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Mesoscale slope current variability in the Gulf of Lions. Interpretation of in-situ measurements using a three-dimensional model

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ABSTRACT

The ECOLOPHY experiments aimed at investigating physical exchanges between coastal and open sea. They were carried out in June and December 2005 over the shelf-break in the North-eastern part of the Gulf of Lions (Northwestern Mediterranean Sea). This area is considered to be the generation zone for the eddy and meandering structures of the Northern Current (NC). The objective of the present work is to examine mesoscale variability of this coastal slope current in the light of available data. Numerical modeling is used to support the field data analysis. ADCP current measurements over a one-year period show that mesoscale activity is maximal in late winter, correlating with the seasonal variability of the NC and, also, partly with local winds. Measured currents exhibit mesoscale fluctuations with periods ranging from 3 to 30 days, in agreement with previous analyses. Fluctuations of periods longer than 10 days are found to be mainly oriented in the direction of the mean current, whereas more frequently observed high frequency fluctuations tend to be oriented cross-slope, suggesting a relationship with the NC mesoscale meandering. Moreover, trajectories of surdrift buoys launched in the NC vein exhibit mesoscale phenomena, such as current meanders or eddies and on-shelf intrusions. Numerical modeling provides a synoptic point of view and is used hereafter to support physical interpretation of punctual eulerian or lagrangian measurements. Therefore, modeled hydrodynamic fields are used to analyze surdrift buoy trajectories and computed vertically averaged current and Ertel potential vorticity provide a better understanding of these behaviors.

1. Introduction

1.1. Background

Coastal slope currents exhibit unstable behavior due to barotropic and baroclinic instabilities (Middleton and Cirano, 1999; Mysak et al., 1981), which generate mesoscale eddies and meanders resulting from number of interactions (wind forcing, tides, buoyancy, bathymetry…). This kind of mechanisms can play a role on the current intrusions across the continental shelf and were investigated in a number of regions for the Kuroshio (Guo et al., 2006; Miyazawa et al., 2004) and for the Gulf Stream (Blanton et al., 1981; Brooks and Bane, 1983). In our area of interest, in the microtidal Mediterranean Sea, process-oriented investigations have been performed on the curvated Catalan slope current along Ebro delta site's narrow shelf (Gjevik et al., 2002; Xing and Davies, 2002) and of the Gulf of Lions (GoL) (Flexas et al., 2002; Flexas et al., 2004). These previous investigations especially pointed the importance of the wind forcing, inertial motion and complex bathymetry on the cross-shelf fluxes in microtidal sea. The purpose of this paper is to examine the mesoscale slope current variability observed in the continental slope of the eastern GoL during the ECOLOPHY cruises with the help of numerical simulation. In our case, a realistic wind forcing was made available, allowing investigation of the origin of eddy and meander structure of the Northern Current (NC) with the help of a high-resolution model.

The NC is the northern branch of the general cyclonic circulation in the western Mediterranean basin, where relatively fresh surface water flows from the Atlantic Ocean (Atlantic Water, hereafter called AW) through the Gibraltar Strait into the semi-enclosed Mediterranean Sea, to compensate for evaporation losses. This current results from the junction of the Western Corsican Current (WCC), flowing north-eastward from the Algerian Basin, and the Eastern Corsican Current (ECC) arising from the Tyrrhenian Sea through the Channel of Corsica (Astraldi and Gasparini, 1992). The NC is a slope current flowing along the coast from the Ligurian Sea up to the Balearic Sea. Several cruises performed over the two last decades have shown that this current exhibits a seasonal variability with maximum flux in winter, ranging from a minimum of 0.2 Sv ($1\,Sv = 1\times10^6\,m^3\,s^{-1}$) in summer to a maximum of 1.2 Sv in winter across a transect off

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Marseille (Lapouyade and Durrieu de Madron, 2001) and from 1 to 1.6 Sv between 0 and 300 dbar from autumn to summer off the city of Nice (Albérola et al., 1995). It is a wide (ca. 50 km) and shallow (down to 250 m depth) current in summer; it becomes narrower (ca. 30 km) and deeper (ca. 450 m) in winter; with a maximum velocity near the surface (30–50 $cm\,s^{-1}$), then linearly decreasing with depth.

This current generally flows to the south of France, along the deepest half of the continental slope of the GoL, where it bounds and controls the shelf circulation. Depending mainly on wind forcing conditions, it may intrude on the continental shelf, especially in the eastern, and sometimes in the central, parts of the gulf (Millot, 1979; Millot and Wald, 1980; Estournel et al., 2003; Petrenko, 2003). The complex GoL continental slope is intersected by a number of irregular canyons (Fig. 1). These irregularities, considering the potential vorticity conservation can generate mesoscale current features, such as meanders, filaments and secondary eddies on the inner side of the NC (Flexas et al., 2002). Therefore, water exchanges across the GoL continental slope are influenced by mesoscale instabilities of the NC, and by strong northwestern (Tramontane) and northern (Mistral) continental winds, which generate classical oceanographic small-scale features such as coastal up- and down-wellings along coasts (Millot, 1979) and inertial motions (Petrenko, 2003). Water exchanges are also influenced by dense water cascading induced by wintertime continental winds (Dufau-Julliand et al., 2004; Guarracino et al., 2006). However, this last process, acting with an interannual variability is not in the purpose of the present study.

1.2. Evidence of mesoscale current variability

The NC displays intense mesoscale variability, which mainly appears as meanders and anticyclonic eddies occurring at the jet edge over the upper continental slope, exhibiting different noticeable length scales. These meanders have a wide range of wavelengths (some 10–100 km), phase speeds of 10–20 $km\,day^{-1}$ (Albérola et al., 1995) and major variability occurs within a 2 to 10 day period. Durrieu de Madron et al. (1999) and Lapouyade and Durrieu de Madron (2001) observed a seasonal signal with stronger mesoscale variability in winter than in summer, when other authors (Taupier-Letage and Millot, 1986) reported significant mesoscale activity during an extended winter from December to May, highlighting a good correlation between maximum momentum energy in the NC and a high mesoscale variability. Although major mesoscale activity is usually assumed to occur in late autumn and decrease in late winter, meanders have been observed from satellite images throughout the whole year (Millot, 1999).

Current records obtained near the bottom of the GoL continental slope revealed that topographic waves propagate at a period of about 8 days with a mean phase speed of 11 $cm\,s^{-1}$, the bottom slope acting as a wave-guide (Millot, 1985). According to *in situ* data recovered off Nice during the PRIMO-0 (December 1990–May 1991), PROLIG-2 and PROS-6 experiments (May–December 1985), in a location just upstream from the entrance of the GoL (Albérola et al., 1995; Sammari et al., 1995), two frequency ranges appeared in winter: a more energetic 10 to 20 day band and a weaker 3 to 6 day band. During the MATER HFF experiment (March–May 1997) current observations at 240, 650 and 1230 m and hydrographic data showed that meanders occupied a large part of the water column (Flexas et al., 2002). From these data, two main peaks were observed with different characteristics: along-slope fluctuations with a 7 day period and isotropic fluctuations with a 3.5 day period. Using current measurements and analytical models, Flexas et al. (2002) proposed that the large NC meanders with a 10 to 40 day period and those with a 7 day period could be due to baroclinic instabilities. The case of the 3.5-day period fluctuations was investigated in detail in Flexas et al. (2004), who indicated that barotropic instability was one of the possible mechanisms (co-existing with baroclinic-type instabilities) responsible for such oscillations. According to Flexas et al. (2002), the 7 and 3.5 day period current fluctuations probably reflect propagating topographic Rossby waves (Pedlosky, 1979).

1.3. Present study

The ECOLOPHY experiment is part of the French National Atmosphere–Ocean program (Programme National Atmosphere–Océan à Multiéchelles). This research project was initiated to improve the understanding of NC variability as a major process in

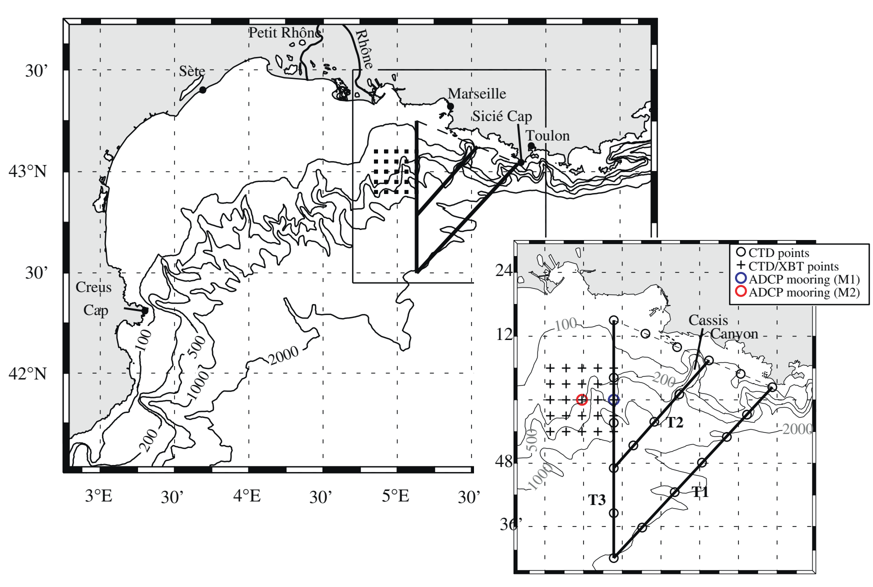

Fig. 1. Geographic and bathymetric map of the GoL. Isobaths at 100, 200, 500, 1000 and 2000 m are given. The ECOLOPHY experimental area, hydrological stations, mooring positions and main transects are indicated.