LONGTERM VARIABILITY OF THE WATER MASS STRUCTURE ON THE ROMANIAN BLACK SEA SHELF

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Abstract. The long-term changes in the water mass thermohaline structure during the last four decades (1971 – 2010) is analyzed using the data collected on the 55 km hydrological section along the 44°10′N (NIMRD data base). For the middle months for each season (February, May, August and November), the changes of the temperature and salinity vertical distribution from one decade to another are relatively small. The upper mixed layer becomes warmer (about 0.1°C/year) while the cold water mass temperature is practically constant. The air temperature increases with 0.05°C/year for the analyzed period. At the same time the salinity decreases by 0.02 – 0.03 PSU/year in the entire water column. The 8°C isotherm boundary of cold water mass is more appropriate for shallow waters as 70% of the upper limit densities are below 14.2 kg/m³ and the average cold water density in the summer period is only 14.24 kg/m³.

Key words: Black Sea, Cold Intermediate Layer (CIL), upper mixed layer (UML), thermohaline structure.

1. INTRODUCTION

The vertical distribution of the water temperature depends on the thermal regime of the atmosphere and the sea dynamical factors (currents and wave) that generate the water mass mixing. Intense water mixing usually reaches depths of 100 – 150m, and only seldom 200m. Intermediate and deep water masses (88%) of the sea volume), although in a continuous but slow exchange with the upper layers, undergo only slight variations of their thermohaline parameters.

The most important factors controlling the vertical salinity stratification are the components of the salt and water balances and their variations with time. The halocline depth and its shape are also dependent on wind and thermal forcing and are influenced by the water depth and bottom topography.

The surface quasi-homogeneous layer (SQL) as part of the active layer is subject to seasonal variations in thickness and parameters; its temperature and salinity evolution having a well-defined annual cycle. The balance between the potential energy of the density stratification and the turbulent kinetic energy generated by the tangential wind stress determines the thickness of the layer. The former is governed by the exponential absorption of the solar radiation, but the surface cooling can also produce convective mixing. The later strongly depends on the changes in the wind direction and speed [1].

The cold intermediate layer (CIL) is the result of the winter convection on the
northwestern shelf and/or above the pycnocline domes of the two halistatic zones located in the center of the cyclonic circuits [1,2,3]. The CIL is conventionally defined as being delimited by the 8°C isothermal surfaces [3]. The lower limit, relatively stable, coincides with the upper limit of the permanent pycnocline. During its formation period, the upper limit is at the surface, since the temperature can be lower than 8°C. With the onset of the upper layer warming, its density decreases, precluding the vertical exchanges. The absorbed thermal energy is redistributed through turbulent mixing only within the SQL, which becomes homogenous in both temperature and salinity. At its bottom, the seasonal thermocline is formed, a layer with a thickness of the order of a few meters in which the vertical temperature gradients can exceed 10°C/m. This results in an isolation of the CIL, whose thermohaline parameters have an independent evolution, driven only by turbulent mixing and mesoscale dynamic processes.

Separated from the SQL, the CIL is subject to advection by the main Black Sea current around the entire basin. Its core – the level of minimum temperature – is located at 50 – 120m depth, depending upon season, region and local mesoscale circulation.

The halocline, a layer with high vertical gradients of salinity (1 Practical Salinity Unit (PSU)/m), constitutes the base of the CIL and represents the transition from the active layer to the deep water mass, relatively stable (the temperature and salinity increase slowly to about 9°C and 22.2 PSU respectively, and the density 14.5kg/m$^3$). It is also the upper limit of the hydrogen sulfide zone (the anoxic layer).

![Figure 1. Example of T-S diagram (temperature and salinity observed between 1981 – 1985 at Constanta offshore station)](image)

The characteristics of temperature and salinity of the water masses reflect the history of formation, driving circulation and finally, they are used as descriptors for these water masses. The water mass types, with their characteristics, can be described using T–S diagram, as example: the diagram for Constanta offshore stations (Figure1). The high temperature and low salinity data, on the left, are characteristic for the sea water near the surface, the sea temperature decreases to a minimum of about 8°C in the Cold Intermediate Layer (CIL) and then, the salinity increase continuously from 18.0 PSU, as well as the sea temperature, on the right,
toward characteristics of the deep waters.

The Cold Intermediate Layer (CIL) is formed in the seas from the temperate and cold zones as a result of the winter convection. In the Black Sea, the CIL is more enhanced due to the high vertical density gradient, resulting in slow vertical water mass mixing [4]. The narrow range of its temperature and salinity characteristics allow for its identification in different parts of the Black Sea [5].

Despite of the significant efforts made in this field, the Black Sea CIL remains a subject of scientific debate. At present, it is known where and how this water mass is generated [6,7, 8, 9].

Prior to 1960, it was assumed that the CIL is the relict of the cold water formed by the winter convection down to the permanent pycnocline, subsequently isolated and preserved by the formation of the seasonal thermocline [10, 11].

Later, new data indicated that the temperature, salinity and density of the water masses formed in the northwestern part of the sea and in the halistatic zones do not coincide with the CIL parameters. In the open sea, the convection reaches greater depths (smaller salinity gradients) resulting in lesser cooling of the water column [4].

The advective hypothesis [12] takes into account the hydrological features of the northwestern region. According to this theory, also supported by other authors [13, 14, 15, 16], the CIL waters are formed in the coldest part of the basin, the edge of the northwestern and western shelf, where the winter convection depth reaches 80 – 100m. These cold waters are then transported around the basin by the rim current (Main Black Sea Current), gradually renewing the old CIL [5]. However, the winter more intense cooling cannot compensate for the salinity differences (around 1-2PSU) between the shelf waters (16.5–17.5PSU) and the open sea (18.5–19.0PSU) [4]. Warmer waters replace the locally formed cold water during spring [13, 17].

The formation of the cold-water masses in the inner part of the basin, inside the main cyclonic current [18] is supported by several field data [6]. The extent of CIL water renewal depends on winter severity. The process also take place in the area of the mesoscale cyclonic eddies [19, 20] during very cold winters.

The process of propagation of waters of the CIL over the halocline also affects the subsurface velocity field [9]. The waters formed in winter in the western part of the sea penetrate to the east, mainly in the southern part of the sea near the Anatolia coast, where, in summer, the temperature minimum of the cold intermediate layer is accompanied by a weakly pronounced salinity minimum up to the meridian of Sinop [9, 21].

In 2003, the in-situ data and the model results of MOM (Modular Ocean Model), analyzed from the cold layer formation point of view indicated that the cold water masses are formed in different regions of the Black Sea: a) the continental slope in the northwestern part of the sea (with the ratio of 42%); b) the interior deep basin (dominated by the Rim current cyclonic circulation) with a ratio of 28%; c) the north-western shelf (with a ratio of 20%) and d) the eastern basin (10%). Also, it is estimated that the cold intermediate layer is fully replenished about every 5.5 years [22].

The aim of this paper is to point out the importance of the cold water masses, the specific features of their formation on the Romanian shelf, the long-term variability of the structure of CIL using in-situ data from different periods of the last four decades.
2. DATA AND METHODS

For the long-term variability of the water mass structure on the western shelf of the Black Sea, vertical profiles for the sea temperature, salinity and density were constructed as decadal averages for the 1971-2010, period along the East-Constanța section (44°10’N). A total number of about 16,500 data for sea temperature, salinity and density have been used from the National Institute for Marine Research and Development “Grigore Antipa” Constanța -Romania database. The standard oceanographic were carried monthly until 1980, and seasonally afterwards. The standard East-Constanța stations: (Figure 2): Constanța1 (28°41’E with the maximum depth of 14m), Constanța2 (28°47’E with the maximum depth of 28m), Constanța3 (28°54’E with the maximum depth of 36m), Constanța4 (29°08’E and 47m maximum depth) and Constanța5 (29°22’E and 54m maximum depth).

Figure 2. Location of the sampling station Constanța shore and offshore Constanța stations, 1971-2010

For the analysis of the shallow water masses, the data for the same period (1971-2010), from the Constanța shore station (44°14’N, 28°38’E) have been used. The sea temperature was measured with reversing thermometers. The salinity was determined using Mohr-Knudsen method and the sea water density was calculated according to [23].

On the temperature – salinity diagrams: every water sample is represented as the point determined by the sea water temperature (°C) and the salinity (PSU) while the sea water density (g/cm³) is indicated by the isopycnal curves.

3. RESULTS AND DISCUSSIONS

The continental cold water mass parameters – depth location, thickness, core and average temperature and salinity – are strongly dependent not only on the severity of winter (low air temperatures and high wind speeds), but also on the Danube inflow. Generally, the seasonal cycle of the Danube’s discharges exhibits a maximum in April–May and a minimum in September–October [24, 25].

In the inner Romanian Black Sea shelf, the cold water masses are formed as a part of the active surface layer. At the beginning of the winter season a so-called
“inverse thermocline” can be formed. In most cases, the winter convection reach the bottom in the shallow waters (less than 50 depth), which become the lower limit of the cold layer.

The 18.0 isohaline marks, at the sea surface (Figure 1), the limit between the coastal and central waters. In the winter, this isohaline is moving toward the coast while in the other seasons an increase in area of the coastal waters can be observed. The drift of the frontal area to the coast in the winter is followed by an increase of the salinity in the central area. During the summer, the salinity reaches minimum values, due to the increase of the Danube input and the spring rainfall.

The temporal variability of the Western Black Sea water masses was analyzed and described in relation of the sea surface temperature with salinity and density. The ranges and the appropriate depth, averages, standard deviation and medians of the physical parameters data for the period 1971-2010 are presented in Table 1.

Table 1
Descriptive statistics for the physical variables in the Black Sea offshore Constanta stations, during 1971 - 2010

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Period</th>
<th>No. samples</th>
<th>Min. Depth</th>
<th>Max. Depth</th>
<th>Average Depth</th>
<th>Average</th>
<th>Std. dev.</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{water}$ (°C)</td>
<td>1971 - 1980</td>
<td>2863</td>
<td>0.34 10m</td>
<td>27.30 0m</td>
<td>11.15 6.09</td>
<td>9.09</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1981 - 1990</td>
<td>1037</td>
<td>0.06 10m</td>
<td>25.71 0m</td>
<td>11.02 6.65</td>
<td>9.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1991 - 2000</td>
<td>727</td>
<td>1.96 0m</td>
<td>27.69 0m</td>
<td>11.32 6.98</td>
<td>7.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2001-2010</td>
<td>863</td>
<td>1.57 10m</td>
<td>27.20 5m</td>
<td>13.42 6.98</td>
<td>11.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$S$ (PSU)</td>
<td>1971 - 1980</td>
<td>2864</td>
<td>6.37 0m</td>
<td>19.76 50m</td>
<td>17.20 1.62</td>
<td>17.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1981 - 1990</td>
<td>1047</td>
<td>10.07 0m</td>
<td>18.87 40m</td>
<td>16.71 1.39</td>
<td>17.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1991 – 2000</td>
<td>728</td>
<td>9.68 0m</td>
<td>19.32 40m</td>
<td>16.79 1.41</td>
<td>17.16</td>
<td></td>
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<tr>
<td></td>
<td>2001-2010</td>
<td>866</td>
<td>8.15 0m</td>
<td>19.14 10m</td>
<td>16.72 1.63</td>
<td>17.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma_t$ (kg/m$^3$)</td>
<td>1971 - 1980</td>
<td>2856</td>
<td>3.74 0m</td>
<td>15.40 40m</td>
<td>12.74 1.83</td>
<td>13.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1981 - 1990</td>
<td>1035</td>
<td>5.90 0m</td>
<td>14.76 40m</td>
<td>12.33 1.83</td>
<td>13.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1991 – 2000</td>
<td>726</td>
<td>5.42 0m</td>
<td>15.11 40m</td>
<td>12.32 1.80</td>
<td>12.83</td>
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</tr>
<tr>
<td></td>
<td>2001-2010</td>
<td>861</td>
<td>3.51 0m</td>
<td>14.91 50m</td>
<td>11.95 1.98</td>
<td>12.35</td>
<td></td>
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</tr>
</tbody>
</table>

3.1. Winter

The water column has two evident layers in the western corner of the Black Sea, where the maximum depth is 50m and the salinity is similar to a typical estuary (Figure 3a). In the surface layer, the spatial distribution of salinity is variable, depending on local circulation and Danube flow variations (Figure 3b, Figure 4b,d,f,h). In winter, the salinity has a homogeneous distribution (Figura 4a,c,e,g), values are higher than the rest of season due to the low intake of fresh water from the Danube but also, due to the saltier waters upwelled from 40 – 50m depth to the surface (winter convection) in the Romanian continental shelf. Seasonal variations, recorded at 0m ranges between 14.6 to 15.1PSU and 17.0 to 19.0PSU at 50m depth (Figura 3b, Figure 4b,d,f,h).
The principal external factors affecting the intensity of renewal of waters in the CIL are the interannual oscillations of the heat fluxes on the sea surface in the winter period and the long-period oscillations of water budget and, hence, of the level of salinity in the sea [26].

In winter (February) the upper limit of the cold continental waters lie on the surface (Figure 3) when the recorded water temperature is less than 8°C. The near-shore areas (0 - 8km) average in the decades 1981-1990 and 1991-2000 (Figure 4c,e), are significantly lower than in the decades 1971 – 1980 and 2001 – 2010 (Figure 4a,g).

The severe weather conditions at the Romanian coast of the Black sea in winter of 1985 – 1986, when the air temperature (daily average) varied from -10°C down to -15°C, favored the freezing of the coastal waters while at the offshore Constanta stations, the sea water temperature at 0m, in February 1986, varied between 0.6°C at Constanța1 to 5.0°C at the extreme offshore station Constanţa5. The sea water temperature, in the deep layers (under 30m), ranged from 3.1°C (Constanta3, at the depth of 30 m) up to 5.0°C (Constanta5 at 50m).

Peculiarities of the continental cold water formation process depends on the initial state (the stratification at the end of autumn) and on the winter severity. The combination of these factors leads to different results (Figure 5).

Thus, during moderate winters conditions (the average of the air temperature in January and February 1995 was +3.7°C) the cooling affects only the upper 20m layer, whose temperature is lower than the cold water mass of the previous year. The presence of the inverse thermocline (vertical gradient of +0.2°C/m) maintains the stratification of the sea water density, due to the higher salinity of the bottom waters.

In the central shelf, the winter convection can reach the bottom (50m) even in the warm winters, if the salinity is relatively small. In 2001, when the average temperature of the two winter month was +8.2°C, the water column, with salinities of about 17.5PSU was homogeneous at the temperature about 7.6 – 7.9°C.
During a cold winter (in 2003, the average of the air temperature was -0.6°C), the sea water temperature dropped down to approximately 5.6°C, driving an intense vertical mixing of the water masses with high salinity (18.1 PSU).

The freezing point of the sea water lies between -0.25°C and -1.05°C, corresponding to the long-term salinity range at Constanta shore station (4.5 - 19.5 PSU). Generally, the ice coverage phenomena are quite rare and, are mostly limited to a narrow strip near the Romanian coast. From 1929 until now, fifteen such events were recorded, most frequently in February (the month with minimum air and sea water temperatures). In many cases the ice floes dislocated from the Danube drift to the western coast of the Black Sea. The width of the affected area varied from several hundred meters to over ten miles. The ice floes forms range from large irregular thick clusters (fluvial origin, compacted afterwards at the seashore) to almost circular “pancake ice” with raised edges, locally formed and welded together. In the last case, the thickness of the ice is small; as its formation
drastically reduces the heat loss at the surface. There is no periodicity of these phenomena, the interval between two events ranging from one to twelve years.

Figure 5. Vertical profiles for temperature (°C), salinity (PSU) and density (kg/m³), winter, (44°10’ N, 29°22’ E)

In the analyzed period, the temperature of the upper layer in shallow waters (at Constanta shore monitoring station), reached the freezing point in seven years (1985, 1986, 1987, 1996, 2003, 2006, 2010) but, only in three years the ice coverage of the coastal marine waters were recorded (1985, 2006, 2010).

3.2. Spring

The temperature distribution in May is relatively typical for the end of cooling period, when the winter convection already reached the maximum possible depth. The upper limit of the cold water mass shifts downward to depths greater than 10m in the 1971-1980 periods (Figure 6a). At the shallow station, Constanta1 (distance 1Nm), in 1976, the specific temperature of the cold layer (8°C) was recorded at the surface (0m) while at the extreme offshore station, Constanta5 (30Nm) is situated at the 25m depth as a result of the upwelling events.

The variations of the inter-decadal seasonal sea water temperature are relatively small; at the offshore stations the upper limit of shelf cold water is located at the depths between 12 and 24m. The maximum sea water temperature at the surface, for the whole period, was recorded at Constanta3 station in 1981, with the value of 21.11°C while in the bottom layer 6.41°C at 30m depth. The 2001 – 2010 period is characterized by an average temperature of the cold layer recorded under 20m depth (at the distance ranging from 5 to 25 Nm while, at the offshore station Constanta5, the upper cold layer deepens below 40m depth (Figura 6g).

The vertical distribution of salinity (Figure 3b, Figure 6d) ranged from 10.61PSU (at the surface) to 18.08PSU (at 50m depth). The Danube discharge and the wind driven sea surface currents affect the saline feature of the offshore marine water from the surface to the 10m depth.

During 1991 – 2000 (Figure 14g), the distribution of salinity at the surface is more complex, the minimum value is not measured near the coast but at the distance of 10 Nm (12.07PSU at Constanta2 and 12.55PSU at Constanta4). At 20 Nm distance from the coast, although the value of salinity in the surface layer is
high (16.8 ‰ PSU), there is a large gradient in the layer of 5 m to 25 m depth. This structure is the result of so-called “dome” in the central section (Figure 6f). In 1996 and 1997, due to the fresh water from the Danube and the local circulation, less salty waters were recorded offshore, 10.62 PSU at Constanta2 at 50m depth and at Constanta5 station with salinity at the surface of 11.11PSU and 14.57PSU at 50m depth.

Figure 6. Distribution of the decadal average sea temperature (°C) and salinity (PSU) at the Offshore Constanta stations, spring 1971 – 2010

3.3. Summer

In the summer, the upper SCW boundary shifts downwards as a result of heating of the surface waters and the vertical mixing is suppressed by intense stratification. The seasonal pycnocline, located between 10 and 20m depth on the entire section (Figure 8a,c,e,g) is well defined, with gradients reaching 1.4°C/m.
The sharpening of the seasonal pycnocline in summer and the suppression of vertical mixing does not mean that the bottom shelf waters are completely arrested – they can still be involved in horizontal (isopycnal) exchanges with deep sea waters [27].

In August, the average salinity in the bottom layer is about 0.5PSU lower than the winter average (February), the values ranging between 17.8 to 18.4PSU (Figure 7b) and the seasonal average of the temperature (Figure 7a) has the highest values (between 14.58 to 16.0°C).

Heating characteristics of the superior mixing layer and the process of forming the seasonal thermocline depends not only by the intensity of the thermal exchanges at sea-air interface, but also by the peculiarity wind regime.

In the surface mixed layer (Figure 3a), sensitive to the specific air temperatures, the temperature distribution is homogeneous on the entire shelf (Figure 8a,c,e,g) with high values down to the 10m depth \((T_{\text{water}} > 20^\circ\text{C})\). The cold layer upper limit, varies within decade but general downward offshore (Constanța5 station), from the 30m depth to 40m depth. Is observed closed to the-shore about 20m depth (Constanța2) reaching 30m offshore (Constanța5), during in the decades 1971 – 1980 (Figure 8a) and 1981 – 1990 (Figure 8c). Continental waters, in the decade 2001 – 2010 (Figure 8e), is near the bottom (15m) in the shallow waters and to 30 - 40m depth, offshore (Constanța5).

The exponential absorption of the solar radiation and the positive heat balance at the surface lead to the accumulation of potential energy in the density stratification. On the other hand, the kinetic energy generated by the vertical shear of the currents, alter the stratification and homogenize the upper layer.

Generally, the winds have low speeds during summer and the frequent changes of the direction due to the sea breezes. This instability makes the seasonal thermocline not always very pronounced, with high gradients (Figure 9).
Figure 8. Distribution of the decadal average sea temperature (°C) and salinity (PSU) at the Offshore Constanta stations, summer 1971 – 2010

Figure 9. Vertical profiles for temperature (°C), salinity (PSU) and density (kg/m³), summer, (44°10’ N, 29°22’ E)
3.4. Autumn

The combined effects of changes in the Danube flows, changes in heat balance and circulation transition model generates short-term changes and seasonal distribution of water masses over the continental shelf.

At the end of the warm season, the seasonal thermocline is much deeper (Figure 10a,c,e,g) than in the summer (Figure 8a,c,e,g), being clearly defined only at the outer half of the section, where the vertical gradients amount to about 1°C/m. The decrease of the Danube input and further cooling period leads to deepening of the thermocline.

Cold water layer is homogeneous in autumn, reaching depths below 50 m in the last decade (2001-2010) but the mean temperature of the upper mixing layer
(0 - 20m) during 1991 to 2010 are higher than 1971 - 1990 (Figure 3, Figure 10a,c,e,g, Figure 7).

Low values in the sea surface salinity are recorded near the coast – about 14.0 PSU in 1974; 11.8 PSU in 1984; 14.8 PSU in 2000, 15.1 PSU in 2003, but less saline waters are observed up to 10 nautical miles offshore (Figure 10b,d,f,h).

The salinity gradually increases down to 20m, where the values are around 17.0-18.0 PSU. The less saline waters layer is only about 1-5m thick (Figure 10b,d,f,h).

4. CONCLUSIONS

The Shelf Cold Water (SCW) is the result of the winter convection over the western shelf. In the inner shelf zone (depths shallower than 50m) its upper boundary is at the surface, as the temperature is less than 8°C, while in severe winters the lower limit is at the bottom, the intense cooling and strong winds resulting into a deep mixing.

The use of the 8°C isotherm as a conventional criterion for defining the Cold Intermediate Layer (CIL) upper limit is more appropriate than the 14.2/14.5 isopycnal surface, taking into account the fact that 70% of the surface density values are lower than these values and the average density in summer is only 14.24 km/m³.

The salinity role in the annual cycle of the water density stratification is very important, as the discharges are low in autumn and winter (the upper layer salinity is about 17.0-18.0 PSU), thus allowing for a deeper convection, and very high in May (upper layer salinity decreases to about 12 PSU), hindering the vertical mixing and enhancing the seasonal pycnocline.

The annual average temperature in the Romanian Black Sea area is 12.0-14.0°C, exceeding by 2-3°C that of the air. During winter, the seawater temperature often drops below 1°C in the near-shore zone. In the very cold years, ice of 15-20cm thickness can form at the shoreline. In May, the surface water temperature reaches an average of about 13.0°C near the shore and 20°C in the central part of the shelf. Sensible decreases of temperature occur since the beginning of September.

The strong summer heating affects only the upper 10-30m of the active layer, the sea surface temperature rising above 25°C, while only minor variations of the parameters occur in the CIL.

Although the inter-decadal changes of the thermohaline parameters do not present an obvious regularity, long-term trends can be detected. For the central part of the shelf, the surface water temperature increases by about 0.1°C/year during the 1971-2010 period. The change at mid-depth (30m) is less of the half of that value (~0.03°C/year), while at the bottom; the average temperatures are practically constant. By contrast, the salinity values decrease with approximately 0.03 PSU/year in the entire water column, except for the surface, where it changes by only 0.02 PSU/year.

REFERENCES