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ON THE STERIC CONTRIBUTION TO THE FLUCTUATIONS OF THE MEDITERRANEAN SEA LEVEL

O STERIČKIM PROMJENAMA RAZINE MORA U MEDITERANU

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Thermal, haline and total steric departures of the Mediterranean Sea level were calculated using the international hydrographic data (210 stations) in winter and summer seasons.

The thermal and haline components are different in magnitude and phase. In. winter the thermal departures range between —7.8 cm in the north of the Western basin and 40 cm in the south Levantine Sea. A positive thermal departures exist in the Eastern Mediterranean Sea, while the negative departures are found in the Western side. In summer, they are positive all over the Mediterranean Sea and range in winter, they range between —12.8 and 21 cm, while in between 0 and 40 cm. The haline departures in winter and summer are negative in the east and positive in the west. summer they vary between —15 and 35 cm.

The total steric departures, in general, are positive all over the Mediterranean Sea, except in the central part of the Levantine Sea in winter. They range between —4 and 21 cm in winter and between 10 and 40 cm in summer. The positive steric departures lead to the increase of the mean sea level in the Mediterranean Sea.

The steric departures are low in winter and high in summer. These departures coincide with the phase of the observed sea level fluctuations in the Mediterranean Sea.
I — winter season.

INTRODUCTION

The study of sea level variations has attracted the interest of many oceanographers for a long time. Much of the work was well summarized by Pattullo (1963). Lisitzin and Pattullo (1961) discussed the principal causes of sea level fluctuations, emphasizing the relative contribution of steric

(thermal and haline) and atmospheric pressure components. The effect of water density on the sea level was recognized long time ago and a number of studies on this subject have been extremely prolific. Especial rewarding in this connection was the research work done by Pattullo *et al.* (1955).

Brunson and Elliott (1974) calculated the thermal, haline and total steric departures of sea leval off the Oregon coast. Maiyza and Eid (1986) computed the differences of steric departures between anomalous warm and cold years in the Eastern Mediterranean Sea. The most important conclusion of this study was that, the effect of water density on sea level may reach 50% of the seasonal observed values of sea level fluctuations.

In the present work we report an intensive study of the thermal, haline and total steric departures in the Mediterranean Sea in winter and summer seasons, and try to get relation between the hydrographic conditions and the steric fluctuations in the different basins of the Mediterranean Sea.

MATERIALS AND METHODS

The hydrographic stations, used in the present study, were selected to cover the Mediterranean Sea from the international hydrographic data center. The sources of these data are shown in Table 1. The total steric departures

Table 1. Sources of the hydrographic data used in the present work

Cruise	Nationality	Year
I — winter season		
Atlantic	USA	1961
Mevooot Yam	Israil	1965
Shikmona	Israil	1969
Jean Charcot	France	1969
Ichtyalog	USSR/Egypt	1971
Passat	USSR	1974
Prof. Pogarov	USSR	1977
II — summer season		
Calypso	France	1955
Mevoot Yam	Israil	1963
Bannok	Italy	1964, 1965
Shikmona	Israil	1969
Ichtyalog	USSR/Egypt	1971

were computed for 131 hydrographic stations in winter (February) and 79 stations in summer (August). Some of these hydrographic stations were used to calculate the thermal and haline departures (32 stations in winter and 39 stations in summer). Fig. 1, shows the distributions of these hydrographic stations.

RESULTS AND DISCUSSION

Pattullo *et al.* (1955)'s equation were used to calculate the thermal, haline and steric departures from mean sea level (MSL):

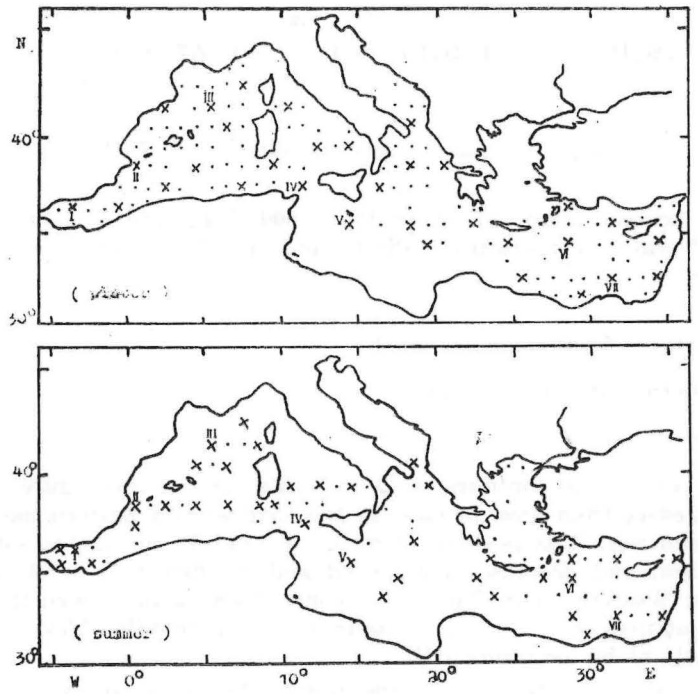

Fig. 1. Location map
*: stations at which the thermal, haline and total steric departures were calculated
•: stations at which only the total steric departure was calculated

$$Z_t = g^{-1} \int_{P_a}^{P_o} \left(\frac{\partial \alpha}{\partial t}\right) \Delta T \, dP$$

$$Z_s = g^{-1} \int_{P_a}^{P_o} \left(\frac{\partial \alpha}{\partial s}\right) \Delta S \, dP$$

$$Z_\alpha = g^{-1} \int_{P_a}^{P_o} \Delta \alpha \, dP$$

Here Z_t, Z_s and Z_α are the thermal, haline and steric departures from MSL, respectively; g is the accleration of gravity; P_a is the atmospheric pressure and P_0 is the pressure to which the integration has to be carried out, presumably the pressure where all seasonal effects vanish. ΔT and ΔS are the differences between the annual mean temperature ($\overline{T}$) and salinity ($\overline{S}$) and the youngest, medium and oldest postlarvae from the P_1, P_3 and P_6 and P_7 to small ΔT and ΔS and is given by:

$$\Delta\alpha = \alpha\,(T,S,P) - \alpha\,(\bar{T},\bar{S},P) = \left(\frac{\partial\alpha}{\partial t}\right)\Delta T + \left(\frac{\partial\alpha}{\partial s}\right)\Delta S \ldots$$

Where $\frac{\partial\alpha}{\partial t}$ and $\frac{\partial\alpha}{\partial s}$ are to be eventuated at $\bar{T}$, $\bar{S}$, P.

In the present study we chose P_o as 500 dbar, and $\bar{T}$, $\bar{S}$ and $\bar{\alpha}$ as the averages of water temperature, salinity and specific volume for all stations at that level.

Steric departures from mean sea level

a — Thermal departures (Z_t)

i) — In winter: —

Fig. 2a shows the contours of Z_t in winter. From this figure, it is clear that, Z_t increases from west to east. In the Central and Eastern basins of the Mediterranean Sea, Z_t is positive. It varies around 40 cm, in the south of the Levantine Sea, and decreases northward and westward to —7.8 cm, in the north of the Western basin. There is a contour line along which there are no thermal departures ($Z_t = 0$). This contour lies at the middle of Tyrrhenian Sea, approximately along longitude 11°E.

Fig. 2a, also, shows that, in the north of the Levantine, Central and Western basins, there are areas of low Z_t. These areas coincide with the areas of cyclonic eddies.

ii) — In summer: —

The contours of Z_t in summer show an increase in Z_t values from west to east. It varies gradually from 0 to 40 cm (Fig. 2b). Due to the higher water temperature in that season, Z_t are positive all over the sea. They range betwenn 0—10 cm in the Western basin, 15—20 cm in the Central basin and 25—40 cm in the Eastern basin.

Fig. 3a, shows the profile of Z_t at different levels from surface to 500 m depth in winter and summer seasons. In the Eastern and Central basins (IV—VII), the values of Z_t increase with depth (positive depatures). In the Western basin (I—III), Z_t increases (positive departures) to 100 m depth followed by negative departures. In general, Z_t, in the Mediterranean Sea, in summer is larger than that in winter.

b — *Haline departures* (Z_s)

i) — In winter: —

Z_s contours, in winter, are shown in Fg. 4a. In this figure Z_s values decrease from west to east (from positive to negative). The maximum value (20 cm) is found near Gibraltar Strait (minimum salinity), while the minimum (—12.8 cm) is found in the centre of the Levantine Sea (maximum salinity).

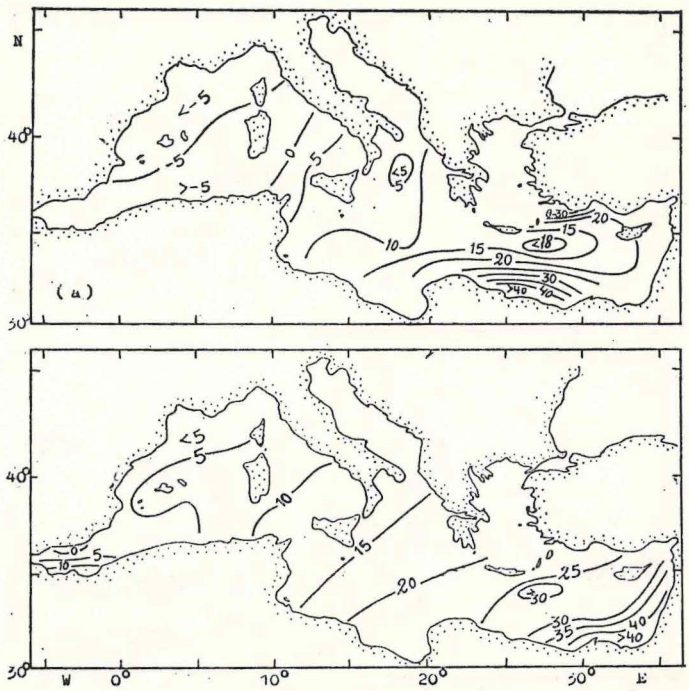

Fig. 2. Contours of thermal departures from MSL in the Mediterranean Sea, in winter (a) and summer (b), (Z_t in cm)

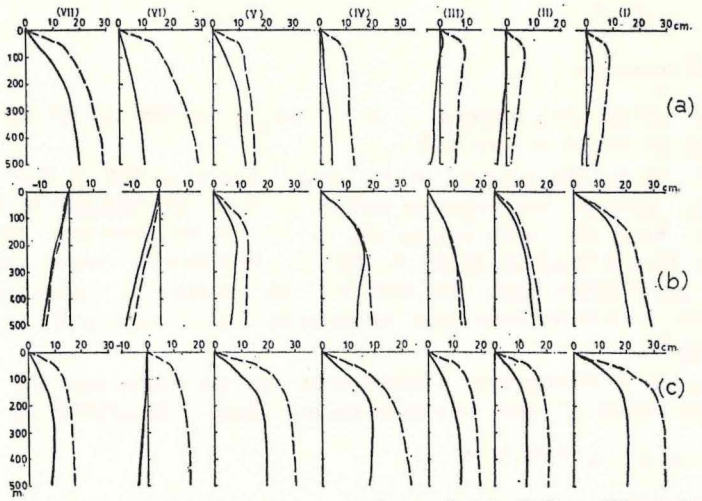

Fig. 3. The vertical profiles of thermal (a), haline (b) and total steric departures (c) at some selected stations in the Mediterranean Sea during winter (———) and summer (— — —). The locations of these stations (I—VII) are shown in Fig. 1.

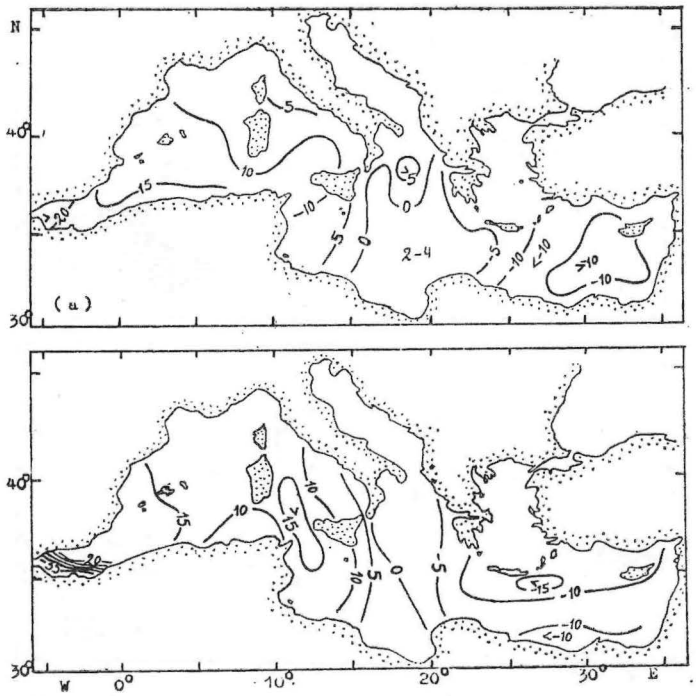

Fig. 4. Contours of haline departures from MSL in the Mediterranean Sea, in winter (a) and summer (b), (Z_s in cm)

ii) — In summer: —

In that season, the pattern of Z_s is similar to that in winter, but with larger range (from 35 to —15 cm).

Fig. 3b. shows the profiles of Z_s, from surface to 500 m level in winter and summer seasons. The negative values of Z_s in the Eastern basin (VI and VII), nearly have the same magnitude in winter and summer, and decrease with depth. In the Western basin (I—III), the positive Z_s values increase with depth. In the Central basin (IV and V), the positive Z_s values exist in the surface layer (to 150 m level) and the negative values appear below that level to 500 m depth.

In general, Z_s in summer is larger than that in winter and the differences of Z_s values between these two seasons are small compared with that of Z_t.

c — Total steric departures (Z_α)

i) — In winter: —

The contours of Z_α in winter, are shown in Fig. 5a. In the Mediterranean Sea the magnitude of Z_α, due to temperature and salinity, is positive, except in the centre of the Levantine Sea, where negative depatures are found.

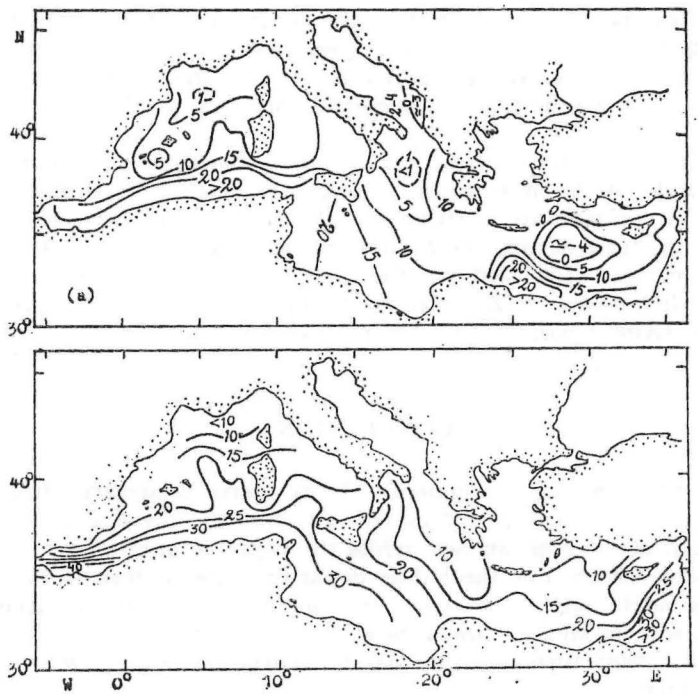

Fig. 5. Contours of total steric departures from MSL in the Mediterranean Sea, in winter (a) and summer (b), ($Z\alpha$ in cm)

In the Eastern basin, the magnitude of Z_α varies from —4 to 28 cm. The distribution of Z_α coincides with the known large cyclonic gyre in the north of the Levantine Sea (Ovchinnikov, 1966; Gerges, 1976). In the centre of this gyre, the water density is larger than the surrounding, because of the lower temperature and higher salinity.

In the Central basin Z_α ranges between 1 and 20 cm, increasing westward. Also, the minimum values in the north coincide with the cyclonic eddy there.

In the Western basin, the magnitude of Z_α ranges between 1 cm in the north, and 30 cm in the south. Also, in the north of that basin the lower values of Z_α are found within the area of cyclonic gyre.

ii) — In summer: —

Z_α, in summer, as shown in Fig. 5b, is different from that in winter, especially in the Levantine Sea, where the cyclonic gyre is not clear in summer.

In the Levantine Sea, Z_α varies from 10 cm in the north to 31 cm in the north-eastern part, while the higher values (30 cm) in the south-west of the basin.

In the Western basin, the magnitude of Z_α varies from 10 cm in the north to 40 cm near Gibraltar Strait.

From Figs. 5a&b, it is clear that, the magnitude of Z_α along the African coast is larger that that along the European one, due to the inflow of Atlantic Waters of low salinity, along the African coast. This means that, the water density along the southern coast is smaller and the sea level is consequently higher.

Fig. 3c, illustrats the vertical profiles of Z_α in winter and summer seasons. The magnitude of Z_α in summer is larger than that in winter. The steric departures in summer are positive for all stations and increase with depth. In winter, the steric departures for the Eastern basin (V and VI) are positive in the upper layer (150—300 m), followed by negative departures to 500 m depth. The differences in Z_α between summer and winter has its maximum value in the Eastern basin (about 20 cm, Fig. 4c).

CONCLUSIONS

The thermal, haline components of the steric departures from MSL, in the Mediterranean Sea were calculated. The positive thermal departure exists in the Eastern Mediterranean Sea, while the negative ones exist in the Western part in winter season. For the haline departure, the pattern is the reverse in both winter and summer seasons. In summer the thermal departures are positive all over he Mediterranean Sea.

The steric departures show a seasonal variation being low in winter and high in summer.

The magnitude of steric departures along the African coast is larger than that along the European coast. This coincides with the fact that, the sea level is higher along he African coast than that along the European coast (Lisitzin, 1965).

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KRATKI SADRŽAJ

Termalne, salinitetne i ukupne anomalije razine mora u Mediteranu računate su iz hidrograskih podataka za zimsko i ljetno razdoblje.

Termalna i salinitetna komponenta staričkih promjena razine mora razlikuju se međusobno u fazi i iznosu. U zimi se termalne anomalije razine mora kreću između —7.8 cm na sjeveru Zapadnog Mediterana i 40 cm na jugu Istočnog Mediterana. Pozitivne termalne anomalije opažene su u Istočnom, dok su negativne nađene u Zapadnom Mediteranu. U ljeti su međutim pozitivne u cijelom Mediteranu i kreću se između 0 i 40 cm. Salinitetne anomalije su i ljeti i zimi negativne na istoku a pozitivne na zapadu. Zimi variraju od —12.8 do 21 cm a ljeti od —15 do 35 cm.

Ukupne steričke anomalije su općenito pozitivne u cijelom Mediteranu osim u središnjem dijelu Levanta zimi. Njihova se vrijednost zimi kreće između —4 i 21 cm, dok se ljeti ta vrijednost nalazi u intervalu od 10 do 40 cm. Pozitivne steričke anomalije znaće porast razine mora.

Steričke anomalije manjeg su iznosa zimi nego ljeti. Ovakav se odnos podudara sa do sada opaženim sezonskim promjenama razine mora u Mediteranu.