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Exchanges between the shelf and the deep Black Sea: an integrated analysis of physical mechanisms

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This study provides an integrated analysis of exchanges of water, salt and heat between the north-western Black Sea shelf and the deep basin. Three contributing physical mechanisms are quantified, namely: Ekman drift, transport by mesoscale eddies at the edge of the NW Black Sea shelf and non-local cascading assisted by the rim current and mesoscale eddies.

The semi-enclosed nature of the Black Sea together with its unique combination of an extensive shelf area in the North West and the deep central part make it sensitive to natural variations of fluxes, including the fluxes between the biologically productive shelf and predominantly anoxic deep sea. Exchanges between the shelf and deep sea play an important role in forming the balance of waters, nutrients and pollution within the coastal areas, and hence the level of human-induced eutrophication of coastal waters (MSFD Descriptor 5).

In this study we analyse physical mechanisms and quantify shelf-deep sea exchange processes in the Black Sea sector using the NEMO ocean circulation model. The model is configured and optimized taking into account specific features of the Black Sea, and validated against in-situ and satellite observations. The study uses NEMO-BLS24 numerical model which is based on the NEMO codebase v3.2.1 with amendments introduced by the UK Met Office. The model has a horizontal resolution of $1/24\times1/24^\circ$ and a hybrid s-on-top-of-z vertical coordinate system with a total of 33 layers. The horizontal viscosity/diffusivity operator is rotated to reduce the contamination of vertical diffusion/viscosity by large values of their horizontal counterparts.

The bathymetry is processed from ETOPO5 and capped to 1550m. Atmospheric forcing for the period 1989-2012 is given by the Drakkar Forcing Set v5.2. For comparison, the NCEP atmospheric forcing also used for 2005. The climatological runoff from 8 major rivers is included. We run the model individually for 24 calendar years without data assimilation.

For the analysis of propagation of cold waters formed on the NW Black Sea shelf we use a passive tracer method. The tracer is treated as an artificial dye that "stains" a water parcel within the defined area as soon as it cooled below a 7°C temperature. To quantify the shelf–deep sea exchange, the transport of water, salt and heat between the NW shelf and deep-sea regions is calculated across an enclosed boundary (a "fence") approximating the 200 m isobath on the NW shelf plus two short segments connected to the coast. Partial transports are also calculated for the surface layer (top 20 m) and the under-surface layer (from 20 m to the bottom). The 20 m level is approximately equal to the Ekman depth in summer. It is also close to the depth of the biologically active euphotic layer.

For validation of the NEMO-BLS24 configuration we present comparisons of the model with satellite-derived sea surface temperature measurements and with ship-derived cross-sections that show the vertical structure. We also compare the model to observations carried out during Black Sea cruises in 2004, 2007 and 2008. The model represents well the sea surface temperature, the depth of the upper mixed layer and the depth of the CIL, while overestimating the temperature in the core of the CIL by approx. 0.5 °C.

Mechanism 1: exchanges due to a frontal eddy. Numerical simulations for the year 2005 (for which comprehensive remote sensed data is available) shows that a significant cross-shelf transport was generated by a long-lived anticyclonic eddy impinging on the shelf, sometimes assisted by a cyclonic meander of the Rim Current. Over 69 days between April 23 and June 30, 2005, a volume of 2.84×10^{12} m3 of water (102% of the entire volume of the shelf waters) was transported out of the shelf and a similar amount onto the shelf (see details in Zhou et al. 2014).

Mechanism 2: exchanges due to Ekman drift. During the short but intensive wind events of April 15 – 22 and July 1 – 4, 2005, 23% and 16% of shelf waters, were moved into the deep-sea region, respectively. Due to the high intensity of cross-shelf exchanges, the average renewal time for the NW shelf in the Black Sea was only 28 days in the summer of 2005 (Zhou et al. 2014).

Mechanism 3: exchanges due to assisted cascading. Using the model run for 2003 as an example, we examine the fate of the tracer after 5.5 months of model integration. At 100m depth we identify four anti-cyclonic eddies: two eddies west of the Crimea peninsula, one north of Sinop and one west of Batumi. These eddies can be seen to assist cascading into the basin interior of cold waters formed on a shallow NW shelf to a depth greater than at which they were originally formed. The important result is that for many of the 24 studied years a significant proportion of dense shelf water does not cascade locally off the NW shelf, but is transported by the Rim Current over hundreds of kilometres before cascading into the deep basin in the southern and southeastern Black Sea.

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References

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