Comments on “Cascades of dense water around the world ocean”

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Abstract

Evidences of temperature-controlled dense water cascading off the Gulf of Lion shelf, in the northwestern Mediterranean, and several Aegean shelves in the northeastern Mediterranean are reported. Together with the Adriatic shelf, already listed by Ivanov, Shapiro, Huthnance, Aleynik, & Golovin (2004), these zones represent the major coastal areas of the Mediterranean Sea where dense water is produced.

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1. Introduction

In a recent comprehensive study, Ivanov, Shapiro, Huthnance, Aleynik, and Golovin (2004) itemized 61 sites of dense water formation and cascading off continental shelves around the world. For the Mediterranean Sea, a mid-latitude semi-enclosed sea, they showed evidence of cascading off the Adriatic shelf and reported possible cascading off the Ebro shelf. However, they omit to mention a couple of sites that also exhibit such a process; namely the Gulf of Lion shelf in the northwestern Mediterranean and various shelves in the Aegean Sea. This note aims at complementing their inventory.

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2. General setting

Wintry heat losses as well as evaporation – caused by cold and dry northerly winds – induce cooling and mixing of the coastal waters of the northern Mediterranean shelves (Fig. 1(a)). Despite the gain of buoyancy induced by fresh or brackish water inputs (the Rhone for the Gulf of Lion and the Po for the Adriatic are the largest Mediterranean rivers; the Dardanelles Strait supplies large amounts of Black Sea water to the North Aegean), cold shallow waters eventually get denser than the surrounding waters and sink. After traveling on the shelf, they flow down the continental slope until they reach their equilibrium (neutral density contrast) level.

3. Gulf of Lion

The Gulf of Lion (Fig. 1(b)) has a large flat outer shelf and a steep slope cut by numerous canyons that favour exchanges with the open ocean. Bougis and Ruivo (1954) first showed the formation of dense water along the south-western coast and their cascading at the slope. During the winters 1969 and 1971, Fieux
(1974) and Person (1974) traced dense water cascading in the Lacaze–Duthiers canyon down to 800 and 350 m, respectively.

Further evidence was gained during winter 1995 by Lapouyade and Durrieu de Madron (2001) at the same location; they observed a cascade at its final stage with a large tongue of cold water escaping the shelf and reaching its neutral density level around 170 m depth (Fig. 2). A recent high spatial resolution survey performed in 2004 along the axis of the Cap Creus Canyon (Fig. 3) shows a cold and less saline filament, attached to the seabed, down to 350 m. The section exhibits a transitional case, as the leading edge has not reached the neutral density level, between 400 and 500 m. In both cases, the advection of turbid shelf waters produces a turbidity maximum associated to the dense water tongue. Dufau-Julliand, Marsaleix, Petrenko, and Dekeyser (2004) showed for the winter 1998–1999 that dense water formation occurred on the whole shelf; the plume spread over the western part of the shelf and finally escaped at its south-western end.

Fig. 2. Density (solid lines) and temperature and salinity distribution (shaded areas) along the Lacaze–Duthiers Canyon section on the 10th February 1995. See Fig. 1(b) for location of section.
In all cases, the contribution of temperature versus salinity contrasts to density contrast between the dense water on the shelf and the ambient slope water ($\alpha \Delta T / \beta \Delta S > 1$) confirms that temperature is the sole driver of cascading (negative salinity contrast hinders cascading). When dense waters escape the shelf and spread around the shelf break depth (150–200 m), they form the so called winter intermediate water with typical properties $T = 12.5^\circ \text{C}$, $S = 38.0$. In the case of dense shelf waters cascading to deeper levels, they eventually mix with the warmer and saltier levantine intermediate water layer ($T = 13.2^\circ \text{C}$, $S = 38.5$) that extends between 200 and 1000 m depth, or with the underlying Western Mediterranean Deep Water.

The monitoring of temperature and current conducted since 1993 in the lower part of the Lacaze-Duthiers canyon (mooring location in Fig. 1(b)) reveals an interannual variation of the shelf water
overflow intensity (Fig. 4). Béthoux, Durrieu de Madron, Nyffeler, and Tailliez (2002) inferred that during the abnormally cold 1998–1999 winter, the intense shelf cascading contributed to the renewal of the bottom waters of the deep Western Mediterranean Basin. This event, which lasted one month, was traced at 1000 m depth on the continental slope and had down-slope velocities of up to 60 cm s$^{-1}$.

4. Aegean shelves

The Aegean Sea has been recognized as one of the regions of dense water formation since the earliest oceanographic studies of the Mediterranean Sea (El-Gindy & El-Din, 1986; Lacombe, Tcherinia, & Benoist, 1958; Miller, 1974; Nielsen, 1912; Plakhin, 1971, 1972; Schott, 1915). The complexity of the Aegean Sea’s geometry and sea-bottom topography suggests that there are several wide shelves where the formation of dense water may take place (Fig. 1(c)). The shelves of the Samothraki Plateau and Thermaikos Gulf are exposed to very cold and dry northerlies from the Balkans (May, 1982; Poulos, Drakopoulos, & Collins, 1997). However, the low-salinity surface layer originating in the Black Sea outflow through the Dardanelle Strait plays an insulating role, hindering dense water formation processes in the regions north and northwest of the island of Lemnos (Zervakis, Georgopoulos, & Drakopoulos, 2000); dense water formation over the Samothraki Plateau seems to be largely controlled by the thickness of the surface low-salinity layer and thus shows high inter-annual variability (Zervakis, Krasakopoulou, Georgopoulos, & Souvermezoglou, 2003). On the contrary, the northward flow of waters of Levantine origin advects salt into the Southern and Central Aegean Sea, thus favouring dense water formation over the Cyclades (Theocharis, Balopoulos, Kioroglou, Kontoyiannis, & Iona, 1999) and Lemnos Plateau (Georgopoulos, Salusti, & Theocharis, 1992).

Direct evidence of Aegean Sea dense water formation over the Samothraki and Lemnos plateau in 1987 was reported for the first time by Gertman, Ovchinnikov, and Popov (1990) and Theocharis and Georgopoulos (1993). During the same year, dense water formation was also witnessed over the Cyclades Plateau (Fig. 5). The dense plume was recorded immediately after the passage of an extreme cold surge over the Aegean Sea (Lagouvardos, Kotroni, & Kallos, 1998), which caused massive dense water
formation over the whole Central and Northern Aegean Sea (Zervakis et al., 2000). In Fig. 5, temperature appears as the controlling parameter of the dense water formation process, whereas the high salinity over the plateau clearly played a preconditioning role. The cascading is at an early stage, as defined by Ivanov et al. (2004).

Finally, recent data from the Thermaikos Gulf collected in February 2002 (Fig. 6) present a clear signature of a mature event of dense water formation over the inner Thermaikos Gulf, recorded as a dense water plume flowing toward the South (V. Zervakis, unpublished data). Here, the density of the current is clearly controlled by temperature. The convection event was preceded by persistent strong northerlies during December 2001 and January 2002. Current-meter measurements of the near-bed density current at 60-m depth revealed that the southward flow of the newly formed waters lasted about two months, and had a mean velocity of $9 \pm 4$ cm s$^{-1}$. 

Fig. 5. Density (solid lines) and temperature and salinity distribution (shaded areas) across the Cyclades plateau on the 16–17th March 1987. See Fig. 1(c) for location of section.
5. Conclusion

The Adriatic Shelf, listed by Ivanov et al. (2004), the Gulf of Lion and the Aegean Shelves are the major sites in the Mediterranean Sea where dense water is produced on the shelf. Together with open sea convection, shelf production in the above sites contributes to intermediate and occasionally deep waters, thus providing the engine to the Mediterranean thermohaline circulation.

References


