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Seasonal variation of the cold intermediate water in the Southwestern Black Sea and its interaction with the the Sea of Marmara during the period of 1996-1998

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Abstract

Seasonal variations of the cold intermediate water (CIW) in the southwestern Black Sea and its entrance into the Strait of Istanbul (Bosphorus) within the upper layer flow have been studied by using monthly oceanographic data sets collected in 1996-1998 period. In addition, the advection of the CIW via Strait Of Istanbul to the Sea of Marmara has been investigated.

The CIW is a permanent and characteristic water mass of the Black Sea, markedly observed in the northwestern Black Sea. It is transported with the Rim Current along the boundary of the basin. The average temperature of the CIW is about 6° C. The 8° C isotherms defines its upper and lower boundaries. The upper boundary of CIW rises up to the 20 m depth in the shelf and coastal upwelling regions with a thickness of 40 m. On the other hand, the depth of the upper boundary may decrease down to 40 m with a thickness of 120 m in the anticyclonic regions.

The CIW, located between 30 and 65m depths, was observed from April to September at the northern approaches of the Strait of Istanbul in the Black Sea. However, the CIW, within the Black Sea's upper layer flow, does not enter into the strait in the beginning (April, May) and at the end (September) of this period. The CIW between 20 and 50m water depths was observed in the northern entrance of the strait in summer (June, July and August) and it was carried into the strait by the southbound surface current. Its temperature increases southwards along the strait, due to the mixing with the warmer surface and bottom layers. This increment ranges between 2 and 4° C depending on the rate of mixing. The physically altered waters enter the Sea of Marmara with temperature of 11-14° C.

In the Sea of Marmara, a residual cold intermediate layer (CIL) is observed in summer, it is just placed on top of the halocline. The average temperature of the upper layer increases from spring to autumn. In some months, however, there is a decrement in the average temperature of the upper layer. The altered CIW waters entering the Sea of Marmara may be responsible for this cooling.

Keywords: CIW, Black Sea, Sea of Marmara, Strait of Istanbul.

Introduction

The Black Sea represents a unique environment in that it is a relatively small, deep basin, which is connected via a shallow water passage, the Strait of Istanbul, to the Mediterranean Sea. Therefore, it forms a semi-stagnant basin with anoxic conditions below 150-200 m water depth.

The Black Sea posseses restricted water exchange with the Mediterranean Sea and relatively large amount of the river discharges (STANEV, 1990). The deep water, relatively highly saline and anoxic, is placed below the permanent halocline which is restricted to upper layer (150-200m). The upper layer consists of several layers, which are mixed layer, seasonal termocline and CIW. The seasonal termocline at 15-30m depth depends on spatial and temporal variability. The cold intermediate layer, which is defined by the temperatures less than 8°C, takes place between the seasonal and permanent termocline (TRUKHCHEV *et al.,* 1985; STANEV, 1990). It can be observed when the surface layer temperature is higher than 8°C.

Cold intermediate water (CIW) is formed by the sinking water which cools surface layer of northwestern Black Sea in winter (TOLMAZIN, 1985; STANEV, 1990; OGUZ *et al.*, 1998). The CIW is advected by the Rim Current characterised by a predominantly cyclonic, time depended and spatially structured basin-wide circulation. During its course around the basin, it is entrapped by the associated eddy field, where it is continuously modified (OGUZ *et al.,* 1992). In the peripheries of the anticyclonic eddies there is observed a rising of CIW, often creating an anamolous cold patch on the shelf (ADRIONOVA & KHOLOPTSEV, 1992).

When the seasonal termocline is sharp in late spring and summer, the heat and salt transport into the CIW is limited and therefore the characteristics of the CIW do not change significantly. However, the vertical transport of the heat and salt into the CIW increases in autumn due to the weak seasonal termocline (OGUZ *et al.,* 1992; SUR & ILYIN, 1997).

The CIW is a dynamically passive layer (STANEV, 1990) and it can be easily influenced by the surrounding water. CIW is advected by the upper layer flux coming from the Black Sea to the Strait of Istanbul. In the vicinity of the strait, the Mediterranean water interacts with the CIW and their temperature and salt content change (OZSOY *et al.,* 1991).

In the Sea of Marmara, an intermediate cold layer presents just above the salinity interface in summer months. This layer is partially formed within the Sea of Marmara in winter months, and is partially advected from the Black Sea (UNLUATA *et al.,* 1990).

In this study, monthly temperature variations along the Strait of Istanbul are evaluated in order to elucidate the effects of the upper and lower fluxes on the CIW. We investigated the relation of the monthly temperature variations observed in the Sea of Marmara during summer months with the CIW's seasonal changes in vicinity of the strait. We also studied the cold intermediate layer which only existed in the Sea of Marmara from May to September.

Material

The monthly CTD data were collected by the research vessel R/V Arar of the Istanbul University, Institute of Marine Sciences and Management (IMSM-IU) during the period of February 1996 - December 1998. The location of the monthly station are given in Figure 1. Our analyses are also based on the CTD measurements in the Black Sea exit obtained by the Department of Navigation, Hydrography and Oceanography (DNHO). The DNHO's sea trials were realised in November 1995 and 1996, May, June, July 1996 and October 1997 in different number of stations (Fig. 2).

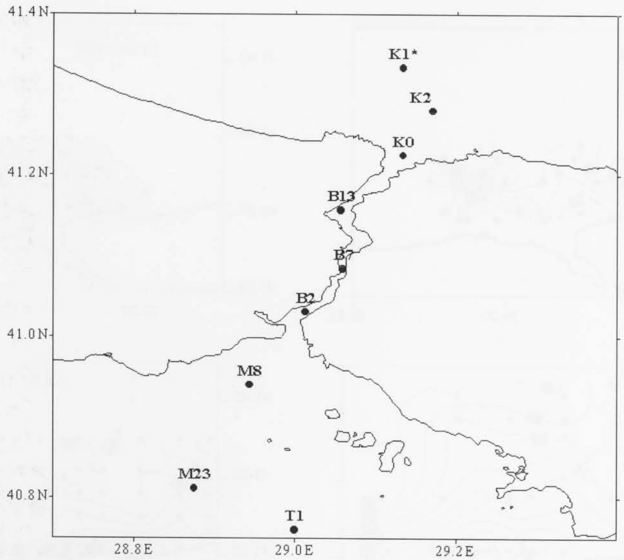

Fig. 1: Locations of monthly visited stations with R/V Arar (K1 one in 3 months).

Seasonal Variation of CIW in the Southwestern Black Sea

In the southwestern Black Sea, approaches to the Strait Of Istanbul, different water masses meet and interact with each other. The upper layer of the Black Sea is influenced by the Rim Current and river discharge. The CIW is advected by the upper layer into the area. Another water mass is the Mediterranean water coming from the strait. The seafloor morphology plays important role on the transportation of the Mediterranean water which flows in a channel defined by the 55m isobath, with a width ranging between 650 and 1950m. The length of channel is approximately 7.5km in the direction of 33°T. Then it turns and extends 2.5 km toward north. The sill depth is 61m and its length is 3.75km (YUCE, 1996). Since the Mediterranean water comes across the CIW at first, its salinity and temperature decreases. The starting depth of CIW is determined by the upper layer, while its ending depth is determined by the Mediterranean water, if it is there depending mainly on the water depth. However, the CIW is generally lowermost layer due to shallowness (<100m).

In order to determine the seasonal variations of the CIW, the depths of 8°C temperature were plotted for each survey. The upper layer boundary of the CIW takes place 28-36m in May 1996 (Fig. 2). The higher depth values were observed in deeper regions. In June 1996, the starting depth of CIW was observed between the depths of 30 and 38m. The upper layer thickness increases due to atmospheric heating. In the end of June 1996, during another cruise in an extended area, the upper layer boundary of the CIW is in the range of 24-40m. In July 1996, 10 days later, it ranges between 24-32m. In addition, the starting depth of CIW seems to be higher in the channel which the Mediterranean water flows in Figure 2.

In October 1997, we did not observed the upper layer boundary of the CIW in the shallow shelf area. For deeper areas, the depths of the 8°C thermocline was between 58 and 64m uplifting offshore direction. In November 1996, it was about at 60m water depth. In November 1995, the spatial variation of CIW is again observed in deep areas, varying between 60 and 75m below sea level (Fig. 2).

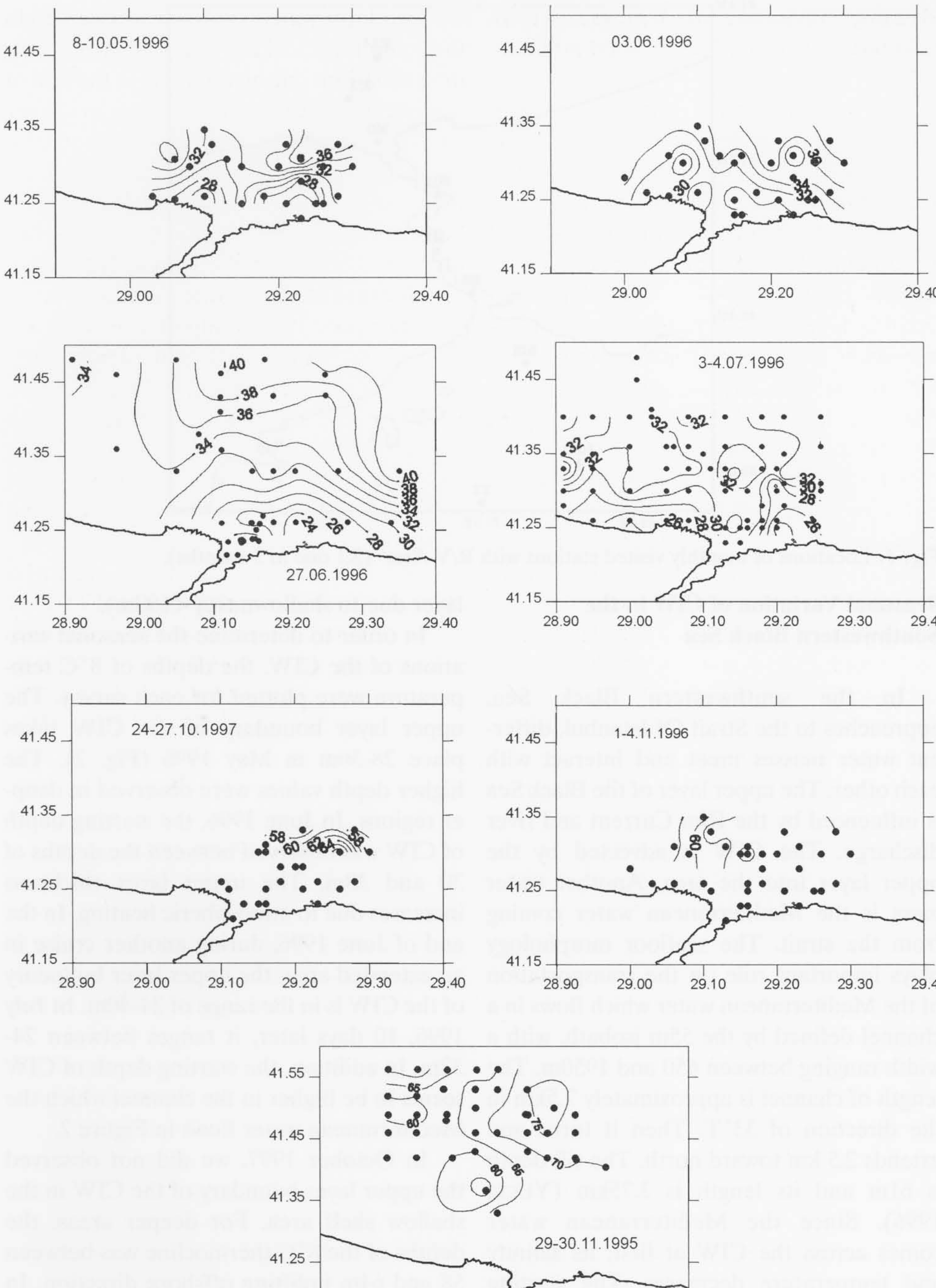

Fig. 2: The starting depth of the CIW in the Southwestern Black Sea.

Monthly variation of temperature in Northern entrance of strait of Istanbul

The comprehensive data set collected from February 1996 to December 1998 reveals monthly and interannual variabilities in the temperature at the stations K0 and K2 (Fig. 1). The overlay temperature profiles of these station (dashed lines refers the station K2) are given in Figure 3. The March and October 1998 data are missing for both stations while the January and September 1997 data are only missing for the station K2. In 1996, the station K2 was measured only for two months (August and November). The temperature profiles in station K0 provides us the monthly variation of entering water from the Black Sea. Temperature distribution in the station K2 indicates the characteristics of the south-western Black Sea. The monthly variations of the upper layer, cold intermediate layer and the Mediterranean water can be seen in Figure 3.

Two-layer water column was observed in the stations K0 and K2, except some uncommon situations during the year. In the end of autumn, the temperature of the upper layer was not distinguished from the temperature of the lower layer, since their temperature were very close to each other (~14°C). In February 1998, the Mediterranean water was not observed in the station K2 due to the blockage of the Mediterranean water.

The upper layer temperature indicates the seasonal changes. The minimum temperature was observed as 3.0°C in February 1996 and the maximum temperature was found to be 24.8°C in August 1998. The upper layer thickness ranges from a few meters to 50-65m down to where exists the Mediterranean water.

The Mediterranean water can be observed in all months expect February 1998 in the station K2. Its temperature was in the range of 13.5-15.0°C. Its thickness changes seasonally between 5 and 20

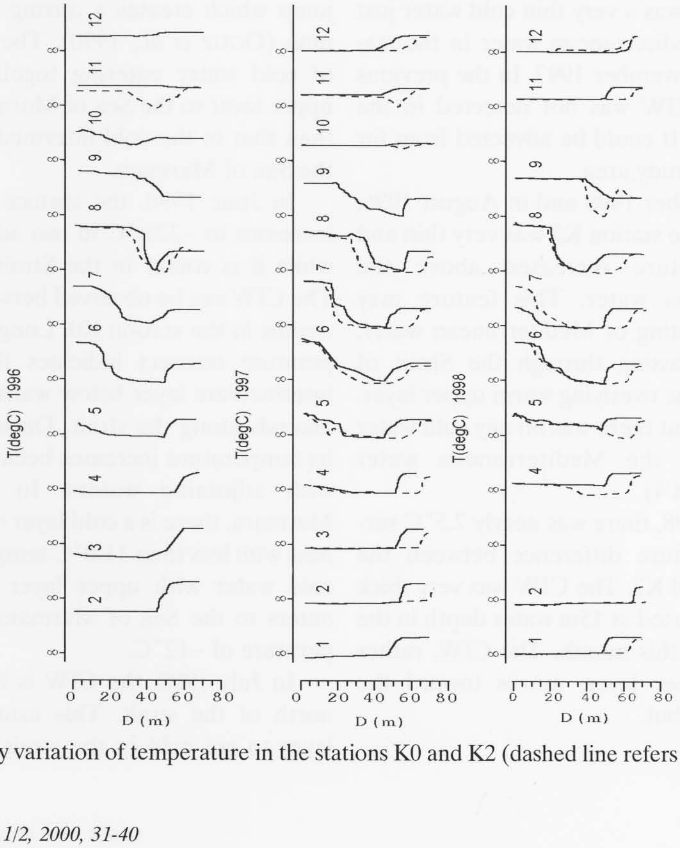

Fig. 3: Monthly variation of temperature in the stations K0 and K2 (dashed line refers the station K2).

meters, reaching the minimum values in winter and early summer months. The temperature and thickness of the Mediterranean water were determined by the hydrographic conditions in the Strait of Istanbul.

The surface water temperature increases as a result of seasonal heating in April. In the station K0, the topmost 5-m water layer were heated in April 1996 and 1997. In April 1998, on the other hand, the warm upper layer extends down to nearly 50m water depth and its temperature was almost 10°C. In the station K2, the CIW was between 40 and 60m depths in April 1998. From May to August, the CIW was observed below the seasonal termocline in the station K0. During this period, in the station K2, the CIW take places as a thicker and colder layer than that in the station K0 (Fig. 3).

The temperature of the upper layer starts to decrease in September and it reaches to a minimum value in February. Although the CIW was not observed in this period, there was a very thin cold water just above the Mediterranean water in the station K2, in November 1997. In the previous month, the CIW was not detected in the same station. It could be advected from far shore to the study area.

In September 1998 and in August 1996, the CIW in the station K2 was very thin and the temperature increased above the Mediterranean water. This feature may imply the heating of Mediterranean water, while it is passing through the Strait of Istanbul, by the overlying warm upper layer. This means that there was no any cold water contact with the Mediterranean water (Figures 3 and 4).

In July 1998, there was nearly 7.5°C surface temperature difference between the station K0 and K2. The CIW was very thick and nearly started at 15m water depth in the station K0 in this month. The CIW, rather than the upper layer, moves toward the Strait of Istanbul.

CIW Modification in strait of Istanbul

The temperature transects along the Sea of Marmara, Strait of Istanbul and at the Black Sea exit are given in Figure 4 from May to September 1998 which can be observed the CIW in Black Sea exit of the strait.

In May 1998, temperature of the surface layer is about 15°C in northern part of the Strait of Istanbul. It decreases to less than 14°C in the station B2. In the Sea of Marmara, the surface temperature is greater than 14°C. There is a cold layer of 5-6m thickness and its temperature is less than 11°C, below 20m depth in the Sea of Marmara. The CIW was found in vicinity of the strait (station K1 and K2) between 55 and 65m. As noticed from the figure, the CIW does not effect significantly the upper layer of the strait. It effects the Mediterranean water in the station K2, as decrease its temperature. Cooling of the surface water in the station B2 is due to a hydraulic jump which creates a mixing in water column (OGUZ *et al.,* 1990). The temperature of cold water entering together with the upper layer to the Sea of Marmara is higher than that in the cold intermediate water in the Sea of Marmara.

In June 1998, the surface temperature increases to ~22.0°C in two adjacent basins while it is colder in the Strait of Istanbul. The CIW can be observed between ~40-50m depths in the station K0. Longitudinal temperature transect indicates that the cold intermediate layer below warm upper layer ascends along the strait. During transition, its temperature increases because of mixing with adjoining waters. In the Sea of Marmara, there is a cold layer of 5-6m thickness with less than 11.0°C temperature. The cold water with upper layer of the strait enters to the Sea of Marmara with a temperature of ~12°C.

In July 1998, the CIW is thicker to the north of the strait. This cause the upper layer to get cold in the strait. The surface

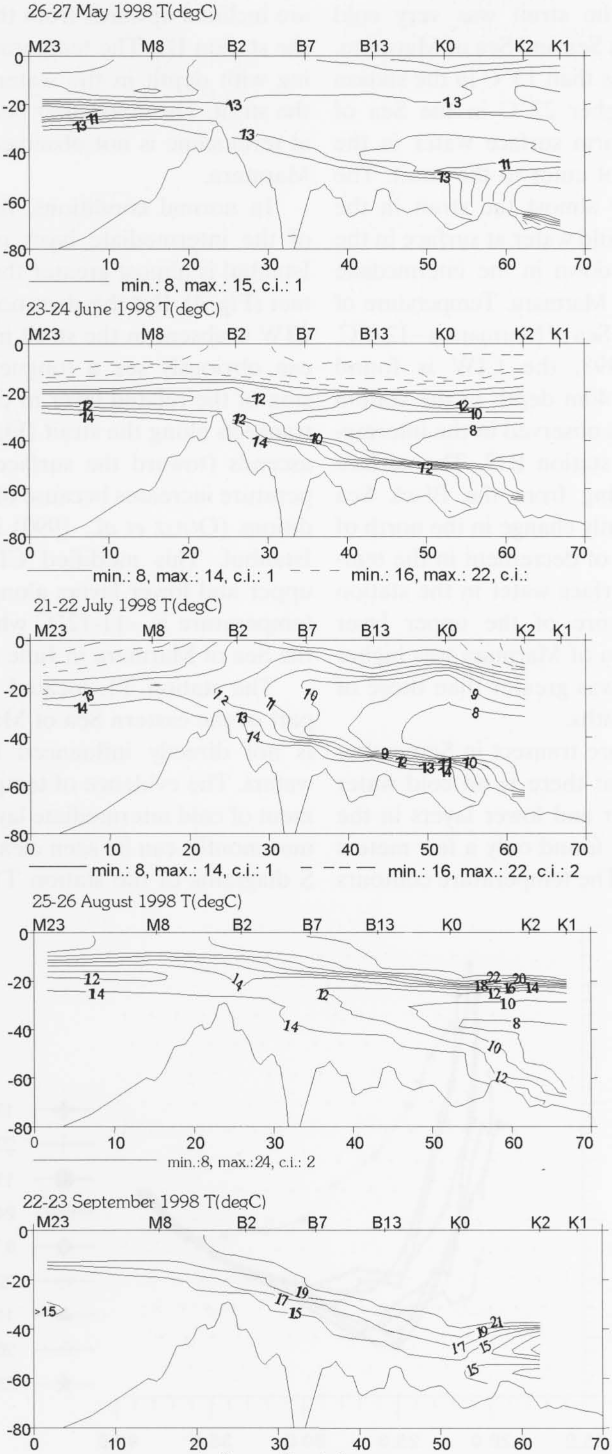

Fig. 4: The temperature transects in the Strait of Istanbul and its south and north approaches.

temperature in the strait was very cold according to Black Sea and Sea of Marmara. Especially, it is less than 13°C in the station B2 while it is higher 22°C in the Sea of Marmara. The warm surface water in the Black Sea does not enter to the strait. The cold waters cover almost the strait in the upper layer. The cold water at surface in the station B2 settles down in the intermediate layer in the Sea of Marmara. Temperature of the cold layer in the Sea of Marmara is ~12.0°C.

In August 1998, the CIW is found between ~30 and 40m depth in the station K0. Its influence is observed in the intermediate layer up to station B13. The surface temperature coming from the Black Sea does not significantly change in the north of the strait. In spite of decrement in the temperature of the surface water in the station B2, the temperature of the upper layer entering to the Sea of Marmara was higher than 14°C which was greater than those of the previously months.

The temperature transect in September 1998, indicates that there is no cold water between the upper and lower layers in the strait. The CIW is found only a few meters in the station K2. The temperature contours are inclined upwards from the station K0 to the station B2. The temperature is decreasing with depth in the water column along the strait. The cold water below the seasonal termocline is not observed in the Sea of Marmara.

In normal conditions, the temperature of the intermediate layer in the Strait of Istanbul is almost greater than 8°C in summer (Fig. 4). But this does not mean that the CIW is absent in the strait in summer. One can obviously see a tongue-shaped extension of the related layer in the temperature transects along the strait (Fig. 4). This layer ascends (toward the surface) and its temperature increases because of hydraulic conditions (OGUZ *et al.,* 1990) in the Strait of Istanbul. This modified CIW mixes with upper and lower layers along the strait. Its temperature is ~11-12°C when it enters to the Sea of Marmara in June and July.

The station T1, located at the deepest part of the eastern Sea of Marmara (Fig. 1) is not directly influenced by the coastal waters. The evidence of temperature decrement of cold intermediate layer during summer months can be seen clearly from the T-S diagrams of the station T1 (Fig. 5). The

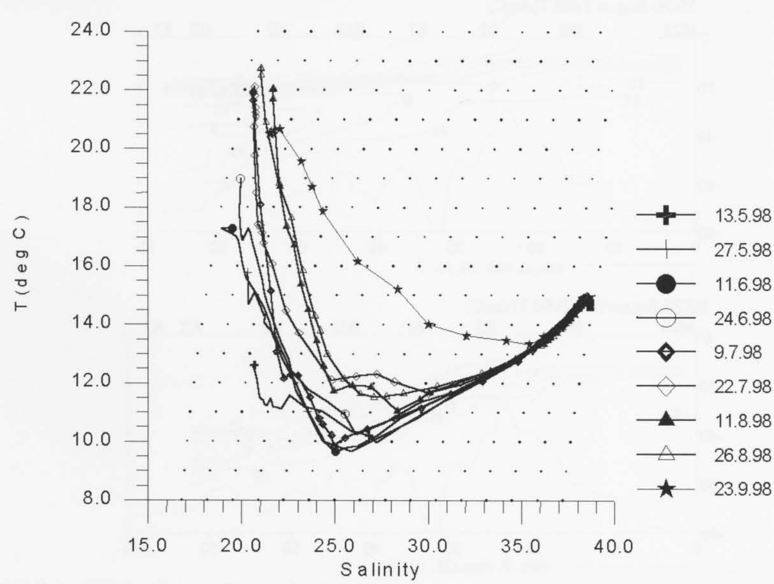

Fig. 5: T-S diagrams in station T1 located in the eastern basin in the Sea of Marmara.

temperature and salinity data were collected from May to September 1998.

As noticed, there are three water masses in the Sea of Marmara, except in September 1998. The temperature of the surface waters with a salinity of 20-22 salinity is ~13°C in May 1998 and increases to ~23°C in August 1998. A cold water mass with ~25 salinity and 9-10°C temperature underlies the surface layer. Its temperature and salinity increase to 11-12.5°C and ~26.5 from May to July. The temperature and salinity values of the lower layer are ~14.5°C and ~38.5, respectively.

Even the temperature of this cold water mass in Sea of Marmara increases during summer, this increase is not regular. For example, the temperature (~9.5) of cold water mass in July 9th 1998 was colder than that (~10.3°C) measured on June 24th 1998. The source of this cold water can explain the modification of the CIW coming from the Black Sea through the Strait of Istanbul.

Conclusions

The starting depth of CIW observed in the northern approaches of the Strait of Istanbul in Black Sea gets deeper from May to November. The spatial variation of the CIW indicates that it is found in early summer even near-shore. Because the seasonal termocline is placed at ~20m water depth. However, when the seasonal termocline is deeper in autumn, the upper boundary of CIW can be observed at ~60m water depth.

In the northern exit of the Strait of Istanbul, the CIW can be observed from May to August. Its starting depth increases from 10m (May) to 65m (August). It generally reaches its maximum thickness in June and July. When the volume of the CIW is larger in the northern exit of the Strait of Istanbul, its interaction with the upper layer in the strait increases. This increases mixing of the CIW with bounding layers. Thus, the temperature of the upper layer in the strait decreases southward. In the southern exit of the strait, as a result of hydraulic jump over the southern sill, the mixing degree is higher and a colder water mass forms in this region. Since this cold water mass is denser than the surface waters in the Sea of Marmara, it sinks. We have observed that there was a temperature decrement in the cold intermediate layer in the Sea of Marmara in summer. This modified cold water coming from the strait together with the upper layer cause further temperature decrement in the cold intermediate layer of the Sea of Marmara.

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