



Glider and satellite high resolution monitoring of a mesoscale eddy in the algerian basin: Effects on the mixed layer depth and biochemistry



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ABSTRACT

Despite an extensive bibliography for the circulation of the Mediterranean Sea and its sub-basins, the debate on mesoscale dynamics and their impacts on bio-chemical processes is still open because of their intrinsic time scales and of the difficulties in their sampling. In order to clarify some of these processes, the "Algerian BASin Circulation Unmanned Survey-ABACUS" project was proposed and realized through access to the JERICO Trans National Access (TNA) infrastructure between September and December 2014. In this framework, a deep glider cruise was carried out in the area between the Balearic Islands and the Algerian coast to establish a repeat line for monitoring of the basin circulation. During the mission a mesoscale eddy, identified on satellite altimetry maps, was sampled at high-spatial horizontal resolution (4 km) along its main axes and from the surface to 1000 m depth. Data were collected by a Slocum glider equipped with a pumped CTD and biochemical sensors that collected about 100 complete casts inside the eddy. In order to describe the structure of the eddy, in situ data were merged with next generation remotely sensed data: daily synoptic sea surface temperature (SST) and chlorophyll concentration (Chl-a) images from the MODIS satellites, as well as sea surface height and geostrophic velocities from AVISO. From its origin along the Algerian coast in the eastern part of the basin, the eddy propagated northwest at a mean speed of about 4 km/day, with a mean diameter of 112–130 km, mean amplitude of 15.7 cm; the eddy was clearly distinguished from the surrounding waters thanks to its higher SST and Chl-a values. Temperature and salinity values over the water column confirm the origin of the eddy from the Algerian Current (AC) showing the presence of recent Atlantic water in the surface layer and Levantine Intermediate Water (LIW) in the deeper layer. The eddy footprint is clearly evident in the multiparametric vertical sections conducted along its main axis.

Deepening of temperature, salinity and density isolines at the center of the eddy is associated with variations in Chl-a, oxygen concentration and turbidity patterns. In particular, at 50 m depth along the eddy borders, Chl-a values are higher (1.1–5.2 µg/l) in comparison with the eddy center (0.5–0.7 µg/l) with maximum values found in the southeastern sector of the eddy.

Calculation of geostrophic velocities along transects and vertical quasi-geostrophic velocities (QG-w) over a regular 5 km grid from the glider data helped to describe the mechanisms and functioning of the eddy. QG-w presents an asymmetric pattern, with relatively strong downwelling in the western part of the eddy and upwelling in the southeastern part. This asymmetry in the vertical velocity pattern, which brings LIW into the euphotic layer as well as advection from the northeastern sector of the eddy, may explain the observed increases in Chl-a values.

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1. Introduction

The Algerian Basin occupies most of the southern part of the Western Mediterranean Sea and is characterized by the presence of both fresh surface waters coming from the Atlantic (Atlantic Water-AW)

and more saline waters from the Mediterranean region (Millot, 1999; Millot et al., 2006). The interaction between AW and the resident saltier waters occurs at different scales, including the basin-scale, sub-basin-scale and mesoscale structures that together characterize the basin dynamics (Robinson and Golnaraghi, 1994; Fusco et al., 2003; Vidal-Vijande et al., 2011).

AW flows along the Algerian slope, forming the Algerian Current (AC), the along-slope flow that drives this water mass from Gibraltar

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to the rest of the Western and Eastern Mediterranean basins (Millot, 1985). Due to complex hydrodynamical processes, this along-slope current generally becomes unstable, meanders and generates mesoscale eddies (e.g., Millot, 1985; Font et al., 1998; Font et al., 2004; Salas et al., 2002; Olita et al., 2011). A typical AC instability can be described as a meander associated with cyclonic and anticyclonic mesoscale eddies (Moran et al., 2001). Previous studies based on in-situ and satellite data have described the typical origins, paths and evolution of these structures (Millot, 1999; Ruiz et al., 2002; Taupier-Letage et al., 2003; Millot and Taupier-Letage, 2005). According to these studies, AC meanders usually carry an embedded (coastal) anticyclonic eddy that is associated with an upwelling cell on its southwestern side; often there is an accompanying short-lived shallow cyclonic circulation on the meander crest (e.g., Obaton et al., 2000; Moran et al., 2001).

The anticyclonic eddies (hereafter Algerian Eddies, AEs) can rapidly grow to up to 50–100 km in diameter, reach vertical extents of hundreds or thousands of meters (Ruiz et al., 2002), and drift eastwards along the slope at a few km/day. Owing to topographic forcing when approaching the Sardinia channel, they successively separate from the AC and drift northward. AEs then skirt the Sardinian slope where they interact with the Levantine Intermediate Water (LIW) vein (Millot, 1987; Millot and Taupier-Letage, 2005). Finally, AEs propagate offshore (westward) into the central part of the basin, following a counterclockwise pathway in the Eastern Algerian Basin that can also include several loops (Millot, 1999; Fuda et al., 2000; Ruiz et al., 2002; Taupier-Letage et al., 2003).

AEs have been observed since the 1980s in satellite infrared images (Taupier-Letage and Millot, 1988), and can last for many months or even years (Millot et al., 1997; Puillat et al., 2002). They can have a strong impact on the general circulation of the entire Algerian Basin, with marked repercussions for the distribution of water masses and biochemical parameters and, hence, on ecosystems. For example, when located along the Algerian slope AEs can dramatically alter the AC, eventually forcing the latter to flow perpendicularly to the coast for months (Millot et al., 1997; Taupier-Letage and Millot, 1988), altering its usual along slope flow (Font et al., 1998). More recent studies using satellite altimetry data and numerical modelling (Pujol and Larnicol, 2005; Pascual et al., 2007 and Pascual et al., 2014; Escudier, 2015) have shown that the AC and associated eddies are characterized by high levels of eddy kinetic energy.

Studies based on remote sensing have shown close correlation between thermal and ocean color satellite signatures, demonstrating that mesoscale dynamics modulate biological activity (Arnold and La Violette, 1986; Taupier-Letage, 1988; Arnold et al., 1990; Taupier-Letage et al., 2003). Consequently, biological activity is also characterized by large mesoscale spatial and temporal variability (e.g., Lohrenz et al., 1988a, 1988b; Robinson, 1983; Morel and André, 1991). A large anticorrelation between sea level anomalies and phytoplankton biomass has also been found by Olita et al., (2011) in the central zone of the basin, suggesting a clear biological response to the shoaling/deepening of isopycnals, and thus to nutrient injection (removal) into (out of) the euphotic layer.

To describe these processes it is therefore important to conduct frequent multi-platform and mesoscale-dedicated monitoring activities in the study area with data collection at small sampling intervals, without neglecting useful information from larger spatial scales. To properly address these scientific challenges, new technologies for in situ data collection, mainly Autonomous Underwater Vehicles (AUVs) and reliable satellite data are being progressively implemented. AUVs allow the collection of high resolution physical and biological data, providing useful contributions to the understanding of mesoscale and sub-mesoscale dynamics (Ruiz et al., 2009) while remote sensing provides a better understanding of the processes at basin scale.

This paper focuses on the description of the structure of a mesoscale eddy in space and depth and its effects on mixed layer depth and biochemistry. In this work we take advantage of new technologies

combining use of AUV observations and a large set of satellite-observed variables. In particular, a Slocum deep glider mission was carried out during September–December 2014 in the framework of the ABACUS (Algerian BASin Circulation Unmanned Survey) project supported by the Joint European Research Infrastructure network for Coastal Observatories (JERICO).

The paper is structured as follows: first a description of the glider characteristics and mission, the satellite datasets and the methodology for the analysis performed on the data are presented; then the main results and discussion follow.

2. Data and methods

From September 15 to December 19 2014 two deep SLOCUM G2 glider missions were carried out in the Algerian Basin in the framework of the ABACUS project. The glider missions were supported by JERICO TransNational Access (TNA – Seventh framework programme) and were designed to perform a Mallorca-Algeria monitoring repeat line, and eventually investigate the presence of mesoscale structures thanks to the gliders' adaptive sampling capabilities. As a large surface eddy was detected in AVISO altimetry maps South East of Mallorca, the original sampling strategy for the first glider mission was modified. After concluding a first transect from Mallorca to Algeria, the glider sampling route was modified in order to cross the eddy along two transects collecting physical and biochemical measurements (Fig. 1).

In situ data collection was supported by continuous monitoring of remotely sensed data from different platforms. Successive satellite images of altimetry (AVISO), sea surface temperature (SST) and chlorophyll-a concentration (Chl-a) from NASA were used to depict the large scale dynamics of the area of interest for eddy presence, location of mesoscale structures and, consequently, definition of the sampling track.

2.1. Glider characteristics, sensors and sampling plan

Gliderers are autonomous underwater vehicles providing high-resolution hydrographic and bio-chemical measurements. These vehicles control their buoyancy to allow vertical motion in the water column and make use of their hydrodynamic shape and small fins to make horizontal motions (Bouffard et al., 2010). In particular, ABACUS project field activities were performed in collaboration with the Balearic Islands Coastal Observing and Forecasting System (SOCIB) and Instituto Mediterráneo de Estudios Avanzados (IMEDEA CSIC-UIB) using a SLOCUM G2 glider for deep water (1000 m maximum depth) with a vertical speed of 0.18 ± 0.02 m/s resulting in an horizontal velocity of about 0.36 m/s. Real time data transmission from the glider can be configured. For this mission this occurred every 8 km (6 h) and permitted the retrieval of a first overview of the data collected, as well as transmission of new sampling and navigation directives to the glider.

In this paper we focus on the glider data from the mission conducted from 15 September to 20 October 2014 over the area of interest for the presence of a mesoscale eddy (Fig. 1).

The pre-mission activities were carried out at the SOCIB glider facility (Tintoré et al., 2013) and included all ballasting and adjustment operations needed to assure the glider capability to reach the surface. Within this scope, the climatological maximum value of temperature and minimum value of salinity for the studied area and period have been analyzed. These data were used as extreme hydrographic characteristics of the water to be navigated and allowed us to derive the minimum density (1024.0683 Kg/m^3) needed to precisely tune the glider for the target waters.

Resolution of sampling was defined according to the scientific aims of the mission (high resolution in both horizontal and vertical directions) and considering the energetic constraints of the platform.

The data acquisition strategy was set in order to complete a sawtooth navigation pattern (Fig. 2) allowing the glider to dive with an

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