LONG-TERM VARIABILITY OF THE BLACK SEA COLD INTERMEDIATE LAYER PROPERTIES

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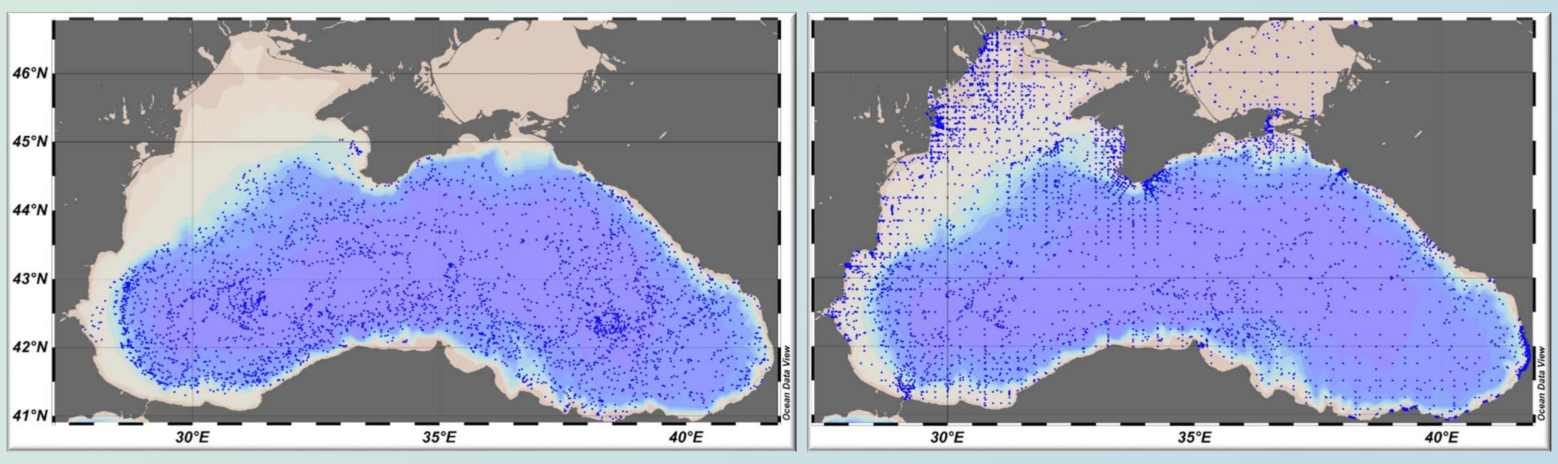
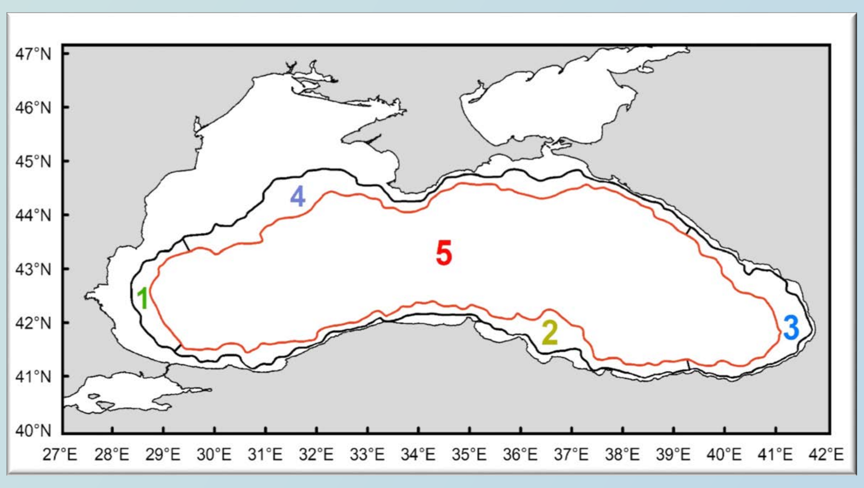
Main statement. **Representing the interface between surface and deep waters, the Cold Intermediate Layer (CIL) is a distinctive feature of the Black Sea thermo-haline dynamics. The presence of CI waters is extremely important for the Black Sea ecosystem because they are rich in oxygen and mark the upper boundary of the anoxic zone. The process of regional warming penetrating downward to intermediate depths results in a decrease of the thickness and reduced replenishment of the layer. Concurrently, the core temperature has risen with about 2.0°C over the past 25 years resulting even in CIL disappearance in several instances. In spite of the subsequent recovery, the drop of temperature difference between boundary and core waters as well as shoaling of the layer's lower limit represent a major threat for the Black Sea thermo-haline balance and ecosystem function.**



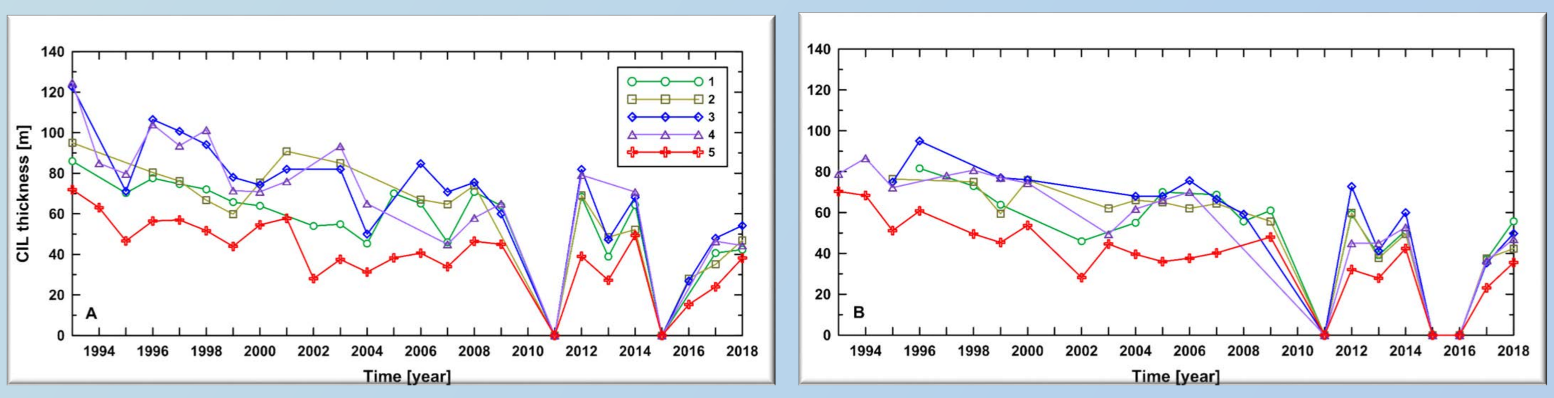
Spatial distribution of available Argo floats (left) and shipboard (right) data

Data & Methods. **The studied time period encompasses 26 years (1993-2018). Assessment is performed for two timespans (seasons) within each calendar year, during which the cold intermediate layer is observable as a vertical profile feature. Data consist of more than 5000 T profiles originating from both in-situ shipboard (48%) and Argo profiling floats (52%) observations. A seasonal bias in sampling is observed as profiles sampled in autumn represent only 38% of total coverage. The entire Black Sea basin where CIL can be observed (typically at depths of more than 200 m) is covered by the study. In order to distinguish between areas of specific mesoscale dynamics, the basin is divided into 5 subregions, of which four were delimited within the anticyclonic periphery – western, northern, eastern and southern; and one comprising the cyclonic interior, confined appro-ximately by the 1400-m isobath (denoted as 1, 2, 3, 4 and 5).**



Division of Black Sea into 5 subregions - 4 peripheral and 1 interior

Several cold intermediate layer features were monitored such as thickness, core temperature and depth, isotherm defining layer boundaries, and temperature difference between boundary and core waters as an indicator of the cold intermediate layer cooling capacity. In order to determine the isotherm surface marking out the layer limits, herewith, a dynamic criteria was adopted rather than fixed values. Thus, the lower boundary was set out with respect to thermal conditions in the profiles' mid-pycnocline area.



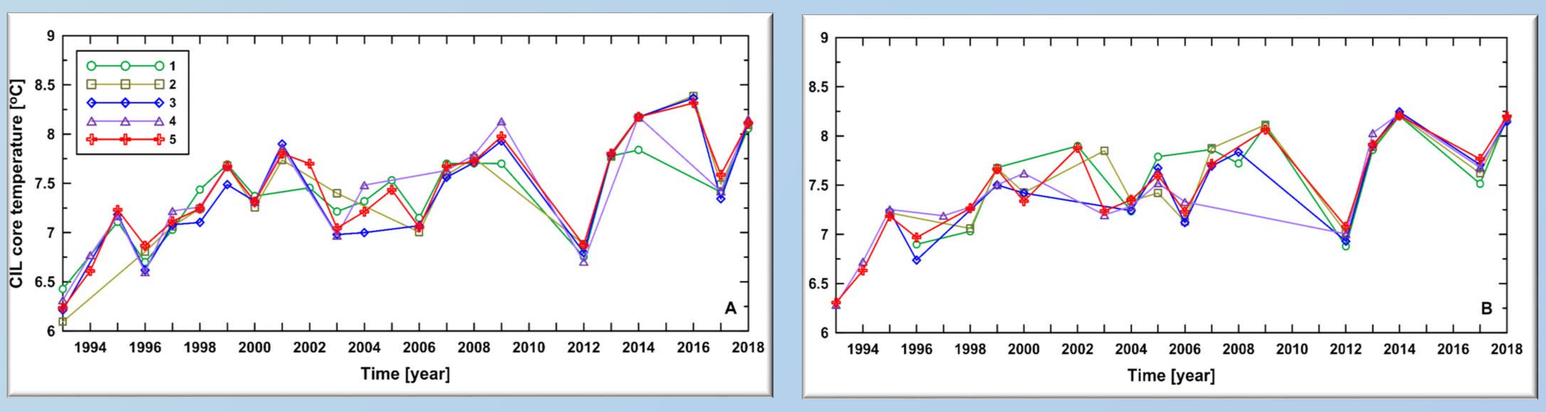
Interannual variability of CIL thickness averaged over: A) summer and B) autumn

Main findings. **CIL thickness interannual variability shows a steady decreasing trend. The layer was found to grow thinner as its thickness dropped by more than half in the course of the study period, from hundred in the beginning to several tens of meters by the end depending on the subregion. More specifically, in summer, the thickness changed from 95 - 125 m in 1993 to 45 - 55 m in 2018 in the anticyclonic periphery, and between 73 m and 38 m, respectively, in the basin interior. In autumn, CIL grows even thinner from 72 - 95 m in 1993 to 42 - 56 m in 2018 within the margins, and from 70 m to 27 m, respectively, in the inner basin. The analysis reveals that CIL thickness fluctuations are (quasi) synphase in all subregions as periods of rise and fall alter every 4-5 years, in summer, in particular.**

The suggested cycle is in agreement with previous studies, which imply the existence of teleconnection between Black Sea regional atmospheric condition and large scale atmospheric pattern driven by the North Atlantic Oscillation. More specifically, this refers to a sequence of cold and mild winter cycles with approximately 5-year duration.

Ever since 1995, the intensity of cold intermediate layer replenishment has been reducing. Several exceptions were noted in 2003, 2004, and 2006, which corresponds to mean climatic conditions. Later on, following a sequence of not particularly cool winters, bringing forth weak ventilation of the active layer, cold inter-mediate layer disappeared twice – in 2011 and 2015-2016 with no clear evidence for its existence in 2010 either.

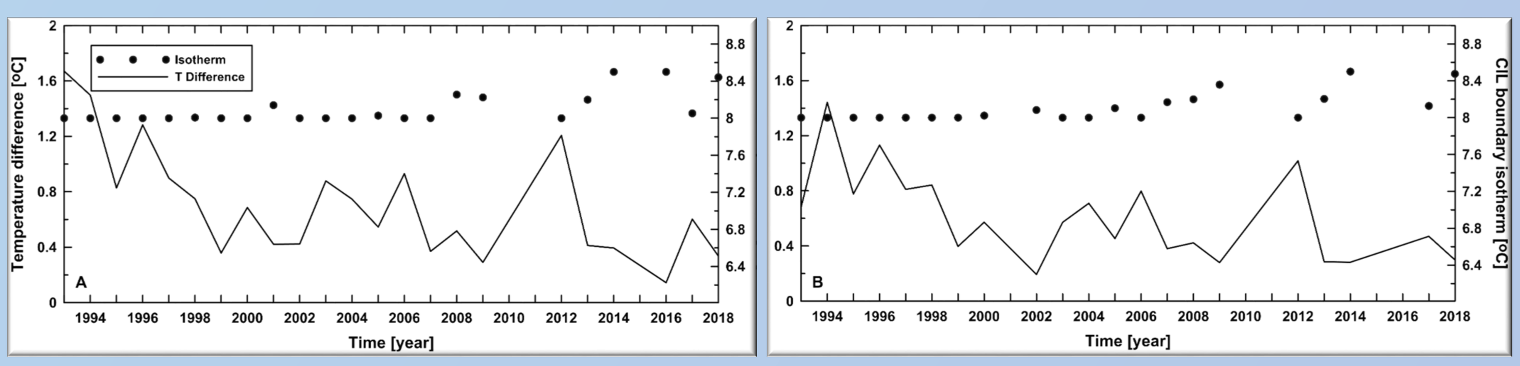
Nevertheless, it appears that the thickness decrease (so as the layer shrinking) is not an irreversible process since as a result of the 2012 winter cooling, in only a year timespan, the CIL grew thicker being renewed to reach the levels of the mid-2000s. Evidently, the presence of severe winters with consequent intensification of vertical and horizontal mixing leads to pycnocline deepening so as to a more effective replenishment. Most recently, a slight recovery has also been observed since the drop in 2016.



Interannual variability of CIL core temperature averaged over: A) summer and B) autumn

Concurrently, the temperature in the CIL core has been constantly growing higher from 6.3°C in 1993 to the absolute maxima of 8.2°C observed in 2014-2016 – the period in which the layer was disrupted.

Nevertheless, temperature in the peripheral parts of the sea is slightly lower. By autumn, due to anticyclonic eddies activity, it increases with 0.15°C on average (maximum increase of 0.26°C is noted for subregion 1) while in the inner basin no temperature changes were registered. The CIL recovery in 2003, 2006 and 2012 was accompanied by lowering of the core temperature down to about 7°C, which was the level in the late 1990s. The maximum cooling with 1.13°C was observed in 2012.



Interannual variability of isotherm defining CIL boundaries (dots) and temperature difference between core and boundary (thick line) averaged over: A) summer and B) autumn

The process of increased warming of the Black Sea surface waters for the past 10 years has led to alteration of isotherm surfaces marking out the CIL limits. Once defined by the isotherm 8°C, since 2007 it had started gradually shifting towards higher values to reach 8.4°C during the period preceding the 2012 cooling. After the recovery this temperature were increasing again and in recent years it has been set in the range of 8.4 - 8.5°C. On the other hand, the temperature difference between the layer's core and boundary was found to diminish in the course of the study period from more than 1.6°C in summer and 1.2°C in autumn to less than 0.4°C and 0.3°C, respectively, which indicates considerable lowering of the cold content.

Finally, the CIL core depth was found to exhibit no significant seasonal and interannual fluctuations. It is located at average depth of 68 m in the periphery and 53 m in the central part. The observed thickness decrease is rather related to deepening of the upper and rising up of the lower limits as the latter is more pronounced. This is considered as a consequence of not sufficient cooling, which weakens the ventilation of intermediate waters and results in only a partial renewal of the layer.

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