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# HORIZONTAL CIRCULATION OF THE EASTERN MEDITERRANEAN WATERS DURING WINTER AND SUMMER SEASONS

## HORIZONTALNA CIRKULACIJA VODA ISTOČNOG SREDOZEMLJA TIJEKOM ZIME I LJETA

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The water circulation of the Eastern Mediterranean was computed using the dynamic method. The reference level was taken at the 1000 db surface. The fulfilment calculations evidenced the considerable stabillity of the geostrophic water circulation in the eastern and central basins of the Mediterranean Sea. The most pronounced features of the geostrophic circulation during the winter and summer seasons were: the vast cyclonic gyre in the Levantine Sea, enveloping the southern part of the Aegean Sea; the cyclonic gyre in the Ionian Sea; and the anti-cyclonic gyre in the Libyan Sea and near the Egyptian coast.

The geostrophic current velocity varied between 5—10 cm/sec in Libyan Sea, 15—25 cm/sec near the Egyptian coast and between 35—40 cm/sec in the eastern part of the Levantine Sea. At the strait of Crete island, in reached 15—30 cm/sec. The differences between the winter and summer surface current velocity in the eastern and central basins of the Mediterranean Sea were not particularly pronounced.

## INTRODUCTION

The shortage of direct current measurments for the Mediterranean Sea has lead to the development of indirect methods; by constructing T-S diagrams, and sections of horizontal and vertical distributions of some physical and chemical properties of sea water such as salinity, temperature and oxygen (Nielsen, 1912; Lacombe and Tchernia, 1958, 1960; Miller, 1963; Moskalenko and Ovchinnikov, 1965); by the so-called core method of Wűst (1960, 1961).

The first modelling study carried out to describe the seasonal circulation of the Mediterranean Sea were the detailed dynamical computations by Ovchinnikov and Fedoseyev (1965), implemented by Ovchinnikov (1966, 1976) to include further data from non-Russian cruises. He constructed the charts of geostrophic currents for winter and summer, at 100, 200, 500 m levels relative to the 1000 db surface taken as the level-of-no-motion. The justification for the choice of this reference level lies in the observed slight spatial variations of the hydrographic properties at 1000 m depth below. Moskalenko (1974), studied the steady wind-driven circulation in the Eastern Mediterranean. His model was basically Stommel's model (1948) for the transport stream function, with bottom friction and on the $\beta$-plane, only extended to include variable topography. Gerges (1976, 1977) used Starkisian's (1966) diagnostic model to study the Mediterranean circulation for the winter season. He used the model on the $\beta$-plane, with the observed winter density distribution and wind field. The real bottom relief was used as the lower boundary in the computations and the effects of coasts nad islands were included. For completeness the paper by Dzhioyev and Drozdov (1977) is in fact a literal copy of the Gerges study in the Eastern Mediterranean (1976). Menzin and Moskalenko (1982), used the some approach used by Moskalenko (1974) for computing the circulation in the Eastern Mediterranean. Only here they neglected any interior density stratification. Thus their ocean was homogeneous, on the f-plane and with variable depth.

Because the phenomenological and theoretical knowledge of the Eastern Mediterranean are very poorly known compared to other interesting regions of the world's oceans, the UNESCO and IOC adopted a favorable attitude toward the POEM program in December 1982. The data collected during the first two POEM coordinated cruises in the Levantine Basin have been analysed and interpreted. Water circulation in terms of the dynamic height relative to 800 db was computed. Details of these results are given in Malanotte-Rizzoli and Hecht (1988); Brenner (1988) and Ozsoy *et al.* (1988).

For the last two decades the hydrographic observations in the Eastern Mediterranean have been increased. Therefore, the aim of the present work is to: construct the water circulation maps using the more recent observations; compare them with the previous works taken from the literature; determine the degree of stability (or changeability) of the water circulation; and define the more accurate details of the current system in the central and eastern basins of the Mediterranean Sea and also in the Aegean Sea (Fig. 1).

## MATERIALS AND METHODS

The used data were collected from several expeditions carried out by different countries during the last 20 years (1963—1982). Water temperature and salinity were taken from 680 hydrographic stations in the winter, and from 658 stations in the summer (obtained from the Hydrographic Data Centre B, Moscow). The winter was represented by the data collected du-

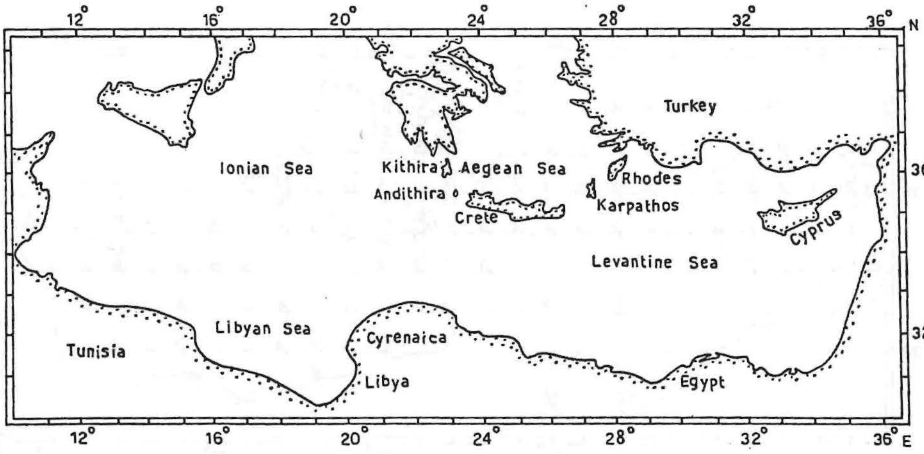


Fig. 1. The Eastern Mediterranean Sea

ring the period from 15 January to 31 March, while the summer was determined by the period from 15 July to 30 September. Vertically unstable stations were either corrected for temperature or salinity or rejected if many levels of instability were observed.

The average values of temperature and salinity of these collected data were computed, using the optimum interpolation of the correlation algorithm, at stations distributed in a regular net for winter and summer seasons as shown in Figs. 2 and 3. Therefore, the estimate of errors, the choice of the optimum selection of the gride size of the net in different regions of the investigated area as well as the finding of the spatial correlation functions of temperature and salinity have been determined (for details refer to S a i d, 1984a).

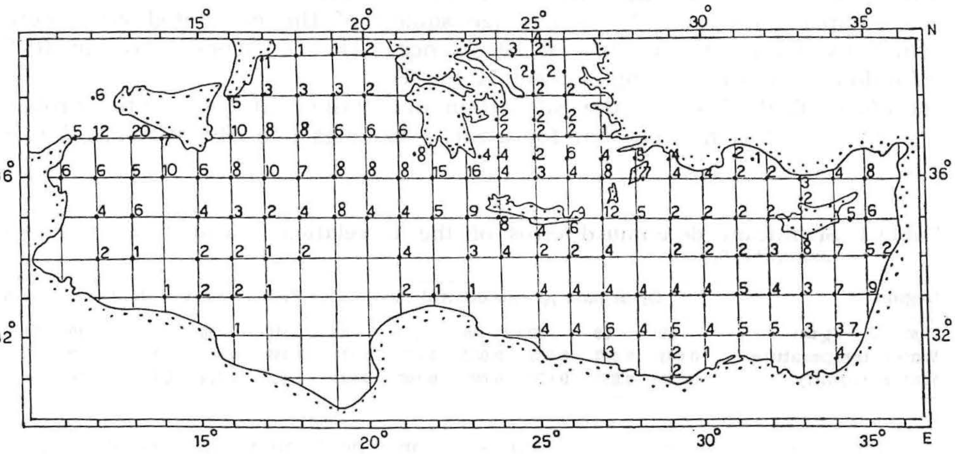


Fig. 2. The number of stations by which the average temperature and salinity were calculated at points distributed in regular net in the summer

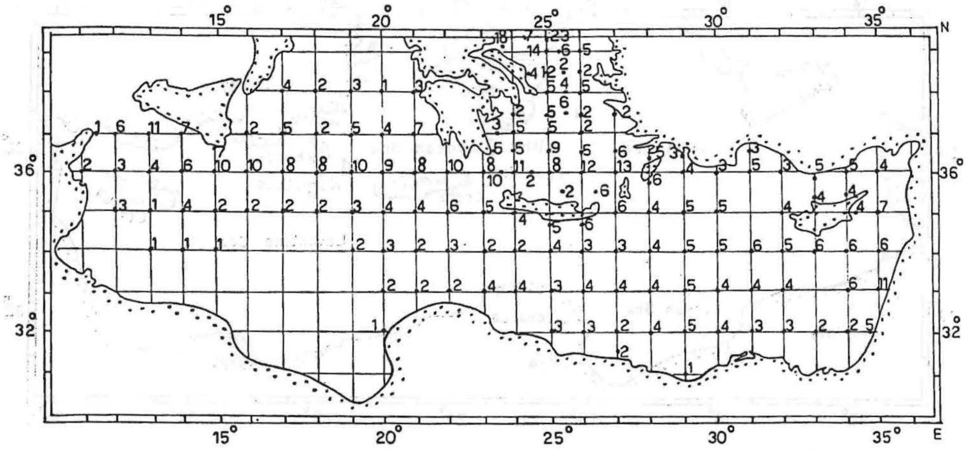


Fig. 3. The number of stations by which the average temperature and salinity were calculated at points distributed in regular net in the winter

One source of errors arised from the limited number of selection necessary for the calculations of the significant correlation functions to distinct the best among the spacing gradations. Then the probability of the maximum errors in determining the significant correlation functions or the degree of confidence in those readings of errors would not turn out, was calculated according to the normal low:

$$\text{Probability } (|R - R_1|) < \lambda = \delta = \varphi \frac{\lambda}{\delta_R \sqrt{2}}$$

where $R_1$ is the truly significant correlation function of calculated value R, $\varphi$ — Laplace function, $\delta_R$ — average square of the calculated error determined by $\lambda$ and the number of occurrences. The confidence level in R for a random error $\lambda$ is varying between $R + \lambda$, $R - \lambda$
therefore, Table 1 shows the calculation of obtained at confidential probability $\delta = 0.9$. It is noticed that for a large spacings i. e. $R < 0.3$—$0.2$, $\lambda$ exceeds 0.1.

Table 1. Significant determined erros of the correlation functions at confidental probality 0.9

| Region | Open part of the central basin | | | | | | Eastern part of the Levantine See | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Distance (km) | 10 | 20 | 30 | 40 | 60 | 80 | 10 | 20 | 30 | 40 | 60 | 80 |
| Water temperature | 0.024 | 0.043 | 0.065 | 0.082 | 0.098 | 0.115 | 0.049 | 0.098 | 0.131 | 0.159 | — | — |
| Water salinity | 0.049 | 0.063 | 0.076 | 0.095 | 0.102 | 0.124 | 0.082 | 0.114 | 0.147 | 0.164 | — | — |

The second source of errors arised from the time variations of measurements between the significant centre of correlation and the other points lying on the circumference of the circle having this centre. Fortunately, these time variations do not change correlation moments, corresponding to different spacings from the correlation centre and do not overstate the dispersion as any accidental error.

Conclusively, the statistical treatment showed that significant correlation functions are slowly decreasing with increasing radius of correlation within the range of 100—130 km corresponding to side length of one degree (Fig. 4) for the open regions in the central and eastern basins of the Mediterranean Sea, while it decreases only to 50—60 km corresponding to a side length of

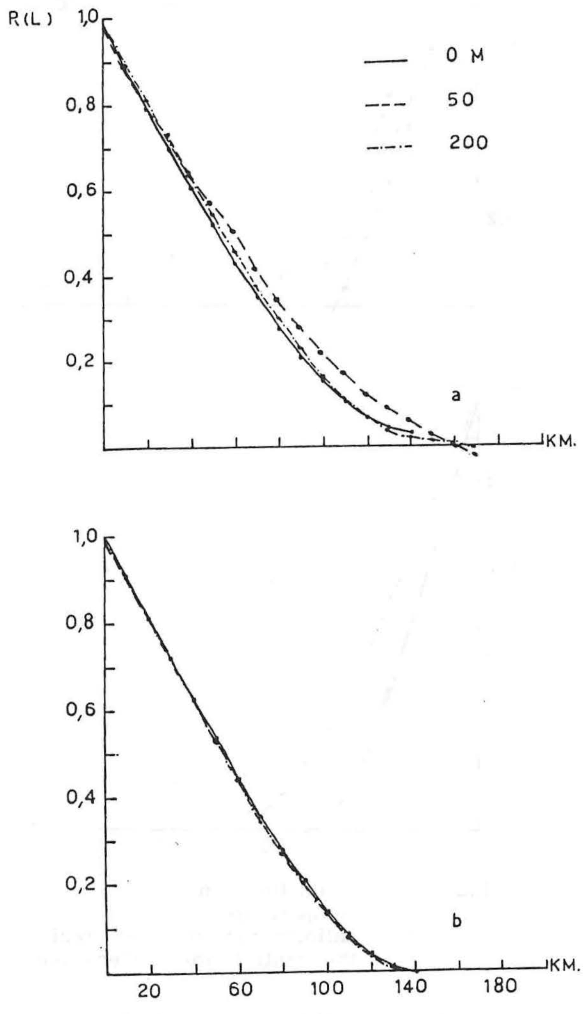


Fig. 4. Corelation functions:
a — temperature;
b — salinity for the eastern part of the Levantine Sea

a half degree (Fig. 5) in the eastern part of the Levantine Sea. For shallow regions, the radius of correlation is not more than 40 km, which have a complicated bottom relief.

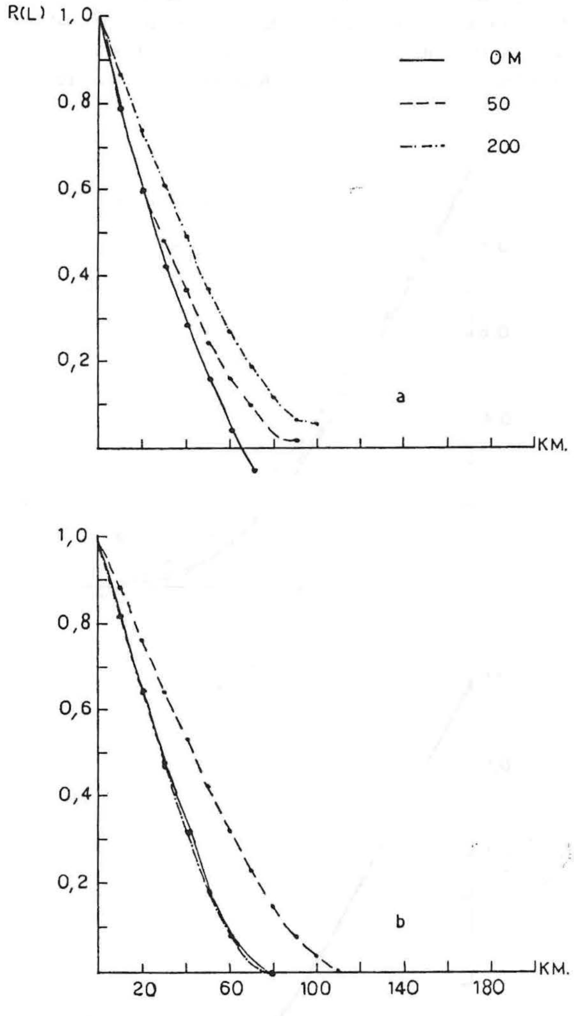


Fig. 5. Corelation functions:
a — temperature
b — salinity for the open regions of the central and eastern basins

As a result, the water temperature and salinity were averaged in a regular net one degree latitude by one degree longitude in the open regions. In the regions of complicated structures, the averages were made at half degree latitude by a half degree longitude.

The obtained averages of water temperature and salinity were used for computing the dynamic heights. The reference level was taken at the 1000 db surface. Selection of the reference surface at a depth of 1000 db, where in general there is still a nonstationary current, does not apparently introduce significant errors into the average current diagrams obtained. Irregularity in the distribution of density affecting current velocity is restericted to the 0—1000 m layer, since below 1000 m the horizontal density gradients of Mediterranean water are normaly very weak (Ovchinnikov, 1966).

## RESULTS AND DISCUSSION

The fulfilment calculations evidenced the considerable stability of the geostrophic circulation of the Eastern Mediterranean Sea. Figs. 6 and 7 illustrate the dynamic relief of the free sea surface for winter and summer seasons. At these maps, the lines of equal dynamic heights were constructed trough 50 dyn. mm. for the surface layers and through 20 dyn. mm. for the 300 db surfaces. The first figures (were the same for the whole area) were refused and we constructed the maps depending on the last figures, which illustrated the dynamic relief variations at each isobaric surface. From figs. 6 and 7, the most pronounced features of the geostrophic circulation in the central and eastern basins of the Mediterranean Sea during the both seasons are: the vast cyclonic gyre in the Levantine Sea, enveloping the southern part of the Aegean Sea; the cyclonic gyre in the Ionian Sea; and the anticyclonic gyre in the Libyan Sea. In the winter season, the cyclonic gyres are well-defined, better than those in the summer. This is, may be, due to the circulation of the atmospheric cyclones over the Mediterranean Sea present mainly in the wanter.

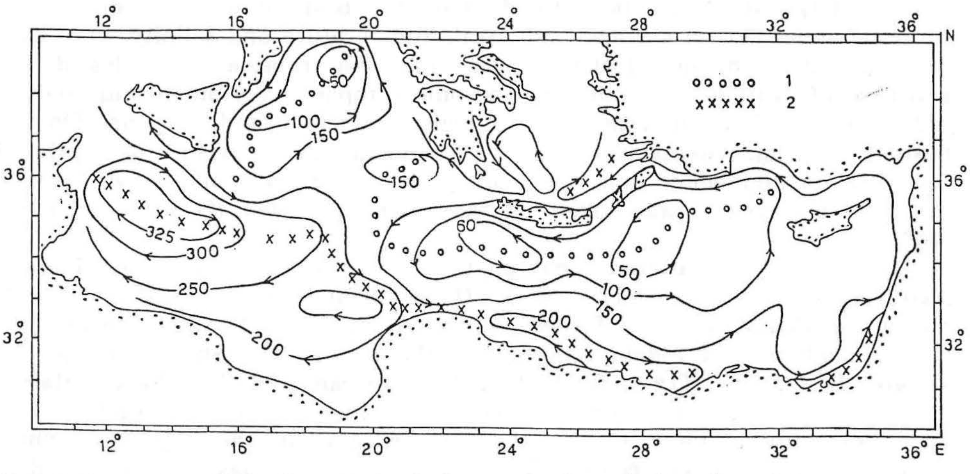


Fig. 6. Dynamic relief (dyn. mm) of the sea surface during the winter season.
1 — depression
2 — crest of the dynamic relief

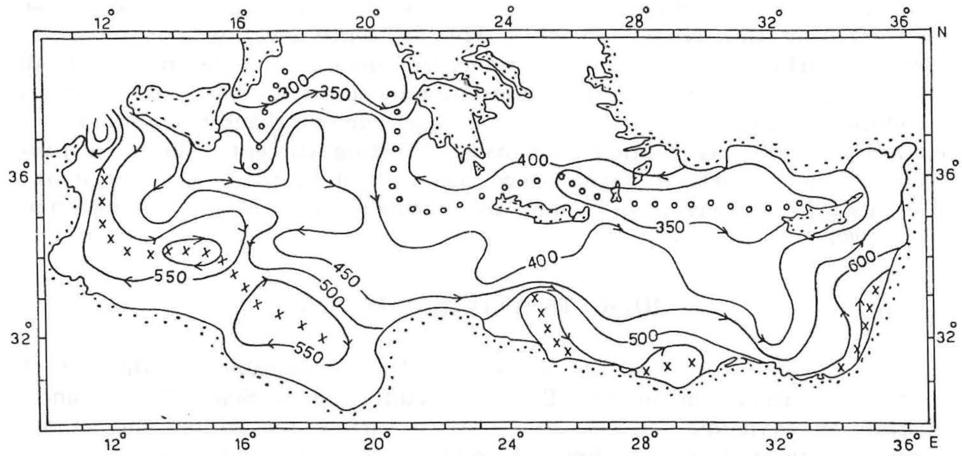


Fig. 7. Dynamic relief (dyn. mm) of the sea surface during the summer season

These main features of the dynamic relief were also observed Ovchinnikov (1966 & 1976) and during the POEM Research Project (Malanotte-Rizzoli and Hecht, 1988; Brenner, 1988 and Ozsoy *et al.*, 1988) and the stability of the Mediterranean water circulation tested trough long standing survey. In Ovchinnikov's work, charts of geostrophic currents have been constructed for the winter (January, February & March) and summer (July, August & September) by evaluating all available information on the hydrology of the sea. Dynamic calculations were made on the basis of mean seasonal long-term temperature and salinity values for trapezia of one degree of longitude by one degree of latitude. The records of most expeditions during the last fifty years have been included in the averaging. Gaps of large area have been filled in on the basis of a few hydrographic surveys carried out in October and April. Temperature and salinity were averaged and the dynamic calculations were made for trapezia with sides of half a degree of latitude and longitude in some comparatively small and shallow regions of the Mediterranean and in regions where islands abound. On the basis of the slight spatial variations of hydrologic characteristics at depths of 750—1000 m and below, and the inadequacy of observations below 1000 m, the 1000 db surface was taken as the reference level (Ovchinnikov, 1966).

In contrast to the traditional picture of the circulation in the Eastern Mediterranean by Ovchinnikov (1966, 1976) and the results obtained durnig the POEM Research Project which are based on the objective analysis of the combined CTD data collected by the Israeli R/V Shikmona and the Turkish R/V Bilim (Ozsoy *et al.*, 1988), one can find that the circulation is actually composed of several sub-basin scale gyres with an energetic mesoscale field superimposed. One is the cyclonic gyre in the northwest which consists of three smaller centres. This overall structure has been observed in the past and named the Rhodes gyre. The second subbasin system is an anticyclonic gyre in the southeast which is also composed of three smaller centres. Of these three centres, the one closest to Cyprus appears to be a quasi-permanent feature which first appeared in early 1983 and has been called the Cyprus high by Brenner (1988). There is also an intensive anticyclone in the southwest whose size places it between sub-basin scale and mesoscale. This anticyclone has been called the Egyptian anticyclonic gyre by Said (1984b), the Mersa Matruh gyre by Ozsoy *et al.* (1988) and the Egypt high by Brenner (1988).

Comparing Ovchinnikov's map (Fig. 8) with the results of the present work, one can find that:

Firstly, the anticyclonic gyre in the Libyan Sea in the present work is greater than that described by Ovchinnikov. At the southern outlying area, the North-African current carries the Atlantic water to the east and returns it back towards the Gulf of Tunis. A part of this water enters the Levantine cyclonic gyre. The directions of these isolines of the dynamic relief are perfectly corresponding to the isohalin forms in the southern half of the central basin, which slightly differ from the corresponding isohaline forms obtained by Ovchinnikov (1976). In the middle part of the central basin, the isohalines bent eastward forming a tongue of low salinity. At longitude 10°—21° E, they acquire the meridianal direction. In the southern part of the Levantine Sea, the isohalines bent, on the contrary, to the west forming a weakly tongue of high salinity.

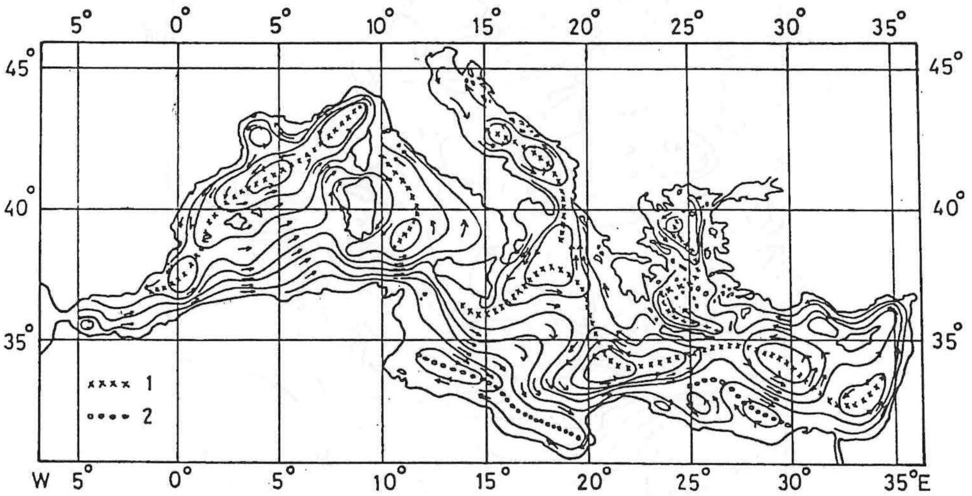


Fig. 8. Geostrophic components of the Mediterranean currents at the surface in winter (after Ovtchinnikov, 1966, 1976)
1 — divergences
2 — convergences

Secondly, the circulation of the Levantine cyclonic gyre (Figs. 6 and 7) is much more definite than that observed by Ovchinnikov and Fedoseyev (1965) and Ovchinnikov (1966, 1976). This gyre covers the whole eastern basin and partly moves to the central basin. Its western segment at about longitude 20°E. The northern part of the gyre moves from east to west at north and south of Crete, i. e. it covers the southern part of the Cretan basin of the Aegean Sea.

North of Crete, there exists a crest of the dynamic relief, dividing the cyclonic gyre of the southern part of the Aegean Sea from the Levantine one. A line of convergence is passing through the crest's axis.

This crest was absent in the previous works, but is clearly observed in the present work, due to: i — the significant increase in the number of the hydro-

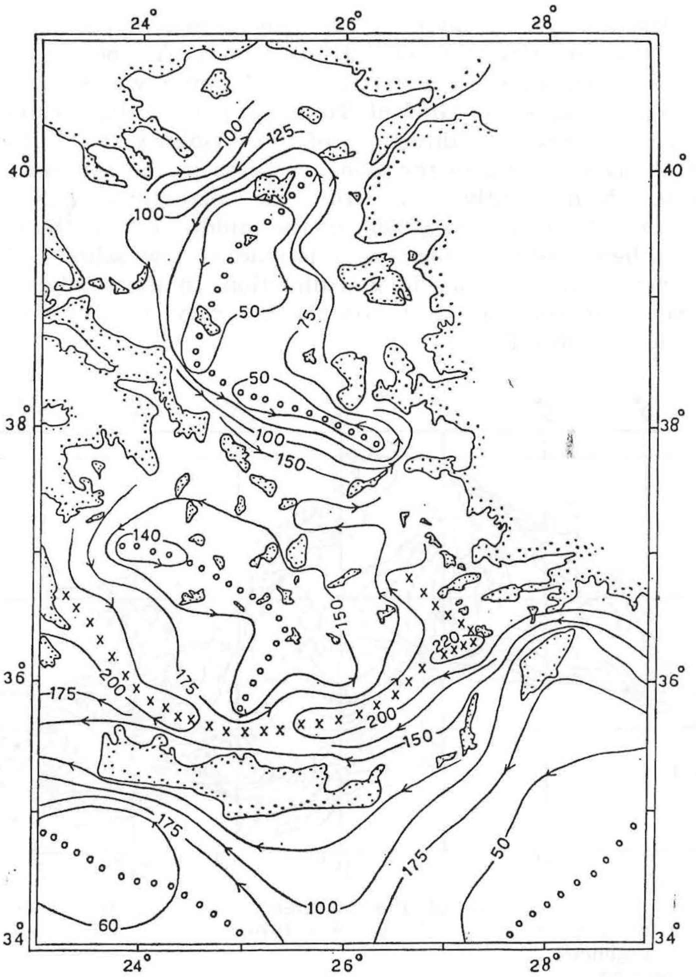


Fig. 9. Dynamic relief (dyn. mm) of the Aegean Sea surface during the winter season key: see Fig. 6

graphic stations which were carried out in this region by the Russian R/V Ykov Gakkel during the last years. Ü — may be, due to the method used for obtaining the average data in a regular net for the Aegean Sea. The dynamic relief at the free surface of the Aegean Sea in winter is shown in Fig. 9. The crest of the dynamic relief at about longitude 25°E is interrupted by a depression situated in the centre of the cyclonic gyre of the Cretan basin. Accordingly, the dynamic relief of the moving sea surface current along the northern outlying area of the Levantine Sea, is divided by the island arc into two branches. One of them, moves water south of Crete closing the gyre, and the other through Rhodes to the Aegean Sea. Waters of both the branches move westward along the outlying area of the crest. Water of the southern border of the crest continues its motion westward along Crete to the central basin through Andithria and Kithira islands. The northern border of this branch carries water from west to east and furter along the Turkish coast to the north, including in the cyclonic motion of the Aegean Sea water. Through Kassos and Karpathos islands the effective geostrophic motion will be small, since the differences in the dynamic heights through the straits arc very small (Fig. 9).

In the Aegean Sea, two large cyclonic gyres are observed in the southern and northern parts of the sea. These two gyres were described by other authors, but our observations for the last years have verified their configuration and allowed us to estimate the significant geostrophic currents.

Inside the general cyclonic gyre of the eastern basin of the Mediterranean Sea, two gyres are observed. These gyres are clearly identified at the 50 and 100 db surfaces maps (Figs. 10—13). One of them is settled in the central Levantine Sea, and the other is at the Cyrenaican Peninsula.

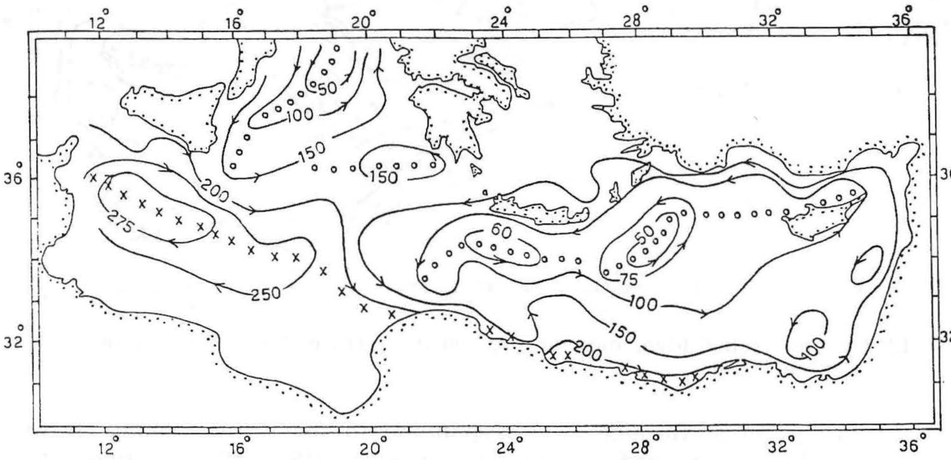


Fig. 10. Dynamic relief (dyn. mm) at the 50 db surface during the winter season key: see Fig. 6

In the southern part of the Levantine Sea, partly at the coast of Libiya and partly at the Egyptian coast, a small anticyclonic gyre is found. This could be called Egyptian anticyclonic gyre. In spite of the horizontal dimensions of the eddy, a crest is clearly observed along its axis, and a line of

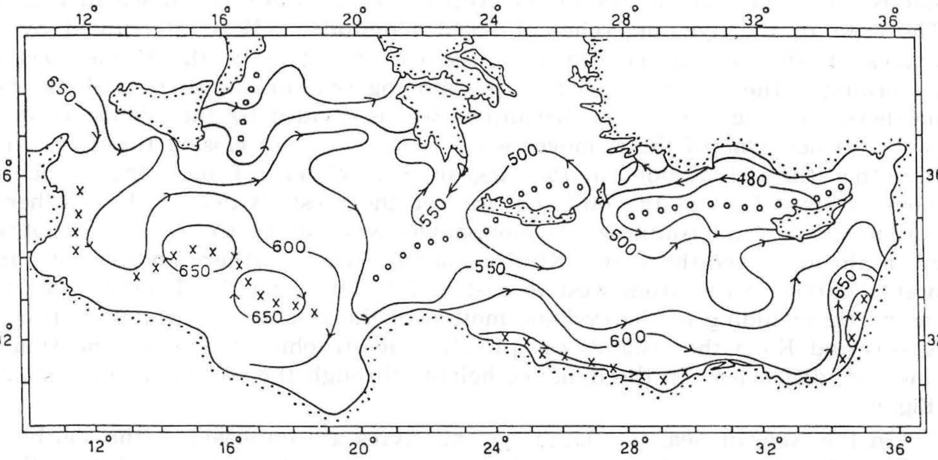


Fig. 11. Dynamic relief (dyn. mm) at the 50 db surface during the summer season key: see Fig. 6

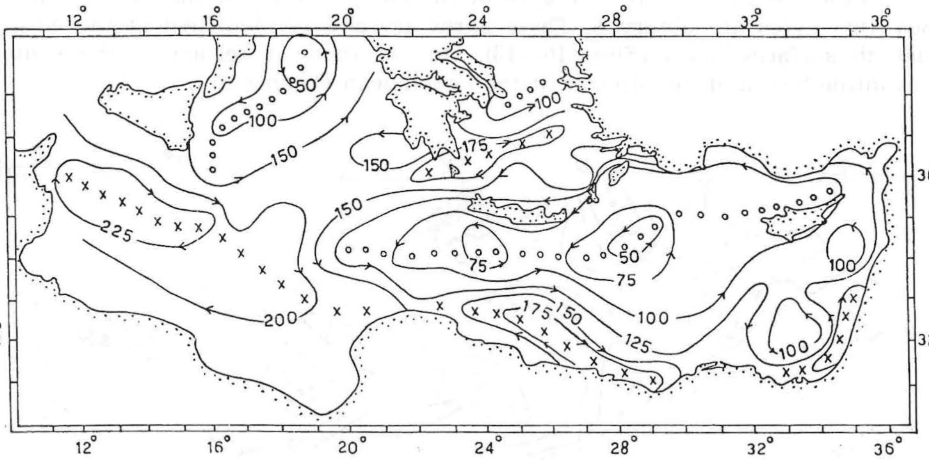


Fig. 12. Dynamic relief (dyn. mm) at the 100 db surface during the winter season key: see Fig. 6

convergence passing through it corresponding to the water sinking. It was also observed and described by Ovchinnikov (1966, 1976). Between this gyre and Crete, a depression of the dynamic relief corresponding to the cyclonic water motion.

The special features of the geostrophic water circulation in the central and eastern basins of the Mediterranean Sea are clearly reflected by the changes in the thickness of the upper homogeneous layer in the summer. In the summer season, due to the warming surface water, the density convection is absent and the mixing is approximately the same everywhere in the eastern

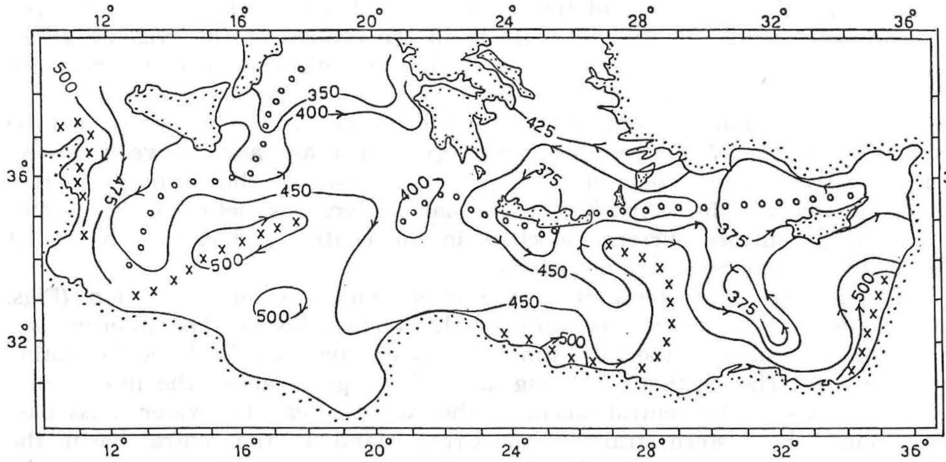

Fig. 13. Dynamic relief (dyn. mm) at the 100 db surface during the summer season key: see Fig. 6

part of the Mediterranean Sea, then the upper boundaries of the layer of the rapid change in temperature determine the current system. Fig. 14 illustrates the thickness of the therminal mixed layer in the summer season. The lines of equal thickness conform well with the lines of equal dynamic height. Along the crest of dynamic relief, the thickness of the upper isothermal layer is > 25 m, in the centres of the anticyclonic gyres in the southern part of the sea it is > 40 m and reaches 55 m in some places of the net. In some years, the thickness of the thermal layer was about 75 m in the centres of the anticyclonic gyres. This confirms the intensification of the circulation in these years.

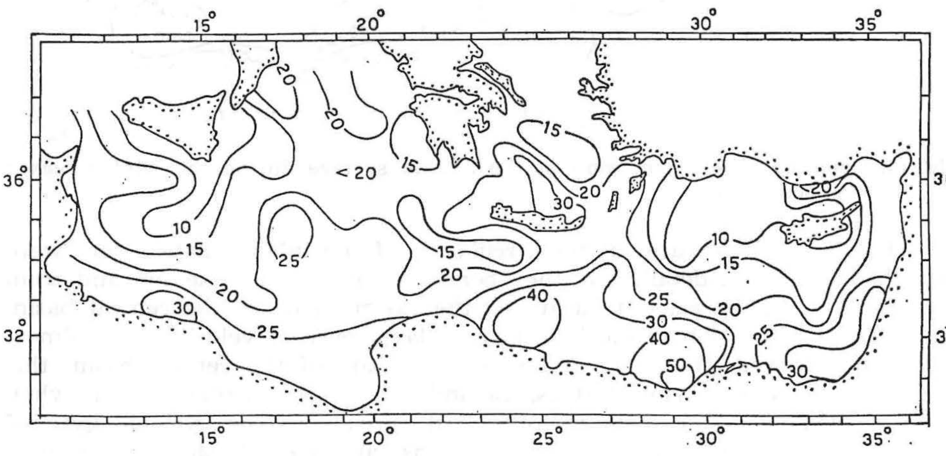

Fig. 14. Thickness of the thermal mixed layer (m) in the summer season

Through the depression of the dynamic relief, the thickness of the upper thermal layer is 10—15 m, and < 10 m in the centres of the cyclonic gyres. In these regions in some years, the layer of the rapid change in temperature startsdirectly from the sea surface.

The geostrophic current velocity varied between 5—10 cm/sec in the Libiyan Sea, 15—25 cm/sec near the Egyptian coast and between 35—40 cm/sec in the eastern part of the Levantine Sea. At the straits of Crete island, it reaches 15—30 cm/sec. Particular Differences between the winter and summer surface current velocities in the central and eastern basins of the Mediterranean Sea were not marked.

The general characteristics of the intermediate water circulation (Figs. 15 and 16) remain exactly as those of the surface layers. The intermediate water mass formed in the Levantine Sea, is involved in the large Levantine cyclonic gyre. The northern outlying area of the gyre carries the intermediate water mass to the central basin. In the Aegean Sea, this water mass passes through the eastern straits of the Crete island. In the central basin, the intermediate water is carried by the cyclonic gyre of the Ionian Sea to the north, while the Libyan anticyclonic gyre carries it westward to the Gulf of Tunis.

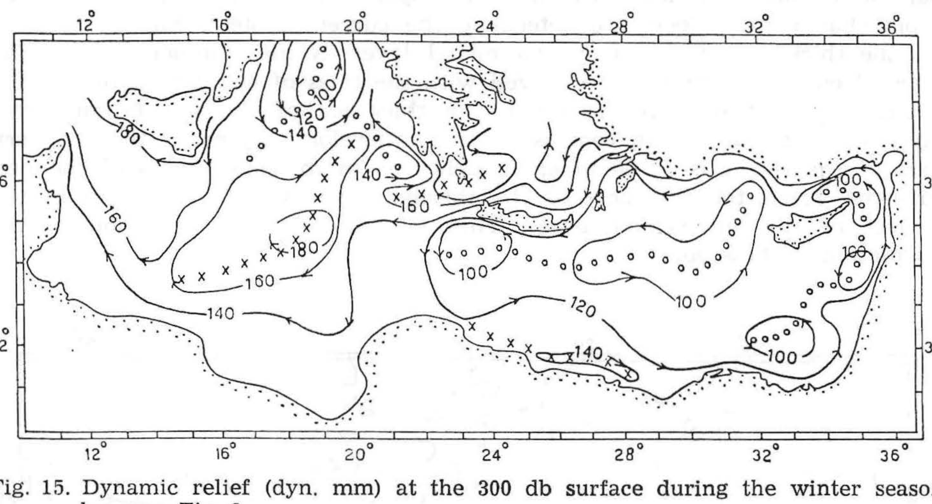


Fig. 15. Dynamic relief (dyn. mm) at the 300 db surface during the winter season key: see Fig. 6

These general features of the circulation of the intermediate layers were described earlier in detail, i. e. they persist from season to season and from year to year. In the eastern basin and the eastern part of the central basin, the seasonal distinction in the intermediate layer current velocities has almost not been observed. However, in the western part of the central basin, this distinction is well developed (Figs. 15 and 16). In the winter season, when the intermediate water mass is formed, it spreads in the cyclonic gyre of the eastern and partly to the central basins, arises significant density gradients between the eastern and western parts of the central basin, as a re-

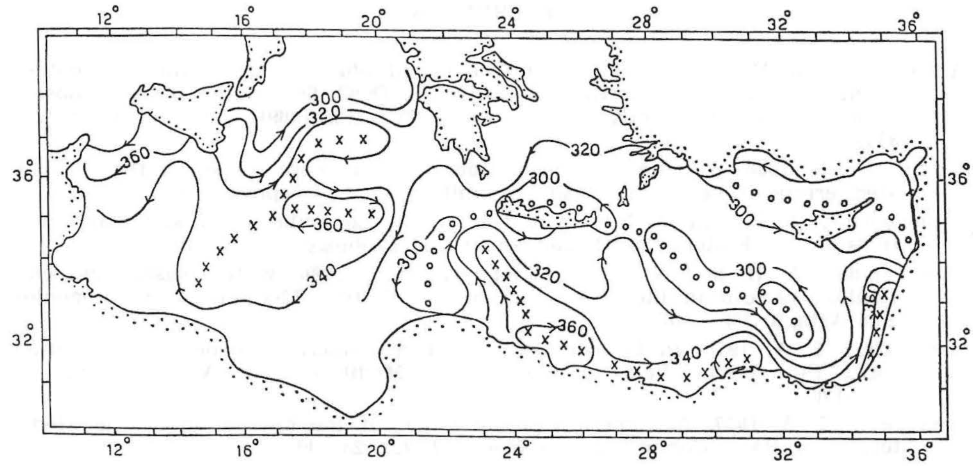

Fig. 16. Dynamic relief (dyn. mm) at the 300 db surface during the summer season key: see Fig. 6

sult the Levantine intermediate counter-current approaches the Gulf of Tunis and in the Gulf itself becomes particulary well pronounced. It is almost not at all observed in the dynamic relief charts of the summer season.

The characteristics of water circulation at the charts of 500 db surface were as those observed in Figs. 15 and 16, only the horizontal gradients on these charts became smaller, and indicate slow weakening of the circulation with depth.

The relative circulation of the deep layer, owing to extremely low values of the current velocity and insufficient number of observations, nothing could be added to the schemes of the deep waters spreading which were described by Pollak (1951); Ovchinnikov and Blakhin (1965); Anati and Stommel (1970); Novel (1970); Sankey (1973); Lacombe (1974) and El-Gindy and Sharaf El-Din (1986).

## CONCLUSION

The fulfilment calculations evidenced the considerable stability of the geostrophic water circulation in the eastern and central basins of the Mediterranean Sea. The most marked features of the geostrophic circulation during the winter and summer seasons were: the vast cyclonic gyre in the Levantine Sea, enveloping the southern part of the Aegean Sea; the cyclonic gyre in the Ionian Sea; and the anticyclonic gyre in the Libyan Sea and near the Egyptian coast.

The geostrophic current velocity varied between 5—10 cm/sec in Libyan Sea, 15—25 cm/sec near the Egyptian coast and between 35—40 cm/sec in the eastern part of the Levantine Sea. At the strait of Crete island, it reached 15—30 cm/sec. Differences between the winter and summer surface current velocity in the eastern and central basins of the Mediterranean Sea were not pronounced.

## REFERENCES

Anati, D. and H. Stommel. 1970. The initial phase of deep water formation in the northwest Mediterranean, during MEDOC, 69, on the basis of observations made by Atantis II (Jan. 25 — Feb. 12, 1969). Cah. Oceanogr., 22: 343—351.

Brenner, S. 1988. Structure and evolution of warm core eddies in the Eastern Mediterranean Levantine Basin. Submitted to J. Geophys. Res.

Dzhioyev, T. Z. and V. N. Drozdov. 1977. Computation of stationary currents in the Eastern Mediterranean Sea. Oceanology, 17: 17—19.

El-Gindy, A. H. and S. H. Sharaf El-Din. 1986. Water masses and circulation pattern in the deep layer of the Eastern Mediterranean. Oceanologica Acta, 9: 239—248.

Gerges, M. A. 1976. Preliminary results of a numerical model of circulation using the density field in the Eastern Mediterranean. Acta Adriat., 18: 163—176.

Gerges, M. A. 1977. A numerical investigation of the circulation in the Mediterranean. Rapp. Comm. int. Mer Medit., 24 (2): 25—30.

Lacombe, H. and P. Tchernia. 1958. Teperatures et salinités profondes en Mediterraneé en periode d'ete. Etude Preliminaire. Bull. Comm. Océanogr., Etudes Cotes, 10: 209—214.

Lacombe, H. and P. Tchernia. 1960. Quelques traits généraux de l'hydrologie Meditérranéenne. Cah. Océanogr., 12, p. 527.

Lacombe, H. 1974. Deep effects of the Energy transfers across the sea surface: the formation of deep waters. The western Mediterranean, as an example. Process Verbaux, (IAPSO First Special Assembly at Melbourne), 13 (13): 52—85.

Malanotte-Rizzoli, P. and A. Hecht. 1988. Large-scale properties of the Eastern Mediterranean: a review. Oceanologica Acta, 11: 323—335.

Menzin, A. B. and L. V. Moskalenko. 1982. Calculation of wind-driven currents in the Mediterranean Sea by the electrical simulation method (homogeneous model), Oceanology, 22: 537—540.

Miller, A. R. 1963. Physical Oceanography of the Mediterranean Sea: a discourse. Rapp. Comm. int. Mer Médit., 17 (3): 857—871.

Moskalenko, L. V. 1974. Steady-state wind-driven currents in the eastern half of the Mediterranean Sea. Oceanology, 14: 491—494.

Moskalenko, L. V. and I. M. Ovchinnikov. 1965. Water masses of the Mediterranean Sea. Izdat. Nauka, Moscow. (in Russian).

Nielsen, J. N. 1912. Hydrography of the Mediterranean Sea and adjacent waters. Rap. Dan. Oceanog. exped., 1908—1910, 1: 77—191.

Novel, E. 1970. Eight NATO expeditions explore the Mediterranean. Atlant. Community Quart, 8: 120—127.

Ovchinnikov, I. M. and E. A. Blakhin. 1965. On the formation of the deep water masses in the Mediterranean Sea. Okeanologiya, 5: 625—634 (In Russian).

Ovchinnikov, I. M. and A. F. Fedoseyev. 1965. The horizontal circulation of the water in the Mediterranean Sea during the summer and winter season. In: »Basic features of the geological structure, hydrological regime and biological regime and biology of the Mediterranean«, L. M. Fomin (Ed.), Translation of the Institute for Modern Languages for the U. S. N. Oceanogr. Office, 185—201.

Ovchinnikov, I. M. 1966. Circulation in the surface and intermediate layers of the Mediterranean Sea. Oceanology, 6: 49—59.

Ovchinnikov, I. M. 1976. Water circulation in the Mediterranean Sea. In: »Hydrology of the Mediterranean Sea«, Borkov (Ed.), Leningrad, pp. 240—313.

Ozsoy, E., A. Hecht and U. Unlüata. 1988. Circulation and hydrography of the Levantine Basin: Results of POEM Coordinated Experiment 1985/1986. Submitted to Deep Sea Res.

Pollak, M. I. 1951. The sources of the deep water of the Eastern Mediterranean Sea. J. Mar Res, 10: 128—152.

Said, M. A. 1984a. The spatial statistical structure of water temperature and salinity of the Mediterranean Sea. J. Meteorology, Climatology and Hydrology, 20: 56—61. (in Russian).

Said, M. A. 1984b. Water circulation in the central and eastern basins of the Mediterranean Sea and the formation of the intermediate water masses. Ph. D. Thesis, Odessa, 163 pp. (in Russian).

Sankey, T. 1973. The formation of deep water in the northwestern Mediterranean. Progress in Oceanography, vol. 6, Pergamon Press, pp. 159—180.

Sarkisian, A. S. 1966. Fundamentals of the theory and circulation of oceanic currents. Izdat. Leningrad. (In Russian).

Stommel, H. 1948. The westward intensification of wind-driven ocean currents. Trans. Am. Geophys. Union, 29: 202—206.

Wüst, G. 1960. Die Tiefenzirkulation des Mittelländischen Meeres in den Kernschichten das Zwischen und des Tiefenwassers. Deut. Hydrograph. Z., 13; p. 105.

Wüst, G. 1961. On the vertical circulation of the Mediterranean Sea. J. Geophys. Res., 66: 3261—3271.

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# HORIZONTALNA CIRKULACIJA VODA ISTOČNOG SREDOZEMLJA TIJEKOM ZIME I LJETA

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## KRATKI SADRŽAJ

Cirkulacija vode istočnog Sredozemnog mora izračunata je dinamičkom metodom. Dubina na 1000 m uzeta je kao referentni nivo. Ovom kalkulacijom potvrđena je velika stabilnost geostrofičke cirkulacije vode u istočnom i središnjem bazenu Sredozemnog mora. Naizraženije značajke geostrofičke cirkulacije tijekom ljeta i zime su slijedeće: veliki ciklonalni vrtlog u Levantu koji obuhvaća južni dio Egejskog mora; ciklonalni vrtlog u Jonskom moru i anticiklonalni vrtlog u Libijskom moru u blizini obala Egipta.

Brzina geostrofičke struje kretala se od 5—10 cm/sek u Libijskom moru, od 15—25 cm/sek u blizini egipatske obale i od 35—40 cm/sek u istočnom dijelu Levantskog mora. U tjesnacu otoka Krete brzina je dosegla 15—30 cm/sek. Razlike između zimske i ljetne brzine strujanja u površinskom sloju istočnog i središnjeg bazena Sredozemnog mora su gotovo beznačajne.