



Research papers

Surface circulation and upwelling in the Sardinia Sea: A numerical study



Antonio Olita*, Alberto Ribotti, Leopoldo Fazioli, Angelo Perilli, Roberto Sorgente

CNR-IAMC, Istituto per l'Ambiente Marino Costiero, Loc. Sa Mardini, 09170 Torregrande, Oristano, Italy

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ABSTRACT

The surface circulation of the Sardinian Sea (the shelf-slope region west of Sardinia, western Mediterranean sea) and the coastal upwelling were studied through the analysis of a 4-years interannual simulation performed with a hydrodynamic 3D numerical model. The model (an implementation of the Princeton Ocean Model) was forced with realistic atmospheric and oceanic fields (analyses) for the quadrennium 2008–2011. The model assimilates sea level data using a 3D-variational assimilation software. Simulated velocities were decomposed in their mean and turbulent part. Eddy kinetic energy and eddy momentum flux, able to describe synthetically in terms of kinetics the fluctuating part of the flow, have been calculated. The EOF decomposition was used to get further insight on the simulated dataset and shed light on the variability of the main dynamical features, as well as to identify and separate the coastal upwelling signature. At surface the mean circulation is characterized by a southward current flow getting closer to the coast in correspondence of the southern corner of the Island where it flows over the shelf edge. Eddy momentum flux field suggests that this southward stream is accelerated by a transfer of momentum from the eddy to the mean field in the area where it reaches maximum velocity. The presence of such a stable stream, having also a consistent fluctuating part, is argued to precondition the coastal upwelling in the southern area. The phenomenology of such a coastal upwelling along the western coast of Sardinia is then described for the first time. The upwelling, especially evident in the southern part of Sardinia, constitutes the main surface temperature signal of the modeled SST anomalies. A significant correlation was found with both wind directions and current intensity, suggesting that both mechanisms (current and wind driven upwelling) participate to precondition and enhance (respectively) upwelling. SST satellite imagery support such a pattern found in the model results.

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1. Introduction

The Sardinian Sea, as in the zonation proposed by Bethoux (1980), is the portion of the Algero–Provençal Basin (western Mediterranean sea) located between $\sim 7^\circ\text{E}$ at west and the western Sardinian coast at east, while northern and southern boundaries are located at 42°N and 38°N respectively. From a dynamical perspective the Sardinian Sea is localized in between two areas characterized by strongly different dynamics, as already described in Olita et al. (2011a): (1) the Algerian Basin at south, where the Algerian Eddies (AEs) are generated by baroclinic instabilities of the Algerian Current (AC) flowing easternly along the northern African coast through the Sardinian Channel. Here the intermediate and deep circulation is cyclonic (Algerian Gyre, Testor et al., 2005b) as well cyclonic is the path normally

accomplished by AEs detaching from the AC; (2) the Provençal Basin at north where a surface cyclonic gyre enhances the primary production during early spring (Lévy et al., 1998) and constitutes one of the necessary preconditioning phases for the deep water formation process taking place in windy-cool-winters (Schroeder et al., 2010). Newly formed deep waters spread throughout the Provençal Basin advected by cyclonic and anticyclonic eddies (Testor and Gascard, 2003). The southern branch of this cyclonic gyre contributes to the formation of the North Balearic front (Fuda et al., 2000; Testor and Gascard, 2003) which represents the separation between the Atlantic waters reservoir of the Algerian Basin and the saltier and denser waters of the Provençal basin. The eastern side of the buffer area between Algerian and Provençal basins is occupied by the Sardinian Sea (see the red square drawn in Fig. 1). The literature specifically devoted to the variability of the circulation of this stretch of Mediterranean, at scales relevant to investigate of regional and near-shelf processes, is poor notwithstanding the relevance of this region for example for tuna-trap (Addis et al., 2012) fisheries at local scales.

* Corresponding author. Tel.: +39 3285321116.
E-mail address: antonio.olita@cnr.it (A. Olita).

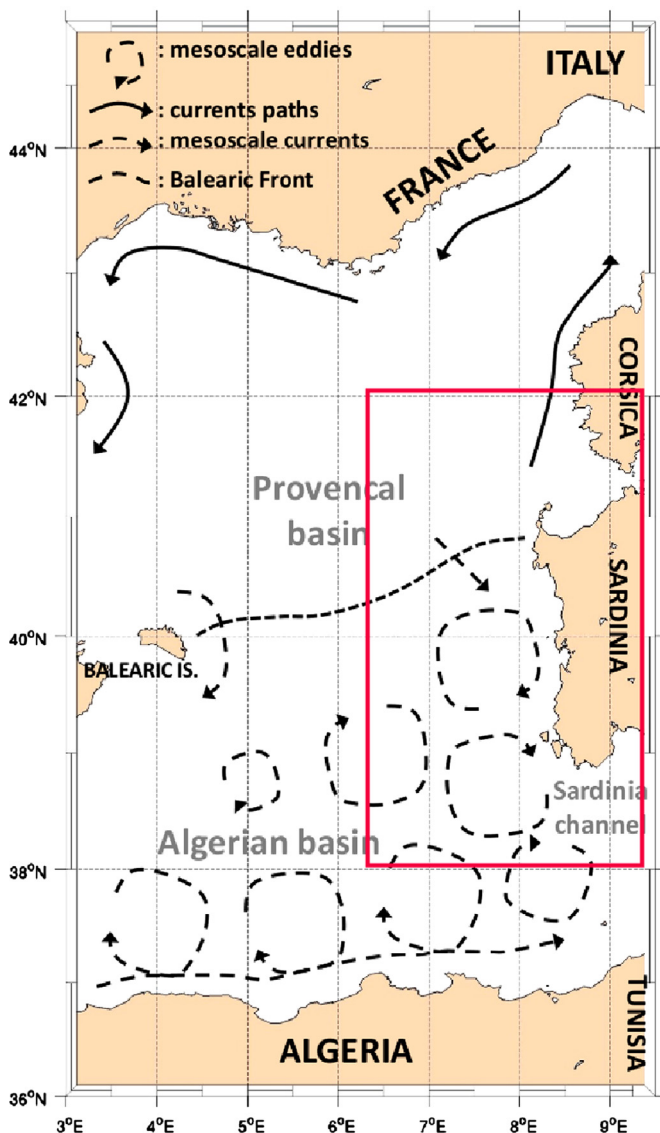


Fig. 1. The area of the Sardinian Sea (red square) in the frame of the Algero-Provençal basin. The main circulation features, as known from the literature, are also indicated. Modified from Olita et al. (2011a). (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

The Sardinian Sea is known to be interested by the transit (Puillat et al., 2002; Ribotti et al., 2004) and formation (Testor and Gascard, 2005; Testor et al., 2005a) of anticyclonic eddies of different origins. Ribotti et al. (2004) studied the mesoscale surface circulation of the slope/shelf area of the Sardinian Sea and Channel making use of a set of CTD profiles collected during five different oceanographic cruises. They found a significant mesoscale activity in the Sardinian Sea guessing that sampled anticyclones were originated from the Algerian Current as they embed water of Atlantic origin. Upwelling was detected on some spots along the northern part of the sampled area. The data they analyzed do not showed evidences of eddies locally generated. On the contrary, Testor et al. (2005a) studied, through data and model, the formation and life cycle of the so-called Sardinian Eddies, i.e. anticyclonic eddies formed at intermediate-deep layers (at about 600 m depth) by flow separation of the westward LIW from the Sardinian slope. They often accumulate in the area between Minorca and Sardinia. These eddies usually show a surface signature after some weeks (5–6) from their deep formation. Santinelli et al. (2008),

using data collected during two oceanographic cruises conducted in March and September 2001, focused his attention to the Dissolved Organic Carbon (DOC) content relative to water masses and dynamics of the Sardinian shelf area. They found a DOC distribution strongly influenced by eddies activity. The authors also identified in the Sardinian Sea the main water masses usually retrieved in the rest of the western Mediterranean sea (Western Mediterranean Deep Water, Winter Intermediate Water, Levantine Intermediate Water and Atlantic Water). Millot et al. (1999) first showed that the Levantine Intermediate Water (LIW), as well as Mediterranean deep waters, flows northward along the western Sardinian coast with a more or less steady path. Subsequently Millot and Taupier-Letage (2005); Schroeder et al. (2008) observed that such a LIW flow along the western Sardinian slope can be partially diverted westward, toward the middle of the Algerian Basin, by the action of anticyclonic eddies. The eddies system of the Algerian Basin seem also responsible for an AW southward flow along the western Sardinian shelf, detected by Schroeder et al. (2008) in spring 2005.

We are not aware of any specific study about the variability of the circulation of the Sardinian Sea, except the information extrapolated from basin scale studies (e.g. Bethoux, 1980; Millot et al., 1999; Schroeder et al., 2008) that, for limitations due to temporal and/or spatial scales, were unable to assess the mean and turbulent circulation patterns at regional scale. To study mean and turbulent circulation and relevant processes of such a coastal area is necessary to solve (sub-)mesoscales with models/observations for a period of some years.

The present paper aims to study the mean and turbulent surface circulation of the shelf-slope region west of Sardinia and to describe the western Sardinian coastal upwelling. For contiguity reasons, in the present paper we extended the study area to part of the Sardinian Channel, as the two systems are strictly connected. The Sardinian Channel (SC), conversely to the Sardinian Sea, was studied by several authors (e.g. Pinardi et al., 1997; Sammari et al., 1999; Bouzinac et al., 1999; Astraldi et al., 2002; Millot and Taupier-Letage, 2005) as it is one of the main passageways for mass and energy transport in western Mediterranean.

To do this we analyzed a four years-long simulation performed with a 3D mesoscale-resolving hydrodynamic model assimilating Along Track Sea Level Anomalies (SLA) data. The modeled output constitutes therefore an *Analysis* i.e. the best estimate of the sea *true state* that merges simulation (the model) and observations (the assimilated data). The analysis of the simulated dataset was performed by decomposing the mean and fluctuating part of the flow, as well making use of multivariate decomposition methods able to get a further insight on the dataset variability. Satellite SST daily free-gap data have been used both to validate model results and to observe independently the upwelling phenomenology. The study area is shown in Fig. 2. In Section 2 methods and data used are presented while in Section 3 the mean and turbulent circulation is described for surface layers. Then, in Section 3.2, we describe characteristics, variability and forcing of the coastal upwelling which is one of the major features of the surface circulation. Finally, Section 4 draws the conclusions.

2. Methods and data

2.1. Numerical system

WMED (Western MEDiterranean regional model) is a three-dimensional primitive equation hydrodynamic model based on the Princeton Ocean Model (POM, Blumberg and Mellor, 1987). POM solves the equations of continuity, motion, conservation of temperature, salinity and assumes hydrostatic and Boussinesq approximation. It uses the Mellor and Yamada (1982) turbulence closure

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