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Interannual variability of Black Sea's hydrodynamics and connection to atmospheric patterns

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ABSTRACT

The long term variability (1962–2000) of the Black Sea physical processes (e.g. temperature, main circulation, cold intermediate layer, sea level) and its relation to atmospheric conditions and large scale climate patterns are investigated using an eddy-resolving tridimensional model in combination with statistical tools (e.g. Empirical Orthogonal Functions, Self Organizing Maps). First, the ability of the model to represent the interannual dynamics of the system is assessed by comparing the modeled and satellite sea surface temperature (SST) and sea level anomaly (SLA) decomposed into their dominant Empirical Orthogonal Functions (EOFs). The correlation between the spatial and temporal EOFs modes derived from model and satellite data is usually satisfactory and this gives some confidence in using the model as a tool to investigate not only the SST and SLA dynamics but also the dynamics of connected variables.

Then, the long term variability (1962–2000) of the Black Sea hydrodynamics is assessed by decomposing into their dominant EOFs modeled SST, SLA and selected key hydrodynamical variables associated to the main circulation and vertical structure of the water column. Significant correlations between the EOFs associated to these variables are investigated in order to link the variability of surface fields and the internal dynamics of the system.

In particular, the intensity of the general cyclonic circulation (the Rim Current) is shown to impact strongly (1) the mean sea level, (2) the SST response to air temperature (AT), (3) the formation of the cold intermediate layer, (4) the meridional repartition of the SST anomaly and (5) the exchanges of heat between the north-western shelf and the open basin.

In order to appraise the variability of atmospheric conditions over the Black Sea during 1962–2000 and their role in driving the hydrodynamics, a self-organizing maps technique is used to identify spatial recurrent patterns of atmospheric fields (i.e., AT, wind stress and curl).

The impact on these patterns of large scale climatic variability over the north Atlantic, Eurasia and the Pacific Ocean (estimated by respectively the north Atlantic oscillation (NAO), the east Atlantic/west Russia oscillation (EA/WR) and the El Niño southern oscillation (ENSO) indexes) is assessed. Distinct time scales of influence of the large scale teleconnection patterns on the AT are identified: EA/WR drives the short scale (1–5 years) variations of SST, while the long term (> 5 years) trends of the NAO drive the long term SST trends.

The drastic changes that have occurred in the Black Sea deep sea ecosystem at the end of the 80s are connected to an intensification of the general circulation that has promoted an export of riverine materials from the eutrophicated north-western shelf to the deep sea.

Finally, in the last two decades, we find an increased duration of persistent atmospheric anomalies regime that has the potential to drive the system away from its average state as occurred in the late 80s. If persistent in the future, such long lasting atmospheric anomalies may have a significant impact on the ecosystem functioning.

1. Introduction

The important river discharge characterizing the almost enclosed Black Sea, combined with the import of salty Mediterranean waters through the Bosphorus, results in a strong

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permanent halocline which restricts the "active part" to upper ~150 m. This confinement makes the Black Sea surface layer particularly sensitive to changing environmental conditions.

The north-western part of the Black Sea (i.e. the north-western shelf denoted in the following as the NWS) consists of an almost 200-km wide shelf representing about 13% of the total area and receiving the fresh water inputs of the Danube, Dniestr and Dniepr rivers (the Danube being by far the most important river bringing about 75% of the total river input into the whole sea). The surface circulation consists of a persistent cyclonic coastal current referred as the Rim Current (Fig. 1). Between this main current and the coast, a number of seasonal anticyclonic eddies develop. The Batumi eddy in the extreme East of the basin and the Sevastopol eddy situated over the NWS slope, West of the Crimea peninsula, are the most permanent mesoscale structures of the Black Sea (Korotaev et al., 2003; Staneva et al., 2001). The permanent halocline is dome-shape, due to the geostrophic dynamics associated with the Rim Current. This curvature is enhanced in winter by the intensification of the Rim Current. In summer, a seasonal thermocline creates a double pycnocline structure which allows the existence of the cold intermediate layer (CIL), a layer of minimal temperature situated between the halocline and the thermocline and defined by the 8 °C isosurfaces. Two important regions of formation coexist for the dense and cold waters constituting the CIL (CIW). The first one, accounting for ~42% (Stanev et al., 2003) of the annual CIW production, is a small area West of the Crimea peninsula, where the strong winter cooling is accompanied by the possibility of mixing with underlying salty waters (the latter is not true for the northernmost NWS area where surface cooling is however more important). The second area, in the northern part of the central basin, accounts for ~28% (Stanev et al., 2003) of the annual CIW production. Surface cooling in this area is not as important as on the NWS, but the outcropping of the deep isopycnals, associated with the winter intensification of the Rim Current, allows the cooling to penetrate directly to the density levels of the CIL.

The Black Sea region is located at the edge of various atmospheric systems and their relative influences combine differently over the seasons and over the years, leading to abrupt and significant changes of the weather conditions (Cherneva et al., 2008). Teleconnection patterns are often invoked to account for these different weather conditions (e.g. Kazmin and Zatsepin, 2007; Krichak et al., 2002; Oguz et al., 2006). They refer to large-scale (hemisphere) coherent modes of variation in the distribution of atmospheric masses. These have been growingly used in the scientific literature, since they have potential to explain large scale correlations in the variations of weather conditions, oceanic conditions and consequent ecosystem changes (e.g. Niermann et al., 1999). Although the north Atlantic Oscillation (NAO) has been found to have a strong impact on the Mediterranean weather (e.g. Hurrell and Deser, 2010), and on the Black Sea hydrodynamics (e.g. Ginzburg et al., 2004; Oguz et al., 2006; Stanev and Peneva, 2002) the east Atlantic/west Russia (EA/WR) pattern (alternatively called the North-Sea/Caspian pattern by Kutiel and Benaroch (2002)) has been found to be better associated to the sea surface temperature (SST) of the Black Sea during some years (Oguz et al., 2006). The El Niño southern Oscillation (ENSO) was found by Ginzburg et al. (2004) to promote the occurrence of extreme (i.e. minima and maxima) SST values in the Black Sea.

Through the last decades, the Black Sea ecosystem and particularly its NWS has been the scene of drastic changes (e.g. eutrophication, collapse of fish stock, alien species invasion) with important consequences for the surrounding economies (Langmead et al.,

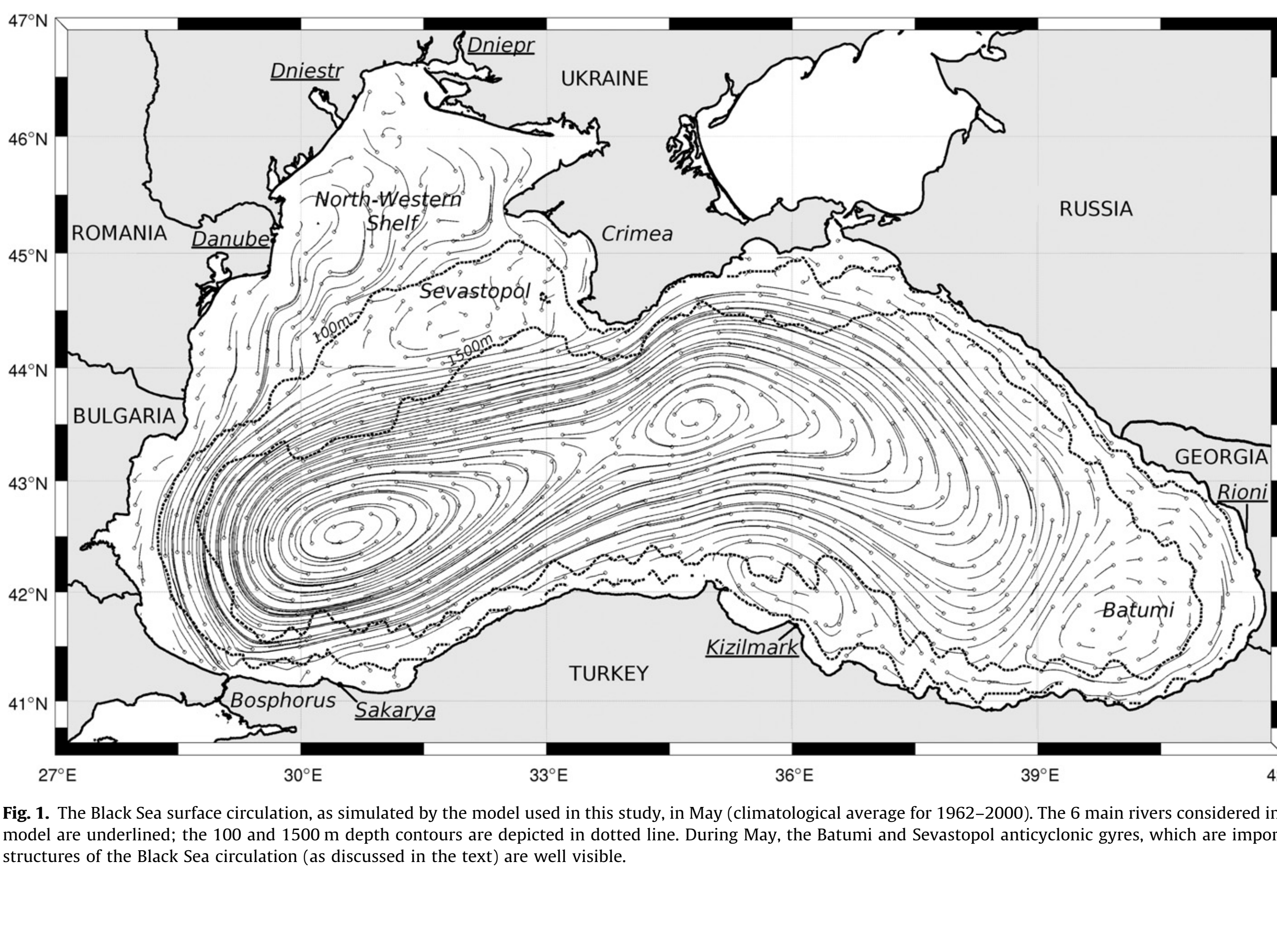

Fig. 1. The Black Sea surface circulation, as simulated by the model used in this study, in May (climatological average for 1962–2000). The 6 main rivers considered in the model are underlined; the 100 and 1500 m depth contours are depicted in dotted line. During May, the Batumi and Sevastopol anticyclonic gyres, which are important structures of the Black Sea circulation (as discussed in the text) are well visible.