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Sea Surface Variability in the Aegean Sea

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Özet: ***Ege Denizi'nde yüzey suyu değişimleri.*** Ege Denizi'nde fiziksel parametreler iklimsel değişimler, tatlısu girdileri ve su döngüsü gibi faktörlere bağlı olarak yer ve zamana göre değişim göstermektedir. Farklı su kütleleri, özellikle Çanakkale boğazından gelen soğuk Karadeniz suyu ve güney kısımdan girmekte olan Levanten suyu Ege Denizi su özelliklerinin karmaşık yapısına katkıda bulunmaktadır. Bu çalışmada Ege Denizi yüzey suyu sirkülasyonu ve fiziksel özelliklerinin değişimi yerinde ölçümler kullanılarak 1986-1994 periyodunda incelenmiştir. Yüzey verisi analizleri yüksek tuzluluk ve yoğunluk değerlerinin ilk olarak Kuzey Ege'de oluştuğunu göstermektedir.

Anahtar Kelimeler: Ege Denizi, sirkulasyon, fiziksel parametreler.

Abstract: The physical parameters show seasonal and spatial variability depending upon climatic changes, freshwater input and water exchange throughout the Aegean Sea. Different water masses, especially colder Black Sea Waters (BSW) advected from the Strait of Çanakkale, and warmer Levantine Waters (LW) entering from the southern region constitute the complex structure of the Aegean Sea waters. This work describes the sea surface circulation and distribution of physical parameters in the Aegean Sea for the period between 1986-1994 by using *in-situ* measurements including Conductivity, Temperature, Depth (CTD) data. Analysis of surface data showed that the high salinity and density values first occurred in the North Aegean Sea since the beginning of 1987.

Key Words: Aegean Sea, circulation, physical parameters.

Introduction

Aegean Sea, situated between Turkey and Greece, constitutes one of the main parts of the Eastern Mediterranean. It comprises both of territorial waters of these two countries and international waters. It can be described as a confluence zone, where colder Black Sea waters coming from the Strait of Çanakkale meet warmer waters of Eastern Mediterranean origin entering the basin through the southern straits (Figure 1).

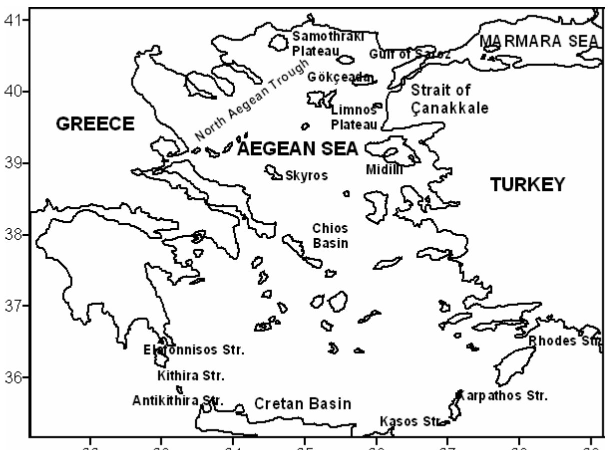

Figure 1. Major basins and islands in the Aegean Sea

In the last decade, climatic and oceanographic studies have shown that there have been significant changes in the Aegean Sea (Klein *et al.* 1999; Lascaratos *et al.* 1999; Malanotte-Rizzoli *et al*., 1999; Roether, *et al.* 1996; Theocharis, *et al.* 1992). These changes lead to the variations in physical properties not only in the Aegean Sea also in the Eastern Mediterranean. The main mechanism responsible for this major change is the climatic anomaly in the region (Ozsoy, *et al.* 1996). The salinity increased by about 0.15 psu in the Cretan Sea due to the reduced rainfall during 1987-1992 periods. The second period (1992-1994) is characterized by a remarkable cooling of the deep waters resulted from very cold winters of 1992 and 1993 (Theocharis *et al.* 1999). The variations of surface layer that is affected from this climatic anomaly will be discussed within this study.

In recent years sea surface oceanographic conditions of the Aegean Sea have been investigated by combination of *in-situ* measurements with satellite data and integration of circulation models. Zodiatis *et al.* (1996) used NOAA/AVHRR images and model simulations to study flow patterns and advection of the Black Sea Waters in the north Aegean Sea. Marullo *et al.* (1999) describes the sea surface temperature field in the Eastern Mediterranean, including Aegean Sea by using AVHRR. Cordero (1999) used AVHRR thermal data as an indicator to find out dense water formation sites in the Eastern Mediterranean. The North Aegean waters are also presented by Yüce, 1991.

In-situ Measurements and Data Analysis

Conductivity, Temperature, Depth (CTD) data used in this work was provided from 'The Mediterranean Hydrographic Atlas' (MEDATLAS) (MEDATLAS group, 1997) with combination of Dokuz Eylül University, Institute of Marine Sciences and Technology (IMST) measurements.

The CTD data includes November 1986, March 1987, August 1987, September 1988, August 1991, and June 1994 measurements. The CTD data covering Aegean Sea was downloaded from the MEDATLAS database. The IMST data including temperature, salinity and depth were stored on a disk and analyzed using the CTD data acquisition software Seasoft™. Data was converted to engineering units by using Seasoft™ module which is called DATCNV. The converted data was averaged with BINAVG module according to depth bins and bin size was chosen to 1.0 (Sea-Bird Electronics Inc., 1994). Finally all data were exported to a FoxPro™ database and Surfer™ software was used to make contour maps and Kriging method was applied for interpolation of in-situ data.

Surface Circulation

The circulation of surface layer in the Aegean Sea is mainly cyclonic. Thermal frontal zone in the North Aegean Sea separates colder BSW from warmer Levantine origin water (LW). This frontal zone is very wide (50 km) and long (130 km) in the summer season whereas thermohaline gradients diminish in winter period (Zodiatis, 1993). In general, sea surface temperature, salinity and density are increasing from north to south.

The distributions of temperature, salinity and density at 10 m from 1986 to 1994 are presented in Figure 2 through Figure 4 in order to describe upper layer circulation in the Aegean Sea.

Autumn is a transitional period between summer and winter (Poulos, 1997). In November 1986, the sea surface temperature varies between 15°C in the north and 20°C in the south (Figure 2 a). The colder (16 °C), less saline (37 psu) and less dense (27.2 kg/m^3) BSW occupy the northeastern part of the Aegean (Figure 2 a, b, c). The LW with a 38.2 psu salinity and 28.2 kg/m^3 density occupy the southern part of the area. They tend to intrude from Eastern Cretan Straits into the Aegean and outflow through the Western Straits after circulating the central basin up to Chios Basin.

In winter 1987, the North Aegean Trough and Samothraki Plateau are greatly affected by the brackish BSW and river runoff. The relatively colder (12°C) and less saline (37.7 psu) and less dense (28.6 kg/m^3) waters in the northeastern basin can be result from the Meriç river (Figure 2 d, e, f). There is a strong thermohaline front identified over the Limnos Plateau where colder and less saline BSW encounters with the warmer LW (Zodiatis, 1994). BSW (13 °C temperature, 37.7 psu salinity, and 28,9 kg/m^3) spreads out to the northern Aegean while LW are intruding intermittently over the south of Limnos island with a 14.5 °C temperature, 38.9 psu salinity, and 29.1 kg/m^3 density (Figure 2 d, e, f). The high density values exceeding 29.2 psu in the Cyclades Plateau and south of Limnos is the surface indicator of the changing water column in this period. In contrast, lower temperatures (12 °C) and higher densities (29 kg/m^3) values between the Limnos and the Gökçeada can be related to upwelling event and explain the source of dense water formation in the area.

August 1987and September 1988 data shows that the North Aegean Sea is occupied with the cold waters due to the cessation of Etesians and gradual increase of river discharges (Figure 3 a, b, c and Figure 3 d, e, f). In the north of Limnos cold and dense water with a 22 °C and 24 kg/m^3 respectively indicate upwelling in 1987. Warmer LW (22.5-25 °C, 39 psu and 27.5 kg/m^3) that is intruding from the eastern straits take place over the eastern part of the Central and South Aegean Sea. These waters tend to circulate cyclonically over the Limnos Plateau and flows out through the Western Cretan Straits.

In summer 1991, colder (22-23°C), less saline (34 psu) and dense (22-23 kg/m^3) BSW advected from the Strait of Çanakkale is propagating to the south, southwest and then turns to the southeast direction (Figure 4 a, b, c). The main reason of this cyclonically circulation is the Etesian winds which is common in the area during the summer months. SST is increasing from east (22 °C) to west (25 °C). North and northeastern part of the area is also dominated by the BSW with a 23-25 °C temperature, 33-35 psu salinity and 22-24 kg/m^3 density. In the Gulf of Saroz, upwelling occurs due to the intense northeast winds. The temperature and density is increasing in this area. The highest density is observed in the surrounding area of Midilli island. Moreover, the dominant wind in this area is westerly which remove BSW outside the region and leads to the salinity (39 psu) and density increase (28 kg/m^3). The central and south Aegean is covered by the Levantine waters with a 23-25 °C temperature, 39-40 psu salinity and 29 kg/m^3 density. In the Rhodes Strait warmer, saltier and denser surface water is intruding from the Levantine Basin. Summer 1994 data reveals a typical summer sea surface distribution as explained in summer 1991 (Figure 4 d, e, f). However, higher densities (23 kg/m^3) and salinities are observed (35 psu) in the North Aegean with compared to summer 1991 (Uckac, 2004).

Time Series of Surface Physical Parameters

The physical properties of the water column such as temperature, salinity and density are good indicators of the variations and the series of the CTD data shows the evolution of event depending on time.

The combination of the MEDATLAS data and IMST measurements are grouped into two regions, namely the North Aegean and the South Aegean. Figure 5 and 6 shows the variability of physical parameters in the North and South Aegean surface waters respectively. The surface layer of the North Aegean shows great variability due to the low temperature, salinity and density values of BSW which encounter with high temperature, salinity and density waters of Levantine origin in this region. Thus, surface temperature varies between 12°C in winter and 23.5°C in summer (Figure 5 a). The surface salinity and density values range between 35.8-39.2 psu and 24.5-29.5 kg/m^3 respectively (Figure 5 b, c). The minimum temperature occurs in winter 1992 whereas salinity and density are higher in this year as compared to previous years (Figure 5 b, c).

The surface salinity, temperature and density of the South Aegean are more uniform with compared to the North Aegean (Figure 6 a, b, c). The temperature values have been decreasing since 1987 while salinity and density values have been increasing since 1987.

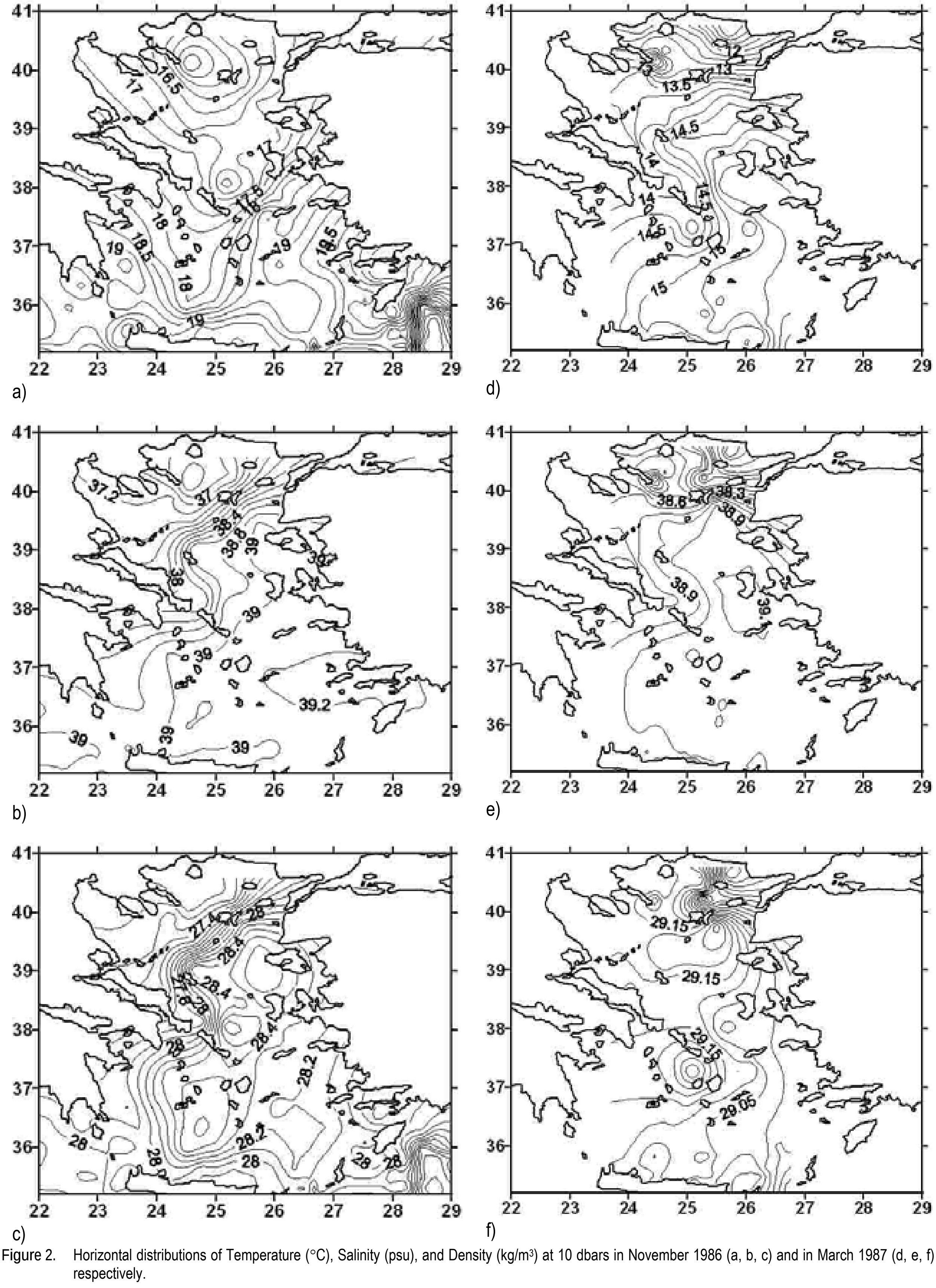

Figure 2. Horizontal distributions of Temperature (°C), Salinity (psu), and Density (kg/m³) at 10 dbars in November 1986 (a, b, c) and in March 1987 (d, e, f) respectively.

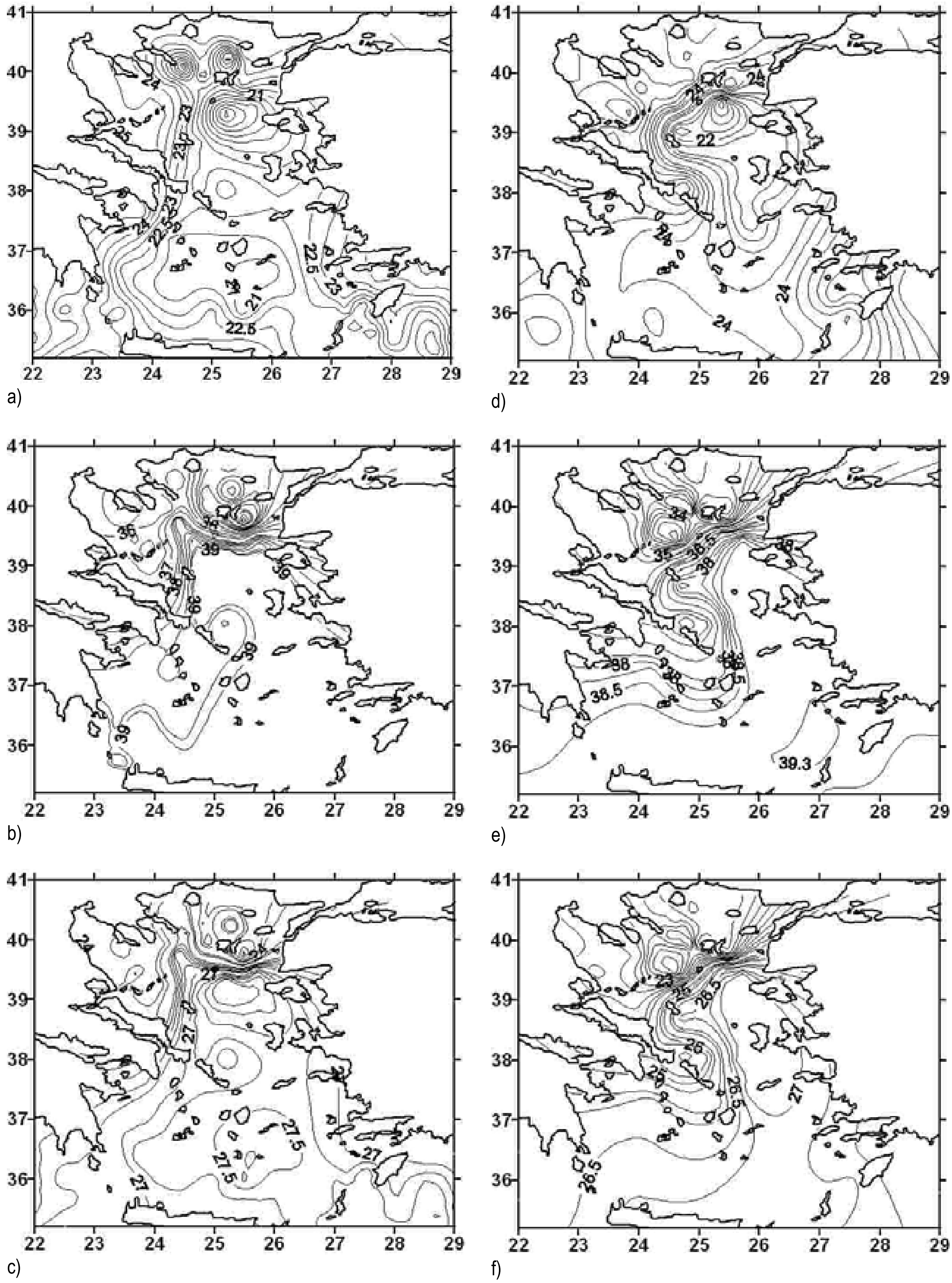

Figure 3. Horizontal distributions of Temperature (°C), Salinity (psu), and Density (kg/m³) at 10 dbars in August 1987 (a, b, c) and in September 1988 (d, e, f) respectively.

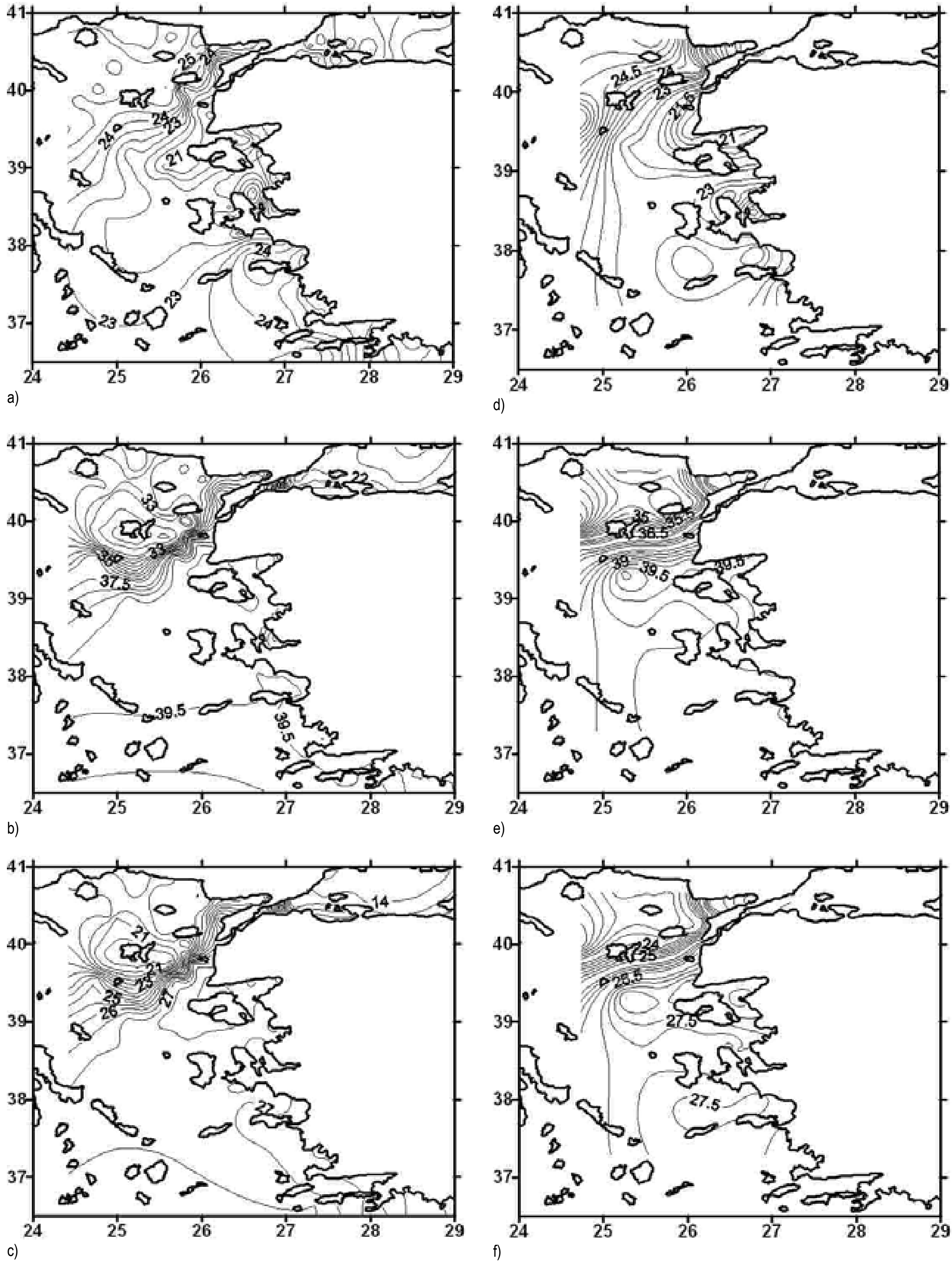

Figure 4 Horizontal distributions of Temperature (°C), Salinity (psu), and Density (kg/m³) at 10 dbars in in August 1991 (a, b, c) and in June 1994 (d, e, f) respectively.

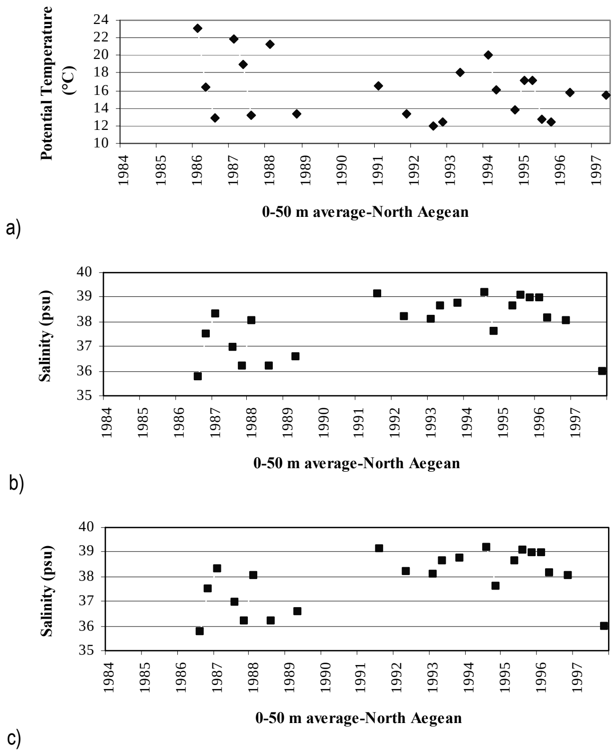

Figure 5. Time series of physical parameters on surface layer (0-50 m) in the North Aegean, a) Potential temperature (ºC), b) Salinity (psu), c) Sigma-θ (kg/m³).

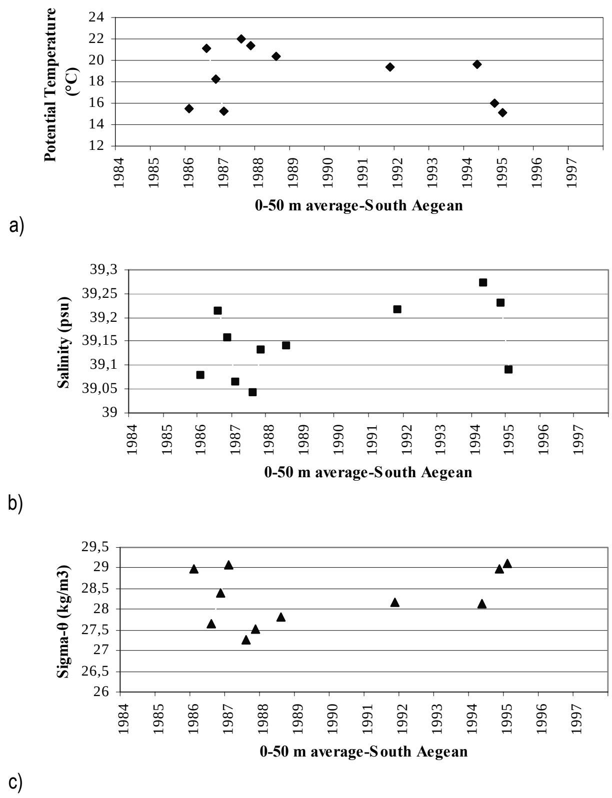

Figure 6. Time series of physical parameters on surface layer (0-50 m) in the South Aegean, a) Potential temperature (ºC), b) Salinity (psu), c) Sigma-θ (kg/m³)

Conclusion

Spatial and temporal distribution of the surface circulation pattern in the Aegean Sea varies depending upon many factors such as meteorological conditions, bottom topography and river discharge rates in the area. The surface circulation in the North Aegean Sea is mostly counter-clockwise and the main surface water mass occupying the region is BSW. BSW advected from the Strait of Çanakkale flows mainly westward and it bifurcates into southerly and northerly directions. During winter the main volume of BSW concentrates north of Limnos island. In summer, BSW spreads out to southwest and the core of this water mass appears south of Limnos.

The year of 1987 was the extremely cold winter in the Aegean Sea (Zervakis, 2000). The air temperature was below the 2°C during the first half of the March. The reduction of the precipitation and two successive cold winters in 1991 and 1992 caused further salinity increase, temperature drop in the Aegean.

The time series of surface temperature, salinity and density data reveal that the higher density waters first occurred in the North Aegean and then they were transported to the south and finally to the Cretan Sea.

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