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Dense-water bottom currents in the Southern Adriatic Sea in spring 2012

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ABSTRACT

In February 2012, a severe cold spell in the European region triggered a massive production of very dense water on the northern Mediterranean Sea shelves. The spreading phase of the newly formed dense water was extensively studied in the Adriatic Sea by means of 2 ship surveys and 5 moorings fully equipped to monitor the flow of the bottom layer. For the Adriatic Sea, opposite to the Gulf of Lions, the area of cascading is far from the source area and this implies substantial modifications, adjustments and dilution of the source water mass along its path, with a spreading phase lasting several months. Indeed all the moorings detected events, although weaker than in the preceding months, until June 2012. The surveys detected 2 branches of NAdDW on the shelf, the first branch not denser than 29.7 kg/m^3 and the second branch not denser than 29.5 kg/m^3. Despite the extremely dense water generated in the Northern Adriatic, during events of dense-water flow, moorings recorded temperatures generally between 12.5 and 13 °C, seldom less. Temperatures along the shelf break also did not fall below 13 °C at depths greater than 400 m. Turbulent mixing, therefore, heavily modified the cascading plumes, which left the shelf with thicknesses between 10 and 30 m. Mooring data in the lowermost 100 mab suggest that the thickness of the cascading layer increased by several tens of meters downslope, as a consequence of entrainment. Detraining frictional layers as well as locations of active cascading were identified mostly by isolated casts, highlighting the submesoscale domain of the downsloping plumes. The use of LADCP data allowed identification of very energetic bottom flow (40–50 cm/s in many locations), with otherwise little signature in tracers, not previously observed. The Bari Canyon System (BCS) was so far recognized as a hot spot for cascading in the Southern Adriatic. However, during the 2012 event, this is not the only preferred site for cascading. Significant dense flow was detected in other locations. The northernmost mooring site, closer to the inception of the cascading process, in particular showed active cascading and several dynamical differences from the BCS: denser water with thinner boundary layer, events organized in multiple pulses with sub-inertial periodicity and with very short duration (12 h to 1 day) that is generally not seen in other locations.

1. Introduction

The shallow and broad continental shelf of the Northern Adriatic is one of the shelves of the northern Mediterranean Sea known to be prone to dense shelf water production (Hendershott and Rizzoli, 1976; Artegiani and Salusti, 1987; Artegiani et al., 1989, Vilibić and Supić, 2005). Intense winter cooling and evaporation, associated with dry and cold north-easterlies (Bora winds), favors the production of a water mass known as Northern Adriatic Dense Water (NAdDW). The process of generation is principally temperature driven (Shapiro et al., 2003), although lateral advection of salinity from the Southern Adriatic, as well as the freshwater discharge from rivers along the coast, do have an impact in the preconditioning phase in assisting or limiting the production.

The newly generated dense water moves southward along the isobaths of the Italian continental shelf and slope as a buoyancy driven current. If dense enough, a portion of the water mass fills the Jabuka Pit, a 270 m deep depression where NadDW accumulates, eventually flushing lighter and older water masses (Bergamasco et al., 1999; Vilibić and Supić, 2005; Marini et al., 2016–in this issue). Usually after 2–4 months (Vilibić and Orlić 2002), the buoyancy current travelling along the Italian shelf reaches the Southern Adriatic, where it sinks through successive cascading events. A known site for cascading events is the Bari Canyon System (BCS), as anticipated by pioneer works in the '80s (e.g., Bignami et al. 1990a, 1990b) and recently observed during a dedicated field study (e.g., Turchetto et al., 2007). While descending the slope, the plume entrains Levantine Intermediate Water (LIW), becoming warmer and saltier. The cascading process plays a relevant role in biogeochemical cycles (Shapiro et al., 2003), as cascading NAdDW

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ventilates the intermediate and abyssal layers of the Southern Adriatic and sustains transport of particles and organic matter (Turchetto et al., 2007; Tesi et al., 2008; Cantoni et al., 2016–in this issue; Langone et al., 2016–in this issue; Taviani et al., 2016–in this issue). Despite the biogeochemical relevance, due to inherent difficulties in observing cascading events, there are still open issues not fully addressed by sporadic shipborne surveys. While waiting for a distributed network of moving platforms to allow for high-resolution monitoring of the flow of dense water (e.g., Vilibić and Mihanovic´, 2013), recently the scientific community concentrated efforts on moorings to monitor the flow of dense water in various key areas of the Southern Adriatic (e.g., Bensi et al. 2013; Turchetto et al., 2007; Langone et al., 2016–in this issue).

In February 2012, the European region experienced a 2-week severe cold spell, sustained by a large Siberian high and associated blocking of the Atlantic flow. This synoptic configuration allowed for retrogression of westward flow of dry and cold arctic air masses from eastern Russia along the southern flank of the anticyclone all the way to Europe, causing temperature as low as −40 °C in northeastern Europe and −10° to −20 °C in central Europe, with significant snowfall in southern Europe associated with deep lows in the Mediterranean Sea (Grazzini, 2013). The Northern Adriatic was heavily impacted by this cold spell, which caused large decrease of surface temperature and the onset of severe northeasterly Bora winds (see Fig. 2(b) in Raicich et al., 2013), blowing almost continuously and intermittently reinforced by cyclogenesis in the western Mediterranean. A significant heat loss took place in the basin, inducing water temperature as low as 4 °C and potential density anomaly of 30.6 kg/m^3 (Mihanovic et al., 2013). Raicich et al. (2013) computed the ratio between temperature-induced and salinity-induced buoyancy loss by air–sea interaction during the event in the Gulf of Trieste (North-eastern Adriatic), with the former roughly three times larger than the latter, supporting the general idea of temperature-controlled dense-water production in the Northern Adriatic. Yet, the not-negligible evaporation during the event (Raicich et al., 2013) and dry atmospheric conditions with consequent lower-than-usual river discharge in the preceding months (Mihanović et al., 2013; Janeković et al., 2014) did contribute to exceptional seawater density. Also other shelves of the Mediterranean Sea experienced a massive production of dense water in February 2012 (e.g., Gulf of Lions; Durrieu de Madron, 2013), although with potential density anomaly values (29.7 kg/m^3) not as large as in the Northern Adriatic Sea.

Following this severe winter 2012 cold outbreak in the northern Adriatic, CNR-ISMAR set up two rapid-response cruises to study the occurrence, amount, timing and properties of the newly formed dense water, aiming at characterizing the vertical structure and spatiotemporal variability of the benthic layer and its modification during down-flowing regimes. The Southern Adriatic was therefore extensively sampled by the R/V Minerva Uno (leg 1, 23 March–2 April 2012) and R/V Urania (leg 2, 14–20 April 2012) with CTD-rosettes equipped with additional sensors for fluorescence, dissolved oxygen, Lowered Acoustic Doppler Current Profilers (LADCP) as well as ship-borne ADCP and XBTs. In addition to the 3D snapshot carried out during the surveys, five moorings continuously measured temperature, salinity, currents and downward particle fluxes by means of SBEs, ADCPs and automatic sediment traps. Mooring locations were carefully chosen based on depositional and erosional features suggestive of intense bottom flow (Foglini et al., 2016–in this issue) and key areas identified by means of numerical ocean-model experiments.

2. Data

Two cruises were carried out to monitor dense-water flow in the Southern Adriatic (Fig. 1), in late March and mid-April, respectively,

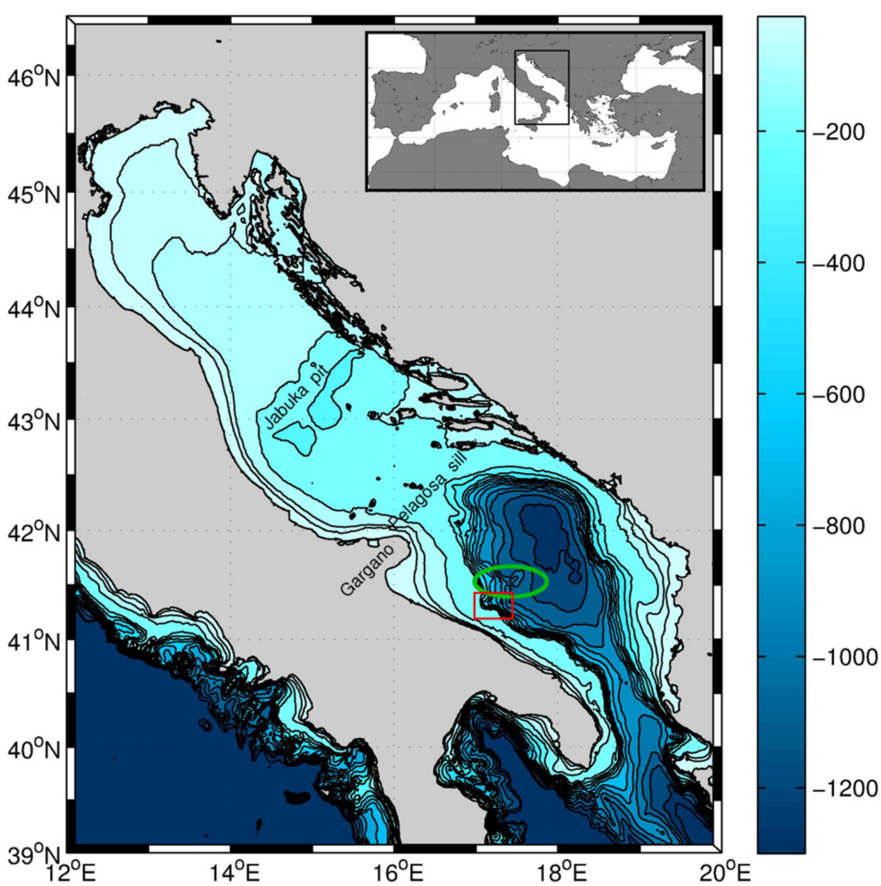

Fig. 1. Adriatic Sea bathymetry (color, m). The red box indicates the location of the Bari Canyon System and the green circle is the Gondola Slide. In the upper right panel is the Mediterranean Sea with the square indicating the Adriatic Sea.