High-resolution measurements of an upwelling filament during the CAIBEX survey

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1. Satellite observations

Upwelling filaments were first observed through satellite images some 30 years ago. They consist of elongated (\sim 100 km) shallow (\sim 100 m) structures developing from the coast and transporting upwelled water offshore (Fig. 1).

\textbf{Figure 1.} An upwelling filament off Cape Chin on July 31st, 2009, seen through satellite SST.

2. Numerical modeling

Upwelling filaments have been studied for several years (e.g., Strub et al., 1991; Polvoy et al., 2005). We strive to explain the general process in terms of potential vorticity. An injection of positive vorticity north of the Cape forces the jet to turn offshore, in virtue of the principle of vorticity conservation.

The Regional Ocean Modelling System (ROMS; Shchepetkin and McWilliams, 2005) is implemented in the Cape Chin region, with horizontal resolution lower than 1 km. A set of process-oriented experiments has been designed in order to determine the mechanisms at the origin of the filament (Troupin et al., 2011).

\textbf{Figure 2.} Modeled temperature and normalized relative vorticity at 10 m on September 22. The SeaSoar tracks (white diamonds), the CTD casts (black dots) and the drifter deployment positions are superimposed on the temperature field.

3. Oceanographic survey

The CAIBEX cruise took place from August 16 to September 5, 2009, with the objective of describing the hydrography of the filament at the mesoscale/micromesoscale range and to test the model hypothesis. This was achieved through repeated SeaSoar sections and CTD transect, as shown in Fig. 3. The first sketch of the cruise tracks was divided following the model results.

SeaSoar: SeaSoar measurements permits high vertical and horizontal resolution measurements (Fig. 3). The filament is easily identifiable by its low temperature signature at the surface (Fig. 3a), centered around 30°N, and its higher chlorophyll concentrations (Fig. 3d). Near 250 m, the lowering of the isotherms between 30° and 31°N is striking (Fig. 3c) and may be interpreted as the signal of an anticyclonic eddy.

\textbf{Figure 3.} SeaSoar data during tracks 6 and 9 (\textit{VC}2009) for temperature (\textit{a}) and (\textit{b}), salinity (\textit{c}) and fluorescence (\textit{d}).

CTD: a transect was carried out along the 31°N meridian; the filament signal is observed at stations 70 and 71 (Fig. 4a). These stations are also characterized by a high chlorophyll concentration between 15 and 30 m (Fig. 4b) and low transmittance due to the abundance of particles in the water column.

\textbf{Figure 4.} Analyzed fields of temperature and fluorescence with the data from the CTD sections.

Drifters: a set of 5 drifters with the drogue at 10 m were launched in the core of the filament, while 1 with the drogue at 300 m was dropped in the convergence zone (Fig. 2, north of the filament). The trajectories (Fig. 5), starts by a northwestward motion, possibly due to the filament current, around 30°N, the drifters undergo a cyclonic trajectory, to finally follow a southeasterward direction due to the Canary Current. The 300 m drogue drifters describe a series of cyclonic loops with a rotation period $T \approx 5-6$ d.

\textbf{Figure 5.} Trajectories of the drifters (left) launched on September 3rd, 2009. Drifter no. 95565 (right) has its drogue at 300 m.

An anticyclonic eddy is observed and corresponds to the region of higher temperature (Fig. 7). Such an eddy is believed to come from an interaction between the upwelling undercurrent with the bathymetry.

\textbf{Figure 7.} Temperature and normalized relative vorticity fields at 300 m on September 3.

A meridional sections extracted from the model results is presented in Fig. 8 in order to show the filament vertical structure.

Temperature: the upwelling is visible in a confined area near the coast, while the filament surface signature is about $\mathcal{O}(100)$ km width. Drowning of the isotherms take place at a depth around 200 m, below the filament and 50 km off the coast.

Meridional velocity: the velocities reach values up to 0.5 m/s. A weak $v < 0.05$ m/s polarward undercurrent appears below 75 m, as well as an anticyclonic eddy 100 km offshore.

\textbf{Figure 8.} Transect at 31°N for modeled temperature and meridional velocity on September 3.

Satellite image analysis

In order to check if the drifters were correctly dropped in the filament, original satellite images from Medaspection server (http://www.medaspection.org) were processed using the DINEOF method (Alvarez-Asrar et al., 2005).

\textbf{Figure 9.} Transect at 31°N for modeled temperature and meridional velocity on September 3.

All the measurements made during the survey were analyzed in order to provide overall picture of the situation in the area. Figure 5 shows the temperature field at 25 m and 300 m: the coastal upwelling and the filament signal appear clearly, at 300 m, a core of warm water near the coast is observed.

\textbf{Figure 6.} Temperature field at 25 and 300 m, constructed using all the measurements made during the cruise.