Potential roles of jet instability and turbulence in controlling the bio-optical ocean proprieties

A. Benazzouz[1], S. Mordane[2], K. El Had[1], A. Naghib[1], H. Demarcq[3]

[1] Institut Supérieur d'Etudes Maritimes, Casablanca-Morocco; [2] Faculté des Sciences Ben M'Sik; [3] Institut de Recherche pour le Developpement, French;

Abstract

In the Canary Current System (CCS), coherent structures and concurrent movement of surface waters to offshore regions such as meanders, filaments and eddies strongly control the bio-optical proprieties response to coastal upwelling process. One of the outstanding problems is to understand the mechanisms of the bio-optical proprieties transfer and the coast-open ocean connection mechanism.

We use a combination of satellite data and derived mesoscale indicators to provide a comprehensive view of the relationship between the physical and bio-optical proprieties off North-west Africa upwelling region (part of the CCS) in terms of wind impulse responsible of sea turbulence, sea surface temperature (SST) response of the wind stress and ocean color proprieties considered as bio-optical ocean response.

To optimize the predicted ranges of these parameters, Generalized Additive Model (GAM) was applied.

We conclude that the energetic mesoscale structures as seen from altimetry satellite observations can provide insight into dominant transport pathways controlling the horizontal bio-optical exchange from the coastal area to the ocean interior.

1. Introduction

Transport in the Canary Current System (CCS) is inherently chaotic (Fig. 1 and 2). Instabilities generated in the upwelling jet is spatially structured into filaments and eddies that remain coherent, relatively persistent and recurrent for several weeks, penetrating up 300's of kilometers offshore and transporting bio-opticcally important materials far into the ocean interior.

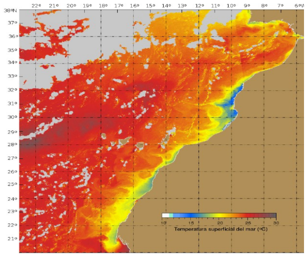


***Fig1:** Sea surface temperature highlighting a strong mesoscale activity*

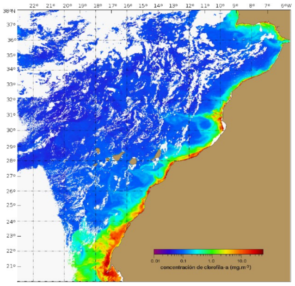


***Fig2**: Ocean color highlighting a strong mesoscale activity and offshore extension of the coastal bio-optical proprieties*

The horizontal exchange of organic material and nutrients between filament and surrounding offshore waters could sustain high production rates outside the upwelling zone, or, alternatively, nutrient upwelling generated by the filament dynamics could significantly contribute to the offshore productivity (Jones et al. 1991).

2. Climatological data sets and the derived indices

2.1. Remote Sensing Data

The signatures of upwelling through remote sensing are cooler sea surface temperatures, high chlorophyll-a concentration, lower sea level and intense along shore wind stress.

SST data have been gathered by the Advanced Very High Resolution Radiometer (AVHRR) sensors of the National Oceanic and Atmospheric Administration (NOAA) satellite series. The ocean color data is provided by MODIS (or Moderate Resolution Imaging Spectroradiometer)

Satellite altimetry is taken from the Archiving, Validation and Interpretation of Satellite Oceanographic Data (AVISO)

The ocean surface winds at 10 meters of sea surface are provided by NOAA/NESDIS utilizing measurements from ASCAT aboard the EUMETSAT METOP satellite.

2. 2 Mesoscale hydrodynamic indicators

Several mesoscales indicators have been derived from satellite products:

- *Cross Shore Ekman Transport ($m^3/s/m$):*

The classical atmospheric forcing variable is the Ekman-upwelling, or Bakun index (Bakun, 1973). Under the assumption of an alongshore balance between Coriolis force and alongshore wind stress, the offshore Ekman transport per unit length (CSET) is given by:

$$CSET = \frac{\tau_{alongshore}}{\rho f}$$

where $\tau_{alongshore}$ is the alongshore surface wind stress, ρ is the surface water density, and f is the Coriolis parameter.

- *Turbulence indice ($(m/s)^{-3}$):*

The energy transferred through the water column by the wind creates turbulence in the surface layers. A wind-mixing index in the upper layer is therefore usually calculated as the cube of wind speed. We used this index as an indicator of turbulence in the surface layers (Patti et al., 2007).

$Tur = S^3$ *where S is the wind speed at the sea surface*

- Thermal Coastal Upwelling index (CUI_{SST} (°C)):

The ocean response to the wind stress has been classically expressed in terms of SST difference index, calculated as the difference in temperature between upwelled water over the shelf ($SST_{\min}$) and water further offshore($SST_{\max}$) (Nykjaer and VanCamp, 1994; Benazzouz et al.,2014):

$$IUC_{SST} = SST_{max\,offshore(lat\,,t)} - SST_{min\,coastal(lat\,,t)}$$

- Gradient Index $Grad_{Index}$ (°C km^{-1})

$$Grad(SST(i\,,j)) = \frac{Mean(SST_{(0:i+kernel,\,j-1:j+1)}) - Mean(SST_{(i-kernel:0,\,j-1:j+1)})}{Dist[kernel]}$$

- Filament index

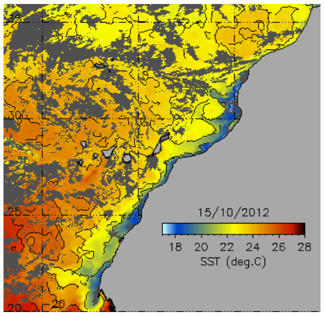


Fig3*: Thermal fronts detection*

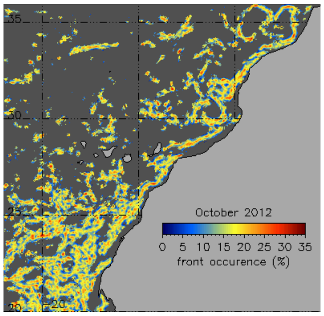


Fig4*: Thermal fronts occurrence*

- Altimetry derived indices:

We potentially derived the geostrophic flow (Fig.5 and 6) considered as the balance between Coriolis force and pressure gradient force.

$$\bar{u} = -\frac{g}{f}\frac{\partial(ADT)}{\partial y} \qquad \bar{v} = \frac{g}{f}\frac{\partial(ADT)}{\partial x}$$

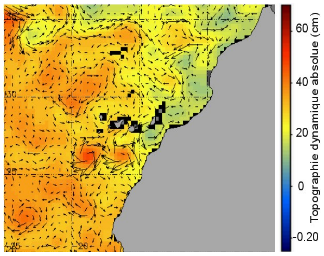


Fig5*: Overlapping of sea surface height and derived geostrophic velocity fileld*

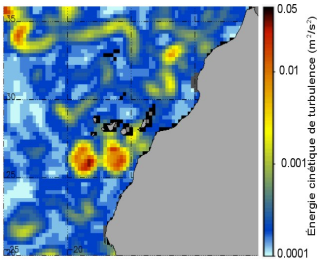


Fig6*: Eddy Kinetic Energy derived from AVISO data*

-Eddy Kinetic Energy: EKE (m/s)^2

$EKE = \frac{1}{2}(\bar{u}^2 + \bar{v}^2)$ where $\bar{u}^2$ and $\bar{v}^2$ are the zonal and meridional geostrophic flow components.

- Ocean Color Integrated chlorophyll index: Chl_{index} (mg/m^3 km)

$$Chl_{index} = \int_0^{bath200} (chl_a)\, ds$$

3. Results

3.1 Seasonal variability

The inter relationship between the forcing factors and responses shows that wind forcing, SSH and SST (Fig.3 an 4) response do exhibit a similar pattern. Bio-optical proprieties on the inner shelf of the NW Africa to a large degree mirrors the pattern of wind stress variability (Fig. 7).

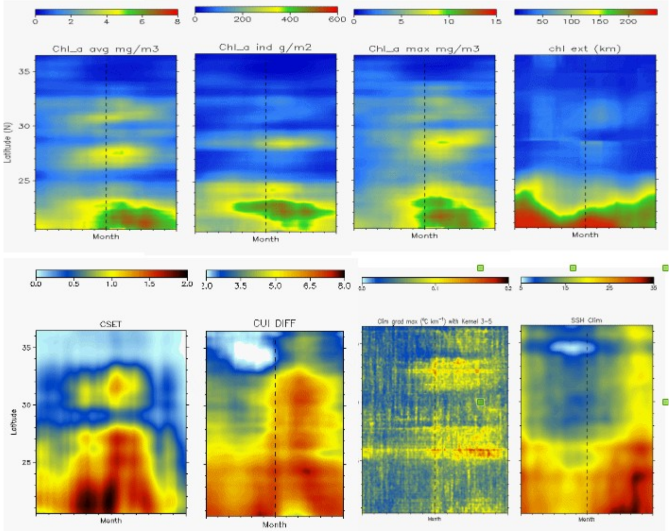


Fig7*:Hovmoller diagrams of the seasonal variability off the mesoscale indices along the Moroccan Atlantic coast*

It's can be depicted that the maximum extent of the bio-optical proprieties in the southern part of the system is approximately up to 300kms from the coast. This offshore extent is likely dominated by the Edie kenetic Energy and turbulence.

3.2 Modelling approach and indicators inter relationship

In order to explore the relationship between mesoscale indices and bio-optical proprieties, a correlation analysis was performed. The output is therefore quantised.

3.2.1 Scatter plots: mesoscale indices vs bio-optical proprieties

The scatterplot (Fig.8) shows that the chlorophyll offshore extension is correlated to the Edie Kenetic Energy (EKE) (R2=0.41), to the SSH (R2=0.42) and slightly correlated to the Turbulence (R2=0.22).

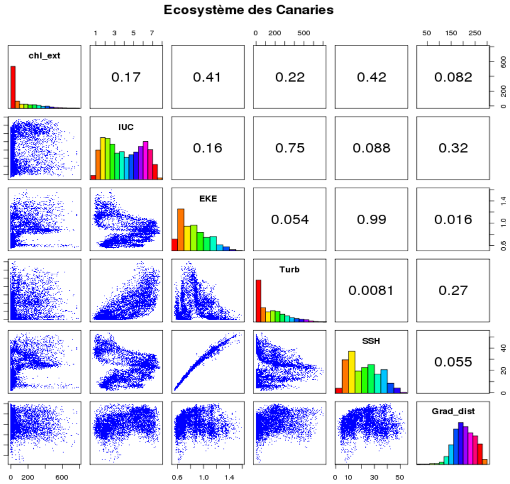
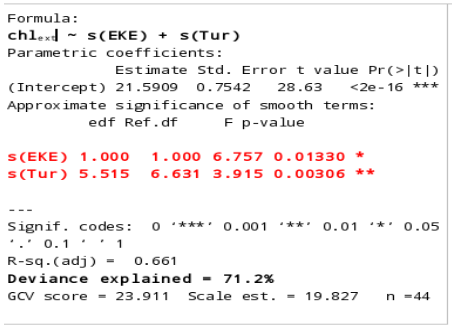


Fig8: Scatter-plot and correlation between mesoscale indicators and bio-optiacl proprieteis

3.2.2 General Additive Model:

To identify the functional relationships between the predictive oceanographic environmental variables and the predicted bio-optical (Chl_ext) proprieties, Generalized Additive Model (GAM) was applied (Table 1).

***Table1:** GAM results*



```
Formula:
chlext ~ s(EKE) + s(Tur)
Parametric coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 21.5909   0.7542   28.63   <2e-16 ***
Approximate significance of smooth terms:
         edf Ref.df      F p-value

s(EKE) 1.000  1.000 6.757 0.01330 *
s(Tur) 5.515  6.631 3.915 0.00306 **

---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05
‘.’ 0.1 ‘ ’ 1
R-sq.(adj) =  0.661
Deviance explained = 71.2%
GCV score = 23.911  Scale est. = 19.827   n =44
```

The GAM is a non-parametric generalization of multiple linear regressions, which is less restrictive in assumptions of the underlying statistical data distribution (Hastie and Tibshirani 1990). The GAM was used to determine the nature of the relationship between the offshore chlorophyll extension and the environmental variables. Only two variables (Tur and EKE) were included in the GAM.

$$Chl_{ext} = s(EKE) + s(Tur)$$

The relationship between Chl_{ext} and the two variables EKE and Turbulence was significant when it applies the GAM.

A GAM (Table 1) , taking turbulence and EKE as the co-variables and including an interaction term, showed that the Chl_{ext} is significantly and positively correlated to the turbulence and the EKE in the Canary region ($p < 0.001$).

4. Discussion and Conclusions

We have examined the dynamics of coastal upwelling off NW Africa through the seasonality off potential mesoscale indicators.

A detailed analysis on available remote sensing data basically based on Hovmoller diagrams and scaterplots has paved the way to establish the linkages between predicted bio-optical proprieties chlorophyll extent and predictive mesoscales indicators derived (wind stress, SSH and SST).

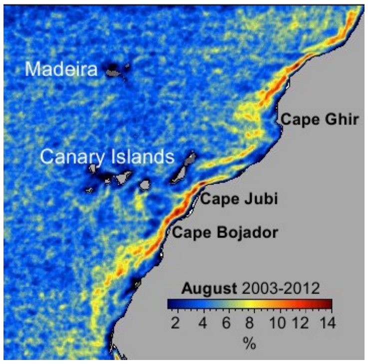


***Fig.9**: SST image highlighting the climatological frontal structure and the corridor connecting the coastal area to the ocean interior*

Therefore, we could possibly expect that the connection between the coastal area and the open ocean would closely dominated by the eddies and the frontal structures which are spatially structured into corridors connecting Moroccan area to the Canary Island (Fig.9).

5. References

Bakun, A., (1973) *Coastal Upwelling Indices, West Coast of North America, 1946–1971*, U.S. Department of Commerce, NOAA Technical Report NMFS–SSRF–671.

Benazzouz, A., S. Mordane, A. Orbi, M. Chagdali, K. Hilmi, A. Atillah, J. L. Pelegrí, and H. Demarcq, (2014) An improved coastal upwelling index from sea surface temperature using satellite-based approach – The case of the Canary Current upwelling system, *Cont. Shelf Res.*, 81, 38-54.

Jones BH, Mooers CNK, kenecker MM, Stanton T, Washburn L (1991) Chemical and biological structure and transport of a cool filament associated with a jet-eddy system off northern California in July 1986 (OPTOMA21). J Geophys Res 96(C12):2220-22225