CLIMATE-DRIVEN CHANGES IN THE BLACK SEA IN FRONT OF THE BULGARIAN COAST

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Abstract


The world is heating up and assessment of the magnitude of temperature increases refers to the Earth’s seas and oceans. The seas and oceans act as a giant rechargeable battery for the Earth. It takes a lot of energy and time to change sea temperature so that seas and oceans can be called the ‘memory’ of the Earth’s climate system. The Black Sea in front of the Bulgarian coast becomes climate change affected area. Research in the 30-mile Black Sea zone in front of the Bulgarian coast, down to 100-m isobaths was done, with aim climate-driven changes to be established. In-situ measurements of temperature, salinity, oxygen and oxygen saturation were done. Processing of samples for nutrients was performed via unified methods for marine waters. Climate-driven transformation of the thermo-haline structure was ascertained. Because of warming, the Black Sea Cold Intermediate Layer in front of the Bulgarian coast was warmer in the frame of isotherms of 8˚C, with greatly elevated bottom border. Salinity was above the long-term average throughout the 100 m investigated layer. The greatly elevated Cold Intermediate Layer bottom border brought about rise of high-salinity deep waters. Owing to crucially reduced fresh water inputs, extremely low were the concentrations of nutrients. The organic nitrogen share was dominating at total nitrogen formation in the open-sea.

Key words: Black Sea, climate change impact, Danube River stream

Abbreviations: Cold Intermediate Layer (CIL); Cold Intermediate Water (CIW); Organic nitrogen (ON); Sea surface salinity (SSS); Sea surface temperature (SST); Total inorganic nitrogen (TIN); Total nitrogen (TN)

Introduction

The world is heating up and the assessment of the magnitude of temperature increases refers to the Earth’s seas and oceans. The seas and oceans function as vast reservoirs of heat. Covering the greater part of the Earth’s surface, the oceans directly absorb the majority of solar heat, storing it for long periods by comparison to either the land or atmosphere. The seas and oceans act as a giant rechargeable battery for the Earth. It takes a lot of energy and time to change sea temperature so that seas and oceans can be called the ‘memory’ of the Earth’s climate system. Tracking sea surface temperature over a long period is the most reliable way of measuring the precise rate at which global temperatures are increasing. Heat energy slowly released from the sea is the dominant driver of atmospheric circulations and weather pattern. Sea surface temperature influences the rate of energy transfer to the atmosphere, as evaporation increases with temperature.

The predicted effects of climate change are numerous (Dineva, 2010; Dineva and McKay, 2012) and some effects of recent climate change may already be occurring. There is much need to assessing the rate, magnitude
and duration of unwelcome global and regional climate-driven events related to water environment.

Black Sea low-salinity surface waters by river origin overlie high-salinity deep waters by Mediterranean origin, and as a result, a permanent pycnocline (halocline) develops, with a depth between 100–150 m varying horizontally according to the local hydrodynamics, that inhibits the exchange between the surface and deep waters. Owing to these conditions, the Black Sea is almost anoxic, with oxygen only in the upper 150 m layer (13% of the sea’s volume), and hydrogen sulphide and methane in the deep waters. The atmospheric forces affect only the sub-surface layer and cold intermediate waters (Grégoire and Beckers, 2004).

The most important characteristics of the Black Sea vertical stratification (Ryabinin et al., 1991; Grégoire and Beckers, 2004) are the sharp halocline (from greek: hals – salt) from the sea surface down to 200 m (upper halocline from 0 m down to 20 m, and permanent halocline – from 50 m down to 200 m), and the Cold Intermediate Layer. The western periphery of the Black Sea is unlike eastern mainly owing to penetration of Danube Transformed Waters (Sapozhnikov, 1992) and waters by river origin of northwestern part of the sea.

The Black Sea in front of the Bulgarian coast (Dineva, 2008; Dineva, 2009; Dineva, 2010) becomes high sensitive to climate change and climate footprint assessment is much needed. Notable temperature extremes during 2003 included a severe heat wave (NOAA, 2004) in the summer of 2003 across Europe. Research in the 30-mile Black Sea zone in front of the Bulgarian coast, down to 100-m isobaths was done in 2003, with aim climate-driven changes to be established.

Material and Methods

The 30-mile Black Sea zone in front of the Bulgarian coast was studied down to 100-m isobath (Dineva, 2004) in 2003. Observations were performed aboard the IFR R/V Prof. A. Valkanov. Research was done along Capes Kaliakra, Galata and Emine, with sampling at 1, 3, 10, 20 and 30 miles, and at St. B5 in the Varna Bay (Figure 1).

Measurements of temperature, salinity, oxygen and oxygen saturation were done by CTD 60 (2001), which is a high quality, high accuracy multiparameter probe for oceanographic measurements of physical and chemical parameters, with calculations according to UNESCO formulas. Comprehensively study of the essential forms of nitrogen, including total inorganic nitrogen and total nitrogen in the 30-mile zone in front of the Bulgarian Black Sea coast (Dineva, 2004) was carry out as part
of Danubs project. Samples were collected at standard depths (0, 10, 25, 50, 75, and 100 m) to study NO$_2$-N, NO$_3$-N, NH$_4$-N, total inorganic nitrogen, organic nitrogen, and total nitrogen. Processing of samples was performed via unified methods for marine waters (Gashina, 1993; UNESCO, 1994). Concentrations of NO$_2$-N, NO$_3$-N and NH$_4$-N were established (Dineva, 2004) by Japanese Spectrophotometer HITACHI-U 2001 UV/Vis (1995). Regional Environmental Inspections – Varna found Keldal’s nitrogen concentrations with a Gerhardt system for mineralization and distillation.

**Results and Discussion**

After 2002, global temperatures remain high. In 2003 (NOAA, 2004), global temperatures (IPCC, 2001) were above the long-term average, ranking 2003 the second warmest year on record, which tied 2002. Temperatures for the year were above long-term average across large parts of Asia, Europe and the western United States. Warmer-than-average temperatures also covered much of South America, Australia, Canada and parts of Africa.

Over 2003, notable temperature extremes comprised severe heat wave in the summer of 2003 across Europe (NOAA, 2004). Daily maximum temperatures ranged from 30 to 37°C across France, Switzerland and the Mediterranean region, killing approximately 25,000 people. The record summer heat wave contributed to the large annual anomalies in Europe. The all-time maximum temperature record in the United Kingdom was broken on August 10, when the mercury reached 38.1°C at Kent.

Sea surface temperature in front of the Bulgarian coast in August 2003 was 0.86°C above the 1992-2000 mean (Dineva, 2007), and sea temperature was with anomaly in excess of 1.26°C at 10 m depth. The adjacent Figure 2 depicts warmer than average sea temperatures that were spread in front of Cape Galata. Sea temperatures in this region were 1.41°C above the 1992-2000 average in the 10-25 m layer (Figure 2B).

In the Black Sea a Cold Intermediate Layer commences near on 40 m depth and influences on the temperature distribution, been in the summer a physical border between sub-surface and deep waters (Ovchinnikov, 1989). Vertically, the CIL is situated between isotherms of 8°C (Vladimirtsev, 1964), and covers the criterion about limits of salinity: 18.6 psu < S < 20.0 psu (Ryabinin et al., 1991). The CIL thickness depends on the severity of previous winter as increase of storms brings about deeper penetration of winter cooling. The CIL is presented throughout the whole year, although during much of the year it is enough near to well warm waters (Bogdanova, 1959a). According to Ovchinnikov and Popov (1987), CIL is forming in the centres of the cyclonic gyres in the central part of the sea during term of maximum cooling of the surface, and the Basic Black Sea Current spreads these waters. The winter convection
in the cyclonic gyres is the basic source of replenishment and refreshing. Later on, a new analysis of the Cold Intermediate Water formation was presented by Ivanov, Beşiktepe and Özsoy (1997), based on the new data sets, having high resolution and full basin coverage. They established that CIL forming process is an outcome of both convective and advective contributions, most actively taking place along the ‘convergence zone’.

In August 2003, the upper CIL border was on 45 m depth at 20 miles in front of Cape Galata, on 42 m depth at 30 miles in front of Cape Galata, and on 38 m depth at 20 miles in front of Cape Emine. The bottom CIL border was on 89 m depth at 30 miles in front of Cape Galata, and on 97 m depth at 20 miles in front of Cape Emine. Temperature anomalies of CIW, based on 1992–2000 mean (Dineva, 2007) were between +0.04°C and +0.39°C. Because of warming, the Black Sea Cold Intermediate Layer in front of the Bulgarian coast was warmer in the frame of isotherms of 8°C, with greatly elevated bottom border than 90s – with 46 m in front of Cape Galata and with 35 m in front of Cape Emine. The upper border was raised only with 4 m in front of Cape Galata, and with 10 m in front of Cape Emine. Based on 1992–2000 mean (Dineva, 2007), the CIL vertical range was reduced with 42 m in front of Cape Galata, and with 25 m in front of Cape Emine, i.e. CIW volume was greatly reduced than 90s.

A temperature anomaly of waters on 25 m depth in front of Cape Emine, which are situated above the CIL, based on 1992–2000 mean (Dineva, 2007) was –4.66°C. It was due to reduced intensity of the turbulence exchange in the layer of sharper thermocline, which has inhibited the heat penetration into that layer.

Salinity of the 30-mile zone in front of the Bulgarian Black Sea coast during 2003 was above the long-term (1992–2000) average (Dineva, 2007) throughout the 100 m investigated layer (Figures 3 and 4).

Salinity of the Bulgarian Black Sea was unusually high in April under impacts of several factors: slight Danube River influence, upwelling, and slight coastal river run-off. Sea surface salinity was 16.93 PSU at 10 miles in front of Cape Galata and was increased in the direction of the coast: at 3 miles it was 17.00 PSU, and at 1 mile – 17.39 PSU. Salinity was highest and abnormal in the Varna Bay, with SSS – 17.98 PSU, and in the bottom layer – 18.13 PSU.

A sharp SSS decrease has occurred in May. The stream of Danube transformed waters was at 10 miles in front of Cape Galata (Figure 5). The influence was throughout the whole layer, but most affected was the 10 m layer, with SSS – 15.08 PSU, and on 10 m depth salinity was 15.80 PSU. In the Varna Bay, only surface waters were refreshed, and SSS minimum of 15.45 PSU was recorded. Salinity was again high in August (Figure 3), above the long-term (1992–2000) average throughout 100 m layer, with a positive SSS anomaly of 1.05 PSU, and greatest positive anomaly of 1.63 PSU at 100 m depth (Figure 4).

The dissolved oxygen is an indicator of the balance of the marine ecosystem, which gives a possibility for assessment of the production-destruction processes (Di-
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There are three main sources of oxygen in the sea – direct diffusion from the atmosphere, wind and wave action, and photosynthesis. From these, photosynthesis by aquatic plants and phytoplankton is very important (Sapozhnikov, 1992). Oxygen depletion occurs when oxygen consumption exceeds oxygen production. Increases in oxygen consumption can be caused by an over-abundance of marine plants or algae in the ecosystem, increased organic waste entering the water, death and decay of organic matter, or by certain chemicals that remove oxygen directly from the water column. Oxygen plays a very active role in the chemistry and biology of coastal waters, and its concentration is a major indicator of water quality. In some areas, large quantities of nutrients enter coastal waters. These nutrients stimulate the rapid growth of phytoplankton. When the produced organic matter settles into the deeper bay waters, its decomposition can deplete the dissolved oxygen, and the result is death of fishes.

In March, the nearest coastal zone in front of Cape Galata was most oxygen super-saturated – 126.49% in the layer of 1 mile offshore. In May, the highest super-saturation was again at 1 mile in front of Cape Galata – 121.08% (5 m), while much different was the state of the Varna Bay – an increased oxygen deficiency (82–88% saturation), recorded as early as April (90–94% saturation). In August, the waters in front of the Bulgarian coast were oxygen super-saturated down to 75–80 m, with oxygen

![Graph A](image1.png)

**Fig. 4.** Black Sea summer salinity in the 30-mile zone in front of the Bulgarian coast (coastal and open sea waters) in 2003 with respect to the average salinity from 1992 to 2000: (A) Summer sea salinity (psu) in the 100 m layer in front of Cape Galata. (B) Positive anomaly of the summer salinity (psu) in the 100 m layer in front of Cape Galata. (C) Summer sea salinity (psu) in the 100 m layer in front of Cape Emine. (D) Positive anomaly of the summer salinity (psu) in the 100 m layer in front of Cape Emine.
saturation maximum of 181.10% at 10 miles in front of Cape Kaliakra, 29 m depth. Along all transects, the peaks of oxygen super-saturation down on the vertical were in accordance with the rule that the maximum of the dissolved oxygen occurs in the layer of the thermocline (Bogdanova, 1959b), and this maximum is as bigger as the thermocline is sharper. The peaks are not so much owing to the intensity of photosynthesis but rather owing to favourable conditions for oxygen accumulation, according to diminution of the vertical exchange in the layer of maximum gradient of density. The forming of sustainable layer in the zone of photosynthesis creates conditions for accumulation of the produced oxygen in this layer.

Owing to the process denitrification, the amount of available N (nitrate, nitrite and ammonium) appears to be the limiting nutrient in the sea (Topping, 1976), unlike fresh water systems where phosphate appears to be the nutrient controlling the production of plant life. The denitrification process results in the formation of nitrite and finally ammonia, and in some extreme cases, N₂ gas is produced and there is a net loss from the system (Horn, 1972; Leonov, 1980).

Global precipitation was below the 1961–1990 average in 2003 for third year in a row (NOAA, 2004), and has negatively affected the Black Sea in front of the Bulgarian coast and its watershed. The adjacent Figure 6 depicts this negative impact on the nutrients.

Nitrite and nitrate nitrogen concentrations were significantly below the long-term average (Dineva, 2007) in March, and the situation has continued to deteriorate through the year. In May, nitrate nitrogen concentration was highest at 10 miles in front of Cape Galata – in the stream of Danube transformed waters (5–10 m layer). In August, in the 50 m open-sea layer in front of Cape Galata and Cape Emine there were only traces of nitrite nitrogen and below 50 m there was no nitrite. The nitrate concentration was considerably lowered – 0.29 μM throughout surface-bottom layer. The situation was similar along Kaliakra transect – minimal nitrite and nitrate nitrogen concentrations, including a considerable number of nitrite nitrogen concentrations under the detection limit. The nutrient fund was in a crucial state owing to severe drought, minimal river run-off, and increased consumption by phytoplankton. In 2003, ammonium nitrogen depletion was reached only in the bottom waters at 1 mile in front of Cape Galata in the summer. The maximal year’s ammonium concentration was recorded in April in the surface waters of 1 mile in front of Cape Galata – 10.51 μM. A high ammonium nitrogen concentration – 9.81 μM was established in the Varna Bay sur-

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**Fig. 5.** May Sea surface salinity (psu) in the Varna Bay (B5), and in the Bulgarian Black Sea coastal zone in front of Cape Galata – at 1 mile offshore (G1), 3 miles offshore (G3), and 10 miles offshore (G10)

**Fig. 6.** Monthly nitrate nitrogen (μM) variability at 3 miles in front of Cape Galata (Bulgarian Control Station) in 2003 with respect to the long-term (1995–2000) average: (A) In the surface waters. (B) In the bottom waters.
Fig. 7. Ratio between nitrite nitrogen, nitrate nitrogen and ammonium in the layers of Varna Bay (B5), and at 1 mile in front of the Bulgarian Black Sea coast (Coastal zone) in August 2003: (A) in front of Cape Kaliakra (K1); (B) in front of Cape Galata (G1); (C) in front of Cape Emine (E1); (D) in the Varna Bay (B5)

Fig. 8. Ratio between total inorganic nitrogen (TIN) and organic nitrogen (ON) in the layers of Varna Bay (B5), and at 3 miles in front of the Bulgarian Black Sea coast (Coastal zone) in August 2003: (A) in front of Cape Kaliakra (K3); (B) in front of Cape Galata (G3); (C) in front of Cape Emine (E3); (D) in the Varna Bay (B5)
face waters in March. In the Varna Bay under influence of Varna Lake, higher total inorganic nitrogen level than the coastal zone was formed. TIN concentrations were from crucially low – 0.30 μM (August, 1 mile in front of Cape Galata, bottom) to 17.27 μM (March, Varna Bay, surface waters). In August, TIN distribution at 1 mile in front of the Bulgarian Black Sea coast and in the Varna Bay was as follows on Figure 7.

The summer of 2003 was crucial for the ecosystem. The organic nitrogen share was dominant at total nitrogen formation (Figure 8). In 2003, TN concentrations have ranged from 0.30 μM at absence of organic nitrogen (summer, 1 mile in front of Cape Galata, bottom) to 40.33 μM (summer, 1 mile in front of Cape Kaliakra, surface).

Conclusions

During severe heat wave across Europe in the summer of 2003, SST in front of the Bulgarian Black Sea coast in August was 0.86°C above the 1992–2000 mean, and sea temperature was with anomaly in excess of 1.26°C at 10 m depth. In front of the Cape Galata, temperature was 1.41°C above the 1992–2000 average in the 10-25 m layer. Down, the CIL was also affected. Temperature anomalies of Cold Intermediate Water based on 1992-2000 mean were between +0.04°C and +0.39°C in front of the Bulgarian coast. Because of warming, the Black Sea CIL was warmer in the frame of isotherms of 8°C, with greatly elevated bottom border than 90s. Based on 1992-2000 mean, the CIL vertical range was reduced with 42 m in front of Cape Galata and with 25 m in front of Cape Emine, i.e. CIW volume was greatly reduced than 90s. During 2003, climate-driven transformation of the haline structure was established in the 30-mile investigated zone in front of the Bulgarian Black Sea coast. Salinity was above the long-term (1992–2000) average throughout the 100 m surveyed layer. Owing to upwelling and slight river run-off, salinity of the Bulgarian Black Sea was unusually high in April. Salinity was again high in August, above the long-term (1992–2000) average throughout 100 m investigated layer, with a positive SSS anomaly of 1.05 psu, and greatest positive anomaly of 1.63 psu at 100 m depth. Strong upwelling in the 3-mile zone in front of Cape Kaliakra was ascertained. The elevated greatly CIL bottom border than 90s, with 46 m in front of Cape Galata and with 35 m in front of Cape Emine, brought about rise of high-salinity deep waters. The waters in front of the Bulgarian Black Sea coast were oxygen super-saturated down to 75–80 m in August, approaching 181.10% saturation at 10 miles in front of Cape Kaliakra, 29 m depth. Nitrite and nitrate nitrogen concentrations were significantly below the long-term average throughout the year. In August, in the 50 m open-sea layer in front of Cape Galata and Cape Emine there were only traces of nitrite nitrogen, and below 50 m there was no nitrite. The nitrate concentration was considerably lowered – 0.29 μM throughout surface-bottom layer. The situation was similar along Kaliakra transect – minimal nitrite and nitrate nitrogen concentrations, including a considerable number of nitrite nitrogen concentrations under the detection limit. The nutrient fund was in crucial state owing to severe drought, minimal river run-off, and increased consumption by phytoplankton. Total inorganic nitrogen concentrations were from extremely low – 0.30 μM to 17.27 μM. The organic nitrogen share was dominant at total nitrogen formation. Over the year, total nitrogen concentrations were from 0.30 μM (at absence of organic nitrogen) to 40.33 μM.

Acknowledgements


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