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Review

Sensitivity of the sea circulation to the atmospheric forcing in the Sicily Channel

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ABSTRACT

We investigate the sensitivity of the sea surface circulation in the Sicily Channel to surface winds, using a 15-year long (1994–2008) air-sea coupled numerical simulation. Analysis is based on the clustering of six main wind regimes over the Sicily Channel domain. The analysis of the corresponding sea current clusters shows that sea circulation in this area is sensitive to surface wind patterns. This wind modulates the strength of the two main branches of the sea circulation in the Sicily Channel (i.e. the Atlantic Tunisian Current and the Atlantic Ionian Stream). The modulation of these two currents depends on the wind regime, and displays a strong seasonal variability. It is also shown that the sea circulation in the Sicily Channel is strongly controlled by the thermohaline circulation and the bathymetry (geostrophic current). However, the contribution to the total current of its ageostrophic component forced by the surface winds is significant, with a correlation coefficient varying from 0.3 to 0.7.

Contents

1. Introduction

The Sicily Channel (SC) connects the Mediterranean's western and eastern sub-basins, and represents an important area for the

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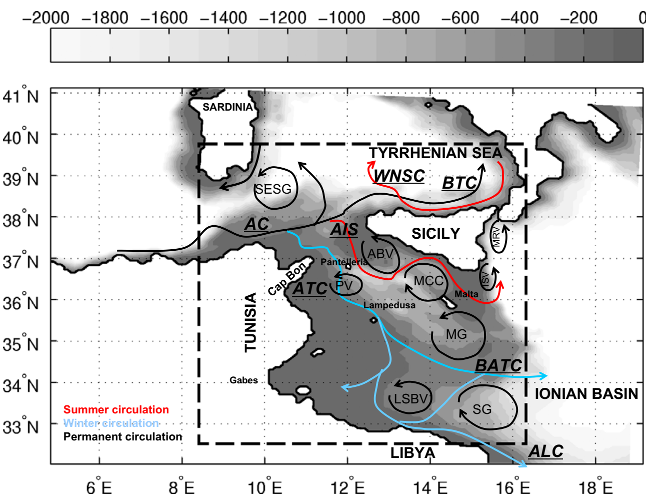

Fig. 1. The seasonal surface circulation in the SC Béranger et al. (2004) and Sorgente et al. (2011). The dashed box represents the SC domain considered in this study. Acronyms are referenced in Table 1.

general Mediterranean Sea circulation. Investigating the dynamics of the circulation in the SC is therefore crucial to the understanding of the Mediterranean basin-scale circulation and its seasonal and interannual variabilities. The SC has a minimum width of about 150 km, a length of about 600 km, and a mean sill of about 400 m depth. It has a highly irregular bottom bathymetry, characterized in the southwest by the wide Tunisian continental shelf and in the northeast by the Sicilian shelf. These two shelves, each of about 250 m depth, are separated by an axial trough, with a submarine mountain around Pantelleria in its center. The large-scale circulation between the two Mediterranean sub-basins is governed by density gradients (Molcard et al., 2002) in a two-layer system. Near the surface, the upper fresh water flows eastwards and is mainly composed of the Atlantic Water (AW). Above the sill, the bottom salty water flows westwards and is mainly composed of Levantine Intermediate Water (LIW) (Robinson and Golnaraghi, 1993) (Fig. 1). It is also an energetic area characterized by significant mesoscale and seasonal variability covering a large spectrum of temporal and spatial scales (Robinson et al., 2001; Sorgente et al., 2011). Due to its geographical position, the SC region is subject to the channeling of the Mediterranean winds: the Mistral and Tramontane from the north, the Sirocco from the south and the Bora from the northeast (Burlando, 2009).

Concerning the surface circulation, the eastward flow formed by the Algerian Current (AC; Millot, 1985) splits into two surface branches at the SC entrance. One branch is the Bifurcation Tyrrhenian Current (Astraldi et al., 1996; i.e. BTC, see Sorgente et al., 2011) which flows towards the Tyrrhenian Sea whilst the second branch flows towards the eastern Mediterranean sub-basin. Based on idealized simulations, Herbaut et al. (1998) relate the splitting of the AC to the interactions of Kelvin waves with the shelf break at the channel entrance. A numerical sensitivity experiment by Pierini and Rubino (2001) shows non-linear effects. Taking into account the two deep-channel bathymetries, the simulations of Onken et al. (2003) and Béranger et al. (2004) show that the variability of the AC bifurcation is not influenced by the use of a realistic bathymetry. The branch entering the eastern Mediterranean also splits into two sub-branches: the Atlantic Ionian Stream (AIS; Lermusiaux, 1999; Robinson et al., 1999) and the Atlantic Tunisian Current (ATC; Poulain, 1998; Sammari et al., 1999; Béranger et al., 2004). The main stream associated with the ATC either flows southeastward or remains confined in the center of the SC (Manzella et al., 1988, 1990). A new sub-branching scheme is proposed by Sorgente et al. (2011) with a splitting at the level of Lampedusa, in which a southward sub-branch above the continental Tunisian shelf flows towards the Libyan coast (Atlantic Libyan Current, ALC) and a southeastward sub-branch flows along the Tunisian shelf break towards the eastern Basin (Bifurcation Atlantic Tunisian Current, BATC). In the vinicity of the SC, these large-scale flows are strongly modulated by mesoscale features (Lermusiaux, 1999; Napolitano et al., 2003; Ciappa, 2009; Sorgente et al., 2011), which could be related, amongst other to topographic Rossby modes (Pierini, 1996), baroclinic instabilities (Onken and Sellschopp, 1998) and Sicilian upwelling (Piccioni et al., 1988). The AIS represents a strong free jet current flowing eastward along the southern coast of Sicily, especially during summer (Lermusiaux and Robinson, 2001). At the same time, the ATC is stronger in winter and barely present in summer. According to monthly estimates based on observations and modelling studies (Béranger et al., 2004, 2005), the seasonal eastward transport mainly composed of AW displays a maximum in winter (≈1.3 Sv) and a minimum in summer (≈0.8 Sv). The seasonal influence of the wind on the surface circulation was first shown by Poulain and Zambianchi (2007) using drifter trajectories. Later, Sorgente et al. (2011) quantify the wind contribution to the mean and fluctuating components of the 5-m thick surface layer circulation. Comparable contributions were found at seasonal scales for mean currents and mesoscale features.

Available observations are often characterized by poor spatial and temporal coverages, and are usually confined to the Italian coasts, while there is a lack of observations over the Tunisian (Ben-Ismail et al., 2014) and Libyan continental shelves (Bonnano et al., 2014). Only a few data sets have adequate temporal and spatial resolution to capture the small scale circulation (Lermusiaux and Robinson, 2001; Onken et al., 2003; Ben Ismail et al., 2012). Using a 10-year drifter trajectory data set, Poulain and Zambianchi (2007) studied the wind impact on the SC surface circulation. They showed the correspondence between ATC and AIS and Mistral-like wind regimes, while low currents were found to be associated with weaker southerly wind regimes. Even if the correlations between the wind regimes and the currents was found to be low (0.28), the separation into two specific regimes seems robust, highlighting a local contribution of the winds to the modulation of the large scale circulation. These results confirm those of Béranger et al. (2005) who estimated, using numerical simulation, a relatively low wind contribution with a correlation of 0.3 between the intensity of the local wind along the SC and the eastward transport through the SC.

As mentioned above, the surface circulation in the SC, although density-driven by large scale circulation features, appears to be prone to a short-term variability, related to the local winds, in particular in summer when the intensity of the surface circulation can reach ten times its mean values (Poulain and Zambianchi, 2007). A schematic of the surface circulation is therefore hard to draw, in particular taking into account the recent results based on short periods of observations or modelling studies suggesting several bifurcation branches (Gerin et al., 2009; Sorgente et al., 2011).

The aim of this study is to investigate the role of surface winds in modulating the mesoscale variability of the near-surface circulation in the SC region. We use a high resolution air-sea coupled numerical model, a suited tool to fill the observational gaps, to study the short-term scale variability and to quantify the direct effects of the air-sea interactions. A clustering technique is applied to the surface wind in order to determine the main wind regimes in the SC and their impact on the ocean circulation. The rest of this paper is organized as follows: Section 2 describes the models and the data-set as well as the clustering technique methodology; Section 3 details the wind regimes and the corresponding sea-surface circulation; In Section 4, the impact of the surface winds on the