Evaluation of the new Black Sea Reanalysis system

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DESCRIPTION OF THE SYSTEM

The Black Sea (BS) is the largest land-locked basin in the world with an area of 4.2 x 105 km^2, a volume of 5.3 x 105 km^3 and a maximum depth of 2200 m (Ozsoy and Unluata, 1997). It is connected to the Marmara Sea and Azov Sea through the straits of Bosporus and Kerch, respectively. It is an estuarine basin, characterised by a positive net freshwater balance, mainly due to the outflow of some of the largest European rivers such as the Danube and Dniepr, and a high-rate of precipitation which in total exceeds the total evaporation most of the time over the basin (Kara et al., 2008). The resulting salinity of about 18 psu in the upper layer forms a strong stratification all over the basin where a saltier water of Mediterranean origin, crossing the Marmara Sea and the Bosphorus Strait.

Another main characteristic of the Black Sea is the Cold Intermediate Layer (CIL) formed at the depth of the winter convection (Ozsoy and Unluata, 1997). The upper layer circulation of the Black Sea is dominated by the Rim Current, a quasi-permanent cyclonic jet following the bottom topography which interacts with several anti-cyclonic eddies (e.g. Batumi, Sevastopol) along its pathway in the basin (Korotaev et al., 2003).

BS Reanalysis (BS-REA) configuration:

Initial Condition
01/01/1988
January climatology (1992-2018) from the previous reanalysis. **Spin up:** 5 years

Atmospheric Forcing: ERA5
0.25°, 1 hr frequency
(msl, u10m, v10m, t2m, d2m, clc)
and **GPCP monthly climatological precipitation**

Land Forcing:
72 climatological river inputs from SESAME Project

NEMO v3.6
1/36° x 1/27°, 31 z-lev
partial steps, Δt = 150 s

Closed boundary Condition
@ the Bosporus Strait with
updates in the region near the Bosporus exit:
improved bathymetry and application of local damping for T/S

Data assimilation OceanVar
CMEMS Reprocessed
SLA L3 Satellite and T/S in situ from CMEMS and SeaDataNet
SST relaxation: SST-L4 from CMEMS SST TAC

Data assimilation (OceanVar):

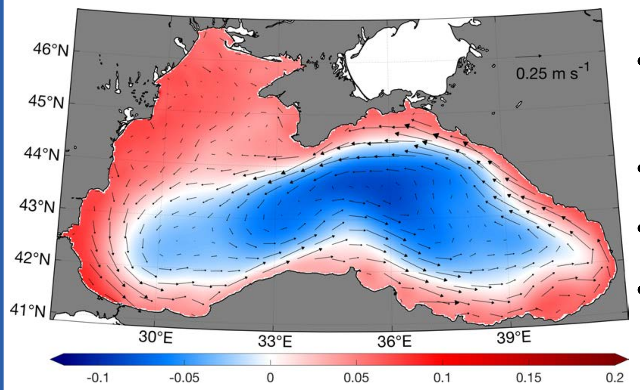
The data assimilation scheme is the OceanVar (Dobricic and Pinardi, 2008) that is a three-dimensional variational (3D-Var) assimilation algorithm. The 3D-Var scheme aims to iteratively find an optimal analysis field, x_a, that minimizes a cost function (*Eq. 1*).

$$J = \frac{1}{2}\delta x^T B^{-1} \delta x + \frac{1}{2}(H\delta x - d)^T R^{-1}(H\delta x - d) \quad (1)$$

$\delta x = x - x_b$, where x is the unknown ocean state, equal to the analysis x_a at the minimum of J, $d = y - Hx_b$ is the misfit between an observation and its modeled correspondent (in the observation space) where H, the observation operator, maps the model fields at the observation location. In OceanVar, in order to avoid the inversion of the B matrix and to precondition the minimization of the cost function, the B matrix is defined as $B = VV^T$, in which V is decomposed in a sequence of linear operators: $V = V_\eta V_h V_v$. In addition, a new control variable v is used for the minimization step by considering the transformation $v = V^+\delta x$ and thereby $\delta x = Vv$; the superscript "+" indicates a generalized inverse. The inclusion of the control variable in *Eq. 1* results in a rearranged cost function, as follows:

$$J = \frac{1}{2}v^T v + \frac{1}{2}(HVv - d)^T R^{-1}(HVv - d)$$

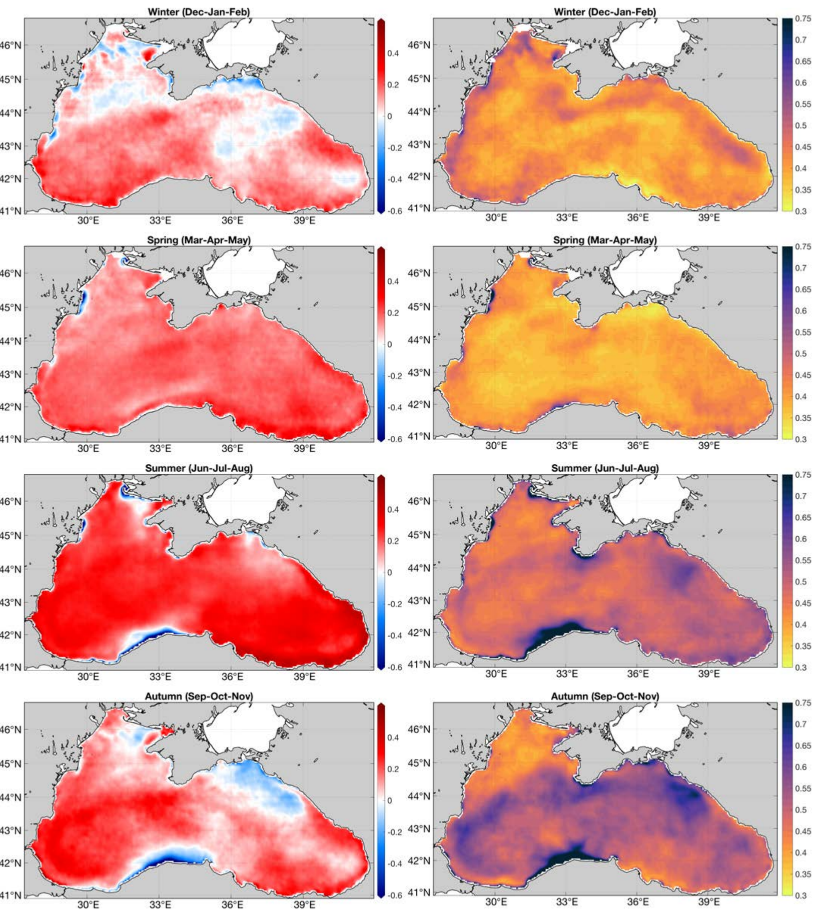
model-based MDT

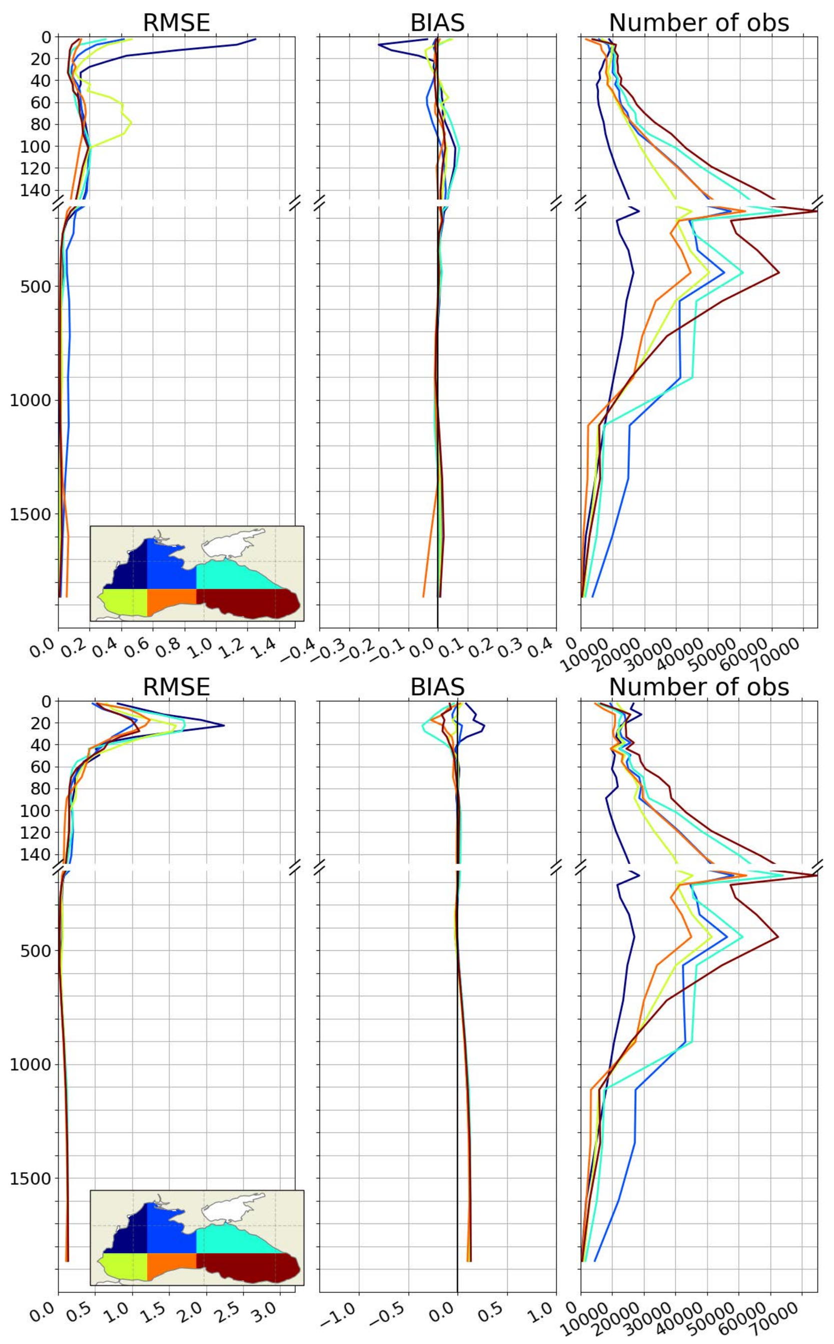


- New EOFs to estimate the temperature and salinity vertical covariances though the operator V_v.
- New observation window: 4-day centered at the analysis time.
- Initialization with incremental analysis update (IAU).
- New model-based MDT to compute the model-equivalent sea level anomaly in DA.

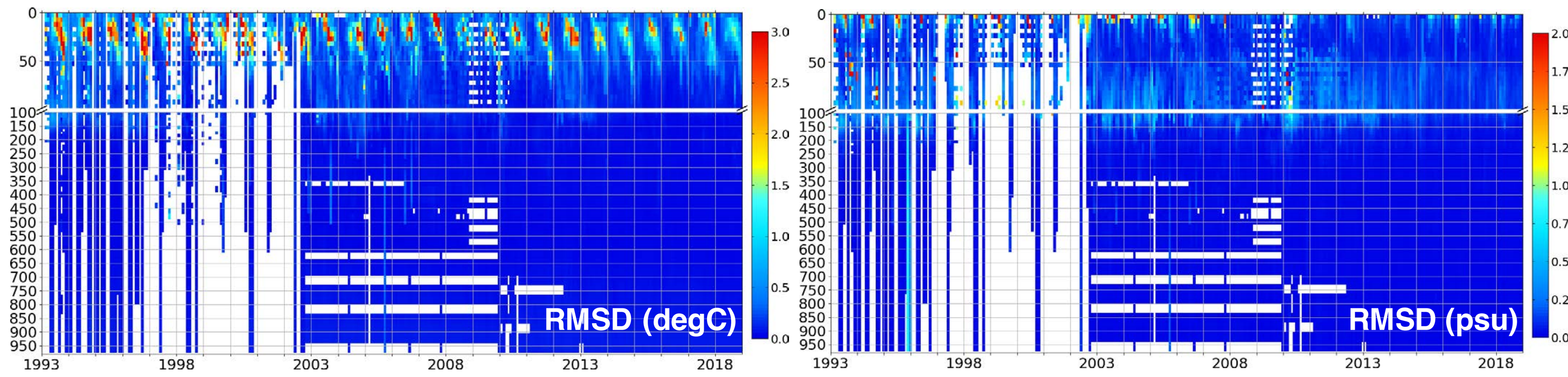
BS-REA EVALUATION

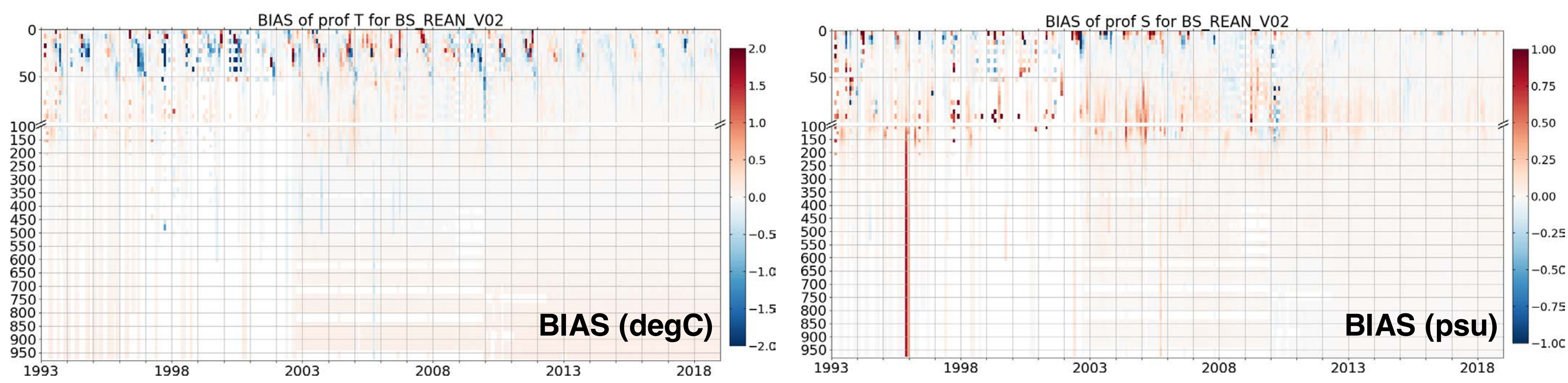
There is a predominance of positive SST bias all over the basin while a negative bias manifests in limited zones such as the western Anatolian coast in summer and autumn, and river influenced areas in the northwestern shelf all the year and the vicinity of the Azov Sea except in spring. The BS-REA exhibits the lowest RMSD in spring, whereas the highest RMSDs are reached in the summer and autumn. For instance, the RMSD exceeds 0.75 °C along the upwelling region centered at 33°E (Ozsoy and Unluata, 1997) in the Turkish coast in summer and autumn.



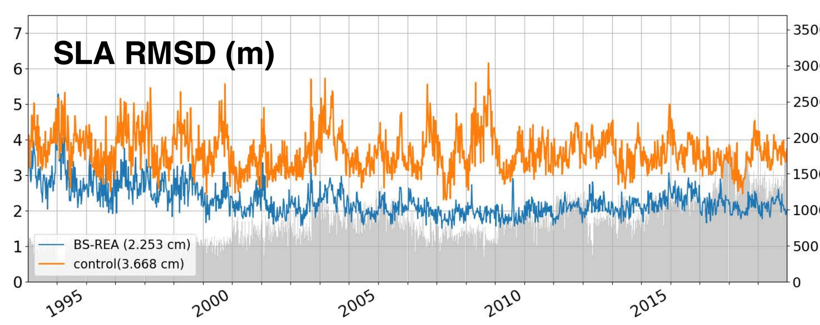


The temperature RMSD is relatively higher in the northwestern region (dark blue) that is under the influence of the Danube river where a maximum RMSD close to 2.25 °C arises around the thermocline. The other two regions with relatively large errors are the northeastern (light blue) and southwestern ones (green),

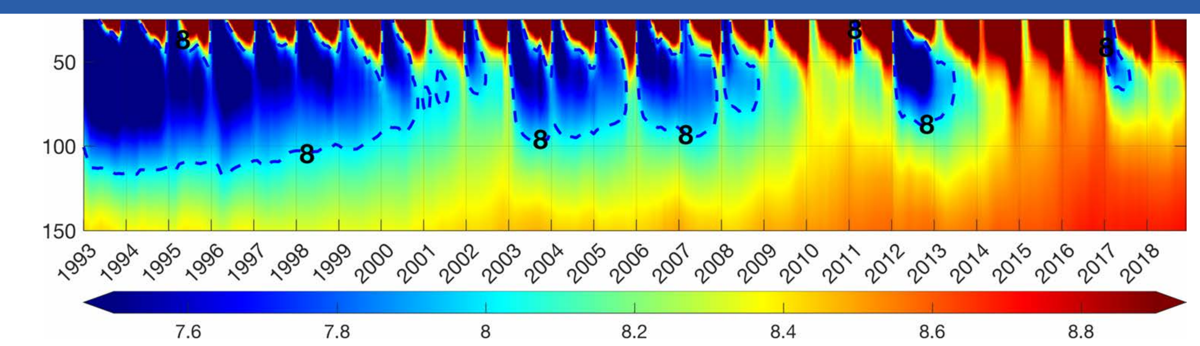




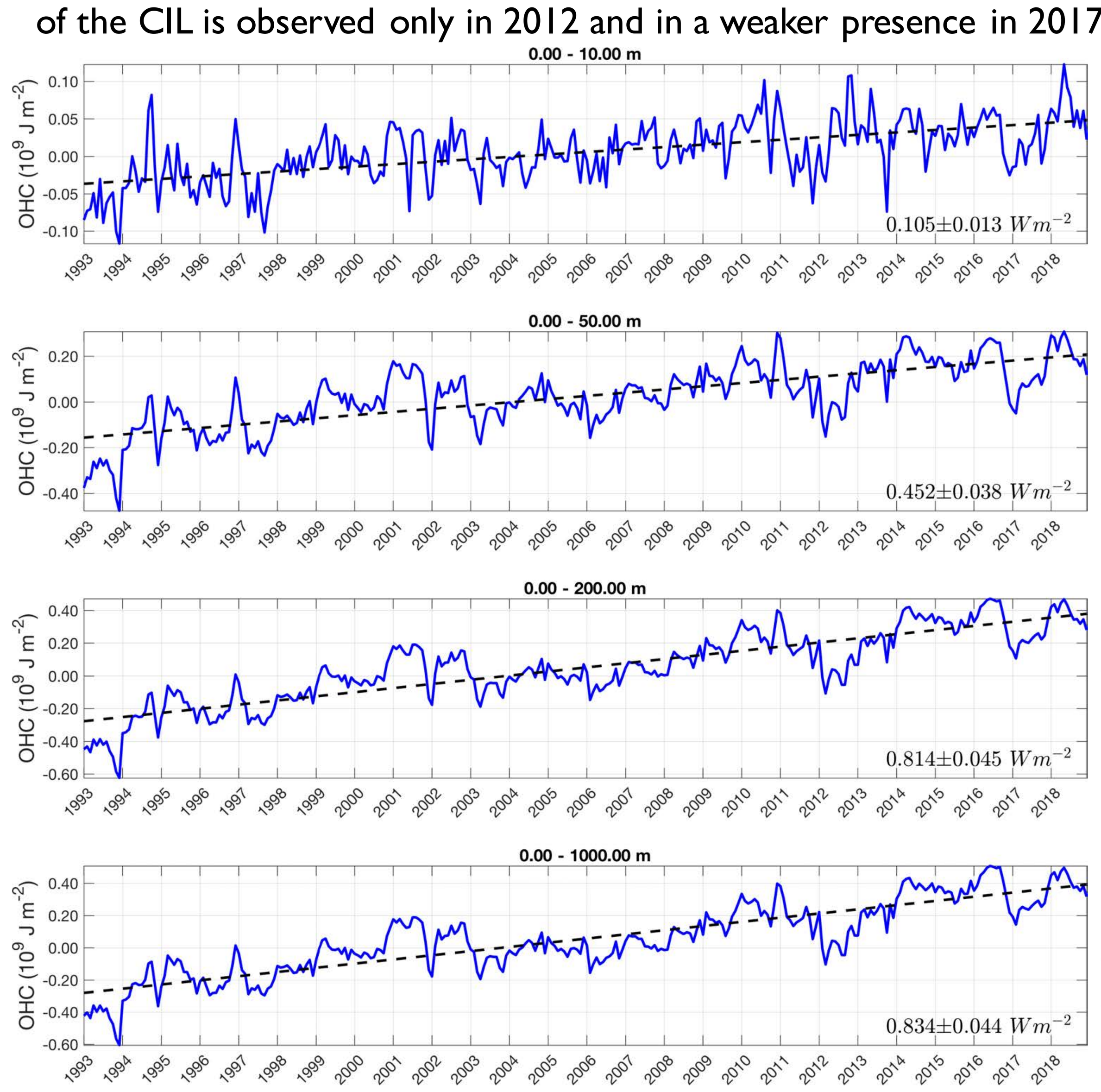
Hovmöller diagrams show that both salinity bias and RMSD remain low over the time. However, we note large RMSD that may surpass 1.5 PSU near the surface, mainly during some temporal intervals before 2008.



OCEAN HEAT CONTENT

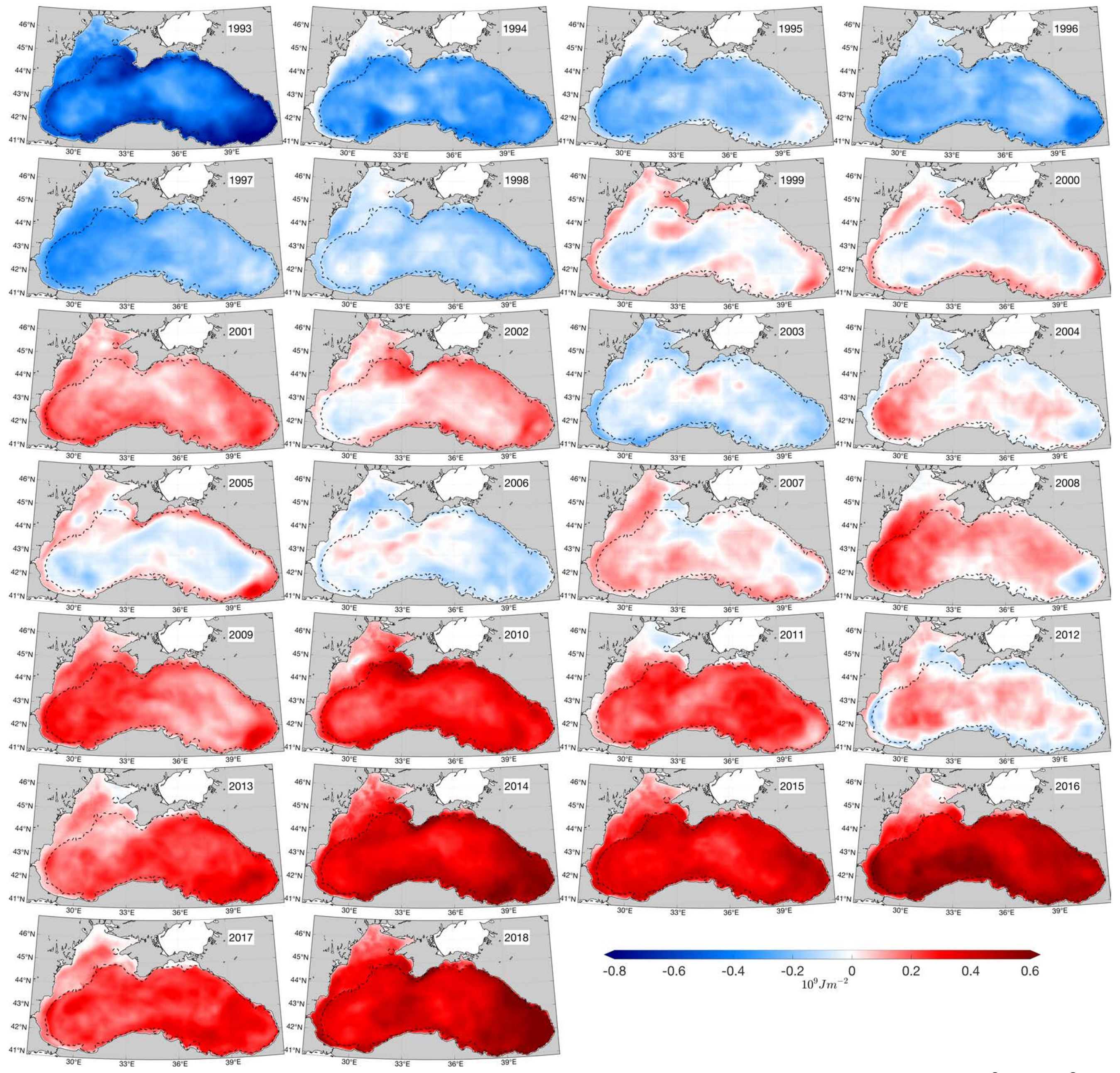


The CIL formation is related to the water cooling during the winter and its presence is evident until 2008. The pattern completely changes after 2008, when the temperatures clearly increase in such a way that the CIL disappears most of the time. After 2008, the formation and presence of the CIL is observed only in 2012 and in a weaker presence in 2017.



As thicker layers are considered, the trends increase, whereas time series present a lower variability over time.

From 2007, the warming signal is very clear, but this continuous warming is interrupted in 2012 and less explicitly in 2017, years in which a replenishment of the CIL is verified.



The yearly depth-integrated (0-200 m) ocean heat content anomalies (in 10^9 J m^{-2}) estimated for the BS-REA and defined as the deviation from the reference period of 1993-2012. Black isoline indicates the 200 m isobath.

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