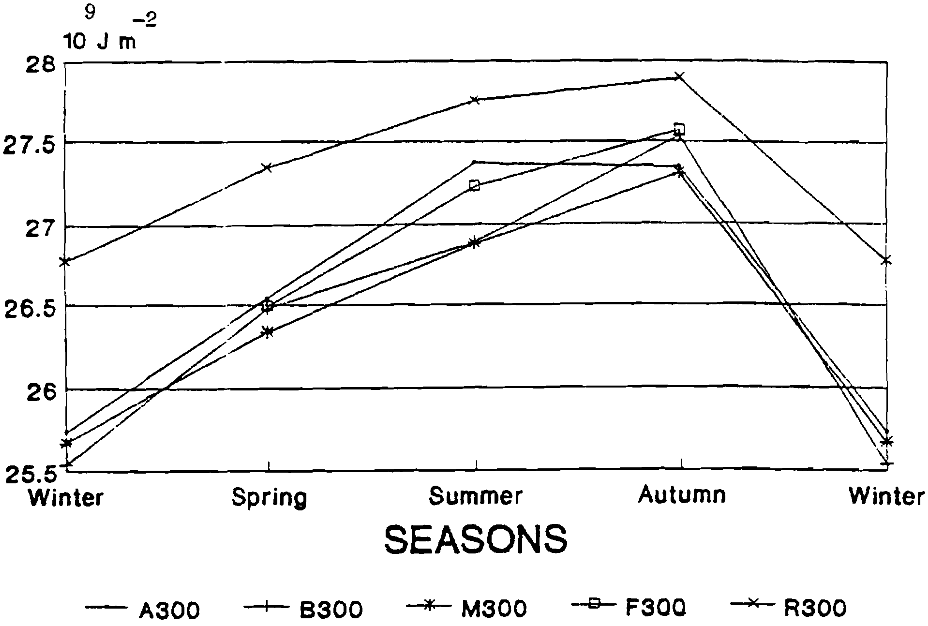


**Fig. 4; Seasonal trend of heat storage (HS), in the upper 300-m layer, for different Gulf of Aqaba zones.**

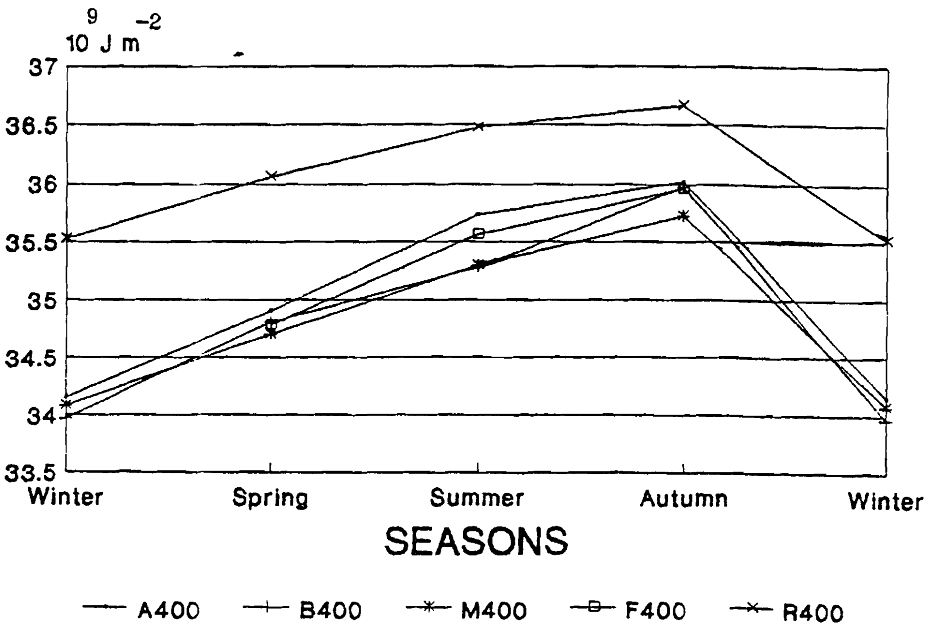


**Fig. 5; Seasonal trend of heat storage (HS), in the upper 400-m layer, for different Gulf of Aqaba zones.**

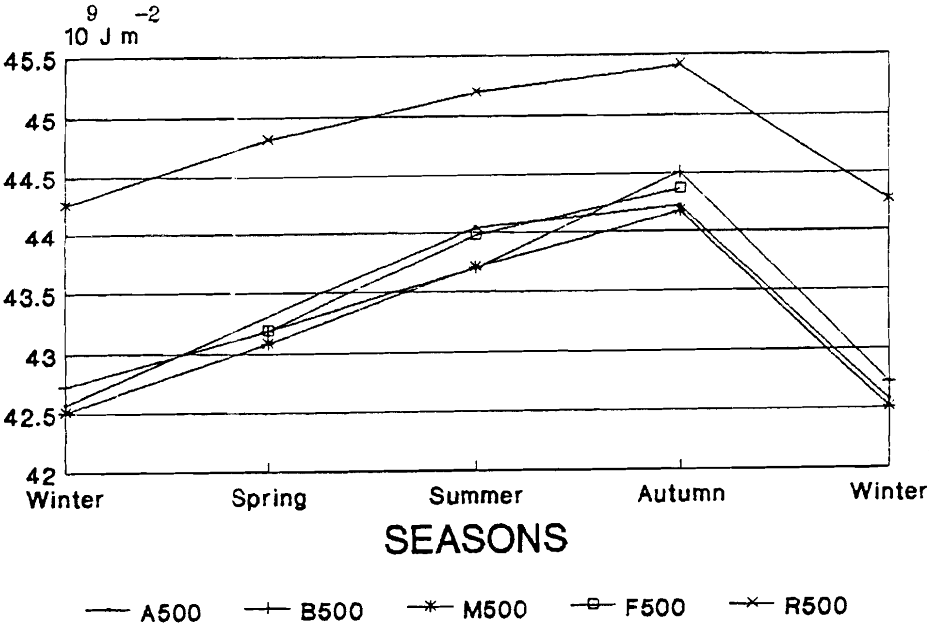


**Fig. 6; Seasonal trend of heat storage (HS), in the upper 500-m layer, for different Gulf of Aqaba zones.**

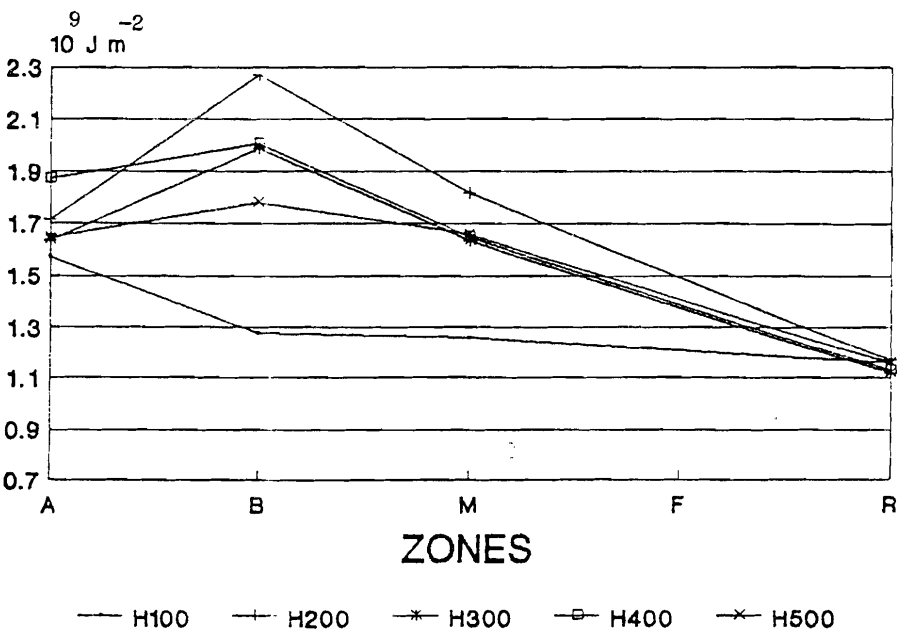


**Fig. 7; The amplitude of the annual signal in the upper 100-, 200-, 300-, 400- and 500-m layers for different Gulf of Aqaba zones.**

of Gulf to more than 2.25 x $10^9$ J $m^{-2}$ in the zone B and then decreases southward.

The upper 300-,400-,500-m layers, have the same trend as that of the upper 200-m layer, but lower in magnitude as shown in figure 7. The only exception is that, for the upper 400-m layer in zone A (extreme northern part), the amplitude of annual signal is high (1.87 x $10^9$ J $m^{-2}$).

The amplitude of annual signal outside the Gulf is very low compared with that inside (about 1.12 x $10^9$ J $m^{-2}$). Also the amplitude of annual signal decreases slightly with depth.

## *DISCUSSION AND CONCLUSIONS*

Although the HS in the upper 100-m layer is higher, the amplitude of annual signal is generally small inside the Gulf with lower values in zone B and M which suggests that vertical convection is more active (more than 100m) in the northern half of the Gulf especially in the central northern and center of its parts. The relatively higher amplitude of annual signal in the extreme northern part may be due to the fact that, the wind action in the north being relatively lower due to the topographic features to the north of the Gulf. Also the low amplitude of annual signal in that layer (Fig. 7) can be attributed to the absence or weak thermocline (Polard and Anati, 1979).

In the upper 200-m layer, the amplitude of the annual signal is maximum specially in zone B and slightly in zone M. The migration of the thermocline layer up and down between 100-m and deeper than 200-m depth through out year can be the reason of such maximum amplitude of annual signal. The upper 300- and 400-and slightly 500-m layers have the same trend of the upper 200-m layer with lower magnitude which can lead to conclude that, the vertical convection may reach to more than 500-m depth.

The relative high amplitude of annual signal in the upper 400- m layer in the northern tip of the Gulf (zone A) can be attributed to high heat storage in that layer in Summer than in Autumn ( the reverse is true in the 0-100 m layer; Fig. 7). Such phenomenon can lead to conclude that this water mass of

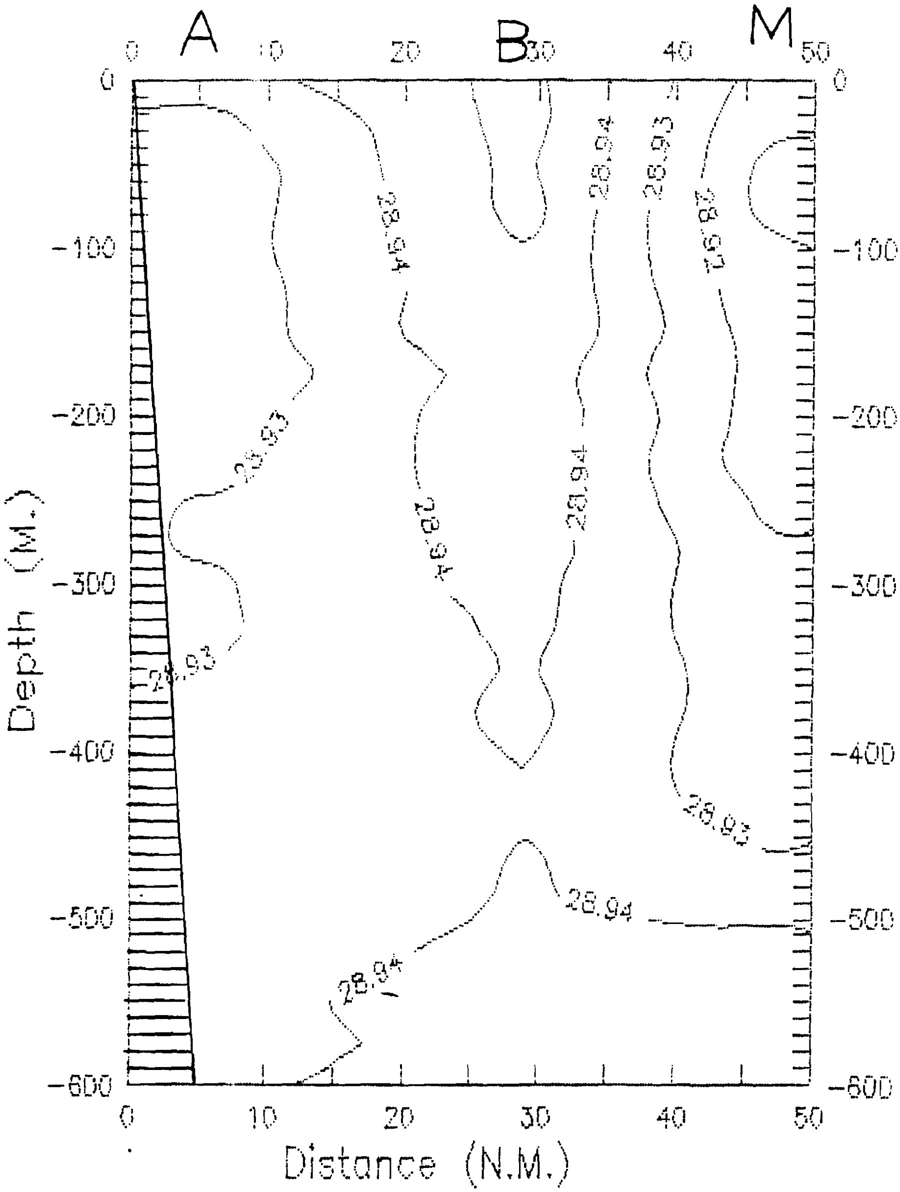


**Fig. 8; Vertical distribution of potential density( σθ ) in the northern half of the Gulf of Aqaba, February, 1993.**

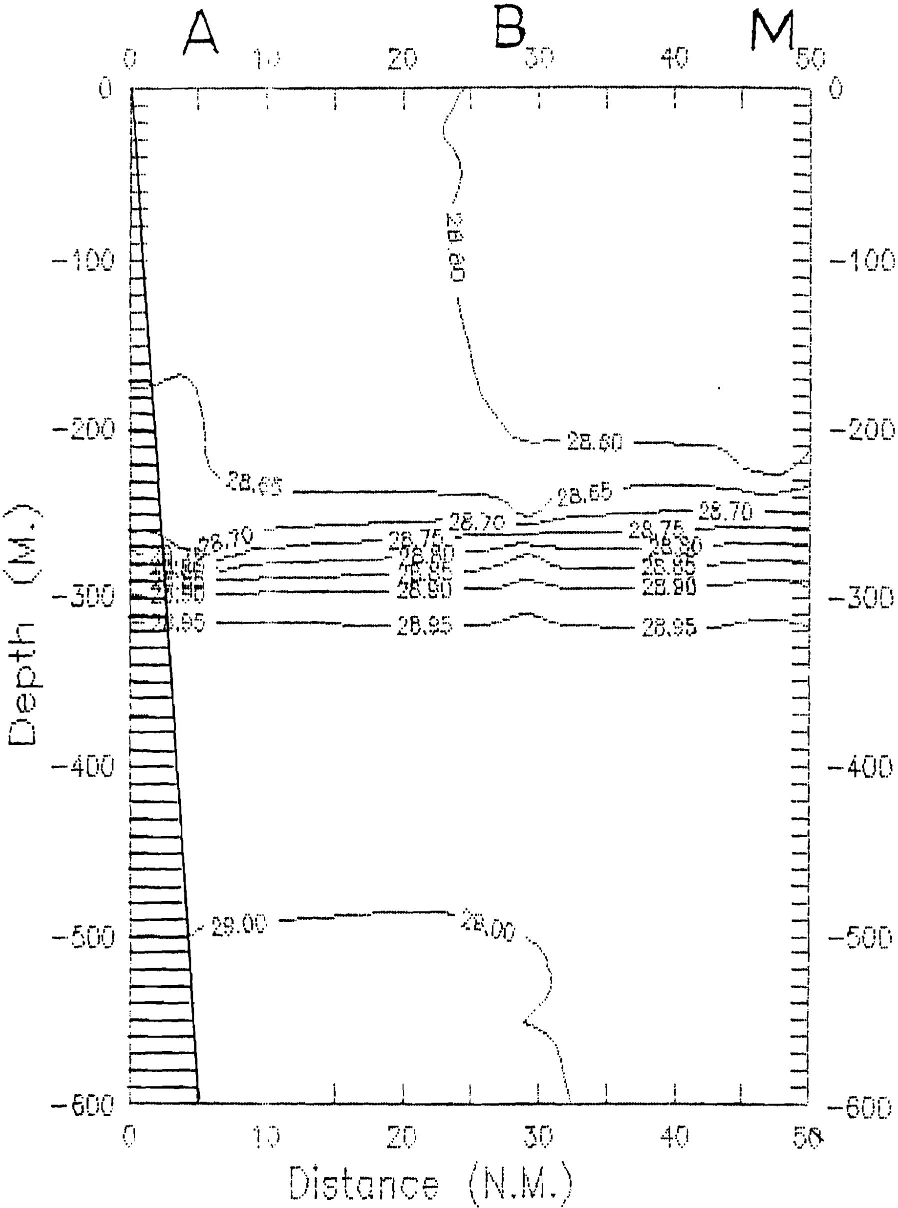


**Fig. 9; Vertical distribution of potential density( $\sigma_\theta$ ) in the northern half of the Gulf of Aqaba, February, 1994.**

high HS being shifting north-ward from zone B in the layer between 300 and 400 m depth.

Putting in consideration that, zone B (northern central part of the Gulf ) has a high HS and maximum amplitude of annual signal in all layers (except the upper most one )in Autumn, gives the reason to conclude that the vertical convection in the northern part of the Gulf can reach to more than 500m, specially in zone B centered at about 29 NM south of Elat in front of Nuewba port.

Due to increasing salinity (by evaporation) and the Winter cooling on the surface, the water density increases and the water sinks downward to more than 200m spreading everywhere horizontally and vertically downward depending upon the Winter condition of different years. Figure 8 & 9 illustrates the vertical distribution of potential density along a longitudinal section extending from north tip of the Gulf to its center (zones A, B & M) in February 1993 and 1994. From which, the previous conclusion is fairly clear for Winter 1993, when the surface denser water sinks from the surface downward to more than 500 m depth with potential density of more than 28.94. In Winter 1994, such phenomenon is not clear due to the peculiar cold Winter conditions of 1993 than that of 1994.

The main conclusion from the present work is that, the Gulf of Aqaba needs to intensively covered by monthly or seasonally net of hydrographic stations for long period to study its variability in space and time.

## *ACKNOWLEDGMENT*

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