Abrupt changes in the characteristics of Atlantic and Levantine intermediate waters in the Southeastern Levantine basin

Southeastern Levantine basin
Levantine water masses
Levantine Intermediate Water
Atlantic inflowing waters
Levantine surface waters

Bassin levantin du Sud-Est
Masses d'eaux levantines
Eaux levantines intermédiaires
Eaux atlantiques
Eaux levantines de surface

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ABSTRACT

Data from twenty consecutive cruises, carried out over a period of five years, were investigated in order to reveal temporal changes in the characteristics of the AW (Atlantic Waters) and the LIW (Levantine Intermediate Waters) in the Southeastern Levantine basin. The results indicated a seasonal trend in the AW, which appear to be poorly defined during winter and spring but which, as the year progresses and as the LSW (Levantine Surface Waters) form and penetrate downward, become better defined, and occupy a narrower layer whose depth increases. There appeared to be no season related variations in the LIW.

Moreover, abrupt, significant, and apparently irreversible changes in the characteristic salinity of the AW and the LIW occurred in the Southeastern Levantine basin during 1982. Therefore we are witnessing a change in the volume and the rate of exchange of waters between the Atlantic Ocean and the Mediterranean Sea. These changes can be attributed either to the enhanced diversion and utilization of river waters (in particular the Nile waters), or to regional climatic changes due to the greenhouse effect. In all probability both causes have contributed their share. However, whereas the exploitation of fresh waters can be well monitored, we are almost entirely ignorant with regard to the rate of local climatic changes and their effects on the formation of the local water masses. Close and persistent monitoring of AW inflow, LIW formation, and the dispersion of the two water masses could provide us with a sensitive tool for enhancing our understanding of climatic change processes.

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RÉSUMÉ

Changements brusques des caractéristiques des eaux atlantiques et des eaux levantines intermédiaires dans le bassin levantin du Sud-Est

Les données obtenues au cours de vingt croisières réalisées pendant cinq ans ont été traitées pour découvrir les variations des caractéristiques des Eaux Atlantiques (AW) et des Eaux Levantines Intermédiaires (LIW) du bassin du Levant du Sud-Est. Les résultats montrent une tendance saisonnière des AW, mal définie en hiver et au printemps; au fur et à mesure que l'année s'avance, et que les Eaux Levantines Superficielles (LSW) se forment et pénètrent en profondeur, les AW deviennent plus facilement identifiables et forment une couche plus étroite qui devient de plus en plus profonde. Il ne semble pas exister de variations saisonnières des LIW.

Par ailleurs, des changements brusques, significatifs et apparemment irréversibles de la salinité caractéristique des AW et des LIW ont eu lieu dans le bassin du Levant du Sud-Est en 1982. Nous assistons donc à un changement du volume et du rythme d'échange des eaux entre l'Océan Atlantique et la Mer Méditerranée. Ces changements peuvent être attribués, soit à la déviation de plus en plus fréquente des cours d'eau et à l'utilisation de plus en plus intensive de leurs eaux (en particulier les eaux du Nil) soit aux changements climatiques régionaux dus à l'effet de serre. Ces deux causes ont probablement joué un rôle dans ces modifications. Alors que l'exploitation des eaux douces peut être facilement mesurée,nous ignorons presqu'entièrement le rythme des changements climatiques et leurs effets sur la formation des masses d'eau locales. La surveillance étroite et permanente des entrées d'AW, de la formation des LIW et de la dispersion de ces deux masses d'eau pourrait fournir un instrument sensible pour une meilleure compréhension des changements climatiques.

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INTRODUCTION

The Mediterranean Sea is a concentration basin. By this we mean that evaporation exceeds precipitation and runoff. Its volume continuity is maintained by waters ingressing from the Atlantic Ocean and from the Black Sea (the flow of waters through the Suez Canal is negligible). Salt continuity is maintained by waters egressing into the Atlantic Ocean and the Black Sea. The ingressing Atlantic Waters (AW) can be traced along the entire Mediterranean Sea and reach as far as its eastern shores where they contribute to the formation of the Levantine Intermediate Waters (LIW) (*e. g.* Oren, 1971; Morcos, 1972). The LIW can be traced from their origins in the Levantine basin throughout the Mediterranean Sea to the strait of Gibraltar where they flow out into the Atlantic Ocean (*e. g.* Wust, 1960; Katz, 1972). Additional information and details on the general circulation of the Western Mediterranean can be found in Hopkins (1985), and on that of the Eastern Mediterranean in Unluata (1986) as well as in Malanotte-Rizzoli and Hecht (1988).

On their way westward the LIW entrain some waters from the shallower layers above them as well as some of the deep waters from the Eastern Mediterranean basin. In particular, it has been shown that the egressing waters contain LIW as well as Western Mediterranean Deep Waters (Bryden and Stommel, 1982; Kinder and Parrilla, 1987). Thus, the egressing waters are usually described as Mediterranean Waters (MW) rather than Levantine Intermediate Waters. The MW are warmer but also saltier and denser than the surrounding waters and therefore descend precipitously to a depth of about 1 200 m where they spread. Their particular S/T characteristics make them traceable and they could be followed horizontally across the ocean as far as a longitude of at least 70°W (*e. g.* Katz, 1970; Worthington, 1976; Plakhin and Smirnov, 1982; McDowell, 1986) as well as vertically down to 3 000 m (*e. g.* Worthington and Wright, 1970).

The contribution of the MW to the mid-depth general circulation (*e. g.* Reid, 1981) of the Atlantic is significant. To a lesser extent, the MW also contribute to the composition of the deep waters of the Atlantic (*e. g.* Warren, 1981) as well as to the shallower layers of that ocean (*e. g.* Ambar, 1983; Schlosser *et al.*, 1983). The dynamics of the MW outflow has been investigated by Needler and Heath (1975) and by Arhan (1987).

One of the interesting aspects of MW dispersion into the Atlantic is the formation and motion of lenses and eddies or, as they are sometimes called "Meddies". These are parcels of water characterized by their distinct temperature and salinity and related to the Mediterranean outflow, reported for the first time by Zenk (1970 and 1971) who discovered them relatively close to the strait of Gibraltar. They were later observed much farther from their origins (*e. g.* McDowell and Rossby, 1978; Zantopp and Leaman, 1982) and eventually proved to be an ubiquitous feature of the Atlantic Ocean mesoscale circulation patterns (Armi and Zenk, 1984; Lindstrom and Taft, 1986). These eddies are mostly anticyclonic; their diameters range from 20 to 200 km; they are vertically confined within a few hundred metres, and appear to have a lifetime of several years and a propagation velocity of several cm/s. In addition to particularities of salinity and temperature, these eddies appear to maintain other anomalous properties as well, *e. g.* dissolved oxygen and nitrates (Riser *et al.*, 1986), thus they could be very effective in the transportation of non-diluted water properties, as well as pollutants, across the ocean. Persistent mesoscale and submesoscale eddies have been observed in the Western Mediterranean (*e. g.* Millot, 1991), in the Ionian Sea (*e. g.* Robinson *et al.*, 1991) as well as in the Levantine basin (Robinson *et al.*, 1987; Feliks and Itzikowitz, 1987; Hecht *et al.*, 1988; Ozsoy *et al.*, 1988; Brenner, 1989). These eddies have been shown to trap and retain pockets of AW as well as LIW (Hecht *et al.*, 1988; Millot, 1991), and to demonstrate other chemical properties (Brenner *et al.*, 1991). Feliks and Itzikowitz (1987) suggest that the eddies they investigated propagate eastward; however, they could move westward just as they do in the Atlantic (*e. g.* Nof, 1981; 1982; 1983) and, indeed, Parilla *et al.* (1986) find examples in the Alboran Sea. Thus such LIW eddies could deliver undiluted water "parcels" from the Levantine basin perhaps as far as Gibraltar and even into the Atlantic (Yemel'yanov and Fedorov, 1985). Their existence and persistence in the Atlantic as well as in the Eastern Mediterranean basin may lead us to change our approach to the computation of mixing rates of substances into the oceanic environment, i.e. the mixing rates of either pollutants or of CO_2 (*e. g.* Shiller, 1981), the last having a direct bearing on possible climatic changes.

The exchange of waters through the strait of Gibraltar renews the water masses of the Mediterranean and it has been estimated (*e. g.* Ovchinnikov, 1983) that the renewal of the entire water mass requires about 100 years, while the renewal of the deep waters of the Western basin requires about 40 years and the renewal of the deep waters of the Eastern basin, defined by Ovchinnikov as the waters below the LIW, requires about 70 years. Roether and Schlitzer (1991) divide the layer below the LIW into two: one layer between 500 and 1 000 m; and another from 1 200 m to the bottom. They estimated that the renewal of the water in the deeper layer of the Eastern Mediterranean requires 126 years, while the renewal of the layer from 200 to 1 000 m requires some 20 to 30 years. Recently, Manzella and LaViolette (1990) as well as Manzella *et al.* (1990) found that the seasonal variation in the outflow through the strait of Gibraltar can be related to the seasonal variation of the outflow of LIW through the strait of Sicily. However, Millot (1991) argues that there are no significant seasonal changes in the flow through the strait of Gibraltar. Obviously, the quantities of water flowing in and out through the various straits are bound to show some variations and therefore estimates of the water budget components vary significantly from one investigator to another (Carter, 1956; Ovchinnikov, 1974). Whether these variations are significant and periodical (*i. e.* seasonal) seems to require further research.

Changes in the components of the water budgets in the region of the LIW formation, whether anthropogenic, *e. g.* the consequence of river damming and the utilization of the fresh water, or climatic, *e. g.* the result of changes in evaporation or rain due to the greenhouse effect, will affect the balance of the inflow-outflow at the straits (*e. g.* Bethoux 1979; Nof, 1979) as well as the residence time of the waters in the Mediterranean Sea (*e. g.* Lacombe *et al.*, 1981; Ovchinnikov, 1983). Some investigators have thus made a particular effort to determine the initial temperature and salinity characteristics of the egressing Mediterranean waters and relate those to the characteristics of the water at formation (*e. g.* Plakhin and Smirnov 1984).

Changes in the characteristics of the LIW will therefore affect not only the entire Mediterranean circulation and the quality of its waters, but also the Atlantic circulation through the type and quality of water "exported" from the Mediterranean in general and from the Levantine basin in particular (*e. g.* Yemel'yanov and Fedorov 1985). It is consequently important to monitor and document any changes in the physical properties and the quality of the waters in the Levantine basin. The present paper describes an attempt to analyze the data from a relatively long series of oceanographic cruises in order to reveal seasonal and interannual changes in the AW and the LIW in the southeastern part of that basin.

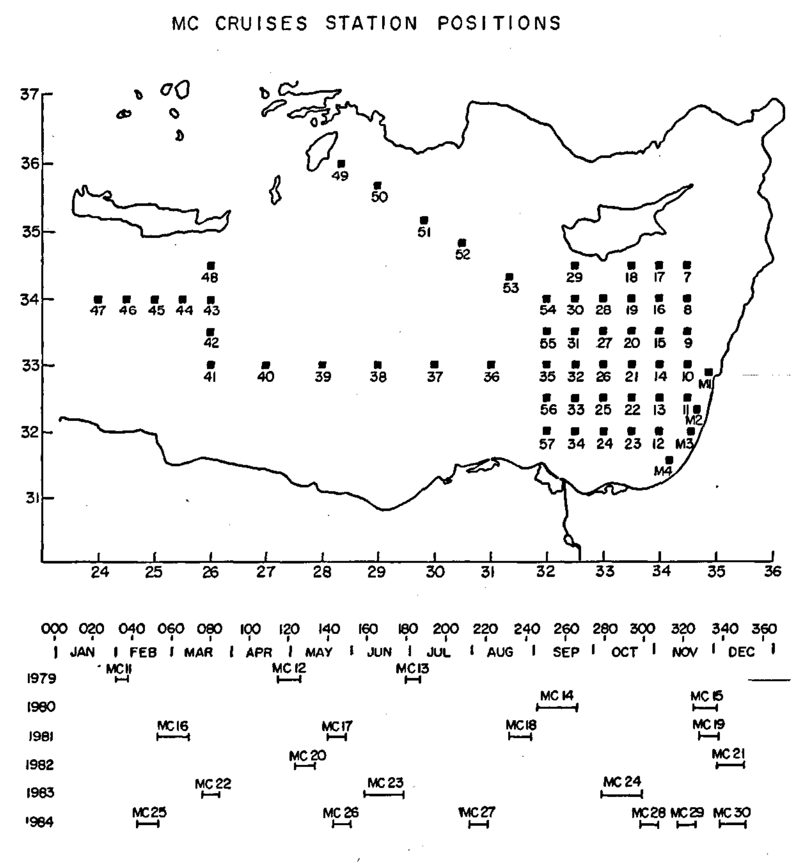


Figure 1

MC cruises, station location and time table.

DATA

The data were acquired during a five year (1979-1984) series of 20 Israeli cruises known as the MC (Marine Climate) series. Each of these cruises lasted for about ten days and was planned so as to occupy the same grid of 28 stations situated at 0.5° intervals in a rectangular domain defined by 32°00' to 34°30'N, and by 32°30' to 34°30'E (Fig. 1). Two of the cruises (MC23 and MC24) were somewhat more extensive than the others and occupied stations across the Rhodes Gyre - a region considered to be one of the major sites of LIW formation - as well as stations leading to and into the Cretan Passage. Station positions were determined by satellite navigation. The measurements, practically continuous from surface to bottom, were acquired with a Neil Brown CTD and were carefully calibrated against numerous rosette samples of temperature, pressure and salinity collected on every single cast. This data set and its preliminary analysis has been described in greater detail in Hecht *et al.* (1988).

In the following paper the climatological profile of a particular parameter is defined as the level-by-level average of all the measurements of that parameter. Obviously, the number of measurements available at each level diminished with depth. Thus, while we have about 600 measurements in the upper layers, we have about 400 measurements at 1 000 decibars and only some 50 measurements at 2 000 dbars. Even 500 measurements may not be sufficient for the computation of representative climatological means; consequently, the term, as used here, is merely a convenient reference for the average of a parameter over the entire data set and has some validity in the sense that the measurement of later cruises (*e. g.* POEM cruises) appear to fall close to their "climatological profile". Similarly, the cruise profile of a parameter is defined as the level by level average of all the measurements of the parameter for that particular cruise.

Since we are to investigate the spatial and temporal variability of the water mass properties as exhibited during the MC cruises, it is important to verify the accuracy and the repeatability with which these properties were measured. The climatological temperature and salinity profiles (Fig. 2) show that the standard deviations of these parameters diminish with depth and, below 1 000 decibars, approach the level of the accuracy of our measurements. The cruise averages of temperatures and salinities at selected depths (Tab. 1 *a* and 1 *b* respectively) indicate that at depths exceeding 1 500 dbars the standard deviations of our measurements are not larger than ± .02°C in temperature and ± .01 in salinity. These appear to be reasonable and conservative values for CTD data-calibrated *versus* reversing thermometers and bottle salinity samples. The standard deviations in deeper layers (*e. g.* 2 000 dbars) are even lower, but the scarcity of measurements there prevents us from using these levels as a reference. Within these limits, one can conclude that, in the MC region, and during the period of the MC cruises, the water body below 1 000 dbars is temporally and spatially invariant.

RESULTS

On a typical summer salinity profile (Fig. 3 *a*, station 10 of the MC18 cruise of August 1981), one can see the characteristic salinity of three of the four main water masses of the Levantine basin: 1) the local Levantine Surface Water (LSW) - an upper shallow layer of relatively very high salinity; 2) the Atlantic Water (AW) - a subsurface narrow layer of relatively low salinity; 3) the Levantine Intermediate Water (LIW) - a deeper broad layer of high salinity. The fourth water mass - the Levantine Deep Water (LDW) - begins below the depicted profile. The related temperature profile (Fig. 3 *b*) does not appear to show any particularly conspicuous characteristics at levels where the salinity profile indicates the presence of the water masses. A typical winter salinity profile (Fig. 3 *c*, station 10 of the MC22 cruise of March 1983) is quite different from a summer profile. However, one can still identify clearly the LIW layer, as indicated by the deep subsurface maximum. Obviously, the LSW is absent since this is an ephemeral feature present only during the summer. The salinity of the upper layer is lower than in summer, but not as low as the salinity of the AW observed on the summer profile: this has led some investigators to attribute the low salinity of the surface layers to local winter precipitation and runoff and to question whether, in winter, the Atlantic waters do reach as far as the eas-

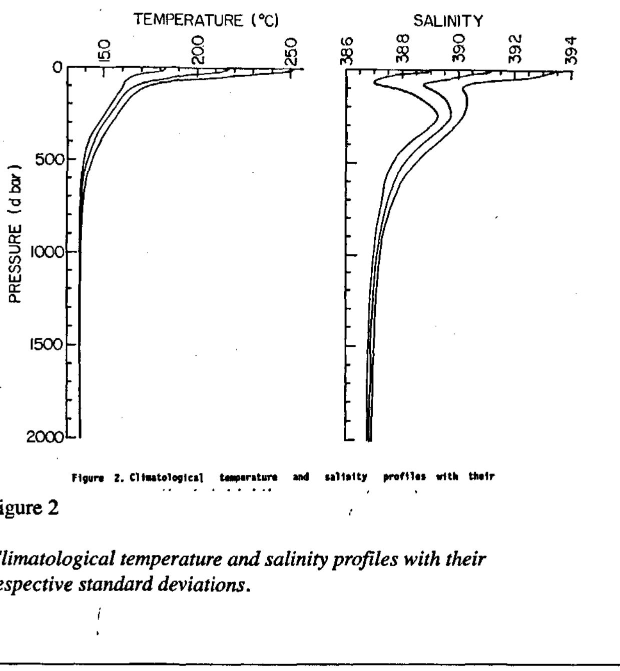


Figure 2

Climatological temperature and salinity profiles with their respective standard deviations.

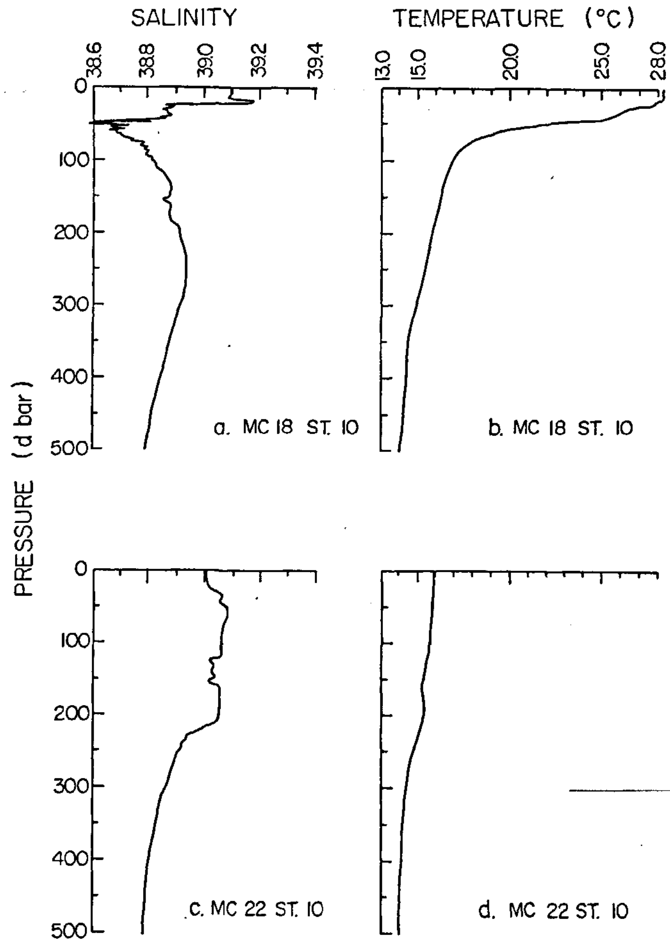


Figure 3

Typical summer and winter salinity and temperature profiles - MC18 of August 1981, MC22 of March 1983 - respectively.

Table 1 *a*

Cruise average temperatures and their respective standard deviations at selected pressures.

Cruise and date		Pressure (d bars) 0	500	1000	1500	2000	
MC11	Feb. 1979	17.34 ± .48	14.14 ± .16	13.66 ± .02	13.63 ± .013		
MC12	May 1979	18.86 ± .54	14.17 ± .18	13.68 ± .03	13.65 ± .016	13.683	1
MC13	June 1979	26.01 ± .45	14.18 ± .21	13.68 ± .03	13.65 ± .009	13.681	2
MC14	Sep. 1980	26.81 ± .79	14.09 ± .12	13.66 ± .02	13.63 ± .008		
MC15	Nov. 1980	21.74 ± .70	14.09 ± .13	13.67 ± .03	13.64 ± .012	13.680 ± .005	3
MC16	Feb. 1981	16.39 ± .22	14.13 ± .15	13.67 ± .02	13.64 ± .008	13.677	2
MC17	May 1981	20.37 ± .50	14.14 ± .14	13.68 ± .03	13.63 ± .015	13.678	1
MC18	Aug. 1981	27.22 ± .56	14.09 ± .14	13.67 ± .04	13.64 ± .014	13.688 ± .008	3
MC19	Nov. 1981	21.04 ± .52	14.11 ± .19	13.65 ± .03	13.62 ± .010	13.660	2
MC20	May 1982	19.48 ± .91	14.03 ± .13	13.64 ± .03	13.61 ± .016	13.657 ± .005	5
MC21	Dec. 1982	19.35 ± .63	13.99 ± .11	13.62 ± .03	13.60 ± .014	13.653 ± .003	4
MC22	Mar. 1983	15.99 ± .21	14.03 ± .18	13.64 ± .04	13.62 ± .021	13.663 ± .010	3
MC23	June 1983	23.90 ± .70	14.02 ± .18	13.62 ± .04	13.60 ± .017	13.643 ± .005	6
MC24	Oct. 1983	24.89 ± .70	14.07 ± .27	13.63 ± .04	13.62 ± .015	13.657 ± .004	6
MC25	Feb. 1984	17.03 ± .25	14.08 ± .29	13.63 ± .05	13.61 ± .019	13.652 ± .004	6
MC26	May 1984	21.62 ± .68	14.06 ± .30	13.62 ± .05	13.61 ± .016	13.653	1
MC27	July 1984	26.25 ± .61	14.08 ± .35	13.62 ± .05	13.61 ± .017	13.650 ± .005	4
MC28	Oct. 1984	24.57 ± .68	14.07 ± .38	13.62 ± .02	13.60 ± .024	13.650 ± .003	4
MC29	Nov. 1984	22.53 ± .68	14.02 ± .24	13.61 ± .05	13.60 ± .014	13.647 ± .000	3
MC30	Dec. 1984	20.72 ± .82	14.04 ± .32	13.62 ± .06	13.61 ± .016	13.651	2
Climatology		21.73 ± 3.4	14.08 ± .23	13.64 ± .05	13.62 ± .022	13.660 ± .014	
		627	551	427	195	58	

Table 1 *b*

Cruise average salinities and their respective standard deviations at selected pressures.

Cruise and date		Pressure (d bars) 0	500	1000	1500	2000	
MC11	Feb. 1979	38.78 ± .21	38.83 ± .04	38.73 ± .01	38.71 ± .008		
MC12	May 1979	38.77 ± .07	38.81 ± .04	38.71 ± .02	38.69 ± .018	38.669	1
MC13	June 1979	38.99 ± .09	38.82 ± .04	38.71 ± .01	38.69 ± .011	38.683	2
MC14	Sep. 1980	39.18 ± .10	38.81 ± .02	38.71 ± .01	38.70 ± .010		
MC15	Nov. 1980	39.15 ± .04	38.80 ± .03	38.70 ± .01	38.68 ± .005	38.676 ± .003	3
MC16	Feb. 1981	38.80 ± .10	38.81 ± .03	38.70 ± .02	38.68 ± .015	38.666	2
MC17	May 1981	38.83 ± .07	38.81 ± .03	38.70 ± .01	38.67 ± .003	38.667	1
MC18	Aug. 1981	39.19 ± .07	38.80 ± .03	38.70 ± .01	38.68 ± .007	38.682 ± .008	3
MC19	Nov. 1981	39.22 ± .04	38.81 ± .04	38.70 ± .01	38.68 ± .008	38.681	2
MC20	May 1982	39.04 ± .04	38.80 ± .03	38.71 ± .01	38.68 ± .006	38.677 ± .013	5
MC21	Dec. 1982	39.33 ± .06	38.79 ± .02	38.70 ± .01	38.68 ± .007	38.671 ± .003	4
MC22	Mar; 1983	38.99 ± .21	38.78 ± .03	38.70 ± .01	38.68 ± .003	38.680 ± .003	3
MC23	June 1983	39.18 ± .07	38.78 ± .03	38.70 ± .01	38.68 ± .005	38.674 ± .006	6
MC24	Oct. 1983	39.47 ± .09	38.81 ± .05	38.70 ± .01	38.69 ± .006	38.682 ± .007	6
MC25	Feb. 1984	38.94 ± .18	38.81 ± .05	38.70 ± .01	38.68 ± .005	38.672 ± .002	6
MC26	May 1984	38.93 ± .06	38.80 ± .05	38.70 ± .01	38.68 ± .005	38.672	1
MC27	July 1984	39.19 ± .09	38.80 ± .06	38.70 ± .01	38.68 ± .005	38.670 ± .005	4
MC28	Oct. 1984	39.28 ± .35	38.80 ± .06	38.70 ± .02	38.68 ± .009	38.683 ± .006	4
MC29	Nov. 1984	39.32 ± .07	38.80 ± .04	38.70 ± .01	38.68 ± .003	38.673 ± .004	3
MC30	Dec. 1984	39.28 ± .35	38.80 ± .06	38.70 ± .01	38.68 ± .006	38.675	2
Climatology		39.12 ± .23	38.80 ± .04	38.70 ± .01	38.68 ± .010	38.676 ± .009	
		627	550	427	195	58	

Last column shows the number of measurements at 2 000 dbars. Last row shows the number of measurements used for the climatological averages.

tern coast of the Levantine basin (*e. g.* Oren 1971; Hopkins 1978). However, it may also be argued that the Atlantic waters do reach the eastern shores of the Mediterranean also in the winter. The higher salinity of the upper layers in the winter (relative to the salinity of the AW in the summer) could be attributed to enhanced evaporation and mixing with the LIW below-processes which, during the summer, are inhibited by the "lid" of the LSW. As in summer, the related winter temperature profile (Fig. 3 *d*) does not seem to show any particular characteristics at the level of the LIW.

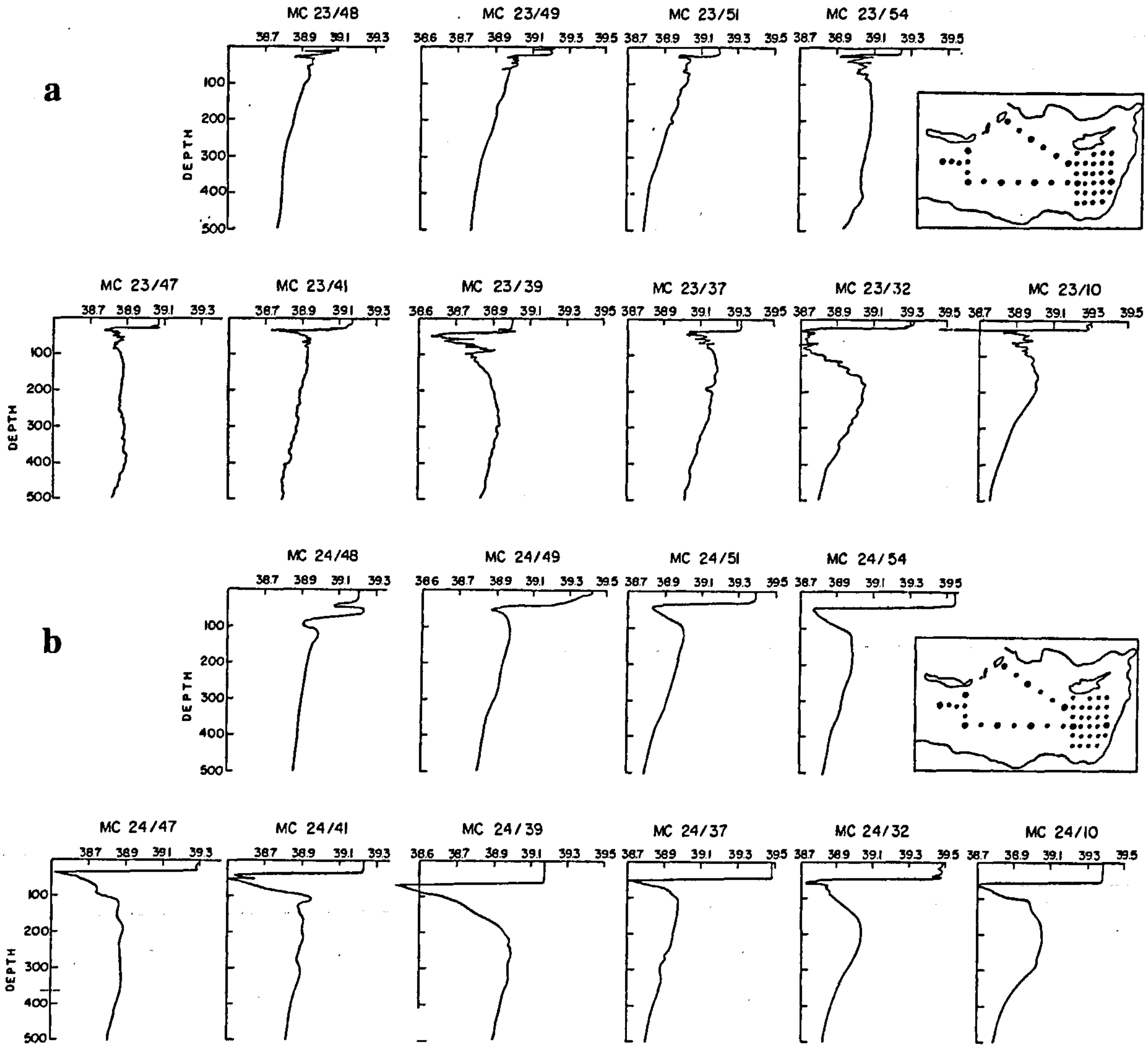


Figure 4

Salinity profiles from different parts of the basin, measured during MC23 of June 1983 (a), and MC24 of October 1983 (b). Thick dots on the map indicate the positions of the selected stations, the respective station numbers appear above each profile (for the positions of those stations see also Figure 1).

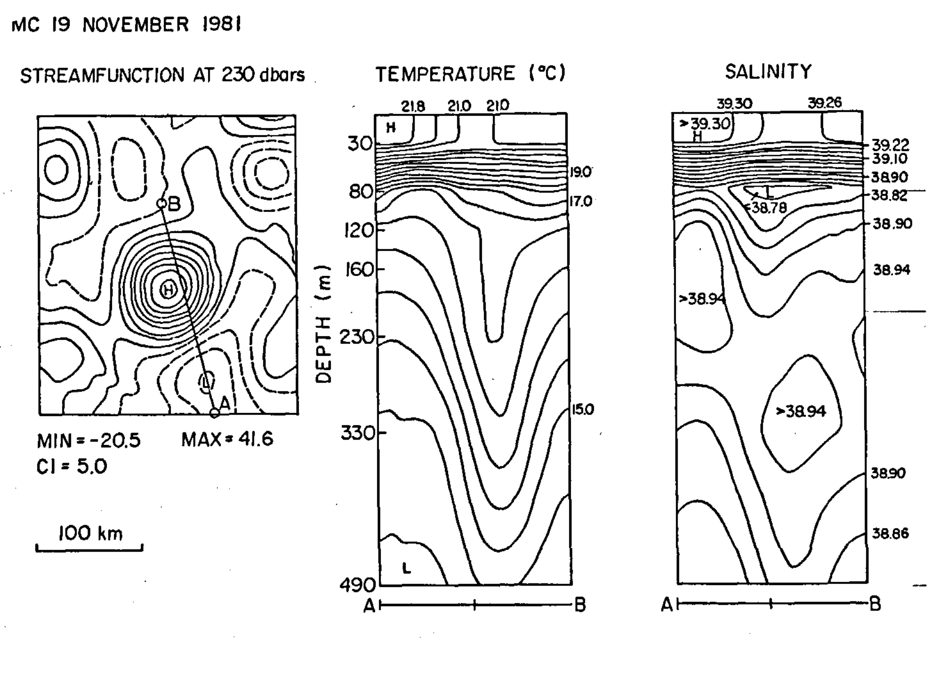


Figure 5

Temperature and salinity sections through eddies, from Hecht, Pinardi and Robinson (1988).

The lack of any characteristic temperature signal at the levels where we find the particular Levantine water masses repeats itself throughout all the measurements we have made. Therefore, the definition of the water masses of the Levantine basin is based solely on the characteristic extrema of the salinity profile and the position of this extrema in the water column. Thus, the LSW are defined as the upper layer (surface layer) waters of relatively very high salinity: the LIW are defined as the waters with a subsurface salinity maximum; and the AW are defined by the subsurface salinity minimum located in the waters above the LIW. Obviously, these definitions identify only points on a salinity profile, whereas for any quantitative investigation we shall need to identify a water mass or a water layer. Moreover, the upper layers of the Levantine basin are neither homogeneous nor isotropic and these extrema, although present throughout the basin, vary significantly, one could say almost randomly, from one location to another - *e. g.* the salinity profiles from MC23 or MC24 , Figure 4 *a* and 4 *b* respectively - and from time to time - *e. g.* compare the salinity profiles of MC23 (Fig. 4 *a*) with those measured three months later on the same station (MC24, Fig. 4 *b*). One of the reasons for this is that the AW and LIW are trapped in small-scale pockets within eddies (*e. g.* Fig. 5, from Hecht *et al.*, 1988; *see also* Yemel'yanov and Fedorov, 1985). Therefore, any attempt at a quantitative investigation of these water masses must begin with an objective definition: my suggestion is to define them statistically. Indeed, cruise averages of the salinity appear to preserve the characteristics of the water masses. On a typical summer cruise average salinity profile (Fig. 6 *a*, MC18 of August 1981), one can see the LSW with a salinity of about 39.2 from the surface to about 30 decibars, the AW with a salinity of about 38.7 at about 40 dbars, and the LIW with a salinity of 38.94 at about 265 dbars. On a typical winter cruise average salinity profile (Fig. 6 *c*, MC22 of March 1983) there is obviously no indication of LSW; the 38.8 salinity minimum at about 10 dbars may indicate the presence of AW but it is not as conspicuous as in the summer profile since there is no contrasting LSW above it; and there is a subsurface maximum of 39.04 at 155 dbars indicating the presence of LIW. As before, there are no characteristic cruise average temperature signals associated with any of those salinities (Fig. 6 *b* and 6 *d*).

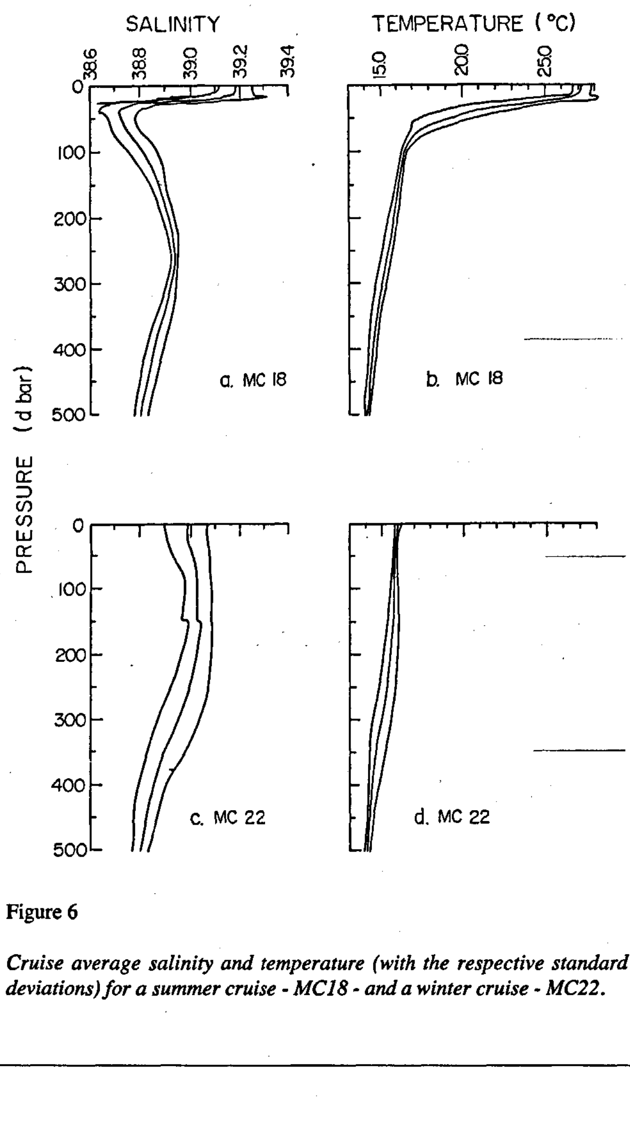


Figure 6

Cruise average salinity and temperature (with the respective standard deviations) for a summer cruise - MC18 - and a winter cruise - MC22.

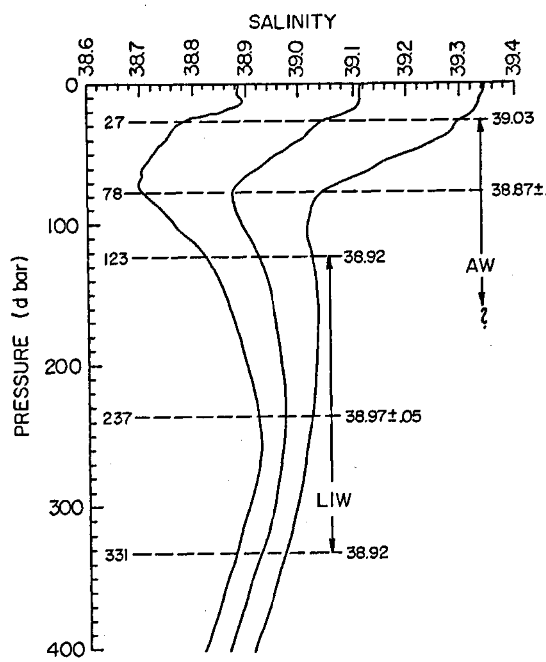


Figure 7

Climatological salinity profile showing the AW and LIW water masses and their limits.

The characteristic extrema of the salinity profile is preserved even in the climatological profile (Fig. 2 *b*), where one can see the distinct imprint of the main water masses of the region: from the surface to about 15 dbars the high salinity - 39.11 - LSW; at 78 dbars the low salinity - 38.87 - AW; at 237 dbars the subsurface maximum - 38.97 - of the LIW. As pointed out before, on the climatological temperature profile (Fig. 2 *a*), the temperatures related to those characteristic salinities do not seem to be particularly conspicuous. Therefore one could use the statistical properties of the climatological salinity profile for the objective definition of the various water masses. Since on the climatological salinity profile the subsurface salinity maximum, situated at 237 dbars, has a value of 38.97 and a standard deviation of ± .05 we can define the climatological LIW as the layer extending from 123 to 331 dbars where one finds the 38.92 salinities above and below the maximum (Fig. 7).

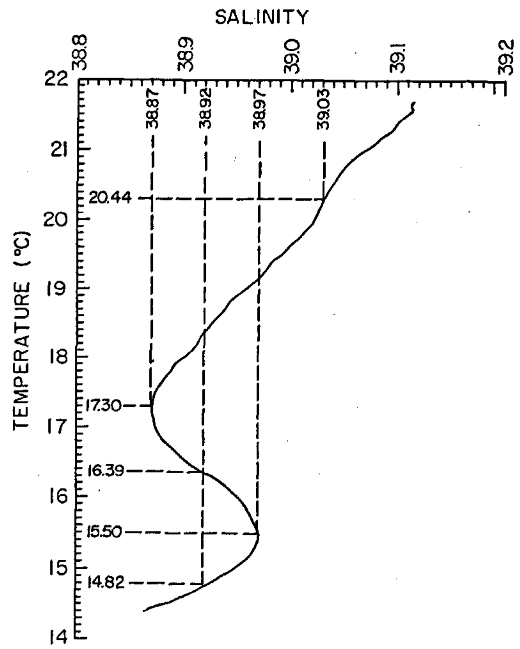


Figure 8

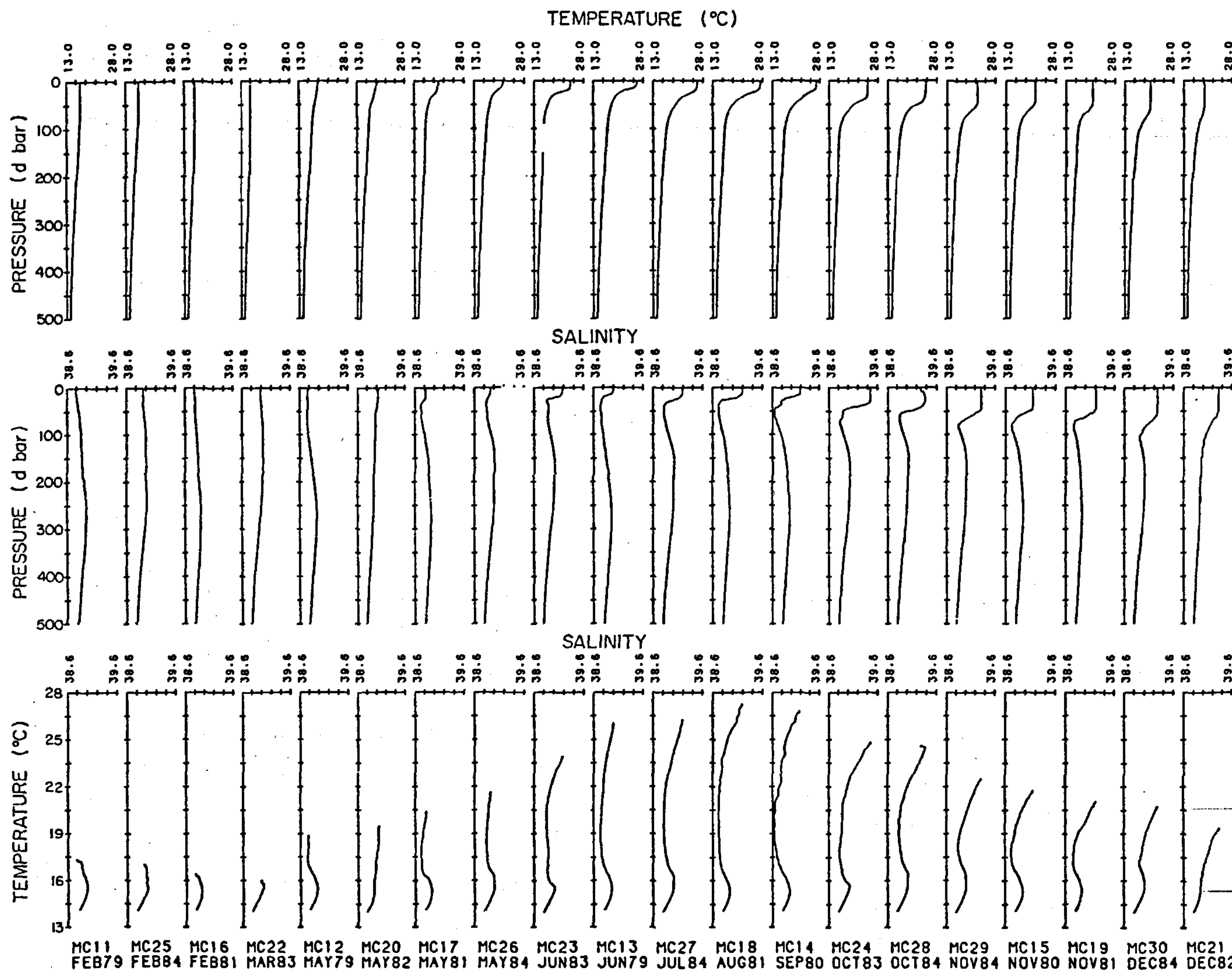
TS climatological profile for the determination of the temperatures of the water masses.

Moreover, through the climatological T/S diagram (Fig. 8) one can determine a temperature range associated with the LIW *e. g.* 14.8 to 16.4°C. Similarly, on the climatological salinity profile (Fig. 7), the AW is situated at a depth of 78 dbars and has a value of 38.87 ± .16, thus extending between the 39.03 values on the climatological salinity profile. While, due to the presence of the LSW, such a value can be found above the minimum at 27 dbars, it can not be found below the minimum and we encounter a problem in the definition of the AW. This difficulty could be circumvented by limiting the downward extent of the AW to the beginning of the LIW at 123 dbars. As in the case of the LIW the S/T diagram (Fig. 8) can be used to define the upper temperature limit of the AW at 20.4°C.

While these definitions may be useful for some quantitative climatological computations, they can not provide us with any information on the seasonal changes in the AW and the LIW. In order to attempt the investigation of the

Figure 9

Seasonal distribution of cruise average profiles, irrespective of the year in which they were measured, arranged according to the midday of each cruise.



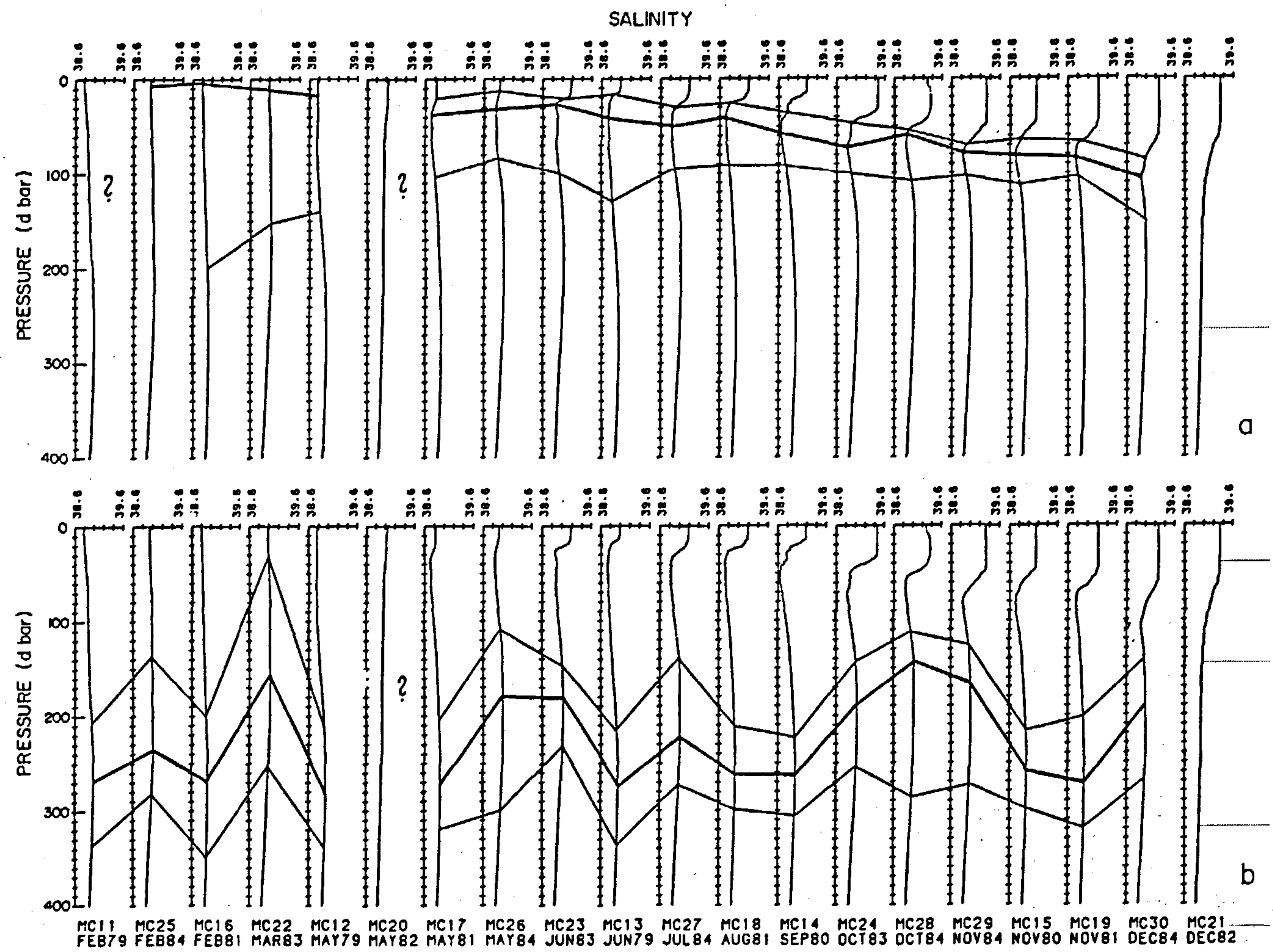


Figure 10

Depth and width of the AW (a) and LIW (b) layers on the seasonally organized salinity profiles from the MC cruises. The thick line indicates the cruise average depth of the layer, the two thin lines indicate the ± one standard deviation from the cruise average.

seasonal changes in the AW and the LIW, I used the procedures described above for the determination of the location and extent of the layers for each cruise average profile. Moreover, I arranged the cruise average profiles in the order of the midday of the cruise irrespective of the year in which the cruise was carried out. Thus we have at least one representative for every month of the year except January and April (Fig. 9). Although these cruises were carried out at practically random intervals one is amazed to see the regularity with which each fits into its seasonal slot. The development of the temperature profile follows without a hitch from the mixed column oceanic winter low temperature in March (16.0°C), through a short spring transition period and to its peak temperature (27.2°C) and steepest thermocline of the oceanic summer in August, thereafter declining through the autumn transition period towards the winter minimum. The S/T diagrams follow as regular a pattern as the temperature profiles. We can follow the development of the local water masses throughout the year from the oceanic winter, when one can see the sole presence of the LDW and LIW, to the peak of the oceanic summer, when we have already the LSW and the AW; further on, we can see the dissipation of the LSW and of the AW as we approach the following winter. The regularity of the salinity profiles, if it exists, is less easy to grasp. In general one can follow the increase in the sea surface and upper layer salinity as well as the formation of the halocline from the winter to the summer. However the development is not as smooth and as monotonous as that of the temperature. The lowest sea surface salinity was observed during MC12 of May 1979 (or was perhaps attained during the missing April) and the highest was observed during MC24 of October 1984.

On the "compacted" time series of cruise-average salinity profiles I depicted the AW and LIW layers, expecting to discover some regular seasonal change. Indeed, the AW (Fig. 10 *a*) appeared to show a reasonable seasonal behaviour. In common with previous investigators (*e. g.* Oren 1971) I could not identify a salinity minimum either at the beginning or at the end of the year (MC11 and MC21), *i. e.* during the winter. Nor could I identify a clear salinity minimum in MC20 of May 1982, but in the Levantine basin May is a transition period and sometimes during this period the sea exhibits a winter regime. Later in the year

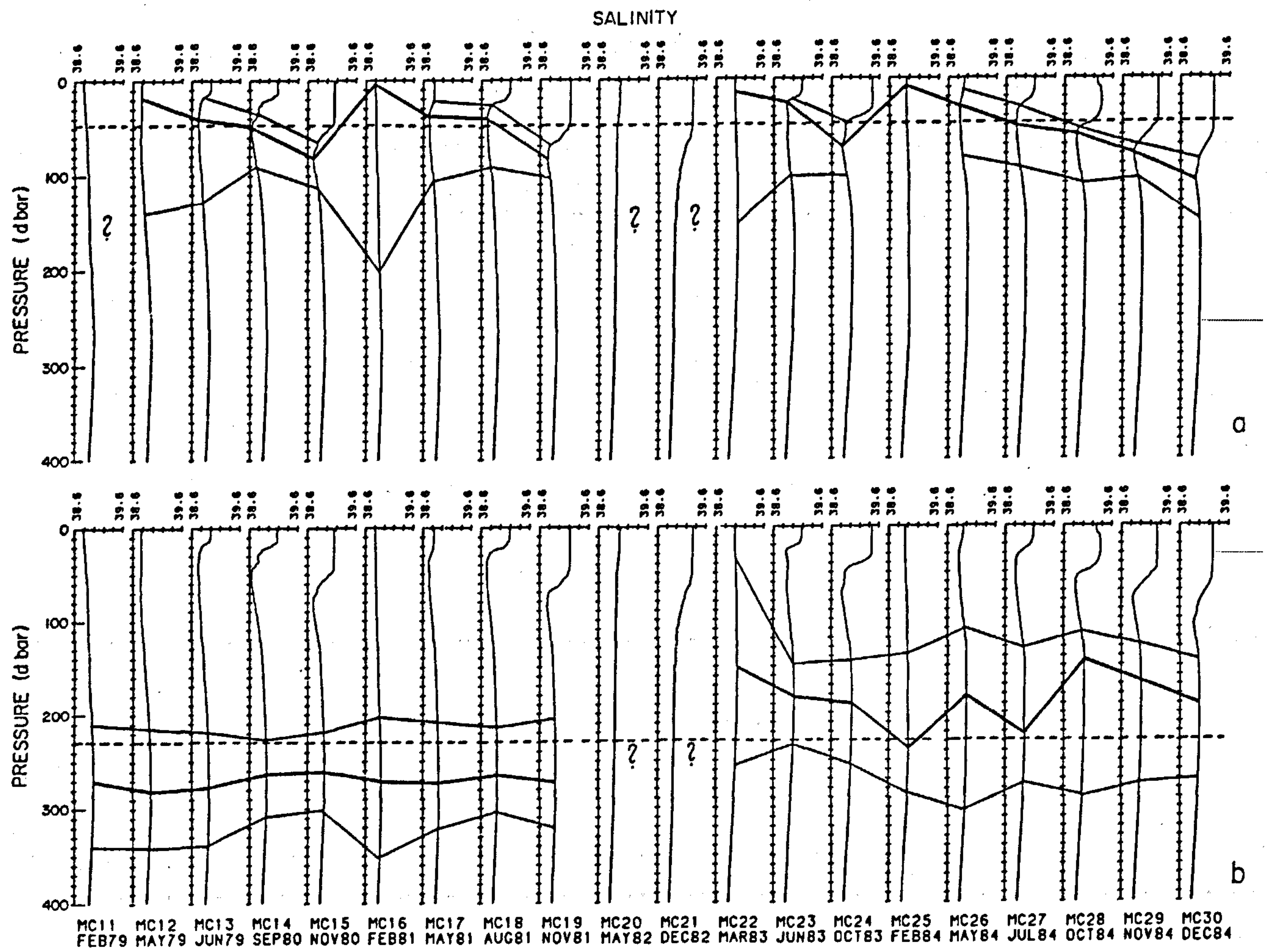


Figure 11

Depth and width of the AW (a) and LIW (b) layers on the sequentially organized salinity profiles from the MC cruises. The thick line indicates the cruise average depth of the layer, the two thin lines indicate the ± one standard deviation from the cruise average, The broken lines indicate the average depth of the layer.

the subsurface salinity minimum was identifiable and followed a downward trend. In other words, as the year progressed and as the LSW become more defined and occupied a wider layer, the salinity minimum was found at a deeper level and the width of the AW layer became narrower, indicating a more homogeneous spread of this layer.

The subsurface salinity maximum (Figure 10 *b*) could be identified throughout the year with the exception of May and December 1982. However the location of the maximum did not appear to be in any way related to the season during which the measurements were obtained and in fact seemed to be random. The most that could be deduced from this particular depiction of the LIW is that the LIW is situated at about 230 dbars and occupies a layer of about 150 dbars.

Having no incentive to depict the LIW on an artificially contrived seasonal time series, I reverted to the original sequence of the cruises and on them depicted the AW and LIW as before (Fig. 11). In so far as the AW is concerned (Fig. 11 *a*) one could, with some effort, notice the seasonal trend described in the paragraph above. However the LIW (Fig. 11 *b*) presented us with a surprise. From February 1979 and until November 1981 the LIW appears at an almost constant depth in a fairly well defined layer. As pointed out above, I could not identify a subsurface maximum, either in May 1982 or in December 1982. From 1983 onwards the depth of the LIW is at a shallower level and far less regular than before.

Hence, with respect to the presence of the AW and LIW, we can clearly identify two periods: period I before 1982; and period II beginning from 1983. For period I, the average AW salinity is 38.72 ± .05 at an average depth of 45 ± 28 dbars, while for period II we find 38.87 ± .06 and 50±33 dbars respectively (Tab. 2). Thus, for the AW, we find a .15 difference in salinity and a 5 dbar difference in depth. For period I, the average salinity of the LIW is 38.95 ± .02 at a depth of 271 ± 7 dbars, while for period II we find 39.02 ± .02 and 187 ± 30 dbars respectively (Tab. 2). Thus, for the LIW, we find a .07 difference in salinity and an 84 dbar difference in depth. It must be stressed once again that throughout this entire series of cruises the values of the salinity and that of the temperatures at deeper levels, *i. e.* below 1 000 dbars (*e. g.* Tab. 1), did not change. Thus the changes in the shallower layers are trustworthy and cannot be ascribed to an instrumentation or data analysis error. Moreover, those changes are larger than the usual error level of our data as may be seen from the variability of the measurements in the layers below 1000 dbars (*e. g.* Tab. 1).

From the statistical point of view the number of samples is small, but a Student's t test could indicate just how significant are the differences between the two periods. As shown in Table 2, the difference in the depths of the AW is insignificant. However, the probability that the AW salinities, the LIW salinities, and the LIW depths for the two periods are actually equal and that the difference between the two periods is due to chance alone, is less than .1 % and for the LIW is even less than .01 %.

The results reflect the statistical characteristics of a region; nevertheless, it may be of interest to determine the picture presented by a single station. One particular station, station 10, was sampled more frequently than the rest, since, in order to obtain some information on the changes that occurred during a cruise, we always occupied this station at the beginning as well as the end of the cruise. In so far as the AW and the LIW are concerned, with slight differences, station 10 time series reflects the two periods described above (Tab. 3). Primarily, the differences lie in the fact that I could identify subsurface minima and maxima on both stations 10 of MC20 but could identify neither minima nor maxima on both stations 10 of MC23. However, I must point out that the depths and the values of the minima and the maxima on MC20 stations 10 do not appear to conform to any of the previous or the later data (that is, except for the salinity of the LIW on MC20.1001). The statistical analysis of the measurements obtained on station 10 (without MC20) suggests once again that there is a very low probability that the differences are due to chance alone (Tab. 3).

To complete the picture, we also examined the deep salinity measurements on station 10 (Tab. 4). Usually the first cast on this station was carried out down to the bottom, but the other casts were not carried out below 1 200 decibars, therefore we did not present the salinities at lower levels.

Table 2

Salinities and depths of AW and LIW layers as determined from cruise average salinity profiles and their respective standard deviations.

Cruise and date		Atlantic waters Salinity psu	min dbar	AW dbar	max dbar	width dbar	Levantine intermediate waters Salinity psu	min dbar	LIW dbar	max dbar	width dbar
MC11	Feb. 1979	No min.					38.99±.04	210	271	340	130
MC12	May 1979	38.76 ± .06	0?	18	142	142	38.96 ± .03	215	282	342	127
MC13	June 1979	38.73 ± .10	18	41	130	112	38.96 ± .03	219	278	339	127
MC14	Sep. 1980	38.63 ± .13	38	49	93	55	38.96 ± .02	227	265	309	82
MC15	Nov. 1980	38.71 ± .09	65	83	114	49	38.95 ± .02	219	261	301	82
MC16	Feb. 1981	38.79 ± .10	0?	4	202	198	38.93 ± .03	203	271	352	149
MC17	May 1981	38.72 ± .09	23	38	106	83	38.93 ± .02	208	274	321	113
MC18	Aug. 1981	38.71 ± .08	27	41	93	66	38.94 ± .01	215	265	303	88
MC19	Nov. 1981	38.75 ± .06	69	84	107	38	38.93 ± .02	204	274	321	117
MC20	May 1982	No min.					No max.				
MC21	Dec. 1982	No min.					No max.				
MC22	Mar. 1983	38.98 ± .08	0?	13	155	142	39.04 ± .04	34	155	257	223
MC23	June 1983	38.85 ± .09	23	27	101	78	39.03 ± .02	148	184	233	85
MC24	Oct. 1983	38.82 ± .09	48	74	103	55	39.04 ± .02	146	190	257	111
MC25	Feb. 1984	38.94 ± .17	0?	8	?		39.01 ± .03	138	238	286	148
MC26	May 1984	38.84 ± .07	15	32	86	71	39.00 ± .05	110	183	301	191
MC27	July 1984	38.81 ± .09	31	51	97	66	39.01 ± .03	131	225	276	145
MC28	Oct. 1984	38.84 ± .12	57	59	111	54	39.03 ± .06	115	146	289	174
MC29	Nov. 1984	38.84 ± .08	72	80	106	34	39.01 ± .03	128	169	276	148
MC30	Dec. 1984	38.89 ± .09	88	108	152	64	39.00 ± .03	145	193	270	125

Averages ± standard deviations

	Salinity psu	Pressure dbar	Salinity psu	Pressure dbar
Period I	38.72 ± .05	45 ± 28	38.95 ± .02	271 ± 7
Period II	38.87 ± .06	50 ± 33	39.02 ± .02	187 ± 30
All	38.80 ± .09	48 ± 30	38.98 ± .04	229 ± 48
Degrees of freedom	15	15	16	16
t	5.22	0.31	6.77	7.28

0.1 % level of confidence for 15 degrees of freedom	4.07
0.01 % level of confidence for 15 degrees of freedom	5.24
0.1 % level of confidence for 16 degrees of freedom	4.02
0.01 % level of confidence for 16 degrees of freedom	5.13

Table 3

Depth and salinity of AW and LIW at station 10 of the MC cruises.

AW	LIW					
Station	**Date**	**Time**	**Pressure (dbar)**	**Salinity**	**Pressure (dbar)**	**Salinity**
MC11.1001	04 Feb. 1979	1111	90	38.77	257	39.02
MC12.1001	25 Apr. 1979	1714	58	38.75	179	39.00
MC12.1002	06 May 1979	1451	56	38.71	240	38.95
MC13.1001	29 June 1979	0300	45	38.81	217	39.00
MC14.1001	02 Sep. 1980	1449	62	38.64	210	38.98
MC14.1002	23 Sep. 1980	1842	55	38.41	280	38.97
MC15.1001	20 Nov. 1980	1930	54	38.60	231	38.97
MC15.1002	02 Dec. 1980	0757	89	38.52	253	38.97
MC16.1001	22 Feb. 1981	1312	0	38.72	255	38.94
MC16.1002	10 Mar. 1981	0809	13	38.65	267	38.95
MC17.1001	20 May 1981	1446	30	38.66	304	38.95
MC17.1002	29 May 1981	1921	35	38.62	293	38.96
MC18.1001	20 Aug. 1981	1532	51	38.59	244	38.94
MC18.1002	30 Aug. 1981	1738	67	38.60	245	38.94
MC19.1001	22 Nov. 1981	1459	67	38.65	214	38.95
MC19.1002	24 Nov. 1981	1606	67	38.55	227	38.95
MC19.1003	04 Dec. 1981	2030	69	38.63	243	38.95
MC20.1001	04 May 1982	0908	09	38.98	61	38.96
MC20.1002	14 May 1982	0908	09	38.89	52	39.02
MC21.1001	03 Dec. 1982	1002				
MC21.1002	07 Dec. 1982	1922				
MC21.1003	16 Dec. 1982	2224				
C22.1001	17 Mar. 1983	1806				
MC22.1002	26 Mar. 1983	1533				
MC23.1001	09 June 1983	1835	32	38.71	211	39.04
MC23.1002	28 June 1983	1156	25	38.48	151	39.02
MC24.1001	05 Oct. 1983	2034	70	38.61	171	39.04
MC24.1002	26 Oct. 1983	0819	65	38.70	220	39.05
MC25.1001	12 Feb. 1984	1700	56	38.73	303	39.03
MC25.1002	23 Feb. 1984	1030	16	38.74	255	38.99
MC26.1001	22 May 1984	1725	20	38.90	218	39.02
MC26.1002	22 May 1984	1926	24	38.83	140	39.07
MC26.1003	31 May 1984	0827	26	38.94	152	39.07
MC27.1001	30 July 1984	1542	36	38.64	144	39.05
MC27.1002	08 Aug. 1984	0411	33	38.71	221	39.01
MC28.1001	25 Oct. 1984	1700	65	38.76	189	39.03
MC28.1002	03 Nov. 1984	0720	59	38.82	126	39.03
MC29.1001	13 Nov. 1984	1623	58	38.83	128	39.04
MC29.1002	22 Nov. 1984	0949	58	38.83	125	39.02
MC30.1001	04 Dec. 1984	1713	71	38.84	120	39.02
MC30.1002	04 Dec. 1984	1908	68	38.84	114	39.01

Averages ± standard deviations

Period I	53 ± 24	38.64 ± .10	245 ± 31	38.96 ± .02
Period II	46 ± 20	38.76 ± .11	176 ± 54	39.03 ± .02
All	49 ± 22	38.70 ± .12	210 ± 56	38.99 ± .04
Degrees of freedom	32	32	32	32
t	.9	3.23	4.43	8.53

1.0 % level of confidence for 32 degrees of freedom	2.75
0.1 % level of confidence for 32 degrees of freedom	3.65
0.01 % level of confidence for 32 degrees of freedom	4.48

Table 10 shows that, in the deep layers, there is no apparent change in the salinity throughout the entire series of cruises. This further supports our conclusion that the salinity changes observed in the shallower layers are real.

Unfortunately, the MC series was discontinued at the end of 1984, but station 10 was visited on a number of other cruises. Thus, on 1 November 1985, during the POEM01 cruise, we find the minimum subsurface salinity (AW) of 38.76 at 56 dbars, and the maximum subsurface salinity (LIW) of 39.09 at 198 dbars. On 31 March 1986, during the POEM02 cruise, we find the minimum subsurface salinity (AW ?) of 39.01 at 45 dbars,and the maximum subsurface salinity (LIW) of 39.05 at 208 dbars. On 26 March 1989, during the LDSB01IS cruise, we could not identify a subsurface salinity minimum, but the subsurface salinity maximum appears to be 39.12 at 73 dbars. The results of these

Table 4

The salinity at selected depths on station 10 of the MC cruises.

			Pressure dbar			
Station	**Date**	**Time**	**900**	**1000**	**1100**	**1200**
MC11.1001	04 Feb. 1979	1111	38.73	38.73	38.72	38.72
MC12.1001	25 Apr. 1979	1714	38.74	38.73	38.73	38.73
MC12.1002	06 May 1979	1451	38.70	38.69	38.69	
MC13.1001	29 June 1979	0300	38.72	38.71	38.70	
MC14.1001	02 Sep. 1980	1449	38.72	38.70	38.70	
MC14.1002	23 Sep. 1980	1842	38.72	38.71	38.70	
MC15.1001	20 Nov. 1980	1930	38.71	38.70	38.69	38.69
MC15.1002	02 Dec. 1980	0757	38.71	38.70	38.69	38.69
MC16.1001	22 Feb. 1981	1312	38.70	38.70	38.69	38.68
MC16.1002	10 Mar. 1981	0809	38.69	38.68	38.67	38.66
MC17.1001	20 May 1981	1446	38.71	38.70	38.70	38.69
MC17.1002	29 May 1981	1921	38.71	38.70	38.69	38.68
MC18.1001	20 Aug. 1981	1532	38.70	38.70	38.69	38.69
MC18.1002	30 Aug. 1981	1738	38.70	38.69		
MC19.1001	22 Nov. 1981	1459	38.70	38.70		
MC19.1002	24 Nov. 1981	1606	38.70	38.70	38.69	38.68
MC19.1003	04 Dec. 1981	2030	38.70	38.70	38.69	38.68
MC20.1001	04 May 1982	2011	38.70	38.70	38.69	38.69
MC20.1002	14 May 1982	0908	38.71	38.70		
MC21.1001	03 Dec. 1982	1002	38.72	38.71	38.70	38.70
MC21.1002	07 Dec. 1982	1922	38.71	38.70	38.70	38.69
MC21.1003	16 Dec. 1982	2224	38.70	38.69	38.69	38.68
MC22.1001	17 Mar. 1983	1806	38.71	38.70	38.70	38.69
MC22.1002	26 Mar. 1983	1533	38.70	38.69	38.69	38.68
MC23.1001	09 June 1983	1835	38.72	38.71	38.70	38.69
MC23.1002	28 June 1983	1156	38.70			
MC24.1001	05 Oct. 1983	2034	38.71	38.71	38.70	38.70
MC24.1002	26 Oct. 1983	0819	38.70	38.70		
MC25.1001	12 Feb. 1984	1700	38.71	38.70	38.69	38.69
MC25.1002	23 Feb. 1984	1030	38.71	38.70	38.69	38.68
MC26.1002	22 May 1984	1725	38.71	38.70	38.69	38.69
MC26.1001	22 May 1984	1926	38.71	38.70	38.70	38.69
MC26.1003	31 May 1984	0827	38.71	38.70	38.70	38.69
MC27.1001	30 July 1984	1542	38.70	38.69	38.69	38.68
MC27.1002	08 Aug. 1984	0411	38.70	38.70	38.69	38.69
MC28.1001	25 Oct. 1984	1700	38.70	38.70	38.69	38.68
MC28.1002	03 Nov. 1984	0720	38.70	38.69	38.68	38.68
MC29.1001	13 Nov. 1984	1623	38.70	38.69	38.69	38.68
MC29.1002	22 Nov. 1984	0949	38.70	38.70	38.69	38.68
MC30.1001	04 Dec. 1984	1713	38.70	38.69	38.69	38.68
MC30.1002	04 Dec. 1984	1908	38.69	38.68	38.68	38.67
Average			38.71 ±0.01	38.70 ±0.01	38.69 ±0.01	38.69 ±0.01

sporadic samples appear to be irregular, but seem to indicate that the salinities extrema and the depths at which they are found did not revert to their pre-1982 values.

DISCUSSION

There is a growing interest in what appear to be interannual changes in previously assumed "stable" characteristics of the deep water masses of the world ocean, since these changes are attributed to climatic changes and could be used as a sensitive tool to monitor and investigate the effects of climatic changes. Such interannual changes were reported in the Western North Pacific by White and Meyers (1982), and in North Atlantic by Brewer *et al.* (1983) as well as by Roemimch and Wunsch (1984).

In the Mediterranean Sea, Bethoux (1979) describes the factors that could lead from a climatic change to a change in the water characteristics and flow. Lacombe *et al.* (1985), in a detailed study of the deep waters of the Western Mediterranean, report on the sporadic appearance of warmer and more saline bottom waters, distinct from the overlying deep waters. They ascribe the formation of these waters to open-sea deep convection interacting with the other water masses advecting into the region, *i. e.* Local Intermediate Waters and Levantine Intermediate Waters. They conclude that the most important cause for the production of the "new" bottom waters should probably be sought in the variation of the surface heat budget, but a "quick look" at the recent rain statistics along the French coast did not yield any information. Parilla *et al.* (1986) also found real interannual changes in the LIW in the Alboran Sea. Charnock (1989) points out that the trend described by Lacombe *et al.* (1985) is continuing and that there are indications that the Deep Water of the Eastern Mediterranean Sea is changing. Charnock also points out that "changes in the characteristics of the Deep Water reflect changes in sea-surface energy exchange processes and are linked to changes in weather and climate, possibly not only locally but over the whole Mediterranean basin". Thus, concludes Charnock, the monitoring of those changes can provide a sensitive indicator of climatic changes on a time scale of about one hundred years. Bethoux *et al.* (1990) found that in 1988 the deep waters of the western Mediterranean were significantly warmer and more saline than in 1959. They conclude that this has been a continuous trend during the past three decades and ascribe the effect to greenhouse-induced warming.

Theocharis *et al.* (1985), report that from 1972-1976 to 1980-1982 an unusual and significant (.8) decrease in the integrated salinity of the upper 60 m layer occurred in the Saronikos Gulf. Although they observed an increase in precipitation during 1976-1982, they conclude that this was not sufficient to explain the decrease in the salinity and, by a process of elimination, attribute this change to advection of fresher than usual Black Sea waters into the Aegean Sea. Lascaratos (1989) uses the same data as well as additional data from the Evoikos Gulf and, in conjunction with evidence of the sea level changes in the Aegean, reaches the conclusion that these are "obviously related to some climatic oscillation in the area".

A thirty-year time series of measurements in the middle of the Adriatic Sea, analysed by Zore-Armanda *et al.* (1988), and Zore-Armanda and Gacic (1991) indicate a clear upward trend in salinity amounting to about .2 during the last twenty years of the series. A less conspicuous increase in temperature was also observed. After failing to find corresponding changes in the local components of the mass balance equation (*e. g.* precipitation or runoff), they conclude that the salinity change is due to the erection of the Aswan High Dam on the Nile and the subsequent reduction in the Nile runoff from about 40 km^3 per year to about 4 km^3 per year (Gerges, 1976). The temperature change is attributed to the different value at which vertical convection takes place.

In the shallow waters along the coast of Israel, the effects of the Nile floods were quite dramatic (*e. g.* Hecht 1964). Within about a month of the beginning of the flood the salinity along the coast of Israel dropped significantly (*i. e.* from about 39 to as low as 33, Fig. 12 *a*). The salinity distribution in the coastal region was quite sensitive to the volume of the discharge (*e. g.* Fig. 12 *a versus* Fig. 12 *b*). The "fresh waters" along the coast dispersed within about a month and the salinity distribution returned to "normal" (*e. g.* Fig. 12 *c versus* Fig. 12 *d*). Thus, the effects of the erection of the High Dam at Aswan on the physical characteristics and on the bio population of the waters along the coast of Israel became apparent quite early (Oren, 1969; Oren, 1970; Oren and Hornung, 1972). However, the dam affected not only the Israeli coast but was reported to affect the entire circulation of the southeastern Levantine basin (*e. g.* Gerges, 1976; Sharaf El Din, 1977). Nof (1979) showed that, in the Mediterranean Sea, the diversion of all the fresh water could be responsible almost solely for changes in the circulation pattern in general and in the salinity of the waters egressing from the strait of Gibraltar in particular. He also showed that other factors, such as changes in the contribution of the Black Sea and changes in evaporation due to a change in the salinity are negligible. He concludes that, due to the diversion of the Nile alone, the flow through the strait of Gibraltar should achieve steady state in about 25 to 50 years (*i. e.* between 1990 and 2015) and by then the flow will be larger by about .5 % (about eight

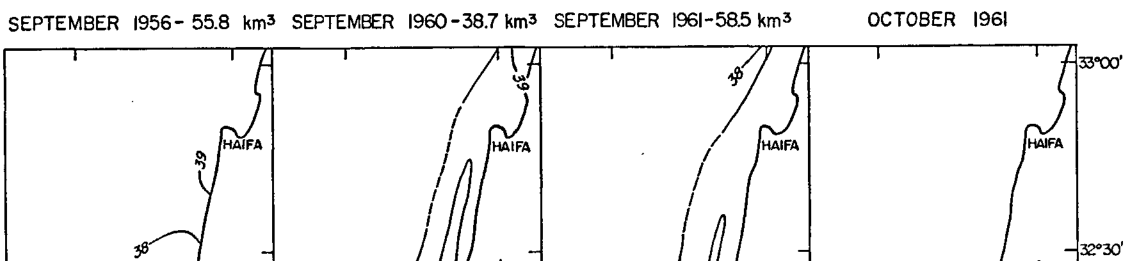


Figure 12

Nile waters along the coast of Israel during the Nile floods. The volumes shown at the top of the figures indicate the Nile discharge during the respective years.

times the volume of the diverted waters); the salinity of the egressing waters will increase by about .016 and that their temperature will also be higher. Qualitatively, this means that the salinity of the Levantine Intermediate Water must increase although, an increase in the salinity of the waters entrained in the egressing flow, *i. e.* the deep waters of the Mediterranean or the ingressing Atlantic waters, could also contribute to the increase of the salinity of the egressing flow. A quantitative estimate of the increase in salinity at the source (*i. e.* in the Eastern Mediterranean) appears to be quite difficult; qualitatively, however, this increase is bound to be significantly larger than that of the waters egressing from the strait of Gibraltar.

A comparison between the average LIW subsurface maximum before and after 1982 (38.95 *versus* 39.02 respectively) reveals an increase of .07, *i. e.* about four times as much and ten years earlier than predicted by Nof for the straits. According to Nof (1979), if all the rivers were diverted, the salinity increase in the lower layer of the strait would increase by about .1. Since the Nof (1979) paper, more, though not all, rivers have been diverted. Thus, even if one takes into consideration the dispersion of the LIW from the Levantine basin to Gibraltar, the salinity increase observed by us still appears to be conspicuously large.

Finally, the fact cannot be ignored that the salinity change was abrupt, which does not fit the Nof (1979) model, and that it occurred at the end or perhaps even in the middle of 1982. Now, 1982 is notorious for witnessing the most extreme El Nino of the century (*e. g.* Rasmunsson and Wallace, 1983) and the Southern Oscillation that induced that event had far-reaching effects on the meteorology and the oceanography of many regions of the globe (*e. g.* Cane, 1983; Wright, 1985; Rasmunsson, 1984). The abrupt change which occurred during 1982 was also reflected in the mesoscale circulation of the region (*see* Fig. 16 *in* Hecht *et al.*, 1988) and preceded the establishment of a "new" quasi permanent eddy there. Moreover, Brenner *et al.* (1991), in their investigation of the same region, point out that still a "newer" eddy replaced the previous one during the first half of 1987. Once again, this appears to coincide with a stronger than moderate El Niño. Unfortunately the MC series were discontinued before 1987 and therefore the results presented by Brenner *et al.* (1991) relate only to a small part of the region previously covered by the MC series. Moreover, the series from the Adriatic does not extend beyond 1982, and therefore we do not know whether 1982 or 1987 present us with any particularly conspicuous changes in that region. Lascaratos, however, in a personal communication, advises me that the series in the Saronikos Gulf was continued and they observed an abrupt return to "normally high" salinities in 1983.

The parameters that are usually affected by an ENSO (*i. e.* sea surface temperature, cloudiness, precipitation, and winds) have a direct bearing on the mass and salinity continuity equation. Therefore one can hardly avoid the speculation that the changes that we have observed in the AW and LIW characteristics could be related to ENSO. However, I am not aware of any study that has shown ENSO-related meteorological effects in the Eastern Mediterranean and my own attempts at demonstrating some ENSO effects in the South Eastern Levantine basin were not conclusive.

SUMMARY AND CONCLUSIONS

The original purpose of the investigation was to reveal seasonal changes in the AW and the LIW similar to those reported in the strait of Sicily and the strait of Gibraltar. The results indicated a seasonal trend in the AW, which appear to be poorly defined during winter and spring but which become better defined, as the year progresses and as the LSW form and occupy a deeper layer, and form a narrower layer whose depth increases. There appeared to be no season related variations in the LIW.

The present investigation also revealed an abrupt and seemingly permanent change in the characteristics of the AW and LIW which occurred in the South Eastern Mediterranean during the middle of 1982. The change in the AW did not interfere with the recognition of the seasonal trend in the AW. The time series analysed in the present report was discontinued but later measurements (in 1985, 1986 and 1989) at the site of station 10 of the MC series indicate that water masses did not revert to their pre-1982 state and in fact there may be some indications that the changes persisted.

One obvious cause of the change, and a reason adopted by some other investigators when and where such changes have been observed, is the diversion of the waters of the Nile and the diversion or diminution of the runoff from other less voluminous rivers. Although the monitoring of river water diversion should be a simple task and indeed seems to be carried out, it is difficult to locate the relevant information. As pointed out above, the changes seem to persist, which may indicate that we have not yet reached a steady state; thus it is still important to convince the involved parties to publish the information referred to. Quantitatively the effect appears to be stronger than expected, but lack of proper models prevents the computation of precise estimates.

On the other hand, it is very tempting, in the light of facts, as well as current fashion, to ascribe those changes to climatic variations. Obviously, a change in the regional climate would change the components of the mass and salinity continuity equations. However, the suddenness of the changes is not in keeping with a gradual climatic change, although such abrupt changes or jumps are known to occur in regional-scale climatic series (*e. g.* Flohn and Weber, 1986). Moreover, we still have to show that the changes are in the right direction - *i. e.* enhanced evaporation and/or diminished precipitation - which is far from a simple task. GCMs which predict climatic changes are notoriously inaccurate in predicting regional and local changes. Wigley (1988) sums up the predictions from four different GCMs as follows: "...very few clear indications of precipitation changes. However, the data suggest increased winter precipitation in the north and decreased winter precipitation in the south, which could mean drying of the southern portion of the Mediterranean Basin relative to the north". This of course would support the thesis that the observed changes in the AW and LIW are the results of changing weather. There are however conflicting reports (*e. g.* Alpert *et al.*, 1991) which maintain that mesoscale models show a marginal increase in precipitation; particularly, Ben-Gai *et al.* (1991) demonstrate a definite increase in the annual rainfall in southern Israel from 1963 to 1985. The latter, however, is thought to be linked with an intensive agriculture and afforestation programme.

Obviously, I cannot conclude that the AW and the LIW changes are the result of a particular set of circumstances; most probably they are the result of a combination of events. However, as was pointed out from the very beginning, the AW and the LIW have far-reaching influences on the entire body of the Mediterranean Sea as well as on the Atlantic Ocean. Since the LIW contributes to the western Mediterranean deep waters, an increase in the temperature and the salinity of LIW would induce similar changes in the western Mediterranean intermediate and deep waters - as observed by Bethoux *et al.* (1990) - and eventually, the egressing Mediterranean waters will contribute to the increase in the temperature and the salinity of the Atlantic deep layers, as observed by Roemmich and Wunsch (1984). Consequently it is critical to monitor the characteristics and the quality of the AW and LIW in the Eastern Mediterranean Sea.

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