FISHERIES MONITORING IN THE CABO VERDE REGION USING ERS DATA

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ABSTRACT

The aim of this study is the application of ERS data (ATSR2 and radar altimetry) to fisheries monitoring in the Cape Verde region. This work is being done in the scope of the ESA A03-265 project.

The Cape Verde Archipelago lies under the influence of the southern portion of the Canarias Current, where it turns westward and becomes the North Equatorial Current. Cold and nutrient-rich waters upwelled at the Western African coast are transported south-westward along this current system. However, due to the seasonal north-south migration of the current system, the south-eastern region of the islands can be affected by the Equatorial Countercurrent. Two very different water masses meet forming a large scale frontal system in the vicinity of the archipelago. These frontal zones are potentially favourable for the aggregation of large pelagic highly migratory fish species. The knowledge of the front location and variability has a great socio-economic importance for the local fishing industry, as well as in the support of global stock management of these species.

Using maps of sea surface topography and sea level anomalies derived from satellite altimetry and maps of sea surface temperature from ATSR2, the general features of the ocean circulation in the study area have been investigated. Due to the fact that Cape Verde region has very cloudy conditions, the synergy of microwave and infra-red data is of great importance for this study. The methodology used in this analysis and the results obtained so far are presented.

Future work involves the use of in situ data to validate satellite derived information and the investigation of the relationships between fishing success and the ocean conditions measured by satellite and in situ methods. The ultimate goal will be the development of an operational methodology for the location of potential favourable areas for the concentration of large pelagic fish in the area of local fishing fleet activity.

INTRODUCTION

The study area is the North Atlantic surrounding the Cape Verde Archipelago ($4^\circ \le \varphi \le 24^\circ$, $-34^\circ \le \lambda \le -16^\circ$). This region possesses very rough topography and bathymetry (Fig.1), with areas of very deep ocean, more than 6000 m depth, and islands with heights above 1000 metres.

The main objective of this study is the application of remote sensing data to fisheries monitoring in the Cape Verde region. The satellite data used are mainly ERS-2 data: Sea Surface Temperature (SST) from ATSR2 and altimetry from the Radar Altimeter (RA). Bearing in mind that this is a particularly cloudy area the synergetic use of altimetric and SST data is of valuable help.

This work is under the scope of ESA AO3-265 project. This paper presents a status report of the studies being done in the framework of this project.

Altimetry and infra-red remote sensing have been applied with success to the study of large scale circulation patterns and fronts [1], [2], [3], and have proved to be a powerful tool in fisheries research [4], [5].

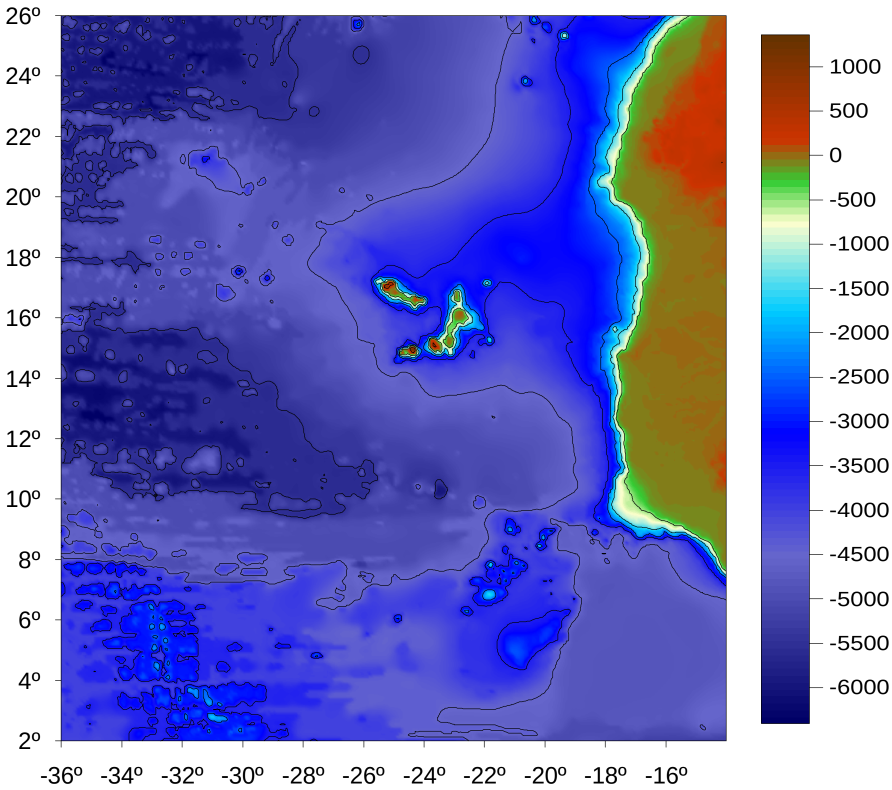

Fig. 1. The Cape Verde region. Colour scale shows bathymetry and topography from JGP95. Contour interval =1000 m.

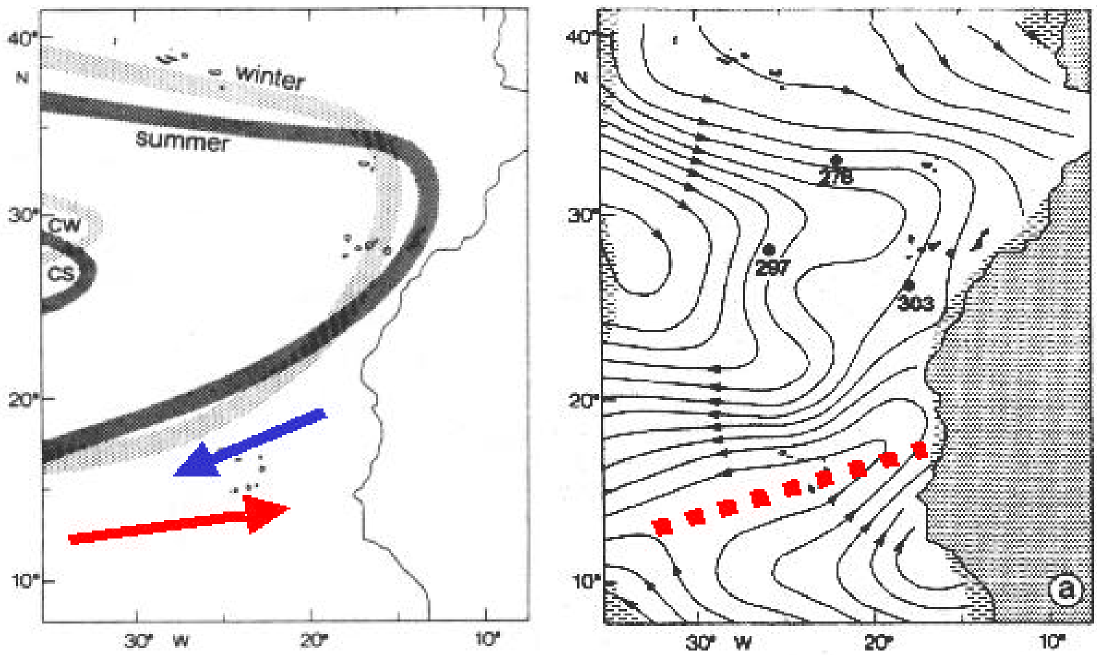

Fig. 2. Idealised location of the North Atlantic Subtropical Gyre at winter and summer (left) and mean integrated transport of the upper ocean from 0 to 200 m (right),[6].

Cape Verde is located at the eastern boundary of the North Atlantic Subtropical Gyre at the southern limit of the Canary Current System. The southern limit of the gyre, transporting cold waters south-westward (North Equatorial Current), meet warmer tropical waters of the Equatorial Counter-Current, generating a large scale frontal System at the latitudes of Cape Verde (Fig. 2). The waters transported southward by the canary current are nutrient rich and consequently important from the biological point of view. On the other hand, tropical mid ocean waters are poor in what concerns biological production.

As the Equatorial Counter-Current approaches the coast, it recirculates northward, originating a dome at the Southeast of Cape Verde. These recirculated waters then enter the North Equatorial current as a southern branch.

Due to the seasonal variability this large scale circulation structure migrates meridionally and significant changes are observed in the transport at the upper ocean as calculated from historical hydrographic data [6].

The same general features can be seen in a map of the mean sea surface topography as given by the global oceanographic model POCM4-B [7], Fig. 3.

Seasonal variability also affects the cloud coverage in the zone, associated with the position of the tropical convergence zone. This fact will be an important caveat as clean summer thermal imagery will be less frequent.

The methodology used in this study is explained next. First, the general features of the ocean circulation in the study region are derived from satellite altimetry and ATSR data. Maps of absolute dynamic topography (ADT) and sea level anomalies (SLA) have been derived from satellite altimetry. For the derivation of absolute dynamic topography maps, a regional gravimetric geoid has been computed. Using these data sets, the main features and variability of the large scale frontal system formed in the vicinity of the archipelago are analysed.

The next three sections describe data processing and methodology used in the computation of a regional gravimetric geoid, maps of sea surface height (SSH) variability from satellite altimetry and maps of SST from ATSR data. The last two sections present a preliminary data analysis and the future work to be done in the scope of the ESA project AO3-265.

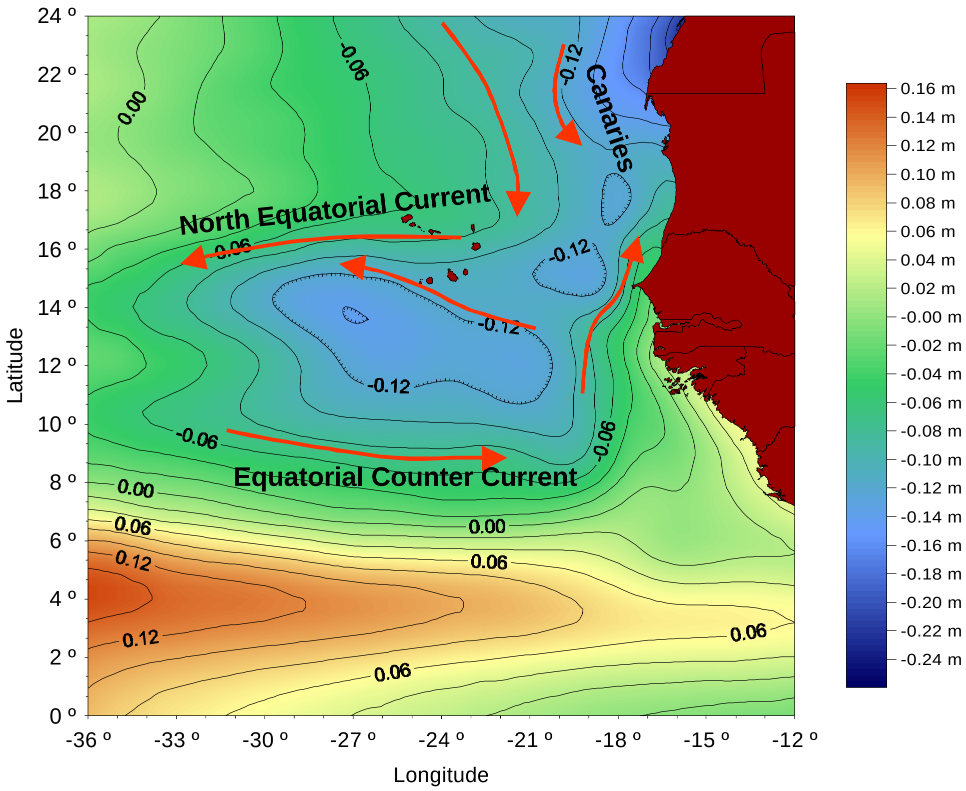

Fig. 3. Mean sea surface topography and main current system around Cape Verde, from global model POCM-4B. Contour interval: 0.02 m.

COMPUTATION OF A REGIONAL GRAVIMETRIC GEOID

The marine gravity data available over the study region have been provided by BGI (Bureau Gravimetrique International). These data have a very uneven spatial distribution, as shown in Fig. 4. The accuracy of this data set is difficult to access and is variable but usually not better than a few mGal. Data has been validated by comparison with existing gravity anomaly data sets derived from satellite altimetry (GSFC00 and KMS99). A description of these models and comparison with respect to other existing solutions is presented in [8]. After editing and validation, marine gravity data have been separated into profiles and a profile adjustment has been performed by minimizing the differences at the tracks intersections, solving for a bias for each profile. Since the ship data presents large gaps in spatial coverage, these gaps were filled with gravity anomalies from the GSFC00 model, using a method described in [9].

The geoid computations have been performed with the GRAVSOFT software package [10]. The method used in the geoid computations was the remove-restore method. This splits the geoid undulation (N) into three components:

$$N = N_{MODEL} + N_{RTM} + N_{res} \tag{1}$$

N_{MODEL} represents the contribution from the reference model, N_{RTM} the residual terrain effect contribution and N_{res} the residual anomaly field after removal of the two previous contributions.

In a similar way the observed gravity anomalies are split into three components:

$$\Delta g_{obs} = \Delta g_{MODEL} + \Delta g_{RTM} + \Delta g_{res} \tag{2}$$

The geopotential model used in the computations is EGM96 [11]; the terrain model is JGP95. The information about JGP95 can be found in the readmeJGP95.txt file available in the anonymous ftp address: ftp://cddisa.gsfc.nasa.gov/pub/egm96/, written by N. K. Pavlis. The computations of the residual terrain model (RTM) contributions were made by prism integration.

The statistics of the surface gravity reduction are presented in the first three rows of table 1.

Table 1- Statistics of gravity reduction (in mGal)

	number of points	Mean	St. Dev.	Min	Max
Δg_{obs}	174072	2.03	21.51	-72.45	424.20
$\Delta g_{obs} - \Delta g_{EGM96}$	174072	-0.44	11.90	-105.18	338.10
$\Delta g_{res} = \Delta g_{obs} - \Delta g_{EGM96} - \Delta g_{RTM}$	174072	-0.16	11.76	-133.05	133.39

The computation of the residual contribution, N_{res}, has been performed by Fast Fourier Transform (FFT).

For use with FFT methods a grid with spacing 0.05º x 0.05º was built, using the original surface data and the selected altimeter derived anomalies. The gridding was performed by collocation, using a correlation length of 18 km and 8 points per quadrant. To reduce the discontinuities between the surface and the altimeter derived gravity a Butterworth filter of second order with a half power point at 50 km (half-wavelength) has been applied. This procedure smoothes the gravity field and yields a smoother geoid solution, which serves our purposes of determining the absolute sea surface topography at wavelengths longer than 100 km.

The geoid solution obtained is presented in Fig. 5. This is a preliminary solution, which needs further improvement. An inspection of the residuals of this regional model with respect to EGM96 and the global mean sea surface (MSS) solution CLS_SHOM99 [8], reveals patterns associated to some of the ship gravity profiles, an indication that the editing and adjustment of the marine gravity data can still be improved. In spite of this, this regional model allows the determination of a first picture of the absolute dynamic topography of the region, as it will be explained in the next section.

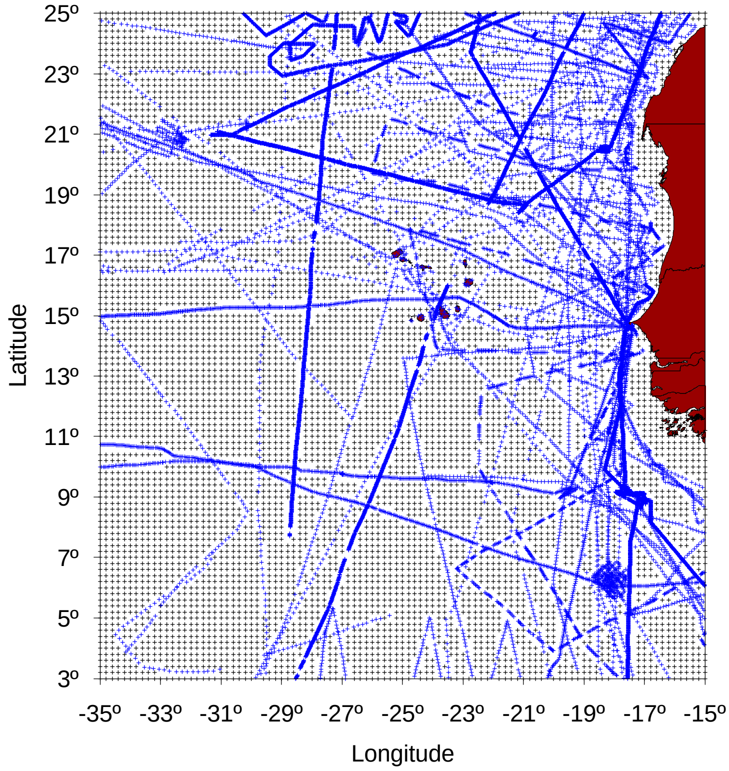

Fig 4. Gravimetric data distribution: blue points - ship data; black points - altimeter derived gravity anomalies (GSFC00).

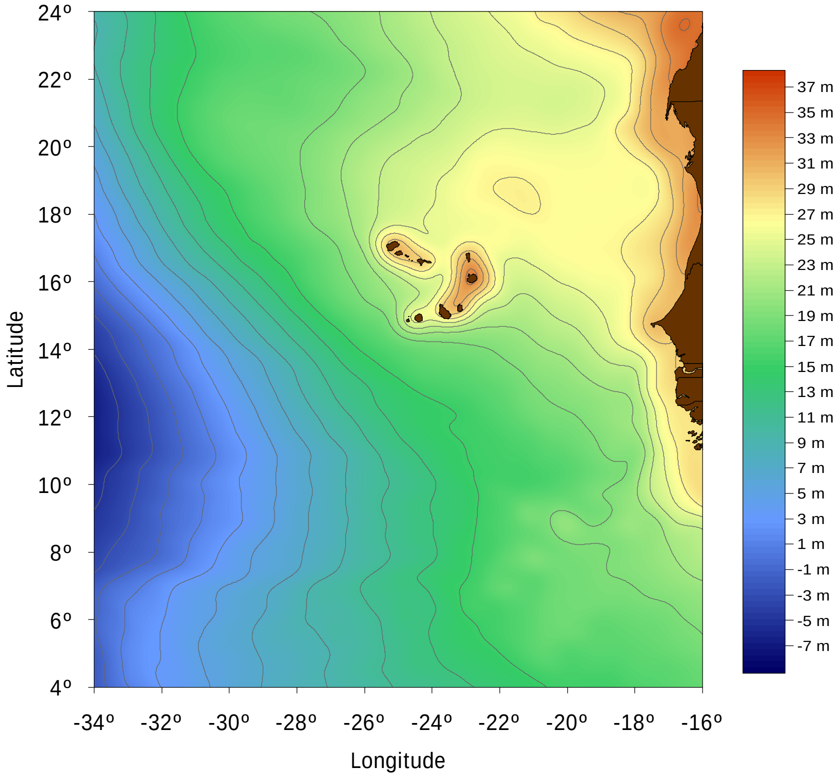

Fig. 5 - Regional gravimetric geoid. Contour interval = 2 m.

ALTIMETRIC DATA PROCESSING

The altimeter data used in this study are OPR02 data from ERS-2, provided by ESA (European Space Agency) in the scope of the Third Announcement of Opportunity project A03-265. This data set comprises 21 ERS2 cycles (26 - 46), from October 1997 to October 1999. The across-track spatial resolution of these data is about 80km. For each measurement point the instantaneous Sea Surface Height (SSH) has been computed by:

$$\mathrm{SSH} = h_s - (h_a + \mathrm{corrections}) \quad (3)$$

where h_s is the satellite height relative to the reference ellipsoid (WGS84) and h_a the altimeter measurement corrected for instrument corrections. The following geophysical corrections have been applied [12]:

- dry and wet troposphere (radiometer correction)
- ionosphere
- solid earth tide
- pole tide
- ocean tides and tidal loading (CRS4.0 model)
- inverse barometer effect
- sea state bias [13]
- SPTR (Scanning Point Target Response) and USO (Ultra Stable Oscillator) drift

The satellite orbits used are the precise DGM-E04 orbits available from Delft University of Technology [14]. The time tag bias associated with these orbits was applied ($1.3\mathrm{x}10^{-3}$ sec). No crossover adjustment has been performed. However it was found that the rms of crossover points differences was about 6 to 7 cm and that the use of the CSR4.0 model systematically reduced these differences by 1 to 2 cms with respect to the FES95.2.1 model [15].

The altimeter data were then separated by cycle. For each cycle, a grid has been computed for the whole study region, using the krigging method implemented in the commercial software SURFER. These grids have been filtered using a Butterworth filter of 2nd order, with a half power point at 100 km (half-wavelength). The difference between each SSH grid and the geoid (regional model) has been computed, providing grids of absolute dynamic topography (ADT). Fig. 6 shows the ADT maps for cycles 29 (January/February) and 33 (June/July) 1998 respectively.

In a similar way, the difference between each SSH grid and the Mean Sea Surface (MSS) given by the CLS_SHOM99 model [8] has been computed, providing grids of Sea Level Anomalies (SLA). Fig.7 shows the SLA maps for cycles 29 (January/February) and 33 (June/July) 1998 respectively.

ATRS-2 DATA PROCESSING

Four periods of 35 days were chosen to match the existing altimetry:

- cycle 29 (Jan/Feb 98)
- cycle 33 (June/July 98)
- cycle 39 (Jan/Feb 99)
- cycle 44 (July 99)

A total of 198 SST images were selected, each 512 by 512 pixels, from the ‘quicklooks’ available at the ESA web site. The total number of images was later reduced to 120 due to cloud cover.

The images have been processed using the image processing software PCI. Each SST image was processed to remove the cloudy pixels (values set to 0) and the land pixels (values set to 1), using the information flags provided. The ‘Nadir’ and ‘Dual view’ SST data [16] were processed independently. Pixels with SST above 30ºC were considered to be noise and therefore set to 0. To reduce the noise, which occurs mainly on the boundaries between cloudy and non-cloudy areas, a 3 by 3 median filter was applied to the SST images.

Each SST was rectified into a georeferenced data set covering the area of interest. The georeferenced data set is an image of 1696 pixels by 1760 lines, with a pixel size of approximately 30 arc seconds in latitude and longitude.

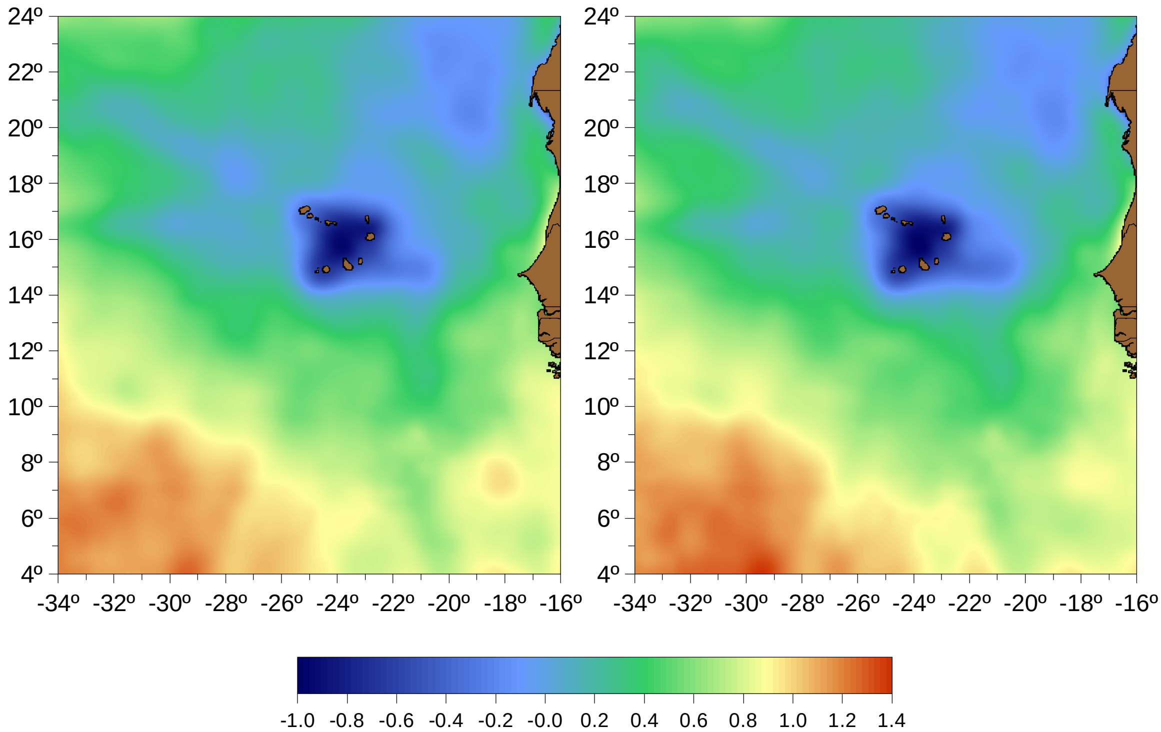

Fig. 6. Abolute Dynamic Topography for cycle 29, January/February 1998 (left) and cycle 33, June/July 1998 (right).

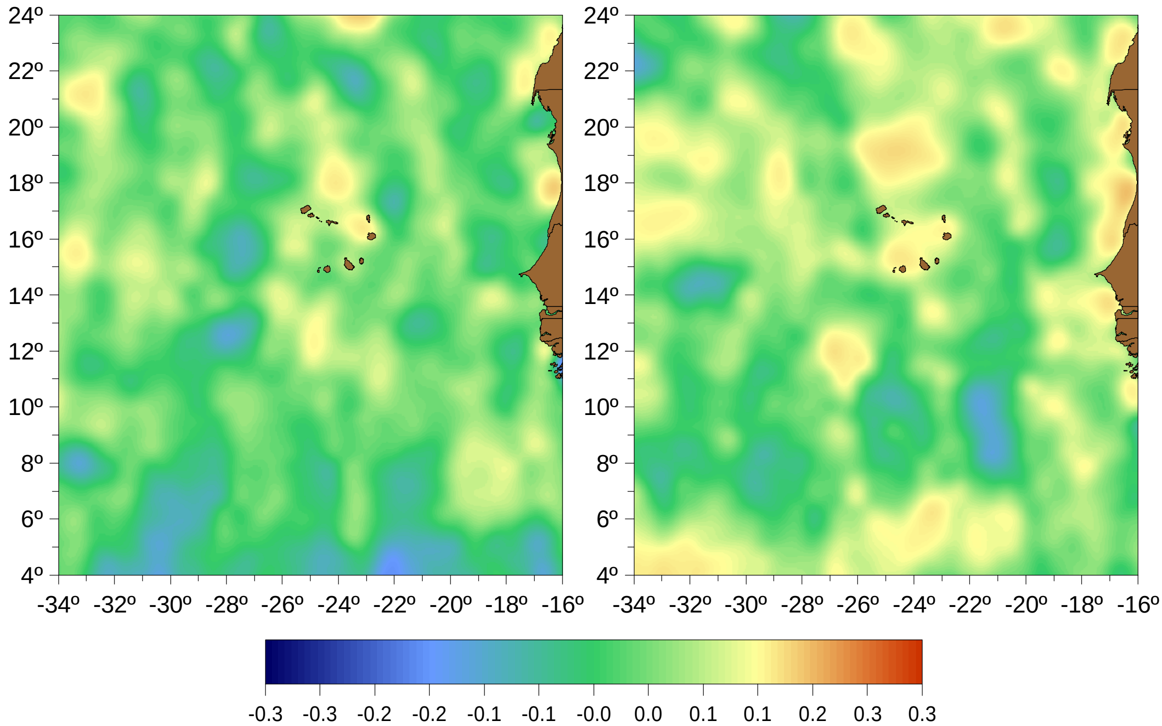

Fig. 7. Sea level anomalies for cycle 29, January/February 1998 (left) and cycle 33, June/July 1998 (right).

The individual images from each of the four periods of study were aggregated into a single image, using the maximum SST value, when more than one image covered the same area.

As the coverage was not satisfactory due to cloud cover, the ‘Nadir’ and ‘Dual view’ SST images were aggregated into a single image, to which a 5 by 5 median filter was applied. The final SST images are displayed in 8 bits, covering SST values between 10ºC and 30ºC, with 0.1º increments, using a pseudo colour table ranging from dark blue (colder) to dark red (warmer) for visual interpretation purposes.

The resulting mosaics for the winter (cycle 29) and summer (cycle 33) of 1998 are presented in Fig. 8. We can see that the winter image gives a clear position of front system. In the summer image, in spite of the very poor coverage due to clouds, it is possible to see the northern migration of the front.

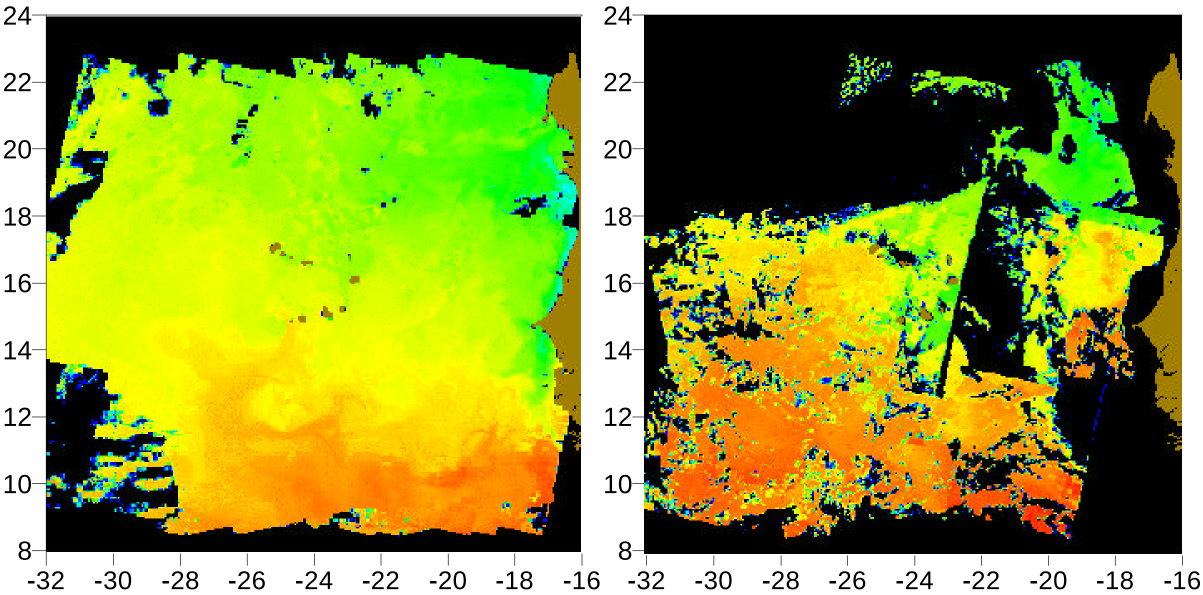

Fig.8. ATSR mosaics of winter (left) and summer (right) 1998.

DATA ANALYSIS - PRELIMINARY RESULTS

The ultimate aim of the project is to use satellite information for the determination of the potentially important structures, from the fisheries point of view, within the area of action of the local fisheries fleet.

The scales of interest in the zone of Cape Verde are not only related with the mean location of the frontal system itself but also with sub-frontal structures associated with the mesoscale activity along the front. Besides the natural large scale horizontal wave motions typical of large frontal systems [17], a wide range of scales are expected. These scales are mainly related to the oceanographically important parameter, the Rosby radius, defined as,

$$R_0 = \frac{N\,H}{f} \qquad (4)$$

where N represents the Buoyancy frequency, a measure of the internal stratification state of the ocean, H the depth and f the Coriolis parameter. A crude estimate of R_0 for the study zone is about 200 km (using IPIMAR hydrology data). This scale, sometimes called the internal ocean radius, constitutes the frequency of response of the ocean to any kind of disturbance. We thus expect that the main eddies and frontal structures in the area will have scales from R_0 up to $2\pi R_0$. This upper limit constitutes an estimate for the length of baroclinic unstable modes, e.g., scales at which the transfer of energy from large scale to mesoscale structures will preferentially happen.

We also expect that smaller scale motions resulting from the interactions of the above ones or from the topographic forcing of the islands will be observed on the altimetric maps. In situ data collected by IPIMAR research vessels revealed sub-mesoscale structures of the order of 60 km. Although not significant to the fisheries application they may be important contributors to the sea surface anomalies and altimetry processing.

A clear picture of the Cape Verde frontal zone has been obtained with the ATSR images for the winter months of January/February 1998 (Fig. 9) and 1999. In Figure 9, the position of the front has been marked in black. It is possible to observe that the front is constituted by cold/warm intrusions, dipoles and eddies of different sizes of the scale of the Cape Verde Archipelago itself. These features have spatial scales of the order of 50 to about 1000 km and evolve in time scales of one to several months. The majority of these structures are expected to be detected in altimetric signals.

The maps of sea level anomalies (see example on Fig. 7) clearly show zones of cyclonic (negative anomalies) and anticyclonic (positive anomalies) circulation. A simple interpretation of the flow structure associated with those structures matches that of the cold/warm deformations along the front. The signature of the vorticity structures and their interaction is depicted in Fig. 9.

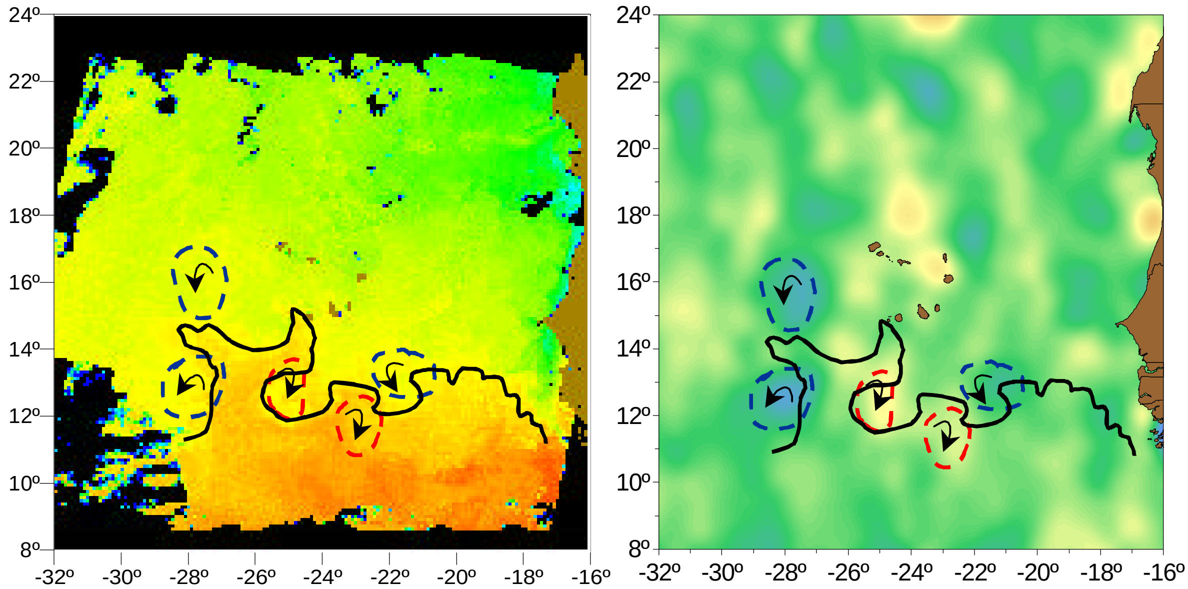

Fig. 9 - Location of the main front structures in the ATSR (left) and SLA (right) images of winter 1998.

An analysis of the maps of absolute dynamic topography (ADT) and seal level anomalies (SLA) shows that the anomaly analysis seems to be better suited for the determination of the sub-frontal structures than for the identification of the large scale front itself. The location of the front should be better determined in the ADT maps. However, since in these maps the permanent signal is about one order of magnitude larger than the variable signal, it is more difficult to detect the sea level variations. If a precise geoid model is used to generate these maps, they should actually reveal the absolute dynamic topography of the area and, therefore, make possible the derivation of the total geostrophic currents. The maps shown in Fig. 5 show that to achieve this, improvement in the data processing is needed mainly in two aspects: geoid improvement and altimetry data processing in the region surrounding the islands. It has been shown [9] that an adequate data processing can substantially improve altimeter analysis in coastal regions such as this.

In conclusion, at the scales of Cape Verde, the frontal structures of interest are those concerned with the mesoscale activity along the frontal system. These structures are mainly associated with instabilities generated along the front and have lengths of about 100 to 1000 km. These structures are observable in both the thermal (ATSR) and altimetric derived maps with compatible spatial scales.

FUTURE WORK

Improvement in the geoid model (and consequent altimeter analysis) and the use of more cloud free winter imagery will make possible to obtain a clearer picture of both the frontal and sub-frontal structures present in this region. The results obtained so far with ERS altimeter data only will be compared and merged with Topex/Poseidon data.

The preliminary data analysis presented here shows that the synergetic use of altimetry and SST allows the characterisation of the main features associated with the front system formed in the Cape Verde region. This analysis can be improved by using other types of satellite data, such as ocean colour or SAR images. Due to the dense cloud cover of this region, in particular in the summer months, it is expected that SAR data will be of valuable help.

Once the main features of the front system have been characterised, the next step will be concerned with the establishment of the relationships between fishing success and the ocean conditions measured by satellite and in situ methods.

The ultimate goal of this study will be the development of a fishery support demonstration programme based on satellite-derived information. Under that demonstration experiment the project team will try to predict potentially favourable fishing zones, and based on that information, give some advice to the local governmental fishing agencies and to the fishing fleet, which in turn is supposed to send feedback information to the research team.

ACKNOWLEDGEMENTS

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