ISSN 1110-0354
*Bull. Nat. Inst. Of Oceanogr. & Fish., A.R.E., 1999. Vol. (25): 33 - 50*

# *NET HEAT GAIN IN THE EASTERN MEDITERRANEAN SEA*

**By**

**EID, F.M*.; A.F. SABRA; I.A. MAIYZA AND S.H. SHARAF EL-DIN.**

* *Oceanography Department, Faculty of Science, Alexandria University, Alex., Egyp*

**Key words: Mediterranean, heat, air-sea interaction.**

## *ABSTRACT*

*The net heat gain in the Eastern Mediterranean Sea is computed using subsurface oceanographic data and wind stress data. The heat gain is determined by the rate of local heating, horizontal heat advection, Ekman transport and vertical advection. The net heat gain is maximum (minimum) during maximum (minimum) incident solar radiation, which implies that the seasonal rates of heat gain or loss by the sea are dominated by the effect of local heating or cooling. The vertical heat advections and heat contents due to wind stress are not sufficient to account for the magnitude of the local heating but the horizontal heat advections are the most important to account for total heat gain in the Eastern Mediterranean Sea.*

*In the Levantine Sea, the horizontal components of geostrophic current increase during autumn and winter (it causes 20 % of the total heat gain during winter and 40 % during autumn), while the other component has no significant contribution. In the Ionian Sea, the horizontal components of the geostrophic current are still slightly affecting heat gain, specially in winter. Also, the other component of wind stress and vertical heat advection has not significant contribution.*

*The pattern of heat distribution for different terms reveals regions of heat loss and heat gain identical with the position of the active zones in the Eastern Mediterranean Sea.*

# INTRODUCTION

The Eastern Mediterranean Basin is separated from the western one by a sill of 330 m depth between Sicily and North Africa. It has a unique character compared with other semi-closed seas in arid zones. It is subdivided into two major depressions, the Ionian and the Levantine sub-basin, by a ridge extending from Greece to Africa.

It is known that the most obvious processes that determine sea surface temperature variations are net surface heat flux, vertical advection, vertical mixing and horizontal advection The net surface heat flux is consideredto be one of the extremely important factors because it is one of the primary ways by which the ocean my be cooled or heated.

Limited works were done on the climatological fluxes. Osman (1973) studied the thermal interaction of the Mediterranean Sea with the atmosphere. He showed that the seasonal variations of total heat gain in the Mediterranean Sea across the air sea boundary are controlled mainly by the input of the solar radiation and the output of the heat by evaporation. The heat balance of the sea is influenced by the vertical and horizontal turbulent advections.

Bethoux (1979) studied the heat budget and the thermal exchange in the Mediterranean Sea. He found that the solar radiation contribution in the heat balance and the evaporation in the eastern basin are more important than in the western Mediterranean, and the increase of heat loss by evaporation was compensated by the solar radiation.

Hecht et al. (1985) studied the regional distributions and temporal variations of heat storage in the southeastern Levantine Basin. Tzvetkov (1985) studied the heat storage in the Mediterranean Sea. Said (1987) calculated the components of the heat budget for the Eastern Mediterranean Sea using Timoviv's equations. He concluded that the heat loss through the sea surface to the atmosphere exceeds the heat gain from the sun during the cold period (from October to March) with maximum amount in December and January. The heat gain from the sun exceeds the heat loss through sea surface from April to September with maximum quantities in May and June.

Maiyza (1993) presented of the monthly climatological fields of heat storage for the Eastern Mediterranean. The zonal annual trends of monthly mean heat storage in the Levantine, Aegean and Ionian seas as well as the horizontal distribution of the amplitude of the annual signal were shown. The geographical distribution of the amplitude of the annual signal was in a good agreement with some general circulation schemes of the Eastern Mediterranean Sea.

Eid (1994) studied the processes of heat exchange between the Mediterranean and the atmosphere. The net energy flux shows that heat loss from the sea surface to the atmosphere during the cold months, with a maximum amount (about 200 $W/m^2$) during December and January; while a heat gain through the sea surface during the months with a maximum value (about 200 $W/m^2$) during May and June.

The present work is concerned with the calculation of the net heat gain within the upper mixed layer in the Eastern Mediterranean Sea Computed from subsurface ocean and wind stress data

## Data and Methods of analysis:

Two categories of basic data have been used in this study. The first one is the subsurface data constituted by four seasonal means of temperature and salinity obtained on a 1° square grid (i,j) from the National Oceanographic Data Center (NODC) and Washington D.C. for two different regions inside the Eastern Mediterranean (Fig.1). Region I (27-32°N; 32-35°E) is located in the Levantine Sea and Region II (17-20°N; 33-38°E) in the Ionian Sea. The second category of data is the climatological means of monthly wind obtained on 1° square grid (i,j) obtained from the National Climatic Data Center (NCDC).

The conservation of heat in a mixed layer of depth (h) according to Behringer and Stomel (1981) is given by:

$$\underset{(I)}{Qn} = \rho\, Cp\, [\, \underset{(II)}{h.(\partial T/\partial t)} + \underset{(III)}{(\partial T/\partial x) \int_{-h}^{0} Ug.dz} + \underset{(IV)}{(\partial T/\partial y) \int_{-h}^{0} Vg.dz} - \underset{(V)}{(\partial T/\partial x).(\tau y/\rho.f)}$$

$$+ \underset{(VI)}{(\partial T/\partial y).(\tau x/\rho.f)} + \underset{(VII)}{(Wh.Dt)/2}\ ]$$

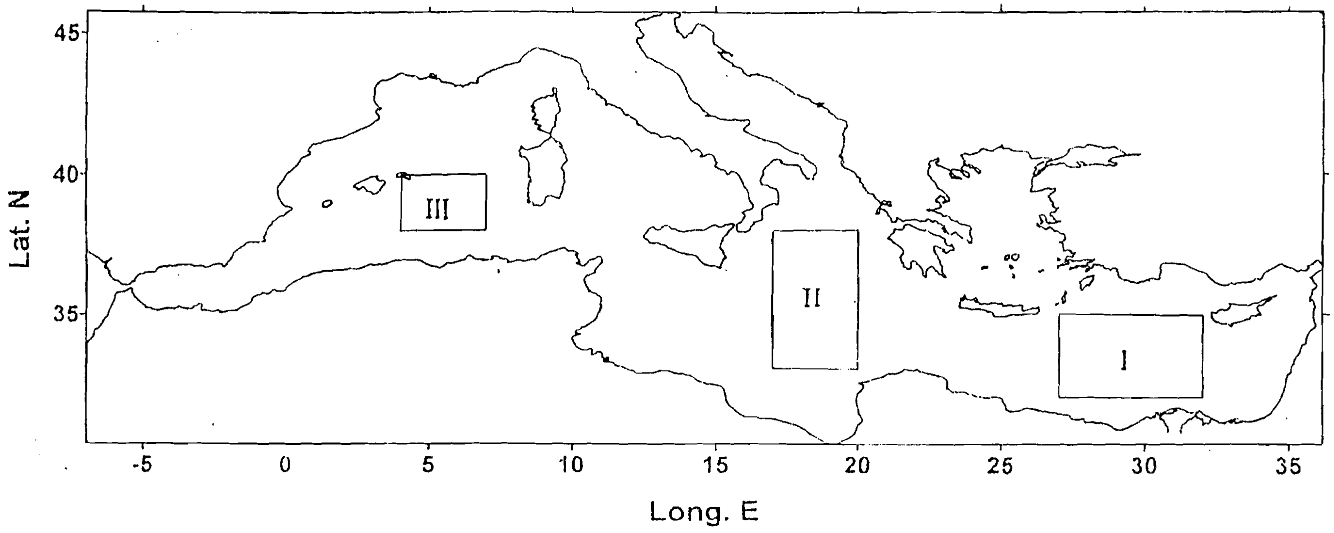


Fig. (1): Location of three selected different region in the Mediterranean Sea.

where:

Qn = The net heat gain through a unit area of the sea surface.
$\rho$ = The density of sea water (Kg/m$^3$).
Cp = The specific heat at constant pressure (J/Kg. $^{o}$C).
h = The depth of a mixed layer (m).
T = The average temperature at (x,y,t) for the mixed layer.
Ug, Vg = The horizontal components of geostrophic current in x- and y-directions (m/sec).
$\tau x$ , $\tau y$ = The components of wind stress vector (Kg/m. sec$^2$).
f = The coriolis parameter (sec$^{-1}$).
Dt = The vertical variation of temperature in a mixed layer (= 1$^{o}$).
Wh = The vertical current for the mixed layer (m/sec).

$$Wh = (\partial/\partial x)\,[(\tau y/\rho.f) - (\tau x/\rho.f)] - (\beta/f)\,.\int_{-h}^{0} Vg.dz$$

where:

$\beta$ = the gradient of Coriolis parameter with respect to the y-direction.

The terms of the above equation correspond to: the net rate heat gain (I), the local heat storage (II), the contribution of zonal geostrophic transport (III), the meridional geostrophic transport (IV), zonal Ekman transport (V), meridional Ekman transport (VI), and vertical advection (VII).

To compute (Qn) from the above equation, the dynamic height was estimated relative to 1000 m for the (i,j) grid for the two selected areas during different seasons. The components of geostrophic velocity vector (Ug, Vg) were then calculated in the (i,j) grid points. The wind stress components ($\tau x$, $\tau y$) were computed with variable drag coefficient Cd which computed as combination of formulas by Wu (1969) and Wu (1980). The depth of the mixed layer, the depth at which the temperature variation (Dt) is 1$^{o}$C lower than at the sea surface, was determined by drawing the vertical profile of temperature for some selected data on the (i,j) grid for the four seasons and then averaged to give the values on the (i,j) grid. The mean temperature of the mixed layer (T) was derived similarly on the (i,j) grid.

## *RESULTS AND DISCUSSION*

### 1) Contribution of different terms on net heat gain :

The effects of heat storage, components of geostrophic velocity, wind stress components and vertical component velocity on heat gain in the mixed layer in two different rectangular regions inside the Levantine and Ionian basins are studied in details. The main results are summarized and listed in Table (1).

From Table (1), it is seen that, the heat storage is the most important term contributing in the net heat gain. Heat is lost during autumn and winter with a maximum mean value of (233 W/m$^2$) during winter in Ionian Sea. Heat is gained during spring and summer with a maximum mean value of 215 W/m$^2$ during summer in Ionian Sea.

Zonal and meridional components of geostrophic current play a second role in the net heat gain. The average values are negative (heat loss) in Levantine Sea for all seasons; except during spring for zonal component and during summer for meridional component. The maximum mean heat loss was 82 W/m$^2$ and observed during summer for zonal component, while it was 35 W/m$^2$ during autumn for meridional component. The mean values of zonal and meridional components of geostrophic current are frequently positive (heat gain) in Ionian Sea with maximum mean value of 21 W/m$^2$ during winter for zonal component and 13 W/m$^2$ during autumn for meridional component. The differences of the heat loss and heat gain in different regions help to form the active cyclonic and anticyclonic gyres.

The zonal and meridional components of wind stress come in the third order of magnitude of their effect on the net heat gain. The zonal transport component is mostly negative in the two selected regions during the different seasons. The maximum mean value of heat loss was 7 W/m$^2$ during winter in Levantine Sea. This result reflects the effect of northwestern wind dominated in the Mediterranean Sea. The mean meridional transport component contributes in heat loss from Levantine Sea for all seasons; except during spring. The maximum mean value of calculated heat loss of 8 W/m$^2$ is found in summer. On the other hand, it contributes in heat gain in Ionian Sea, with maximum mean value of 3 W/m$^2$ during spring.

The contribution of vertical advection in net heat gain is relatively small, Its effective is relatively higher than that of the wind stress. The maximum mean heat loss (12 W/m$^2$) is observed in Levantine Sea during autumn. It means that, the vertical component of current is directed downward, i.e. sinking of water.

Generally, it is clear that, the vertical heat advection and heat content due to wind stress are not sufficient to account for the magnitude of the local heating but the horizontal heat advection, either zonal or meridianal components, besides the local heat storage are the most effective to account for total heat gain in the Eastern Mediterranean.

The temporal variability of different terms contributed in heat content in different regions during the four seasons is shown in Figs. 2 & 3.

In first region (Levantine Sea), Fig.2, the horizontal components of geostrophic current increased during autumn and winter and it represent 20% of total heat gain during winter and 40% during autumn. The other components have no significant contribution.

In second region (Ionian Sea), Fig.3, the horizontal components of geostrophic current are still slightly affecting the net heat gain, specially in winter. Also, the other components of wind stress and vertical heat advection have no significant contribution.

**2) The net heat gain (Qn) :**

The horizontal distribution of net heat gain is represented for different seasons (Figs. 4-7) and the effect of each term on the circulation pattern was studied.

**a- Winter :**

In Levantine Sea (Fig.4a), the distribution of net heat gain shows two areas of maximum heat loss (< -300 W/m$^2$) in the region of a cyclonic gyre detected by different authors (e.g. El-Gindy, 1982). The heat storage and geostrophic current component are the most effective terms on heat gain, while the other terms had no significant effect. The mean value of heat over the selected region is about -267 W/m$^2$.

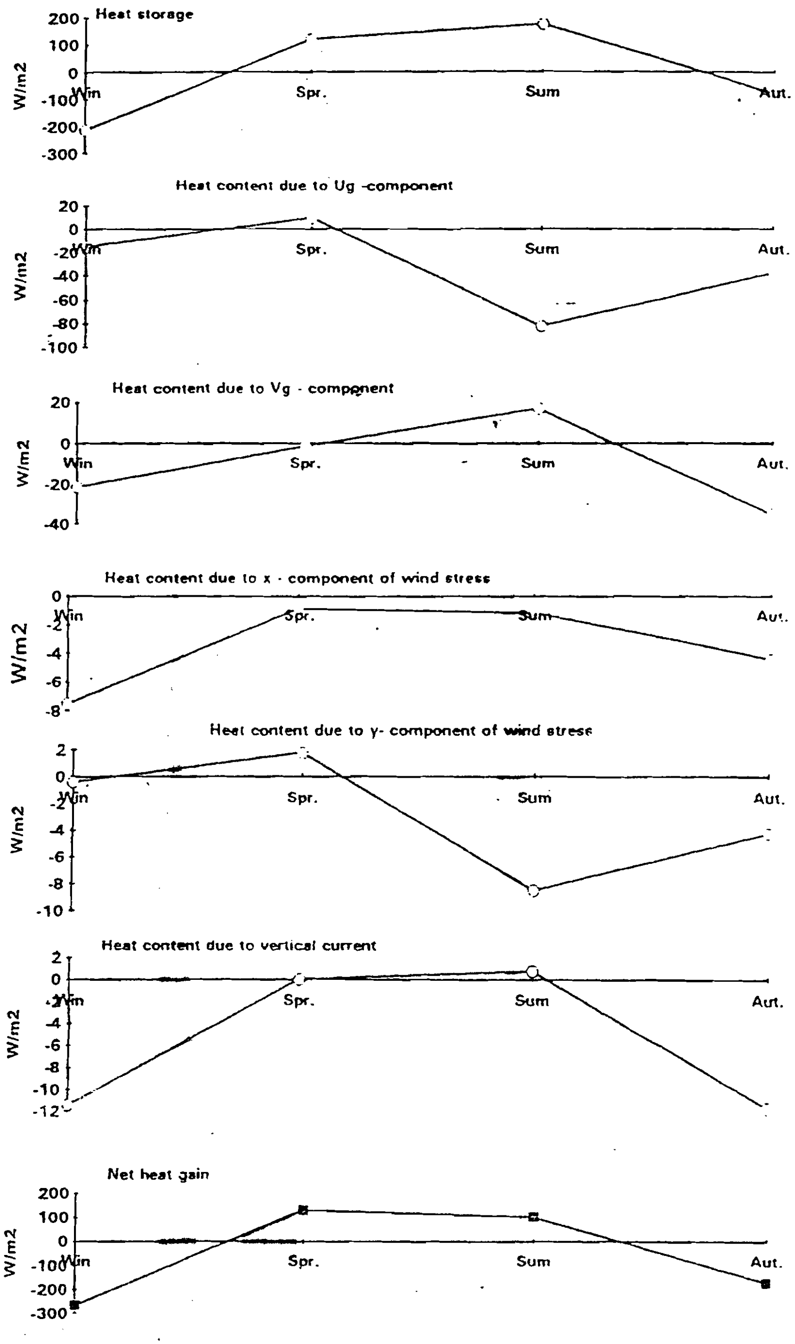


**Fig. (2): Contribution of different terms of net heat gain equation in the area (I) during four Seasons**

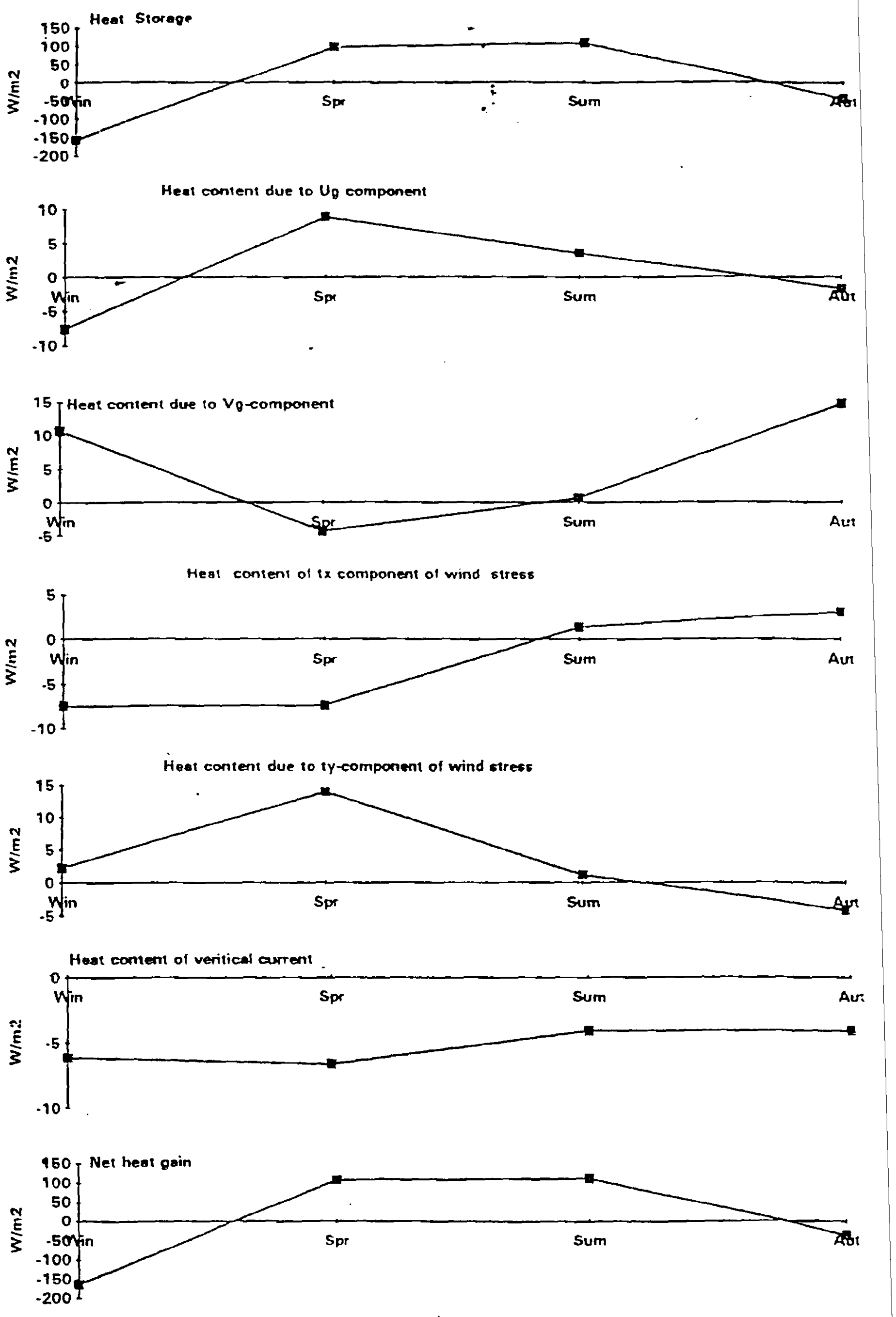
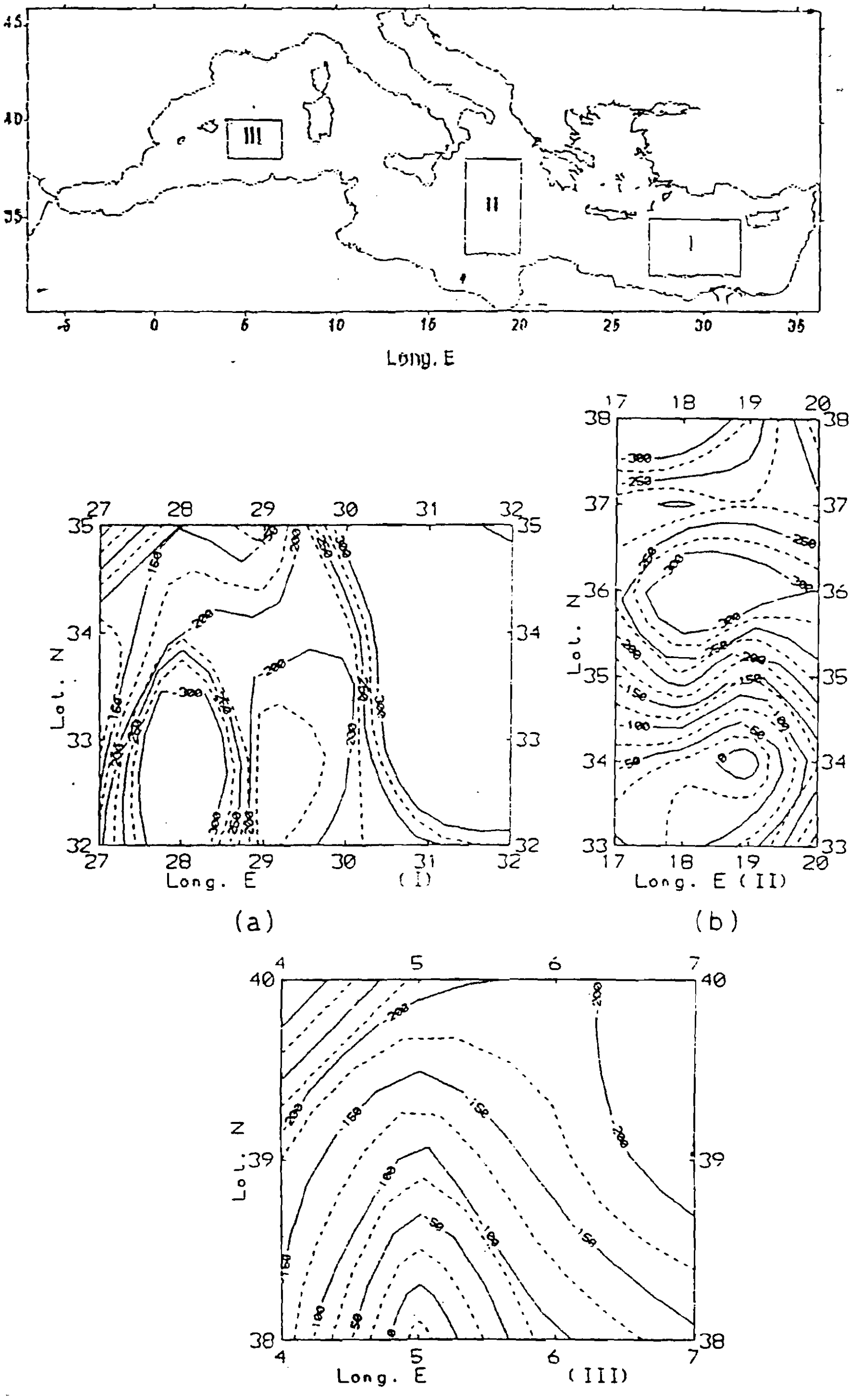


**Fig. (3): Contribution of different terms of net heat gain equation in the area (II) during four Seasons.**



(a)

(b)

Fig. (4a): The distribution of net heat gain (Qn) in W/m$^2$ during winter

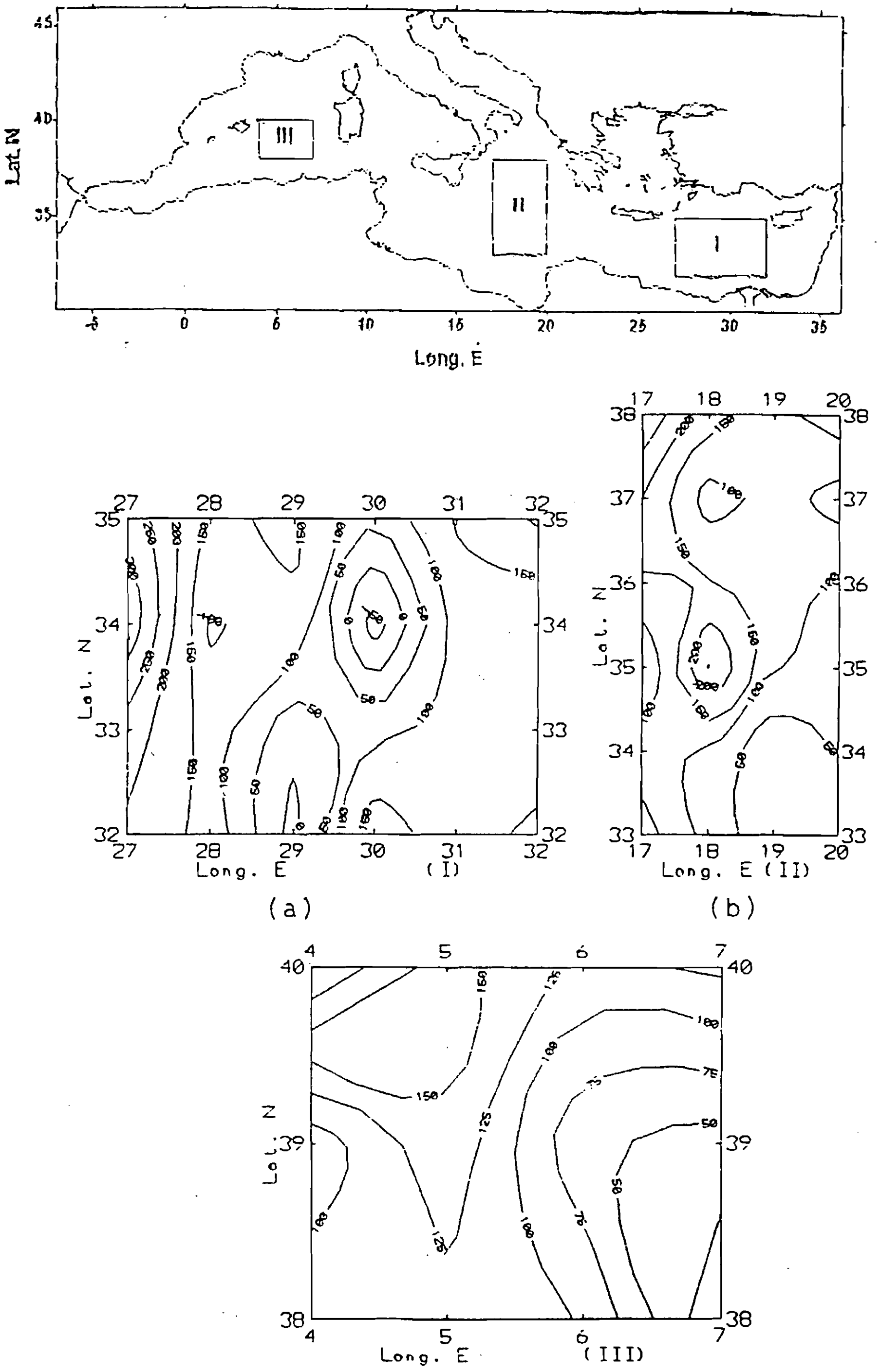


**Fig. (5a): The distribution of net heat gain (Qn) in W/m$^2$ during Spring**

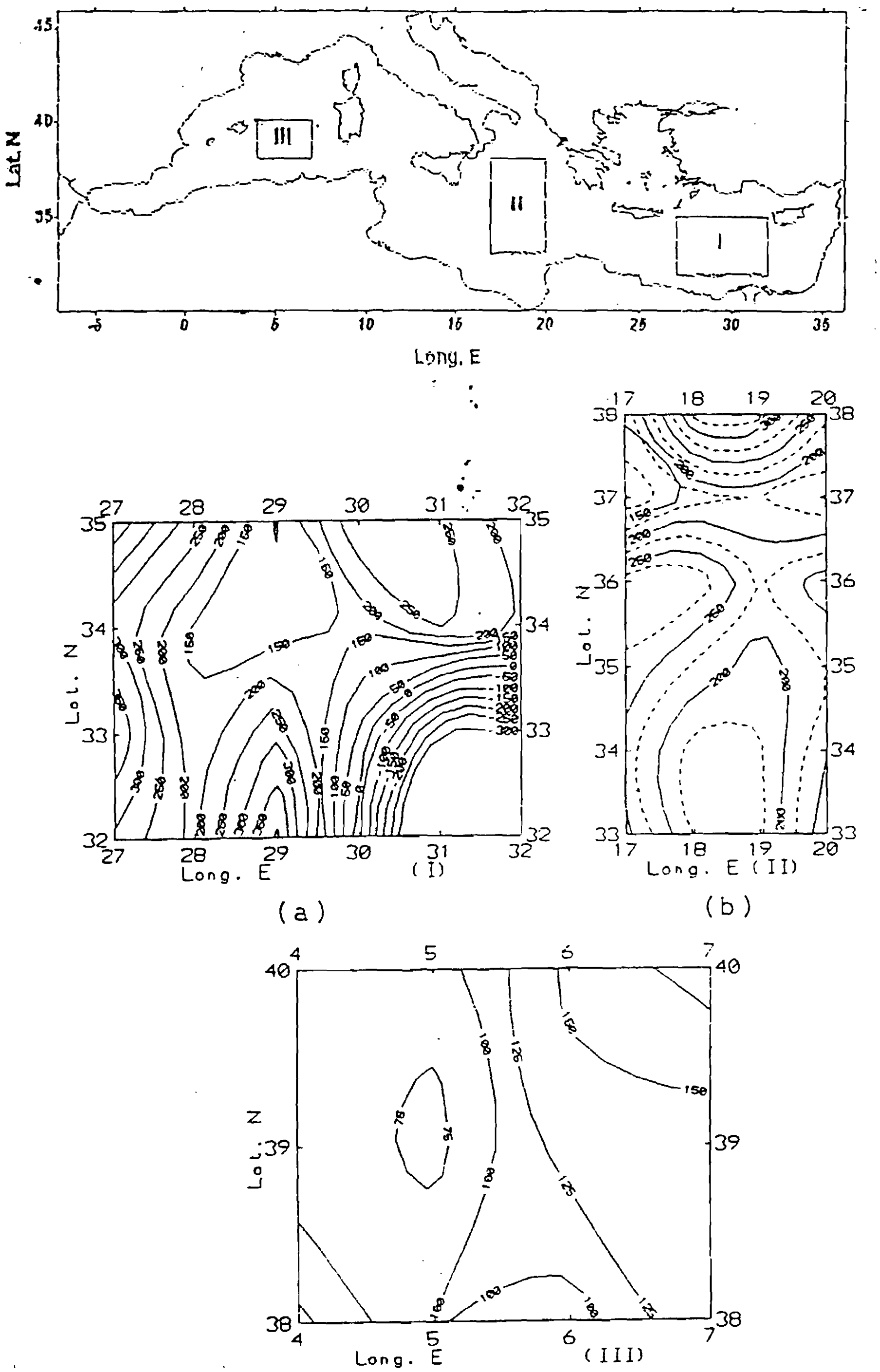


Fig. (6a): The distribution of net heat gain (Qn) in W/m$^2$ during Summer.

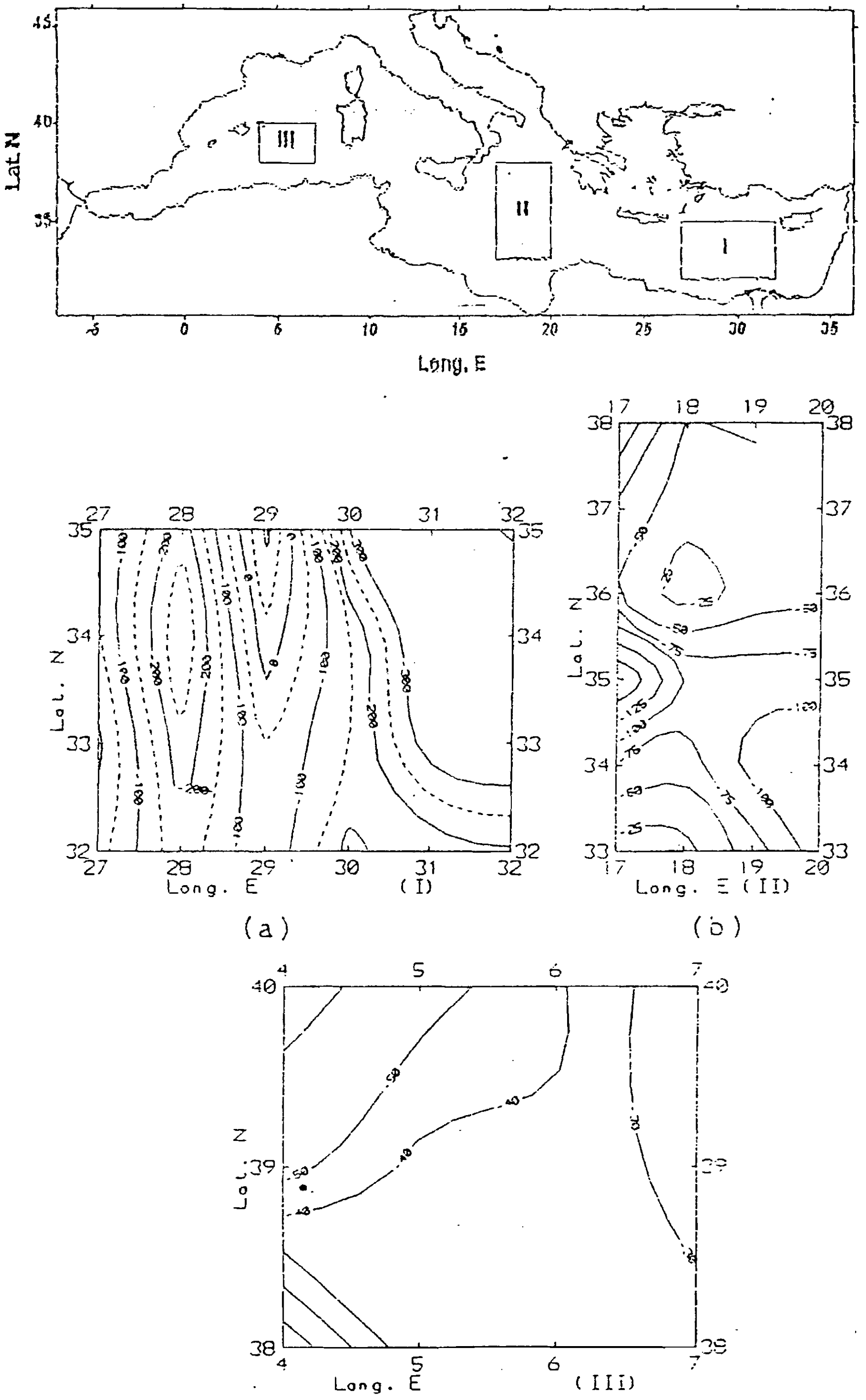


Fig. (7a): The distribution of net heat gain (Qn) in W/m$^2$ during Autumn.

**Table (1): Contribution of different terms in net heat gain (W/m$^2$) during different seasons at two selected regions in Eastern Mediterranean**

| Season | Region (I) Levantine Sea | | | Region (II) Ionian Sea | | |
|---|---|---|---|---|---|---|
| | Min. | Max. | Mean | Min. | Max. | Mean |
| *Local heat storage* | | | | | | |
| Winter | -316 | -113 | -213 | -411 | -112 | -233 |
| Spring | 60 | 183 | 121 | 8 | 296 | 101 |
| Summer | 66 | 293 | 177 | 144 | 326 | 215 |
| Autumn | -157 | - 20 | - 80 | -169 | - 30 | - 83 |
| *Zonal geostrophic transport* | | | | | | |
| Winter | -139 | 64 | -15 | -20 | 80 | 21 |
| Spring | - 95 | 154 | 10 | -40 | 77 | 3 |
| Summer | -300 | 200 | -82 | -65 | 77 | 2 |
| Autumn | -140 | 160 | -37 | -30 | 30 | 3 |
| *Meridional geostrophic transport* | | | | | | |
| Winter | -115 | 26 | -22 | -113 | 114 | 15 |
| Spring | - 66 | 66 | - 1 | - 36 | 95 | 8 |
| Summer | - 79 | 222 | 17 | - 35 | 64 | 1 |
| Autumn | -173 | 102 | -35 | - 5 | 39 | 13 |
| *Zonal Ekman transport* | | | | | | |
| Winter | -15 | 3 | -7 | -24 | 13 | -4 |
| Spring | -15 | 21 | -1 | -10 | 20 | 2 |
| Summer | -15 | 18 | -1 | - 9 | 4 | -1 |
| Autumn | -26 | 13 | -4 | -10 | 10 | 1 |
| *Meridional Ekman transport* | | | | | | |
| Winter | -14 | 18 | -0.4 | - 6 | 10 | 1 |
| Spring | -10 | 16 | 2 | -15 | 10 | 3 |
| Summer | -49 | 14 | -8 | - 6 | 14 | 2 |
| Autumn | -25 | 25 | -4 | -21 | 24 | 0.3 |
| *Vertical advection* | | | | | | |
| Winter | -15 | - 5 | -11 | - 7 | 12 | 2 |
| Spring | -37 | 38 | 0.02 | -11 | 4 | -1 |
| Summer | -21 | 8 | 1 | - 7 | 44 | 2 |
| Autumn | -18 | - 4 | -12 | - 6 | 8 | -0.2 |

In spring, generally, the local heat storage change is the main effective term on the total heat gain, while the geostrophic current components are of a secondary importance. The mean values of net heat in the mixed layer during that season are 130 W/m$^2$ and 116 W/m$^2$ in Levantine and Ionian basins respectively.

In summer, the pattern indicates that the local heat storage change is the most effective factor on the total heat gain. The geostrophic current components have a little effect. The mean values of net heat gain were 102 W/m$^2$ and 221 W/m$^2$ in Levantine and Ionian basins respectively.

In autumn, heat content due to the wind stress components and horizontal component of geostrophic current are more or less similar to that found in heat gain distribution especially the position of minimum and maximum heat content. The vertical velocity component has less effect. The mean values of net heat gain in the mixed layer during that season were -174 W/m$^2$ and -66 W/m$^2$ in Levantine and Ionian basins respectively.

## *REFERENCES*

Behringer, D.W. and Stomel, H., 1981. Annual heat gain of tropical Atlantic computed from subrface Ocean data, Journal of Physical Occeanography, II: 1393-1398

Bermagasco, A.; Malanotte-Rizzoli, P.; Long, R.B. and Thacker, W.C. 1993. The seasonal circulation of the Eastern Mediterranean determined with the adjoint method. Deep Sea Res. II, 40 (6): 1269-1298.

Bethoux, J.P. 1979. Budgets of the Mediterranean Sea. Their dependence on local climate and on the characteristics of the Atlantic water. Oceanologica Acta, 2: 157-163.

Eid, F.M. 1994. The surface heat exchange of the Mediterranean Sea. Bull. Fac. Sc., Alex. Univ., 34 (1): 79-96.

El-Gindy, A.A.H. 1982. Physical and dynamical structure of the Eastern Mediterranean. Ph.D. Thesis, Alexandria University, 213p.

Hecht, A.; Rosentroub, Z. and Bishop, J.; 1985. Temporal and special variations of heat storage in the Eastern Mediterranean. Israel Journal of Earth Sciences, 34: 51-64.

Maiyza, I.A., 1993. Heat storage in the Eastern Mediterranean. Qatar Univ. Sci. J., 13 (1): 169-176.

Osman, M.M., 1973. Thermal interaction of the Mediterranean Sea with the atmosphere (in Russian). Ph.D. Thesis, Moscow State University.

Robinson, A.; Gotnaraght,R.M.; Leslie, W.G.; Artegiani, A.; Hecht, A.; Lazzoni, E.; Michelato, A.; Sansone, E.; Theocharis, A. and Unluata, U.; 1991. The Eastern Mediterranean general circulation: features, structure and variability. Dynamics of atmosphere and ocean, 115: 215-240.

Said, M.A., 1987. Heat exchange processes between the Eastern Mediterranean and the atmosphere. Acta Adriat., 28 (1-2) : 33-43.

Tzvetkov, E., 1985. Heat storage in the Mediterranean and winter precipitation in Israel. Isr. J. Earth Sci., Vol. 34 (2-3): 65-69.

Wu, J., 1969. Wind stress and surface roughness at air sea interface. J. Geophys. Res., 74: 444- 455.

Wu, J., 1980. Wind stress coefficients over sea surface near neutral conditions. A revisit, J. Phys. Oceanogr., 10: 727-740.