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Modelling ocean currents in the northern Adriatic Sea

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ABSTRACT

Ocean circulation in the northern Adriatic Sea is characterised by the interactions of tidal currents, bathymetric constraints, wind forcing and density gradients induced by river input and heat exchange. The MIKE 3/21 modelling system, together with measurements of wind, waves, currents and water levels at one location, has been used to investigate the currents dynamics of the northern Adriatic basin and to assess model sensitivity to the parameterisation of different processes and implementation strategies. An assessment has been carried out against available in-situ observations (waves, currents, surface elevation, and water temperature), and also in comparison with a high-resolution modelling system (COAWST) implemented in the same area during the corresponding period. The MIKE 3/21 system was implemented for a 1-year simulation period and validation of surface elevation, wind, and waves with data indicated a good model performance, statistically very similar to the COAWST implementation. Depth-averaged, surface and bottom currents were more difficult to reproduce by both models, with the observed high variability not being fully captured by the model systems. Some of the differences between the models results may be due to model configuration, spatial resolution and the way they treat atmosphere–ocean momentum and heat transfers, turbulence, and are therefore discussed in the paper. From the thorough analysis of MIKE 3/21 system, wind is found to be the main forcing factor inducing currents in the northern Adriatic; tides and baroclinic motions were of second order, although some specific events seems to be forced by these processes. Waves were found to be highly correlated with local wind, and a rather weak wave–current interaction was observed. Even if the inclusion of wave effects trough radiation stress did not seem to lead to significant improvements in the modelled currents with MIKE 3/21, the full wave–ocean coupling in COAWST was significant in explaining small scale features, especially in the Gulf of Venice. Spectral and SVD analysis showed energy around diurnal and semidiurnal frequencies and that about 50% of variance in the current profile was explained by the first mode, which was well captured by both modelling systems.

1. Introduction

The Adriatic Sea (Fig. 1) is a marginal semi-enclosed basin within the Eastern Mediterranean extending southeastward from (12°E, 46°N) to (19°E, 40°N), approximately 780 km long and 120–200 km wide. The northern Adriatic (NA, north from Ancona, see Fig. 1) is characterised by depths of a few tens of metres, increasing gradually towards the Mid Adriatic Pit, where maximum depth is about 280 m. While the western coastline is mostly featureless except for the Po river delta near 45°N, the eastern coastline is irregular, marked by the mountainous Istrian peninsula and numerous islands and bays. Around and within them, depths are sometimes greater than 80 m.

This portion of the Adriatic Sea has a relatively complex hydrodynamic behaviour, changing its main features during its annual hydrologic cycle, from those of a stratified system to those typical of a homogenous and well-mixed basin (Artegiani et al., 1997a; Russo et al., 2012b). The main thermohaline characteristics of the basin have been described by Artegiani et al. (1997a, 1997b), while Poulain (2001) tackled the surface circulation using Lagrangian devices and a recent thorough climatological assessment has been proposed by Russo et al. (2012a).

During summer time a rather large surface warming is present in the NA area, leading to an almost stratified situation in the shallower portions (Russo et al., 2012a). Evaporation on the northern Adriatic slightly prevails on precipitation giving a net water loss of 30 cm (Picco, 1991). The basin represents a sink of heat, however a fresh

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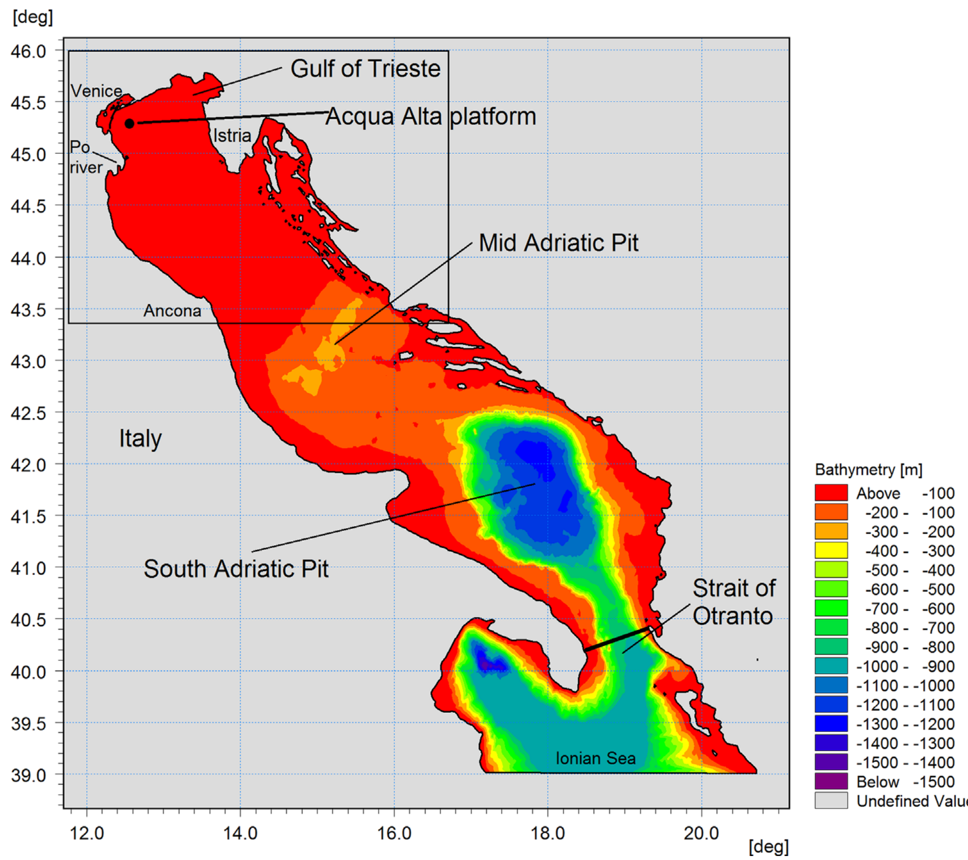

Fig. 1. Adriatic Sea bathymetry and model domain used in the MIKE 3 and MIKE 21 SW models. The figure also shows the location of observational data at “Acqua Alta” platform. The open boundary of the second domain is indicated by a black thick line in the Strait of Otranto. (For interpretation of references to color in this figure, the reader is referred to the web version of this article.)

water balance considering also runoff (evaporation -[precipitation and runoff]) in the Adriatic (Raicich, 1996) indicate that the northern Adriatic is permanently in a negative balance during all seasons. The NA is characterised by a significant river runoff during spring and fall (Artegiani et al., 1997b). Indeed, the Po and the other northern Italian rivers, contributing about 20% of the whole Mediterranean river runoff (Hopkins, 1992), together with atmospheric forcing, are fundamental in determining the NA circulation by injecting fresh water masses (Bergamasco et al., 1999).

The basin is subjected to different wind regimes; during the cold season the prevalent winds are the strong dry and north-easterly (called Bora, see Boldrin et al., 2009; Dorman et al., 2006) and the southeasterly winds (Sirocco), which occasionally blows during warm season (e.g., Signell et al., 2005).

The strong heat and momentum fluxes associated with Bora regime might contribute to the formation of North Adriatic Dense Water (NAdDW); the episodic production and sinking of these heavier and denser waters characterises the NA during the winter season, leading to strong vertical mixing and overturning (Cushman-Roisin et al., 2001; Mihanovic et al., 2013; Vilibic and Nastjenjka, 2005). Consequently, NadDW tends to spread out over the basin, moving to the southern region (Carniel et al., 2012) and triggering a return circulation from the Ionian and Aegean region into the basin. Such waters are transported by the Adriatic Sea eastern currents and influence the local climate by transporting a significant amount of heat and nutrients (Boldrin et al., 2009).

Already in 1987, Zore-Armanda and Gačić (1987) analysed current metre records in the NA under Bora conditions and suggested that the associated wind shear acts on the ocean to form two gyres: one cyclonic gyre forms in the far north. South of it, the circulation is anticyclonic as currents flow northeastward from the Po River mouth to the Istrian coast, southeastward along the Istrian coast, and southwestward from Kvarner Bay to the Italian coast. More recently, as shown by Bignami et al. (2007) and Boldrin et al. (2009), these results were supported by the adoption of high-resolution meteorological forcings, without which many of the observed features were not previously modelled. Adopting a different numerical model, Malačič et al. (2012) showed the topographic control on wind-driven circulation in the Gulf of Trieste during Bora events.

Studies of tidal currents in the NA (Book et al., 2009; Chavanne et al., 2007) have showed a reversing tidal currents at most of locations, at “Acqua Alta” tower (see Fig. 1) the tidal ellipse is more circular and tidal amplitude is of 0.0146 m/s for K_1, 0.0375 m/s for M_2 and 0.0219 m/s for S_2. It was also observed the support of a Kelvin wave by the M2 energy fluxes, and the possible alteration of the tidal propagation near the coast due to stratification and lateral shear induced by the Western Adriatic Current were outlined.

The combination of a relatively small tidal range, strong seasonal atmospheric effects, baroclinic processes and bathymetric controls on the dynamics of the northern Adriatic make the vertical profile of the currents sheared and it is common to find current inversion from bottom to surface (Cosoli et al., 2008). Cosoli et al. (2008) studied the variability of an observed current profile in the NA from September to October 2002, finding that the main component was barotropic, explaining 70% of the signal while the second component was baroclinic. The first component was associated with synoptic scale meteorological events, showing a relatively uniform vertical structure with small reductions in amplitude towards the surface and the bottom and a clockwise veering with depth, related to effects of a bottom-friction. The second one has a baroclinic-like structure with one zero-crossing at 8 m depth and relates to a higher