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

C. Troupin[a] (ctroupin@ulg.ac.be), J. Arístegui[b], J.-M. Beckers[a] & P. Sangrà[b]

[a] Université de Liège, GHER, Sart-Tilman, Liège, BELGIUM

[b] Universidad de Las Palmas de Gran Canaria, Facultad de Ciencias del Mar, Las Palmas de GC, SPAIN

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 waters offshore (Fig. 1).

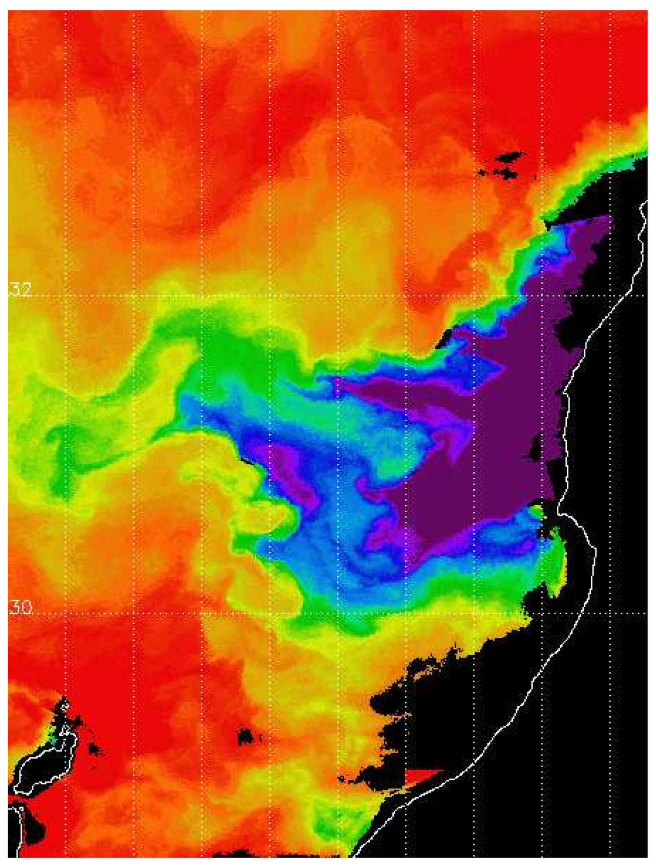

FIGURE 1: *An upwelling filament off Cape Ghir on July 31st, 2009, viewed through satellite SST.*

2. Numerical modeling

Upwelling filaments have been studied for several years (e.g., Strub et al., 1991; Pelegrí 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 Modeling System (ROMS, Shchepetkin and McWilliams, 2005) is implemented in the Cape Ghir 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).

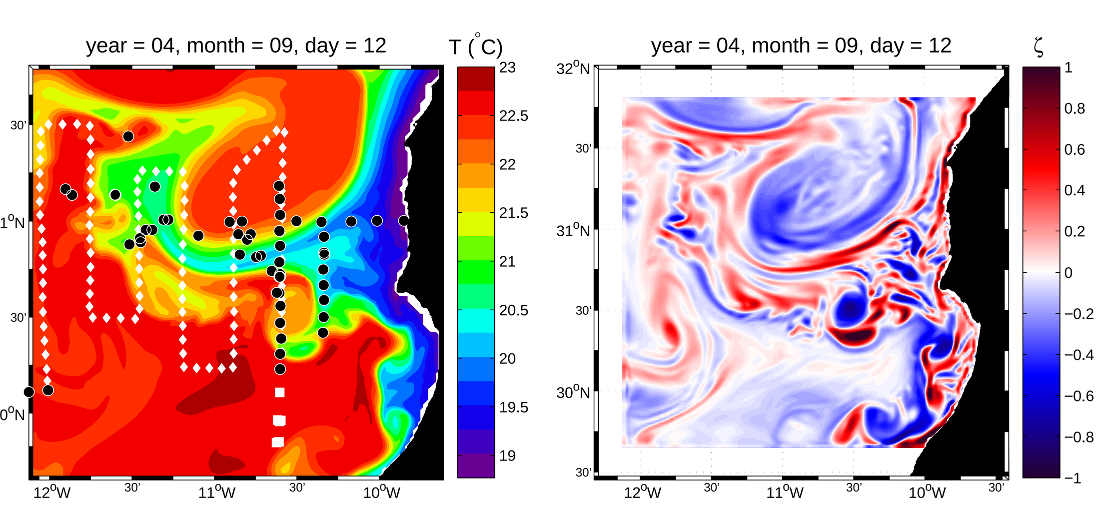

FIGURE 2: *Modeled temperature and normalized relative vorticity at 10 m on September 12. The SeaSoar tracks (white diamonds), the CTD casts (black dots) and the drifter deployment positions are superimposed on the temperature field.*

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/submesoscale ranges and to test the model hypothesis. This was achieved through repeated SeaSoar sections and with CTD transect, as showed in Fig. 2. The first sketch of the cruise tracks was decided 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°40'N, and its higher chlorophyll concentrations (Fig. 3d). Near 250 m, the lowering of the isohalines between 30°40'N and 31°N is striking (Fig. 3c) and may be interpreted as the signal of an anticyclonic eddy.

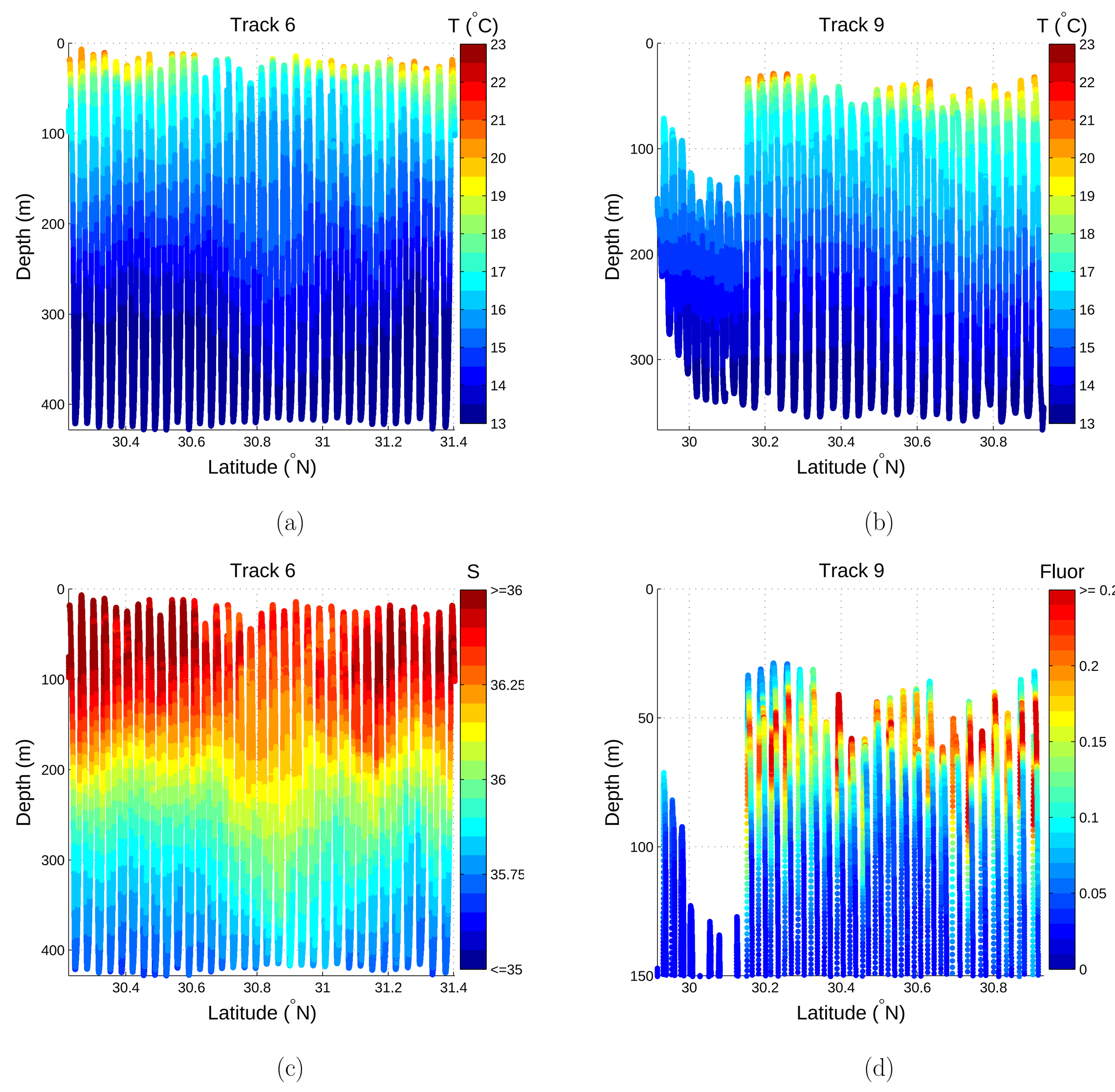

FIGURE 3: *SeaSoar data during tracks 6 and 9 (10°40'N) for temperature ((a) and (b)), salinity (c) and fluorescence (d).*

CTD: a transect was carried out along the 10°40'N meridian; the filament signal is observed at stations T9 and T10 (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.

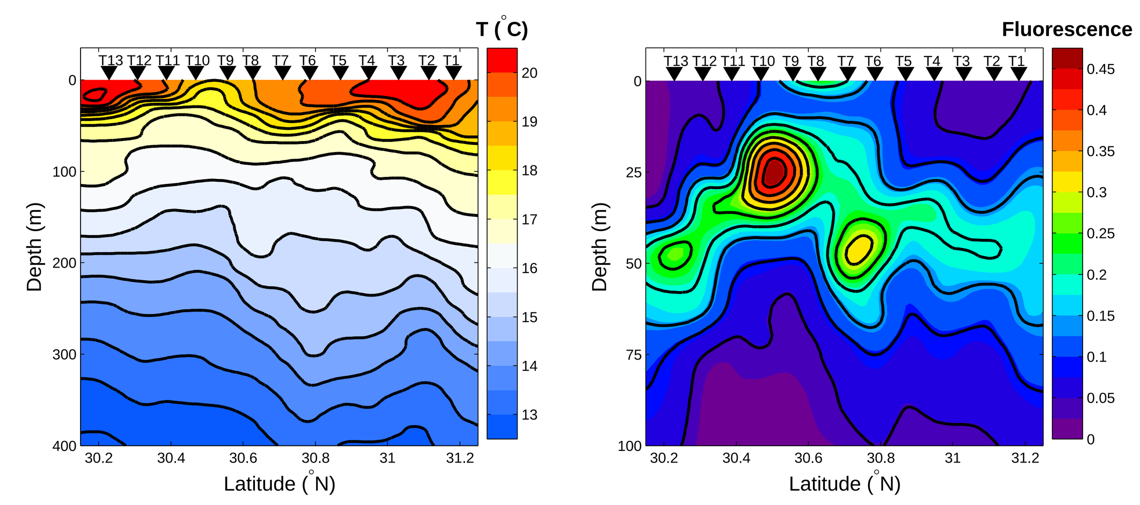

FIGURE 4: *Analyzed fields of temperature and fluorescence with the data from the CTD section.*

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 31°N, the drifters undergo a cyclonic trajectory, to finally follow a southwestward direction due to the Canary Current. The 300 m-drogue drifters describes a series of cyclonic loop with a rotation period $T \simeq 5-6$ d.

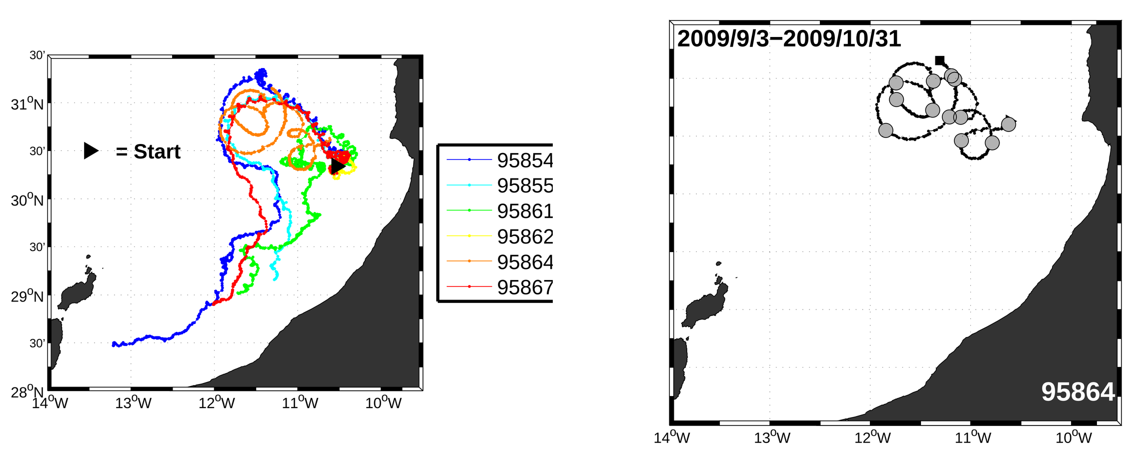

FIGURE 5: *Trajectories of the drifters (left) launched on September 3rd, 2009. Drifter no. 95864 ((right) has its drogue at 300 m.*

4. Model validation

All the measurements made during the survey were analyzed in order to provides overall pictures 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.

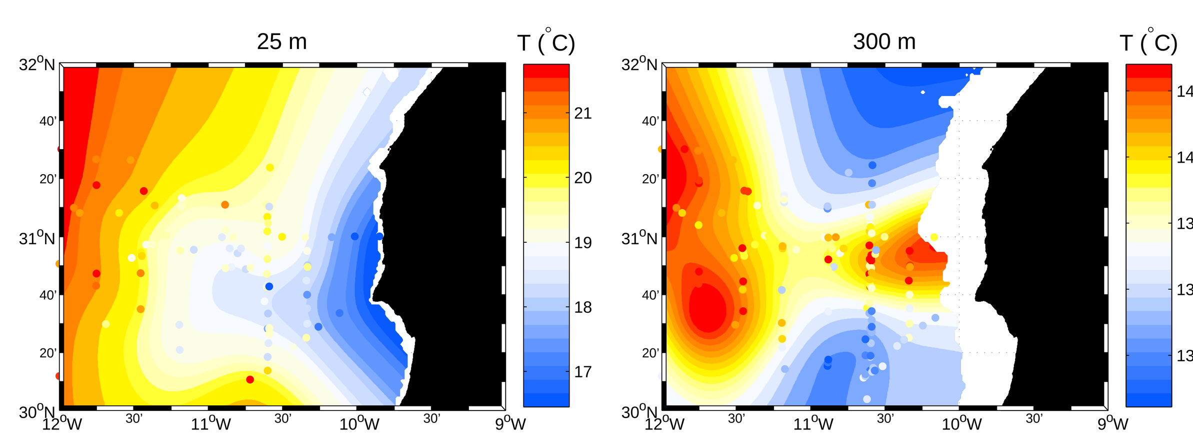

FIGURE 6: *Temperature field at 25 and 300 m, constructed using all the measurements made during the cruise.*

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.

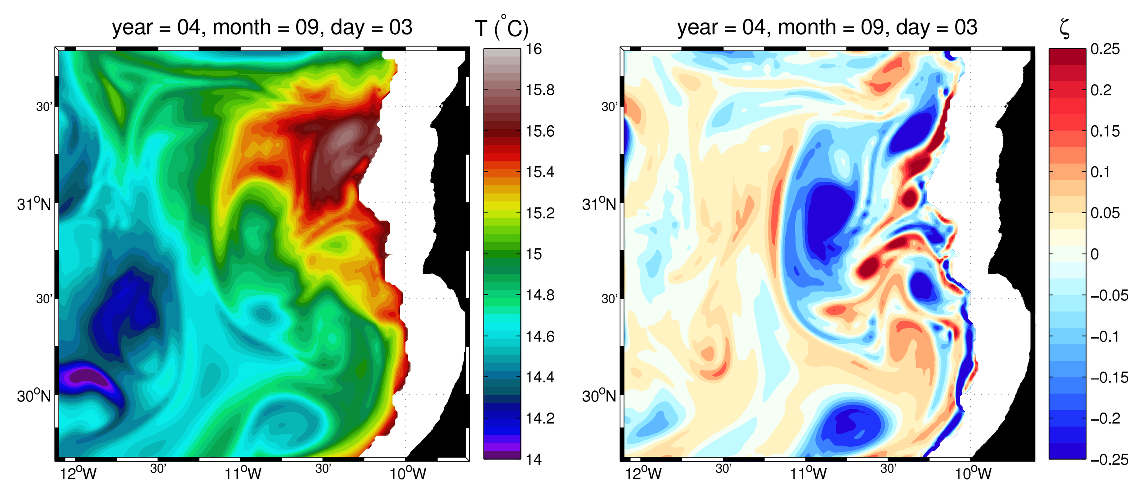

FIGURE 7: *Temperature and normalized relative vorticity fields at 300 m on September 3.*

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 $\mathcal{O}(25\ km)$ width. Dooming 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 0.3 m/s. A weak ($v < 0.05$ m/s) poleward undercurrent appears below 75 m, as well as an anticyclonic eddy 100 km offshore.

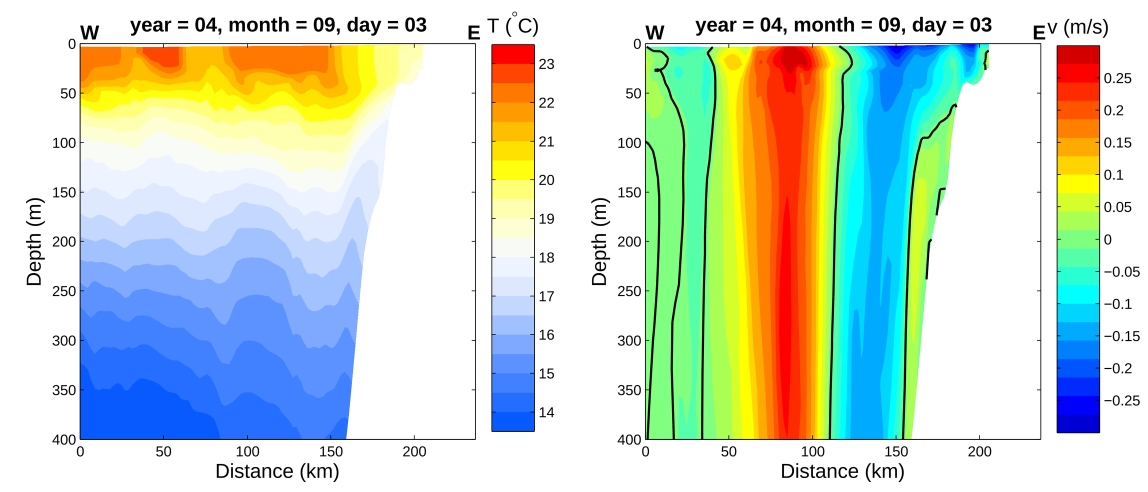

FIGURE 8: *Transect at 31°N for modeled temperature and meridional velocity on September 3.*

Satellite image analysis

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

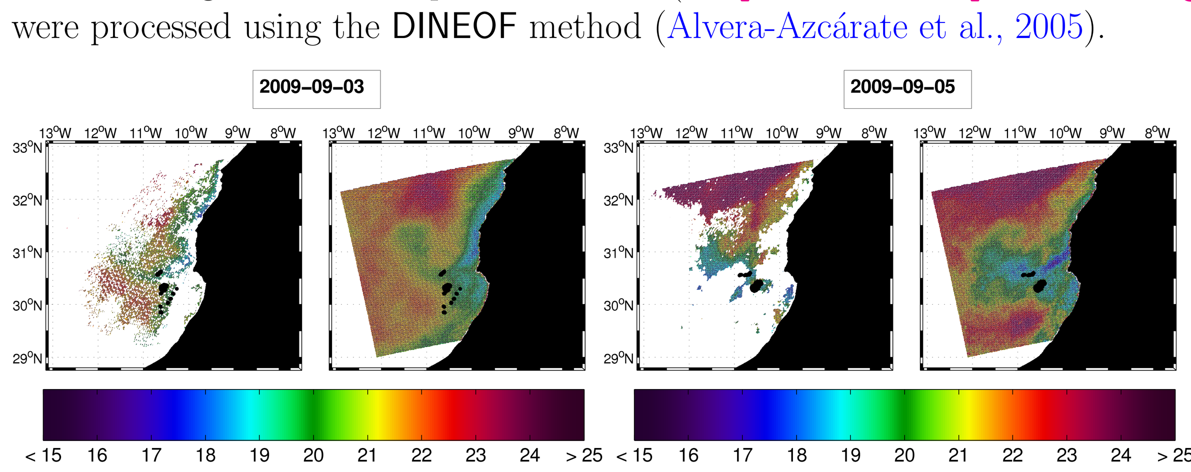

FIGURE 9: *Drifter positions and reconstruction of SST field for September 3rd and 5th, 2009.*

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References

Alvera-Azcárate, A.; Barth, A.; Rixen, M. and Beckers, J.-M., 2005. Reconstruction of incomplete oceanographic data sets using Empirical Orthogonal Functions. Application to the Adriatic Sea. *Ocean modelling*, **9**, 325-346

Pelegrí, J. L.; Marrero-Díaz, A.; Ratsimandresy, A.; Antoranz, A.; Cisneros-Aguirre, J.; Gordo, C.; Grisolía, D.; Hernández-Guerra, A.; Laíz, I.; Martínez, A.; Parrilla, G.; Pérez-Rodríguez, P.; Rodríguez-Santana, A. and Sangrà, P., 2005. Hydrographic cruises off northwest Africa: the Canary Current and the Cape Ghir region. *J. Mar. Syst.*, **54**, 39-63.

Strub, P. T.; Kosro, P. M. and Huyer, A., 1991. The nature of cold filaments in the California Current system. *J. Geophys. Res.*, **96**, 14743-14768.

Troupin, C.; Mason, E.; Beckers, J.-M. and Sangrà, P. Generation of the Cape Ghir upwelling filament: a numerical study, *submitted to Ocean Modelling.*