# INVESTIGATING BAY OF BISCAY MESOSCALE AND COASTAL OCEAN DYNAMICS FROM SATELLITE OBSERVATIONS

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ABSTRACT

Different altimetric data products are analysed in the Bay of Biscay region, to investigate how well they observe the ocean mesoscale dynamics and its relation with the coastal ocean. The Aviso mapped altimetry products are firstly investigated. Sea Level Anomaly (SLA) variability is mainly associated with the seasonal steric effect. However, a band of higher mesoscale variability with periods between 100 and 300 days is visible along 45°N, and can be associated with westward propagating eddies. The generation or modification of these eddies in relation to offshore filaments or jets from the coastal currents cannot be easily seen due to the high frequency aliasing over the continental shelf. Also, Optimally Interpolated (OI) data on a regular grid may not be adapted to local scales and tends to spread eddies out. For these reasons, a dedicated coastal altimetry dataset has been used. With this product, eddy-like features are detected using an along-track wavelet analysis scheme, represented with accurate amplitude and scales and compared to Infrared (IR) and/or Ocean Colour (OC) satellite imagery.

## 1. INTRODUCTION

The Bay of Biscay, in the North-East Atlantic, is a complex environment with a chaotic topography and a wide range of ocean dynamics, including a weak anticyclonic basin-wide circulation, the coastal Iberian Poleward Current, westward propagating mesoscale features and also high frequency shelf dynamics. Several studies have documented these processes, mainly from hydrographical data [1][2] but also from numerical studies [3] and IR or OC satellite imagery [4], the latter being hampered by cloudy atmospheric conditions.

In contrast, altimetric studies are rare, although altimetry is less affected by adverse meteorological conditions and has been widely used in other ocean basins. One of the reasons for this is the aliasing of unresolved high-frequency tidal and wind induced signals corrupting measurements over shallow water parts of the basin. Recent studies have shown that the use of state-of-the-art dealiasing models significantly improves [5] the quality of the data in these highly dynamic regions and improves the access to the lower frequency ocean dynamics.

In this study we investigate the mesoscale dynamics of the Bay of Biscay, and analyse how well they are observed by different altimetry products (using a standard gridded altimetric data product, and a regional altimetric product including the latest available dealiasing corrections and a specific coastal oriented processing) in conjunction with other data sets (remote sensing imagery). We will focus on the ability of these different data (used in combination or separately) to detect mesoscale processes and to document their main characteristics.

## 2. DATA

For this study we used multi-mission gridded SLA over a period from October 1992 to December 2008. Merged SLA grids were produced by SSALTO/DUACS and distributed by Aviso with support from CNES. For the second product, along-track data have been processed using the X-Track processor [5]. It contains up-to-date geophysical corrections (such as the recent GOT 4.7 tide model & MOG2D barotropic model). This data has been generated, validated and distributed by the Centre de Topographie des Océans et de l'Hydrosphère (CTOH/LEGOS, France). MODIS Imagery is produced and distributed by the Ocean Biology Processing Group.

## 3. OBSERVING THE BAY OF BISCAY MESOSCALE DYNAMICS FROM STANDARD ALTIMETRY PRODUCTS

Standard altimetry products have been intensively used in large-scale and meso-scale ocean dynamics studies [6]. When merging the data from several altimeters on a regular grid using an optimal interpolation scheme [7][8], one is able to detect mesoscale features in the ocean with a spatial resolution of ~200 km and a temporal resolution of ~20 days. For Gaussian eddies, this is equivalent to an e-folding scale of ~50 km.

For this study, we have firstly analysed all the available data (1992-2008) in the Bay of Biscay. As expected for the global ocean [9], the annual signal gives the main peak of energy in SSH variability, mainly due to the steric effects of dilation/contraction of surface waters. In the Bay of Biscay, this signal has an amplitude of 3-4 cm offshore, up to 5-6 cm over the shelf.

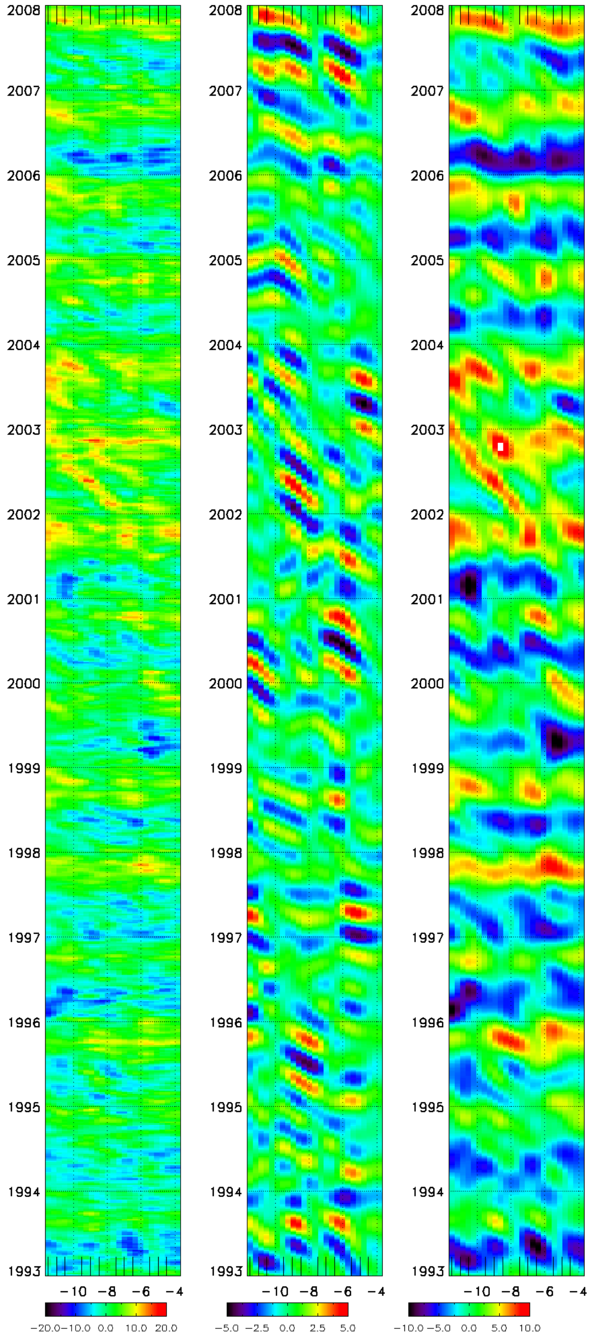


*Figure 1. Hovmöller diagram along 45°N (2° to 12°W) of raw SLA (left panel), SLA filtered from 100 to 300 days (middle panel) and SLA filtered from signals < 300 days (right panel). Units are in cm.*

Another important source of variability in the Sea Surface Height (SSH) is the effect of tides. On a SSH spectrum, one can clearly identify higher frequency peaks (< 100 days), corresponding to aliased sub-sampled tidal components in the SSH signal. M2 & S2 are visible everywhere, and other components increase in energy when moving towards the shelf, introducing a non-negligible noise in the signal in these areas. For this reason, data over the continental shelf should be analysed with extreme caution.

The spectrum also indicates increasing energy in the 100 to 300 day band offshore, around 45°N of latitude. Maps of rms SLA, filtered between 100 and 300 days, show zones of higher variability relative to the surrounding areas, in the deeper part of the inner Bay of Biscay, i.e. around 45°N, west of 4-5°W [10]. Our analysis shows that two clear zones emerge, one centred at 45.5°N / 6°W, and another around 45°N / 8° to 10°W. Between these two zones, the Cantabria Seamount rises to approximately 800m over the sea floor, indicating a possible influence of bathymetry over ocean variability. A Hovmöller diagram at 45°S of the 100 to 300 day signal (fig. 1) shows westward propagation of positive / negative SLA (fig. 1). As seen in fig. 1, we note that part of this signal with frequencies similar to the seasonal variability is removed when filtering the data.

Maps of gridded SLA indicate that these features are associated with zonally propagating eddies, with spatial scales of xx km. Applying a Radon Transform to the filtered data along 45°N indicates westward propagation speeds from 1 to 2 $cm.s^{-1}$, similar to propagation speeds suggested from satellite SST data.

The amplitude of these propagating eddies varies interannually. For example, the Hovmöller analysis shows that during 2001 to 2003 the eddy intensity increased strongly crossing the Bay of Biscay, with implications for an increased westward transfer of mass and nutrients during this period, carried by these eddies.

To monitor the pathways of these eddies in more detail, an eddy-tracking algorithm was applied, based on a tracking of SLA and a quantity Q, equivalent to the Okubo-Weiss parameter, which characterises regions where rotation dominates deformation. This tracking procedure confirmed the westward propagation along 45°N, but showed more details of the eddies deviations around bathymetry, and their regions of splitting, merging or dissipation. Many observed eddy features dissipate rapidly in this dataset. This may be real, but may also be due to the optimal interpolation (OI) scheme, since typical length scales of eddies within the Bay of Biscay (~30 km; as in [11]) are smaller than typical length scales observed from altimetry.

## 4. ALONG-TRACK OBSERVATIONS OF "EDDY-LIKE" FEATURES FROM ALONG-TRACK DATA

[10] have shown that eddies in the Bay of Biscay could be better monitored using a higher resolution grid which implies using an OI scheme adapted to the regional length scales. This is a more sophisticated task, starting from the processing of along-track altimetry data with

specific local corrections, to the coherent mapping of this data using regional length scales.

Here, another approach was chosen. As described by [12], wavelet analysis can be used to detect waveforms varying in time and scale in a signal. The wavelet analysis can also be applied to along-track altimetry data to extract coherent "eddy-like" features along an altimeter pass, as in [13]. The main advantage of this technique is to preserve the along-track resolution of the data, which is high enough to access to the mesoscale and sub-mesoscale variability of the ocean surface.

For this study, we decided to analyse features with scales from 50 to 250km, and in deep water regions deeper than 1000m. A Gaussian wavelet with a good space and time resolution has been chosen.

When projecting the results of the analysis against time, occurrences if eddies along an altimeter track are clearly visible as peaks of energy for the chosen spatial scales. Also, an interannual modulation is visible on the signal, with an increased eddy energy for years 1999 to 2003. Interannual modulation of the signal does not seems to be directly correlated to Navidad development years. This result is in agreement with the gridded data set, however, in the inner Bay of Biscay, the time series is much more energetic, with higher amplitude eddies crossing the track in the along-track data.

These differences can be seen for a specific example (fig. 2), where an oceanic eddy detected by the wavelet analysis is compared to the gridded data set and an ocean colour image. The differences are not only in terms of SLA, but also in scale, and thus in across-track geostrophic velocities, with these variables being underestimated of about a factor of 2 (or more). Time scales are also misrepresented on gridded data, with an overestimated residence time of about 2 weeks.

In a more general way, inside the Bay of Biscay, while scale and amplitude differences between the two products being close to 0 for eddy-like features with scales greater than 225 km, a global bias of about 2 cm and 50km is observable for scales between 100 and 200km. Differences in amplitude can reach 5-6 cm for scales around 175km, which is the average scale for eddy-like features as seen by along-track altimetry in this region (with average scale increasing westward). The resulting reduction of geostrophic velocity anomalies is close to 50% in the gridded data for eddies having amplitudes greater than 5cm on along-track data.

It is also interesting to notice that a spectral analysis of the two data sets show a spectral discrepancy below 100-200 days, with levels of energy lowered on the gridded data below this period.

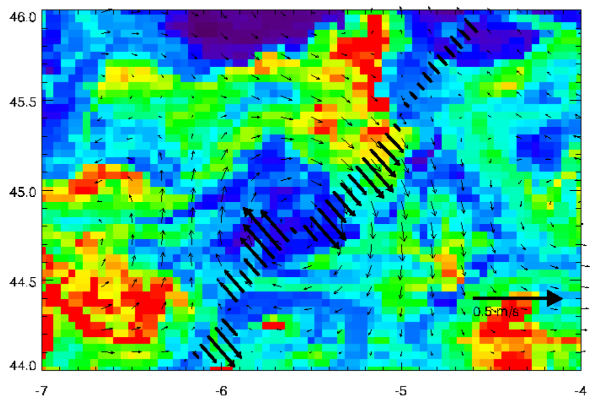


*Figure 2. Modis chlorophyll concentration image from 19th March 2003 taken in the middle of the Bay f Biscay. Across-track geostrophic velocity anomalies for the nearest pass of the Topex/Poseidon altimeter at +- 5j. are represented as arrows along altimeter tracks over the image.*

## 5. CONCLUSION

Evidences of mesoscale activity have been shown on the standard altimetry products in the Bay of Biscay. A band of westward propagation is located around 45°N, with associated periods of 100-300 days. Eddy activity seems to have an interannual variability, which is confirmed by the along-track data. Possible interactions with bathymetry are suggested by the analysis of the 100-300 days signal RMS, Hovmöller diagram and eddy-tracking algorithms.

However, the wavelet analysis has shown that smaller scale eddies, dominant in the region, were badly represented. Spectral analysis indicates that these smaller scale processes with relatively high temporal signature are missing in the gridded data set, with levels of energy underestimated. This missing energy in the mesoscale field makes lagrangian analysis of the data, such as Okubo-Weiss analysis or Finite-Size Lyapunov Exponents, really difficult as these techniques are very sensitive to the velocity field.

Ongoing research will focus on the possibility to track the lifespan of these eddies using a wavelet analysis scheme on the along-track data. This analysis can be coupled to the few satellite imagery available on the zone to confirm or not the presence of eddies at a given location. Other techniques, such as an adapted OI scheme will be tested and/or combination of all the available data for retrieving all scales of variability. In addition, available in-situ data and wind data (from scatterometry), will be used to study the 3D characteristics of the eddies and the influence of the wind on their formation / propagation mechanisms.

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