RESEARCH ARTICLE

SEASONAL VARIABILITY OF THE OCEAN MIXED LAYER DEPTH INMOROCCAN UPWELLING AREAS DERIVED FROM IN SITU PROFILES.

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Manuscript Info	*Abstract*
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	The determination of the ocean mixed layer depth (MLD), in relationship with the upwelling phenomenon, is important to a wide variety of oceanic investigations including ocean productivity, air-sea exchange processes, and long-term climate change. The MLD can be estimated using different methods including the threshold value criteria or the gradient method. The aim of this study was to create scripts combining both approaches using an optimal threshold value 0.5 °C of the temperature relative to the surface and a maximum gradient of each parameter temperature and density determined depending on its profile in water column. Moreover, we used surface distributions of Temperature, salinity, oxygen and Fluorescence in sea surface to detect the upwelling activity. The CTD data was collected along the Atlantic coast of Morocco during the winter season of 2011/2012 and the summer season of 2012. Our results revealed high seasonal variability of the MLD. The MLD is generally much deeper in winter as compared to summer all over the Atlantic coast of Morocco following the spatial and temporal variability of the upwelling phenomenon.

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Introduction:-

Understanding the seasonal variability of the mixed layer depth in the Moroccan Atlantic coast, in relationship with the upwelling phenomena in this region, which is the key to improve our knowledge about the Atlantic flow towards the Moroccan coast. The atmosphere and the ocean are connected through their limit layers where the turbulence is dominant and the MLD is strongly conditioned by air-sea exchanges(Wang et McPhaden 2000).

The mixed layer (ML) is defined as a surface layer with nearly no variation in density with depth (Clayson, et al 2000). The MLD is highly variable in time and space, ranging from 10 m in the equatorial zones and up to 400 m in the high latitude regions in winter season (Brainerd et Gregg 1995) .

In the other hand, the upwelling is an oceanographic phenomenon identified by cool sea surface temperature and high concentrations of fluorescence. The Atlantic coast of Morocco is amid regions characterize by the coastal upwelling in the world (Lazier et Mann 1989).

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The upwelling observed along the Atlantic coast of Morocco is characterize by a cold sea surface temperature (SST) and high ocean productivity (Lazier et Mann 1989). This phenomenon was studied along the Moroccan Atlantic coast since the 50's. An upwelling index is calculated as the difference of temperature in the surface waters and the deep-sea water. The upwelling phenomenon is studying by the National Fisheries Research Institute, Casablanca (INRH) since 90's. They defined four major areas of upwelling activity in the Atlantic coast of Morocco (Makaoui, et al. 2005) (Fig.1).

The objective of this study is to understand the variability of the MLD and its relationship with the activity of the upwelling phenomenon in the Moroccan Atlantic coast.

Figure 1:- The zone of Study and The four zones of upwelling along the Morocco Atlantic coast according to (Makaoui et al., 2000).

Material and Methods:-

The study area is part of the African North-West coast, between latitudes 36°N and 21°N (Fig. 1). The results of this study was based on CDT data (Conductivity, Depth, and Temperature). The data used in this study was the results of the framework of the project CCLME "Protection of the marine ecosystem of the current of the Canary Islands" (GCP/INT/023/GFF). The project was financed by the global environment facility, with the collaboration of the project EAF-Nansen «Strengthening of the base of the knowledge for the implementation of an Eco-systematic approach of sea fishing in developing countries» (GCP/INT/003/NOR). The project was realized by the FAO, two Eco-systematic campaigns were realized aboard the Norwegian N/R ' Fridjof Nansen ' covering the sub-region of Guinea, in the South, to Morocco in the North. The first campaign was realized from October 20th until December 21st, 2011 and the second from May 08th until July 22nd, 2012.

The SST, salinity, windspeed, and the chlorophyll-aDataare from the EU-Copernicus-Marine database.The satellite data for the SST and salinity are combined products from satellite observations (Sea Level Anomalies, Mean Dynamic Topography and Sea Surface Temperature) and in-situ (Temperature and Salinity profiles) on a 1/4 degree regular grid. The windare estimated from ASCAT retrievals. The analyses are estimated as monthly averaged data over global ocean with spatial resolution of 0.25x0.25 degrees in latitude and longitude. For the distributions of the chlorophyll-a is estimated from the OC5ci algorithm, a combination of OCI and OC5 (Gohin, F., et al., 2008.), developed at PML. Separate chlorophyll products are produced from MODIS and VIIRS data.

Usually, because of the difficulty measuring the turbulence, the MLD is often deduced from ocean data CTD profiles. Different methods for determination the MLD were found in literature. We can detect the MLD from the gradient of density (Keith, et al. 1995). Otherwise, the MLD is defined by the gradient of temperature (Montegut, et al. 2004)(Mignot, et al. 2009). Moreover we can define the MLD with a threshold value between 1 °C and 0.1 °C, that's mean that the MLD is defined as the depth in which the temperature is equal to the temperature of surface minus the threshold value.

The 0.2°C is the best value adapted to the global detection of the MLD in the seasonal and internal timescales (Montegut, et al. 2004).In the other hand, the 0.8 °C is the optimal threshold value deduced from statistical

comparisons between observations and climatology (Levitus 1982). We noticed that the threshold value is different depending on the literatures. For the detection of the upwelling areas, distributions of temperature, salinity and fluorescence are necessary, because the upwelling is detected by the appearance of cold, less salt water and a maximum of fluorescence, which are often, visualized on the surface near the coast.

Several studies have noted methods to define the MLD using either density or temperature profiles (Thomson et Fine 2003)(Talley, et al. 2009)(Lorbacher, et al. 2006) and various threshold criteria (Kara, et al.2000) .In our study we defined the MLD with a gradient of Temperature and a gradient of density. In addition, we used the most popular method of the threshold value ΔT because it is simple and can be applied to profiles with various vertical resolutions (Sato et Naoto 2009). In our case we used the $\Delta T = 0.5$ °C as the threshold value for the North Atlantic (Montegut, et al. 2004).

The threshold method is usually defined as the depth where the property has changed by a certain value from the surface, for the case of temperature

$$T(z) - T(0) = \Delta T$$

Where T(0) is the value at the surface and ΔTis the specified difference criterion.

The gradient methods are defined as the depth where the gradient surpasses a specified value, for the case of density.

$$\frac{\Delta \sigma}{\Delta z} = \left(\frac{\partial \sigma}{\partial z}\right)$$

Where Δσ are respectively the difference of the temperature and density over a vertical distanceΔz.

The figure 2 shows the variation in temperature, and density with depth at station N°1016 (Latitude = 09 11.13 N, Longitude = 015 22.51 W, and the estimation of the MLD for the two parameters. The MLD was estimated at 28 m by the gradient method of temperature and density versus depth.
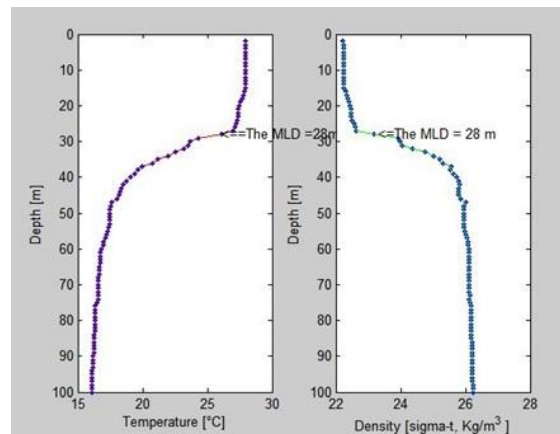
Figure 2:- Vertical distribution at 1016 station (Latitude = 09 11.13 N, Longitude = 015 22.51 W) of the temperature, and the density, plus the estimation of the MLD.

## Results:-
In situ Results:-
In this work, we estimated the MLDs with the threshold value of temperature, the gradient of temperature and the gradient of density in winter and summer season. The Figures 4 and 6 presents the seasonal climatology of the Moroccan Atlantic cost MLD obtained from the analysis of individual in situ profiles. The comparison between the three methods showed similar results. In addition, we made satellite distributions of the average SST, salinity, Chl-a and wind in February 2011 and July 2012 to liken the in situ results and the satellite results.

The results revealed that in winter season, the upwelling activity detected by sea surface temperature and sea surface salinity is marked south of Boujdor cape especially between Dakhla (24° N) and cape of Blanc, where the water salinity is under 36.1psu (Fig.3). In this season, the MLD as calculated by the threshold value methods is over 50 m offshore and the depth of ML is near the surface in the South of Boujdor Cape (Fig. 4).This situation is reflected on

the sea surface chlorophyll which show a high fluorescence in large South area (Fig. 3). Contrarily to the winter season, in summer season, the activity of upwelling is both important in south and north of the Atlantic coast. Fresh and low saline water was detected along the coast (Fig. 5), following by the MLD shallowing to the surface from Cape of Cantin to Cape of Barbas as compared with winter (Fig. 6).

Satellite Results:-

This study has been conducted using E.U. Copernicus Marine Service Information. The satellite distributions of the SST (Fig. 7), show that in winter season we have temperature between 15 and 18°C we have a case homogenize temperature, but in summer season we have a large scale of temperature from 15 to 25°C. the fresh water in the cost it can be explained by the activity of the upwelling in summer season. The Figure 8 confirm this hypothesis because we have less salinity 36 PSU in the regions where the upwelling is active. Moreover, the distributions of Chl_a indicate that the peak is about 3 mg/m^3 in summer and less than 1.2 mg/m^3 in winter (Fig. 9). All this parameters are related to the upwelling phenomena (Makaoui, et al. 2005). In addition, we made the average wind direction and speed for February 2011 and July 2012 (Fig. 10). The distributions of the wind illustrate that we have an intense winds in summer about 6 to 10m/s from the North and the North-Est. Otherwise, in winter the intensity of wind is low, compared to summer about 2 to 8 m/s from the North and the North-Est.
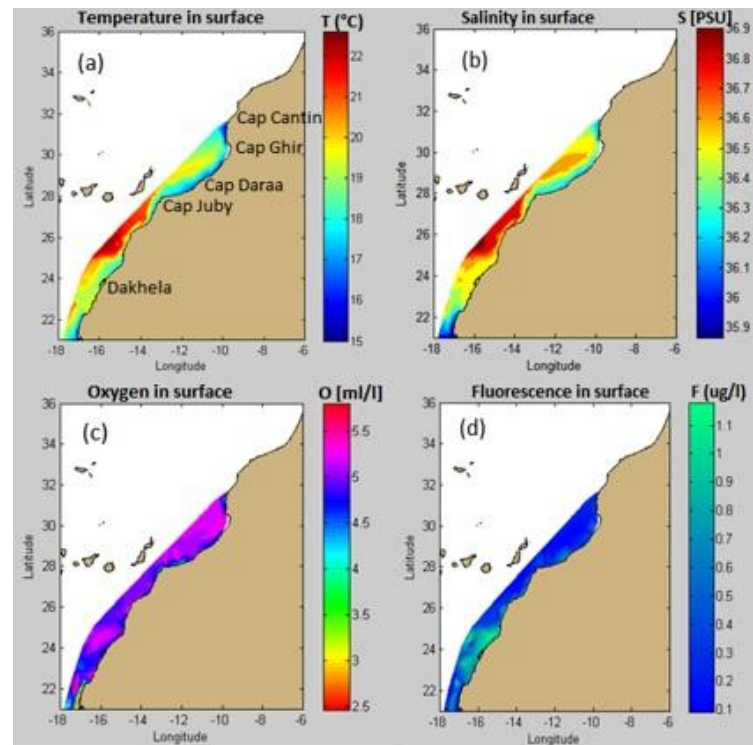
Figure 3:- Winter surface distribution of (A) temperature, (B) salinity, (C) oxygen and (D) fluorescence.
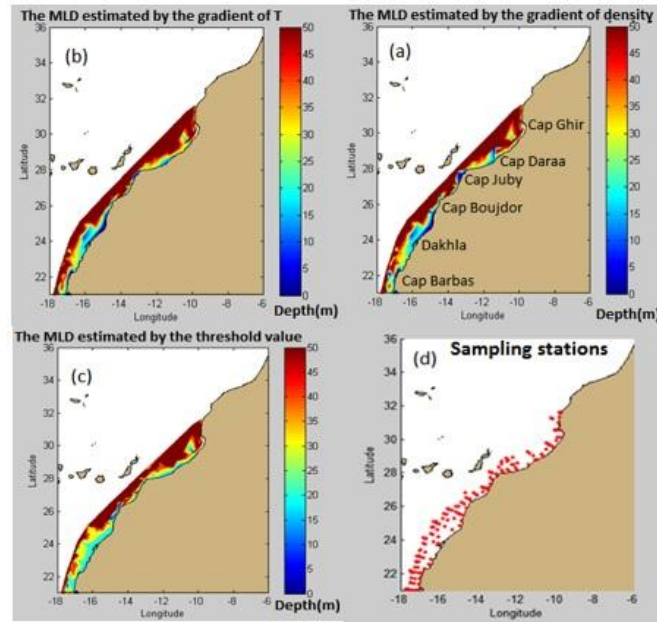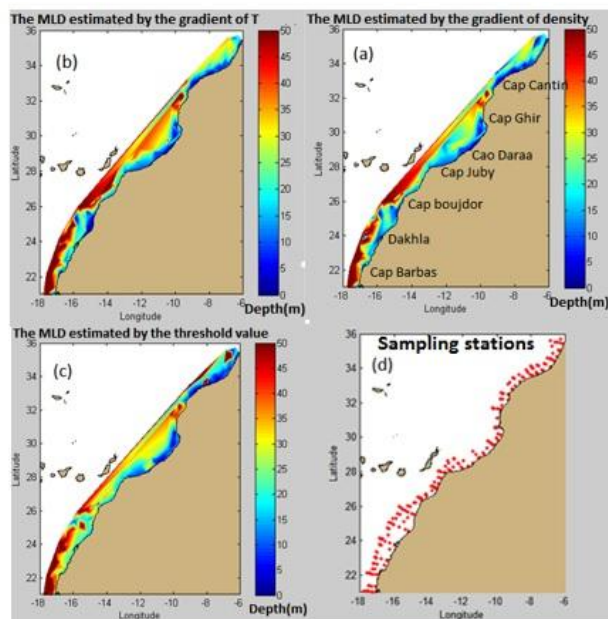
Figure 4:- Localization Of The MLD In Meter Using 3 Methods, (A) Estimation By The Gradient Of Density, (B) Estimation By The Gradient Of The Temperature And (C) Estimation Of The MLD By The Threshold Value Dt=0.5 °C. (D) Is The Sampling Stations In Winter.
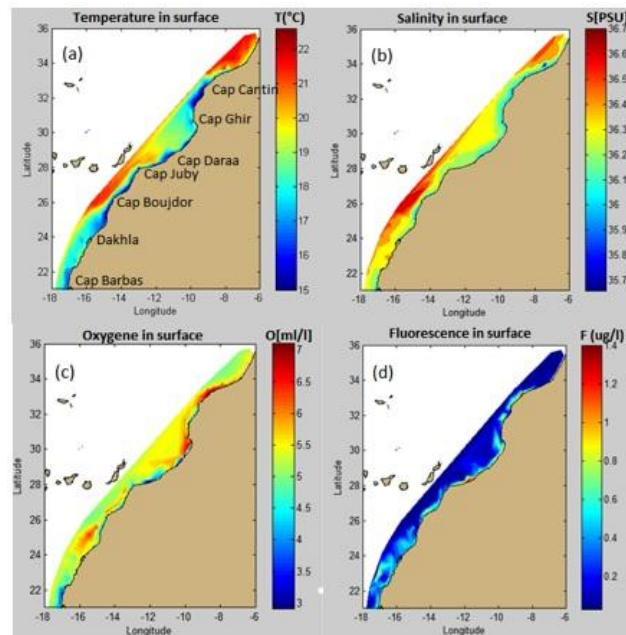

Figure 5 :- SUMMER SURFACE DISTRIBUTION OF THE OCEANIC PHYSICAL PARAMETERS, (A) TEMPERATURE, (B) SALINITY IN SURFACE, (C) OXYGEN IN SURFACE AND (D) FLUORESCENCE IN SURFACE
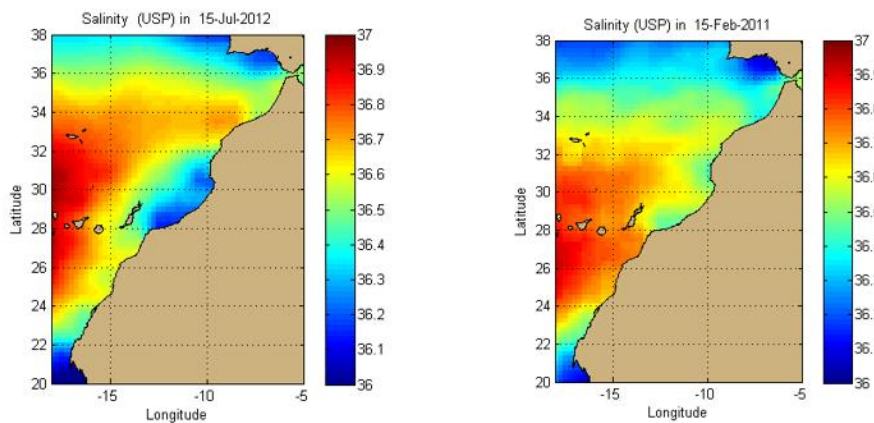
Figure 6:- Localization Of The MLD In Meter By 3 Methods Different With, (A) Estimation By The Gradient Of Density, (B) Estimation By The Gradient Of The Temperature And (C) Estimation Of The MLD By The Threshold Value Dt=0.5 °C. (D) Is The Sampling Stations For Summer.
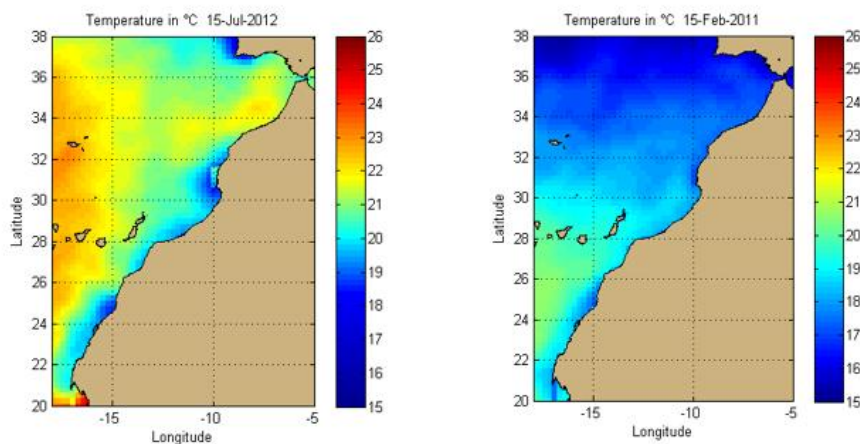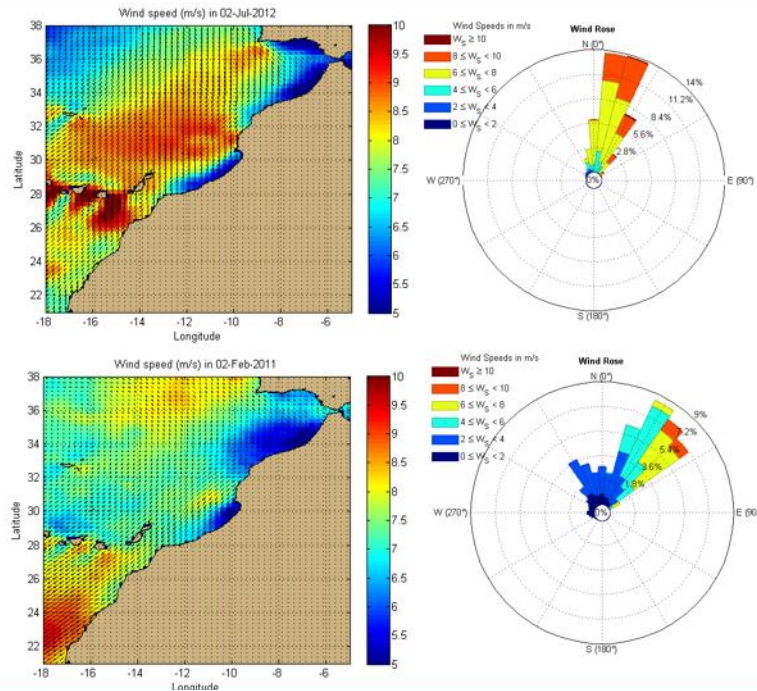

Figure 7:- Sea surface temperature (°C) in July 2012 left and February 2011 right.

Figure 8:- sea surface salinity (PSU) in July 2012 left and February 2011 right.
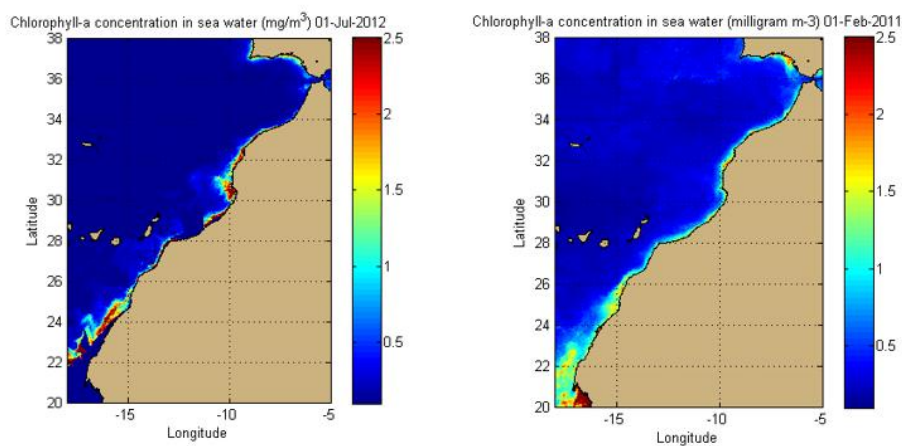
Figure 9:- Chlorophyll-a concentration in seawater (mg/m3) in July 2012 left and February 2011 right.

Figure 10:- wind speed (m/s) top left and top right the wind rose in July 2012, bottom left wind speed (m/s) and wind rose in February 2011.

Discussion:-

In the Moroccan Atlantic coast, we found that temperature-based MLDs are similar to density-based MLDs. This implies that salinity is a less important factor than temperature in determining the MLD distribution. On the other hand, the low salinity in the upper ocean near the Moroccan coast associated with the low depth of the ML exists. However, none of the earlier studies has addressed the relationship between the MLD and the upwelling.

Our results of the MLD in the winter exceeds 50 m. However, in the areas (-18°– -15°E and 21°– 25°N) in winter were less than 50 m, due to highly activity of the upwelling, but detailed analysis is required to confirm the relation and is beyond of our scope. In summer season, the activity of upwelling is both important in South and North of the Atlantic coast. Fresh and low saline water was detected along the coast. The MLD reached the 10m with maximum of the oxygen concentration and cold sea surface temperature. It can be explain by the cool water raised to the surface and reach of nutriments caused by the upwelling activity.

We find that overall good agreement in surface distribution between mixed layer and the fluorescence. The mixed layer shallow corresponding with the elevated fluorescence, while relatively low fluorescence concentration corresponds to deep mixed layer. It can be explained that, in summer, the activity of the upwelling contributes to the elevated fluorescence concentration and to pushing up the MLD to the surface.

Conclusion:-

In this work, we studied the relationship between the MLD and the upwelling activity in the Moroccan Atlantic coast for two different seasons using two different methods to estimate the MLD in the region. Our results show that the MLD is highly variable between seasons and regions. The problem of the limited data is magnified since much of the MLD variability is linked to the seasonal cycle.

The MLD reached the surface along the coast less than 50m, according of the upwelling activity during the summer season. We found that the MLD is in a good agreement with the activity of the upwelling during this season along the Morocco Atlantic coast. While in winter season, when the upwelling is active in the South of Morocco the MLD shallow in the South areas.

The good correspondence in distribution between MLD and Upwelling activity during the season suggests that MLD climatology is important in understanding the spatial pattern of the upwelling dynamics in the Moroccan Atlantic Coast.

Acknowledge:-

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