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HEAT EXCHANGE PROCESSES BETWEEN THE EASTERN MEDITERRANEAN AND THE ATMOSPHERE

PROCESI IZMJENE TOPLINE IZMEĐU ISTOČNOG MEDITERANA I ATMOSFERE

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The monthly loss or gain of heat by the Mediterranean Sea due to the solar radiation, the evaporation, the conductive heat exchange and the effective radiation was calculated using Timoviv's equations. The maximum amount of heat loss is due to the evaporation, where its maximum value is observed in October-January and its minimum value is in April-May. The heat gain from the sun exceeds the heat loss through the sea surface from April to September.

INTRODUCTION

Monthly heat exchanges between the Mediterranean Sea and the atmosphere are computed for an area south of France which show the dominant roles of latent heat exchange and solar absorption in determining the temperature cycle and circulation of Mediterranean water by Bunker (1972). The annual cycle of the thermal regime of the Mediterranean on different points of the Algerian province was studied by Bethoux *et al.* (1976). Bethoux (1977) studied the thermal rxegime and the budgets of the Mediterranean Sea.

The aim of the present work is to study the components of the heat budget for the Mediterranean Sea. These components are: the solar radiation, the effective radiation, the conduction heat exchange and the evaporation were calculated using Timoviv's equations.

MATERIALS AND METHODS

The available monthly mean values of the meteorological elements over the Mediterranean Sea are not great. Therefore 26 points were selected only to cover the area of investigation (Fig. 1). At each point, the meteorological elements namely, sea surface temperature, air temperature, wind speed and direction, absolute and saturate value of humidity and the amount of cloudiness were taken from the Atlas of the Atlantic Ocean (1977). The altitude of the sun was calculated using the Oceanographic tables (Z o b o v, 1957).

The components of the heat budget for the Meditterranean Sea were calculated using Timoviv's equations (1970—1983).

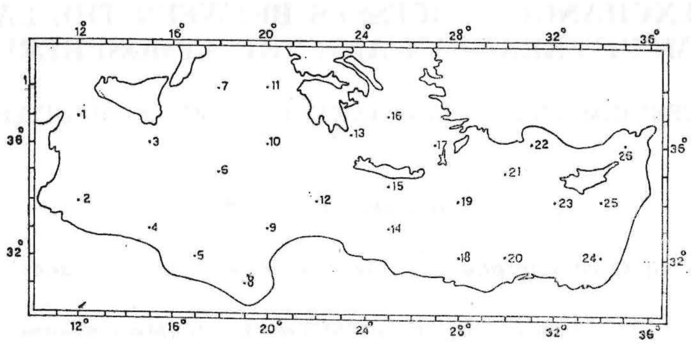

Fig. 1. Area of investigations

These equations were applied for calculating the components of the radiation balance, because the empirical parameters which exist in the equations were determined depending on the actinometric measurements and the observations of the amount of cloudiness were measured on the sea. Therefore Timoviv's method is suitable in this case in the calculation of the components of the radiation balance.

The components of the heat loss through the sea surface i.e. evaporation and conduction heat exchange were also calculated using Timoviv's equations. These equations are given as the following:

The daily integral of total solar radiation is given by

$$Q_n = \gamma Q [1 + \zeta_1 + \zeta_2 (0.25 n + 0.75 n^2)] \quad (1)$$

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

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

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

$\varnothing$ — Latitude, hr-altitude of the sun at midday.

The albedo of the sea surface is given by

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

The calculation of the effective radiation taking into consideration the effect of cloudiness and the vertical distribution of temperature and humidity

$$E_n = 1.10 \sqrt{\gamma^5}\, \delta \alpha\, \overline{T_a}^{-4} (0.39 - 0.0502 \sqrt{\bar{e}}) + \{1.06 [1-(1-\mu)]^{0.54} +$$

$$+ \overline{\Delta\nu\,(\Delta n)} + \frac{4\,(\overline{t_w - t_a})}{T_a \sqrt{\gamma^5}\,(0.39 - 0.0502\,\sqrt{\bar{e}})}\} \quad (3)$$

where t_w, t_a are the temperature of surface water and the air

T_a^4 — absolute air temperature = 273 + ta

e — absolute air humidity δ — constant = 0.90

σ — constant $= 0.567 \times 10^{-10}$ 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.

$$\mu = \frac{Q_n}{\gamma Q}$$

The heat exchange from equation (4)

$$\overline{P} = -0.212\,(\overline{t_w - t_a}) \cdot V \quad (4)$$

and the heat loss due to the evaporation is given from equation (5)

$$\overline{LE} = -0.326\,(\overline{e_o - e}) \cdot V \quad (5)$$

where V — wind speed

e_o — saturation vapour pressure at the temperature of the sea surface.

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

The calculated heat budget from equations (1—5) are the daily amount in MJ/m^2. This amount was converted to kcal/cm^2. In order to obtain the amount of heat budget in a month, it should be multiplied by N, where N is the number of days in a month.

RESULTS AND DISCUSSION

The considerable fluctuation of the yearly heat budget is dependent mainly on the colponents of the heat budget which are the solar radiation, the evaporation, the conductive heat exchange and the effective radiation. From the calculations, the amount of heat loss through the sea surface due to the effective radiation is not more than —4.6 — —6.5 kcal cm^2/month. While due to the conductive heat exchange it is not more than —1 kcal/cm^2/month. From the calculations, the amount of heat loss through the sea surface due of the sun radiation. The heat loss in this month varies between — 5 and — 7 due to the conductive heat exchange it is not more than —1 kcal/cm^2/month. Hence evaporation is the main component which affects the fluctuations of the heat budget from month to month and from season to season when comparing with the other components. Table 1. indicates the quantity of the heat loss through the sea surface due to the evaporation at 10 points. These points were selected in different regions of the Mediterranean Sea. The maximum amount of heat loss through the sea surface due to the evaporation is observed in the north-eastern part of the Levantine Sea. The minimum amount of evaporation is observed in April—May, whale the maximum amount is in October—January.

Table 1. The heat loss from the sea surface due to the evaporation in kcal/cm²/month

Month Coordinate N.	E.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
38°	18°	— 9,35	— 6,79	— 4,95	—4,10	—4,70	—6,58	— 7.72	— 6.84	— 5.32	—10.71	—11.91	—11.54	— 95.51
36°	15°	—10,04	— 7,06	— 4,55	—6,02	—4,87	—4,51	— 6.07	— 6.33	— 7.23	— 9.31	—11.57	—10.65	— 88.21
36°	20°	—11,91	— 8,36	— 5,55	—5,09	—4,12	—4,43	— 7.04	— 6.96	— 7.21	— 8.39	—12.40	—11.89	— 93.35
35°	25°	—13,18	—13,72	—10,28	—5,24	—4,39	—6,58	— 7.22	— 8.73	— 7.64	— 8.85	—12.93	—12.17	—110.93
35°	30°	—10,25	— 9,90	— 8,49	—6,97	—6,13	—8,46	—11.77	—11.32	— 9.10	— 7.66	— 9.67	—10.46	—110.18
34°	34°	— 8,10	— 8,10	— 7,41	—5,63	—6,25	—8,86	—12.17	—11.64	—10.10	— 8.31	— 8.27	— 8.99	—103.83
33°	15°	— 9,92	— 8,29	— 7,41	—6,94	—4,12	—4,07	— 6.77	— 6.11	—10.15	—12.52	—14.15	—12.36	—102.81
33°	20°	—10,22	— 9,03	— 8,31	—5,79	—3,14	—3,71	— 6.58	— 6.89	—10.42	—13.52	—13.86	—13.21	—104.68
33°	25°	— 9,33	—11,06	— 9,93	—6,77	—4,28	—4,62	— 7.34	— 8.70	— 9.31	—11.11	—11.29	—12.92	—106.66
32°	30°	— 9,54	—10,41	— 8,26	—6,34	—5,31	—6,94	— 9.20	— 9.42	— 8.71	— 8.49	—11.14	—10.65	—104.71

The net results of these processes constitute heat loss through the sea surface to the atmosphere or heat gain. In January the heat loss through the sea surface to the atmosphere due to the evaporation, the conductive heat exchange and the effective radiation exceeds the heat gain from the sun. It varies between —9 and —18 kcal/cm^2/month. In the Levantine Sea it increases northward from —9 to —14 kcal/cm^2/month, and from —10 to —13 kcal/cm^2/ /month in the central basin of the Mediterranean Sea. The maximum amount of heat loss through the sea surface reaches —16 — —18 kcal/cm^2/month in the Aegean Sea (Fig. 2). These amounts of heat decrease in February (Fig. 3), due to the decrease in the difference between the water and the air temperature and to the increase of the altitude of the sun and the daily amount of the sun radiation. The heat loss in this month varies betwen —5 and —7 kcal/cm^2/month and —5 and —10 kcal/cm^2/month in the central and eastern Mediterranean respectively. This amount increases northward to reach —12 kcal/cm^2/month (Fig. 3).

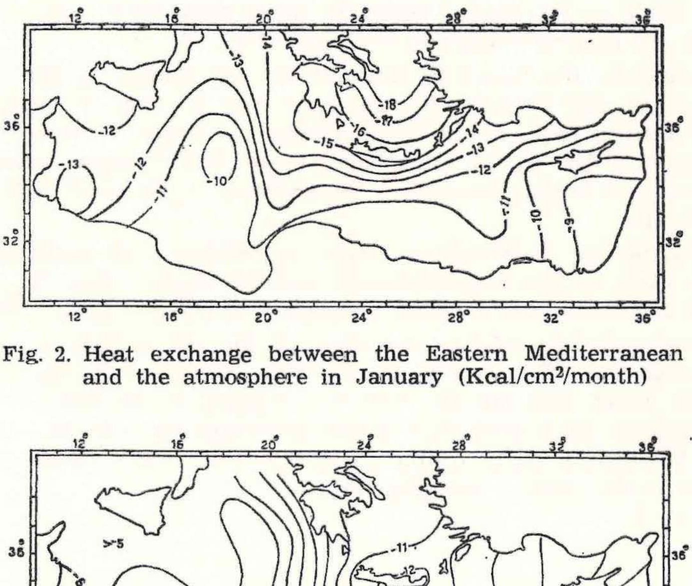

Fig. 2. Heat exchange between the Eastern Mediterranean and the atmosphere in January (Kcal/cm^2/month)

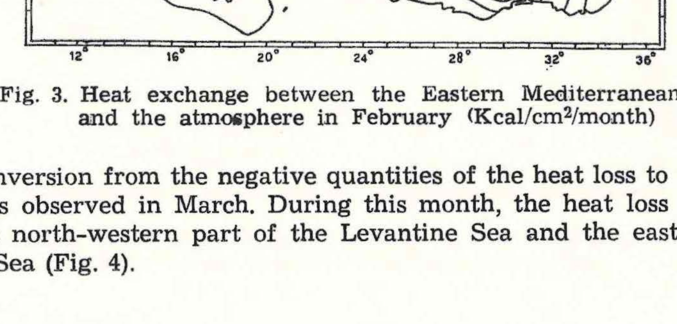

Fig. 3. Heat exchange between the Eastern Mediterranean and the atmosphere in February (Kcal/cm^2/month)

The conversion from the negative quantities of the heat loss to the positive quantities is observed in March. During this month, the heat loss is observed only in the north-western part of the Levantine Sea and the eastern part of the Agean Sea (Fig. 4).

During April, the heat gain from the sun exceeds heat loss through the sea surface. It varies from +5 to +7 kcal/cm^2/month in the eastern basin of the Mediterranean Sea, from +6 to +8 kcal/cm^2/month in the central basin and more than +8 kcal/cm^2/month is observed in the central part of the investigated area (Fig. 5).

The maximum quantities of the heat gain from the sun are observed in May and June (Fig. 6 and 7). These quantities increase westward from + 9 kcal/ /cm^2/month in the eastern Mediterranean to +14 kcal/cm^2/month.

From July, the heat gain from the sun starts to decrease. It varies from +7 to 13 kcal/cm^2/month and from +12 to 12.8 kcal/cm^2/month in the eastern and central basins of the Mediterranean Sea respectively (Fig. 8). This decrease in the heat gain is observed also in August (Fig. 9). From this figure, the heat gain increases from east to west from +5 to > +10 kcal/cm^2/month.

The minimum amount of heat gain from the sun is observed in September. It varies from + 2 to + 3 kcal/cm^2/month in the eastern basin of the Mediterranean. While in the central basin, it varies from > 1.0 kcal/cm^2/month in the south to +6 kcal/cm^2/month in the north (Fig. 10).

From October, the heat loss through the sea surface to the atmosphere starts to increase and exceeds the heat gain from the sun. Fig. (11), indicates that, in the central basin of the Mediterranean it varies between —3 and —7 kcal/cm^2/month. While in the Levantine Sea the heat budget varies from —4 in the west to +3 kcal/cm^2/month in the extreme of the south-eastern part of the sea (Fig. 11).

The heat budget in November (Fig. 12) reaches —13 kcal/cm^2/month in the central basin of the Mediterranean and the Agean Seas. In the central basin of the Levantine Sea it varies between —12 and —5 kcal/cm^2/month.

The great quantities of heat loss through the sea surface are observed in December (Fig. 13). This is due to the high diference in the temperature between the water and the air. The heat budget varies from —10 to —11 kcal/cm^2/month in the eastern part of the Levantine sea, —14 to —15 kcal/cm^2/ /month in the central basin of the Mediterranean, and —19 kcal/cm^2/month in the center of the Aegean Sea (Fig. 13).

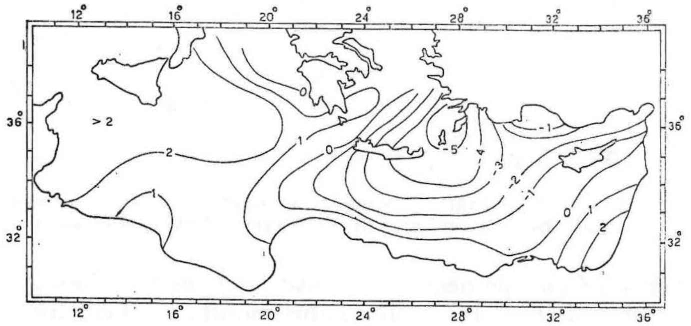

Fig. 4. Heat exchange between the Eastern Mditerranean and the atmosphere in March (Kcal/cm^2/month)

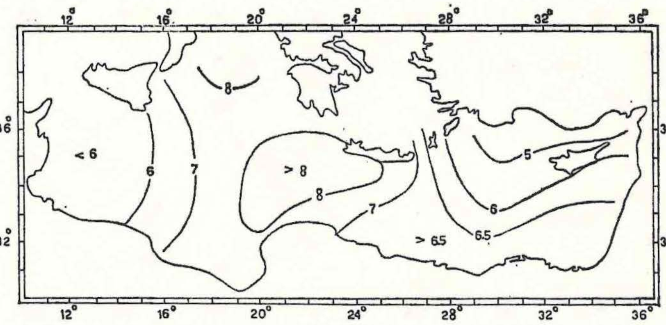

Fig. 5. Heat exchange between the Eastern Mediterranean and the atmosphere in April (Kcal/cm²/month)

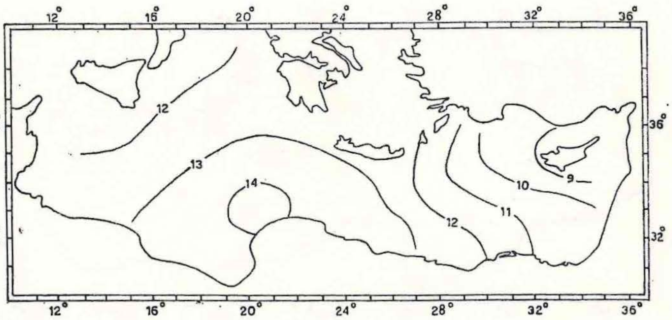

Fig. 6. Heat exchange between the Eastern Mediterranean and the atmosphere in May (Kcal/cm²/month)

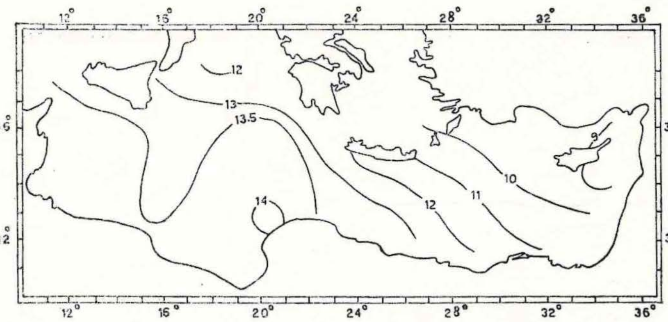

Fig. 7. Heat exchange between the Eastern Mediterranean and the atmosphere in June (Kcal/cm²/month)

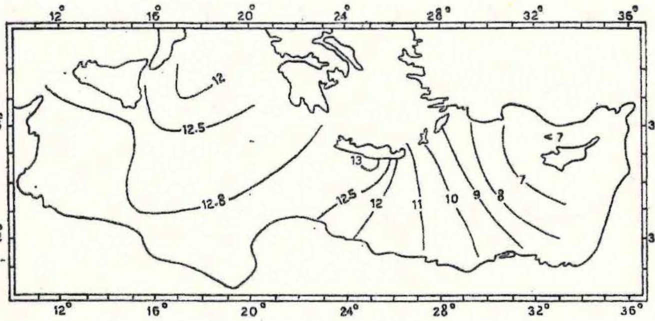

Fig. 8. Heat exchange between the Eastern Mediterranean and the atmosphere in July (Kcal/cm^2/month)

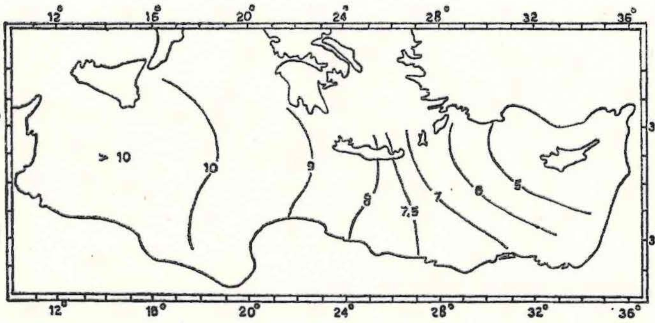

Fig. 9. Heat exchange between the Eastern Mediterranean and the atmosphere in August (Kcal/cm^2/month)

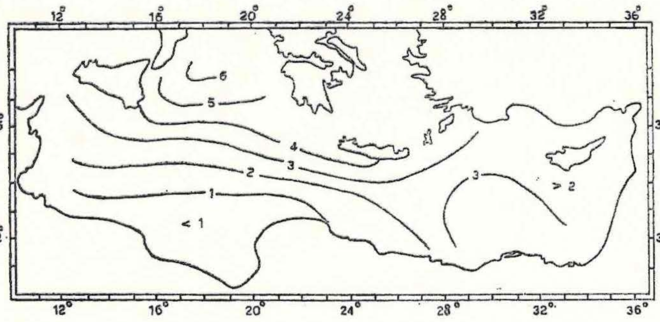

Fig. 10. Heat exchange between the Eastern Mediterranean and the atmosphere in September (Kcal/cm^2/month)

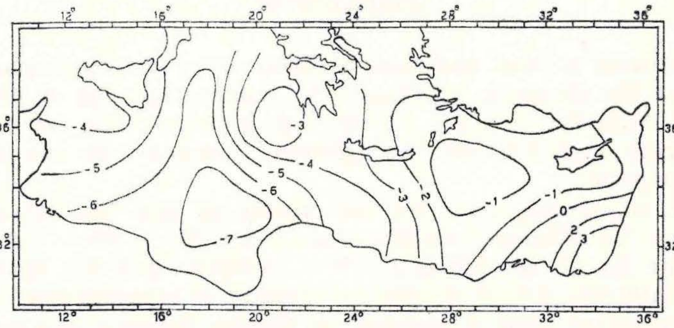

Fig. 11. Heat exchange between the Eastern Mediterranean and the atmosphere in October (Kcal/cm²/month)

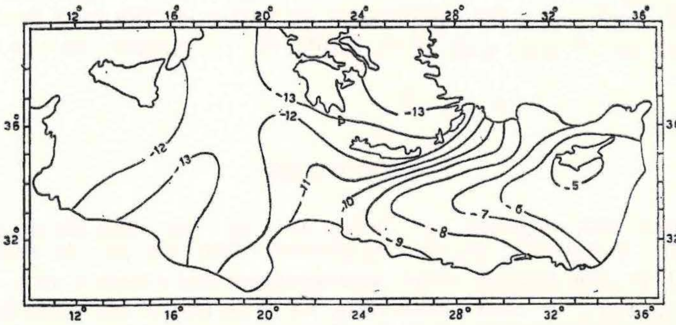

Fig. 12. Heat exchange between the Eastern Mediterranean and the atmosphere in November (Kcal/cm²/month)

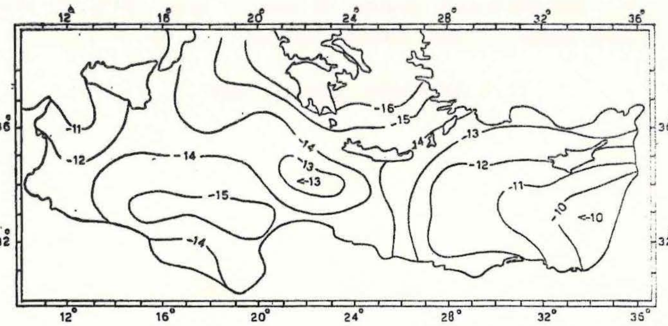

Fig. 13. Heat exchange between the Eastern Mediterranean and the atmosphere in December (Kcal/cm²/month)

CONCLUSION

The processes of heat exchange between water and atmosphere mainly take place at the air-water interface. The monthly net loss or gain of heat by the Mediterranean Sea due to the solar radiation, the evaporation, the conductive heat exchange and the effective radiation was calculated using Timoviv's equations.

The calculations indicated that, the amount of heat loss through the sea surface due to the effective radiation is not more than —4.6 — —6.5 kcal/cm^2/ /month. While due to the conductive heat exchange it is not more than —1 kcal/cm^2/month. The maximum amount of heat loss is due to the evaporation, where its maximum value is observed in October-January and its minimum value is in April—May (Table 1).

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). The maximum amount of heat loss is observed in December and January due to the increase in the difference in temperature between the water and the air.

The heat gain from the sun exceeds the heat loss through the sea surface from April to September. The maximum quantities of the heat gain from the sun are observed in May and June, while the minimum amount is in September.

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PROCESI IZMJENE TOPLINE IZMEĐU ISTOČNOG MEDITERANA I ATMOSFERE

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KRATKI SADRŽAJ

U radu je računat toplinski budžet Mediterana na temelju Timovivovih jednadžbi. Maksimalni gubitak toplote posljedica je evaporacije čiji je maksimum u Oktobru—Januaru i minimum u Aprilu—Maju. Dovod toplote sunčevim zračenjem veći je od odvoda toplote u razdoblju od Aprila do Septembra.