Lagrangian observations, filament transport and budgets

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Introduction

During the second year of the project UWB-a has participated in two cruises, one in summer (*CD114*) and one in winter (*Meteor M43/2*) therefore completing our commitments in terms of the observational tasks (**Task I.1)**. Contacts with BODC have furthered the inventory and processing of previous Acoustic Doppler Current Profiler (ADCP) data sets (**Task II.1.4**) and discussions with other partners have been established to arrive to estimates of fluxes and budgets of scalar properties within the OMEX II-II box. Data collection has consisted in along track ADCP data during both cruises and deployment and tracking of 8 Argos drifters 4 in summer and 4 in winter, plus one short term drifter which was recovered at the end of the summer cruise, together with standard hydrographic measurements.

Our main task in OMEX II-II is **TASK I.1** (On-, Off- and along-shelf transport of water, filament transport and turbulence) of which the description of the 3-D structure of the 42°N upwelling filament is a major component. This was completed during the *CD114* cruise fulfilling our original objectives, like determination of the 3-D structure and flow regime of the filament, its net transport, mixing and lagrangian observations within the filament structure.

The winter cruise on board the *Meteor* (*M43/2*) provided further data for studying the seasonal variability of the filament area (**Task I.1**) and gave us the opportunity to sample the winter regime both with ADCP and CTD. Four ARGOS drifters were released to provide a quantitative description of the mesoscale structure and seasonal variability of the circulation in the upper layer of the ocean within the OMEX II-II region.

Instrumentation and Data analysis

The drifters released are of two types, Horizon Marine Inc. for the summer and SERPE-IESM® spherical (40 cm of diameter) for the winter cruise. Both are mixed layer drifters equipped with cylindrical HOLEY SOCK drogue (8 m length, 1.5 m of diameter) located at a nominal depth of 15 m. All drifters also measure the water temperature with an accuracy of ±0.3°C which is transmitted with every positioning message.

ADCP data collected from *CD114* has been processed at Bangor. A report of the data will be distributed among the cruise participants. *Meteor M43/2* ADCP data is currently being processed and will be also written as a cruise report. Drifter and ADCP data from both cruises will be delivered to BODC in the near future.

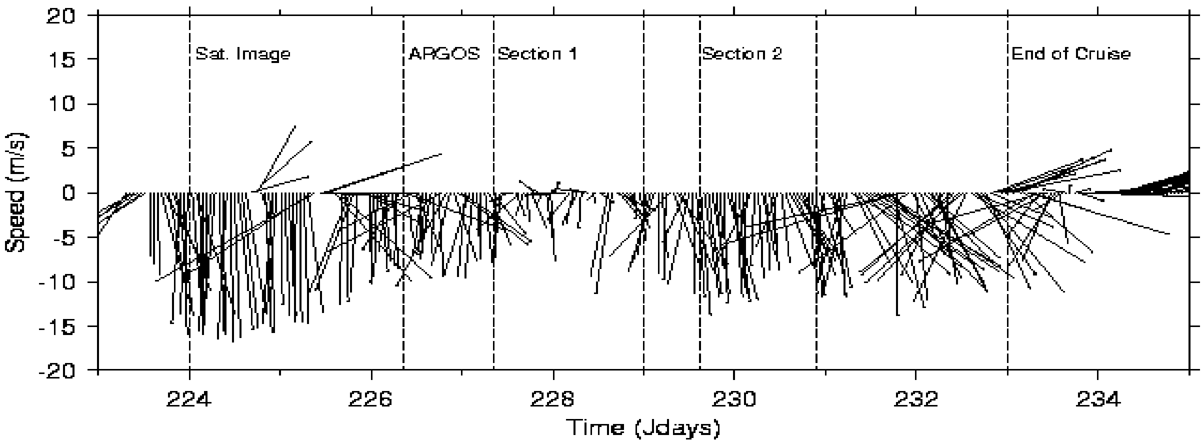
Results

Summer cruise: The Iberian upwelling is abundant in seaward extensions of recently upwelled water referred to as filaments. They are narrow baroclinic jets that flow offshore advecting water from the shelf into the ocean and are easily identified in satellite Sea Surface Temperature images (SST) by their cold signature. They are characteristic of the major upwelling regions of the world and are persistent features in the Iberian coast during the summer (Haynes *et al.*, 1991).

The filament we were to sample was present throughout the cruise and although it went through relaxation and reactivation periods it never disappeared completely. The sampling strategy was designed to support the primary production activity and the spatial survey of the filament. A recoverable drifting buoy equipped with a set of four optical channels was deployed at the centre of a

4 ARGOS drifter cluster of 5 nm side square in the core of the upwelling filament. The deployment position was chosen on the basis of SST images transmitted to the ship. As the buoys drifted we performed across filament transects with CTD, Fly and ADCP interspersed with primary production stations. At the end of the cruise when recovering STABLE mooring, a final section on a newly developing filament around 42.6 was surveyed with CTD, ADCP and FLY probe.
During the cruise the wind alternated between upwelling favourable and very weak (Fig. 1). Strong upwelling favourable winds at the start, which prevented work but provoked filament reactivation, were followed by a wind relaxation which produced a strong signal in the dynamics of the system. The meteorological variability was accompanied by changes in the filament geometry in SST images over the cruise period, ranging from a narrow (17 km) and long (150 km) feature to a short (55 km) and wide (37 km) one. The filament was 30 km wide and over 200 km long at the time of Section 1. During Leg B the whole structure moved northwards and narrowed to 27 km wide.

Fig. 1. Ship wind vectors (1 hour averages) during leg B. The SST image that was used to locate the filament has



been indicated, together with the time of the ARGOS drifters deployment and the 2 filament sections.

The four ARGOS buoys were released on 12 August 1998 (day 226). Minimum tracking was 60 days while one is still being tracked summing up to 420 drifter days (Table 1).

Table 1. Details of the launch of the ARGOS tracked drifters.

Drifter I.D.	Time	Latitude (N)	Longitude (W)	N° of Days
03927	07:40	41° 56.37’	9° 50.89’	6
10312	09:27	41° 58.31’	9° 47.06’	On going
10313	10:09	41° 53.83’	9° 47.29’	103
10314	10:58	41° 53.82’	9° 52.89’	110
10315	08:33	41° 58.71’	9° 53.10’	60

Deployed during the relaxation event, they slowly (0.05 m s^{-1}) converged towards the filament’s southern boundary for two and half days (Fig. 2). Preliminary calculations of subduction velocity based on the convergence rate yielded 16 m day^{-1}. During the renewed upwelling period one drifter traced the offshore extent of the filament with mean velocity 0.28±0.1 m s^{-1} while the others left the filament and recirculated shorewards in an apparent return flow (Fig. 3). It took them 20 days to complete the gyre which is longer than expected (a complete circuit of 7 days has been observed in the Canaries, Barton *et al.*, 1998). The velocities within the filament were also weaker than reported in other upwelling systems. After 20 September the filament seemed to fade, one drifter following a similar eddy like structure while another moved south along the shelf break at a speed of 0.21±0.08 m s^{-1}. There has been a large dispersion of the drifters overall, although one ended up within 100 km of the starting point 110 days after deployment.

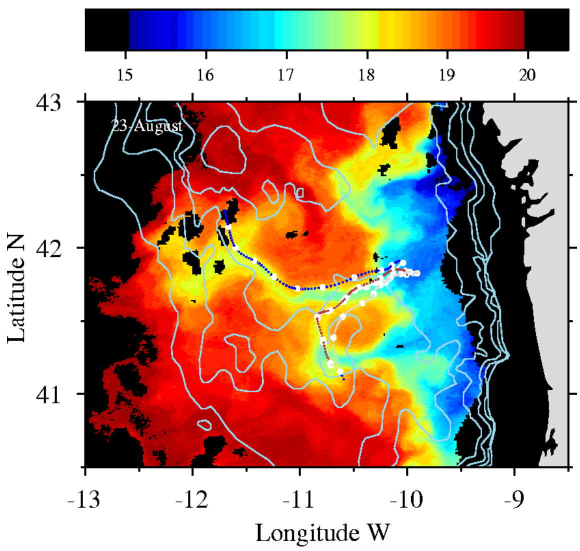


Fig. 2. 23 August SST and ten days of drifter data (5 days before and after the image). Solid dots indicate days.

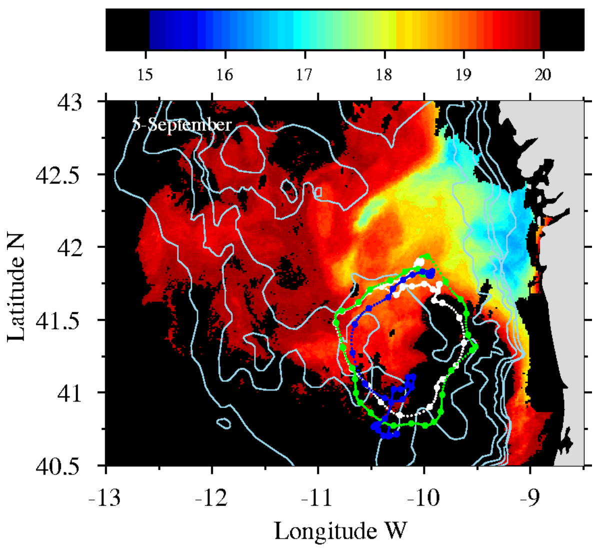


Fig. 3. 5 September SST with complete tracks of drifters while in the eddy (~ 20 days)

The mean surface ADCP data overlaid on the SST image of 18 August (Fig. 4) shows the typical intensification of the flow at the filament boundaries, where there is a strong horizontal shear while in the centre the flow is very weak. Note the differences between the northern and southern boundaries; the latter temperature gradient is sharper (0.75° km^{-1}) with weaker flow than the northern one (0.5° km^{-1}). The first partial section across the filament was carried out during the period of wind relaxation. Although it did not completely cross the northernmost boundary it showed flow intensification at the boundaries (stronger and more baroclinic in the north than in the south).

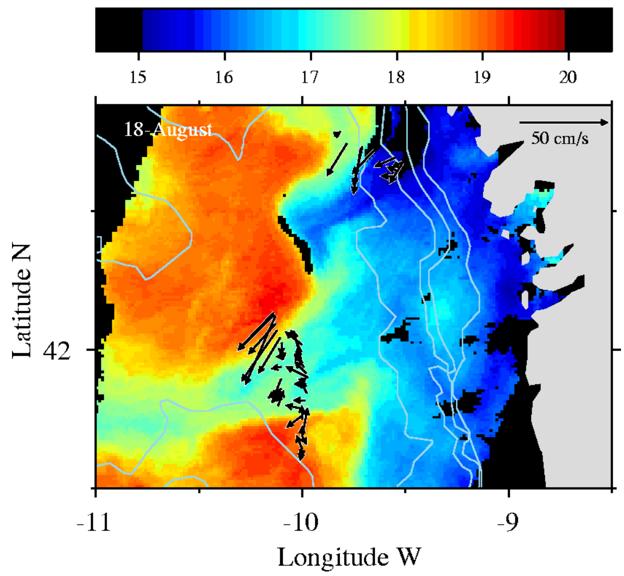


Fig. 4. Top ADCP bin (20 m) overlaid on the SST image of 18 August.

The flow within the filament was generally very weak and offshore down to the maximum penetration of the ADCP (150 m). The filament presented a double core structure resulting from its formation prior to the cruise by of two filaments merging into one, revealed by the SST imagery. The energy dissipation rate (a measure of the mixing of the water column) sampled by partner UWB-b showed enhanced mixing at both fronts, weak mixing in the core of the filament, and mixing largely reduced below the thermocline.

During the strengthening of the wind, 17-18 August, a more complete transect showed again the same north-south asymmetry (Fig. 5, 6). The northern front shows greater deepening of the isotherms, thicker thermocline, and stronger currents than the south front. Again, the inherited double core structure can be clearly seen down to 200 m.

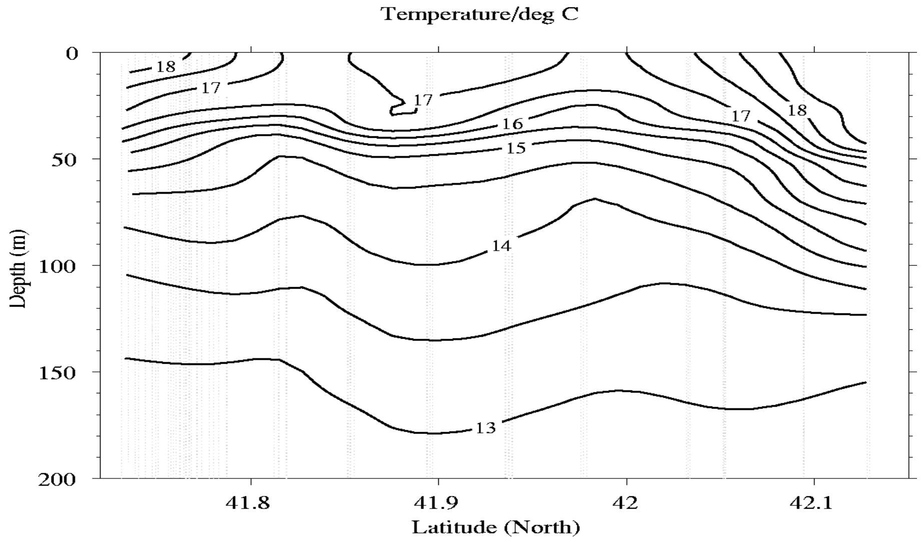


Fig. 5. Temperature section of the filament carried out on the 17 and 18 of August with the FLY profiler.

The baroclinicity previously seen in the northern front was reduced (Fig. 6) and a weak onshore flow can be seen at levels deeper than 50 m in the filament core. As before stronger velocities are found in the north related with steeper isotherms. The change in energy dissipation rate is more spectacular with a general increase in dissipation throughout.

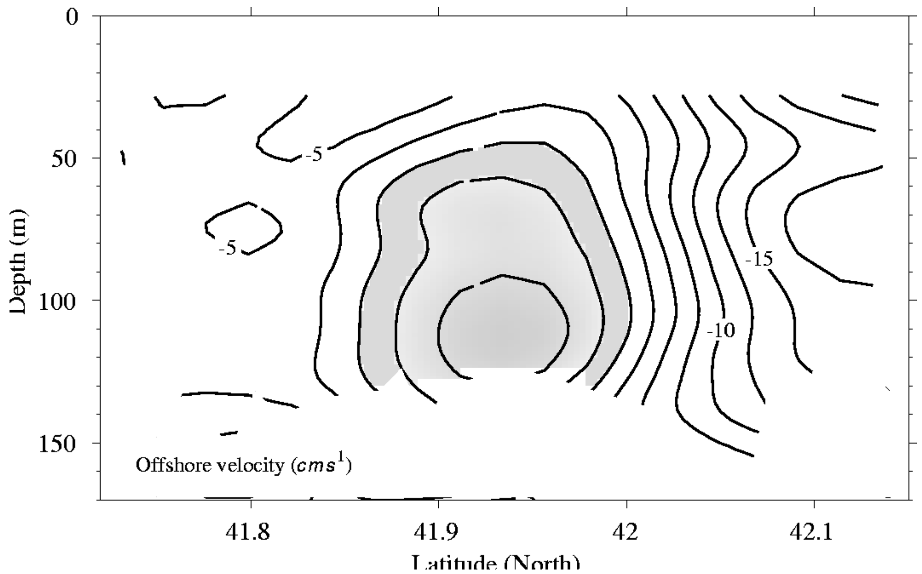


Fig. 6. ADCP derived velocities for the same period as above. Shaded is onshore velocity in cms^{-1}.

A denser sampling on the 17 August of the southern front (Fig. 7) revealed significant fine structure where subsurface mixed layers indicate subduction at the surface convergence. This section was carried out over 3 different sampling periods so the upper 20-30 m are influenced by diurnal heating. The subducting mixed layer at 40 m was associated with a large increase in dissipation in the absence of significant velocity shear.

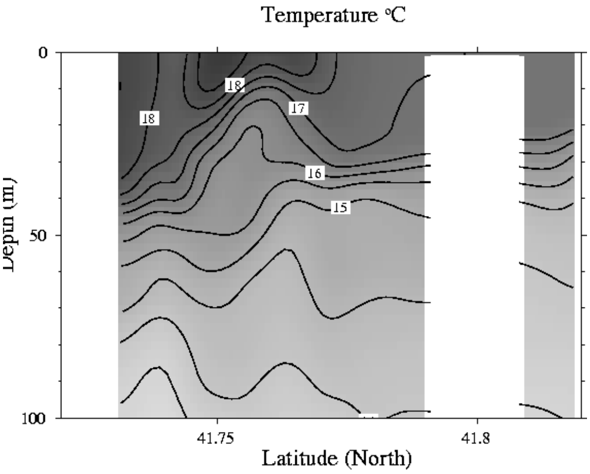


Fig. 7. Enlarged subset of Fig. 5 Temperature section

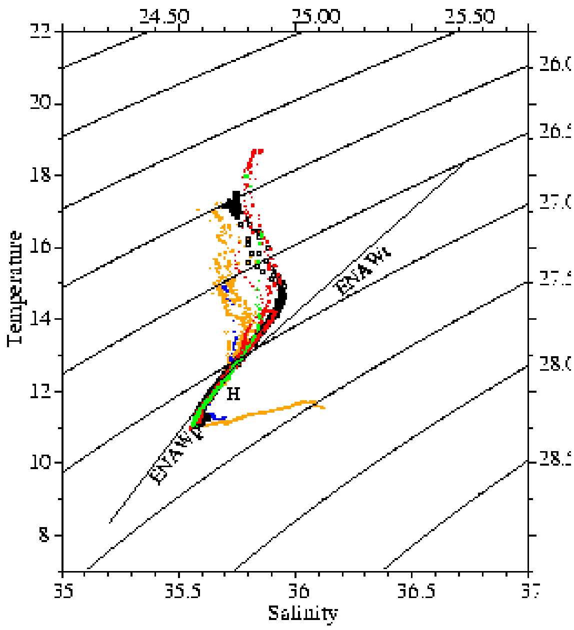


Fig. 8. TS plot showing water mass signals from inside the filament (black), shelf waters (yellow) and offshore water (red).

A TS diagram of selected CTD cast during the cruise (Fig. 8) shows how middepth filament waters (in black) have a signature closer to the surrounding oceanic water (red) rather than shelf-upwelled water (yellow). At the surface the TS properties of the filament water resemble shelf waters which had been advected with the superficial offshore flow. This indicates that the onshore flow seen in ADCP (Fig. 6) was carrying oceanic water shoreward beneath a very superficial filament structure

Winter Cruise. To assess the seasonal variability of the filament area, UWB-a participated in the *Meteor* cruise *M43/2* (28/12/98-14/1/99). During winter, the OMEX II-II region is generally under the influence of south-westerly winds. The upper layer circulation in this season is characterised by the presence of a narrow northward slope current which forms in November and disappears around May. This structure appears as a warm and saline intrusion (temperature 1-3ºC and salinity 0.2-0.3 psu higher than surrounding values), trapped within about 50 km of the shelf break, about 200-600 m deep, with characteristic velocities of 0.2-0.3 m s^{-1}, extending more than 1500 km along shore.

Bad weather conditions and a tight ship time schedule limited the coverage of the OMEX II-II box to only one CTD cross-shelf section along the S line. ADCP data was continuously recorded during the cruise except for times where rough sea reduced the quality of the data and when the ADCP suffered breakage of the communication cable.

Four SC40 ARGOS tracked drifters were released during the cruise. They were launched in a square cluster of 2 nm on 2 January 1999 over the shelf break (1000 m depth). Drifter 10312 deployed in the summer was still being tracked at the time of the cruise and was within 30 km of the release point. Minimum duration of the new drifters was 25 days for one which grounded south of Finisterre. The data amount to 400 drifter days till now. Details of the deployment and tracking are described in Table 2.

Table 2. Details of the launch of the ARGOS tracked drifters.

Drifter I.D.	Time	Latitude (N)	Longitude (W)	N° of Days
4010	08:48	40° 59.97’	9° 24.86’	134
3924	09:22	40° 59.86’	9° 27.75’	On going
4558	09:52	41° 01.85’	9° 27.83’	95
3923	10:27	41° 01.91’	9° 25.37’	33

In winter, westerly or southwesterly winds are expected but exceptional weather during and after the cruise gave conditions similar to summer, therefore upwelling favourable. This situation has been the norm rather than the exception for the winter of 1999. A warm salty poleward flow was expected to develop during the winter but was seen only for the first ten days of January when it was sampled once with CTD and ADCP. They showed the poleward flow to be a slope process extending to a depth of 700 m with typical ADCP velocities of 20 cm s^{-1}. The drifters, in the period 2-10 January moved northward following the bathymetry. Velocity estimates from the drifter positions give a mean value of 0.27±0.08 m s^{-1}. (Fig. 9)

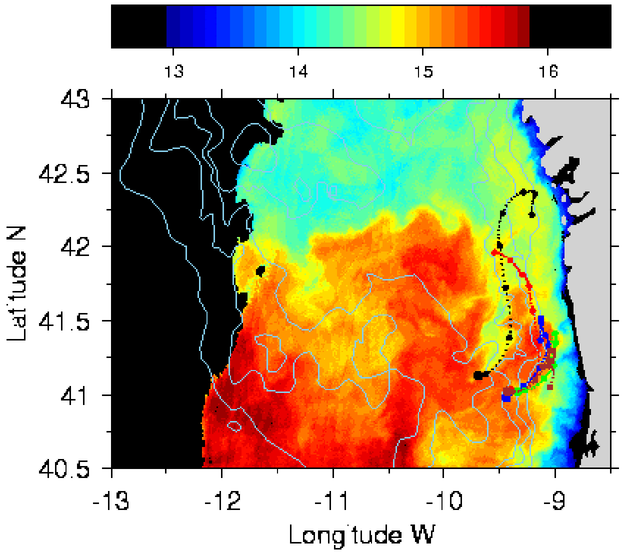


Fig. 9. Drifter tracks during their northward motion (2-10 January) overlaid on the SST image of 6 January.

With the onset of northerly winds the drifters ceased their northward motion and the rest of the winter deployment showed a net southward flow both near and offshore. The offshore southward flow is related to the Portugal Current, the easternmost branch of the North Atlantic subtropical gyre, which showed mean velocities of 0.17±0.08 m s^{-1}. Contrary to expectations there was a net southward transport near the coast which is again related to exceptional weather conditions and upwelling favourable winds that have been "typical" of the 1999 winter season. Mean velocity estimates varied between 0.22 and 0.11 m s^{-1}.

Discussion

The drifter data set has been further analysed statistically following the techniques described in Haynes and Barton (1991). Single particle lagrangian statistics were performed separately for the summer and winter deployment from the dispersion of the drifters. Assuming homogeneous isotropic turbulence from Taylor's theory, eddy diffusivity was calculated, indicating distinctive regimes in the two seasons. In summer, the presence of filaments gives rise to a rich mesoscale field which actively links the shelf and the open ocean at a large variety of time scales but with no clear net transport Eddy diffusion estimates were high and isotropic (zonal K = 9 10^6 cm^2 s^{-1}, meridional K = 9.7 10^6 cm^2 s^{-1}). In winter there is a clear inhibition of the shelf-ocean exchange seen during the summer deployment and drifters are restricted to the shelf with a larger meridional dispersion. Eddy diffusion estimates were smaller than in summer, giving a zonal K = 1.9 10^6 cm^2 s^{-1} and meridional K = 3.3 10^6 cm^2 s^{-1}. A further calculation was performed with all the drifter data available (including that of Haynes and Barton (1991)) giving bulk values for the area as: zonal K = 5.6 10^6 cm^2 s^{-1} and meridional K = 8.5 10^6 cm^2 s^{-1}.(These results are relevant to **Task I.6**, 2 way nested submodel.)

Conclusions

Most publications on filaments describe the structures as narrow surface intensified baroclinic jets flowing offshore with an associated total offshore transport of a few Sverdrup with a return flow further south. Our results showed a surprisingly different picture: the filament was mainly superficial, with very weak velocities and long return flow time scale which would have a limited export capability in terms of advection but the slow return flow would allow for sinking of fast material to occur on the slope and deep ocean rather than on the shelf.

Although weather conditions proved to be very similar during the two drifter deployments there are clear differences in drifter behavior in the summer and winter periods which were confirmed by the statistical analysis. The activity of upwelling filaments marks the summer surface circulation and they act as an active link between the shelf and open ocean but the associated return flow inhibits a net offshore flow of shelf waters. During winter, filaments did not occur, even though upwelling conditions persisted, and shelf waters were isolated from the ocean. During this exceptional winter, there has been a net southward transport over the slope contrary to previous evidence of persistent winter poleward flow.

References

Barton, E.D., J. Arístegui, P. Tett, M. Cánton, J. García-Braun, S. Hernández-León, L. Nykjaer, C. Almeida, J. Almunia, S. Ballesteros, G. Basterretxea, J. Escánez, L. García-Weill, A. Hernández-Guerra, F. López-Laatzen, R. Molina, M.F. Montero, E. Navarro-Pérez, J.M. Rodríguez, K. van Lenning, H. Vélez, K. Wild (1998). The transition zone of the Canary Current upwelling region. *Prog. Oceanog.* **41,** 455-504.

Haynes, R. and E.D. Barton (1990). A poleward flow along the Atlantic coast of the Iberian Peninsula. *J. Geophys. Res.* **95**, 11425-11441.

Haynes, R., E.D. Barton and I. Pilling (1993). Development, Persistence and Variability of Upwelling Filaments off the Atlantic Coast of the Iberian Peninsula. *J. Geophys. Res.* **98**, 22681-22692.