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Seasonal heat budget of the south-eastern Mediterranean waters off Egyptian coast during 1983-1986

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Heat budget components of the Mediterranean waters off the Egyptian coast were studied from August 1983 to July 1986. During this period eight cruises were carried out to the southeastern Mediterranean between longitudes 29°45' E and 33°45'E using the RV NOOR YA NABI. Heat budget components were calculated using Timofeev's equations. The calculations indicated that the amount of heat loss through the sea surface due to back radiations is not more than-68.11 to 83.73 Wm^{-2}, loss due to conductive heat exchange is in the range -0,47 to 50.35 Wm^{-2}. Between -91.17 and -205.57 Wm^{-2} were lost through evaporation. The computed values of heat content from the surface to 100 m depth for the offshore station varied from 715.61 x 10^{4} Kg Jm^{-2} in winter to 1025.64 x 10^{4} Kg Jm^{-2} in summer. Station-to-station differences were evident during all cruises but they were small compared to time variations.

INTRODUCTION

A body of water exchanges heat with its surroundings by the in-coming short-wave solar radiation and the sum of the outgoing long-wave radiation, conduction and evaporation. These processes of heat exchange between water and atmosphere take place mainly at the air-water interface and a summation of these processes gives the net rate of heat exchange per unit area of air-water interface.

The most notable studies of heat budget in the Mediterranean Sea were those of BUNKER (1972) who studied the monthly heat exchange between the Mediterranean Sea and the atmosphere for an area South of France. He discussed the dominant roles of latent heat exchange and solar absorption in determining the temperature cycle and circulation of Mediterranean water. BUNKER *et al.* (1982) studied the heat balance of Mediterranean and Red seas. The annual cycle of the thermal regime of the Mediterranean and Red seas. The annual cycle of the thermal regime of the Mediterranean of different points of the Algerian province was studied by BETHOUX and BETHOUX (1976). BETHOUX (1979) studied the thermal regime and the budgets of the Mediterranean Sea. The monthly loss or gain of heat by the Mediterranean Sea due to the solar radioation, evaporation, conductive heat exchange and effective radiation was calculated and dicussed by SAID (1987).

In this paper, we present the results of the first attempt to study the seasonal variations of the heat budget of the Mediterranean shelf waters off the Egyptian coast.

MATERIAL AND METHODS

Data and Computations

Throughout the period from August 1983 to July 1986, eight cruises were carried out to the South-eastern Mediterranean waters off Egypt on RV NORR YA NABI, in the framework of the project "Biological productivity of the South-eastern Mediterranean in the past High Dam period", co-sponsored by the Department of Oceanography, Faculty of Science, Alexandria University and US Aid for International Development. During each cruise, temperature and salinity were measured at discrete depths from 24 stations located along eight sections extending perpendicular to the coast (Fig. 1). Each section comprises three stations: coastal (< 50 m), middle (50-100 m) and offshore (depth up to 200 m).

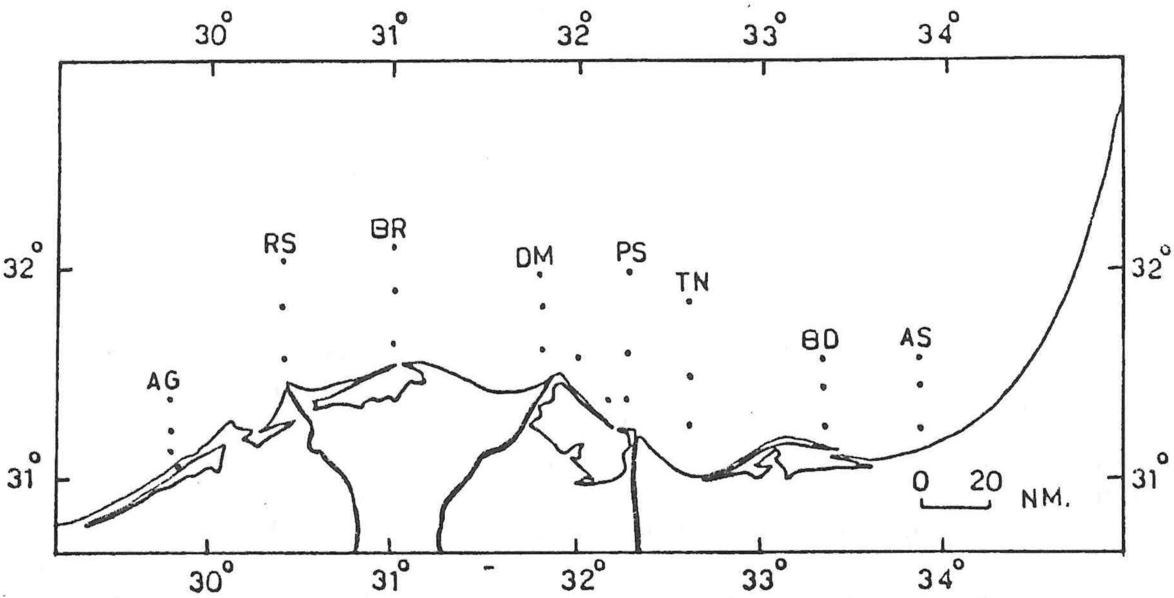

Fig. 1. Area of investigation, sections and stations sampled off the Egyptian Mediterranean coast. Sections: El Agamy (AG); Rosetta (RS); Burullus (BR); Damietta (DM); Prot Said (PS); El-Tina (TN); Bardawil (BD) and El-Arish (AS).

Two separate data sets were used in this study: standard meteorological measurements and hydrographic data. First, the standard meteorological measurements (wind speed, air pressure, cloud amount, dry-bulb temperature, wet-bulb tempeature and sea surface temperature) were used to compute the surface heat budget. These meteorological measurements were taken every 3h while the ship was on station. Water temperature was measured using protected reversing thermometers attached to a Niskin water sampler. Temperature corrections were made using calibration curves. Salinity was measured on a Beckman induction salinometer (Model RS-7C).

The components of the heat budget of the shelf waters of the Egyptian Mediterranean coast were computed using Timofeev's equations (1970, 1983). These equations are as follows (for details, refer to SAID 1987):

The daily integral of total solar radiations is given by

$$\Omega_n - \gamma \Omega [1 + \xi_1 + \xi_2 (0.25 n + 0.75 n^2] \quad (1)$$

Where

Ω – the daily integral of solar radiation when the sky is clear.

γ – parameter, indirectly represents the real concentrations of aerosol in the atmosphere over the sea and varies from 1.0 to 0.9.

n – amount of cloudiness in tenths.

ξ_1, ξ_2 – empirical coefficients are given by:

ξ_1 – 0.05 – 1.10 sin ϕ + (0.045 – 0.44 cos ϕ) hr

ξ_2 – 0.47 + 0.06 sin ϕ + [0.044 cos ϕ + 0.009 cos (ϕ – 47) – 0.0517] hr.

ϕ – latitude. hr - altitude of the sun at midday, calculated using the Oceanographic Tables (ZOBOV, 1957).

The albedo of the sea surface is given by:

$$A_n = A - (A - 0.08)\, n \qquad (2)$$

The calculation of the back radiation taking into consideration the effect of cloudiness and the vertical distribution of temperature and humidity in the lower atmosphere was performed using equation (3)

Where

$$En = 1.10 \sqrt{\gamma^5}\, \partial\, \delta\, \overline{T^4} (0.39 - 0.0502\sqrt{\overline{e}}) + \{1.06\, [1-(1-\mu)]^{0.54} + \overline{\Delta v\, (\Delta n)} + \frac{4\, \overline{(t_w - t_a)}}{T_a \sqrt{\gamma^5}\, (0.39 - 0.050\sqrt{\overline{e}}}\} \qquad (3)$$

Where t_w and t_a are the temperatures of surface water and air.

T_a – absolute air temperature - 273 + t.

$\overline{e}$ – abslute air humidity δ - constant - 0.90

∂ – Constant - 0.567 x 10^{-10} $KWm^{-2}\,{}^{o}C^{-4}$

$\overline{\Delta v\ (\Delta n)}$ – Correction varies from -0.02 to 0.04 and can be calculated from tables using the Aglas of heat balance of Oceans (1970).

$$\mu = \Omega_n / \gamma\, \Omega$$

The heat exchange, p, is given by

$$\bar{p} = -0.212\ (\overline{t_w - t_a}) \cdot V \qquad (4)$$

and the heat loss due to evaporation LE, is given by

$$\overline{LE} - -0.326\ (\overline{e_o - e}) \cdot V \qquad (5)$$

Where

V – wind speed

e_o – saturation vapor pressure at the temperatures of the sea surface. e - the actual vapour pressure. Both quantities are in millibars.

The computed heat budget from equations (1-5) are the daily amount in MJ m^{-2}. This amount was converted to Wm^{-2}.

An estimate of the computation errors, taking into consideration the uncertainty of some constants and the representativeness of the conventional climatic parameters to be used in the heat budget formulas, indicated about 11.75 Wm^{-2} error for Ω_n by changing n in equation (1) by one tenth at a single station.

RESULTS AND DISCUSSION

In winter, surface water temperatures were lowest (16.0 - 17.0 °C) at the near-shore stations, with a general trend of increasing temperature in a direction away from the coast. From February through April, the surface temperatures varied between 18.6 and 20.0°C. During the summer months, the surface water temperatures were mostly between 26.0 and 29.9°C, with a few slightly colder spots (< 25.0 °C). The area of slightly cold water was observed at the middle part of the investigated area off the Nile Delta. In autumn, the water temperatures at the sea surface were lower than those in summer by about 3-5°C. The surface water temperature fluctuated between 22.30 and 24.0°C, with a minimum value close to the coast of Bardawil station and a maximum one at the offshore stations of the Port Said section.

The seasonal variations in water temperature with depth were studied for the deep stations of the eight sections.

In winter, water temperatures showed insignificant variations with depth; they fell by no more than 0.5°C between the surface and a depth of 10-20 m. Below this depth, the water was practically isothermal to a depth of 150 m.

With the beginning of warming in early spring, when stratification started to appear, a seasonal thermocline developed within the upper surface layer of the water. This thermocline occupied the layer between the surface and a depth of 25 m in the western part of the area investigated. In the eastern part, it occupied the upper 50 m. Within this layer, the water temperature decreased by about 2-3°C.

In summer, the water temperature at the surface increased to about 26°C or higher. It decreased with increasing depth and reached 15°C near the bottom (200 m depth). With the increase in the surface temperature and the heating of the upper layer of the water column, the thermocline which was formed near the surface in spring started to descend to occupy, in most cases, the layer between 25 and 75-80 m. Within this layer, the temperature decreased on average by at least 6-7°C giving a greater vertical temperature gradient. The thickness and depth of this layer varied from west to east.

In autumn, the water temperature at the surface droped to about 23-24°C. Except for the El-Agami and Rosetta sections, the thermocline descended further, to set between 50 and 100 m below the surface. At El-Agami and Rosetta stations, it occupied the layer between 50 and 150 m.

This is generally a typical structure of the Egyptian continental shelf waters of the Mediterraneand Sea (MORCOS and HASSAN 1976; GERGES 1978; SAAD 1984; ABDEL-MOATI and SAID 1987).

Upper-water heat budget

From the calculations, the amount of heat loss through the sea surface due to back radiation is not more than -68.11 to - 83.73 Wm^{-2}. The heat loss due to conductive heat exchange ranged between -0.47 and -50.85 Wm^{-2}, and that due to evaporation vaired between -91.17 and - 205.57 Wm^{-2}. Hence, evaporation was the main component affecting the monthly and seasonal fluctuations in the heat budget. Table 1 indicated the quantity of heat loss through the sea surface due to evaporation at the offshore station; the minimum was observed in February, and the maximum in July-August.

The net surface heat budget with all its components was calculated over all eight cruises. In winter, the heat loss through the sea surface to the atmosphere exceeded the heat gain from the sun. In February 1984 it varied between -20.04 and -45.58 Wm^{-2}, whereas in February 1986 it varied from -34.76 to -85.44 Wm^{-2} (Fig. 2). Low quantities of heat loss in February were due to the decrease in the difference between the water and the air temperatures and to the increase of the altitude of the sun and the daily amount of the sun radiation. In April, the heat gain from the sun exceeded the heat loss through the sea surface and consequently a positive heat budget into the surface waters was observed everywhere. It varied from 52.14 to 101.85 Wm^{-2}. The minimum quantities of net heat gain were observed in the eastern part of the area and increased westward to reach maximum values (101.85 Wm^{-2}) at the El-Agami section.

These amounts of net heat gain increased from April to reach their maximum value, 163.55, Wm^{-2} during the summer months (Fig. 3). This maximum was due in part to greater incoming short-wave radiation which resulted from the clear sky and in part to the latent heat flux. The seasonal variation of latent heat flux (minimum in February and maximum in July) was mainly due to the variation in humidity difference (equation 5). The seasonal variation in humidity difference was primarily due to va-

Table 1. Heat loss ($W\ m^{-2}$) due to evaporation from the sea surface at the stations off the Egyptian coast.

	1983	1984			1985		1986	
	August	February	July	October	April	July	February	July
El-Agami (AG)	–	–98.69	–	–113.88	–113.15	–152.62	–104.46	–165.74
Rosetta (RS)	–153.40	–101.19	–147.15	–112.16	–117.83	–159.80	–108.44	–163.87
Burullus (BR)	–151.68	–102.53	–143.72	–114.19	–126.87	–158.09	–108.44	–
Damietta (DM)	–112.47	–97.35	–123.09	–114.66	–129.62	–134.97	–103.42	–122.78
Port Said (PS)	–121.22	–	–120.13	–114.19	–132.04	–133.40	–104.81	–118.72
El-Tina (TN)	–154.90	–	–154.18	–155.27	–146.73	–173.86	–134.55	–163.87
Bardawil (BD)	–	–	–161.99	–	–150.44	–183.86	–	–154.49
El-Arish (AS)	–	–	–143.56	–	–	–	–	–156.37

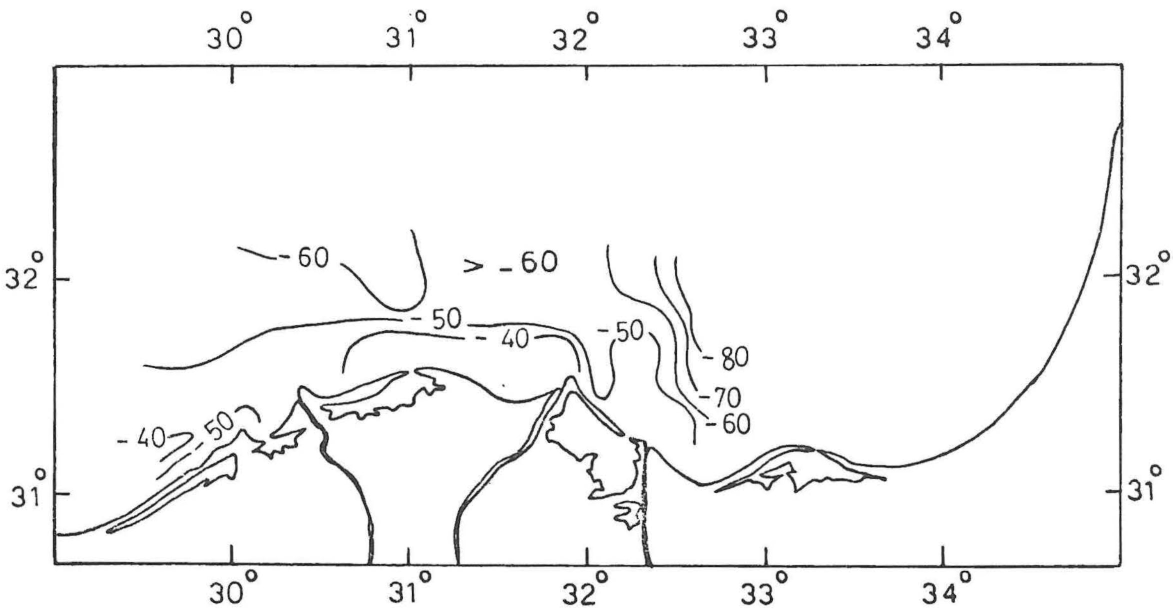

Fig. 2. Heat exchange between the Mediterranean wate-rs off Egypt and the atmosphere in February 1986. Isotherms show net heat loss (Wm^{-2}) from the sea surface.

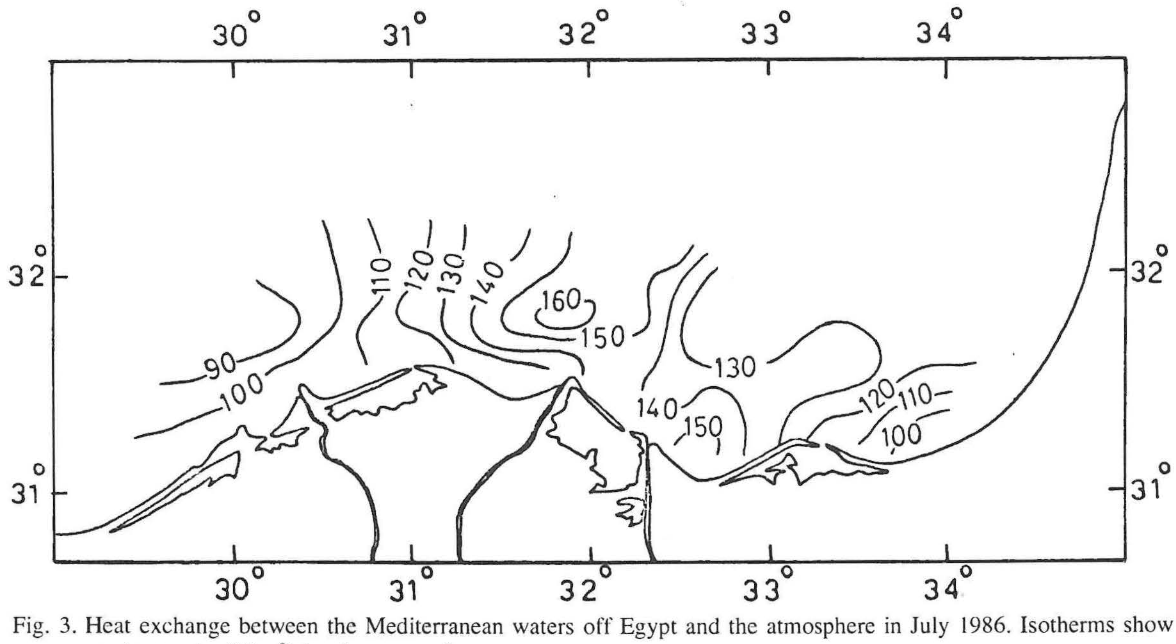

Fig. 3. Heat exchange between the Mediterranean waters off Egypt and the atmosphere in July 1986. Isotherms show net heat gain (Wm^{-2}) by the sea surface.

riations in the air specific humidity rather than to variations in the specific humidity of saturated air at the sea surface temperature. From August, the heat budget started to decrease. It varied from 54.67 to 132 Wm^{-2}. The conversion from the positive quantities of heat to the negative quantities was observed in October. During this month, the heat loss was observed in the western and eastern parts of the investigated area and varied between -7.03 and -28.12 Wm^{-2}. Meanwhile, in the central part, the heat gain varied from 5.78 to 22.65 Wm^{-2}.

Heat content variations for the offshore stations

Temperature was averaged for 25 m intervals from the surface to a depth 100 m and the heat content (expressed as kg cal.cm^{-2}) for the offshore stations was computed using the formula described by PATTULLO *et al.* (1969):

$$H = \sum_{n=1}^{4} \rho Cp\ T\ (\Delta\ Z).10^{-3}$$

Where

H – heat content, kg cal. cm^{-2} This amount was converted to kg Jm^{-2}

ρ – average density, gcm-3, in the nth layer.

C_p – specific heat of water in the nth layer.

T – average temperature, °C, in the nth layer.

Z – thichness of each layer, 2500 cm.

Salinity values needed to determine density and specific heat were obtained by Niskin bottle during data collection from the sampling stations.

Computed values of heat content (Kg Jm^{-2}) from surface to 100 m for the offshore stations are listed in Table 2. The heat content values varied from 715.61 x 10^4 Kg Jm^{-2} at Damietta station in February 1984 to 1025.64 x 10^4 Kg Jm^{-2} at Bardawil station in July 1985. From the Table, the minimum amounts of heat content were observed in February. From February through April, there was little change in the water temperature and consequently in the heat content. From July through August, the water temperature incresed to reach its maximum and the heat content ranged between 822.29 x 10^4 and 1025.64 x 10^4 Kg Jm^{-2}. In October, they varied from 850.63 x 10^4 to 906.78 x 10^4 Kg Jm^{-2}.

The seasonal variations in heat storage are clear. However, these variations are sometimes irregular; the exceptionally high values observed during July 1985 and February 1986 are examples.

Station-to-station differences within zones are evident for all cruises but are small compared with the variations with time. This suggests that time variations of appreciable magnitude have periods that are long compared with the duration of each cruise (7 days). Since time deviations seem similar in the successive month, the time variations (non seasonal) are probably long with respect to a month.

CONCLUSIONS

The principal processes that affect oceanic heat content are radiation (short and long wave), evaporation, conduction between ocean and atmosphere, and advection (PATTULLO *et al.* 1969). In the present work, the most important results are contained in Tables 1 and 2, where heat loss due to evaporation and heat content are averaged over eight transects. In order to compare the time series of evaporation and heat content, a mean value was obtained for each

Table 2. Heat content, surface to 100 m, at the offshore stations. Values ih Kg Jm^{-2} x 10^{-4}.

	1983	1984			1985		1986	
	August	February	July	October	April	July	February	July
El-Agami (AG)	–	716.70	–	906.78	724.65	870.64	744.75	906.57
Rosetta (RS)	852.47	723.48	870.98	852.60	749.14	921.35	759.07	917.29
Burullus (BR)	846.86	720.46	846.11	867.63	745.96	854.11	756.68	–
Damietta (DM)	861.56	715.61	822.29	850.63	753.37	868.30	765.85	867.30
Port Said (PS)	–	–	929.26	883.41	748.39	917.75	775.06	843.97
El-Tina (TN)	905.48	–	911.00	876.42	733.69	877.76	764.47	866.88
Bardawil (BD)	–	–	856.49	–	748.39	1025.64	–	906.65
El-Arish (AS)	–	–	831.88	–	–		–	871.15

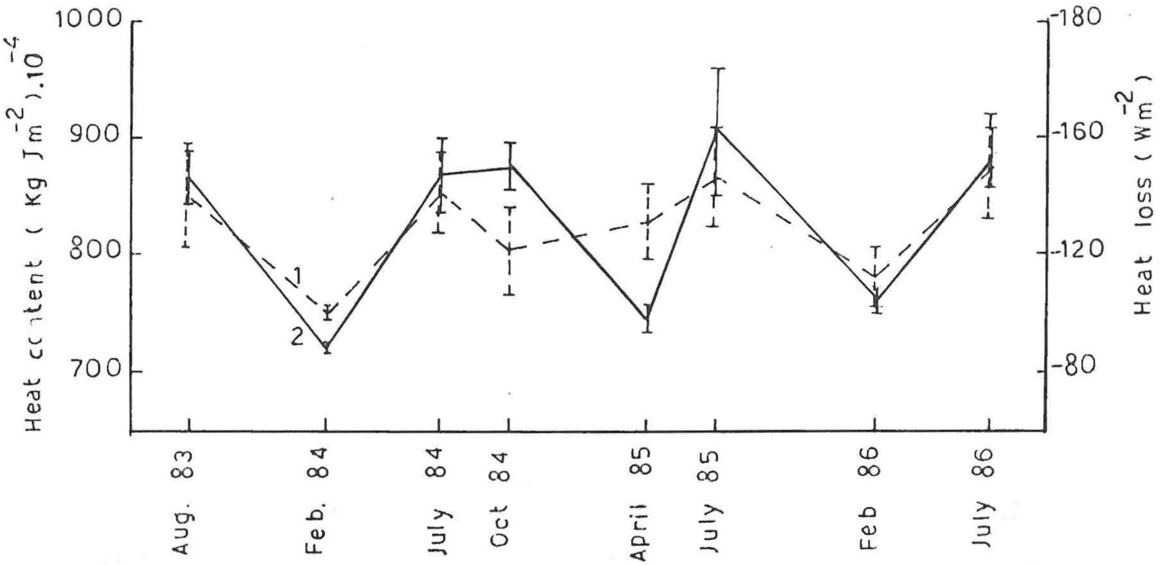

Fig. 4. Quantitative comparison of time series of : 1 - heat loss due to evaporation (Wm^{-2}) and 2 - heat content (Kg Jm^{-2}) for Mediterranean waters off the Egyptian coast.

parameter for each cruise (Fig. 4). Intervals in heat loss due to evaporation and heat content indicate ± one standard deviation and the individual points represent the average over all transects. The heat loss from the sea surface due to evaporation increases with increasing heat content. Lowest values of heat content 719.06 x 10^4 Kg Jm^{-2} and evaporation (-99.41 Wm^{-2}) occur in winter, and the maximum values (905.08 x 10^4 Kg Jm^{-2} and -156.66 Wm^{-2}, respectively) are observed in summer. Between these seasons, values are mosly intermediate between the minimum and maximum values. The seasonal variation in temperature does not vanish at and below 100 m; data suggest that at 200 m the seasonal range in temperature was about 2°C and out of phase with the surface cycle.

REFERENCES

ABDEL-MOATI, A. R. and M. A. SAID. 1987. Hydrographic structure of the Mediterranean shelf waters off the Egyptian coast during 1983-1986. Thalassografica, 10 : 23-39.

Atlas of heat balance of Oceans. 1970. Edit. by A. Q. Kolesnikov, Morsk, Gidrofiz. Inst. Sevastopol, 84 pp. (In Russian).

BETHOUX, J. P. 1979. Budget of the Mediterra-nean Sea. Oceanol. Acta, 2 : 157-163.

BETHOUX, N. and J. P. BETHOUX. 1976. Le cycle annual du bilan thermique de la mer en divers points du basin Liguro Provencal., Rapp. Comm. int Mer Medit., 23 : 25-26.

BUNKER, A. F. 1972. Wintertime interactions of the atmosphere with the Mediterranean Sea. J. Phys. Ocean., 2 : 225-238.

BUNKER, A. F., H. CHARNOCK and R. A. GOLDSMITH. 1982. A note on the heat balance of Mediterranean and Red Seas, J. Mar. Res., 40 : 73-84.

GERGES, M. A. 1978. Thermal structure of the continental shelf waters off the Egyptian Mediterranean coast. Proceeding of the fifth Ocean Thermal Energy Conversion (OTEC) Conference, Miami, U. S. A.

MORCOS, S. A. and H. M. HASSAN. 1976. The water masses and circulation in the southeastern Mediterranean. Acta Adriat., 18 : 195-218.

PATTULLO, J. G., W. V. BURT and S. A. KULAN. 1969. Oceanic heat content off Oregon : its variations and their causes. J. Limn. Ocean., 14 : 279-287.

SAAD, N. N. 1984. Hydrographic structure of the continental shelf area from El-Agami to El-Aris. M. Sc. Thesis, Alexandria University, 104 pp (mineo).

SAID, M. A. 1987. Heat exchange processes between the Eastern Mediterranean and the atmosphere. Acta Adriat., 28 : 33-34.

TIMOFEEV, N. A. 1970. On the external components of the heat balance in the oceans. In the marine

hydrographical investigation, No 1, Morsk, Gidrofiz. Inst. Sevastopol, 148-165 (In Russian).
TIMOFEEV, N. A. 1983. Radioation regime of oceans. Kiev, 24 p (In Russian).
ZOBOV, N. N. 1957. Oceanographic Tables. Leningrad, Hydrometeorology Publication, 406 pp.

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Sezonski toplinski buđet jugoistočnog dijela Sredozemnog mora u otvorenim vodama egipatske obale tijekom 1983-1986.

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KRATKI SADRŽAJ

Komponente toplinskog buđeta Sredozemnog mora, otvorenih voda priobalja studirane su za razdoblje od kolovoza 1983. do ožujka 1986. U tom razdoblju izvršeno je osam putovanja tijekom kojih su izvršena mjerenja između meridijana 29° 45' E i 33° 45' E sa brodom RV NOOR YA NABI. Komponente toplinskog buđeta izračunate su Timofeevim jednadžbama. Rezultati ukazuju povećan gubitak topline kroz površinu mora iz razloga što je povratna radijacija manja od -68.11 do - 83.73 Wm^{-2} ; gubici izmjenom topline kondukcijom u rasponu su -0.47 do -50.35 Wm^{-2}. Evaporacijom se gubi između -91.17 do - 250.57 Wm^{-2}. Izračunate vrijednosti toplinskog buđeta od površine do dubine 100 m u promatranom priobalju variraju od 715.61 x 10^4 Kg Jm^{-2} zimi do 1025.64 x 10^4 Kg Jm^{-2} ljeti. Od postaje do postaje rezultati osmatranja tijekom putovanja ukazuju na očite prostorne razlike, koje su ipak male u usporedbi sa promjenama koje se odvijaju u vremenu.