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The importance of modeling nonhydrostatic processes for dense water reproduction in the Southern Adriatic Sea

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ABSTRACT

Dense water (DW) formation commonly occurs in the shallow Northern Adriatic Sea during winter outbreaks, when there is a combination of the cooling of surface waters by the winds and high salinity as a result of reduced river inputs. These DWs subsequently propagate southwards over a period of weeks/months, eventually arriving in the Southern Adriatic Sea. The investigation is based on a new nonhydrostatic (NH) formulation of the 3D finite element model SHYFEM that is validated for a number of theoretical test cases. Subsequently this model is used to simulate, through high-resolution numerical simulations, an extreme DW event that occurred in the Adriatic Sea in 2012. We perform both hydrostatic (HY) and NH simulations in order to explicitly see the impact of NH processes on the DW dynamics. The modeled results are compared to observations collected in the field campaign of March–April 2012 in the Southern Adriatic Sea. The NH run correctly reproduces the across isobath bottom-trapped gravity current characterizing the canyon DW pathways. It also more accurately captures the frequency and intensity of dense water cascading pulsing events, as the inclusion of NH processes produces stronger currents with different DW mixing characteristics. Finally, the NH run simulates internal gravity waves (IGW), generated during the cascading at the edge of the canyon, which propagate downslope. This IGW activity is not captured in the HY case.

1. Introduction

Dense water (DW), produced on the continental shelf, and its propagation to the deep ocean, via a bottom-trapped gravity current, have been widely studied (Ivanov et al., 2004), not only because of its role in exchanging water masses with different properties between the shelf and the deep ocean, but also because the cascading dynamics can influence the thermohaline circulation in the ocean (Özgökmen et al., 2006; Herrmann et al., 2008). Thus these currents have a role to play in the climate system (Herrmann et al., 2008). DW on the continental shelf can be generated by a number of factors, such as cooling, evaporation (over precipitation), salinization or surface-layer freezing. Once formed, the DW can sink to the bottom and propagate, flowing geostrophically along isobaths. If this geostrophic balance is broken, DW masses can flow down the slope, across isobaths, and this process is called cascading (i.e. in submarine canyons, Trincardi et al., 2007; Canals et al., 2006). This process occurs in many areas, like the Eastern Greenland Shelf (Magaldi and Haine, 2015), the Antarctic (Tanaka and Akitomo, 2000) and the Mediterranean shelf-slope borders (Gulf of Lion – Salat et al. 2010, Adriatic Sea – Bergamasco et al. 1999; Langone et al. 2016; Mihanović et al. 2013; Chiggiato et al. 2016, Aegean Sea – Vervatis et al. 2011). There have been many studies to determine the main characteristics, shape and dynamics of DW flows (Wåhlin and Walin, 2001).

In the Mediterranean Sea, Canals et al. (2006) highlighted the importance of DW flows in transporting sediment loads from the shelf to the slope, contributing to the excavation of the typical canyon structure seen in the Gulf of Lions. DWs are seen as a transport mean for sediments and organic matter, shaping the sea floor, as well as bringing nutrients to the deep ecosystems (Canals et al., 2006). Turchetto et al. (2007) and Trincardi et al. (2007) studied the Bari Canyon System (Southern Adriatic Sea) finding evidence that identify preferential pathways for sediment fluxes, in correspondence with DW events, that are modulated by pulsating behavior. A general assumption is that energy transfer and balance are driving the definition of DW pathways and water transport. DW events can be detected by measurements, though their unsteady nature makes these phenomena extremely challenging to be fully captured temporally and spatially. Measurements have shown that the cascading process occurs once a specific energetic threshold is reached, breaking the geostrophic balance and

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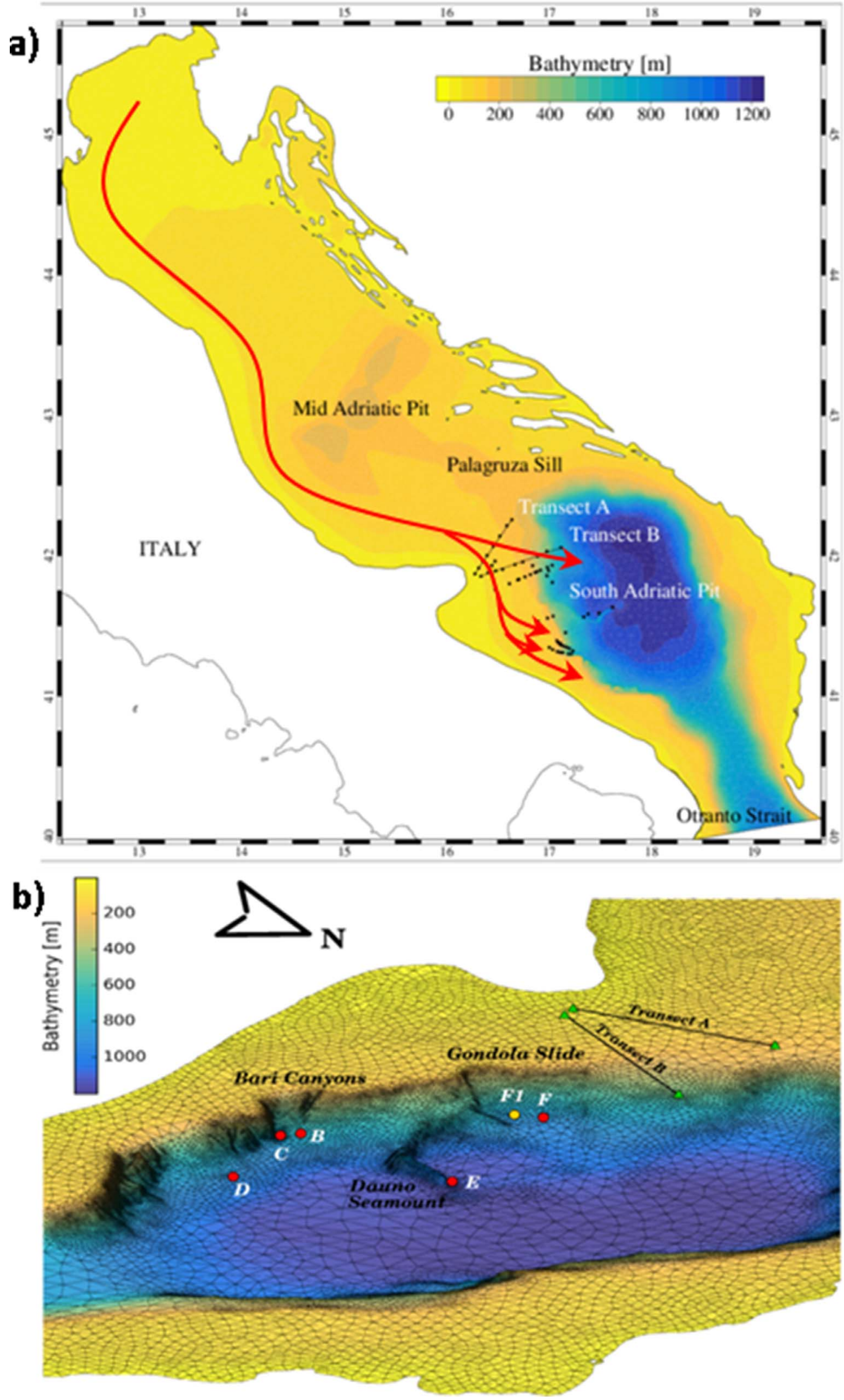

Fig. 1. Simulated domain: (a) bathymetry, with location of CTD casts (black dots) used for model validation; red arrows represent a simplified scheme of DW flow in the Adriatic Sea (b) 3D zoom of the high resolved finite element grid on the area where dense water is spreading. Zoom is stretched along the North-South direction and rotated to allow a better visualization of bathymetric variations present in the Bari Canyon System. Mooring locations are indicated (red dots) and one additional point (F1–yellow dot) is shown and used for DW characterization. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)