Determination of surface mixed layer depth ‘MLD’ in East Equatorial Atlantic waters using 40 years of *in situ* data

KOUAME K. Désiré[1,*], TOUALY Elisée[2], KOUASSI Aka Marcel[1], N’GUESSAN[1] K. Benjamain, BREHMER[3] Patrice

[1]Centre de Recherches Océanologiques (CRO), 29, Rue des Pêcheurs, Treichville BP V 18 Abidjan, Côte d’Ivoire; [2]Université Félix Houphouët Boigny (UFHB), Abidjan-Cocody, 01 BV 34 Abidjan 01, Côte d’Ivoire; [3]Institut de Recherches pour le Développement (IRD), Campus Ifremer, Délégation Régionale France Ouest, UMR Lemar, 29 280, Plouzané, France

** E-mail : kangadesirek@gmail,com*

I. INTRODUCTION

The mixing layer depth is the surface layer MLD of the ocean with nearly uniform hydrographic properties (temperature, salinity and density). The mixing layer generally extends to a depth of 25 to 200 m in the tropics (Pickard and Emery, 1982; Brainerd and Gregg, 1995). It is therefore the place of exchange between the atmosphere and the Ocean (Lukas and Lindstrom, 1991; Brainerd and Gregg, 1995; Dong *et al*., 2008). Such layer are not perfectly homogeneous (De Boyer Montégut, 2005) and is defined as the layer in which the difference in temperature or density with respect to the surface conditions does not exceed a certain threshold. Several studies have been devoted to MLD due to its important role in climate change (Guilyardi, 2001). It greatly affects the evolution of sea surface temperature (Chu and Chenwu Fan, 2011; Rugg *et al*., 2016), the strength of the stratification in MLD limits influence the deeper layers (Schneider and Müller, 1990) and is the first link in the ocean pollution chain (Nerentorp Mastromonaco *et al*., 2017). Most of the pollution in the world's oceans occurs in coastal oceans across the MLD. Given its paramount importance in its ocean-atmosphere interaction in the world's oceans and for its role in enriching the superficial part of the oceans in biological productions, studies have been conducted in recent decades to develop patterns and optimize algorithms for determining oceanic mixing layers (*e.g.,* Caniaux and Planton, 1998; Paci *et al*., 2005; Wade *et a*l., 2011; Da-Allada, 2013). Here we use the numerical methods of Holte and Talley's (2009) “Hybrid Algorithm” for the MLD estimation. Such information are then compared to the results of MLD obtained from the visual inspection of the individual temperature and density profiles in order to identify an optimal method to determinate the MLD.

II. MATERIAL AND METHODS

The data come from the SISMER Database: CTD profiles from Oceanographic surveys in the Gulf of Guinea at 10°W and between latitudes 2°N – 10°S during 1973 and 2017. Computation of 7 outputs MLD in Matlab with the algorithm of Holte and Talley (2009) using individual CTD profiles of temperature, salinity and potential density. Density was computed with the SeaWater Matlab library of EOS-80. From October 1973 to March 2017, 381 profiles including 218 temperature and 153 density profiles from 2 ° N to 10 ° S along the 10 ° W radial were examined. LDMs were determined using six numerical methods, all from the Holte and Talley (2009) method: (1) HT_Temp_Algo, (2) HT_Dens_Algo, (3) HT_Temp_Seuil, (4) HT_Dens_Seuil, (5)) HT_Temp_Grad and (6) HT_Dens_Grad. These six methods were compared to visual inspection MLDs based on the density profile (Visu Dens) and the other on the temperature profile (Visu Temp) using the Taylor diagram which provide a concise statistical summary in terms of their correlation, their root-mean-square difference and the ratio of their variances.

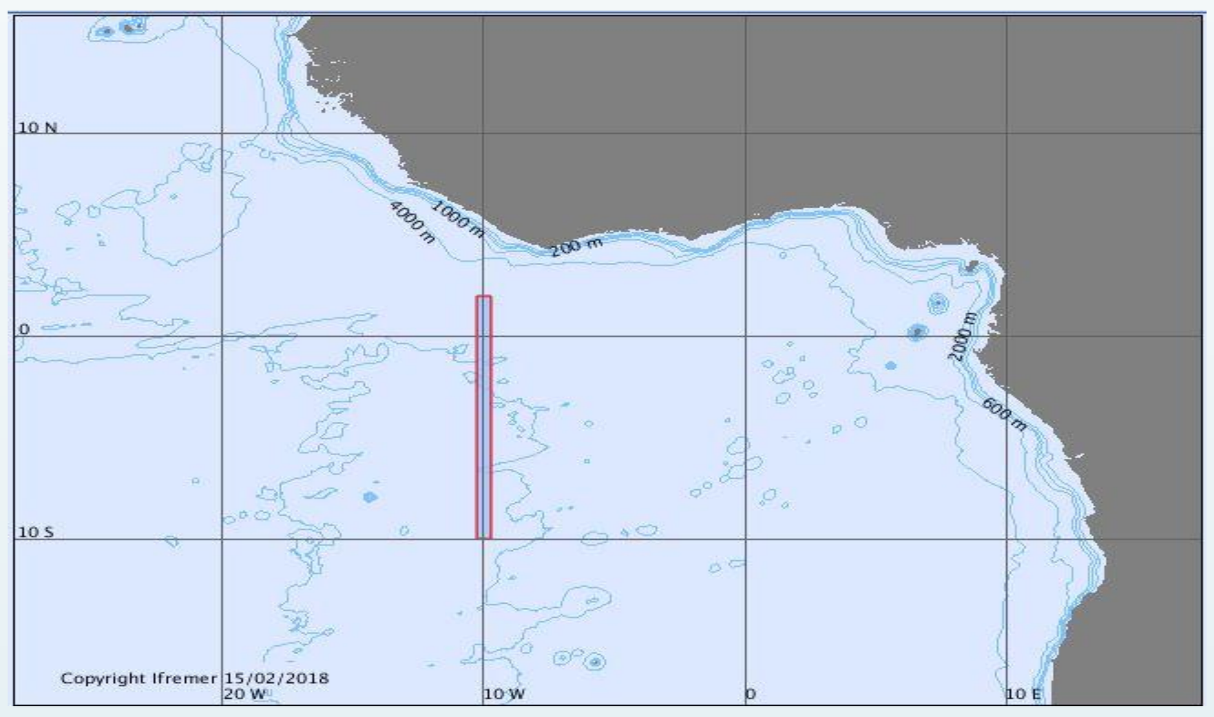

Figure 1: The gulf of Guinea was the study area situated in tropical Atlantic (East Equatorial Atlantic) from 2 ° North to 10 ° South along 10° West.

III. RESULTS

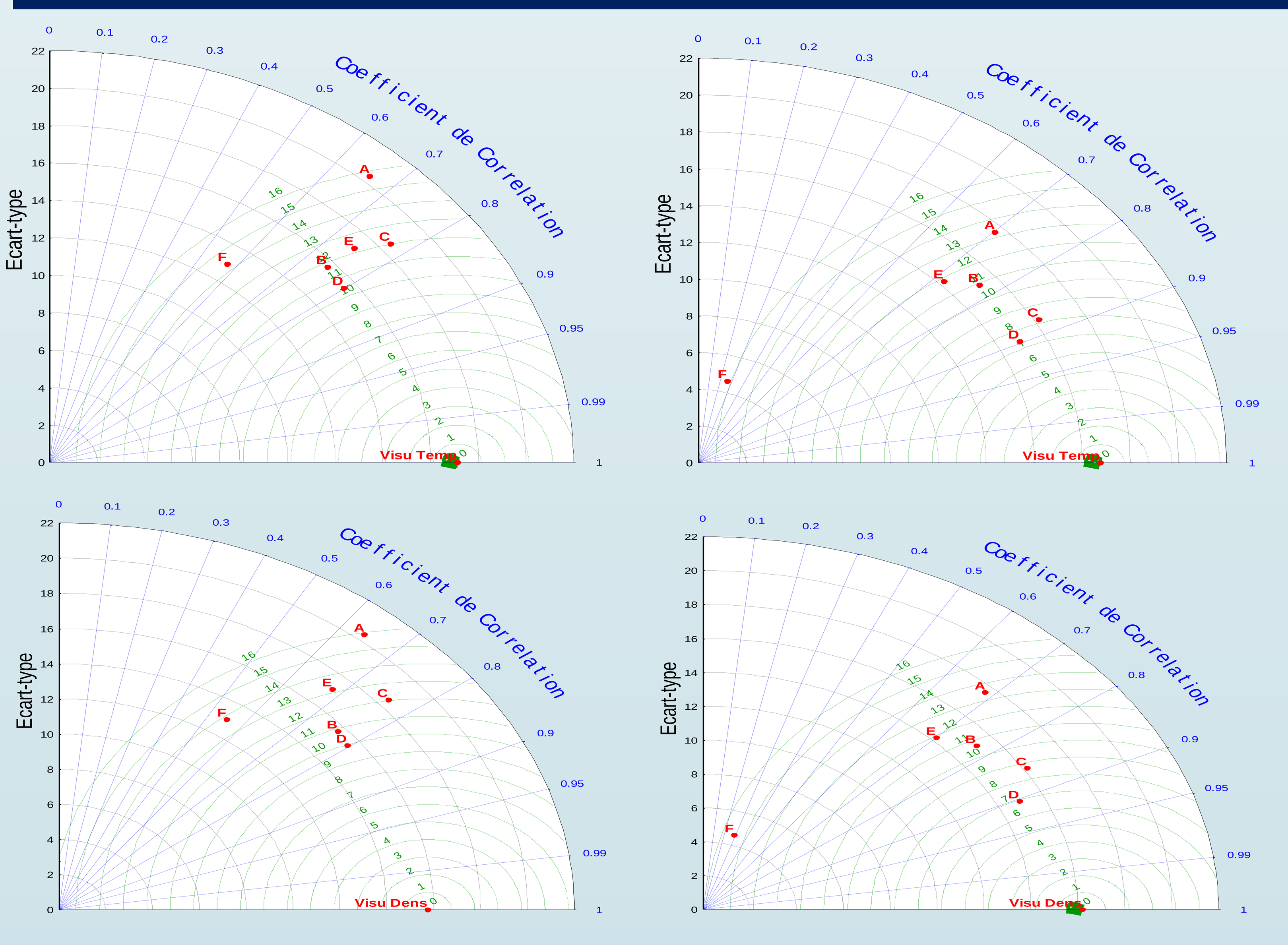

Figure 2: Taylor diagram: Comparison between numerical methods and references. A: Temp Algo HT, B: HT Dens Algo; C: HT Temp Threshold; D: HT Dens Threshold; E: HT Temp Grad; F: HT Dens Grad .; Visu Temp (top) Visu Dens (down): MLD reference based on temperature (top) or density (down); left cold season and right hot season. HT: Hote and Talley (2009), Grad: gradient, Seuil: threshold.

Methods	COLD			HOT		
	STD	RMSE	R^2	STD	RMSE	R^2
Visu_Temp	17,12	0,000	1	16,75	0,000	1
HT_Temp_Algo	20,36	15,72	0,43	17,60	13,28	0,49
HT_Dens_Algo	15,66	11,76	0,55	15,18	10.90	0,59
HT_Temp_Seuil	18,47	12,00	0,60	16,18	8.20	0,77
HT_Dens_Seuil	15,47	10,48	0,63	14,95	7,49	0,80
HT_Temp_Grad	17,13	12,22	0,55	14,23	11,83	0,52
HT_Dens_Grad	12,97	14,33	0,33	4,61	16,15	0,07

Tables : comparison of the values of the STDs, RMSE and R^2 from the reference MLDs (Visu_Temp (top) and Visu_Dens (down)) obtained for the MLDs estimated by the six numerical methods derived from Holte & Talley (2009).

Methods	COLD			HOT		
	STD	RMSE	R^2	STD	RMSE	R^2
Visu_Dens	15,75	0	1	16,18	0,00	1,00
HT_Temp_Algo	20,35	15,88	0,40	17,60	13,50	0,47
HT_Dens_Algo	15,66	10,87	0,57	15,18	10,67	0,59
HT_Temp_Seuil	18,47	12,08	0,58	16,18	8,70	0,73
HT_Dens_Seuil	15,47	9,97	0,63	14,95	6,95	0,82
HT_Temp_Grad	17,13	13,18	0,46	14,23	11,92	0,49
HT_Dens_Grad	12,97	13,82	0,30	4,61	15,47	0,09

During the hot season, the HT_Temp_Seuil and HT_Dens_Seuil methods give R^2 values of 0.77 and 0.80 respectively, which are significant *vs*. the other numerical methods with RMSE values of 8.20 and 7.49 respectively.

Whatever the profile used for the determination of the MLD, the density threshold method is better suited whatever the season, *i.e.,* fit better to the observations. For the comparison based on the density profile, the lowest possible RMSE are obtained (6.95 for HT_Dens_Seuil in hot season and 9.97 < 10.48 for HT_Dens_Seuil in cold season). According to Taylor (2001) the MLDs obtained with the HT_Dens_Seuil method better fit to the observations among the six methods compared to visual inspections (Visu_Dens).

From October 1973 to March 2017, we examined 381 profiles including 218 temperature profiles and 153 density profiles from 2 ° North to 10 ° South along the 10 ° West radial. LDMs were determined using six numerical methods, all from the Holte and Talley (2009) method: (1) HT_Temp_Algo, (2) HT_Dens_Algo, (3) HT_Temp_Seuil, (4) HT_Dens_Seuil, (5)) HT_Temp_Grad and (6) HT_Dens_Grad. We compared these six methods to visual inspection MLDs based on the density profile (Visu Dens) and the other on the temperature profile (Visu Temp) using the Taylor diagramms. Results have shown that only two of these six methods give consistent results in agreement with visual inspection. However, only the MLDs obtained with the HT_Dens_Seuil method ($\Delta\sigma\theta$ = 0.03 kg.m^{-3}) come closest to the observations with a higher coefficient of determination (0.82) and a mean squared error (RMSE) equal to at 6.59 as low as possible. Thus, the threshold density method gives a qualitative result in agreement with visual inspection based on the density whatever the season and the zone in the EEA and perhaps in the Gulf of Guinea.

IV. Perspectives

The next step will be to better characterise the water of the gulf of Guinea considering to use such methodology to evaluate the fluctuation in the primary production, macro nutrient distribution as well as ocean atmosphere heat and gases exchanges. Obviously such methodology will allow to follow any change due to *e.g*. climate change in the study area. On the other hand, the acoustic mapping of the MLD delivered from echosounder data will be considered in later step and will allow to link the MLD physical characteristics with the micronektonic acoustics layer spatial distribution in high sea; similar approach is already in course over the continental shelf.

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