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Interannual variability of the early summer circulation around the Balearic Islands: Driving factors and potential effects on the marine ecosystem

R. Balbín [a,*], J.L. López-Jurado [a], M.M. Flexas [e], P. Reglero [a], P. Vélez-Velchí [c], C. González-Pola [b], J.M. Rodríguez [b], A. García [d], F. Alemany [a]

[a] Instituto Español de Oceanografía, Centro Oceanográfico de Baleares, Muelle de Poniente s/n, 07015 Palma de Mallorca, Spain
[b] Instituto Español de Oceanografía, Centro Oceanográfico de Santander, Spain
[c] Instituto Español de Oceanografía, Centro Oceanográfico de Canarias, Spain
[d] Instituto Español de Oceanografía, Centro Oceanográfico de Málaga, Spain
[e] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA

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ABSTRACT

Six summer surveys conducted from 2001 to 2005 and in 2012 by the Spanish Institute of Oceanography (IEO) reveal that the hydrographic early summer scenarios around the Balearic Islands are related to the winter atmospheric forcing in the northwestern Mediterranean Sea. The Balearic Islands (western Mediterranean Sea) lie at the transition between the southern, fresher, newly arrived Atlantic Waters (AWs) and the northern, saltier, resident AW. The meridional position of the salinity driven oceanic density front separating the new from the resident AW is determined by the presence/absence of Western Intermediate Water (WIW) in the Mallorca and Ibiza channels. When WIW is present in the channels, the oceanic density front is found either at the south of the islands, or along the Emile Baudot escarpment. In contrast, when WIW is absent, new AW progresses northwards crossing the Ibiza channel and/or the Mallorca channel. In this later scenario, the oceanic density front is closer to the Balearic Islands. A good correspondence exists between standardized winter air temperature anomaly in the Gulf of Lions and the presence of WIW in the channels. We discuss the use of a regional climatic index based on these parameters to forecast in a first-order approach the position of the oceanic front, as it is expected to have high impact on the regional marine ecosystem.

1. Introduction

The circulation in the Mediterranean Sea follows a cyclonic path along the continental slope (e.g. Millot, 1985). The inflow of Atlantic Waters (AWs) through the Gibraltar strait extends across the Alboran Sea and follows the North African coast, configuring the Algerian Current (AC). In the northwestern Mediterranean, at the Ligurian sub-basin, the AW flowing from the Algerian sub-basin joins to that coming from the Tyrrhenian Sea (Astraldi & Gasparini, 1992) forming the Northern Current (NC), which flows along the continental slope (Fig. 1A). When it arrives to the Balearic sub-basin a branch of this current flows northeastward along the northern slope of the Balearic Islands, giving rise to the Balearic Current (BC) (García-Ladona et al., 1996; Salat, 1995).

Two water masses are found at intermediate depths: the Levantine Intermediate Water (LIW), formed at the Eastern Mediterranean Sea, and the Western Intermediate Water (WIW), formed in winter over the continental shelf and the slope (e.g. Vargas-Yáñez et al., 2012). Western Mediterranean Deep Water (WMDW) is formed during deep winter convection events in the Gulf of Lions and the Ligurian Sea (MEDOC-Group, 1970) and cascading (Canals et al., 2006; Puig et al., 2013).

WIW is transported by the NC into the Gulf of Valencia and the Ibiza channel between the end of winter and beginning of spring; however, it is not found at the Balearic channels every year. Table 1 resumes the salinity, S, and potential temperature, θ, that characterize the different water masses and their values in the area of study (López-Jurado et al., 2008). The saltier and colder surface water that has stayed longer in the Mediterranean will be denoted as resident AW ($S > 37.5$) and the fresher and warmer water recently arrived through the Strait of Gibraltar will be denoted as new or recent AW ($S < 37.5$).

At the end of the winter the southward transport through the channels decreases (Font et al., 1988). This allows the northward progress of recent AW across the Balearic channels during summer (Pinot et al., 2002). The confluence of new AW with resident AW generate salinity driven oceanic fronts that will be denoted as oceanic fronts from now on.

The presence of WIW at the topographically complex Balearic channels can induce the formation of mesoscale structures able to disrupt the local circulation (Pinot & Ganachaud, 1999; Pinot et al., 2002).

Using a primitive equation model Pinot et al. (1999) find that the accumulation of WIW to the north of the Ibiza Channel in spring has a

* Corresponding author. Tel.: +34 971401561.
E-mail address: rosa.balbin@ba.ieo.es (R. Balbín).

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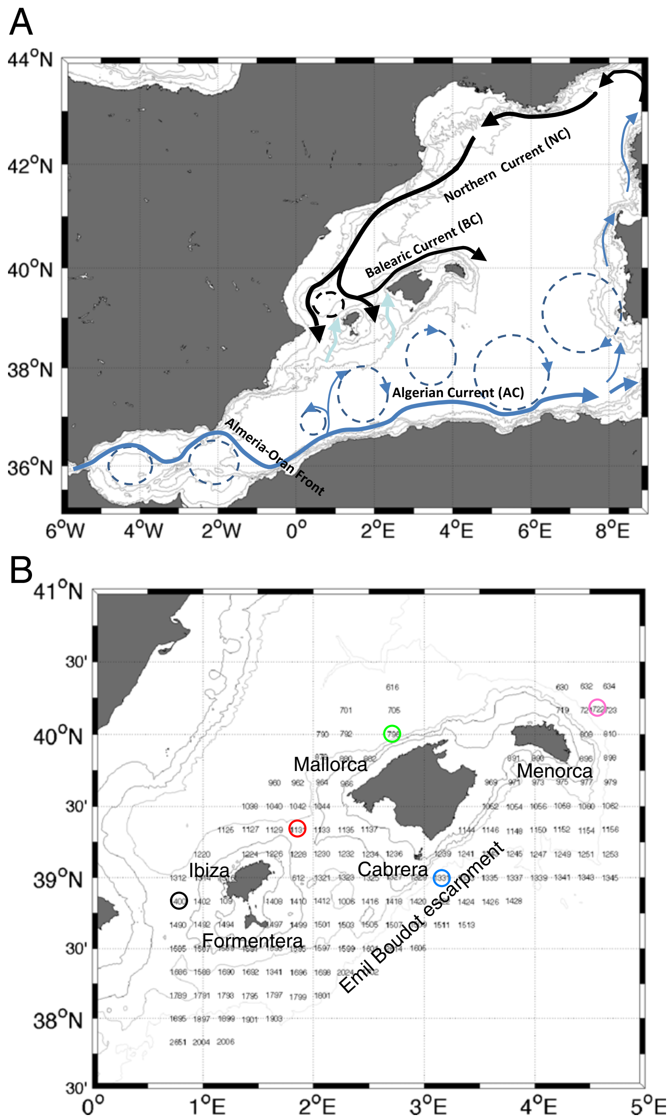

Fig. 1. (A) Western Mediterranean Sea and main currents characterizing the regional circulation. The Algerian, Northern and Balearic currents are shown as dark thick arrows and the Algerian gyres are indicated as light dotted arrows. Light gray lines denote isobaths (100 m, 500 m, 1000 m, and 2000 m). (B) Station distribution used during Atame-0612 as an example of Tunibal standard grid station planning. Main geographical features are sown for reference. Circles (colored in the online version) indicate strategic stations used to characterize intermediate-depth water masses around the Islands (see Fig. 6).

dramatic effect on the circulation and on the water exchange through the channels. They refer to WIW anticycloniceddies as “weddies” and find out they are the main factor leading to a reduction of the southward circulation through the Ibiza Channel. Those anticyclonic “weddies” induce an important branching of the NC, which is partly redirected towards the Balearic slope, reinforcing the BC. The mesoscale regional IDEA index (Monserrat et al., 2008) has satisfactorily characterized the presence or absence of WIW in the Balearic channels during spring and summer, making use of the data on the atmospheric forcing in the Gulf of Lions during the previous winter.

Marine ecosystems respond to the variability on the position of oceanic fronts and eddies (e.g. Landry et al., 2012, and references therein). Fronts and eddies are places where the mechanical energy of the physical system is accessible for augmenting the trophic energy available to biological organisms (Bakun, 2006). Such habitats, though small in a real extent, may contribute disproportionately and importantly to regional productivity, nutrient cycling, carbon fluxes and trophic ecology (Landry et al., 2012). These processes are also observed in the Balearic Sea (e.g. Pinot et al., 1995) where mesoscale structures determine the interannual differences in the spatial patterns of the meroplanktonic communities (Alemany et al., 2010; Torres et al., 2011). The locations of the fronts determine the interannual variability of the spawning habitat of large pelagic predators (e.g. bluefin tuna and albacore (Reglero et al., 2012). Fronts and eddies also play a major role in determining genetic connectivity and geographic fragmentation of fish species populations (Schunter et al., 2011).

The goal of this paper is to examine the possibility of predicting qualitatively the location of the oceanic front separating new AW from resident AW at the beginning of summer using the mesoscale regional climatic IDEA index. The results might provide a tool useful to understand the influence of mesoscale structures on the ecosystems around the Balearic Islands, based on atmospheric conditions in the previous winter.

With this purpose, available data and the methods used for the analysis are presented in the first place. Then, the hydrographical scenarios are described for the different surveys and the presence or absence of WIW in the channels is illustrated. After that we discuss the dependence of the position of the oceanic front on WIW absence/presence on the channels, the use of the IDEA index to forecast the WIW presence on the channels, the implications that the front position has on the biology and the implications of predicting frontal positions using winter atmospheric forcing on understanding the biological systems. Finally, the conclusions are summarized.

2. Data and methodology

Six summer surveys were carried out from 2001 to 2005 and 2012 (Table 2). They will be referred as Tunibal surveys. Hydrographic stations were 10 nmi apart (approximately 18.5 km). Such spatial resolution allows to resolve the typical regional mesoscale structures, which range from 50 km to 100 km (Pinot et al., 2002). Fig. 1B shows the grid of Atame-0612 as an example of Tunibal standard sampling stations.

Conductivity, temperature and pressure (CTD) data from SeaBird 911+ and SeaBird 25 were obtained from surface to 350 m. In every two hydrographic stations (every 20 nmi) measurements were extended down to 600 m for dynamic height calculations. Hydrographic parameters (salinity, S; potential temperature, θ; potential density anomaly, σ_θ) were processed using the Sea-Bird Electronics Data

Table 1
Potential temperature (θ) and salinity (S) ranges of the different water masses in the area of study. AW = Atlantic Water. WIW: Western Mediterranean Intermediate Water. LIW: Levantine Intermediate Water. WMDW: Western Mediterranean Deep Water.

Water mass	Values at origin	Local values
AW	$15.0 < \theta < 18.0$	$15.0 < \theta < 28.0$
	$36.15 < S < 36.50$	$36.50 < S < 37.50$
Resident AW	$13.0 < \theta < 28.0$	$13.0 < \theta < 28.0$
	$37.50 < S < 38.30$	$37.50 < S < 38.20$
WIW	$12.5 < \theta < 13.0$	$12.5 < \theta < 13.0$
	$37.90 < S < 38.30$	$37.90 < S < 38.30$
LIW	$14.0 < \theta < 15.0$	$13.0 < \theta < 13.4$
	$38.70 < S < 38.80$	$38.45 < S < 38.60$
WMDW	$12.7 < \theta < 12.9$	$12.7 < \theta < 12.9$
	$38.40 < S < 38.48$	$38.40 < S < 38.48$

Table 2
Summary of Tunibal surveys.

Survey	Dates (from–to)	Number of CTD stations
Tunibal 0601	16/06/2001–09/07/2001	150
Tunibal 0602	07/06/2002–30/06/2002	193
Tunibal 0703	03/07/2003–30/07/2003	212
Tunibal 0604	17/06/2004–10/07/2004	190
Tunibal 0605	27/06/2005–23/07/2005	190
Atame 0612	21/06/2012–14/07/2012	178