Acta Adriat., 26 (2) : 191—201 (1985) YU ISSN: 0001—5113
AADRAY

UDK: 532.5 (262)
Original scientific paper

THE SOURCES OF FORMATION OF THE INTERMEDIATE WATER MASSES IN THE MEDITERRANEAN SEA

PORIJEKLO INTERMEDIJARNE VODENE MASE U SREDOZEMNOM MORU

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Regions of formation of the intermediate water masses in the Mediterranean have been established.

The quantity of heat which the sea must give to the atmosphere in order that the winter convection reaches the depth of maximum salinity was calculated as well as the actual heat loss through the sea surface in winter.

The past approaches of other authors are criticized.

INTRODUCTION

In the Mediterranean Sea as a whole, exists an Intermediate layer (250—600 m) of high salinity (> 38.70‰) in the western and (< 39.10‰) in the eastern parts of the Mediterranean Sea. The temperature of this water mass changes from 15°C to 16.6°C and from 14°C to 15°C in the eastern and central basins respectively.

The formation of this water mass was studied by:

Wüst (1960—1961) pointed out that along the coasts of Asia Minor, the temperature drops in February to values between 12.5° and 15.5°C. At the same time the surface salinity reaches its maximum of about 39.1‰. As a result of the influence of low temperature and high salinity, a relatively dense surface water is formed on both sides of Rhodes. This homogeneous large water mass is formed in the upper 250 m, from where it spreads in the core layer of what Wüst has called the Levantine Intermediate Water. While spreading westward, it mixes with lower salinity water from above and below, resulting in a decrease in salinity and also temperature, with an associated increase in dept (50—100 m to 100—250 m and finally to 300—400 m). Wüst used for this investigation 182 winter stations and 341 summer stations from all the basins of the Mediterranean during the period 1908 to 1958. Only 27 winter and 49 summer stations were available from the largest basin, the Levantine. Part of the difficulty in studying this problem is the lack of data, especially in winter.

Morcos (1972) expressed the view that the southern Levant may be a possible source of the intermediate water according to the high evaporation and consequently the high salinity. He examined critically this view by comparing the climatological and hydrographic factors in the northern and southern Levant. The stations available from the southern Levant (South of 33°N) during 1908—1958 were 9 winter stations and 8 summer stations and of about 100 deep stations collected during joint programs with Egyptian oceanographers on board the following research vessels: the Japanese »Shoyo-Maru« in March 1959, the Yugoslavian »Ovcica« and »Globica« in October 1959—1961, the USSR »Ichthyology« in October 1964 and December 1965 to December 1966. He showed that the conditions of heat loss from the sea surface along the Egyptian coast are similar in winter to those at the north-east part of the Levantine sea and suitable conditions for convection exist.

Ovtchinnikov (1966) by using the collected Oceanographic data during 1908—1963, suggested another yearly system of formation of the Intermediate water mass. He suggested that, in the center of the cyclonic gyre a cupola of cold water forms and above it exists the surface layer of the rapid change in temperature. Autumn-Winter convection reaches here the center of the Intermediate water mass, and therefore the centers of cyclonic gyres are the sources of formation of the Intermediate water mass.

MATERIALS

The used data were taken from 1338 hydrographic stations collected from several expeditions carried out by different countries during the last 20 years (1963—1982). 658 stations were collected in the summer season and 680 stations in winter. The average value of temperature and salinity of these collected data are calculated in stations distributed in a regular net for summer and winter seasons as shown in figures 1 and 2.

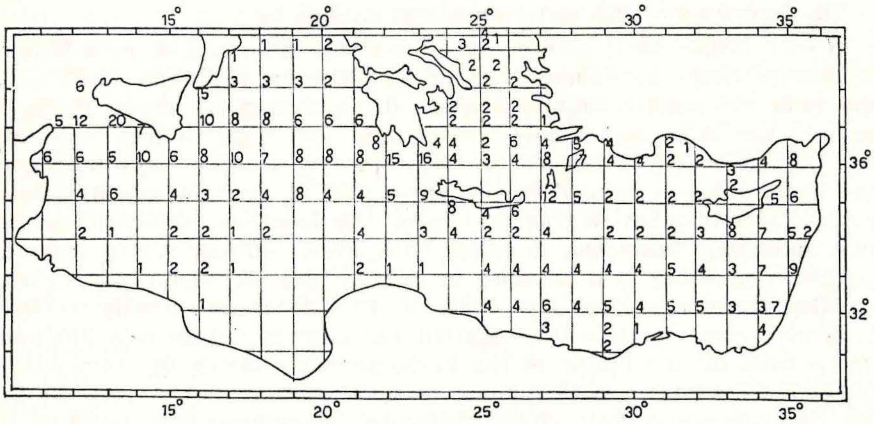

Fig. 1. The number of station by which the average temperature and salinity were calculated in points distributed in regular net in the summer season

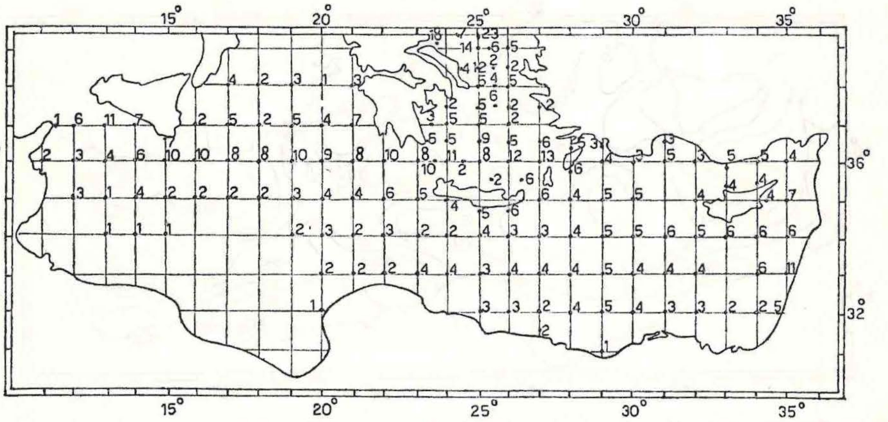

Fig. 2. The number of station by which the average temperature and salinity were calculated in points distributed in regular net in the winter season

The used current data were taken from the Ph. D Thesis written by S a i d 1984. The current components (u, v, w) were accurately calculated. The horizontal components of current (u, v) were calculated using the dynamic method. The refference level was taken at 1000 m. The vertical component (w) was calculated by integrating the equation of continuity (T a s l a k o f et al., 1980).

The meteorological data were collected from 35 stations covering the eastern Mediterranean Sea. These data were taken from the Atlas of the Atlantic Ocean (1977).

RESULTS

The analysis of the data indicates that the thickness of the thermal mixed layer in the summer season (Fig. 3), varies from 10—15 m in the center of cyclonic gyre which lies in the eastern Mediterranean, and to 50 m near the Egyptian Coast. Fig. 4 indicates the distribution of the depth of the Core of the Intermediate water mass determined by a maximum of salinity in the summer season. From this figure the Core of the Intermediate water mass lies at 150 m depth in the center of the cyclonic gyre, at 200 m depth in the eastern Mediterranean and at more than 300 m in the center of anticyclonic gyre. The depth of the maximum salinity increases westward (> 350 m).

The comparison between Fig. 3 and 4 indicates that, the layer of maximum salinity exists below the thermal mixed layer. And therefore the vertical convection from the surface to a depth of maximum salinity disappeared. Consequently there is no ventilation from the intermediate layer in the summer season. This ventilation occurs only in the winter season when the temperature of the surface layer drops and consequently the winter convection develops. This convection occurs quickly in these places which has a depth of the Core of the Intermediate water mass near the surface.

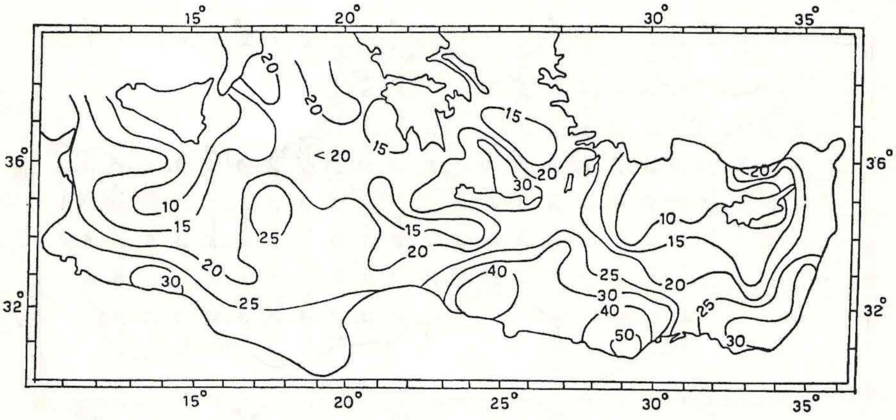

Fig. 3. Thickness of the thermal mixed layer (m) in the summer season

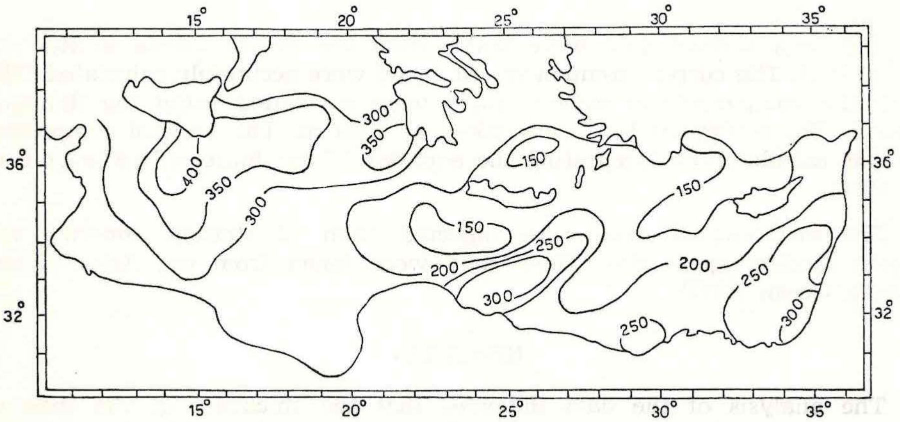

Fig. 4. The depth of maximum salinity in the summer season

In the present work, the quantity of heat which the sea must give to the atmosphere for the winter convection reaches the depth of maximum salinity will be calculated. This quantity of heat was calculated using Z o b o v's method (1947) improved by B o l g a k o v (1975) and is called in this paper the ventilation from the intermediate water mass. The ventilation is given from formula (1):

$$Q_t = C_\rho \rho H (\bar{T} - T^*) \qquad (1)$$

where

C_ϱ — thermal heat capacity, ϱ — density.
$\bar{T}$ — average water temperature in the layer H
T^* — the water temperature of the layer of convection and determined as the function of the specific volume of the layer H and of the average water salinity in this layer and is given by:

$$T^{*} = f\ (V_{Z=H}\ ,\ \overline{S}\ )$$

In fact it is neccessary to take into account, the heat inflow (or outflow) to the layer of convection according to the horizontal transportation of water and heat exchange through the lower boundary of the layer of convection. The effect of evaporation on salinity in the layer of convection and the advection of salt.

The equations of convective transference at the absense of the phase of water transferring can be written as follows:

$$\rho H \frac{\partial T}{\partial t} = \frac{1}{C_\rho} Q_t + \int_0^H \rho \left(U \frac{\partial T}{\partial X} + V \frac{\partial T}{\partial Y} \right) dZ + \rho W T \Big|_{Z=H} + \rho K_Z \frac{\partial T}{\partial Z} \Big|_{Z=H} \qquad (2)$$

$$\rho H \frac{\partial S}{\partial t} = Q_S + \int_0^H \rho \left(U \frac{\partial S}{\partial X} + V \frac{\partial S}{\partial Y} \right) dZ + \rho W S \Big|_{Z=H} + \rho K_Z \frac{\partial S}{\partial Z} \Big|_{Z=H} \qquad (3)$$

$$\rho\ (X, Y, Z) = \rho\ (T, S, P) \qquad (4)$$

here T, S, ϱ, P are temperature, salinity, density and water pressure, H — the thickness of the layer of convection (i, e. the layer which extends from the sea surface to a depth of maximum salinity).

Q_T, Q_S — The inflow of heat and salt through the sea surface X, Y, Z — Coordinites, t- time, K_z — coefficient of vertical turbulant. For the interval of time $\triangle t$, the heat contained in the layer H is given by

$$q = C_\rho \rho H \Delta T = Q_T + \left[\sum_{i=1}^{n} \rho \left(U \frac{\Delta T}{\Delta X} + V \frac{\Delta T}{\Delta Y} \right) \Delta Z + \rho W T \Big|_{Z=H} + \rho K_Z \frac{\Delta T}{\Delta Z} \Big|_{Z=H} \right] C_\rho \Delta t \qquad (5)$$

The variations in salinity are very small and consequently Q_s very small. From equation (5), Q_t plays an important role.

Fig. 5 shows the distribution of Q_t in the area of investigation. From this figure, $Q_t < 30$ K cal/cm^2 observed in the central part of the Levantine sea and north of Crete. In the southern and south-eastern parts of Levantine basin it reaches 60—70 K. cal/cm^2, 90 K. cal/cm^2, near the Egyptian coast and increases westward.

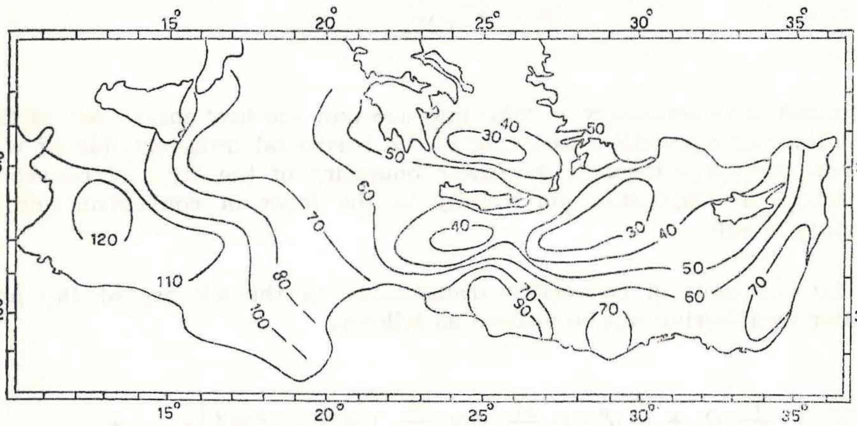

Fig. 5. The ventilation from the Intermediate water masses (K. cal/cm²)

The horizontal advection of heat in the winter has 2—5 K. cal/cm². In some places in the eastern part of the eastern Mediterranean, where the current speed reaches 35—40 cm/sec, the heat advection reaches 10—15 K. cal/cm². The vertical current velocity (w) in the Mediterranean has the order of 10^{-5}—10^{-4} cm/sec (S a i d, 1984), and therefore $\left.\varrho WT\right|_{Z = H}$

is very small, also the vertical temperature gradient $\left.\frac{\Delta T}{\Delta Z}\right|_{Z = H}$

is very small and both are neglected.

The ventilation from the Intermediate water mass due to the vertical convection and the horizontal advection is shown in Fig. 6. The quantities < 30 K. cal/cm² are observed in the central Levantine sea and north of Crete and increase south and westward.

The Intermediate water mass forms in these regions, where the actual heat loss through the sea surface in the winter season reaches the ventilation from the intermediate water mass.

The actual heat loss was calculated using T i m o v i v's equations (1970 and 1983).

The daily integral of total solar radiation is given by

$$Q_n = \gamma Q \left[1 + \xi_1 n + \xi_2 (0.25 n + 0.75 n^2) \right] \tag{6}$$

where, Q — the daily integral of solar radiation when the sky is clear

γ — parameter, indirectly accounts the real concentration of aerosole in the atmosphere over the sea and varies from 1.0 to 0.90.

n — amount of cloudiness.

ζ_1, ζ_2 — empirical coefficients are given by

$$\zeta_1 = 0.05 - 1.10 \sin \Phi + (0.045 - 0.044 \cos \Phi)\ hr$$

$$\zeta_2 = 0.47 + 0.66 \sin \Phi + [0.044 \cos \Phi + 0.009 \cos (\Phi - 47) - 0.0517]\ hr.$$

Φ — Latitude, hr — altitude of sun at midday

Albedo of the sea surface is given by

$$A_n = A - (A - 0.08)\ n \tag{7}$$

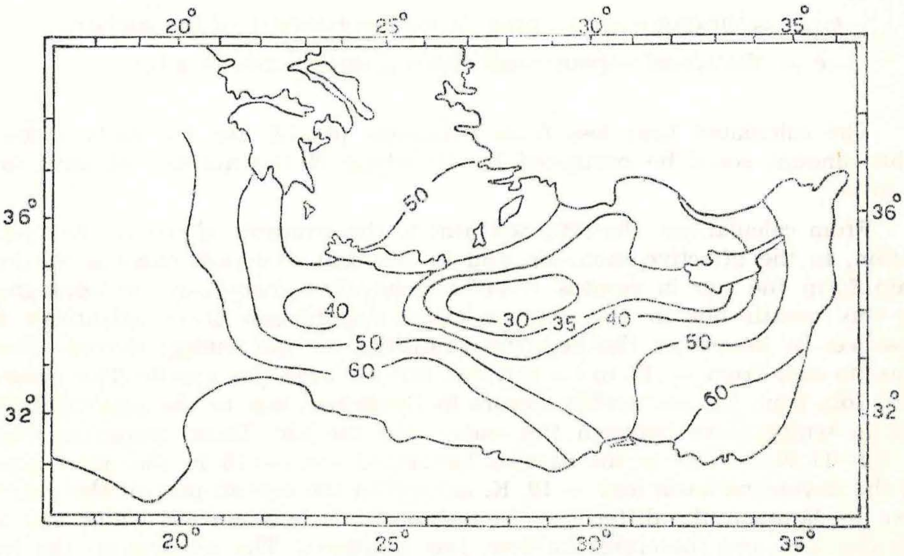

Fig. 6. The ventilation from the Intermediate water masses with accounting the horizontal heat advection

The calculation of the effective radiation taking into consideration the effect of the cloudiness and the vertical distribution of temperature in the lower layer of the atmosphere is given by equation (8)

$$E_n = 1.10\sqrt{\delta^5}\ \delta\sigma\ \overline{T}_a^4 (0.39 - 0.0502\sqrt{e}) + \Big\{ 1.06 \left[1 - (1 - \mu)\right]^{0.54} + \overline{\Delta\nu(\Delta n)} + \frac{4\,(\overline{t_w - t_a})}{T_a\sqrt{\delta^5}\,(0.39 - 0\ 0.502\sqrt{e})} \Big\} \tag{8}$$

t_w, ta — the temperature of surface water and the air

Ta — absolute air temperature = 273 + ta

e — absolute air humidity, δ = constant = 0.90

σ = constant = 0.567×10^{-10} K. wt/m^2. C^{o4}

$\overline{\Delta\nu\ (\Delta n)}$ — correction varies from — 0.02 to 0.04 and can be calculated from tables.

The heat exchange from equation (9)

$$\overline{P} = -\ 0.212\ \overline{(t_w - ta)}\ V \tag{9}$$

and the heat loss due to the evaporation is given from equation (10)

$$\overline{LE} = -\ 0.326\ \overline{(e_0 - e)}.\ V \tag{10}$$

where V — wind speed

e_0 — saturation vapour, press at the temperature of the surface,

e — the actual vapour press. Both quantities are in mb.

The calculated heat loss from equations (6—10) are the daily amount. This amount sould be mutiplied by N, where N the number of days in a month.

From calculations, the returned heat to the atmosphere due to the evaporation, to the effective radiation and to the heat exchange exceeds the heat gain from the sun in ceratus where the negative quantities are very small in this month but in the extreme south-eastern sea these quantities are positive. In November the negative quantities of heat budget decrease from west to east from — 12 to — 5 K. cal/cm^2 all over the month. The greatest heat loss from the sea surface occurs in December, due to the great differences in temperature between the water and the air. These quantities reach — 10—11 K. cal/cm^2 in the eastern Levantine sea, — 15 in the other places of the Levantine basin and — 19. K. cal/cm^2 in the central part of the Aegean Sea. In January, the differences in temperatures between the water and the air decrease and therefore the heat loss decreases. The changes in the heat budget from negative to positive quantites occur in March. The greatest positive quantities (12—14 K. cal/cm^2) were observed in May-July.

The total quantity of the returned heat to the atmosphere through the cold period (October-March) is shown in Fig. 7. From this figure, the minimum quantity of the returned heat (30—33 K. cal/cm^2) is observed in the south-eastern part of the Levantine Sea, 27—28 K. cal/cm^2 onshore. The maximum quantity observed in the Aegean Sea is 60 K. cal/cm^2. In the central basin this quantity varied from 45 to 50 K. cal/cm^2 and reached more than 50 K. cal/cm^2 along the Libyan coast.

The simple comparison between the ventilation (Fig. 6) and the actual heat loss from the sea surface to the atmosphere (Fig. 7) determines the regions of formation of the Intermediate water mass. In order to accurately determine these regions, the differences in the quantites of the actual heat budget through the cold period (6 months) and the ventilation from the Intermediate water mass were calculated. The positive qunatities indicate that, the actual heat loss from the sea surface exceeds the ventilation from the intermediate water mass and the negative quantities indicate the opposite case (Fig. 8). The hashed area shows the regions of formation of the Intermediate water mass.

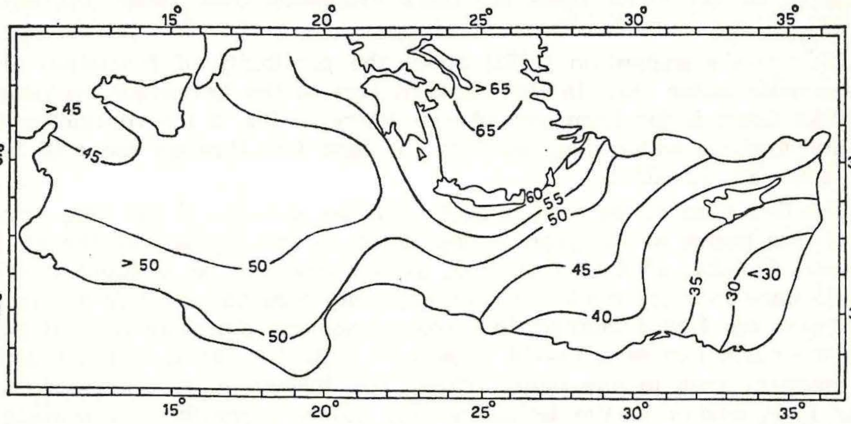

Fig. 7 The actual heat loss brom the sea surface through the cold period (K. cal/cm^2)

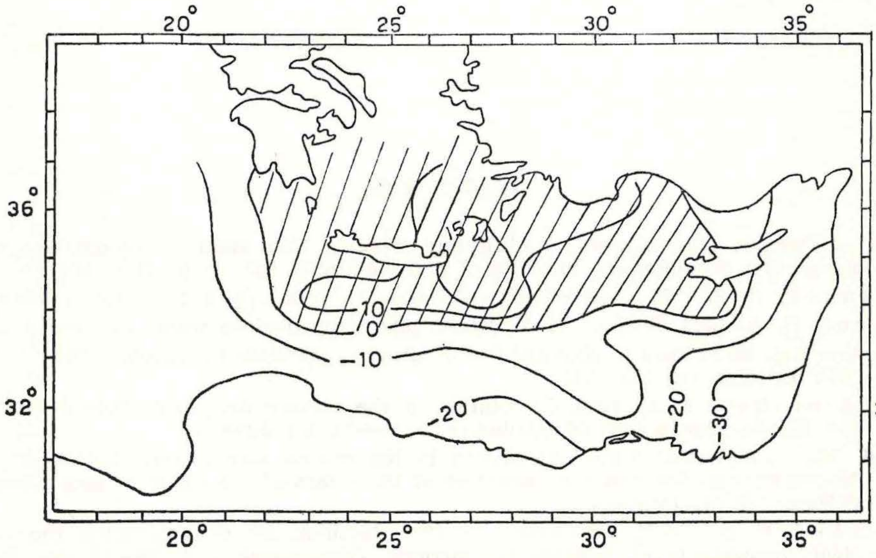

Fig. 8. The differences between the actual heat loss and the ventilation from the Intermediate water masses

DISCUSSION AND CONCLUSION

The received results allow to criticize the opinions of different authors about the processes of formation of the Intermediate water mass and the geographical locations of the sources of formation.

Wüst's opinion (1961) is in general true, that the Intermediate water mass forms around Rhodos, where the heat loss in the winter season exceeds the ventilation from the intermediate water mass. However, the sources of formation of the water mass are more enormous than those supposed by Wüst.

Morcos's suggestion (1972) about the possibility of formation of the Intermediate water mass in the southern part of the Levantine sea near the Egyptian Coast is far from correctness, where in Fig. 8 the ventilation from the intermediate water mass exceeds the heat loss through the cold period by about 20 K. cal/cm^2.

The deviation of the heat budget from the average of the long standing of the cold period of the year, is dependent on the anomaly of the air temperature. Stability of the anomaly of the air temperature of about 2—3°C, is not the same in every winter, but in different years the anomaly of the same sign keeps for 4 or 5 months. In these seasons the deviation of heat budget from the normal cases is 15—20 K. cal/cm^2. This fluctuation of the heat budget indicates that in the chilly winter the formation of the Intermediate water mass occurs in the Levantine sea nearly everywhere, excluding the southern and the extreme eastern parts. In the mild winter the formation occurs only at the centres of the cyclonic gyre of the Levantine sea and north of Crete.

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Received: November 10, 1985

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Acta Adriat., 26 (2) : 191—201 (1985)

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KRATKI SADRŽAJ

Područja iz kojih potječe intermedijarna vodena masa u Sredozemnom moru do sada su s manje ili više uspjeha identificirali Wüst (1960, 1961) i Morcos (1972). Ova se vodena masa formira u područjima gdje zimska konvekcija dosiže dubinu maksimuma saliniteta.

U ovom je radu: (a) količina topline koju more mora predati atmosferi da bi zimska konvekcija dosegla dubinu maksimalnog saliniteta izračunata na osnovu hidrografskih parametara temperature i saliniteta vode i brzine struje; (b) stvarni gubitak topline kroz površinu mora u atmosferu za vrijeme zime izračunat na osnovu meteoroloških elemenata.

Dobijeni rezultati omogućili su da se kritički osvrnemo na mišljenja koja su do sada iznijeli različiti autori u vezi procesa formiranja intermedijarne vodene mase i geografskih lokacija iz kojih potječe.

Wüst iznosi mišljenje, koje je općenito uzevši točno, da se intermedijarna vodena masa stvara negdje oko otoka Rodosa ali postoji daleko veći broj područja u kojima se formira ova vodena masa nego je pretpostavio Wüst.

Mišljenje Morcosa da postoji mogućnost da se intermedijarna vodena masa formira u južnom dijelu Levantskog mora blizu obala Egipta nije u skladu s našim rezultatima.