ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Hydrological variability of the upwelling and the filament in Cape Juby (28°N) Morocco (2010)

Ahmed Makaoui[1], Mohammed Idrissi [1*], Aissa Benazzouz[1], Mohamed Ait Laamel[2], Aziz Agouzouk[1], Jamila Larissi[1], and Karim Hilmi[1]

1. Département d'Océanographie et d'Aquaculture, Institut National de Recherche Halieutique, Bvd Sidi Abderrahmane 2, Casablanca, Maroc
2. Direction de Météorologie Nationale, Casablanca, Maroc

Manuscript Info

Manuscript History:

Received: 15 August 2015
Final Accepted: 22 September 2015
Published Online: October 2015

Key words:

Upwelling, Cape Juby filament, Saharan depressor, transition zone, Seasonal variability.

***Corresponding Author**

Mohammed Idrissi

Abstract

The main target of this work is the investigation of the coastal upwelling phenomenon and the physical processes which result from it as the filament and exchanges of water masses between north and south of the Cape Juby (28°30'N), connecting the Moroccan coast and the Canary Islands.

Our study during the year 2010 shows seasonal variability of climate parameters, as speed and direction of the winds, have a direct impact on the upwelling phenomenon and marine circulation of cape Juby. This area had an invasion of oligotrophic waters manifested by a thermo-halin barrier during fall and spring seasons. This situation is manifested, first by a weaker activity of upwelled cold deep waters, and secondly by a Northern circulation of hot and saline sub-surface water. During this manifested situation, the formation of the filament structure is depending on the variability of the marine circulation.

INTRODUCTION

According to several authors (Wooster et al., 1976; Speth and Detlefsen, 1982; Nykjaer and Van Camp, 1994), the zones located between the Cape Blanc (21°N) and the Strait of Gibraltar (35°N) are subjected to winds favorable to the upwelling all the year, although they are intense north of Canary Islands during the summer and moderate or low during all other seasons. The zone of study located between Cape Ghir (31°N) and Cape Juby (28°N), is characterized by a broad, not very deep shelf and a seasonal upwelling which does not reach the surface (Makaoui et al., 2005). According to Grall et al (1982), the resurgence of this zone, more active during the summer (Grall et al., 1974; Group Mediprod, 1974b; Le Corre and Treguer, 1976; Thiriot, 1976; Treguer and Le Corre, 1979), depends on the direction and the intensity of the wind, which must exceed a certain limit. This phenomenon has a marked seasonal character and limited extension. Rather, this zone has a concave form of the shoreline and a particular morphology of the Atlas chain. This structure is opposed to the activity of the upwelling phenomenon, even during the summer and causes important consequences on the way of the canary current. Indeed, the dissipation of the canary current was estimated to 1.8 + 1.4 SV towards the south (Hernandez-Guerra et al., 2002; Navarro-Perez and Barton, 2001).

Approximately the half of the transport crosses the channel between islands of Gran Canaria and Fuerteventura and other half by the channel between Fuerteventura and the Moroccan Atlantic coast. This transport has a significant seasonal variability, extending between 1.2 + 0.3 SV in May and 2.6 + 0.1 SV in January. The transport by the channels presents inversions (flow towards north) during May (between Gran Canaria and Fuerteventura) and November (between Fuerteventura and Cape Juby). This upwelling is accompanied by a filament structure which was identified by the satellite images as an extension offshore of the water masses. This structure has hydrological characteristics of upwelled waters (low temperature and salinity and strong high content in nutriments) and is called the filament (Brink, 1983; Nelson et al., 1998), and is localized at the zones of coastal upwelling in the form of tongues, feathers or jets (Filament et al., 1985). Although the satellite images describe the state of the filaments on the surface, in situ studies showed that the hydrological characteristics of these phenomena can reach depths (100 m) and are associated with ocean currents from 18 to 80 cm/s (Strub et al., 1991).

The year 2010 knew variable weather on the Moroccan littoral. Indeed, the dorsal related to the anticyclone of the Azores (1025 HPA), during summer 2010, was located at north and supports the local winds blowing of north to north east on the zone of cape Juby. The intensity of the upwelled deep water increase and consequently the coastal euphotic layer became rich in nutrient in late spring and more marked in summer. It is a zone of trapping of the nutrient elements which is concentrated by processes of recycling (Grall J. R. et al., 1974, Le Corre and Treguer, 1976) marked by reducing dissolved oxygen recorded on the continental shelf. That explains the development and increase of the organic matter in the adjacent sediment (Makaoui et al., 2008). So this work is interested for the investigation of the coastal phenomenon and the physical processes which result from it on both sides of the zone from Cape Juby, which is a zone of transition between the seasonal upwelling to north (Cape Draa) and permanent to the south from Cape Boujdor.

Materials and methods

Within the framework of the oceanographic study of the pelagic ecosystem along the Moroccan Atlantic coast and of the collaboration between the INRH and the ULPGC (Las Palmas Gran Canaria University), the INRH institute organized, on board the N/R "Amir Moulay Abdellah (AMA)", four oceanographic cruises relating to the study of the filament of the Cape Juby in the area of the 27°30' N - 28°30'N, from April to December 2010.

These studies consist of the quantification and the follow-up of the exchanges lots of water between the zones north and south of the Cape Juby (27°30'N and 28°30'N) connecting the Moroccan coast and the Canary Islands.

During these programs, the number of the stations carried out varies from one season to another while maintaining radial the 28°N for the four seasons (figure 1).

The physical parameters (temperature, salinity, density, fluorescence and transmission) were carried out by the CTD (SBE911plus) connected to SBE32 caroussel. The profiles of the CTD are carried out until a maximum depth of 150 to 200m. The test sample selections of sea water were carried out on standard levels (0, 25, 50, 90, 150m). The level of 25m varies according to the situation of the maximum in fluorescence and the thermoclin. Dissolved oxygen is carried out by the method of Winkler on board. The nutrients (PO4, NO3 and NH4) are determined by the method of spectrophotometer.

The maximum level was limited to 150m with the fact that the surface hydrological characteristics of the filaments can reach depths which exceed 100m to 150m (Strub et al., 1991).

Results and discussion

Seasonal variability of the upwelling of Cape Juby:

The circulation variability is reflected on the hydrology of the transect 28°N which connects the Canary Islands and the Moroccan Atlantic coast. Indeed, the vertical distribution of the temperature and salinity along this radial shows an important activity during spring (Juby 2) and summer (Juby 3). This activity is marked by the appearance on the surface of cool waters (17°C) and less salted (36.3psu) of origin 150 to 200m. While the seasons of winter (Juby 1) and autumn (Juby 4) appear by the persistence of the thermoclin in the limit of the continental shelf and stopped the upwelled deep water on the plate. This situation is accentuated in autumn by the invasion of a water mass coming from offshore with higher temperature (21°C) and more salted salinity exceeding 36.8 psu (figures 2 and 3).

The temperature salinity diagram in 28°N transect shows the appearance of cold and less salted upwelled water, visible on the coastal stations, from June to August (figure 4). Indeed, the major upwelled water caused a horizontal thermo-halin stratification between the coast and offshore. Whereas during April and December, the absence of these water masses is very marked by the predominance of one warm and salted water mass, mainly in December of this year.

A statistical analysis of the various parameters shows the impact of the upwelling phenomenon on the physical and chemical parameters by using the dendrograms. Thus, two principal groups were distinguished during the summer season (August 2010) which is marked by a strong activity of upwelling. The group GI show the whole points characterized by high temperatures and salinities varying respectively between 18°C and 23.4°C and between 36.3 and 36.6 psu. The group GII is formed by the points which are localized between coastal surface and 200m and characterized by low temperatures ranging between 15°C and 17°C and low salinities between 36 and 36.4psu. This group shows the important activity of the upwelling and supports the upwelled cold water, which characterized by the important concentrations of the nutrients compared to the group I, which appears by oligotrophic water (figure 5).

During the season of autumn (December 2010), the same statistical analysis highlighted a vertical stratification marked by the formation of two groups. A group in surface, ranging between 0 and 60m, is characterized by warm water mass, more salted and poor in nutrient. And the major deeper group of point is characterized by cool water mass, less salted and rich in nutrient. This vertical stratification marks the persistence of the thermoclin in 60m as a barrier against the upwelling of the deep waters nutrient richness (figure 6) towards surface to start the productivity in the plate. However, predators and nutrients had an interactive effect on algal biomass and size structure. At the low nutrient level, when algal-prey is dominated by edible forms and attained similar biomass regardless of zooplankton presence/absence. At the high level of enrichment, presence of zooplankton favored higher levels of algal biomass and shifted dominance to large, inedible taxa. But, normally, algal biomass increased in response to enrichment regardless of predator presence/absence (John M. Davis et al., 2009).

This situation can be the consequence of the weather seasonal variability of this zone. Also, it has a direct impact on the speed and the direction of the winds and consequently on the upwelling phenomenon. Indeed, the dorsal related to the anticyclone of the Azores (1025 HPA) and the talweg of the Saharan depression has an important role on the variability of the activity of the winds. In June, August and September 2010, the local winds blowing on the zone of Cape Juby were favorable to upwelling with generally direction north to north-east and important velocities reaching 6.30 m/s (figure7). Whereas, in December 2010, the weather situation was characterized by the successive passage of the various depressions of Atlantic north. The studied area was influenced by the talwegs related to these depressions; consequently a wind prevailing of southern sector in south-west was recorded during this month. The direction of the southern winds in south-west, was not only unfavorable for the upwelled deep water, but also recorded less important velocities of approximately 4.13 m/s (figure 7). During April 2010, the first decade has recorded strong winds with a direction North-eastern and speed superior to 7.3 m/s until April 8th. After that, the talweg Saharan caused a decrease of the wind and reach, during the day of April 12th, a speed of 2.8 m/s on the zone of study. This had an impact on SST in the beginning of the year 2010 and showed by an increase in the surface oceanic temperature along the Moroccan Atlantic coast marked on the inter-annual variability of SSTmin from 2003 to 2010 (figure 8).

The impact of the resurgences activity of deep water in the summer period appears on the nutrients vertical distributions on transect 28°N and brought important concentrations of nitrates, phosphates and ammoniums through of the continental shelf. But in December, the absence of the resurgences activity and the persistence of the thermo-clin stopped the upwelled deep waters by supporting the vertical stratification of the water column. This reflected clearly on the low nutrients concentrations on the continental shelf (figure 9). Parsons and Dortch (2002) indicate that the phytoplankton development is favorable in area of nutrient enrichment by re-mineralization of organic material of cape Juby (Grall J. R. et al., 1974, Le Corre and Treguer, 1976).

Seasonal variability of the Cape Juby filament.

The filamentous formations develop at several places along the north-western African coast (Nykjaer et al., 1988; Van Camp et al., 1991; Gabric et al., 1993; Hernandez-Gherra and Nykjaer, 1997; Davenport et al., 1999, Pelegri et al., 2005a; Pelegri et al., 2005b). Most important being localized in the west of Cape Ghir (Stevens and Johnson, 2003) and the Cape Juby and acquire a permanent character because it is detected even in winter, apart from the season of upwelling (Neuer et al., 2001; Garcia-Munoz et al., 2005).

In 2010, during the periods of study area, the satellite images of SST and chlorophyll ``a`` showed seasonal upwelling filament. It started in June and was clearly present in August at approximately 28°30 N and 27°N by strong temperature and chlorophyll ``a`` gradients respectively to north and south of the cape Juby (figure. 10). This structure of the filament seems to be influenced by the situation of the Canary Islands in front of cape Juby and associated with the circulation of water masses in the area especially with a cyclonic eddy as displayed by the geostrphic flow (figure. 11). Navarro-Perez and Barton (1998) had found the diameter of this eddy about 100 km . These filaments are also frequent in other systems of upwelling such as the system of current of California (Bernstein et al., 1977; Flament et al., 1985) and that of Benguela (Armstrong et al., 1987; Shillington et al., 1990) and represent one of the permanent and dominant components dynamics of the systems of upwelling (Chavez et al., 1991). But, the current of canary is the only currents of the border subtropical Eastern that runs through the archipelago of the islands extending from the coast to broad of the ocean on a distance from 94km (Island Lanzarote) to 500km (islands Hierro and Palma). Also, the flow of the current through the islands has as consequence turbulence on méso-scale with the African continent (Aristegui et al., 1997). The disturbances of the flow seem to be strongest in autumn when it switches the direction of the canary current on the southern zone including the zone of Cape Juby (Pelegrui et al., 2004).

In the beginning of autumn, when the current takes a northern direction and the upwelling decline to its low level activity, the North Atlantic Central Water (NACW), hot and very salted (>36.9psu), began to occupy all the continental shelf of the zone ranging between Cape Juby and Cape Ghir (figure 10, 11 and 12). Thus, the filamentous structure appears north of Cape Juby. This situation can be comparable with that of April which marks a low activity of the upwelling and stratification south northern of Cape Juby. The current of drift, on the surface, as well as the winds, recorded for this period of spring (April 2010), indicate a direction similar to that of autumn season and maximum speeds in Cape Juby area. These speeds support the approach at the coast of the hot and very salted NACW (36.7psu) marking absences of the upwelled deep water. Then a south northern stratification of continental sea water of the shelf between Cape Juby and Cape Ghir take place. In this case, the zone presents an unfavorable thermo-halin barrier to the circulation of water towards the south. Also, this situation is in relation with the net air-sea heat flux which is positive from March to August and negative from September to February (Isemer and Hase, 1987) in the Canary Archipelago region.

In summer, the situation is completely reversed. When the current and the winds take a direction from north towards the south, the physical parameters distribution at 20m appear by a coast-offshore stratification of this area allowing a coastal circulation of the cool waters with temperature lower than 16°C and less salted (< 36.3psu). In this period, the net air-sea heat flux is positive (from March to August) (Isemer and Hase, 1987). Consequently, this marine hydrodynamics of Cape Juby area is unfavorable for the formation of the filament in north and can then lead to such a structure in the south of this zone where water derives from coastal upwelling. Barton et al (1998) showed that this zone has a filamentous structure in the south of cape Juby (27°N) in summer period with a strong upwelling. Also, the calculation of the geostrophic current in Cape Juby (28°N) shows an important seasonal variability of marine circulation during the year 2010 (figure 11).

In summer (August 2010), the circulation of water, determined by the northern component of the geostrophic current, indicates that the upwelled water masses, coming from the coastal area in north, tend to derive towards the south. Whereas, in autumn (December 2010), the situation is completely reversed by the recording of a negative current on water column of the plate and the continental slopes supporting a homogeneity and forming a frontal barrier between the Canary Islands and the continent.

Indeed, the impact of this hydrodynamics on the physico- chemical characteristics appears on the distributions of the temperature and salinity and also, on the distribution of the nutrients on 20m depth which are safe from the atmospheric influence. The absence of the resurgences during April and December 2010, the Atlantic coastal water is very saturated in dissolved oxygen, but overdrawn on nutrients (particularity phosphates and nitrates). In the activity periods of the upwelling, we notice an important richness of these nutrients of the coastal area. This richness appears by the localization of the important rates of phosphates and nitrates in both sides of the Cape Juby indicating the drift towards the south of the water masses of upwelling (figure 12 and 13).

The low intensity of resurgences, recorded during April 2010 in the zone between Cape Ghir and Laayoune, is correlated perfectly with the winds of west and south-west and not only unfavorable for resurgences but also very intense (9 m/s). These winds produce a circulation of a flow of the warm waters towards the Moroccan Atlantic coast which conduct to the presence of the thermoclin marked on the mixed layer along 28°N transect and constitute with thermohalin a barrier around 50m depth (figure 14).

For the same period of the previous year (April 2009), we recorded a normal hydrological situation, characterized by a relatively important activity of resurgences marked by the upwelled cold deep water (16°C) and less salted (36.27psu) from 100 to 150m depth (figure 15). This activity was accompanied by a richness of nutrients particularly, phosphates and nitrites which respectively exceeded 0.35 and 0.15 µM. This mineral richness had a positive impact on the phytoplanktonic marked by an important fluorescence on the surface of station 7 and by an increasing important turbidity broad towards the coast.

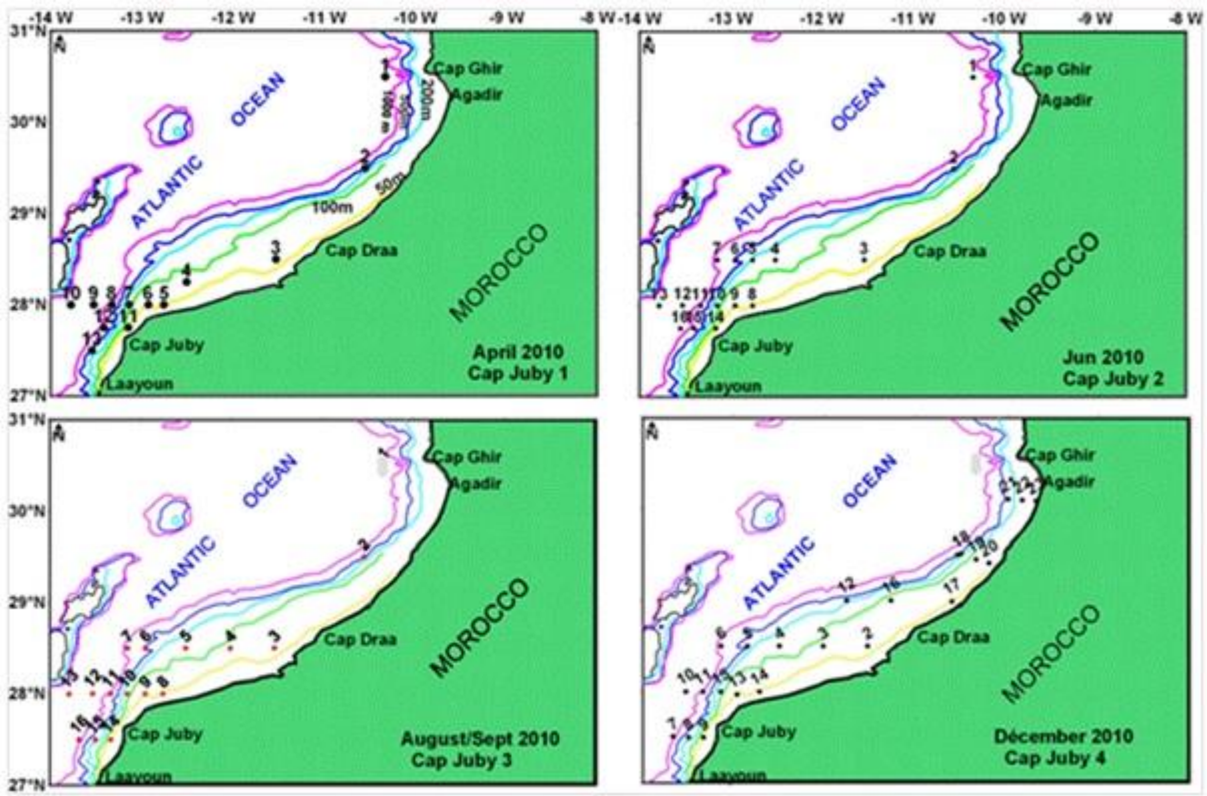


Figure 1: Sampling Survey of the oceanographic cruise (2010)

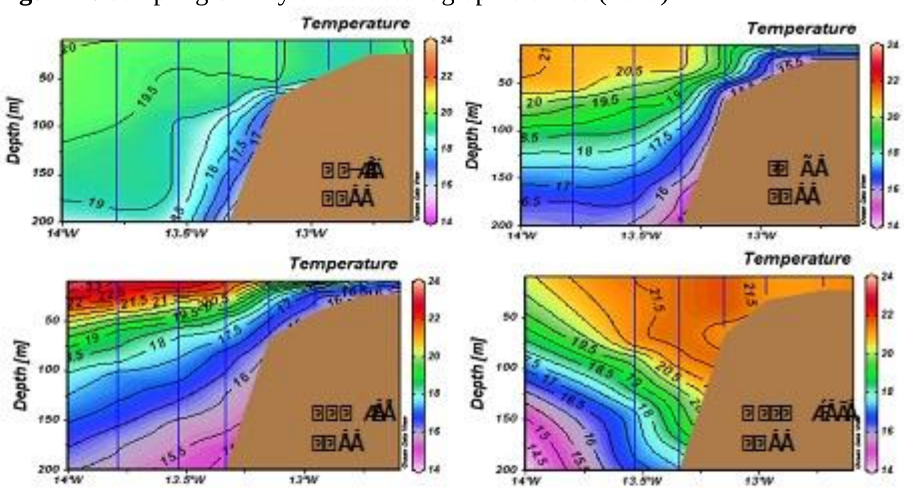


Figure 2: Vertical distribution of the temperature (°C) along radial the 28°N: Cape Juby 1 (April, Cape Juby 2 (June), Cape Juby 3 (August) and Cape Juby 4 (December).

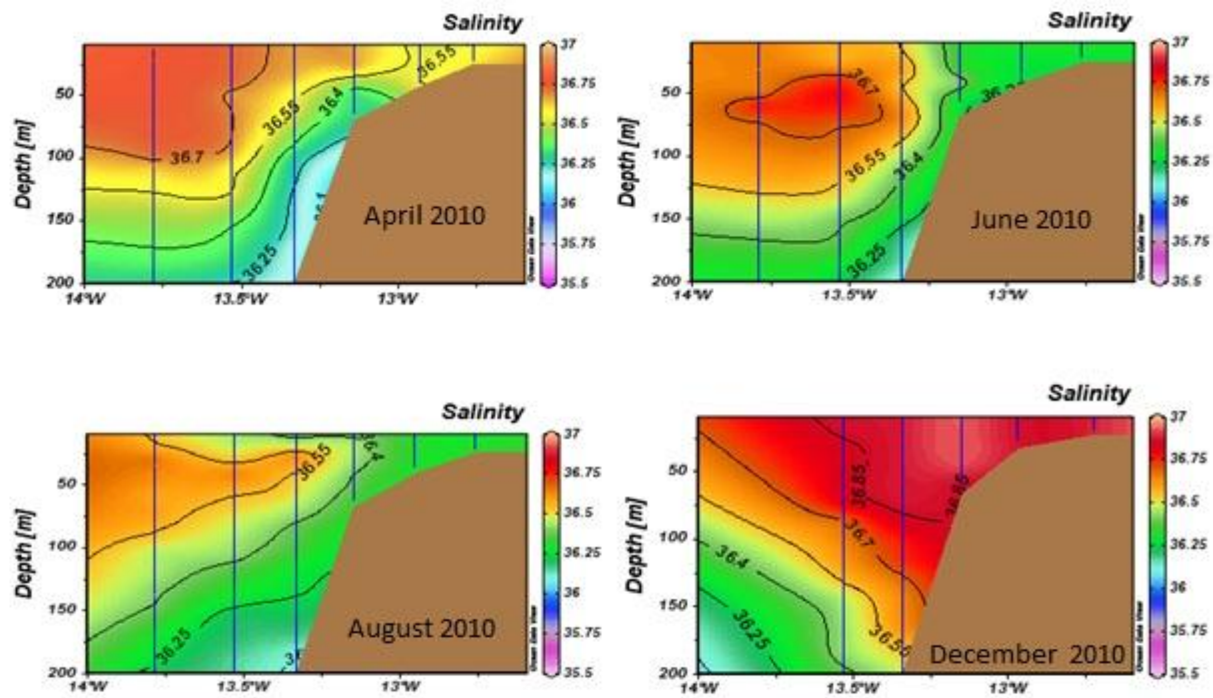


Figure 3: vertical distribution of the salinity (psu) along radial the 28°N Cape Juby 1 (April), Cape Juby 2 (June), Cape Juby 3 (August) and Cape Juby 4 (December).

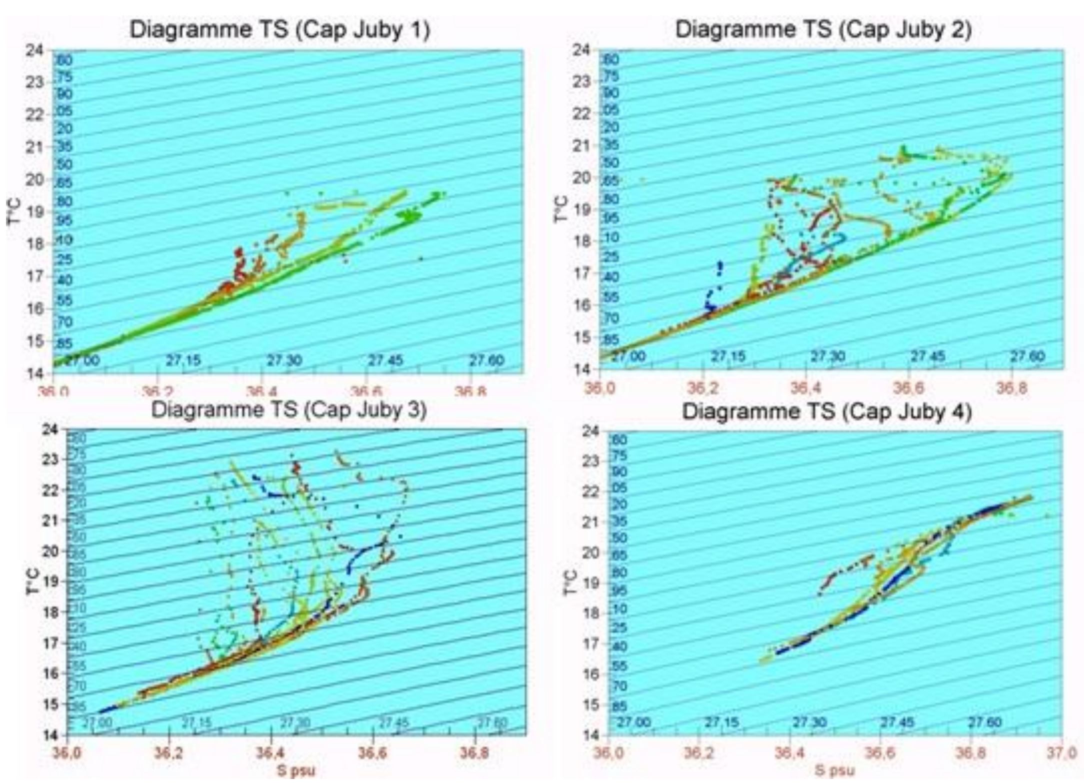


Figure 4: Structure of water masses in Cape Juby area (2010).

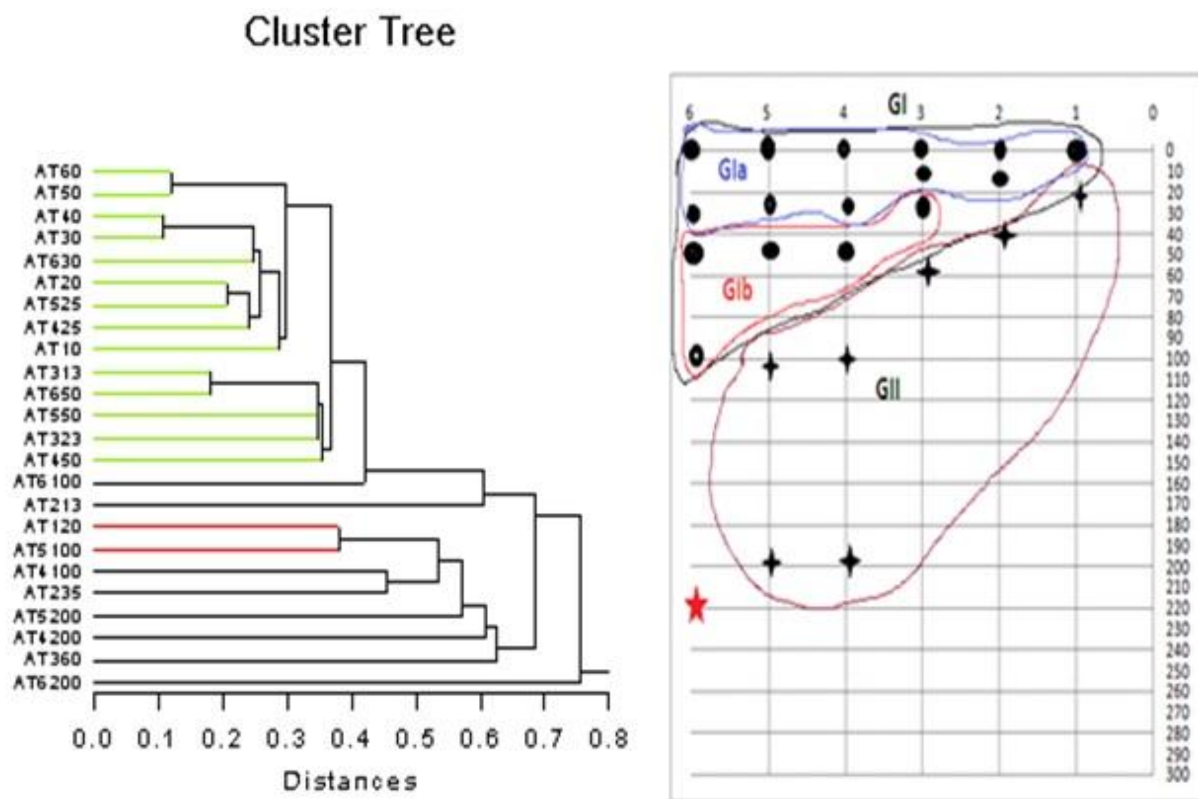


Figure 5: Dendrogram and regrouping of the points having the same physicochemical characteristics in radial 28°N (August 2010)

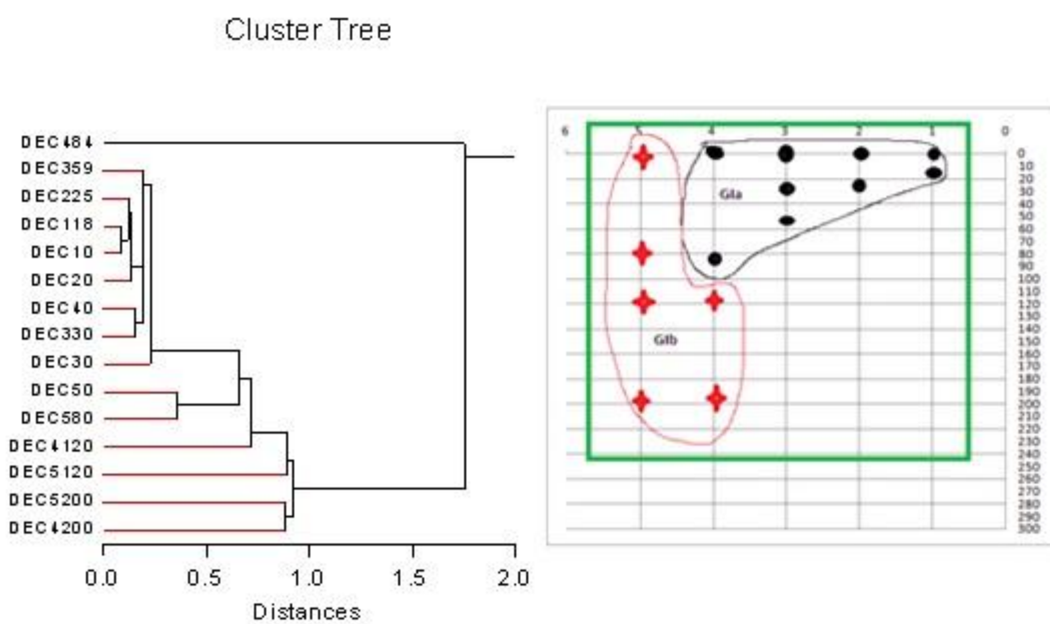


Figure 6: Dendrogram and regrouping of the points having the same physicochemical characteristics in radial 28°N (December 2010)

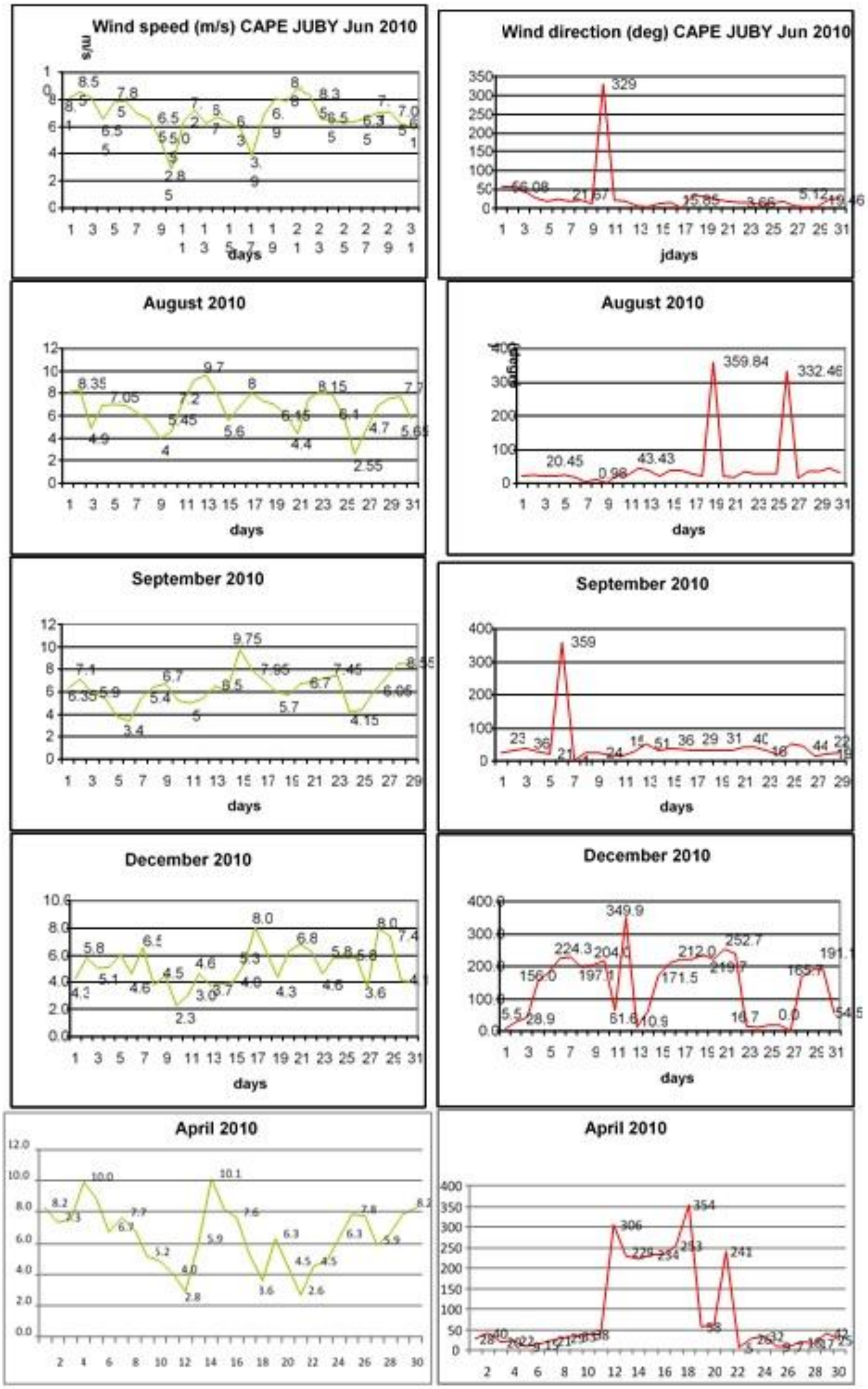


Figure 7: Seasonal variability of the winds in Cape Juby (2010)

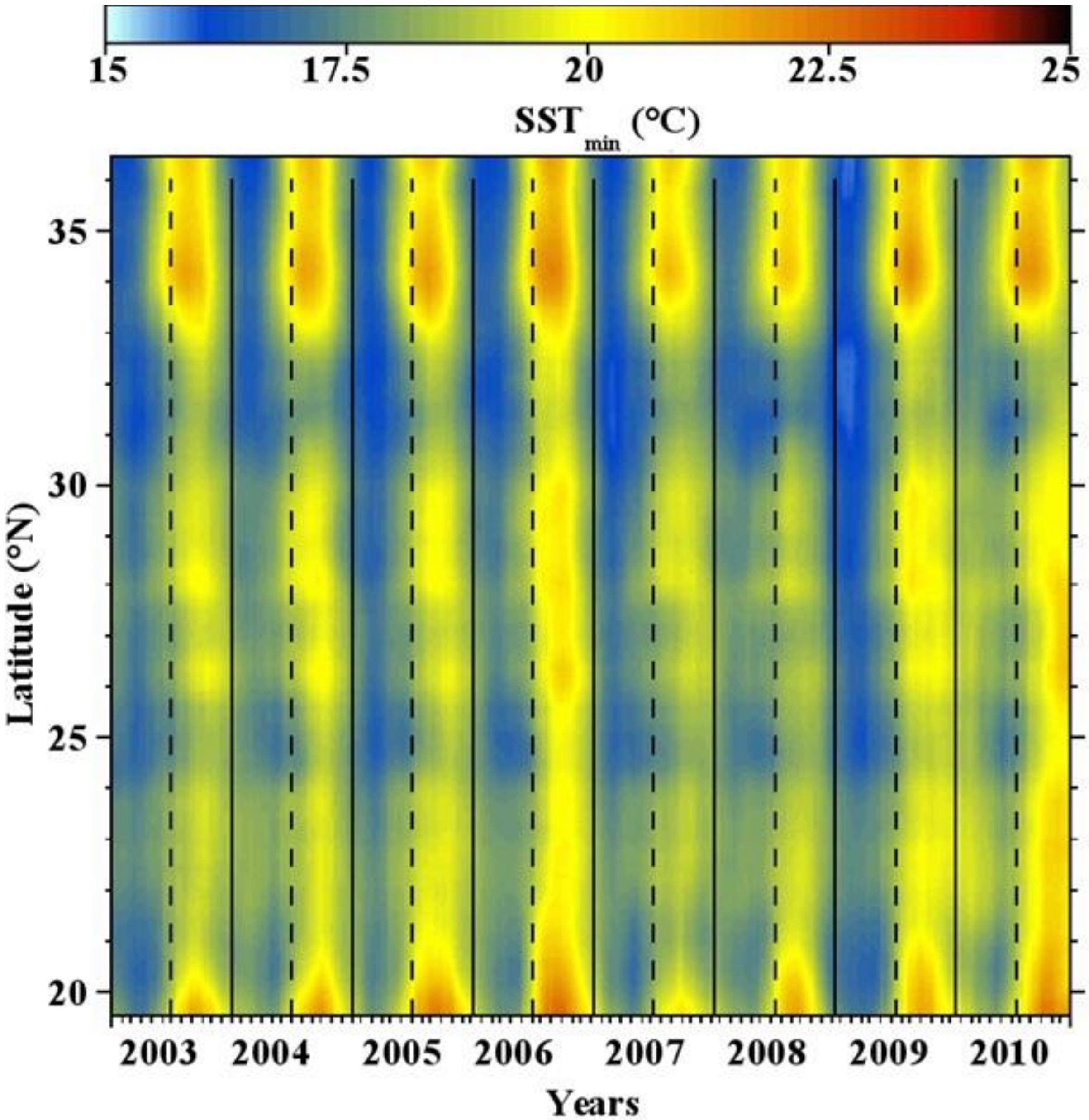
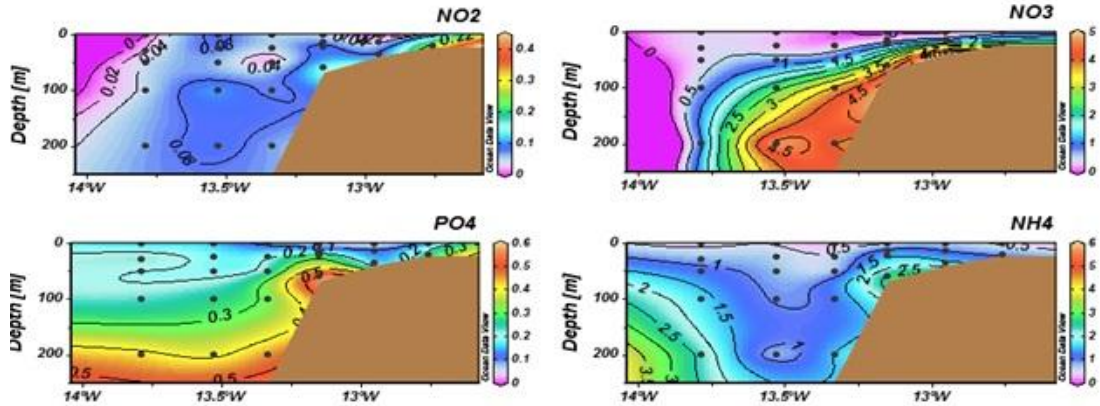
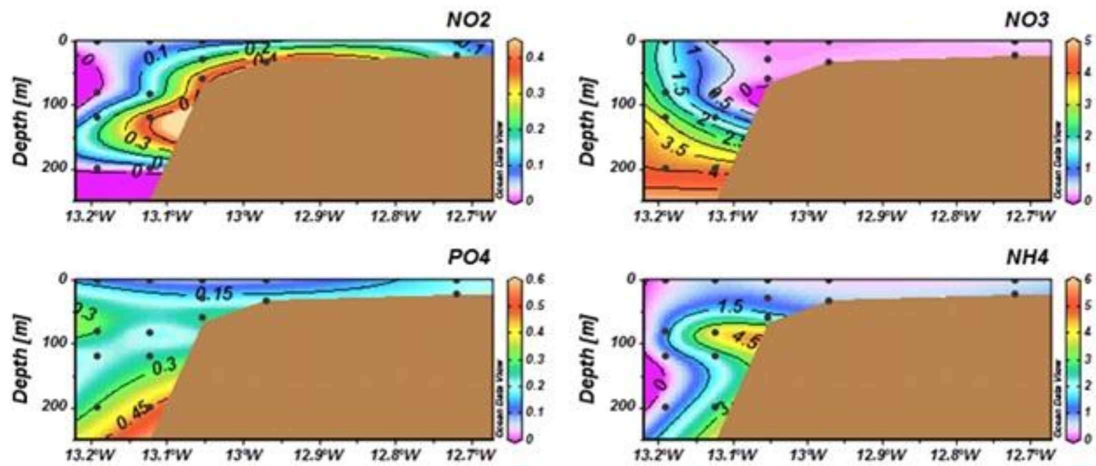


Figure 8: Hovmoller of the interannual variability (2002-2010) of SSTmin (the lowest temperature "upwelling") along the Moroccan Sea



a) August 2010



b) December 2010

Figure 9: Vertical distribution of the nutrients (µM) on the radial 28°N

a) Cape Juby 3 (August 2010) b) Cape Juby 4 (December 2010)

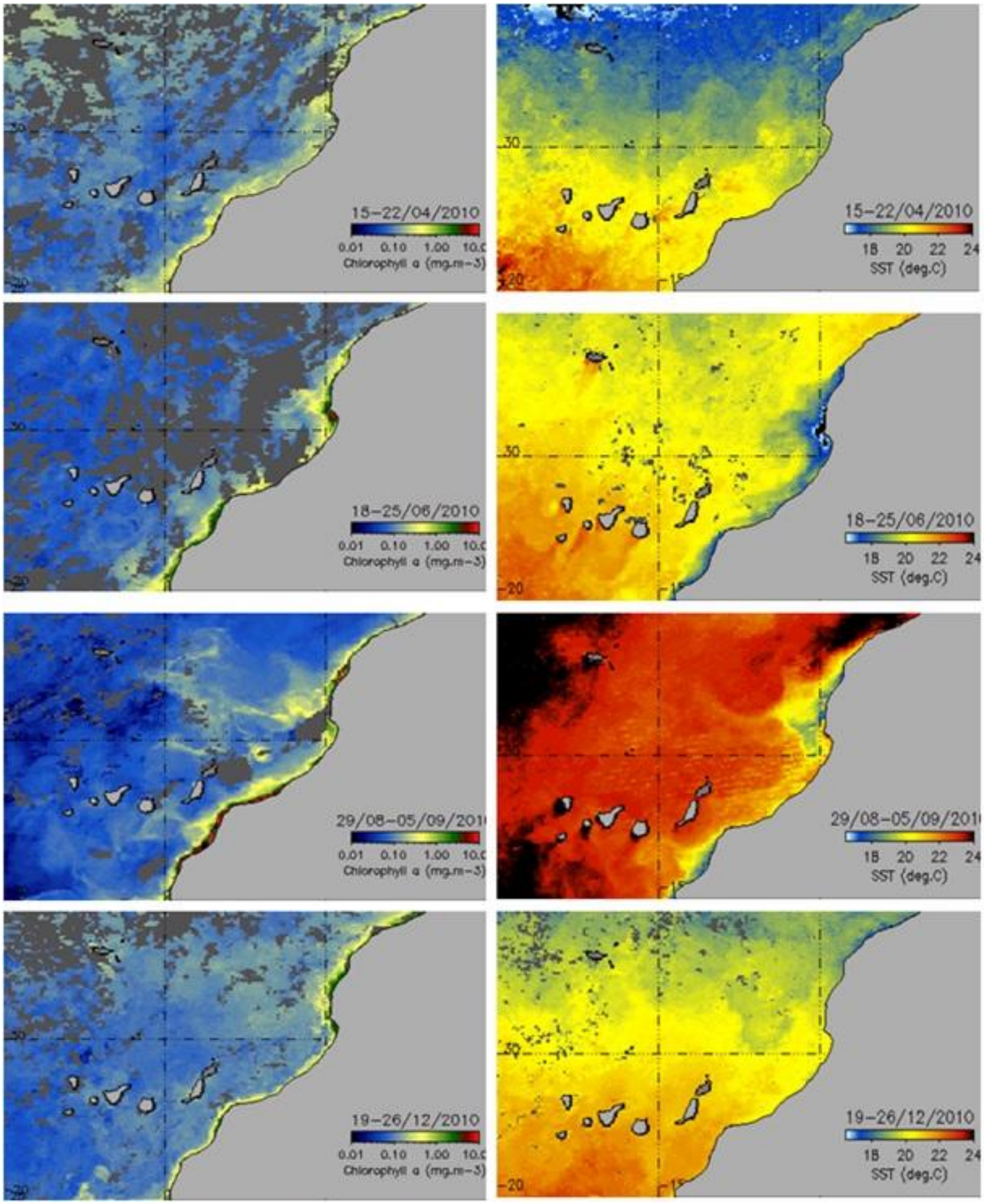


Figure 10: Satellite images of SST and Chlorophyll a derived from Aqua-Modis Sensor (2010)

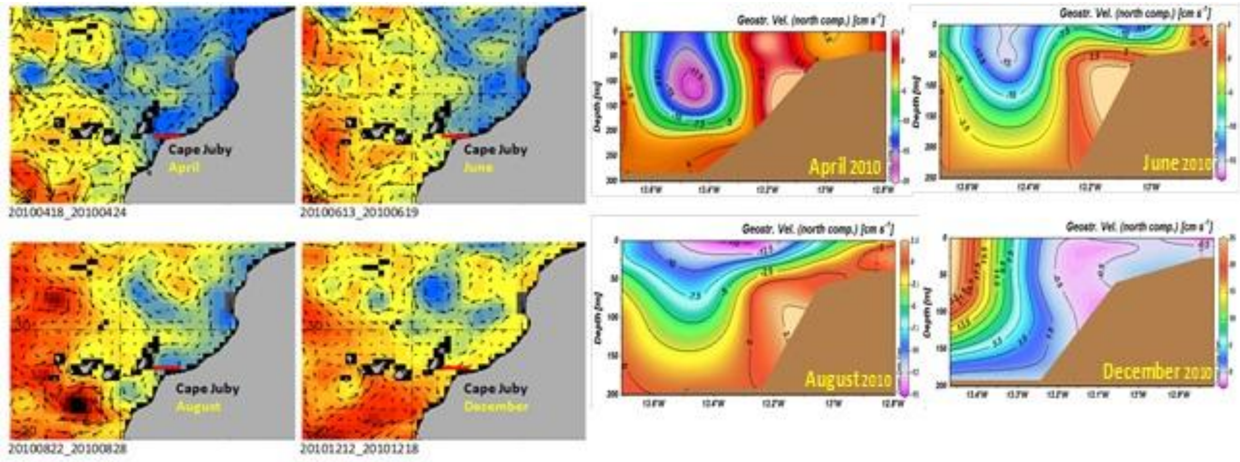


Figure 11: Cyclonic eddy of the surface satellite geostrphic flow (left) and in situ Geostrophic currents in the 28°N transect (2010)

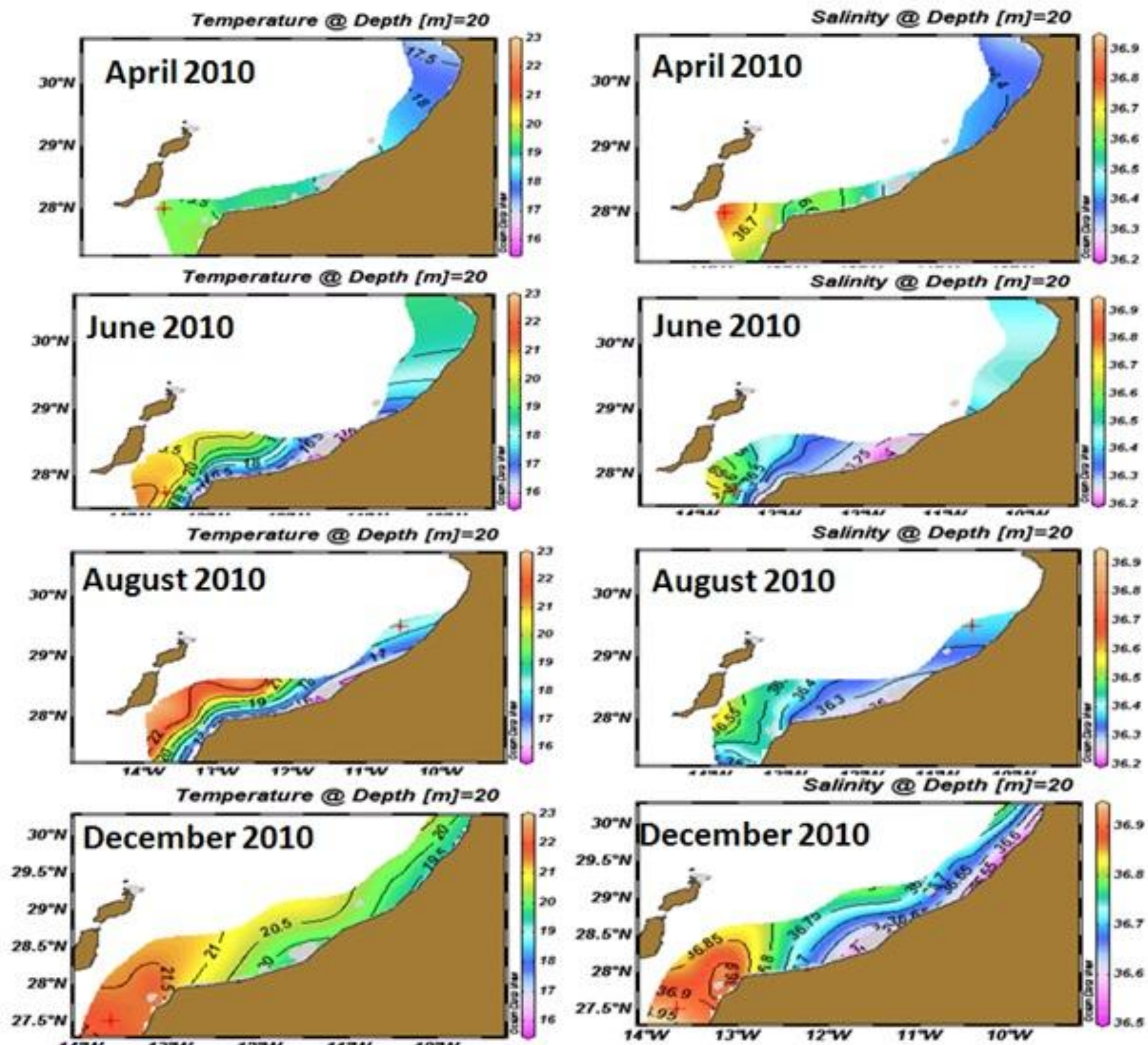


Figure 12: Distribution of the temperature (°C) and salinity (psu) in 20m (2010)

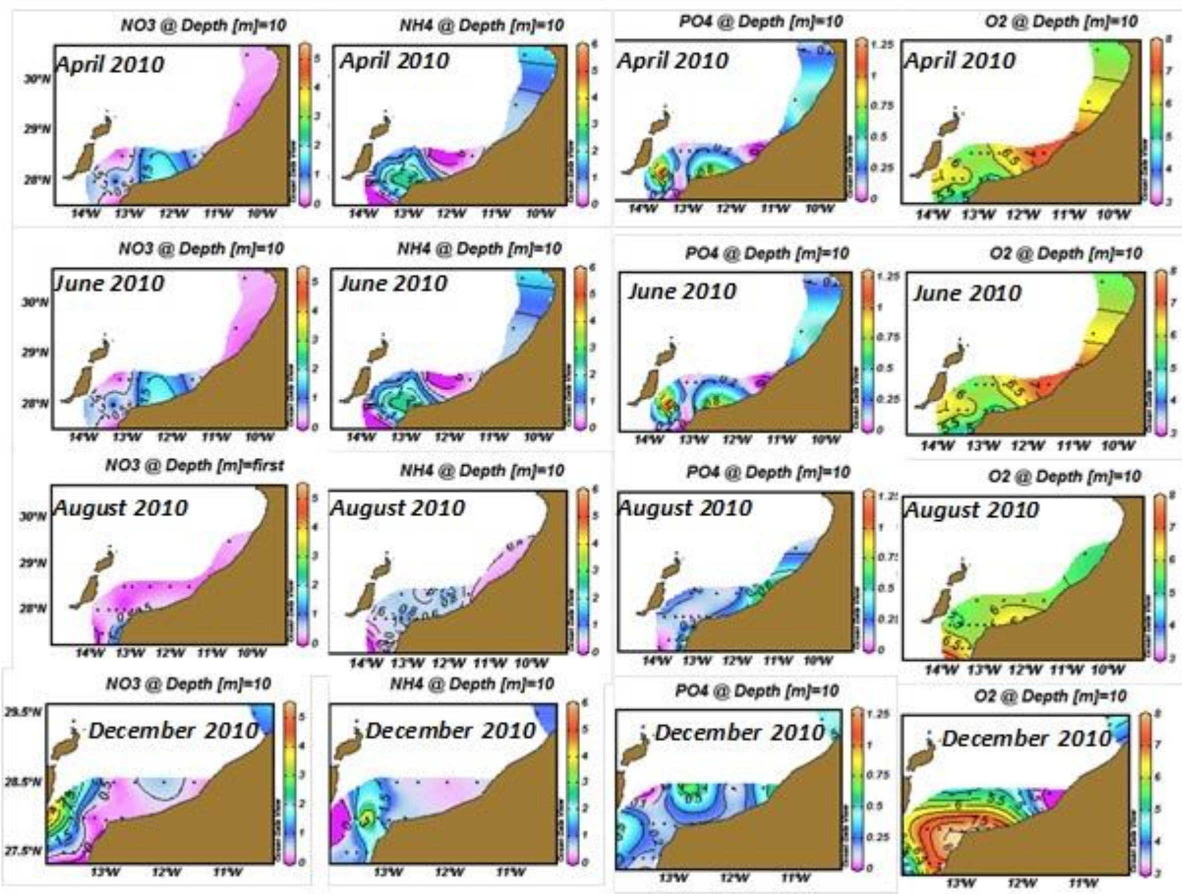


Figure 13: Distribution of the nutrients (Nitrates, Ammonium, Phosphates (µM)) and the dissolved oxygen (ml/l) in 20m (2010)

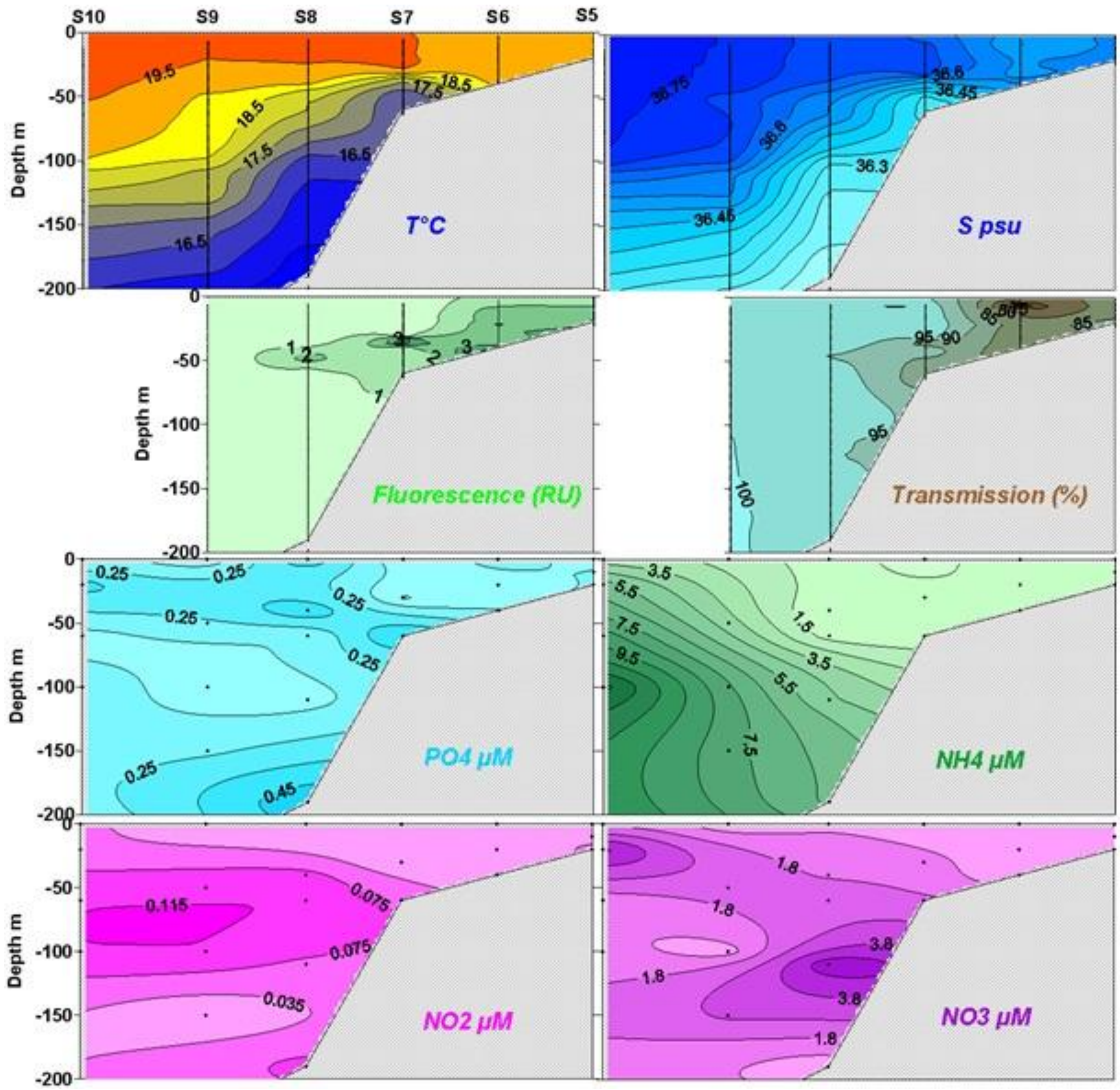


Figure 14: Vertical distribution of the physicochemical parameters in the radial 28°N (April 2010)

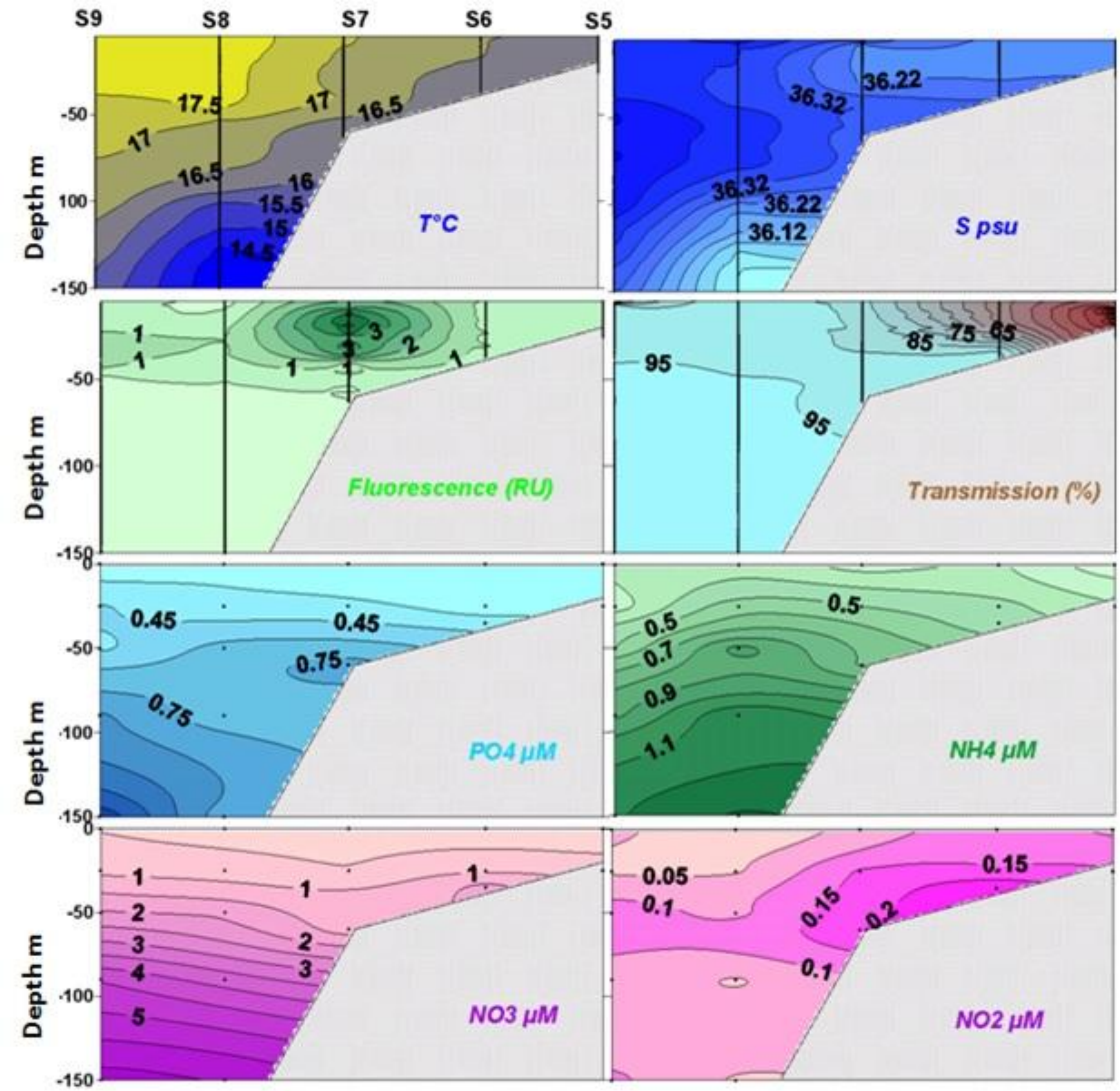


Figure 15: Vertical distribution of the physicochemical parameters in the radial 28°N (April 2009).

Conclusion:

The study, during the year 2010, shows seasonal variability of climate parameters, as speed and direction of the winds, have a direct impact on the upwelling phenomenon and marine circulation of cape Juby. In summer season, when the wind direction is favorable and with the velocity, the upwelling is in highest activity. But, during the season of the spring, we recorded an increase of the temperature and consequently a low mineral richness caused by the absence of resurgences in cape Juby area. This hydrological situation was due to unfavorable winds of west to South-West which abnormally appeared for this period of the year 2010. During autumn, this area is exposed to an invasion of stratified oligotrophic water supporting the formation of a thermo-halin barrier which stopped the upwelled cold deep waters and caused a Northern circulation of sub-surface water. When the current takes a northern direction and the upwelling decline to its low level activity, the North Atlantic Central Water began to occupy all the continental shelf of the zone ranging between Cape Juby and Cape Ghir. Thus, the hydrological situation of the study area is marked by a filamentous structure on both sides of the cape.

It appears north of the cape mainly in autumn and more in south during the activity of major water resurgences in summer.

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