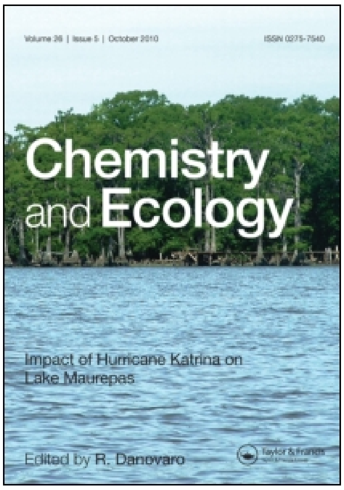

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MESOSCALE CIRCULATION IN THE SURFACE LAYER OFF THE SOUTHERN AND WESTERN SARDINIA ISLAND IN 2000–2002

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Five oceanographic cruises were organized in the Sardinian Sea and Channel in May 2000, March 2001, September 2001, May 2002, and November 2002 to study the characterization of the water masses, Atlantic Water (AW) and Winter Intermediate Water (WIW), and their mesoscale variability. In the Sardinian Channel, an Algerian anticyclonic Eddy (AE) was observed in May 2000, along the Tunisian coast. This induced a greater minimum salinity in a wider and deeper layer than in November 2002, when no AE was observed. Some WIW was observed below it; nevertheless, no link could be established between AEs and WIW occurrences. In the Sardinian Sea, two AEs were observed during spring 2000, and a further two during spring 2002. One AE strongly influenced shelf circulation, in contrast to the other three that were off the continental slope. In the same area, during the end of September 2001, a vertical salinity inversion occurred in the first 30–50 m of depth over the whole sampling field, and a W–NW wind induced a coastal upwelling over the western Sardinian coast (south of 41° N). This upwelling increased the salinity from ~20 to 30 m below the surface to the surface and, thereby led to a lower salinity close to the coast than offshore. This was in contrast to a classical upwelling. Consequently, in the Sardinian Sea, the general circulation, mainly driven by AEs, can meet the coastal wind-driven circulation.

Keywords: Sardinia; AW; WIW; Anticyclonic eddy; mesoscale

1 INTRODUCTION

The areas investigated in this study are the Sardinian Sea, located between the western Sardinian coast and ~7° E, and the Sardinian Channel, located to the south of Sardinia (Figure 1). These two areas are directly connected to the Algerian basin where the general circulation is mainly characterized by mesoscale activity, mostly anticyclonic eddies. Being one of the most energetic Mediterranean basins at mesoscale, at least from an altimetric point of view (Ayoub *et al.*, 1998), the southern and western Sardinian zones are good places to study the influence of mesoscale eddies on water masses and their biological implications.

Since general circulation schemes over the Mediterranean Sea have been recently updated (see Millot, 1999, for a review), only the surface circulation of the Algerian basin, which is the focus of this article, is briefly presented here. The surface layer (~0 to 150–200 m) is

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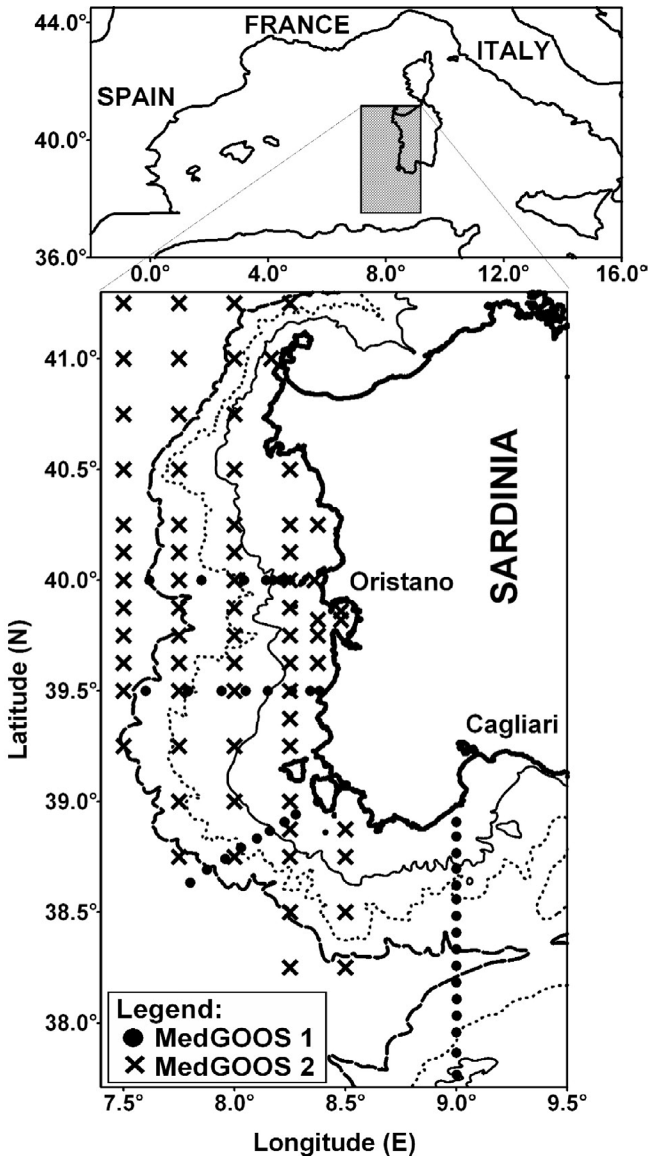

FIGURE 1 Sampling fields during MedGOOS 1 and MedGOOS 2 cruises. Isobaths are plotted for 200 m, 1000 m and 2000 m.

characterized by a water mass of Atlantic origin: the Atlantic Water (AW). The recent Atlantic Water from the Alboran Sea (with salinity (S) $\sim$ 36.5) displays an along-slope cyclonic circulation over the entire Mediterranean Sea. Along the Algerian coast, the AW forms the Algerian current (Millot, 1985), which rapidly becomes unstable (from $\sim$0° E) and can generate anticyclonic eddies on the surface. Until now, only anticyclonic eddies have been observed, and the generic name of Algerian Eddies (AEs) has been used (Taupier-Letage *et al.*, 2003). Their diameter varies between $\sim$50 and $\sim$250 km (Taupier-Letage and Millot, 1988), and their vertical extent ranges from depths of hundreds of metres to all the way to the sea bottom (thousands of metres). They can last 2–3 years in the Algerian basin (Puillat *et al.*, 2002). AEs trajectories begin with an along-sloping downstream propagation at a few kilometres per day along the Algerian slope, and they are considered to be coastal eddies at this stage. Some AEs collapse in the vicinity of the Sardinian Channel where the sea bottom rises. In this area, AEs can be strongly modified and can remain blocked for several months, as shown on infrared images by Puillat *et al.* (2002). The more shallow eddies are able to pass to the east of the Sardinian Channel. A few AEs per year follow the isobaths and break off the Algerian current and slope. Then, AEs follow the Sardinian slope northwards and eventually propagate inside the basin, becoming open-sea eddies. The typical AE trajectory forms a counter-clockwise circle in the eastern part of the Algerian basin (Fuda *et al.*, 2000), where long-lived AEs can loop up to three times (Puillat *et al.*, 2002). Consequently, the AEs transport relatively fresher AW with a salinity lower than 38.0 to the centre of the basin, where most modified AW is present with a typical salinity greater than 38.0. When passing over or close to the Sardinian Sea, AEs would be expected to drive, or strongly disturb, the circulation over the slope and on the shelf. Therefore, a strong mesoscale activity is expected to be due to AEs in this zone, including the shelf.

Just below the AW, an intermediate water mass named Winter Intermediate Water (WIW) is often observed at depths between $\sim$150 m and $\sim$250 m. Its formation has been observed in the Catalan Sea (Salat and Font, 1987), the Ligurian Sea (Albérola *et al.*, 1995; Sparnocchia *et al.*, 1995; Gasparini *et al.*, 1999), and the Gulf of Lions (Conan and Millot, 1995). Mainly in winter, cold and moderately strong north-westerly winds induce surface cooling of AW (Lacombe and Tchernia, 1960). The cooled water becomes denser and is eventually overlaid by the warmer, less dense AW (Conan and Millot, 1995; Fuda *et al.*, 2000). This cooled AW, called WIW, would thus be prevented from any interactions with the atmosphere. Fuda *et al.* (2000) showed that WIW could be formed as late as early April under specific meteorological conditions, and could be observed until the following winter, even though it was progressively more mixed and the volume reduced. WIW is characterized over its whole path by a minimum temperature just below that of AW. As it flows anticlockwise, it mainly spreads south-westward from the northern part where $\theta \sim 12.5$–$13.0\ ^\circ$C and $S \sim 38.1$–38.3 (Salat and Font, 1987). WIW is supposed to flow anticlockwise, so from the northern part, it mainly spreads south-westward through the Channel of Ibiza (Pinot *et al.,* 1995) and then eastward across the Algerian Basin (Perkins and Pistek, 1990; Benzohra and Millot, 1995a, b). WIW was systematically found by Benzohra and Millot (1995a) to be below the Algerian current with a minimum temperature ranging from 12.6 °C near 0° 30′ E to 13.2 °C near 5° E. Therefore, it is partially entrained by the eastward flow of recent AW along the African slope (Benzohra and Millot, 1995a). Consequently, WIW is also observed within and to the east of the Sardinian Channel, with a minimum temperature of about 13.48–13.65 °C in a layer several tens of metres thick, centred at a depth of 100–200 m (Bouzinac *et al.*, 1999; Sammari *et al.*, 1999) and also in the southern Tyrrhenian Sea (Onken and Sellschopp, 2001). Along its circulation, WIW mixes while increasing its temperature. As AW and WIW flow together, they will both be considered part of the surface layer.

Despite the importance of mesoscale in circulation, only a few *in situ* experiments have been dedicated to mesoscale study in each of the two areas, and the Sardinian Sea has not been studied in its whole nor specifically. In addition, these are key zones where intermediate water circulation is still more or less debated (see Millot and Taupier-Letage, in press, for a recent review).

With regard to the biological implications, the mesoscale dynamic variability has a significant impact on the standing phytoplankton stock in the Algerian basin, as indicated first by ocean colour images (e.g. Arnone and La Violette, 1986; Morel and André, 1991) and *in situ* experiments (Millot *et al.*, 1990; Raimbault *et al.*, 1990, 1993; Moran *et al.*, 2001; Taupier-Letage *et al.*, 2003). Nevertheless, mesoscale biological variability has scarcely been studied in the Sardinian Sea, and the phytoplankton distribution is poorly known, especially over the continental slope and shelf.

In order to fill these gaps, the circulation of the main water masses in these two areas was investigated in the framework of the second workpackage (WP2) of the Italian project SIMBIOS (SIstema per lo studio del Mare con Boa Integrata OffShore). Five oceanographic cruises were organized between 2000 and 2002 involving hydrological and biogeochemical measurements. A diagnostic ocean circulation model and infrared satellite images were used to study the surface dynamics.

The aim of this paper is to present mesoscale hydrodynamic variability of the surface circulation observed during these five cruises, by using *in situ* data and satellite images. Model results will be presented here. The secondary objective is to provide a description of the hydrodynamics of the euphotic layer; this could be useful for a better understanding of the physical–biological coupling processes.

The involved supports and methods are described in Section 2. Section 3 presents the main results, and a conclusion follows in Section 4.

2 METHODS

Supported by the Italian Marine Environment cluster (Programma Operativo del Piano Ambiente Marino, Cluster C10, Progetto n. 13—D.n. 778.RIC), WP2 of SIMBIOS project was dedicated to the study of hydrological and dynamic characteristics of water masses in the Sardinian Sea and Channel by combining *in situ* observations, infrared satellite images and an ocean numerical circulation model.

The circulation of the Sardinian Sea was diagnostically simulated with an eddy-resolving primitive equation numerical model (Sorgente *et al.*, 2003). Based on the Princeton Ocean Model (POM) (Blumberg and Mellor, 1987), this is a free surface three-dimensional model. The model domain is between 7.4–8.56° E and 38.6–40.6° N, with a horizontal resolution of $1/60°$, equivalent to 2 km, and has 24 sigma levels.

Five cruises, MedGOOS 1–5, were organized aboard the R/V *Urania* (Tab. I). Hydrological data (conductivity, temperature and depth) were acquired by a SBE911 plus CTD probe (Sea-Bird Inc.) with a 24 Niskin bottle rosette for water-column sampling. During MedGOOS 2, 4 and 5, a couple of temperature and conductivity sensors were added for comparison. The data collected were quality-checked and processed following the MODB instructions (Brankart, 1994) using Seasoft software. Note that in the following pages, temperature refers to potential temperature.

The Sardinian Channel was investigated during MedGOOS 1 (28/05 to 02/06/2000) and MedGOOS 5 (31/10 to 18/11/2002) on a south–north transect (Figures 1 and 2). A large

TABLE I MedGOOS cruises with number of casts and measured parameters.

	Period	*No. of casts*	*Measurements*
MedGOOS 1	28/05/2000–2/06/2000	40	Hydrology, DOC, nutrients, oxygen
MedGOOS 2	23/03/2001–3/04/2001	67	Hydrology, DOC, nutrients, currents, chlorophyll, geophysics
MedGOOS 3	10–20/09/2001	39	Hydrology, DOC, nutrients, chlorophyll, light
MedGOOS 4	10–22/05/2002	80	Hydrology, DOC, nutrients, chlorophyll, light, currents
MedGOOS 5	31/10/2002–18/11/2002	55	Hydrology, DOC, nutrients, chlorophyll, light, currents

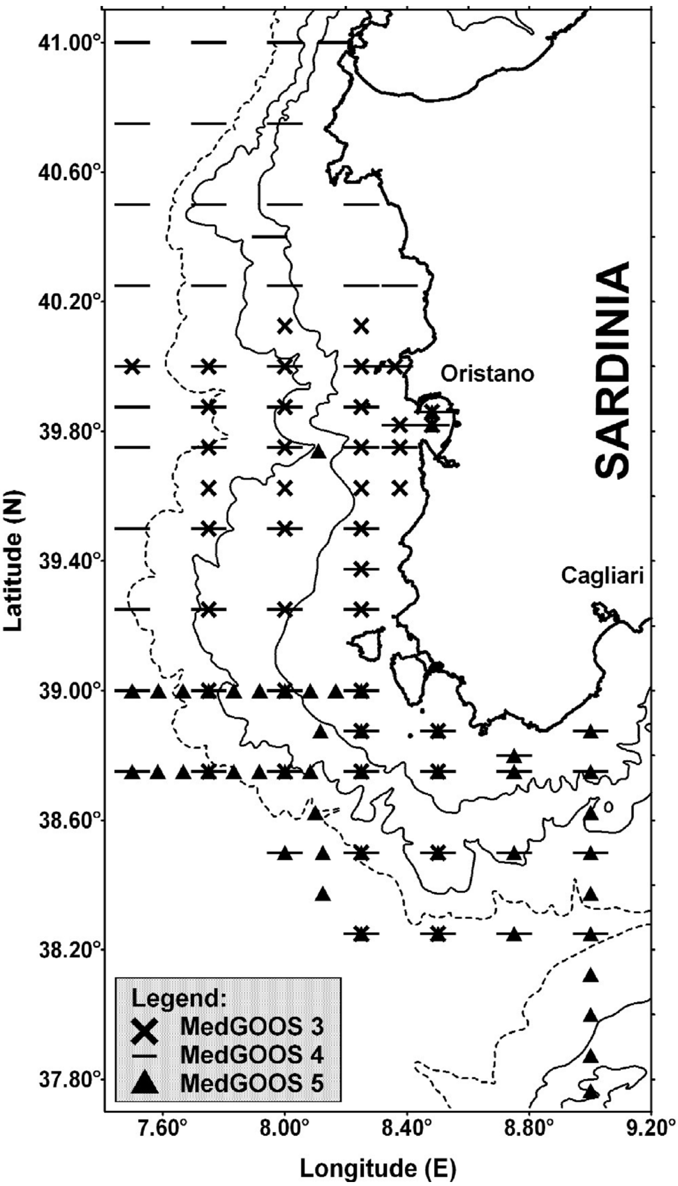

FIGURE 2 Sampling fields during the cruises MedGOOS 3, MedGOOS 4 and MedGOOS 5. Isobaths are plotted for 200 m, 1000 m and 2000 m.

part of the Sardinian Sea was covered during MedGOOS 2 (23/03 to 3/04/2001), MedGOOS 3 (10 to 20/09/2001) and MedGOOS 4 (04 to 23/05/2002) (Figures 1 and 2). MedGOOS cruises 2 and 4 were performed in the spring. Good meteo-marine conditions allowed data to be acquired during these two cruises with similar weather conditions in a relatively short period of time, and so they can be compared. A comparison with MedGOOS 3, conducted at the end of summer, provides information on the seasonal variability.

The sampling points are distributed evenly over the area as required to optimize data interpolation for the model initialization. Nevertheless, only the MedGOOS 2 and 4 data are used for the model, because of the better coverage of the whole area. The choice of a 25 km sampling grid was a compromise between the need to have sufficient spatial sampling to study mesoscale phenomena and the need to cover a relatively large area for the model initialization. A denser sampling grid was carried out in front of Oristano due to biogeochemical needs. *In situ* data were analysed in two ways. In one way, after an accurate quality check, temperature and salinity were interpolated by the Objective Analyses method (Carter and Robinson, 1987) on a regular grid of 2 km. The numerical model was run in diagnostic mode for 10 d, followed by an additional 2 d prognostic calculation. This allowed for adjustment of the observed density field to the model topography and atmospheric forcing. In the second way, data were directly analysed by vertical sections obtained using Ocean Data View free software (Schlitzer, 2001).

Previous studies in the area have shown coherence between eddies signatures on satellite images and contemporaneous *in situ* observations, validating the use of superficial satellite signatures to track these structures (e.g. Millot, 1991; Fuda *et al.*, 2000; Puillat *et al.*, 2002). In order to validate the mesoscale structure observed on the surface layer, we used two types of NOAA/AVHRR daily satellite images of sea surface temperature (SST). Two greyscale images are daily SST composites from the German Aerospace Centre DLR (Fig. 8; http://eoweb.dlr.de) database. For each image, the greyscale is adjusted to show eddies, and so absolute temperatures cannot be compared between images. Dark to light grey tones on black and white images represent cold to less cold water. Note that during spring and autumn, thermal gradients between recent AW and old AW are low, so anticyclonic eddies are difficult to observe. For this reason, during the MedGOOS 2 period, the only good available image is that of 14/03/2001, 10 days before the beginning of the cruise. Two colour images are for NOAA/AVHRR SST (Figs. 5 and 11). These were acquired and processed by the Remote Sensing Group (SIRE) of the Osservatorio Geofisico Sperimentale (OGS, Trieste, Italy) and are not daily composites. These “instantaneous” images are of a better quality because artificial fronts, due to the composition, are not shown. The colour scale has been adjusted to show eddies. Land and clouds are masked for all images.

3 RESULTS

Results are presented according to the investigated area: MedGOOS 1 and 5 for the Sardinian Channel and MedGOOS 2, 3 and 4, for the Sardinian Sea.

3.1 The Sardinian Channel

This area was investigated twice on a north–south transect at 9° E with a sampling interval of about 10 km or less and performed within 1 d. Temperature and salinity sections acquired in May–June 2000 (MedGOOS 1) and in November 2002 (MedGOOS 5) are compared (Figures 3 and 4).

On the surface layer, both sections have the lowest salinity on the Tunisian side due to the eastward flux of the recent AW ($S < 38.0$ against old AW with $S > 38.0$). Nevertheless, on the southern side, salinity values were lower in May 2000 (37.04–38.00) than in November 2002 (37.70–38.00). In addition, the flow of recent AW was wider during MedGOOS 1, as it covered more than half of the Channel. It was also deeper: the 38.0 isohaline reached $\sim$130 m depth at the two southernmost points during MedGOOS 1, whereas it reached only $\sim$60 m depth during MedGOOS 5.

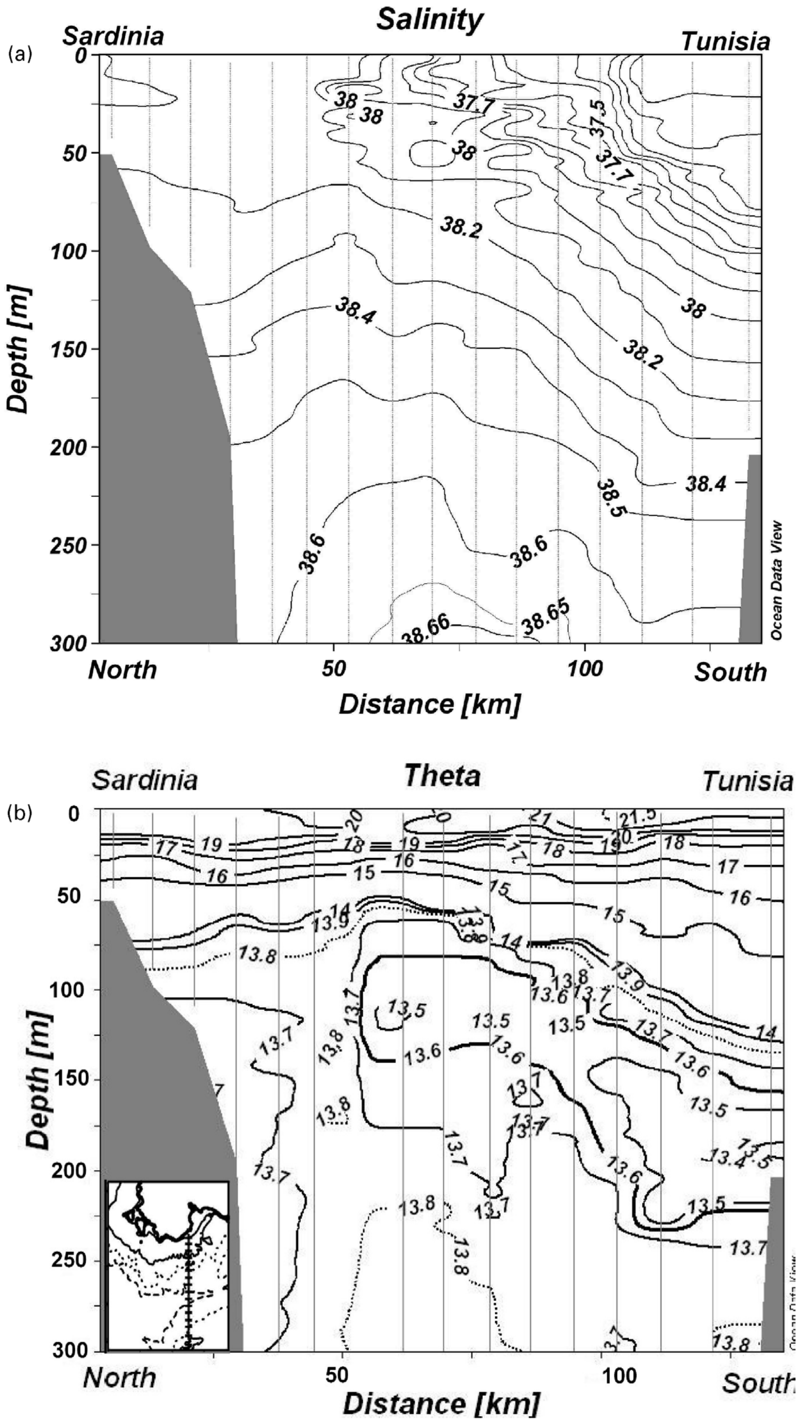

FIGURE 3 (a) Salinity and (b) potential temperature sections at 9° E during MedGOOS 1 (May 2000). The 13.8 °C isotherm is shown by the dotted line, and the 13.6 °C isotherm is shown by the bold line defining WIW mass.

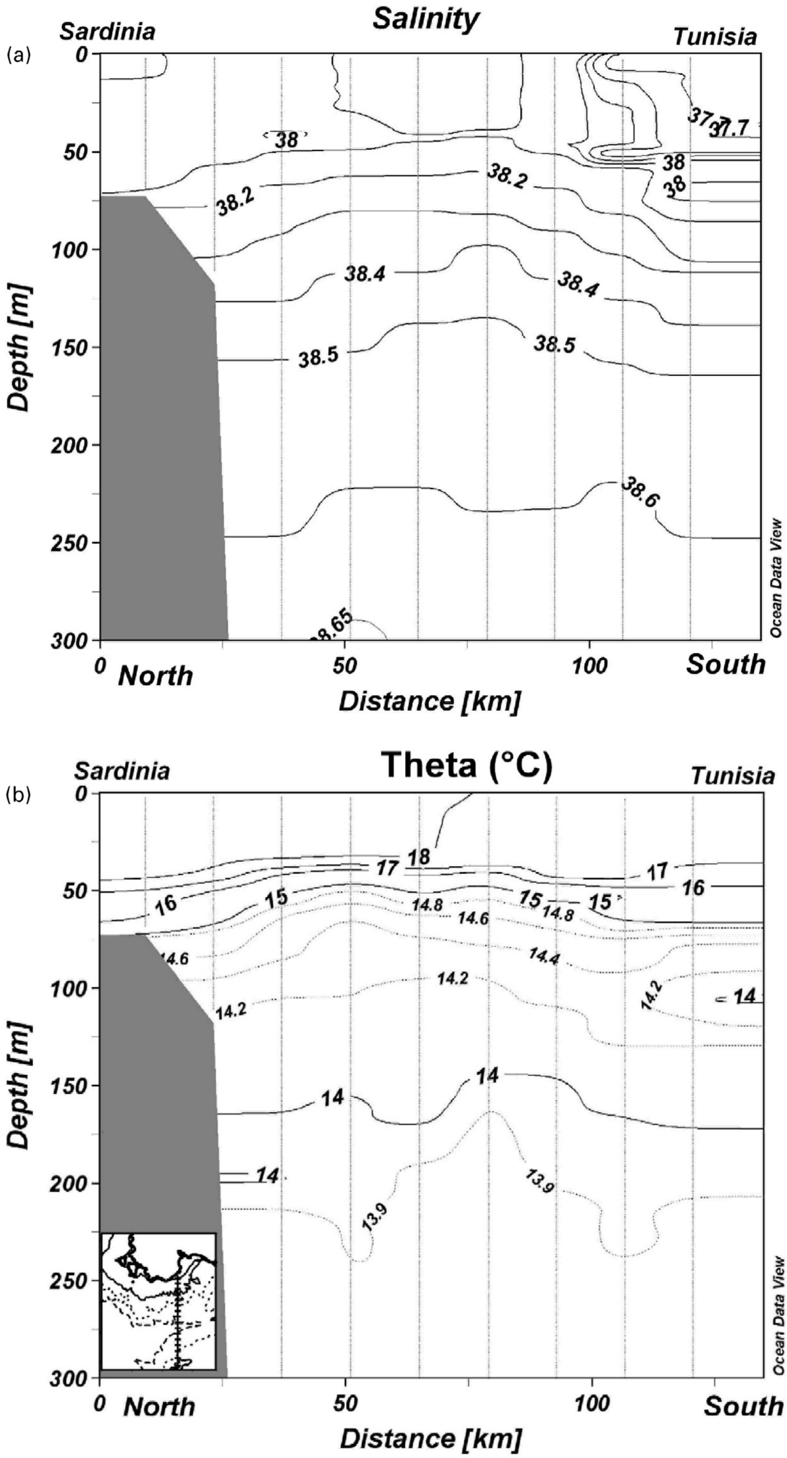

FIGURE 4 (a) Salinity and (b) potential temperature sections at 9 °E acquired during MedGOOS 5 (November 2002).

These facts and SST images lead us to link the MedGOOS 1 feature to the presence of an Algerian Eddy, noted A. The eddy was shallower than ~200 m and was drifting towards the eastern basin. According to the best available image, this eddy was about 100 km wide (Figure 5). This image was recorded 10 d before sampling the area, when the eastern part of A reached the section of the Sardinian Channel. Later images available during measuring (not shown) showed that the centre part of A was sampled. This implies that A drifted at

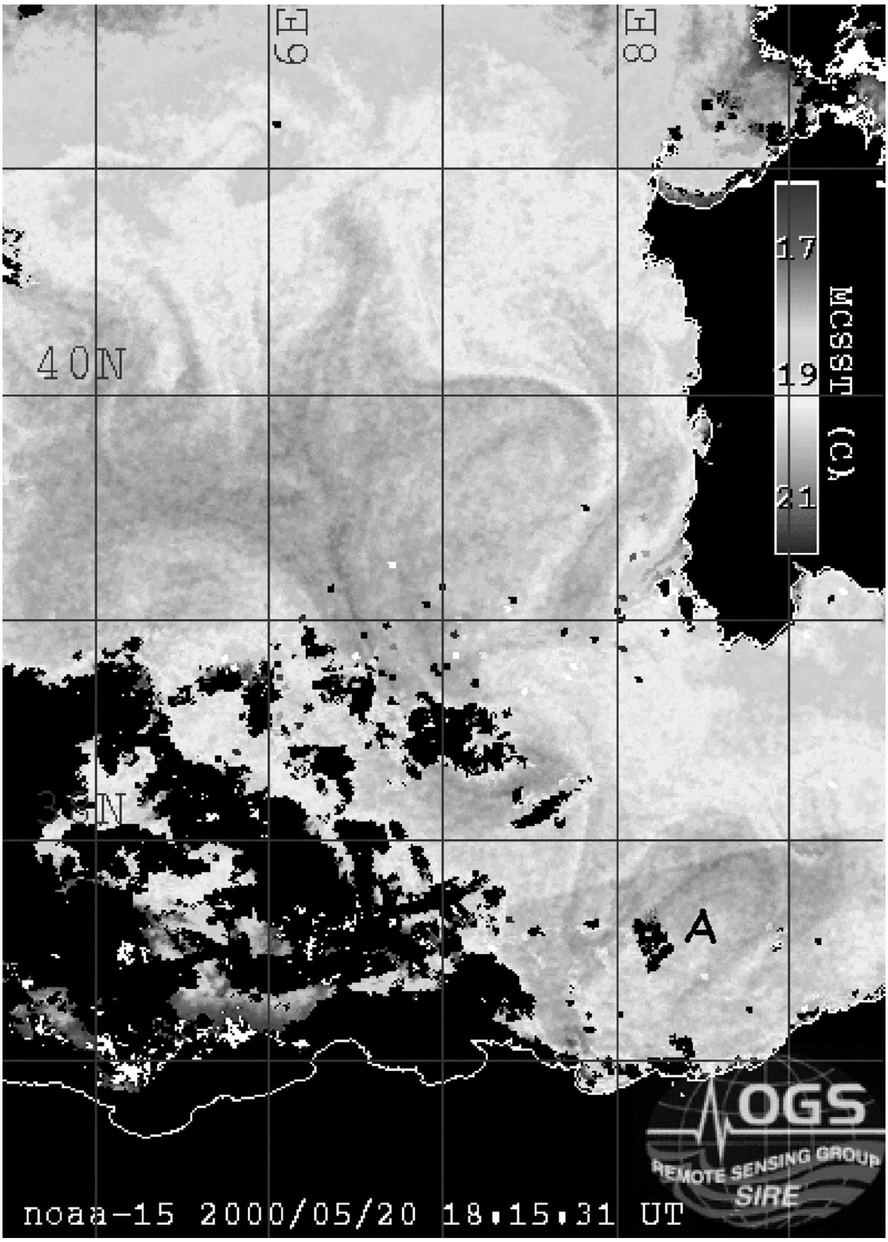

FIGURE 5 NOAA/AVHRR SST image of the 20/05/2000 at 18 h 15 (UTC) by courtesy of the Remote Sensing Group (SIRE) of OGS, Trieste, Italy. A: anticyclonic eddy.

$\sim$5 km d^{-1}, in agreement with past studies (Puillat *et al.*, 2002). The lowest salinity values at the core of A corresponded to those found in AE in the Algerian Basin (Millot *et al.*, 1990). Isohalines were also found to travel downward from the periphery to the centre of A, in agreement with the dynamics of anticyclonic eddies.

This structure does not appear as clearly on the temperature section in the first 30 m (Figure 3b) because of the strong seasonal thermocline between 16 and 19 °C. Below this, minimum temperatures ranging from 13.4 to 13.6–13–7 °C and associated with $S = 38.2$–38.4 characterize the presence of some WIW during MedGOOS 1. This water mass was distributed in a layer which was 50–100 m thick at a depth of 100–200 m. Its horizontal extent corresponds with that of the recent AW brought by eddy A ($S < 38$) as WIW flows with the AW. During MedGOOS 5, WIW was not clearly observed, since the minimum temperature was much higher than usual ($\sim$14.0 °C). As no AE was observed at the same time, the presence of an AE was thought to indicate the occurrence of the WIW. In addition, WIW had already been depicted in the vicinity of and beyond an anticyclonic eddy on a similar section near 9° E in November 1993 (Bouzinac *et al.*, 1999). Its characteristics were quite similar. It was distributed in the vicinity of an AE but also beyond it. In contrast, Sammari *et al.* (1999) found WIW on all the SA transects repeated four times at $\sim$9° 30′ E during May–June 1995, and its presence was independent of the occurrence of anticyclonic eddies. Onken and Sellschopp (2001) suggested the influence of an eventual seasonal variability of the AW flow in the channel. We conclude that WIW presence should not be due to AE occurrence in the recent AW flow, but was more likely due to the interannual variability of the WIW formation and/or a combination of those different variability scales.

3.2 The Sardinian Sea

Observations from MedGOOS 2 and 4 show a strong mesoscale variability due to anticyclonic eddies, while MedGOOS 3 does not. Consequently, the MedGOOS 2 and 4 results are presented together, and the MedGOOS 3 results will follow.

3.2.1 MedGOOS 2 and 4

During the MedGOOS 2 cruise, the AW occupied the upper 150–200 m with 37.0–38.0 salinity at 5 m (Figure 6a) and with temperatures ranging from 14.5 °C in the northern part ($>\sim$40.5° N) to 15.8 °C in the southern part at 5 m (not shown). About one year later, during MedGOOS 4 (Figure 6b), the minimum temperature was higher (17.5 °C), while the maximum salinity was lower ($S \sim 37.4$) in the Sardinian Sea.

For both cruises, the lowest values of temperature and salinity were observed in anticyclonic eddies, as depicted by vertical sections through them (Figure 7), and confirmed on SST images (Figure 8). Eddy A3 appeared to be further west on the horizontal salinity distribution (Figure 6b) than suggested on the corresponding satellite image (06/05/2002). This was due to an insufficiently fine hydrological sampling interval. These eddies are characterized by deepening isolines towards the centre (Figure 7), leading to an estimated diameter of about 100–150 km, as confirmed on SST images (Figure 8).

In March 2001, eddies A1 and A2 were centred at $\sim$40° 10′ N and $\sim$39° 10′ N, respectively. In May 2002, two other eddies were also observed at similar latitudes: A3 was near 40° N, and A4 was near 39° N. Note that during spring 2002, A3 was the closest to the coast and acted on the shelf and slope waters. The vertical size of those eddies can be estimated by looking at the deepening of isopycnals from the periphery to the centre of

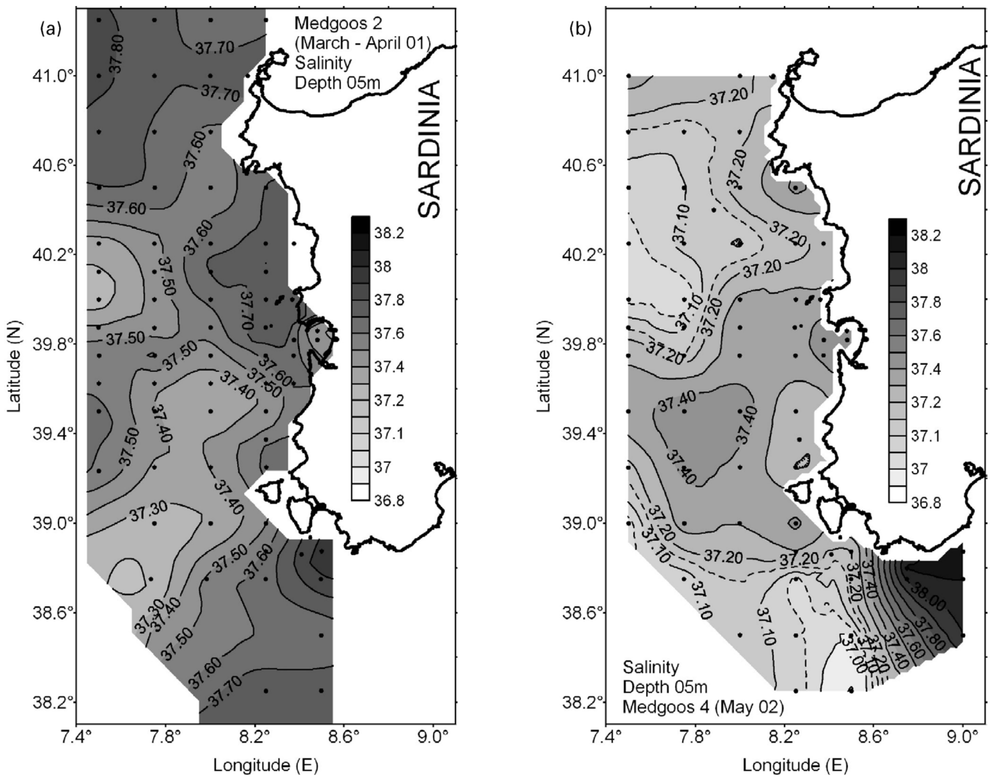

FIGURE 6 Horizontal salinity distribution at 5 m during (a) MedGOOS 2 and (b) MedGOOS 4 with isohalines every 0.1 psu. Contours at 0.05 psu are dotted.

eddies. This estimation is only for a minimum depth, since the deepest part of the water column is more homogenous. Considering isohalines, A1 and A3 were at least 1500 m deep, and A4 was at least 1000 m deep (not shown). In A2, the few available points are at the periphery, so a minimum depth of 300 m is not representative of the whole eddy (not shown).

Velocity fields computed by the model (Figure 9) confirm an anti-cyclonic rotation for A1–A4 (Sorgente *et al.*, 2003). These calculations show that observed velocities should be greater in A3 and A4 where the velocity was $\sim$40 cm s^{-1} and $\sim$55 cm s^{-1}, respectively, than in A1 and A2, where the velocity was $\sim$30 cm s^{-1} and $\sim$15 cm s^{-1}, respectively.

Comparing with AEs recently observed in the Algerian Basin (Puillat *et al.*, 2002; Millot and Taupier-Letage, in press; Taupier-Letage *et al.*, 2003), the dimensions and hydrological and dynamical characteristics were similar. Consequently, A1–A4 were AEs which had drifted from the Algerian coast to the Sardinian Sea. They contained recent AW trapped from the Algerian current in accordance with Millot circulation schemes (e.g. Millot, 1999). As they involved a great part of the Sardinian Sea, up to the shelf for A3, the recent AW did not appear in an individual northward vein off western Sardinia.

Below AW, vertical sections across eddies A1 and A3 revealed a layer characterized by a minimum temperature at $\sim$150–300 m linked to WIW. During MedGOOS 2 (March 2001), WIW was located at $\sim$120–180 m, south of A1 with 13.3–13.5 °C (Figure 10a). In the northern part of A1, 13.1–13.3 °C minima were distributed downward from the periphery

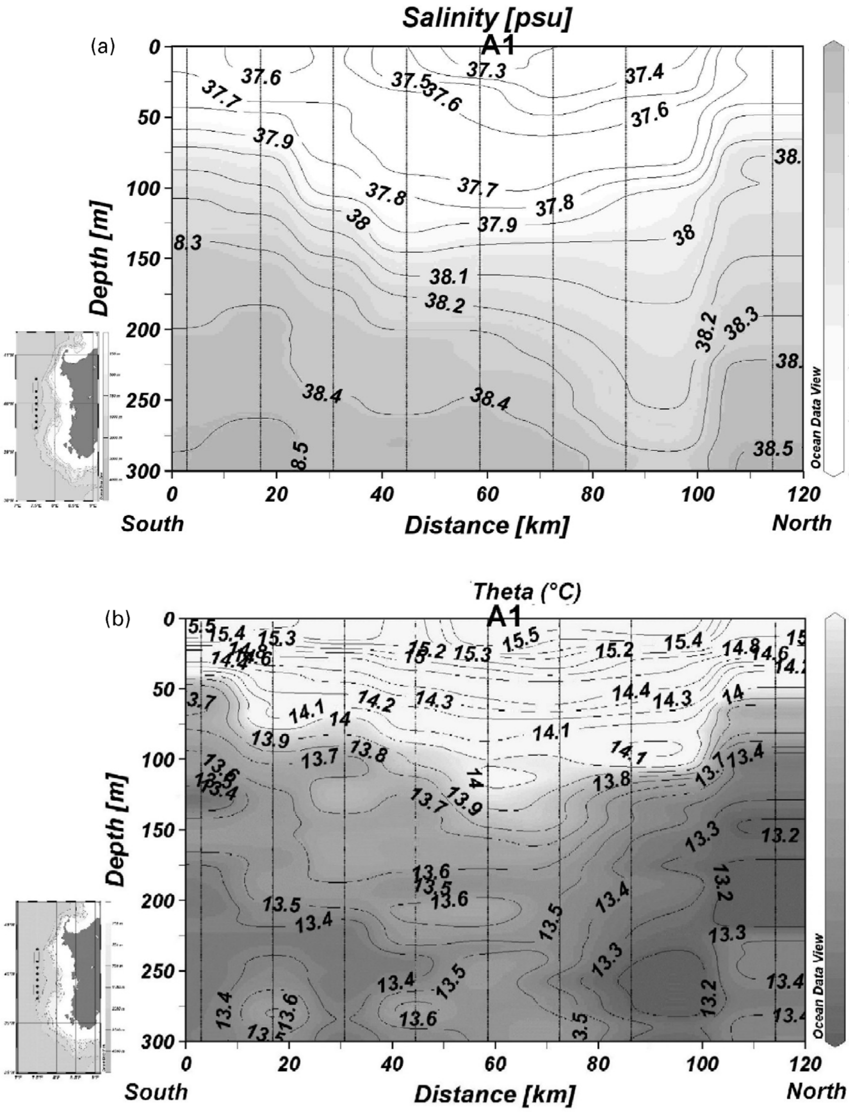

FIGURE 7 (a, c) Salinity and (b, d) potential temperature south–north vertical sections at 0–300 m across the eddy A1 (a, b) in March–April 2001 and the eddy A3 (c, d) in May 2002.

to the centre from ~100 to 300 m (Figure 7b). Such a downward movement was demonstrated by phytoplankton distribution in AEs (Taupier-Letage *et al.*, 2000). Therefore, this deepening is likely to be due to the eddy dynamics. In the southern side of A1, minima were higher with 13.3–13.4 °C, accounting for a more mixed WIW. During MedGOOS 4 (May 2002), 13.3–13.5 °C minima were observed in A3 (Figure 7d), and WIW was generally more patchy in and out of A3 than during MedGOOS 2 (Figure 10b). This could be due to the difference in the dynamics (absolute velocity, shear, etc.) between eddy pairs A1–A2 and A3–A4 and/or to the interannual variability of the WIW formation according to the severity of the winter conditions. The observed minimum temperature range (13.1–13.5 °C) is between minima found in the Algerian Basin near 5° E: ~13.2 °C (Benzohra

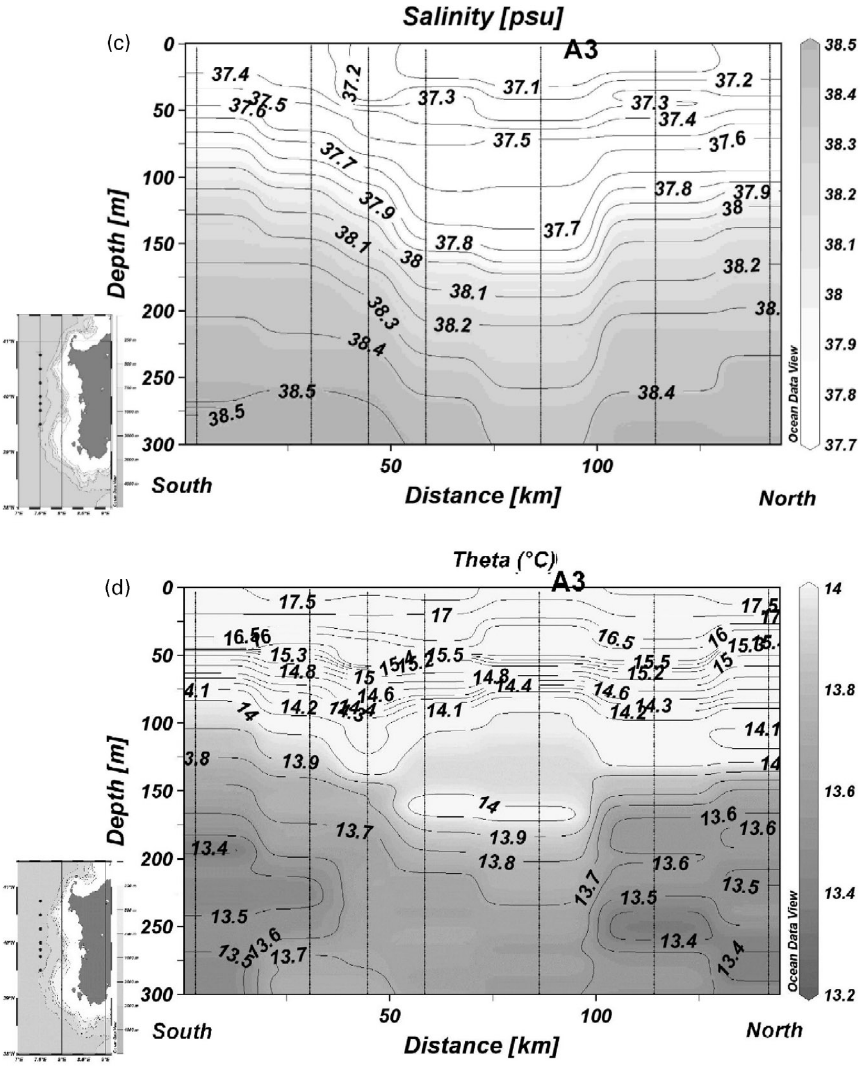

FIGURE 7 Continued.

and Millot, 1995a) and minima in the Sardinian Channel: <13.7 °C found by Bouzinac *et al.* (1999) and 13.5–13.7 °C found by Sammari *et al.* (1999). Consequently, this could mean that WIW is able to be transported more directly in the Sardinian Sea than in the Sardinian Channel and/or that stronger mixing occurs in the latter.

3.2.2 MedGOOS 3

During this cruise, no Algerian eddy was observed on the sampled area according to horizontal and vertical distributions and satellite images (Figure 11). Nevertheless other mesoscale features were observed. Indeed, an upwelling extended all along the western Sardinian coast which was not previously shown in the literature for this area and can be seen on images of the 09–14/09/2002 period. The upwelling persisted for at least 5 d. This upwelling was

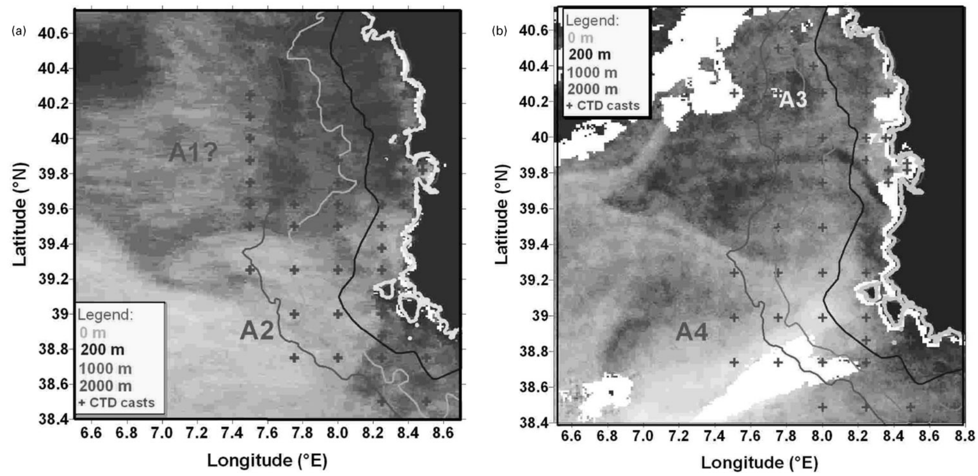

FIGURE 8 NOAA/AVHRR SST images of (a) 14/03/2001 and (b) 09/05/2002 by courtesy of the German Aerospace Centre DLR (http://eoweb.dlr.de). A1–A4 are the four anticyclonic eddies.

more intense between 40° Nand 40° 45′ N, where cold water seemed to spread over ~50 km offshore.

During this period, the wind speeds were 4–12 m s^{-1} and mainly oriented NW for several days. These were favourable conditions for an upwelling, according to the Ekman theory,

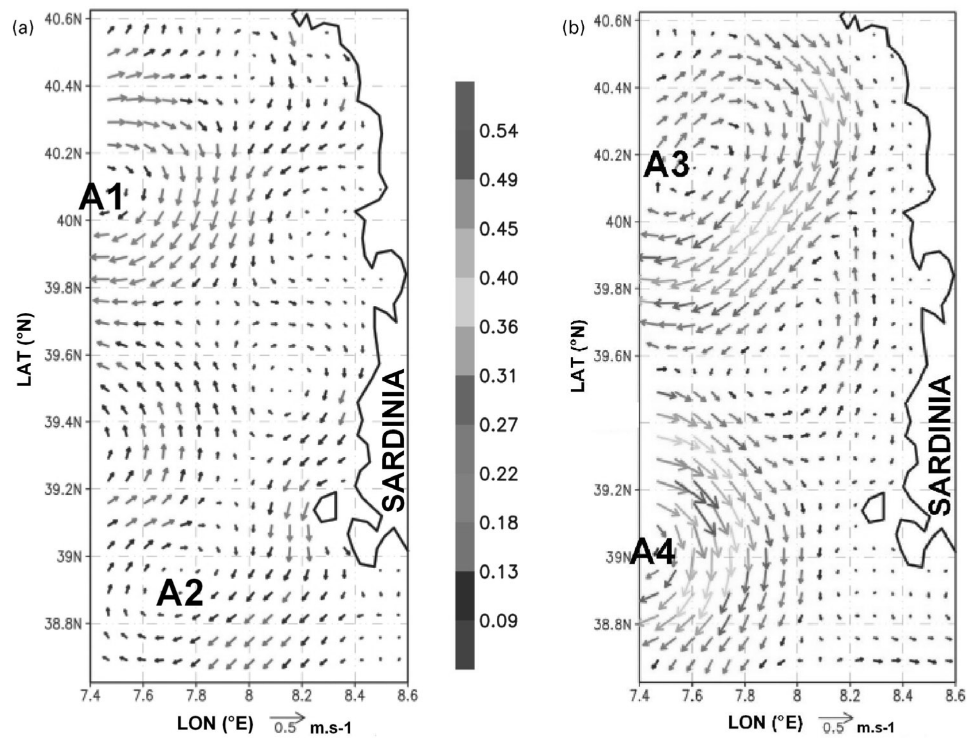

FIGURE 9 Velocity fields computed by the model from the data of the cruise: (a) MedGOOS 2 in March–April 2001 and (b) MedGOOS 4 in May 2002.

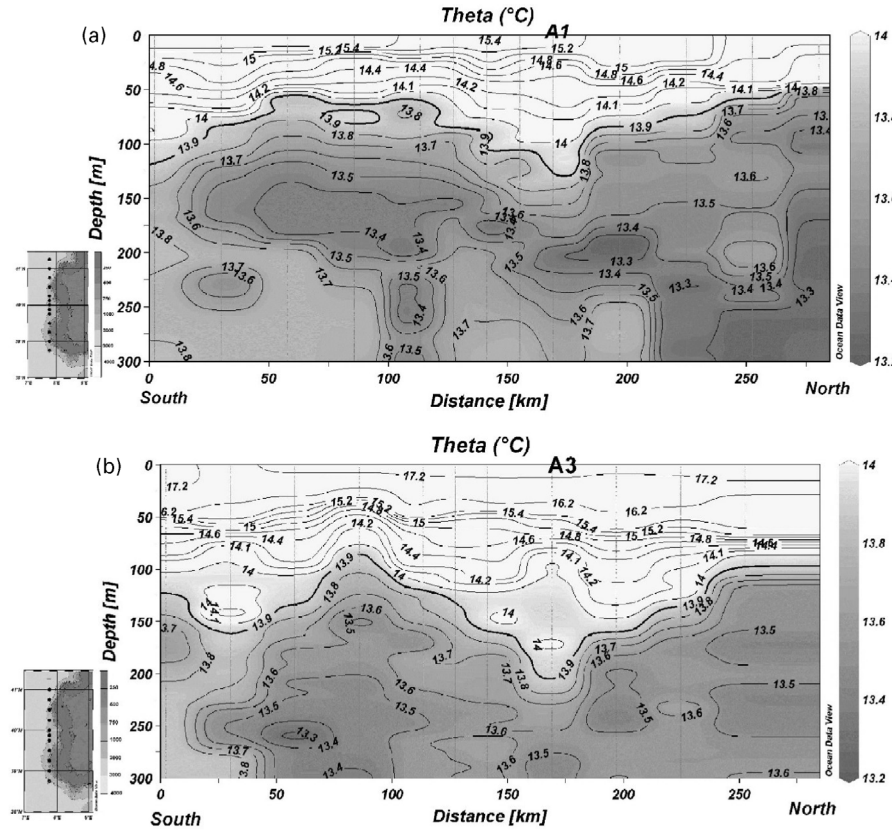

FIGURE 10 Intermediate south–north section of potential temperature for (a) MedGOOS 2 in March–April 2001 and (b) MedGOOS 4 in May 2002.

especially along the part of coast oriented NW–SE (40° N–40° 45′ N). At the same time, a significant vertical inversion in salinity occurred in the first 30–50 m of depth and varied from −0.2 to −0.5 over the entire sampling field: the cross-shore transect near 39° 60′ N (Figure 12). Consequently, the water upwelled from a depth of 30–40 m to the surface close to the coast and induced a lower surface salinity there (37.80–37.90) than offshore (37.90–38.0), in contrast to a classical upwelling.

Some similar seasonal vertical inversions have been reported by Lacombe and Tchernia (1972) and are expected to be less evident eastward. They are attributed to an increase in the surface salinity due to water evaporation during a period of stratification. Such an inversion was also observed in the vicinity of AEs in July 1997 and 1998 (Taupier-Letage *et al.*, 2003). Nevertheless, the vertical inversions observed in open sea AEs were lower: −0.2 in 25 m. This led us to look for an additional process. According to the surface salinity distribution on Figure 6a (MedGOOS 2), salinity can be significantly greater on the shelf than on the slope or offshore where AEs often brought recent AW from the Algerian current. Nevertheless, this recent AW can come locally on the shelf as was the case with A3 (Figure 6b, MedGOOS 4). As for MedGOOS 3, no AE was observed on or close to the shelf: the surface salinity should be greater over the shelf than offshore. In addition, freshwater input is especially low in summer over the Sardinian shelf. Thus, according to the wind-induced Ekman transport, we speculate that NW winds

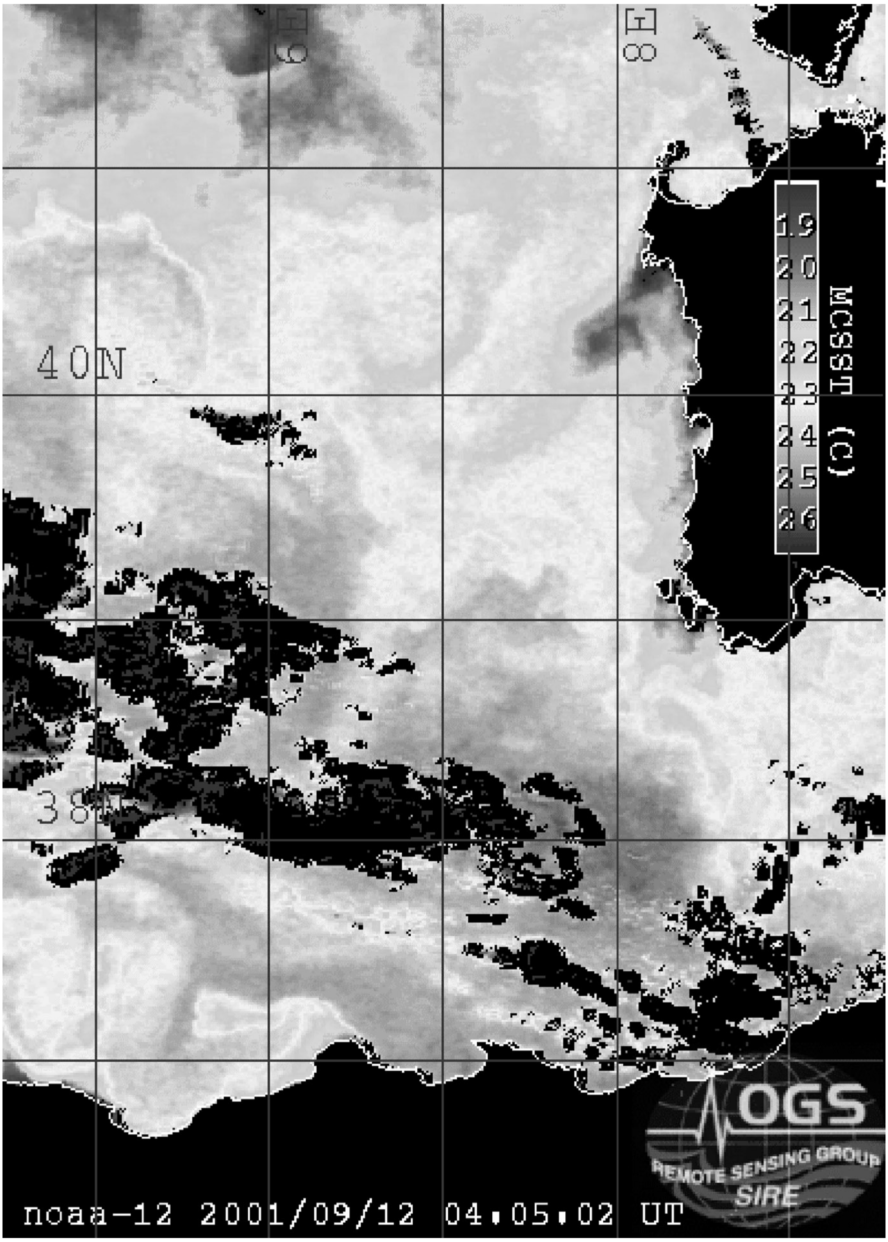

FIGURE 11 NOAA/AVHRR SST images of the 12/09/2002 at 04 h 05 (UTC), by courtesy of the Remote Sensing Group (SIRE) of OGS, Trieste, Italy.

could have pushed this saltier coastal water offshore. However, this water must be warm enough to be less dense than the more recent offshore AW to overlay it. In addition, wind has to transport the coastal water over a relatively long distance. Consequently, a more in-depth study is needed, including thermal exchanges between air and sea in the area. A numerical process study would also help. Therefore, this remains an open subject for further investigation.

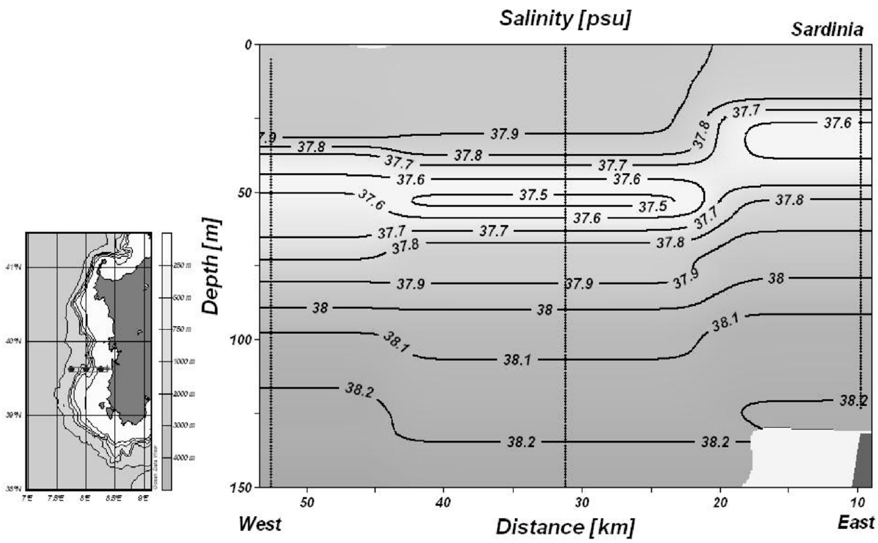

FIGURE 12 East–west vertical salinity section at 39° 60′ N during MedGOOS 3 (September 2002). The contour interval of the isohalines is 0.1 psu.

4 CONCLUSION

Five oceanographic cruises were organized in the Sardinian Sea and Channel in May 2000, March 2001, September 2001, May 2002 and November 2002 to study the hydrodynamics of these regions. The analysis of the gathered hydrological data allowed us to characterize the surface water masses and their variability due to the mesoscale activity in the two regions.

During two of those five cruises, the Sardinian Channel was crossed from north to south in May 2000 and the reverse in November 2003. During May 2000, one AE was observed along the Tunisian coast. This induced a greater minimum salinity in a layer which was wider and deeper than in November 2003, when no AE was observed there. Some WIW was observed below this AE, but no link could be established between AEs and WIW occurrences. WIW occurrence was probably due to the interannual variability of its formation.

Similarly, in the Sardinian Sea, two AEs were observed during spring 2001 and two others in spring 2002. The way they influenced the surface circulation varied. In spring 2002, one AE was centred on the slope and strongly disturbed the shelf circulation by bringing recent AW. This was not the case for other AEs observed. Also, the shelf circulation can be strongly driven by wind, which is mostly N or NW (Bocchini *et al.*, 1991). Indeed, an upwelling was observed over the sampling field in September 2001 during a W–NW wind event. This upwelling persisted at least 5 d according to the mean W–NW wind duration. At the same time, a vertical salinity inversion occurred in the first 30–50 m of depth over the whole sampling field. This upwelling reduced the salinity from a depth of ~30–40 m to the surface and caused the salinity to be lower on the coast than offshore. This was in contrast to a classical upwelling.

Below the AW, the WIW was observed in the Sardinian Sea, but not in a permanent and well-defined layer. It was patchier in spring 2002 than in spring 2001. This could be due to the mesoscale variability which was affected by AEs, as well as to the interannual variability of WIW formation.

Consequently, the Sardinian Sea is strongly influenced by the general mesoscale circulation (mainly characterized by AEs) and episodically influenced by wind-induced advection of coastal water.

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