Water mass characteristics in the deep layers of the western Ionian Basin observed during May 2003

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Received 28 November 2005; revised 2 February 2006; accepted 7 February 2006; published 9 March 2006.

[1] CTD measurements carried out in the southern Adriatic Sea and in the western Ionian basin (Eurafrican Mediterranean Sea) during May 2003 by the German research vessel Poseidon (Poseidon cruise 298) and numerical simulations are used to elucidate aspects of the abyssal circulation of this oceanic region. The observations reveal that dense waters of Adriatic origin were strongly diluted along their way on the Italian continental slope, whilst their characteristics remained better preserved in a region located further east. Numerical simulations carried out by means of a nonlinear, reduced-gravity plume model confirm the observations and contribute to explain their cause: The very steep topographic slope along the Italian shelf in the region of the Gulf of Taranto induces strong entrainment of intermediate waters in the bottom layers. Instead, the bottom waters of Adriatic origin which, along their path further east, encounter gentler topographic variations, are weakly diluted by turbulent mixing and, therefore, better preserve their original characteristics. The remarkable differences in the simulated turbulent mixing along these two different paths are accentuated by the presence of a noticeable zonal gradient of potential density existing in the near-bottom layers of the northern Ionian basin. Citation: Hainbucher, D., A. Rubino, and B. Klein (2006), Water mass characteristics in the deep layers of the western Ionian Basin observed during May 2003, Geophys. Res. Lett., 33, L05608, doi:10.1029/2005GL025318.

1. Introduction

[2] Bottom-arrested currents represent a significant mechanism for the export of dense water masses produced by oceanic convection, the process which sets and maintains the abyssal circulation of the world ocean [see, e.g., Jungclaus and Backhaus, 1994; Rubino et al., 2003]. Such currents, which are deeply influenced by earth rotation, are substantially constrained by the underlying bathymetric features and are mainly forced by their excess of weight, which results from the density contrast with the overlying water [Jungclaus and Backhaus, 1994; Rubino et al., 2003]. Current penetration depth, velocity structure, and rate of mixing for a given oceanic region are determined by these parameters, as well as by the interaction with dynamical features of the upper ocean.

[3] This implies that, in oceanic regions without extremely pronounced bathymetric constrictions like, for example, under-water channels or canyons, long-term oceanic and/or atmosphericspheric variations affecting the production (rate and characteristics) of dense water could cause substantial variations in the pathways of the resulting bottom-arrested currents and thus significantly influence the export of newly formed dense water.

[4] In the Adriatic Sea dense waters are formed during wintertime and are then exported by means of bottom-arrested currents toward the abyssal layers of the Ionian basin [see, e.g., Zore-Armanda, 1974; Malanotte-Rizzoli et al., 1997; Bignami et al., 1990]. Before the “Transient”, a major climatic variation of the eastern Mediterranean, which affected the whole deep circulation in the Ionian basin [Roether et al., 1996; Klein et al., 1999], waters of Adriatic origin occupied the deepest part of the Ionian abyssal plain. During the Transient the cold and relatively fresh Adriatic Deep Water (ADW) was replaced by the substantially warmer and saltier water of the Levantine basin in the bottom layers of the Ionian Sea [Klein et al., 1999]. Among the different variations in the hydrologic structure of the Ionian basin, brought by the Transient, there exists a reverse of the zonal gradient of potential density in the deep layers of the northern Ionian basin [Manca et al., 2003].

[5] There has been intensive hydrographic activity in the Adriatic and Ionian since 1990 in programs as POEM (Physical Oceanography of the Eastern Mediterranean), MATER (Mass Transfer and Ecosystem response) and Sinapsi (Seasonal, Interannual and decadal variability of the atmosphere and ocean and related marine ecosystems) [see, e.g., Manca et al., 2002].

[6] In this paper we report on CTD measurements carried out in the deep layers of the southern Adriatic Sea and of the western Ionian Basin. The data results from a cruise with the German research vessel Poseidon (Poseidon cruise 298, May 2003). From the observations, it emerges that dense waters of Adriatic origin were strongly diluted along their way on the Italian continental slope, whilst their characteristics were found to be better preserved further east. A numerical, nonlinear, reduced-gravity plume model was implemented to elucidate these findings. The model simulations reveal that bottom Adriatic water can follow different paths toward the Ionian abyssal plain. Whilst the very steep topographic slope along the Italian shelf in the region of the Gulf of Taranto induces strong entrainment in the bottom layers, the bottom water flowing further east encounters gentler topographic variations and is thus diluted in a less strong extent. The remarkable differences in the simulated turbulent mixing along these two different paths are accentuated by the presence of a noticeable zonal gradient of potential density existing in the near-bottom layers of the northern Ionian basin.

2. Discussion

[7] During May 2003, in the frame of Poseidon cruise 298 we carried out oceanographic measurements in the

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southern Adriatic and western Ionian Sea in order to investigate the local water mass characteristics of the deep layers and their transformations, especially along the Italian continental shelf. The aim was to follow one or more veins of waters of Adriatic origin flowing as nearly geostrophic adjusted, bottom-arrested currents toward the abyssal plain of the Ionian basin, along the Italian continental shelf. Therefore, the stations had been planned to cover the shelf edge along the Italian coast (Figure 1). On all stations a Seabird CTD coupled with a rosette water sampler was used to obtain water samples for salinity, temperature and oxygen calibration. Additionally, a lowered ADCP was deployed together with the CTD and the shipboard ADCP was collecting data during the whole cruise. The following discussion is based on the data gained with the CTD only.

In the southern part of the Adriatic Sea cold, relatively fresh Adriatic Deep Water (ADW) was clearly recognized at the bottom (Figure 2). Instead, we were not able to identify this water mass further south along the Italian continental shelf. There, the bottom water was significantly warmer and more saline. Figures 3 and 4 show the distri-

Figure 1. Area of investigation. Dots mark the stations occupied during Poseidon cruise 298/leg 1 and leg 2 (May 2003).

Figure 2. TS-diagram of the stations in the southern Adriatic Sea. The data is taken from Poseidon cruise 298/leg 1 (May 2003).

Figure 3. Bottom distribution of temperature, salinity, oxygen and fraction of ADW. ADW is assumed to have a temperature of 13.09°C and a salinity of 38.66. Both values have been determined from profiles of stations in the southern Adriatic Sea taken during Poseidon cruise 298 (May 2003).

Figure 4. Bottom distribution of $\sigma_\theta$. The data is taken from observations of Poseidon cruise 298/leg 2.
bution of the measured water mass characteristics at the bottom. In particular, the temperature, salinity and density distributions encountered on the Italian continental slope identify a bottom distribution similar to that reported by Sellschopp and Alvarez [2003], who ascribed the absence of ADW in the bottom layers along the Italian shelf of the northern Ionian basin to vigorous mixing occurring in the regions of sharp topographic variations in the area of the Gulf of Taranto. In particular, they found that waters of Adriatic origin flowing southward along the Italian shelf were absorbed by mixing at intermediate depth during a mild winter, but they survived as bottom-arrested currents and possibly reached the Ionian abyssal basin during a cold winter. In our data, however, a core of better oxygenated, colder and less saline water ($\sigma_0 = 29.194$), whose characteristics are close to those of ADW is still present in the central Ionian basin. Such observations strengthen the hypothesis of Malanotte-Rizzi et al. [1997], who suggested a second path for ADW along the eastern side of the northern Ionian basin. Note also, that during Poseidon cruise 298 the highest potential density ($\sigma_0 = 29.196$) was found north of the central Ionian basin. Its origin in the Adrianic basin seems improbable, as its salinity and temperature were higher than those characterizing ADW.

[9] In order to verify our hypothesis suggesting that different paths for the southward spreading of ADW exist which are characterized by different entrainment rates, we performed numerical simulations using a nonlinear, reduced-gravity plume model. The model is described in detail by Jungclaus and Backhaus [1994] and Rubino et al. [2003]. In this model the only active layer is the bottom layer, which, due to a simple entrainment parameterisation, can entrain prescribed ambient water over complex bathymetric features. Due to this simplified structure, a very high spatial resolution can be reached. In our case the grid step was 1 km. The bathymetric data was obtained by interpolating the data of ETOPO2 [Smith and Sandwell, 1997]. In the simulations, a constant rate of ADW production ($0.6 \text{ Sv} \left(1 \text{ Sv} = 10^{6} \text{ m}^{3} \cdot \text{s}^{-1}\right)$ at the constant potential density $\sigma_0 = 29.21$) was prescribed in the northern part of the South Adriatic Pit by including a source term in the model continuity equation. Thus, in that area, the difference between simulated and observed density was prescribed to be minimum.

[10] Near the bottom, the ambient density structure was determined by interpolating the near bottom density data of Levitus [1982]. Moreover, from this data set a vertical density gradient was defined, which was used to determine the density difference of the ambient water located between the top of the descending bottom-arrested current and the bottom. Figure 5 shows the area where the simulated bottom plume is characterized by $\sigma_0 \geq 29.194$ (i.e., the part of the plume having density values corresponding to the observed core of ADW), after 270 simulated days. Note that a considerably longer simulation duration (which would result in a further southward spreading of the bottom layer) would imply the additional consideration of intraseasonal or even interannual variability in the source of Adriatic water, which is beyond the scope of our paper.

[11] The simulation evidences that the ADW bottom vein flows toward the abyssal plain of the Ionian basin following different paths. The flow along the Italian coast is characterised by very pronounced mixing, with the consequence that virtually no flow of ADW denser than $\sigma_0 = 29.194$ is able to escape the Gulf of Taranto. The complex flow along the eastern part of the Ionian basin, instead, is affected by mixing to a lesser extent, and, thus, it better preserves its original characteristics. Thus, in our numerical simulations, bottom water masses with characteristics closest to ADW are found in the eastern rather than in the western part of the Ionian basin. In the absence of entrainment, the situation would have been completely different. In Figure 5 we present also the paths of different tracers, located initially within the bottom current at the Strait of Otranto, after 150 simulated days of a run carried out without including entrainment. In this case, obviously, the whole bottom current preserves its original density, as no dilution processes are considered. It flows southward following exclusively the route along the Italian shelf. Such a different behaviour in the two simulations can be clearly explained by the fact that entrainment acts as a further friction term and decreases the density contrast between bottom current and overlying fluid; this considerably enhances the ageostrophic flow behaviour [see, e.g., Smith, 1975; Jungclaus and Backhaus, 1994]. Note also that the obtained results are not substantially affected by small variations in ADW production, entrainment rate, and friction coefficient: a sensitivity study performed varying the values of these parameters confirmed the robustness of the descending path along the Italian shelf, which is characterised by strong mixing, and confirmed also the robustness of the descending path further east, characterized by weaker mixing. These differences in the simulated mixing are accentuated by the presence of a zonal gradient of potential density in the bottom layers of the northern Ionian basin: since the Transient the values of near-bottom potential density increase eastward. This contributes to generate a stronger dilution of the waters of Adriatic origin in the western
rather than in the eastern part of the northern Ionian basin [Manca et al., 2003].

3. Conclusion

In accordance with previous observations [Sellschopp and Alvarez, 2003] our investigation identifies intense mixing occurring in the region of sharp topographic variations within the Gulf of Taranto as responsible for the strong dilution of the ADW observed in the western part of the Ionian basin. It also identifies a second path for the southern spreading of ADW, located further east, where smaller mixing is observed. Our results suggest that the flow of ADW along this path may be responsible for the core of ADW encountered in the eastern part of the Ionian basin. The gross features of the observed characteristics of both paths are explained by our numerical simulations carried out by means of a nonlinear plume model. The simulations indicate that, in the area of the Gulf of Taranto, vigorous mixing induced by the sharp topographic variations existing there is responsible for a noticeable dilution of ADW. Along a second path further east, gentler topographic variations are encountered, which yields a better preservation of the ADW characteristics there. Obviously, using such a numerical model, we did not intend to address the whole complexity of the near-bottom dynamics in that region: we just used the model to corroborate our conjecture based on previous work and on our observations. As the bottom waters present in the region are characterized by density fields confined in a rather narrow range, different scenarios are not excluded: It is possible indeed that, during “very cold” years (during which, e.g., denser water is produced in the Adriatic basin than the one we observed), both paths may contribute to form the deep waters of the abyssal plain of the central Ionian basin (see also the discussion by Sellschopp and Alvarez [2003]). In this case, however, water entrainment (to which determination the density contrast between bottom current and overlying ambient water fundamentally contributes) seems still to constitute the major control of the pathway of dense water descending on the slope. This mechanism is capable of explaining the observed concomitant disappearance of bottom waters of Adriatic origin on the Italian shelf and its presence further east.

More realistic numerical simulations could contribute to assess the magnitude of possible variations in the bottom and intermediate water mass distributions due to climatic variations affecting the convective activity in the Adriatic basin.

References


