Romanian Reports in Physics, Vol. 64, No. 1, P. 232–245, 2012

ATMOSPHERE AND EARTH PHYSICS

BLACK SEA WATER DYNAMICS ON THE ROMANIAN LITTORAL – CASE STUDY: THE UPWELLING PHENOMENA[*]

MARIA-EMANUELA MIHAILOV[1,3], MARIA-IONELA TOMESCU-CHIVU[2], VIORICA DIMA[2]

[1]National Institute for Marine Research and Development "Grigore Antipa" Constanta
Mamaia Blv. No. 300, RO-900591, Constanta, Romania
E-mail: mihailov@alpha.rmri.ro
[2]National Meteorological Administration, Sos. Bucuresti-Ploiesti 97, 013686 Bucharest, Romania
[3] Department of Atmospheric Physics and Earth Sciences, Faculty of Physics,
University of Bucharest, P.O. Box MG-11, 077125, Bucharest-Magurele, Romania

Received July 7, 2010

Abstract. Generally, the Black Sea offshore waters have no vertical circulation, due to the great density stratification, which prevents the deep convection processes. The Black Sea currents are strictly horizontally and therefore there are no permanent upwelling and downwelling phenomena like in other areas of the Planetary Ocean. The paper presents the existence of the upwelling at the Romanian Black Sea littoral, during the summer periods of 2006–2009 years. The analysis of the daily sea surface temperature, salinity, air temperature and wind data of the near shore seawater revealed the presence of upwelling as an effect of the western and southwestern winds. In the Black Sea the upwelling phenomena is of great significance due to the inflow of deep waters, richer in nutrients, to surface in a narrow coastal zone creating a very high bioproductivity of sea water.

Key words: dynamics, Black Sea, upwelling, sea surface temperature.

1. INTRODUCTION

Black Sea is a semi-enclosed basin with relative small dimensions (432 000 km^2 surface and 538 124 km^3 volume), named, in oceanographic literature, "a small scale model of the ocean", "a giant estuary" and "a unicum hydrobiologicum". Although referring to different points of view, all the characteristics that lead at these labels are determined by its hydrological characteristics of the basin. The peculiarities of the water mass structure and dynamics of the Black Sea basin depend on complex processes of interaction with the atmosphere, by the exchange of substance and energy that take place at the interface, resulting in the evolution of the water, salt and heat balance.

[*] Paper presented at the Annual Scientific Session of Faculty of Physics, University of Bucharest, June 18, 2010, Bucharest-Măgurele, Romania.

The Northwestern part is considered, due to his particular hydrological processes, similar to an estuary.

General structure of the Black Sea consists of five water masses disposed in nearly horizontal layers: the quasiomogen upper layer, the cold intermediate layer, the permanent pycnocline, the deep water and the bottom boundary layer (benthic layer).

The quasiomogen upper layer (SSQ) is the result of the seasonal variations of the solar radiation, the global thermal balance at the sea surface and the vertical mixing. SSQ is separated from the CIL by the seasonal thermocline.

The cold intermediate layer (CIL) is an effect of the winter convection above the western shelf of the Black Sea and/or over the pycnocline dome of the two cyclonic halistatic zones. It affects all the dynamics of the Black Sea. The CIL is separated from the deep layer by the permanent pycnocline.

The permanent pycnocline (SPP) a layer with strong density gradients, situated at the base of the CIL, represents the transition from the active layer, affected by the temperature and salinity evolution and the deep water, relatively stable (temperature and salinity increase slowly with the depth, to about 8.9°C and, respectively, 22.2 PSU). Is it also the upper limit of the hydrogen sulfide zone.

Recent studies revealed the existence of the bottom boundary layer (benthic boundary layer, BBL), situated bellow 1 700 m depth, at which the values of potential temperature and salinity are uniform down to the bottom and within the entire basin. The upper limit is characterized by a "step" of the potential temperature of 0.002°C [1].

The Romanian littoral has almost a linear configuration with the exception of build-up areas such as commercial harbours (Constanta, Mangalia and Midia), marinas and coastal protection works in the southern area (groins, breakwater), particularly in Mamaia beach. Mamaia beach is one of the famous beaches of the Romanian Black Sea. It is located close to Constanta city, on a narrow sand bar, 250–350 m wide. The beach consists in alluvial sediments (brought into Black Sea by Danube and transported to the beaches by combined wave action and north to south flowing currents along Romanian Coast) and biogenic shells sediments (especially shells of Mytilus and Mia arenaria). Mamaia is behaving as a coastal cell due to its position between Cape Midia in the north and Cape Singol-Eforie Nord in the south.

The upwelling phenomenon on the Romanian littoral of the Black Sea, in the specialized literature, is poorly investigated. Few scientific reports, on the temperature of the seawater regime, proved that the dominant western winds, during summer period, lead to significance decrease of the seawater temperature in coastal areas [2, 3]. Two scientific papers referees in particular on upwelling recorded in summer of 1973 [4] and during the summer periods of 1970–1979 years [5].

During the summers of 1970 to 1979, on the southern Romanian littoral, the well-developed coastal upwelling was observed in 7 of the 10 studied years. The phenomena were recorded when the winds from the SSE – SW – WNW sectors were blowing constant for several days. The maximum effect was generated by the southwestern and western winds [5].

The divergence processes dominate a total of 33 days, almost 36% from duration of the 1990 summer season. During these 3 months, several upwelling phenomena, with different intensity and continuance have been observed [6].

During 2000–2004, the persistence of the upwelling proved to be a long term process (> 6 days), except the 2002 year when no significant temperature decrease, reflecting the vertical exchange between the upper layer with deeper waters of the sea have been observed [7].

An interesting situation occurred in July 2004 when the temperature decreased with 9.3°C in 3 days – from 22.9°C on July 2nd to 13.6°C in July 5th, then the trend changed, and an increase of 8.7°C was recorded in 4 days due to the moderate blow of the eastern wind after that, in short time, during 4 days the temperature decreases again, with 9.8°C from 22.3°C to 12.5°C [7].

Missing of the long-time divergence process in 2002 is due to the SE – NW component of the wind that hasn't important and persistent values during the summer.

2. DATA AND METHODS

The sea surface temperature and salinity is used as a proxy for upwelling, low temperature and high salinity indicating strong upwelling conditions. The highest correlation is between sea surface temperature and the wind component normal to the coast, sea surface temperature is lowest when the wind blows from land to sea.

Taking into account the considerable variability of the spatial distribution, some representative situations have been thoroughly analyzed. The analysis will be carried out in chronological order.

Samples of marine water (Fig. 1a) have been collected daily in one station located midway, at the Mamaia Casino (44^{0}14’ N and 28^{0}38’ E) since 1959 by National Institute for Marine Research and Development “Grigore Antipa” Constanta, Romania (NIMRD). The surface seawater temperature is measured with reversible thermometers, one hundred degree accuracy (the values are corrected using standard formula). The seawater salinity is determined in laboratory after the Mohr – Knudsen method with 0.02PSU accuracy.

Meteorological data (on sea and air temperature, wind speed and direction and air pressure by National Meteorological Administration) were recorded in the weather stations, (belonging to the national weather stations network): Constanta station (44^{0}13’ N, 28^{0}38’ E) is located on the coast, at a height of 12.8 meters from the sea level. Gloria station (44⁰31' N, 29⁰34' E) was installed on the oil offshore platform in 1976 and it is 70 km from the coast (Fig. 1a). The automatic station measures the observations regarding wind direction and speed at Constanta station, while at Gloria measurements are realized by anemograph (42 m from the sea level). Wind speed values are mediated on two minutes. Regular thermometers installed in standard shelters measure the air temperature values.

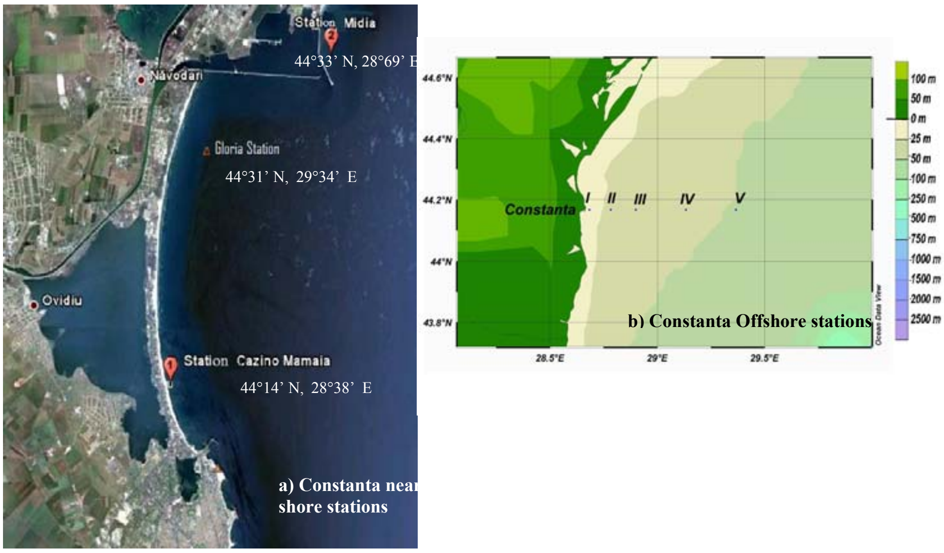

Fig. 1 – Location of seawater sites a) near shore stations at Casino Mamaia (NIMRD) and Gloria (NMA); b) offshore stations – seasonal cruises (NIMRD).

The seasonal cruises, organized by NIMRD, were carried out in the NW Black Sea inner shelf onboard RV/*Steaua de Mare* 1 (Fig. 1b). Are analyzed only the data that corresponding with the upwelling phenomena. The water samples (for physical-chemical and phytoplankton analyses) were collected from standard depths (surface, 5, 10, 20, 30, 40 and 50 m) using Niskin bottles (1.7 l). Temperature was measured using a reversing thermometer. Salinity is measured by titrimetric method of Mohr-Knudsen [8]. The salinity represents the total amount of salt from the seawater, measured in g/l, ‰ or PSU (Practical Salinity Units) from the PSS scale (Practical Salinity Scale, 1978).

The distribution of temperature and salinity with depth are made using Golden Software Surfer 8 with gridding method: kriging.

Satellite images that captured the phytoplankton bloom in the Black Sea basin are downloaded from http://earthobservatory.nasa.gov.

The analyzed data are for the summer period (May – September), from 2006 to 2009, using sea surface temperature and salinity vertical sections and algae bloom satellite image for data validation.

3. RESULTS

Many factors influence water quality including climate and precipitation, soil type, geology, vegetation, groundwater, flow conditions and human activities. The presence in water of nutrients can be associated with the biogeochemical cycles, but also with the industrial activities [9].

Atmospheric winds generate horizontal currents in the sea upper layer. These, in turn, can generate vertical water motions in processes called upwelling and downwelling at the shelf break and at the shoreline. The wind driven surface currents moves about 45 degrees to the right of the winds as a result of Coriolis effect [10, 11]. In deeper layers, the current direction rotates clockwise and the velocity decreases exponentially. The vertical integrated water flux, directed 90 degrees to the right of the wind direction, is called Ekman transport.

The formula for wind stress at the sea surface is:

$$\tau = \rho_{aer} \cdot C_D \cdot U_{10}^2,$$

where ρ_{air} is the density of air, C_D is the drag coefficient, and U_{10} is the wind speed at 10 m above the sea. Correlation between wind speed at 10 m above the sea and the current speed at the sea surface were studied also by Ekman who obtain values for V_0 as a function of wind speed:

$$V_0 = \frac{0.0127}{\sqrt{\sin|\varphi|}} U_{10}$$

for $|\varphi| \geq 10$, were φ = latitude in degrees.

Ekman proposed that the thickness of the affected layer be the depth D_E at which the current direction is opposite to that at the surface, which occurs at a depth $D_E = \pi/a$ ($a = F/m$ = acceleration of the displaced parcel*)*, and the *Ekman layer depth* is:

$$D_E = \sqrt{\frac{2\pi^2 A_Z}{f}},$$

where A_z is the coefficient of eddy viscosity and f is Coriolis parameter ($f = 2\omega \sin\varphi$) [10].

Due to its nonlinear dynamics and involvement in abrupt climate changes, the thermohaline circulation is a key component of the climate system [12].

On the western coast of the Black Sea, the onset of the divergence phenomenon is due to western, south – western and south – eastern winds, which generate an Ekman transport with an offshore component (Fig. 2). That leads, during summer, to a decrease of the seawater temperature (up to 10°C in less 48 hours) and, at the same time, because of the intermediate layer compensatory advection, to significant changes of some water masses parameters [5].

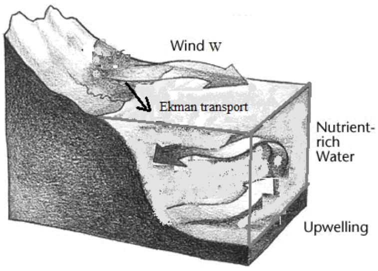

Fig. 2 – Upwelling diagram for NW coast of the Black Sea.

During the cold season the downwelling phenomena is met because of the north – eastern prevailing winds. These events can be identified by studying the temperature and salinity short time variation, due to the divergence and convergence processes [6].

The changes of the sea surface salinity distribution are mainly due to the variation of the Danube discharge and the modification of the surface wind-generated currents. The northern winds generate southerly currents, thus accelerating the general circulation and carrying along the shelf waters where the diffusion of the freshwater is reduced, so that the salinity is lower. In contrast, the currents generated by weak and moderate winds from south, will, firstly diminish or even prevent the general southward circulation, allowing more time and reducing the diffusion area, and secondly will carry the higher saline waters from south to the central part of the shelf.

A special case is strong southern wind or moderate to strong western wind, generating offshore oriented currents and bringing toward the surface the waters from below (shelf cold water), with low temperature and high salinity. This phenomenon take place in early summer, when the thermocline is shallow and the requested energy can be provided by wind.

In 2006 the upwelling is observed (Fig. 3) for three situations (23th May to 26th May, 30th May to 5th June and 5th June to 8th June). The southeastern wind leads to a decrease of the sea temperature with almost 3°C (18.63°C in May 23rd down to 15.5°C in May 24th) when the air temperature is specific for beginning of the summer period (24.1°C in May 23rd). The same wind direction on May 30 influenced the sea temperature to decrease from 17.5°C down to 14.4°C recorded on May 31 but after that the westerly winds decreased the sea temperature with approximately 2°C (June 1st) with the influence also on the air temperature (25.9°C on May 31 down to 20.3°C on June 1st).

But the well developed phenomenon is recorded when the western winds start to blow over the north – western coast of the Black Sea, and the sea surface temperature drops, for example, with 5ºC in 24 hours (a decrease from 16.8ºC in June, 5th to 11.9ºC in June 6th) and the north – eastern wind increase the temperature with 4.4 ºC up to 16.3ºC in the June 7th.

The upwelled water carries large nutrients loads that sustain large phytoplankton blooms. When phytoplankton density is very high and the bloom covers large enough areas, it can be seen from space.

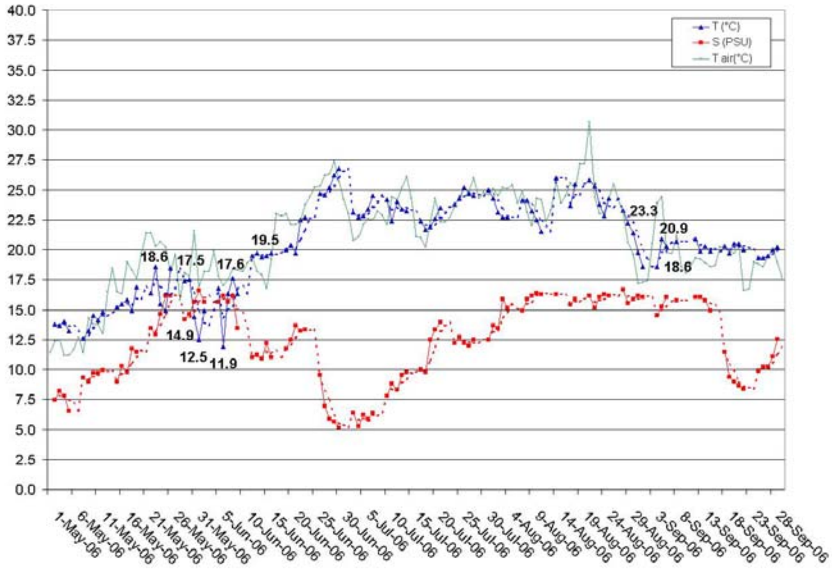

Fig. 3 – Evolution of sea surface temperature and salinity of seawater at Casino Mamaia, May – September 2006.

The Black Sea image, captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite, on 20th June 2006 (Fig. 4), shows swirls of color ranging from deep olive-green to bright turquoise created by a massive phytoplankton bloom that covered the entire surface of the sea.

Fig. 4 – Phytoplankton bloom in Black Sea (20th June 2006) captured by the Moderate Resolution Imaging Spectroradiometer (*MODIS*) on NASA's *Aqua* satellite [13].

The upwelling with persistence of more than 8 days of the phenomena was recorded in 2007 (Fig. 5).

The sea surface temperature distribution in 1–17 May 2007 is specific for an upwelling situation with the winds from west and southwest blows. As a consequence, there are strong zonal and meridian gradients surrounding the at Casino Mamaia site. The salinity of the surface waters confirms the upwelling at the observation point where the measures the salinity was: 16.19 PSU, 15.24 PSU and 14.76 PSU. The recorded air temperature for the analyzed interval is 15.1°C in May 7th (sea surface temperature 11.8°C and the influence of the southwestern winds increased the air temperature with 8°C in May 8th and the sea surface temperature to 13.6°C in May 9th).

The inner shelf measurements made on 8th May 2007 (Fig. 6) shows that the influence of the southwestern wind is felt down to 5 meters depth were the sea temperature down with approximately 4°C. At Casino Mamaia profile (44.2358 N, 28.6284 E) from 12.0°C at 0 meters (surface) to 16.1°C at 5 meters depth and at Constanta North station (44.2178 N, 28.6417 E) from 13.0°C at 0 meters to 16.9°C at 5 meters depth. Specific for Romanian littoral of the Black Sea, were the maximum depth is relatively to 10 m, the Ekman surface current has a small angle direction relative to wind direction. As the dominant direction is oriented N-E toward S-W is normal that the Ekman surface currents are oriented from north to south.

In September, the deepening of the seasonal thermocline due to the beginning of the cooling process, led to the decrease of the temperature values at the surface from 21.2 °C to 12.5 °C in 2 days, this can be also due to the long term blows of the western winds from 6th to 11th of September. At the same time, the maximum of salinity (18.84 PSU) was recorded, being an indicator of local upwelling event disturbing the specific autumn characteristics. The permanence of the western winds in this period leads to an upwelling phenomena more than 20 days long (5–28 September) with daily variations of the temperature (up or down with 2°/day) due to the southern winds changes.

The Black Sea image captured by Moderate Resolution Imaging Spectroradiometer (MODIS) on 18th of August 2007 (Fig. 7) shows swirls of color ranging from green to bright turquoise near the Danube Mouth due to the phytoplankton bloom and the specific currents circulation to the south flow the fresh water discharge to the sea coast.

In annual cycle of air – sea interaction processes that take place on the Romanian Black Sea shore, the month of May can be considered as the middle of the transition period from the cold to warm season. The changes of the thermal fluxes values beginning in March when the seawater starts to warm (due to the increased values of the air temperature) from the surface to the bottom, led to the forming of seasonal thermocline. Taking into account the differences in bathymetry from an area to another, and also the variability of meteorological (air temperature, nebulosity, wind) and hydrological (waves, currents, river flow) conditions, thermohaline stratification of the seawater masses cannot be uniform and the horizontal distribution of the parameters will be spatially non-homogeneous.

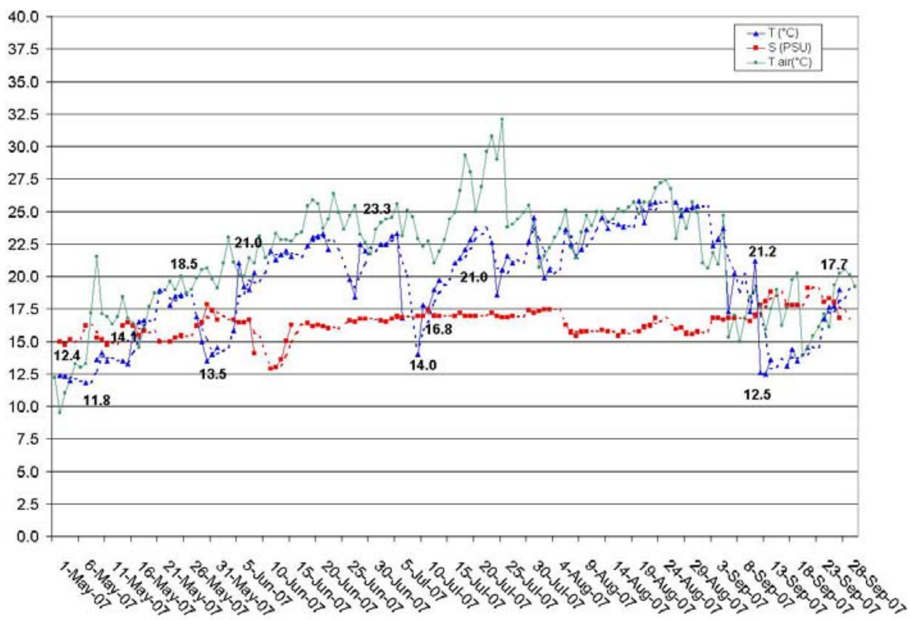

Fig. 5 – Evolution of sea surface temperature and salinity of seawater at Casino Mamaia, May – September 2007.

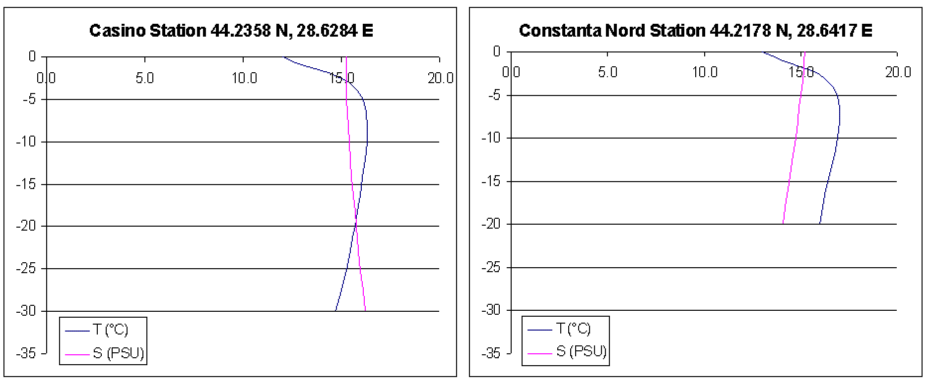

Fig. 6 – Distribution of temperature and salinity of seawater vertical profiles for Casino Mamaia and Constanta North Section (8th May 2007).

Fig. 7 – Phytoplankton bloom in Black Sea (18th August 2007) captured by the Moderate Resolution Imaging Spectroradiometer (*MODIS*) on NASA's *Aqua* satellite [13].

In 2008, the temperature and salinity distribution, modified by the circulation due to the southwestern wind, show an upwelling effect in May, with a decrease of the temperature from 15.7°C in 15th of May to 10.3°C in 19th May (Fig. 8).

In June and July, due to the western winds, the persistence of the upwelling is a long term process (> 10 days) when the sea temperature drops with approximately 6°C in 3 days (from June 16th to June 19th) and due to northwestern winds up to 3°C (from 14.8°C in June 19th up to 17.9°C in June 20th).

A more detailed analysis of the seasonal evolution in the vertical structure of the water masses can be done using vertical distribution of the temperature and salinity in the central part of the shelf, East Constanta section (Fig. 9).

In July 8th the westerly winds, uniform the distribution of sea surface temperature and salinity for East Constanta stations (Fig. 9). The values are typical for the summer period: the sea surface temperature is homogeneous in the thin surface layer, ranging from 24.55°C to 25.35°C, while the 10 meters temperatures are already influenced by the heating, 22.20°C is recorded at 10 m depth (station 3 - 44°17' N, 28.9 E). In the bottom layer, the difference in depth between the stations is evident in the temperature distribution; in this layer the values are smaller than 8°C. This led to high horizontal gradients, due to the fact that at deeper waters, in the eastern extremity of the sections, the temperatures were measured inside the cold shelf water. The minimum cold shelf water temperature was 7.85°C, recorded at 50 m depths in the last station of the Constanta section (the deepest station).

The southern winds with 10 m/s bring toward the surface the waters from below cold shelf layer leading to a decrease of sea surface temperature in 24h down with 5.3°C (from 19.1°C in July 8th to 13.8°C in July 9th). Also, in next 24h, the northeastern winds with 8 m/s, that blows from the offshore Black Sea, brings warm waters that increased the sea surface temperature up to 5°C (from 13.8°C in July 9th to 19.0°C July 10th).

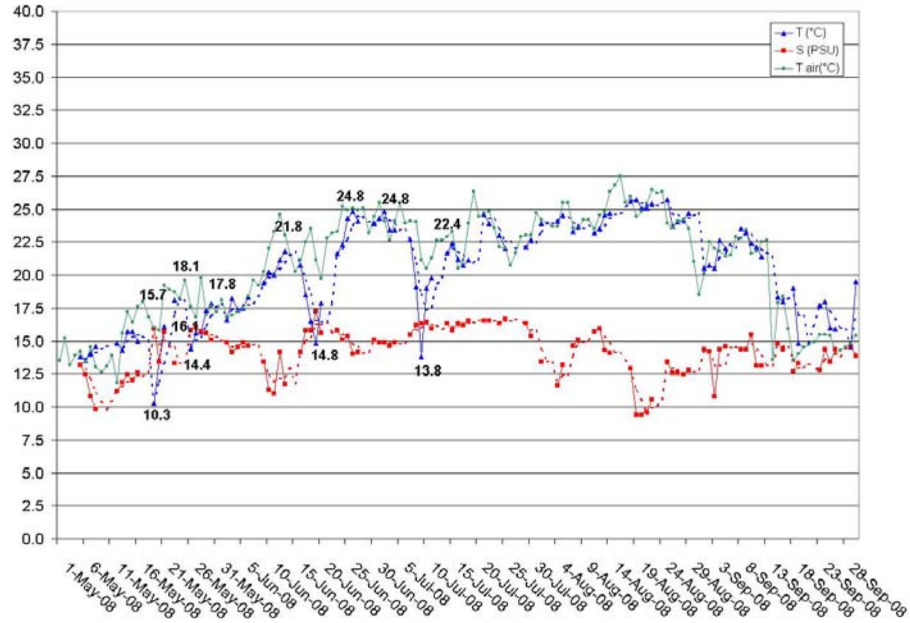

Fig. 8 – Evolution of sea surface temperature and salinity of seawater at Casino Mamaia, May – September 2008.

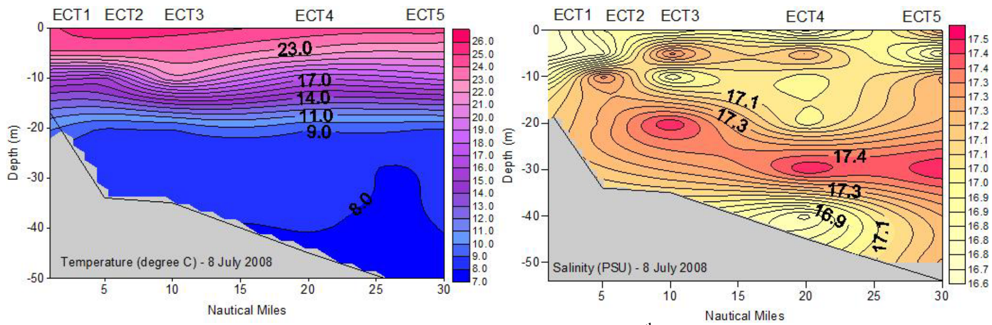

Fig. 9 – Distribution of vertical structure of the water masses, July 8th 2008, on East Constanta stations.

The image of the Black Sea, acquired on June 4th, 2008, by the MODIS on the Aqua satellite, shows swirling blooms of phytoplankton coloring the surface waters dark gray and black (Fig. 10).

In 2009 the upwelling is observed (Fig. 11) in May, similar blooms occurring annually, roughly the same time of the year (according to the samples of marine water that have been collected and satellite image. In 14th May, the minimum of temperature recorded was 12.8°C during a southeasterly wind. Except for this case, no other upwelling phenomena or a significant algae bloom due to the divergence effect have been observed.

Fig. 10 – Phytoplankton bloom in Black Sea (4th June 2008) captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite [13].

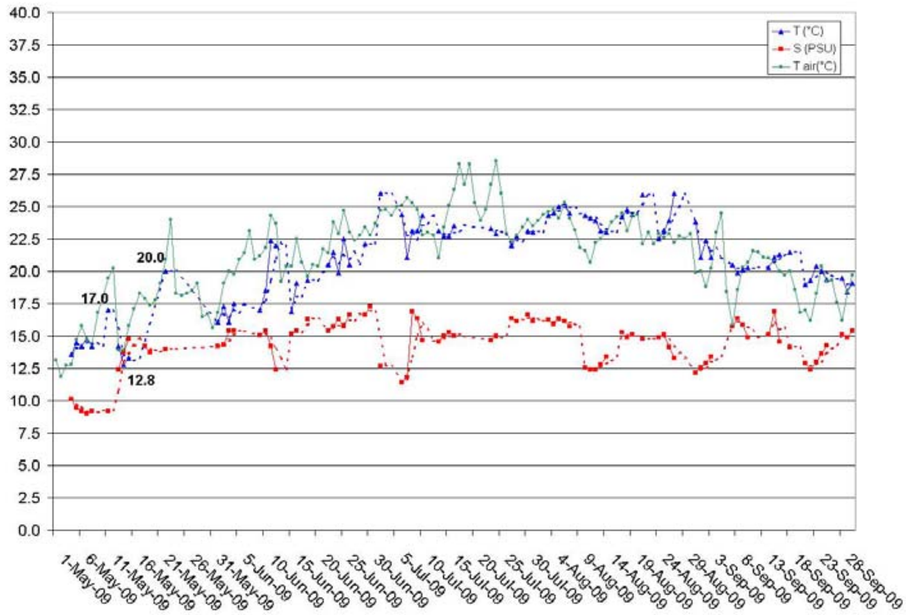

Fig. 11 – Evolution of sea surface temperature and salinity of seawater at Casino Mamaia, May – September 2009.

The true-color image (Fig. 12) shows bright, green-colored swirls across the surface of the Romanian coast of the Black Sea, signaling the presence of a large phytoplankton bloom and sediment from river runoff discolor the water of the Black Sea.

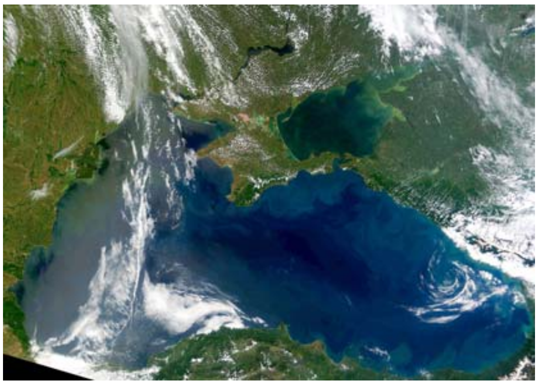

Fig. 12 – Phytoplankton bloom in Black Sea (31th May 2009) captured by TERRA MODIS Land Rapid Response Team [13].

4. CONCLUSIONS

The synthesis of recent results provide details of the sea processes in the northwestern Black Sea and suggest possible physical mechanism of transport, mixing and pathways of nutrient supply.

The strong summer stratification of the active layer waters, combined with the relative shallowness of the upper homogeneous layer is very sensitive to the wind direction, duration and velocity.

Typical sea surface temperature for the summer period, ranging from 24.55°C to 25.35°C and the salinity from 16.6 PSU to 17.0 (18.0 PSU is typical for offshore waters).

During the summer, the well-defined seasonal picnocline results in high horizontal gradients in both temperature and salinity (Fig. 9), but with considerable horizontal homogeneity over the continental shelf.

The upwelling was recorded when the southern, southwestern winds or moderate to strong western wind maintained constant several days (the sea surface temperature decrease with approximately 5°C in 24 hours). The upwelling brings toward the surface the waters from below, with low temperature and high salinity. This phenomenon take place in early summer, when the thermocline is shallow and the requested energy can be provided by wind.

The upwelled waters due to their rich nutrient content, subsequent phytoplankton blooms can occur. Although the coastal upwelling is not a permanent feature of the region, several such events are observed almost every year.

From all the analyzed situations, we observed that the important decreases of the sea surface temperature occurred nearshore. Due to southwestern winds, the minimum sea surface temperature was recorded in 19th of May 2008, when in 4 days down to 5.4°C (from 15.7°C on 15th of May to 10.3°C).

Changes in the salinity of Black Sea waters are due to the freshwater influx of the Danube River. At the beginning of upwelling, the salinity is lower than 15.0 PSU (6.55 PSU on 6th May 2006, 10.00 PSU on 8th May 2007 and 8.54 PSU in 8th May 2009).

Satellite images from Moderate Resolution Imaging Spectroradiometer (MODIS) shows massive plankton bloom developing along the western shelf of the Black Sea. Populations rich in chlorophyll-a are persistent near the freshwater sources in the northwestern shelf.

Also, Mamaia Bay being an intense touristic area, the upwelling consequences are unpleasant for tourists due to strong differences between air and sea temperatures, the „red-tide" in the bathing waters and the presence of marine organisms dead due to the severe hypoxia following intense phytoplankton blooms.

In meteorology the convergent and divergent phenomena's are important due to their effects, as: difficulties in sea surface temperature prognosis, sea fog appearance near shore, as well as breeze intensification due to the strong horizontal thermal gradient.

REFERENCES

1. *** TU – Black Sea Project - http://sfp1.ims.metu.edu.tr/TU-BlackSea/
2. Selariu O., *Some remarks on the hali-thermal regime of marine waters along the Romanian littoral area*, Rev. Roum. Geol. Geophys. et Geogr., **14**, *2*, pp. 243–251, 1970.
3. Serpoianu Gh., *Particularitatile regimului termic marin la litoralul romanesc al Marii Negre si influenta lor asupra conditiilor bilogice si de pescuit*, Bul. ICPP, **22**, *1*, pp. 30–46, 1963.
4. Bulgar Al., *Upwelling at the Romanian Black Sea shore*, Rev. Roum. Geol. Geophys. et Geogr., **18**, *2*, pp. 249–253, 1974.
5. Serpoianu Gh., *Observations sur le phenomene d'upwelling sur le littoral Roumain de la Mer Noir*, CIESM **27**, pp. 31–36, 1981.
6. Gheorghiță-Vitalia S., *Manual de oceanografie şi meteorologie pentru învățământul superior de marină,* Editura ADCO, Constanța, 2003.
7. Mihailov M.E., Gheorghita-Vitalia Sandel, *The Upwelling Phenomena During Summer on the Romanian Littoral of the Black Sea (Mamaia Bay),* Proceedings of the Workshop on "Understanding and Modelling the Black Sea Ecosystem in Support of Marine Conventions and Environmental Policies", pp. 15–22, 2005.
8. Grasshoff et al., *Methods of Seawater Analysis*, 3rd ref., 1999.
9. Miclaus I., Dima M., *Possible effects of solar-induced and internal climate variability on the thermohaline circulation*, Romanian Reports in Physics, **63**, *1*, pp. 275–286, 2011.
10. Chirila V., *Observații asupra condițiilor fizico-chimice ale Mării Negre la Mamaia în anii 1959 – 1969*, Ecologie Marină I, pp. 139–185, 1965.
11. Stewart, R.H., *Introduction to Physical Oceanography,* On-line textbook: http://oceanworld.tamu.edu/resources/ocng_textbook/PDF_files/book.pdf, 2006.
12. Florescu D. et al., *The influence of pollution monitoring parameters in characterizing the surface water quality from Romania Southern area"*, Rom. Journ. Phys., **56**, *7–8*, pp. 1001–1010 2011.
13. *** http://earthobservatory.nasa.gov.