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Temporal evolution of the water characteristics in the bays along the eastern coast of the Aegean Sea: Saros, İzmir, and Gökova bays

Canan ERONAT*, **Erdem SAYIN**
Institute of Marine Sciences and Technology, Dokuz Eylül University, İzmir, Turkey

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Abstract: The seasonal and interannual variability of the local hydrography in 3 bays (Saros, İzmir, and Gökova bays) along the eastern coast of the Aegean Sea are investigated using data sets collected from 1991 to 2010. The data cover the last major deep-water formation episodes and the Eastern Mediterranean Transient (EMT) relaxation period. Aegean Sea hydrology and water mass characteristics influence the water properties of the bays. The data suggest that Saros Bay (North Aegean Sea), İzmir Bay (Central Aegean Sea), and Gökova Bay (South Aegean Sea) have different physical processes and water characteristics. They have their own dynamics independent from the Aegean Sea. At the same time, they are occasionally influenced by the Aegean Sea's physical processes. The time evolution of water properties inside the bays is investigated by analyzing the temperature, salinity, and density. The bays' data show the relaxation period of the EMT, which continued well into the early 2000s. It is known that this variability depends on the changing climate over the Mediterranean area. Our analysis reveals that the dense water formation in the Central Aegean Sea is considerably connected to the anomalous decrease in winter atmospheric temperature during the EMT period. The isopycnal levels started to increase again and reached their maximum after the EMT relaxation period in the summer of 2007 together with a salinity increase in the water column. The outcropping of isopycnals could have been a sign of a new formation of very dense water in the Aegean Sea.

Key words: Aegean Sea, water properties, time series, Eastern Mediterranean Transient (EMT), Saros Bay, Gökova Bay, İzmir Bay

1. Introduction

The Eastern Mediterranean Transient (EMT) is the abrupt change in the well-established Eastern Mediterranean thermohaline circulation due to the switch of the deep-water production areas in the basin from the Adriatic to the Aegean Sea that took place during the early '90s. Following the first observation of the EMT (Roether et al., 1996), a number of studies described various aspect of the EMT phenomenon (Klein et al., 1999; Lascaratos et al., 1999; Malanotte-Rizzoli et al., 1999; Theocharis et al., 1999; Theocharis et al. 2002; Zervakis et al., 2003; Gertman et al., 2006; Roether et al. 2007; Sayın and Beşiktepe, 2010 among others). In the present study, the data from 3 bays (Saros, İzmir, and Gökova bays) along the eastern coast of the Aegean Sea were analyzed in order to determine the water characteristics of the bays during the major water mass formation period and after.

Saros, İzmir, and Gökova bays are located in the eastern part of the Aegean Sea and are representative of the North, Central, and South Aegean hydrographic conditions (Figure 1). Saros Bay, which is situated in the Northeastern Aegean Sea, is connected to the North Aegean with a depth of approximately 600 m to the west (Figure 1). The shelf extends at a water depth of 90–120 m. The length of the bay is about 61 km and the width at the opening to the Aegean Sea is about 36 km. It receives discharge from the Meriç River. The annual average discharge rate of the Meriç River is 298.8 m^3/s (Yaşar, 1994).

İzmir Bay, which is situated in the Central Aegean Sea, has an "L" shaped geometry with the leg of the "L" about 20 km wide and 40 km long, and the base of the "L" about 5 to 7 km wide and 24 km long (Figure 1). It is divided into 3 areas according to their physical characteristics: Outer, Middle, and Inner. The bathymetry of İzmir Bay decreases gradually from Outer (80 m) to Inner Bay (10 m). Outer Bay receives discharge from the Gediz River. The annual average discharge rate of the Gediz River is 85.1 m^3/s (Yaşar, 1994).

Gökova Bay, which is situated in the Southern Aegean Sea, is triangular, extending in an east–west direction between Bodrum in the north and the Datça Peninsula in the south (Figure 1). It has 2 deep basins: the eastern deep basin and western deep basin. The shelf depth reaches 104 m. The depth extends to about 540 m.

* Correspondence: canan.ozturk@deu.edu.tr

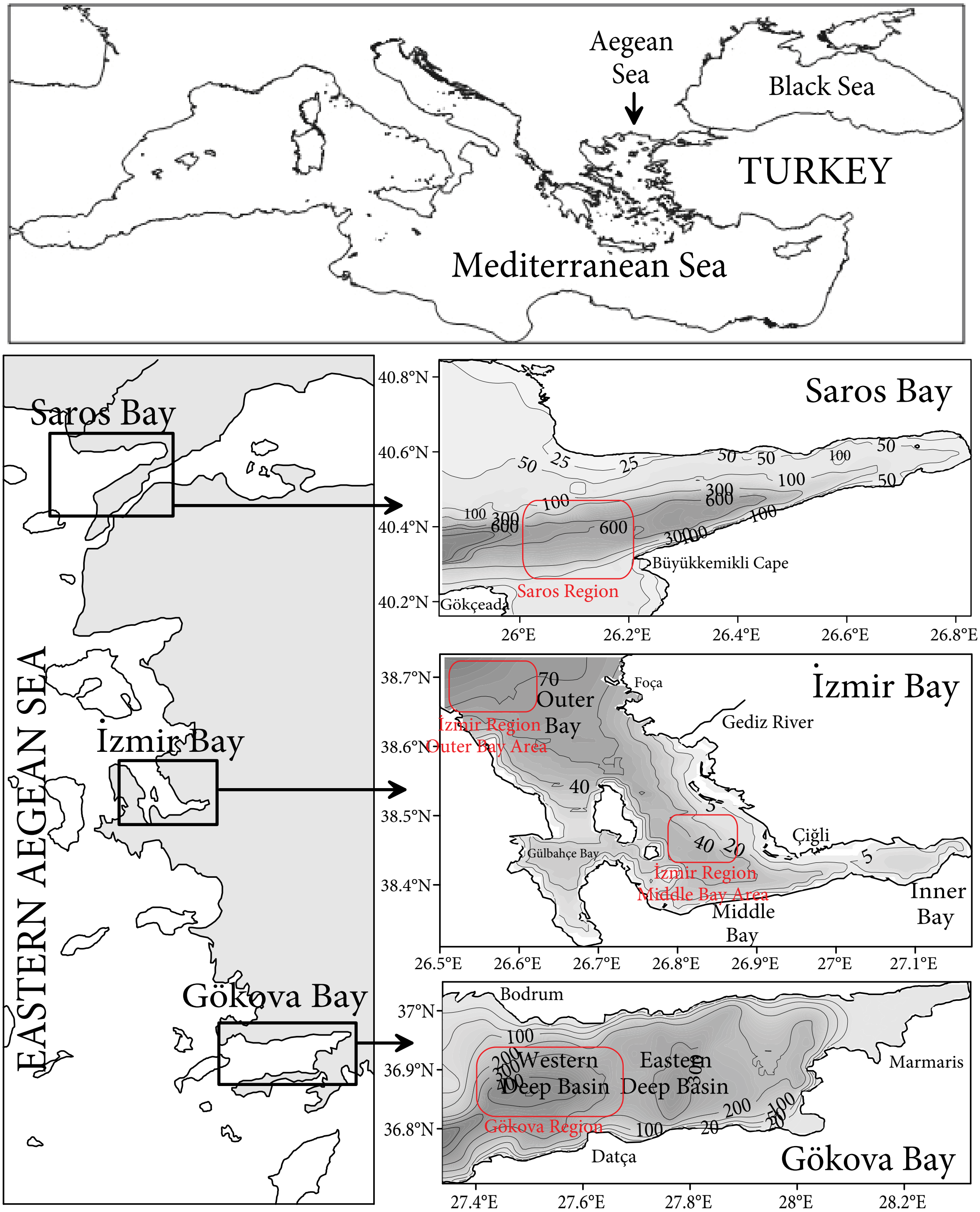

Figure 1. The location and bathymetry of the bays.

The oceanography of the Gökova Bay has not been studied until now. However, several studies on water masses and water quality can be found for İzmir Bay (Sayın, 2003; Sayın et al., 2006, 2007) and Saros Bay (Tokat, 2006; Tokat and Sayın, 2007; Pazı, 2008; Sayın and Beşiktepe, 2010; Uluturhan, 2010).

The physical features of the İzmir Bay were studied by Sayın (2003). The thermohaline structures, the stratification in the bay, the circulation system, and the water exchange between İzmir Bay and the Aegean Sea were analyzed in his study. The quasi-homogeneous system in winter changes to a 2-layer system from late spring to late autumn in the bay. The Aegean Sea surface water (most of time under the influence of wind from the north) enters the bay and continues to flow near the western coast, flowing through the narrow Mordoğan Passage into the small Gülbahçe Bay, which is situated at the southwest of İzmir Bay. The outflowing water occurs mainly in the bottom layer near the coast at Foça.

Sayın et al. (2006) studied the water types in İzmir Bay. Through this study it is known that 3 primary water types exist in İzmir Bay: 2 of them are Aegean Surface Water (ASW) and İzmir Bay Inner Water (IBIW); these are very distinct water types. İzmir Bay Water (IBW) is formed between these 2 water types and is under several local influences. In particular, the cyclonic gyre occurring as a result of wind driven circulation has an important effect on the characteristics of IBW.

Tokat and Sayın (2007) investigated the water properties of Saros Bay, considering the influences of several water masses: the warm and highly saline Levantine waters (Levantine Surface Water (LSW) and Levantine Intermediate Water (LIW)), and the cold and fresh Black Sea Water (BSW). The intermittently formed cold and dense upwelling water off the northern coast of Gelibolu Peninsula also has an impact on the upper water column of Saros Bay.

Pazı (2008) performed a synthesis of 2 datasets (May 2001 and January 2002) for Saros Bay. She found that the amount and physicochemical characteristics of the surface waters originating from the Black Sea show great seasonal variations; the extent, distributional pattern, and depth of penetration are quite variable. The LIW appeared to be poorly defined during January 2002; however, it became better defined in May 2001 in her study.

Sayın and Beşiktepe (2010) used the available data from different parts of the Aegean Sea. One of them was Saros Bay. They analyzed the time series of the water properties and found the major dense formation period occurred in 1993 in the bay.

A major objective of the present paper is to explore the variability of the water properties during the last 2 decades in the Aegean Sea. In order to achieve this, we present time series of physical variables of the bays influenced by the processes in the Aegean Sea during 1991–2010 to describe the temporal evolution of the water properties during the EMT period and after in the bays of the eastern Aegean Sea.

In this study, we describe the data used in section 2. The temporal evolution of the water mass properties in 3 bays giving information about the major deep-water formation episode and after in the Aegean Sea is examined in section 3. The next section deals with a discussion about the comparison with the data in the literature. The last section presents findings and conclusions.

2. Materials and methods

All hydrological data were collected using an SBE 911plus CTD (conductivity, temperature, and depth) probe in Saros, İzmir, and Gökova bays in the Eastern Aegean Sea since 1991.

The data monitoring was realized with different projects that intended to use the data for totally different purposes. The data were brought together giving priority to first selecting the data from the same station or the data from inside the red boxes for every cruise and for every bay (Figure 1). Last of all, we had only 1 CTD profile within the selected regions in the 3 bays for each cruise. Table 1 shows the data summary used in this work. The Ocean Data View (ODV) program is used to remove the erroneousness of the data by assigning different types of flag. As a result, the data in the bays are organized in order to give maximum information about the changing physical properties in time, especially during the major dense water formation period. T–S diagrams of the bays were drawn using the described time series data above (the potential temperature (θ) and potential density (σ_θ) values hereafter will be referred to as temperature and density).

The air temperature and wind stress of the bays are analyzed seasonally or yearly using the hourly data retrieved from the meteorological centers in the vicinity of the bays (Saros, İzmir, and Gökova) for a long time period. The anomaly of time series is constructed as the difference between the observed values and its mean.

We interested in the periods before and after the EMT. Two important periods were defined also with previously published studies (Zervakis et al., 2003; Sayın and Beşiktepe, 2010; Velaoras and Lascaratos, 2010). First is the major dense water formation period which covers also the EMT period and second one is the relaxation period that the densities (which were very high during first period) decreasing gradually with time and some isopycnals belonging the bottom layer disappearing at end of this period.

In order to analyze the time evolution of intermediate water properties, mean integrated values of temperature, salinity, and density in the 100–300 dbar layers were prepared for Saros and Gökova bays. They were compared with the intermediate water properties of the North Central Aegean Sea (obtained from the study by Velaoras and Lascaratos (2005)) in the discussion section. İzmir Bay is a very shallow area. Therefore, the İzmir Bay data are selected only for the winter period from the deep part of the bay to counter the influence of the surface seasonal variations.

3. Temporal evolution of the water characteristics in the bays

The EMT took place during the period ranging from the late ’80s to the early ’90s (Gertman et al., 2006; Velaoras

Table. Data summary as year, season, and month of cruises that provided in-situ data used in this work.

Year	Cruise	Saros Bay	İzmir Bay	Gökova Bay	Year	Cruise	Saros Bay	İzmir Bay	Gökova Bay
1991	Winter				2001	Winter		January	
	Spring					Spring	May	April	May
	Summer	July	August	August		Summer		August	
	Fall					Fall		December	
1992	Winter				2002	Winter	January	February	January
	Spring	May	April	May		Spring		July	
	Summer					Summer		August	
	Fall	September	September	October		Fall			
1993	Winter	February			2003	Winter		March	
	Spring	May	May	May		Spring		May	
	Summer					Summer		August	
	Fall	October	September	October		Fall			
1994	Winter		January		2004	Winter			
	Spring		April			Spring		March	
	Summer	July	August			Summer		August	
	Fall	November		December		Fall		November	
1995	Winter				2005	Winter		February	
	Spring	April		May		Spring		April	
	Summer	August		August		Summer		June	
	Fall	November		November		Fall		September	
1996	Winter		January		2007	Winter		January	
	Spring	March		April		Spring		March	
	Summer	June	June	June		Summer	June	July	June
	Fall	October	October	November		Fall		October	
1997	Winter		January		2008	Winter		January	
	Spring					Spring		April	
	Summer		July, August			Summer	June	July	June
	Fall		November			Fall		December	
1998	Winter		January	February	2009	Winter		February	
	Spring		April			Spring		April	
	Summer					Summer		July	
	Fall		September October			Fall		November	
2000	Winter		March		2010	Winter		February	
	Spring		April, May			Spring		April	
	Summer		July			Summer			
	Fall		November			Fall			

and Lascaratos, 2010). It is also related to the rising isopycnal levels found especially in the intermediate layers of the Aegean Sea. There has been no new severe deep dense water producing episodes in the Aegean Sea since 1993 in the literature. However, some minor quantities of deep water seem to have been produced in 1991 and 2001, already registered by Roether et al. (2007) and Velaoras and Lascaratos (2010). This densest isopycnal level (different for each bay) in the EMT peak period (1993) starts to deepen and does not exist in the water column and is called the EMT Relaxation Period.

In this study, the temporal evolution of the water characteristics was identified in Saros, İzmir, and Gökova bays during the EMT peak period, the EMT relaxation period, and after. This was accomplished by profiles of temperature, salinity, and density from several cruises in the bays extending from 1991 to 2008 (to 2010 for İzmir Bay). The selected regions (Saros, İzmir, and Gökova bays) are representative of different parts of the Aegean Sea with different water characteristics. Although a time gap exists between some fields studies, the evolution of density levels has a similar trend in all bays located in the eastern part of the Aegean Sea. Seasonally data can be compared with data collected in different years. On the other hand, individual bay data can be compared also to the concurrent data from the other bays.

Two processes are crucial for the EMT: first is the winter convection processes especially occurring under the severe winter conditions and the second is the intrusion of the salty water from the Levantine Sea into the Aegean Sea. On the other hand, the other very important mechanism is the depth of the density level in the Cretan Sea. If the isopycnals rise to depths that are over the sills between the Aegean Sea and the Levantine Sea, the dense water of the Cretan Sea flows into the Levantine Basin. It causes an enhancing of the intrusion of high-saline waters into the Aegean Sea related to the water budget of the Aegean Sea. Then the re-distribution of salt is very effective to change water properties in the Aegean Sea and in its eastern bays.

Before explaining the time evolution of the water characteristics in the bays, 2 crucial atmospheric parameters are analyzed that are important for evolution of the EMT. In order to display long-term anomalies in the atmospheric conditions, we used the data from coastal meteorological stations in the vicinity of Saros, İzmir, and Gökova bays. Strong winter convection following a drop in temperature is one of the main mechanisms enhancing the EMT during the cold winters of 1992 and 1993. We presented the winter air temperature data covering the period of 1980–2010. The average winter air temperature values show a decreasing trend and extreme negative anomalies over the Saros, İzmir, and Gökova areas during the major deep-water formation episode (Figure 2). Velaoras and Lascaratos (2005) found an abrupt increase in density in the intermediate depths during 1987 and 1988 in the Aegean Sea due to the decrease in temperature. In 1993, an even more intense density increase was observed, characterized this time by an abrupt salinity increase, as well as a temperature drop. They found sea level mean winter air temperature to be extremely low in 1992 and 1993 over the North–Central Aegean Sea.

Yearly time series of wind stress and anomalies for 1980–2000 were constructed from hourly wind measurements. Additionally, the winter wind stress anomaly is handled by considering the northerly component of wind stress in winter months, which tends to promote upwelling of dense water towards the surface along the eastern coast of the Aegean Sea. Based on the yearly wind stress, there are considerable geographical differences in magnitude. The wind stress over the North Aegean Sea is higher compared to the wind stresses over the Central and South Aegean Sea (Figure 3). On the other hand, the northerly component of wind stress in winter months over the North Aegean Sea causes a positive anomaly during the cold winter in

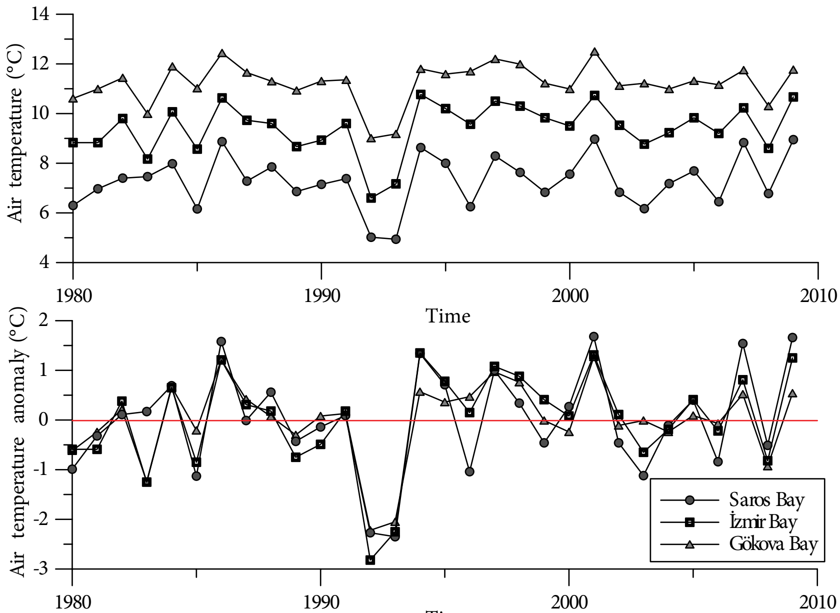

Figure 2. Time series of average winter air temperature (top) and air temperature anomaly for the bays.

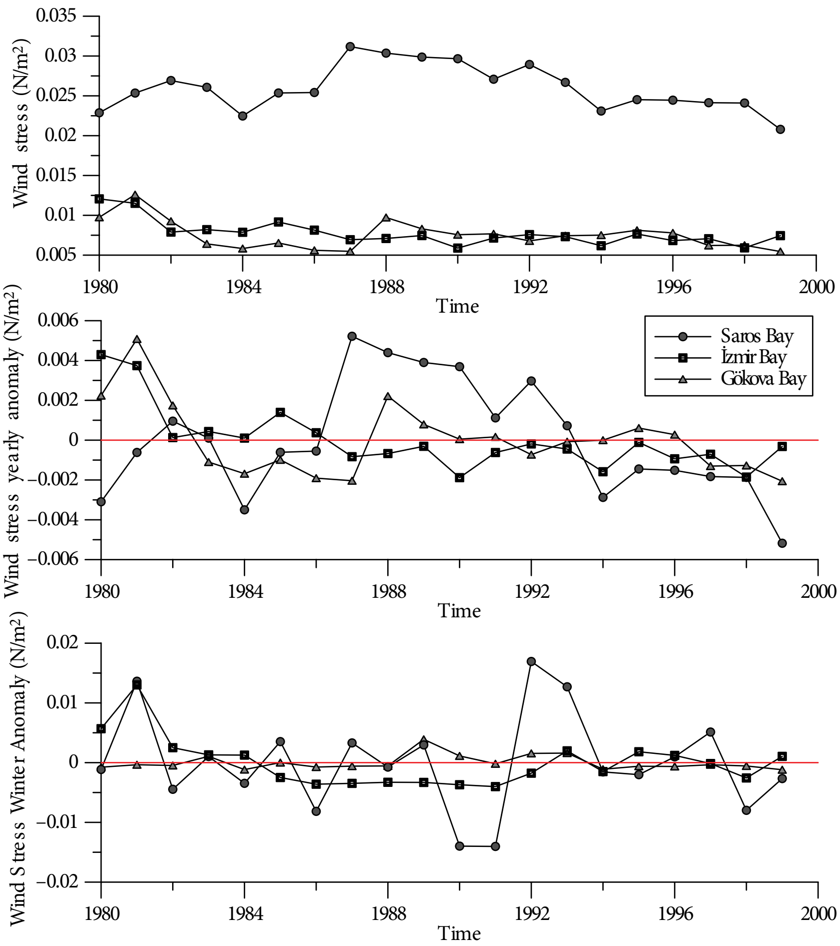

Figure 3. Time series of yearly average wind stress (top), and wind stress anomaly and anomaly of the northerly component of the wind stress in winter months (bottom) for the bays.

1992 and 1993, whereas no considerable changes can be observed over the Central and South Aegean Sea. The yearly wind stress shows positive anomalies from 1987 to 1993. Samuel et al. (1999) also found individual monthly wind stress fields over the Mediterranean for 1980–1993, showing an intensification of the winter mean wind stress over the North Aegean Sea occurred between 1987 and 1993.

3.1. Saros Bay

Saros Bay is chosen to represent the northern shallow area of the Aegean Sea. The data initially were not collected to give information about the EMT. Therefore, the depths of the water column according to CTD measurements are not same in Saros Bay for every cruise and it is difficult to follow the isopycnal levels that developed over time (Figure 4). Saros Bay was studied also by Sayın and Beşiktepe (2010) but for a narrower time span. Density increases in the upper layers because of the decreasing in temperature, and isopycnal 29.3 kg/m^3 starts to shoal by up to 250 m until the end of spring 1993. The σ_θ density levels 29.0, 29.1, and 29.2 kg/m^3 in 1994 are comparable with the levels before the main deep water formation episode (1993). Although the very cold weather condition was registered in spring 1996, the density levels continued to decrease gradually. The main reason for this decrease was the existing low saline water in the water column. This saline water occurs until the depth of 400 m in the bay after spring 2001, showing that the EMT relaxation continues until that time. Then some upper layer density levels started to rise, namely the σ_θ = 29.1 kg/m^3 density level was about 250 m in spring 2001 and rose to approximately 50 m in winter 2002. This level is the same as the level detected in 1993. The density levels of the intermediate layer, i.e. σ_θ = 29.2 kg/m^3, indicate a major dense formation episode in the winter and spring of 1993. The level shoaled to very near to the surface up to 20 m. It was around the depth of 220 m in summer 1991. The existence of saline water was seen even at the surface related to the occurring of the upwelling off-

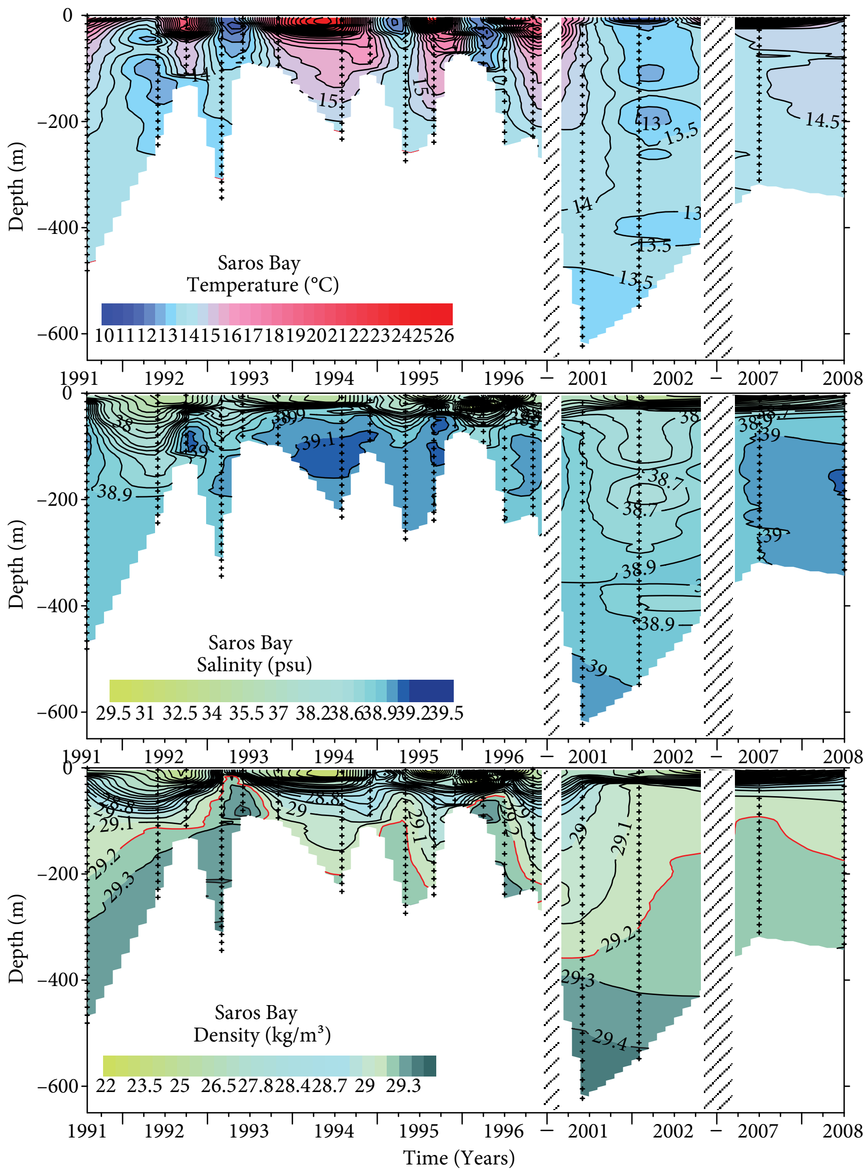

Figure 4. Temporal evaluations of temperature, salinity, and density fields of the Saros region from summer 1991 up to summer 2008. The areas in white represent where data were not collected. The slash lines show the shortening of the long gap in time.

shore side of the Büyükkemikli Cape and to the reaching of LIW up to the entrance of Saros Bay (Sayın et al., 2011). If we consider only the spring density level of σ_θ = 29.2 kg/m^3, it can be seen that the level starts to deepen up to spring 2001 after a major dense formation period, with an exception in spring 1996. Saline water was observed again in the bay firstly in summer 2007 with a rising 29.2 kg/m^3 isopycnal level near the surface up to 100 m. This level is comparable with the level forming during the major deep-water formation episode in the Aegean Sea (1993). This time the main reason is the existence of saline water in the intermediate water column.

High densities are found very near the surface in the major deep water formation period. It can be thought that the first reason for such high densities is the extremely cold air temperature influencing all the Aegean Sea while the second one is the salty LIW penetrating even into Saros Bay.

A T–S diagram was drawn in order to indicate the existence of the Levantine waters and the intensity of dense water formation occurring in the bay. The points with less opacity indicate all T and S values selected for time series analysis. The temperature, salinity, and density values are marked black to show the major deep water formation period on the T–S diagram (Figure 5). The temperature of

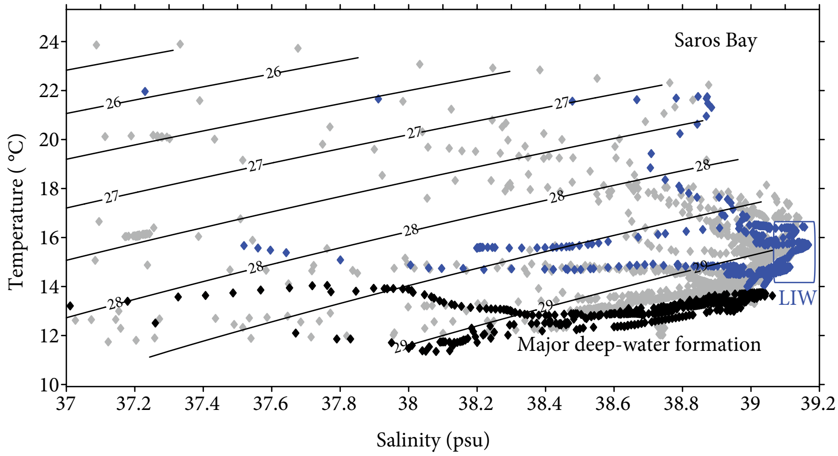

Figure 5. T–S diagram of Saros Bay (the salinity range is rearranged in order to focus on intermediated and deep water characteristics).

the forming dense water (>29.2 kg/m^3) is less than 14.0 °C and the salinity approximately 39.0 psu in winter and spring 1993. The blue marked values are representative for the Levantine Intermediate Water entering the bay, especially during warm seasons. The LIW penetration shown was in summer 1994 with temperature 15.7 °C and salinity 39.18 psu, in summer 2008 with temperature 14.9 °C and salinity 39.12 psu, and in winter 1994 with temperature 16.4 °C and salinity 39.17 psu. It shows that the LIW properties were modified on the way from south to the north and changed over time from cold to warm climatic seasons.

3.2. İzmir Bay

İzmir Bay is chosen to represent the Central Aegean shallow area. İzmir Bay exchanges water with the Aegean Sea almost the whole year long (Sayın et al., 2006). The annual average exchange rate is approximately 6000 m^3/s (Sayın, 2003). Monitoring studies began after 1991 in the bay and more than 50 cruises have been conducted. We concentrate on the outer bay and middle bay (Figure 1). İzmir Bay is the shallowest of the 3 bays. Therefore, the air–sea interactions are more effective over the İzmir Bay area. Especially the local wind force is the main mechanism influencing the water characteristics of the bay. The middle part of İzmir Bay produces its own water mass type: İzmir Bay Water (IBW) (Sayın et al., 2006). Although the water properties are different in the bay from those in the Aegean Sea, they show similar interannual variability according to the evolution of water characteristics influenced by the rising of the isopycnals. It seems that the Middle Bay area is a suitable place for the occurrence of dense water in the core of frequently forming cyclonic gyres. The EMT relaxation period could be identified clearly with the data collected during many cruises in the Outer Bay area where Aegean origin surface water enters the bay. Therefore, these data give detailed information about the major deep-water formation episode and the EMT post-peak period. It means that the Aegean Sea and the bays show similar trends in terms of interannual variability in water characteristics. The water of the Aegean Sea can be influenced by the water masses of such shallow bays through temperature or salt controlled dense water cascading. İzmir Bay Water, which is formed in the Middle Bay Area, flows near the coast at Foça over the topography into the Aegean Sea. The EMT relaxation period continued and the isopycnal level decreased gradually until April 2000, with an exceptional anomaly in January 1996 in both time evolutions of 2 regions in the bay (Figure 6). The decreases can be evaluated from the isopycnal levels σ_θ = 28.8 kg/m^3 and σ_θ = 29.0 kg/m^3 easily in the region Outer Bay and Middle Bay, respectively. In other words, the information obtained from the Aegean Sea and İzmir Bay is in parallel to explain the EMT period. However, the Middle Bay contains more dense water. After April 2000 the isopycnal levels started to increase. In the Outer Bay, the isopycnal level σ_θ = 28.8 kg/m^3 was approximately 70 m during the year 2000. It reached 10 m in July 2007. The level σ_θ = 29.0 kg/m^3 was not observed even in the bottom in the Middle Bay in 2000. It reached 20 m in March 2004 and outcropped at the surface in July 2007 mainly due to the existing high salinities near the surface. A similar trend can be observed by the time evolution of the temperature field in both regions. They contained saline water after the EMT relaxation period around the year 2007. The slowly decreasing isopycnals took place after 2007 until 2010.

İzmir Bay is shallower; therefore, only the Levantine Surface Water enters the bay among the Levantine Waters penetrating the Aegean Sea from the south. The Levantine Surface Water (marked blue in Figure 7) enters the bay especially in warm seasons. The LSW shown in the T–S diagram was in summer 1991 with temperature 24.5 °C and salinity 39.48 psu, in summer 2008 with temperature

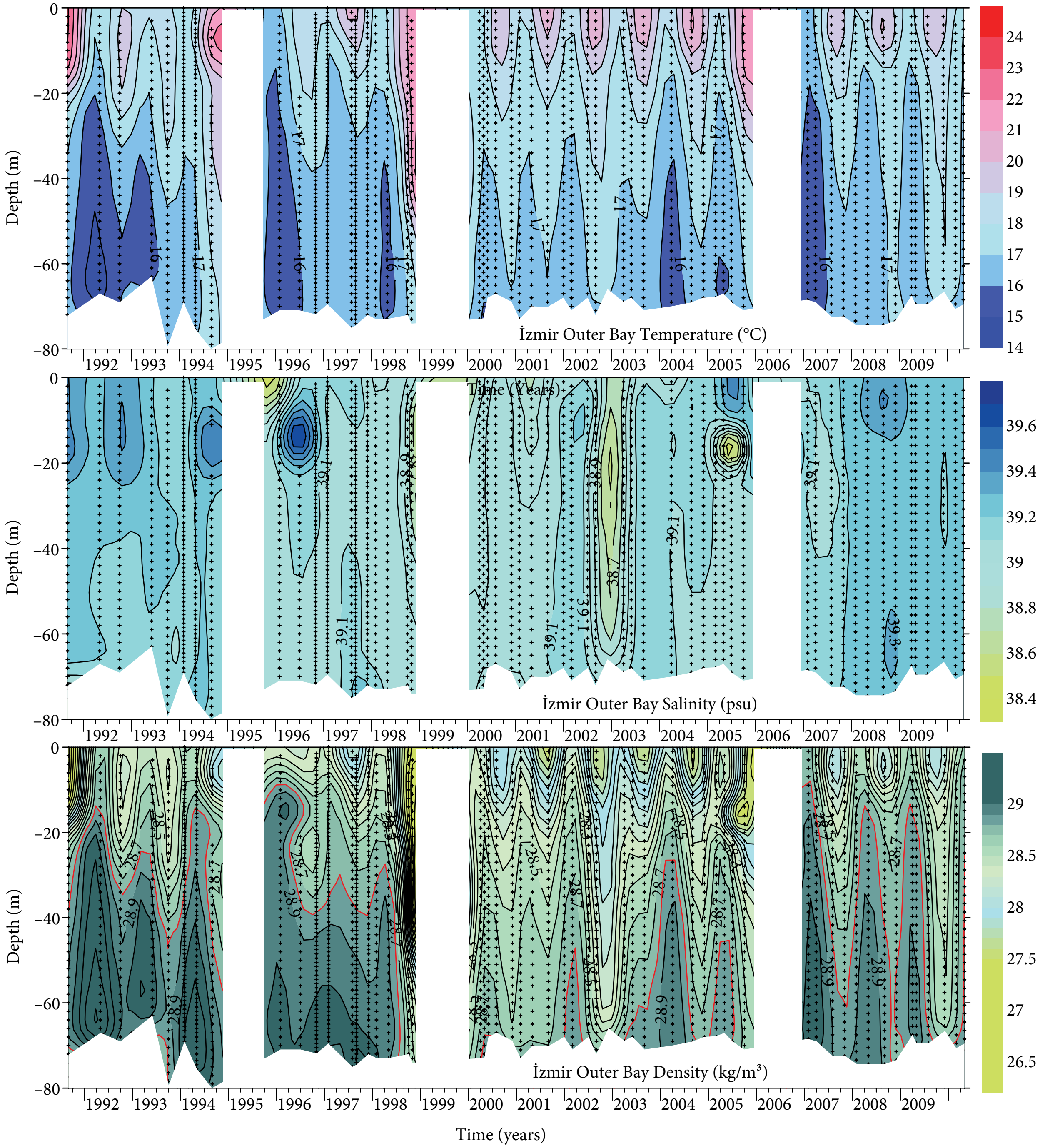

Figure 6. Temporal evaluations of temperature, salinity, and density fields of the İzmir region a) Outer Bay b) Middle Bay Area, from summer 1991 up to spring 2010. The areas in white represent where data were not collected.

23.6 °C and salinity 39.59 psu, and autumn 1992 with temperature 21.4 °C and salinity 39.49 psu. The densest (>29.2 kg/m^3) water was found near the bottom in the major deep water formation period in the İzmir Outer Bay area (marked black in Figure 7), with temperature less than 14.0 °C and the salinity approximately 39.2 psu in spring 1992 and spring 1993.

3.3. Gökova Bay

Gökova Bay is chosen as an area representing the southern Aegean water characteristics influenced by waters originating in the Levantine Basin. In summer 1991, we observed σ_θ = 29.0 kg/m^3 below 250 m in Gökova Bay, while in spring 1992 σ_θ = 29.0 kg/m^3 isopycnal lifted up to 25 m (Figure 8). This level continued until the end of

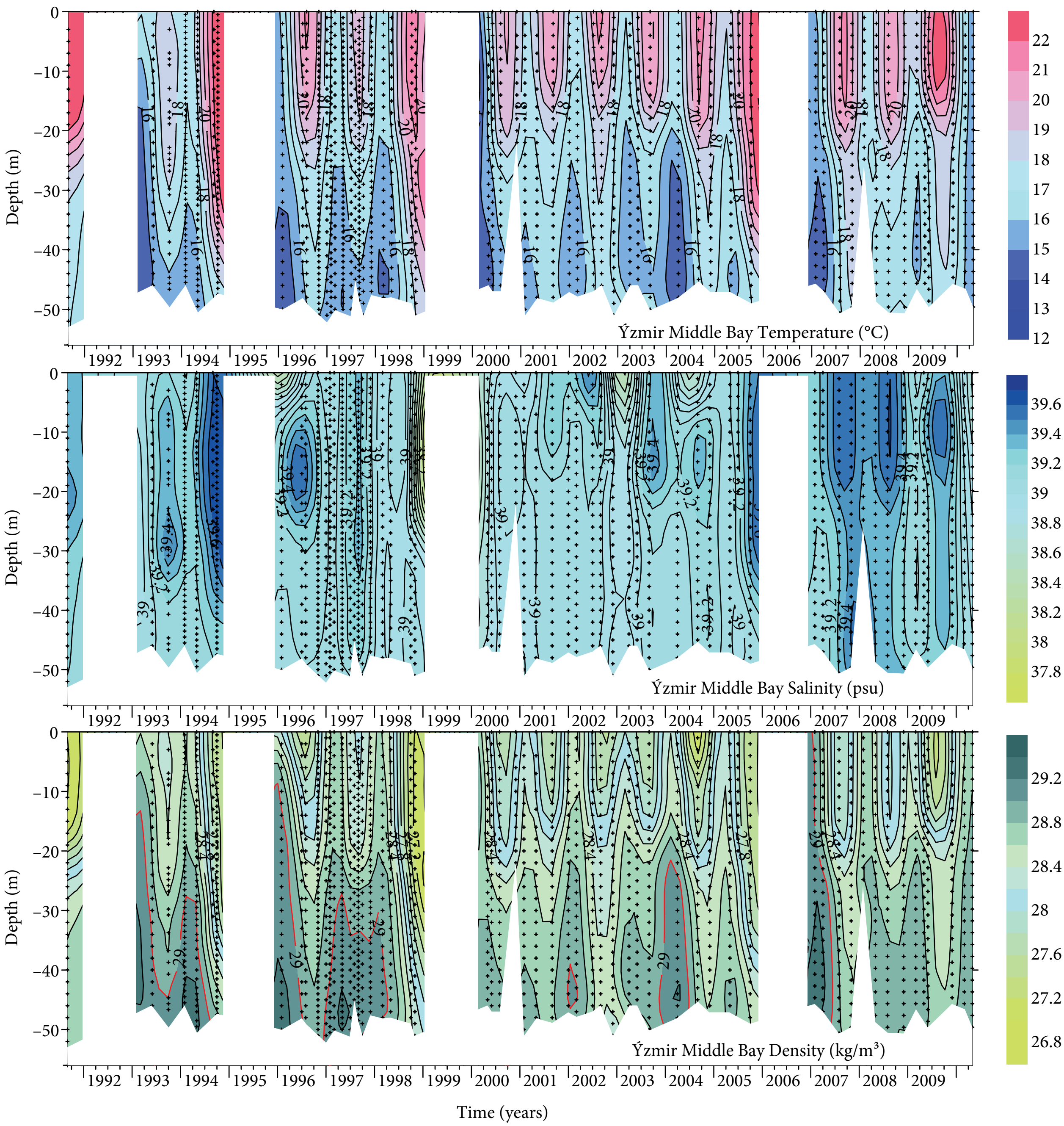

Figure 6. (continued).

1993, possibly decreasing from the surface layer in winter 1993. Deepening of the level of 29.0 kg/m^3 isopycnal is not sharp between October 1993 (100 m) and December 1994 (125 m). In spring 1995 $\sigma_\theta = 29.0$ kg/m^3 isopycnal was observed at the depth of about 230 m. It seems that the EMT relaxation episode had started already and 29.0 kg/m^3 isopycnal level had reached 265 m in spring 1996 and 280 m in fall 1996. The decrease in density inside the basin continued in spring 2001 and winter 2002. The $\sigma_\theta = 29.0$ kg/m^3 isopycnal level decreased to the depth of 320 m in spring 2001 and 350 m in winter 2002.

The winter convection is a seasonally occurring phenomenon that could have brought high density levels near the surface as observed in spring 1992 and 1993. The temperature values near the surface were in accordance with the seasonal trend. However, the subsurface temperature, for example 16 °C, is observed very near the surface (80 m) in spring 1993. The depth of 16 °C isotherms

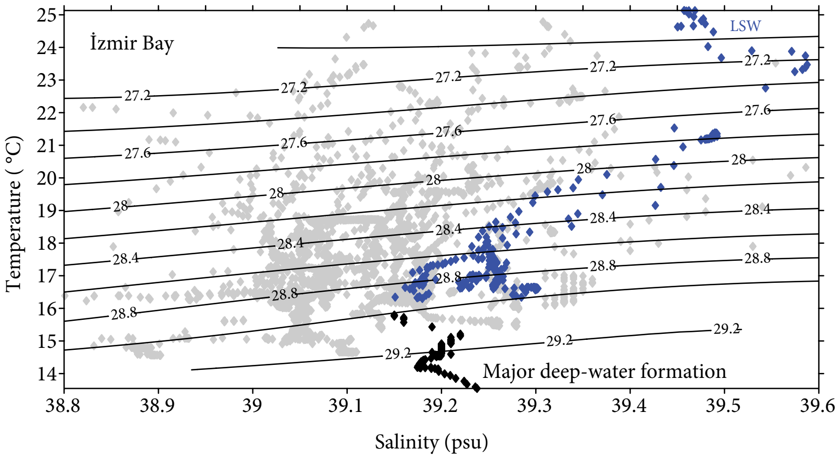

Figure 7. T–S diagram of İzmir Bay (the salinity range is rearranged in order to focus on intermediated and deep water characteristics).

is 215 m in spring 1995 and about 70 m in spring 1996, showing more deep water formation in spring 1996. At the same time, the intermediate densities (28.9 isopycnal) show similar shoaling trend as the 16 °C isotherm during the relaxation time. However, the 29.0 isopycnal did not reach the surface in spring 1996 as was observed in spring 1993. The reason could be the existence of low saline water (may be Modified Atlantic Water with temperature 16–18 °C and salinity less than 38.7 psu) as a thin layer (25 m) in Gökova Bay. The existence of such low salinity and density at the surface layer acts as an insulating lid that makes the air–sea interactions limited, thus hindering the formation of dense water. The water type containing high salinity and high temperature filled the surface layer during fall 1996 as the low salinity water of spring 1996 disappeared. A strong seasonal thermocline and halocline formed at just less than 300 m. Again cold, salty, dense water can be detected in summer 2007 and 2008.

The Asia Minor Current flowing between the Turkish mainland and Rhodes brings the warm LSW and the salty LIW along the western Turkish coast into Gökova Bay. Gökova Bay is open to the Aegean Sea from the west side. The opening part to the Aegean Sea of the bay, especially the southwest corner is appropriate for the Levantine Waters that penetrate up to the middle of the bay in all seasons. The blue marked values in the T–S diagram are representative for the Levantine Intermediate Water entering the bay. The LIW penetration shown was in summer 1991 with temperature 16.37 °C and salinity 39.25 psu, in summer 1995 with temperature 16.42 °C and salinity 39.15 psu, and in spring 2008 with temperature 16.43 °C and salinity 39.33 psu. The temperature of the forming dense water (>29.2 kg/m^3) is approximately 15.0 °C and the salinity more than 39.2 psu in winter 1992 and in spring 1992 and 1993 in the major deep water formation period in Gökova Bay (marked black in Figure 9).

4. Discussion and conclusion

Some studies asserted that the EMT started between 1987 and 1990 (Schlitzer et al., 1991; Theocharis et al., 1999; Gertman et al., 2006). The EMT event was relaxed by about 1995 (Theocharis et al., 2002). Zervakis et al. (2003) gave information about the EMT relaxation period of no ventilation of the deep waters of the North Aegean in the period from 1994 to 2000. The density levels in the northwestern Levantine Sea decreased very moderately between 1995 and 2001 (Roether et al., 2007). The present work confirms the above studies and gives information about the evolution of density during the EMT relaxation in the Aegean Sea especially in İzmir Bay and Gökova Bay. It shows the different characteristics of the intermediate water masses of the Aegean's bays and tries to identify interannual variability consistent with the North–Central Aegean water characteristics.

We would like to compare the values of Saros Bay and the North Central Aegean Intermediate waters layers (obtained from the study by Veloaras and Lascaratos (2005)) first and then to determine the differences in the bays. The isopycnal levels of Saros Bay and the North Aegean Sea (red and blue points in Figure 10, respectively) are comparable to each other during overlapping years because of the observations taken from the same depth interval and the area very close to each other. The data in different years from both regions are complementary to each other. Figure 10 shows this consistency and also the evolution after 2000 (after the EMT relaxation period). The density increase in the Aegean Sea was not observed in certain regions. It was observed in the entire Aegean Sea, including the bays, especially during the major dense water formation period. It is remarkable not only from the deep part of the water column as well as from the surface and intermediate layers indicate this evolution. The intermediate water in İzmir and Gökova bays was

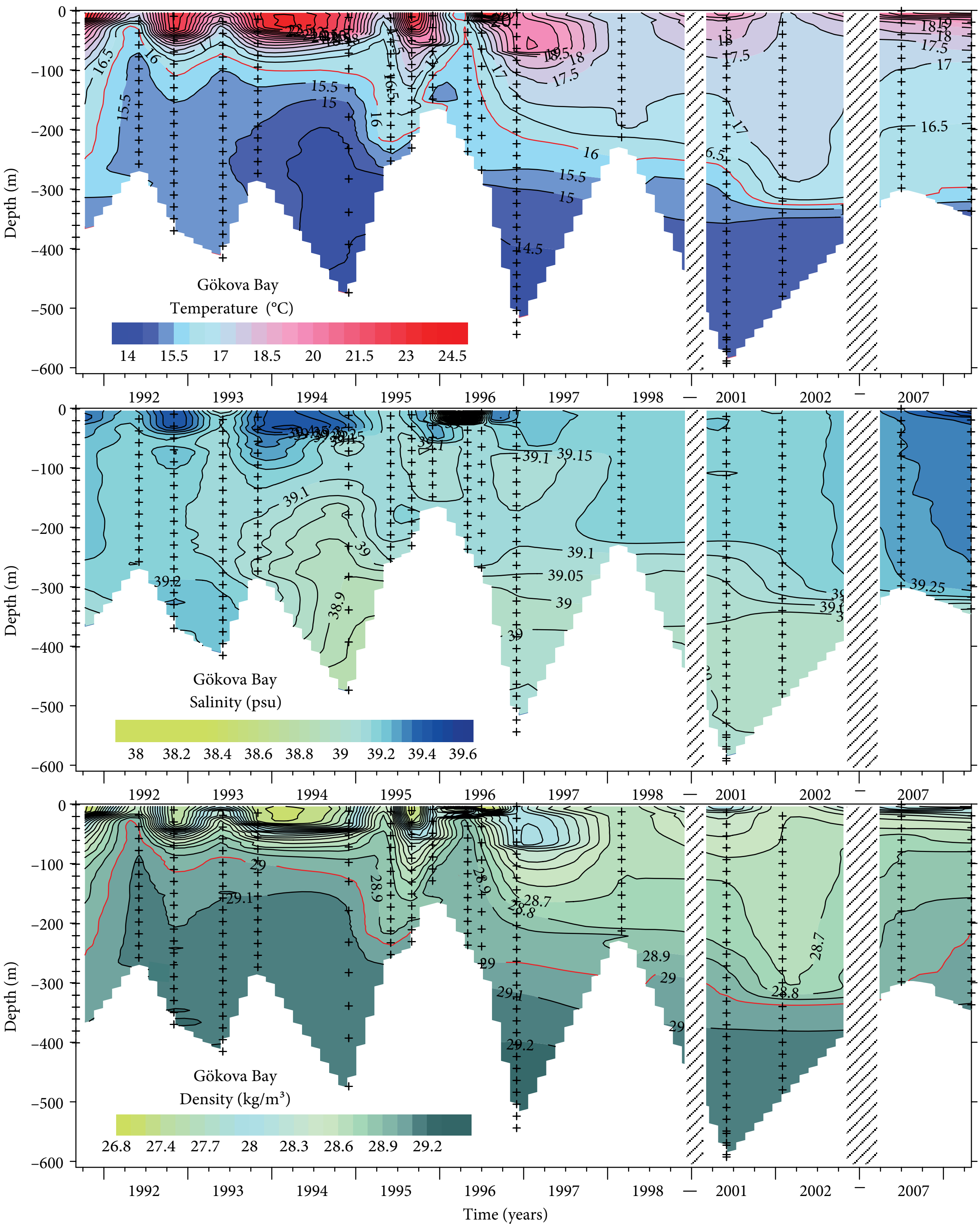

Figure 8. Temporal evaluations of temperature, salinity, and density fields of the Gökova region from summer 1991 up to summer 2008. The areas in white represent where data were not collected. The slash lines show the shortening of the long gap in time.

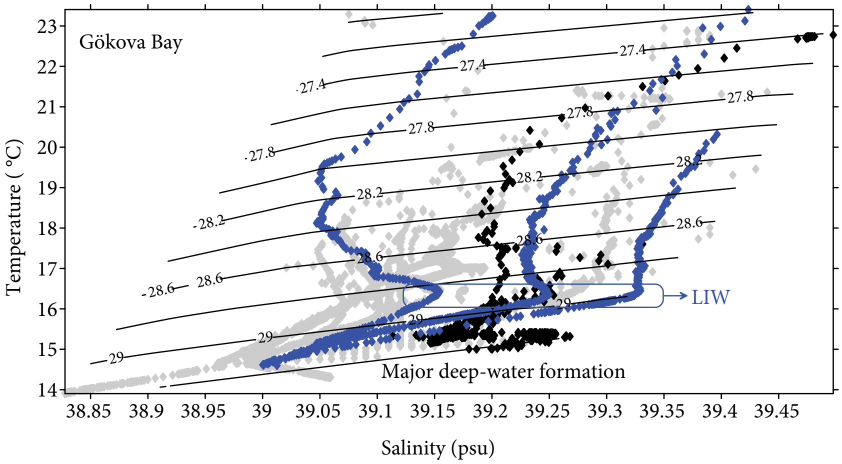

Figure 9. T–S diagram of Gökova Bay (the salinity range is rearranged in order to focus on intermediated and deep water characteristics).

getting denser after 2000 by gaining salt even though the temperature increased. The increasing of the density continued until 2007 in Gökova and İzmir bays and even in Saros Bay. The same trend cannot be observed in Saros Bay from the intermediate temperature time series. It does not allow any solid conclusions to be drawn, apart from the salinity and density evolution with time. High density values were observed in 2007 and the bays were again full of salty water and the isopycnal levels are comparable with the isopycnal levels of 1993.

This variability observed in the intermediate water of the bays showed that the bays have the potential to produce dense water causing dense water cascade from the coast to the Aegean Sea. However, it depends on the meteorological conditions over the eastern Mediterranean and possibly central/eastern Europe (Zervakis et al., 2004). The North Atlantic oscillation (NAO) appears to be responsible besides some regional variability (Oğuz, 2011).

The present study investigated the water characteristics in 3 bays (Saros, İzmir, and Gökova) over time. The important conclusion is the deepening of isopycnal levels in the bays after the peak EMT period, starting from 1993 up to the early 2000s. This is confirmed by the studies by Zervakis et al. (2003), Roether et al. (2007), and Velaoras and Lascaratos (2010). The Aegean Sea and the bays seem to be interconnected during the EMT period. The data of these bays show that their salty, cold, and dense waters change their characteristics during the EMT peak period, EMT relaxation period, and after. This is initiated by the Levantine Waters reaching even the North Aegean Sea. Due to their increased salinity, they are the preconditioning for the outcropping of the isopycnals particularly after coinciding with severe cold winter episodes. The relaxation episode of the EMT was very

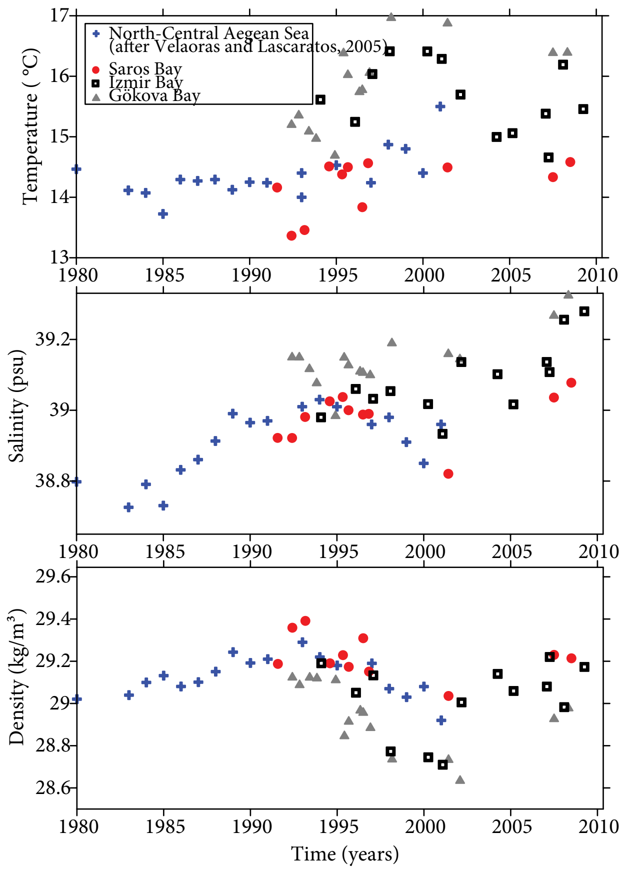

Figure 10. Time evolution of mean integrated values of temperature, salinity, and density in the 100–300 dbar layers in the North–Central Aegean Sea (after Velaoras and Lascaratos, 2005) in Saros and Gökova bays. İzmir Bay is very shallow. The İzmir data are selected only for the winter period from the deep part of the bay to eliminate the influence of seasonal variations.

clear in the 3 bays where the collected data were just after the last major deep-water formation episode (1993). The stagnating deep water in the bays gained buoyancy slowly by losing salt and gaining heat. After the EMT relaxation period the water started gradually to be denser until 2007. The bays were again full of salty water and the isopycnal levels are comparable with the isopycnal levels of 1993. It was the first time after 1993 there were new severe deep-water producing episodes in the Aegean. Unfortunately, it is not known if these isopycnal levels were a sign of a new time for new transient from the Aegean Sea to the Levantine basin.

Acknowledgments

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