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Particle fluxes induced by benthic storms during the 2012 dense shelf water cascading and open sea convection period in the northwestern Mediterranean basin

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ABSTRACT

The effects of deep dense shelf water cascading and open sea convection on the sediment dynamics of the northwestern Mediterranean basin were studied by near-bottom moored instruments recording trapped particle fluxes, suspended particle fluxes, water properties and hydrodynamics from November 2011 to July 2012. During this period, near-bottom currents induced by winter dense water formation generated benthic storms that caused resuspension at 2450 m water depth, increasing by more than one order of magnitude the ambient suspended sediment concentrations, the trapped particle fluxes and the suspended sediment fluxes. During the preconditioning phase of the open sea convection, from December 2011 to mid-February 2012, currents (1–10 cm s^{-1}), suspended sediment concentrations (< 0.1 mg l^{-1}), Chl-a fluorescence values (< 0.063 µg l^{-1}), trapped total mass fluxes (10–50 mg m^{-2} d^{-1}) and trapped organic carbon fluxes (1–4 mg m^{-2} d^{-1}) were low, and organic matter was mainly undegraded and of marine origin. Open sea convection was observed at the study site in mid-February, at the beginning of the violent mixing phase, increasing current velocities up to 26 cm s^{-1} and Chl-a fluorescence values up to 0.074 µg l^{-1}, supplying particles with fresh marine organic matter content. During the last fortnight of February, two major dense shelf water cascading pulses generated Chl-a fluorescence increases (up to 0.116 µg l^{-1}) and large suspended sediment concentration peaks (up to19 mg l^{-1}), suspended sediment fluxes (up to 6500 mg m^{-2} d^{-1}) and trapped total mass flux increases (up to 22,900 mg m^{-2} d^{-1}), which were associated with benthic storms resuspension. During this phase, trapped organic carbon flux increased almost two orders of magnitude (up to 260 mg m^{-2} d^{-1}), with pulses of both marine and terrestrial organic matter. The sinking and spreading phase occurred from early March to mid-June. The signal of deep dense shelf water cascading lasted past early April, and the spreading of the newly formed dense water maintained maximum currents of up to 25 cm s^{-1} and trapped particle fluxes of up to 2000 mg m^{-2} d^{-1} until mid-June. At the beginning of this phase, organic matter was terrestrial and several turbidity peaks occurred during current speed increases generated by benthic storms. At the end of this phase, the organic matter became less terrestrial, trapped organic carbon fluxes decreased from about 190 to 10 mg m^{-2} d^{-1} and turbidity peaks occurred with low current velocities indicating the arrival of storm tails at the mooring site. The large particle fluxes of fresh or relatively undegraded organic carbon induced by deep dense water formation during winter 2012, contributed to the "fertilization" of the northwestern Mediterranean deep benthic ecosystems.

1. Introduction

In the northwestern Mediterranean, dense water formation is produced by surface cooling and evaporation in wintertime due to cold and dry northerly (Mistral) and northwesterly (Tramontane) winds, which cause strong densification and homogenization of the surface-water column (MEDOC group, 1970; Millot, 1990; Durrieu de Madron et al., 2005). This phenomenon occurs both in coastal waters on the Gulf of Lions, causing dense shelf water cascading (DSWC) and on the central part of the northwestern Mediterranean basin, causing open sea convection (OSC). The amount of dense waters formed in each region and their characteristics show a high interannual variability depending on the wind intensity and persistence, on the freshwater inputs preventing DSWC and also on the preconditioning of the water column (Estournel et al., 2003; L'Heveder et al., 2013).

It is well known that in the northwestern Mediterranean OSC occurs

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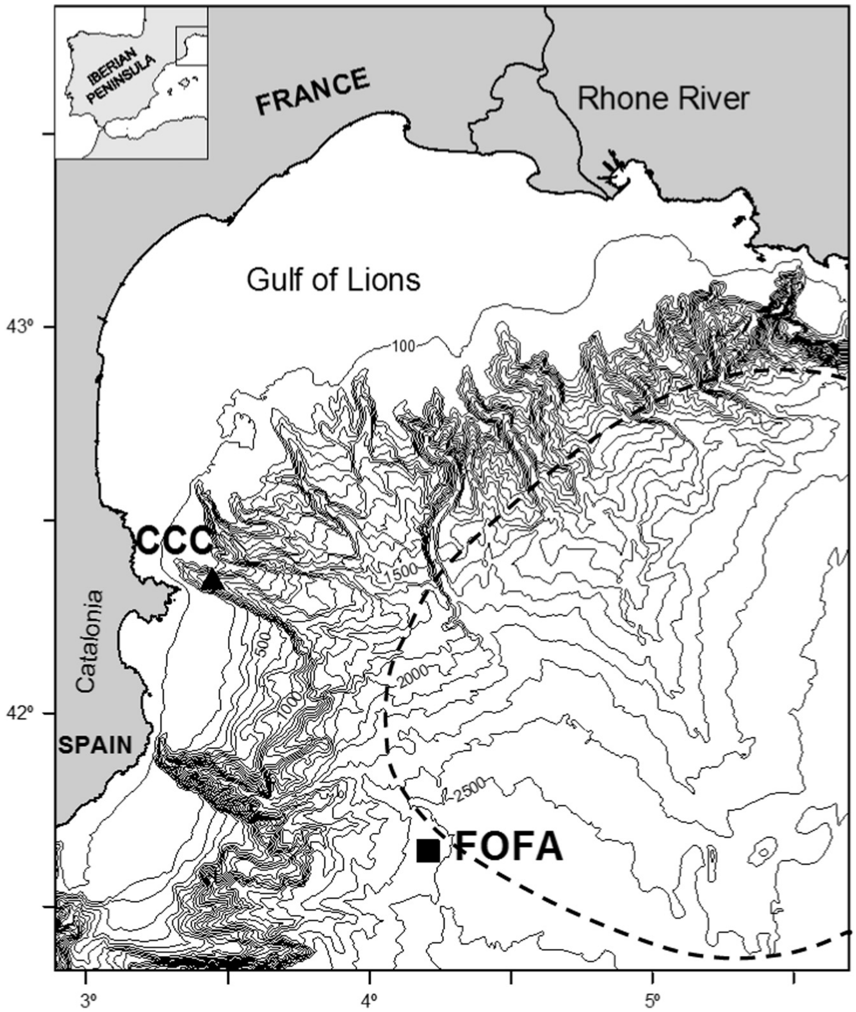

Fig. 1. General bathymetric map of the Gulf of Lions and the northern Catalan Sea, showing the location of the FOFA and the Cap de Creus Canyon (CCC) sites where moorings were deployed. The dashed line shows the area of deep Open-Sea Convection (Houpert et al., 2016).

in three stages or phases. First, there is a weakening of the vertical stratification known as the "preconditioning" phase (Stommel, 1972). It is followed by the homogenization of the water column in various chimneys distributed within the preconditioning area, during a period known as the "violent mixing phase" (Marshall and Schott, 1999). The third stage is the "sinking and spreading phase" (Killworth, 1976), during which dense water fills the deep basin below 1000 m (MEDOC group, 1970; Schott and Leaman, 1991). This spreading mainly results from the action of anticyclonic submesoscale coherent vortices (radius about 5 km and life time > 0.5 years) that can advect lenses of deep water several hundreds of kilometers away from the formation area (Testor and Gascard, 2003, 2006; Houpert et al., 2016).

Concurrent with the OSC process, the dense water is formed over the Gulf of Lions shelf and subsequently cascades downslope across the Gulf of Lions and northern Catalan margins, being mainly channelized through submarine canyons (Palanques et al., 2006; Canals et al., 2006; Puig et al., 2008; Ribó et al., 2011). Dense shelf water flows can reach $\sim 1\ m\ s^{-1}$ and erode and reshape the seafloor, particularly within submarine canyon axes, increasing their suspended and bed load sediment transport as they progress from the shelf edge towards the slope and basin (Canals et al., 2006; Puig et al., 2008; Palanques et al., 2008, 2012; Ogston et al., 2008). Resuspended sediments by DSWC can be detached at the neutral buoyancy level, forming intermediate nepheloid layers, or evolve into a thick bottom nepheloid layer towards the basin (Puig et al., 2013). This suspended particulate matter transfer plays an important role in biogeochemical cycles by exporting phytoplankton and organic matter from shallow productive areas towards deep sea environments (Sanchez-Vidal et al., 2009; Pasqual et al., 2010; Palanques et al., 2011; Tesi et al., 2010), which can ultimately affect the life histories of deep-sea megafauna populations (Company et al., 2008).

Mixing of deep cascading and convection dense waters occurs at a subdecadal recurrence, when atmospheric forcing is intense enough (i.e., cold, dry and windy winters) and DSWC and OSC extends all the way down to the basin (Béthoux et al., 2002; Puig et al., 2013). The interplay between both types of water masses has been analyzed in some recent studies (Font et al., 2007; Palanques et al., 2009, 2012; Durrieu de Madron et al., 2013; Puig et al., 2013; Durrieu de Madron et al., 2017), but their effect on the composition of particle fluxes on the basin has not been studied in detail.

Particle fluxes have been recorded in 2005 when both processes reached the basin (Palanques et al., 2009, 2011), in 2007, 2008 without deep dense water formation, and in 2013 when mainly OSC reached the basin seafloor (Stabholz et al., 2013; Houpert et al., 2016; Durrieu de Madron et al., 2017). These studies include some analysis of major components of trapped particles and they basically show an increase of total mass fluxes and lithogenic content and a decrease of biogenic components, especially organic carbon content. These processes also occur in other Mediterranean areas, such as the Southern Adriatic Margin, where the Bari Canyon System can intercept dense waters and sediments and convey this material into the southern Adriatic pit (Trincardi et al., 2007; Turchetto et al., 2007; Rubino et al., 2012)