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Recent changes in the physicochemical parameters of the Black Sea

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Abstract

Temperature and salinity values from CTD profiles at 9 stations in the southern Black Sea were analyzed. Temporary water types were determined along with the basic 3 types consisting of Black Sea surface water (BSW), Black Sea cold intermediate Water (BCIW) and Black Sea deep water (BDW). From the 1960s to the 1990s, firstly, the changing of dissolved oxygen (DO) concentrations in the middle of the pycnocline by eutrophication and cooling has created another equilibrium situation with lower DO values; later, in 2003, with the decrement in eutrophication and global warming, another equilibrium was formed and it was shown that this equilibrium still holds in 2009. An important difference between today and the 1960s is that DO levels have decreased and the suboxic zone top boundary has increased. The BCIW temperature has increased by 1 °C since the 1960s. Because the residence time of overall BCIW is approximately 5 years, the observations made correspond to the date 5 years earlier. With cooling in 2007, another new equilibrium will be observed after the 2010s that will allow us to more accurately predict the relative importance of convective cooling and eutrophication.

Key Words: CTD data, Black Sea, cold intermediate water, dissolved oxygen, salinity, soboxic zone

1. Introduction

Investigations have shown the existence of 2 large cyclonic gyres in the east and west of the Black Sea, a cyclonic RIM current around it and anticyclonic gyres between the RIM current and the coast (Oğuz et al., 1991; Ivanov et al., 1997). Detailed studies about the oceanography of Black Sea have been performed since the 1960s. In these studies, 3 different basic water types were determined. They are i) Black Sea surface water (BSW), ii) Black Sea cold intermediate water (BCIW), and iii) Black Sea deep water (BDW) (Latif et al., 1990; Oğuz et al., 1991, 1993 1994; Özsoy and Ünlüata, 1997; Oğuz and Beşiktepe, 1999).

Due to the salty water formation in the deep layer as a result of the mixing of Mediterranean water entering from the Bosphorus and surrounding water the permanent pycnocline layer (100-200 m) had blocked the oxygenation of deep layer (2000 m) water and caused the water to become anoxic (Spencer and Brewer, 1971; Deuser, 1974; Murray et al., 2005). Intense eutrophication observed in the Black Sea between 1974 and

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1987 had caused the dissolved oxygen level to decrease in the pycnocline layer and 2 distinct periods (before and after 1987) were distinguished (Konovalov and Murray, 2001; Konovalov et al., 2005). In addition, it was mentioned that the changing of dissolved oxygen concentrations in each period is due to the intensity of the convective mixing happening as a result of the increase and decrease in temperature in the pycnocline layer. Convective mixing brings the cold and oxygen rich water to the pycnocline depth. In 2003, an increase in the dissolved oxygen at the middle of pycnocline was reported indicating a decrease in eutrophication (Konovalov and Murray, 2001; Konovalov et al., 2005). Murray and Yakushev (2006) also suggested that 2 responses of important perturbations in the Black Sea that continue to be observed are climatic forcing (both natural and anthropogenic) and eutrophication

The aim of this study is along with presenting historical information about the evolution of the eutrophication to establish the current situation in the Black Sea by determining the displacements of oxygen levels in the middle pycnocline

2. Materials and methods

Studies at the stations shown in Figure 1 were done in October 2008 at KD02A, KD02B, and KD02C stations, and in May 2008 at KD03, KD04, KD05A, KD05B, and KD05C stations with RV Cesme

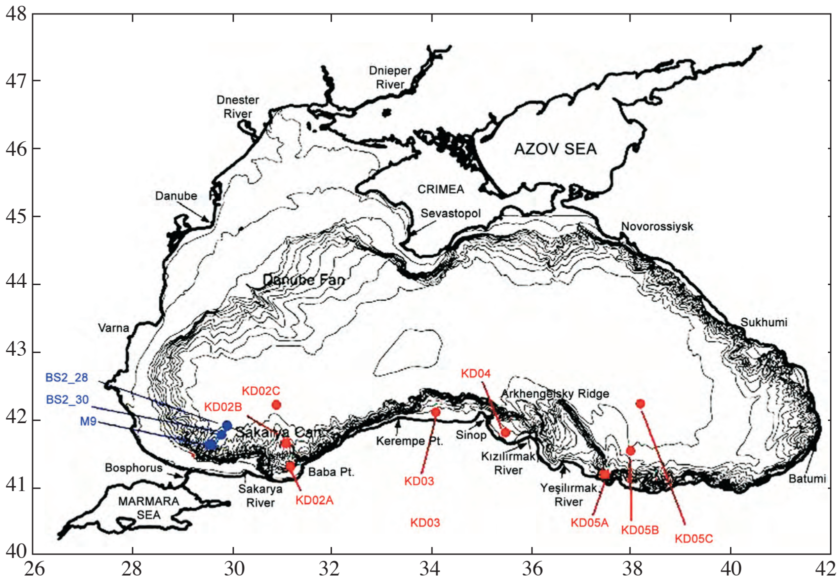

Figure 1. Research stations (modified from Beşiktepe et al., 2001).

Temperature, salinity and depth data were taken by using a SeaBird CTD. DO values for the west Black Sea were taken from the DO and CTD measurements of the ship named RV Aliance from M9 station on 6 February 2009, and BS2_28 and BS2_30 stations on 25 February 2009. Mamayev (1975) was followed for the geometric T-S analyses (Table) Artificial spikes of CTD values that are due to rapid lowering CTD were removed.

3. Results and discussion

The minimum water temperatures of stations KD2C and 5C seem lower than the others. Surface temperatures varied between stations indicating seasonal effects.

Table. The coordinates, water depth, measured parameters, date of sampling, vessel's name and distances from the coast to the sampling stations.

Stations	Latitude	Longitude	Water depth (m)	Measured parameters	Date of sampling	Vessel′s name	Distance from coast (km)
KD02A	41°15′N	31°22′.00″E	100	CTD	20.10.2008	Çeşme	1.6 km
KD02B	41°47′N	31°20′.00″E	800	CTD	14.10.2008	Çeşme	48.0 mm
KD02C	42°18′N	31°15′.00″E	2000	CTD	15.10.2008	Çeşme	124. km
KD03	42°06′N	34°00′.00″E	91	CTD	14.5.2008	Çeşme	13.8 km
KD04	41°45′N	35°31′.00″E	73	CTD	14.5.2008	Çeşme	15.1 km
KD05A	41°04′N	37°55′.00″E	74	CTD, DO	3.6.2008	Çeşme	5.0 km
KD05B	41°29′N	38°04′.00″E	2000	CTD, DO	3.6.2008	Çeşme	51.2 km
KD05C	42°16′N	38°10′.00″E	2000	CTD, DO	3.6.2008	Çeşme	132 km
KD06	41°00′N	39°48′.00″E	200	CTD, DO	08.04.2008, 19.08.2008, 13.02.2009	Sürat Araştırma I	4.1 km
M9	41°33′49″N	29°.32′50″E	1147	CTD, DO	6.2.2009	R/V Aliance	53 km
BS2_30	41°42′49″N	29°.34′.91″E	1617	CTD, DO	25.2.2009	R/V Aliance	72 km
BS2_8	41°55′62″N	29°.47′.84″E	2039	CTD, DO	25.2.2009	R/V Aliance	87 km

In the west, T-S data variability was higher from surface to BCIW core than that of the BCIW-BDW mixing line (Figure 2). Salinity of BCIW decreased from the periphery towards the central region (KD2A). This finding is in contradiction with Oğuz et al. (1994) and Oğuz and Beşiktepe (1999). Oğuz and Beşiktepe (1999) found that transient and saltier water types between the surface and the core of BCIW might show the lateral spread of saltier and denser water masses that sink from the interior of the basin towards the peripheries. This disagreement can be explained by mesoscale eddies separated from the less saline and cold water coming from the northwest shelf. Oğuz et al. (1992) reported that circulation of the Black Sea was dominated spatially and temporally by the meanders and mesoscale eddies.

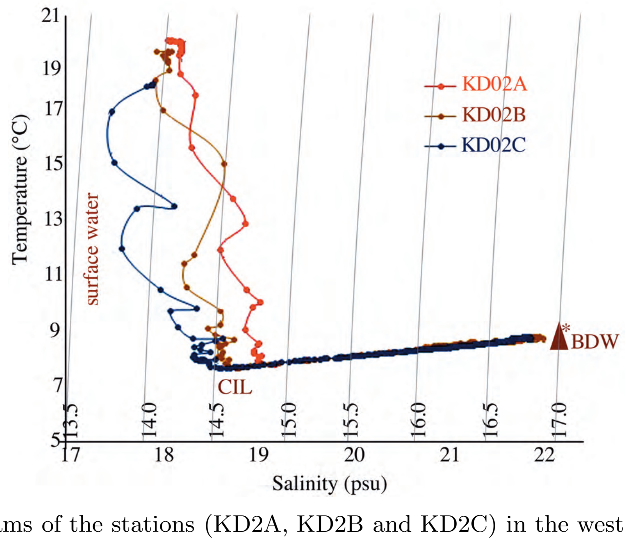

Figure 2. T-S diagrams of the stations (KD2A, KD2B and KD2C) in the west part of the Black Sea.

In the east, the salinity of BCIW increased 0.4 psu from the peripheries to the interior of the basin, increasing salinity consistent with Oğuz and Beşiktepe (1999). On the other hand temperature of BCIW in the central region was lower than that of the peripheries in contradiction with Oğuz et al. (1994). At the station KD5C, data points make a cavity towards the bottom at the BCIW region in the graph. This variation may reflect variability in overturning during the previous winter.

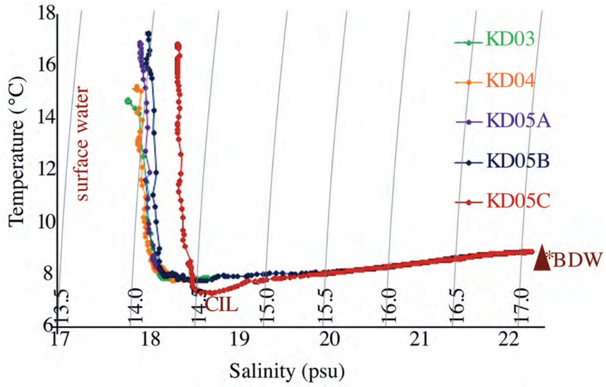

Figure 3. T-S diagrams of the stations (KD03, KD04, KD5A and KD5C) in the east part of the Black Sea.

The evolution of the T/S diagrams from the 1960s to today is shown in Figure 4. It is understood that the current situation has reverted to the situation in 1960. An increase in 1 °C in the BCIW temperature since 1995 may reflect the effects of global warming.

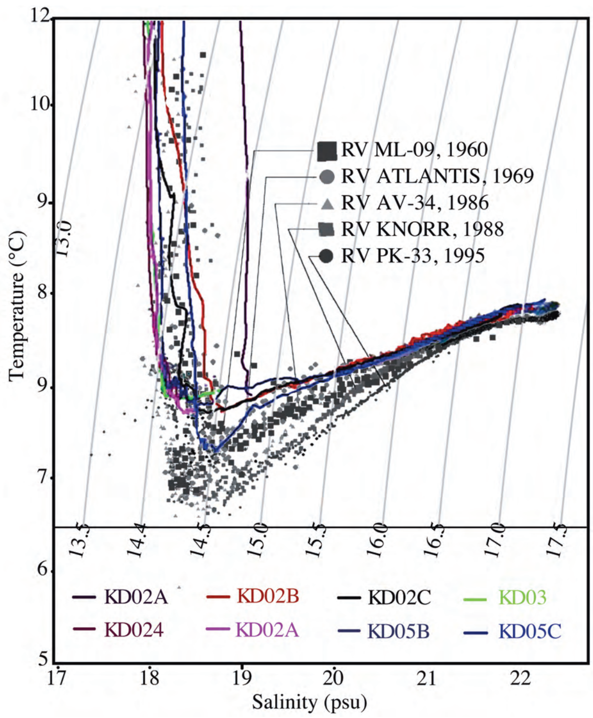

Figure 4. CTD data obtained from expeditions made from 1960 to 2008 by ML-09, 1960; ATLANTIS, 1969; AV-34, 1986; KNORR, 1988; PK-33, 1995 (taken and modified from Konovalov and Murray, (2001): with permission of Elsevier) and CESME boat and data obtained from the Black Sea in the expeditions made in 2008.

Figure 5 presents this situation more clearly. When the data of 2008 and 2009 are added to the graph taken from Konovalov et al. (2005), which includes the temperature and DO data in the middle of the pycnocline corresponding to σ_t 15.4, 3 different equilibrium lines are obtained. The dashed lines represent equilibrium shift downwards because of eutrophication and shift towards the right due to the effect of heating. The decrease in the temperature explains the penetration of the pycnocline temperature and hence the penetration of oxygen. Temperature range of the 3rd equilibrium line (between 2003 and 2009) corresponds to the 1st equilibrium line (1960-1980). On the other hand, the 3rd equilibrium line located above the 2nd equilibrium line (1987-2001) indicates a decrease in eutrophication because at the same temperature, DO levels of the 3rd line will be greater than the 2nd line's DO levels. Starting from 2008, increasing rains and the initiation of cooling will probably carry this final equilibrium position towards the left. Oğuz et al. (2006) suggested that the variations in cooling and warming intensity were related to North Atlantic Oscillation (NAO) and East Atlantic-West Russia (EAWR) System.

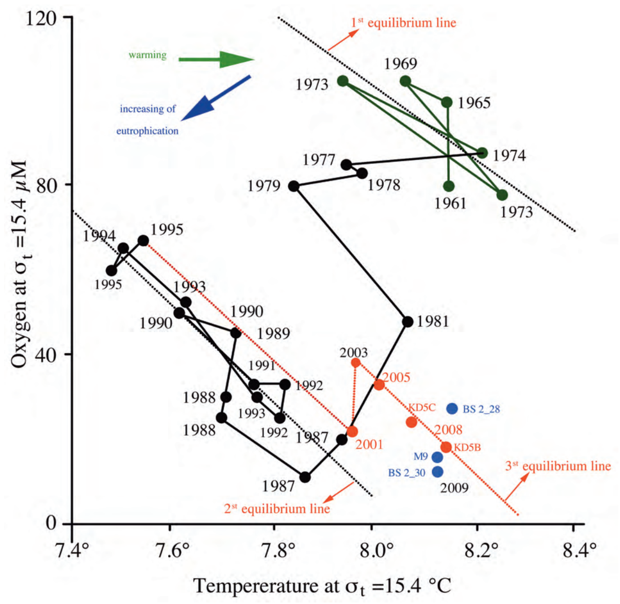

Figure 5. From 1961 to 2010, the variation in dissolved oxygen concentrations against temperature at the middle of the pycnocline (σ_t = 15.4) reveals the existence of 3 periods. These are the first equilibrium line (1961-1974), the second equilibrium line (1987-2001) and third equilibrium line (2003-2009). The Figure containing data before 2008 is taken and modified from Konovalov et al. (2005) and Murray and Yakushev (2006) with the permission of the Oceanography Society, 2008 data are from the CESME expedition and 2009 data are from the RV ALIANCE.

In the southeast cooling surface water does not reach the BCIW temperature therefore supporting that there are fields in which BCIW is being stored rather than formed with the help of anticyclonic region (ACR) convergence (Oğuz et al., 1991). Moreover, Oğuz et al. (1991) reported deeper BCIW in the anticyclonic gyres. With numeric circulation models Staneva and Stanev (1997) concluded that the cold water forming in the continental shelf waters and continental slope were being carried inside the basin and into deeper areas. In addition, in the model formed by dense water mass formation and spreading, it was indicated that in the lateral scattering period following the intense convective sinking phase of the dense water mass, mesoscale eddies play an important role (Marshall and Schott, 1998, In: Oğuz and Beşiktepe, 1999). Waters originating from the northwest shelf join the BCIW at a level between the center and the lower isopycnals' boundary of BCIW. In short, BCIW forming in the northwest shelf in winter is carried to southeast anticyclonic region following the cyclonic region with breaking eddies (Beşiktepe et al., 2001).

In the literature, it is mentioned that low salinity cold waters are continental shelf water originated (Oğuz and Beşiktepe, 1999). Similarly, it was found that there is a decrease in the salinity in the eastern stations from CR to continental shelf regions. However, the more saline waters in the southwestern coasts and the decrease in salinity from west to east can be explained by the fresh water entrance from point and nonpoint sources along the Anatolian coasts and/or can indicate waters coming from the northwestern shelf previously. The salinity of BDW was about 21 psu in 1988, which was a warmer year and was about 24 psu between 1992 and 1994, which were colder years. This shows that higher surface nutrients, export production and higher oxygen consumption in the upper boundary of suboxic zone exceed oxygen supply to this zone by stronger convective mixing.

The oxygen supplied by ventilation from the surface down to the depth of CIL (cold intermediate layer) occurs in winter on both the northwest shelf and the center of cyclonic gyres (Murray and Yakushev, 2006). The main sink of oxygen is the bacterial degradation of sinking organic matter (Konovalov and Murray, 2001). The degree of eutrophication can alter oxygen consumption in the just above the upper boundary of the suboxic zone (Konovalov and Murray, 2001).

4. Conclusions

Fluctuations in export production in relation to nutrient levels affect the balance between oxygen consumption (bacterial respiration) and oxygen injected from the ventilation thermocline. The changing oxygen balance governs the upper boundary of the suboxic zone ($\sigma_\theta = 15.5$) and the oxygen levels just above it ($\sigma_\theta = 15.4$). Monitoring the intensity of ventilation and the eutrophication was done by Konovalov and Murray (2001) using temperatures and DO levels at $\sigma_\theta = 15.4$. Temporal variation in oxygen and temperature on $\sigma_\theta = 15.4$ showed that the inverse trend (temperature versus DO of mid-pycnocline) in the 1960s and early 1970s shifted to a new position with a similar slope and lower oxygen in the late 1970s to 2001-2002.

The second trend developed starting in 1987 and ended in 2001, in spite of strong ventilation of oxycline due to the cold period, showing lower oxygen levels than the 1960s and Murray and Yakushev (2006) interpreted this shift as resulting from increased eutrophication resulting in an increased flux of organic matter due to the increased nutrient fluxes in the Black Sea.

In 2003-2004, oxygen content at $\sigma_\theta = 15.4$ increased back to values for the early 1990s. The present data in 2008-2009 and the data in 2003-2005 described another new position with a similar slope and higher oxygen (decreased eutrophication), but the range of temperature variation changed back to 1960s values. That is to say, this situation indicates a new warm period.

In the warming periods, DO concentrations have to increase as a result of decreased oxygen consumption due to the lower surface nutrient levels (Oğuz et al., 2006). Indeed, this situation occurred but DO levels did not reach 1960s levels. This contradiction may be due to 2 reasons: first, anthropogenic eutrophication as suggested by Konovalov and Murray (2001), Murray and Yakushev (2006), and Oğuz et al. (2006); second, severe warming in the second half of the 2000s in decadal scale (more intense warming when compared with the 1960s). More and more decreased ventilation especially in 2007 probably cannot hold the system in balance in spite of the lower level DO consumption due to the lower export production. On the other hand, Staneva and Stanev (2002) estimated that the time of residence of the BCIW in the 1990s was 5.5 years. This means that the measurements made at a certain time reflect the combination of the effects in climatic conditions from 5 years ago to the measurement time. The cooling observed in 2008 will be reflected in the temperature versus DO graph (Figure 5) as a new period after 2010. Whether be the line will be upward or downward may be related to the intensity of cooling. In the coming years, the monitoring of CTD, DO, nutrient levels, export production and meteorological parameters in the Black Sea will indicate clearly the importance of anthropogenic eutrophication. Because the residence time of BCIW is approximately 5 years, the characteristics of the BCIW do not change considerably during this period. With cooling in 2007, another new equilibrium will be observed after the 2010s that will allow us to more accurately predict the relative importance of convective cooling and eutrophication.

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