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Nitrate supply from deep waters to ocean surface waters at 10 °W in the tropical Atlantic Ocean: insight from three decades of monitoring

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I. INTRODUCTION

The ocean plays a critical role in balancing the "climate machine" that is essential to understand and assess globally. This role is closely linked to the physical and biological processes that take place in the surface layer of the ocean (Gruber et al. 2002). The first interaction of the ocean with climate is mechanical through the mixing layer as a result of the energy received from ocean currents (Alvain 2005). This regulatory role is adaite to nitrate because of its well-known importance in oceanic primary production (Trombetta 2019), critically controlled by nutrient availability, which in turn depends on the dynamics of MLD (Wilson and Coles 2005). Nutrients can be supplied by many processes such as turbulence, internal waves, oblique and vertical convection, eddy diffusion.The aim of this work is to understand the role of changes in MLD depth in the seasonal supply of nitrate from the deepest to the surface layers along the 10 °W radial, in order to develop an ability to predict the response of ocean ecosystems to climate change in the tropical Atlantic.

II. STUDY AREA, DATA COLLECTION AND PROCESSING

This study was conducted at 10 °W between 2 °N and 10 °S (Figure 1) in the Gulf of Guinea (GG) in the Eastern Equatorial Atlantic (EEA) defined as the region extending from 15 °S to 5 °N and from 15 °W to 15 °E (Kolodziejczyk et al. 2014). The hydrologic and nutrient (nitrate) data used were extracted from a box centered at 10 °W ± 0.25° between latitudes 2 °N-10 °S (Figure 1). They come from the EGEE database, which we supplemented with SISMER data. These data cover the period from October 1973 to September 2007 and we used the data of the first 100 meters of the water column . Data processing have been performed as in N'Guessan et al. (2019).

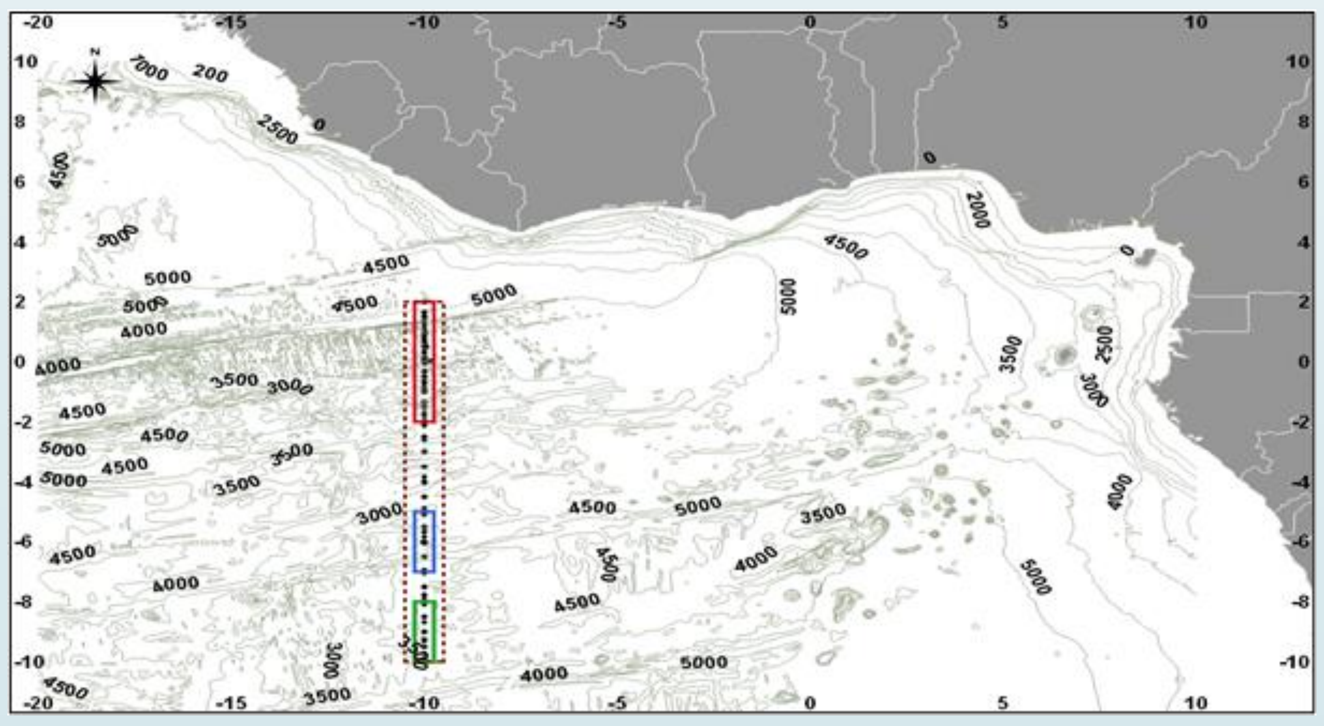


Fig. 1 Study area located in the tropical Atlantic: Gulf of Guinea. CTD stations are indicated by black dots. The three boxes indicate, from top to bottom, the equatorial zone in red (2 °N -2 °S), the 6 °S zone (5 °S -7 °S) in blue and the 10 °S zone (8 °S-10 °S) in green

III. METHODS

a. Determination of the mixed layers using Hdepth (MLD)

The MLD was determined olte and Talley density threshold method with a criterion of 0.03 kg m^{-3} as in N'Guessan et al. (2019).

b. **Determination of the top of the nitracline and corresponding nitrate values**

The realization of the nitrate-density graph, leads to the determination of the polynomial which corresponds best to the cloud of points obtained as in Hemsley (2016). This shows that the densities which seem to correspond to a linear representation are between the densities 1022 and 1030 kg m^{-3} for the equatorial zone and 1024 to 1030 kg m^{-3} for the 6 ° S and 10 °S zones. Then, for each season and for each area, the data is used to find different polynomial fits (Hemsley 2016) using Matlab's polyfit function from the centered and reduced variables.

The nitrate concentration values are then recalculated for each 1 m depth step. The negative concentrations obtained during this calculation are replaced by zero.Thus, as in Aksnes et al. (2007), the top of nitracline is determined by applying a linear interpolation of 1 m from the threshold of 1 mmol m^{-3} as in Voituriez and Herbland (1984) and Lavigne et al. (2013).

c. Spatial and Seasonal variability of MLD, nitracline top and nitrate distribution in the ocean surface layer

Seasonal and spatial variability was studied during he warm (November to April) and cold (May to October) seasons. We therefore split the 2 °N-10 °S zone into three (Figure 1) with the aim of identifying the role of the MLD in enriching the surface layer with nitrate in each zone as advocated by Kouame et al. (2021).The average depth of the mixed layer was calculated as well as the average depth of nitracline and the average nitrate concentration in the surface layers of each zone for each latitude from October 1973 to November 2007 between 2 °N and 10 °S A resolution of 0.5 degrees latitude on the 10 °W radial was applied for the plot. These three parameters were represented simultaneously on a 2D diagram with the depth as a function of the latitude for each zone and each season.

IV. RESULTS

1.Surface nitrate concentrations, top of the nitracline and MLD

Tab : Values of minimum, maximum, and mean of the mixed layer depth (MLD in m), nitracline depth, and mean of the NO_3^- concentrations in the MLD during both seasons in the equatorial zone and in the cold season for the 6 °S and 10 °S to 10 °W zones

Area	Season	Statistical characteristics	MLD (m)	Depth of the Nitracline (m)	Mean of the NO_3^- concentration (mmol L^{-3}) in the MLD
Equatorial Zone	Hot season	Min.	20.50	34.14	2.96
		Max.	64.50	46.19	7.49
		Mean	39.06	41.08	5.35
	Cold season	Min.	10.5	5.47	0.00
		Max.	35.33	28.83	2.06
		Mean	25.88	14.68	1.26
6 °S Zone	Cold season	Min.	30.93	45.99	0.03
		Max.	44.13	79.57	0.66
		Mean	39.72	60.77	0.25
10 °S Zone	Cold season	Min.	10.00	0.00	0.25
		Max.	65.33	113.38	5.41
		Mean	46.15	74.61	1.548

2.Surface nitrate concentrations, top of the nitracline and MLD

2.1. During the cold season

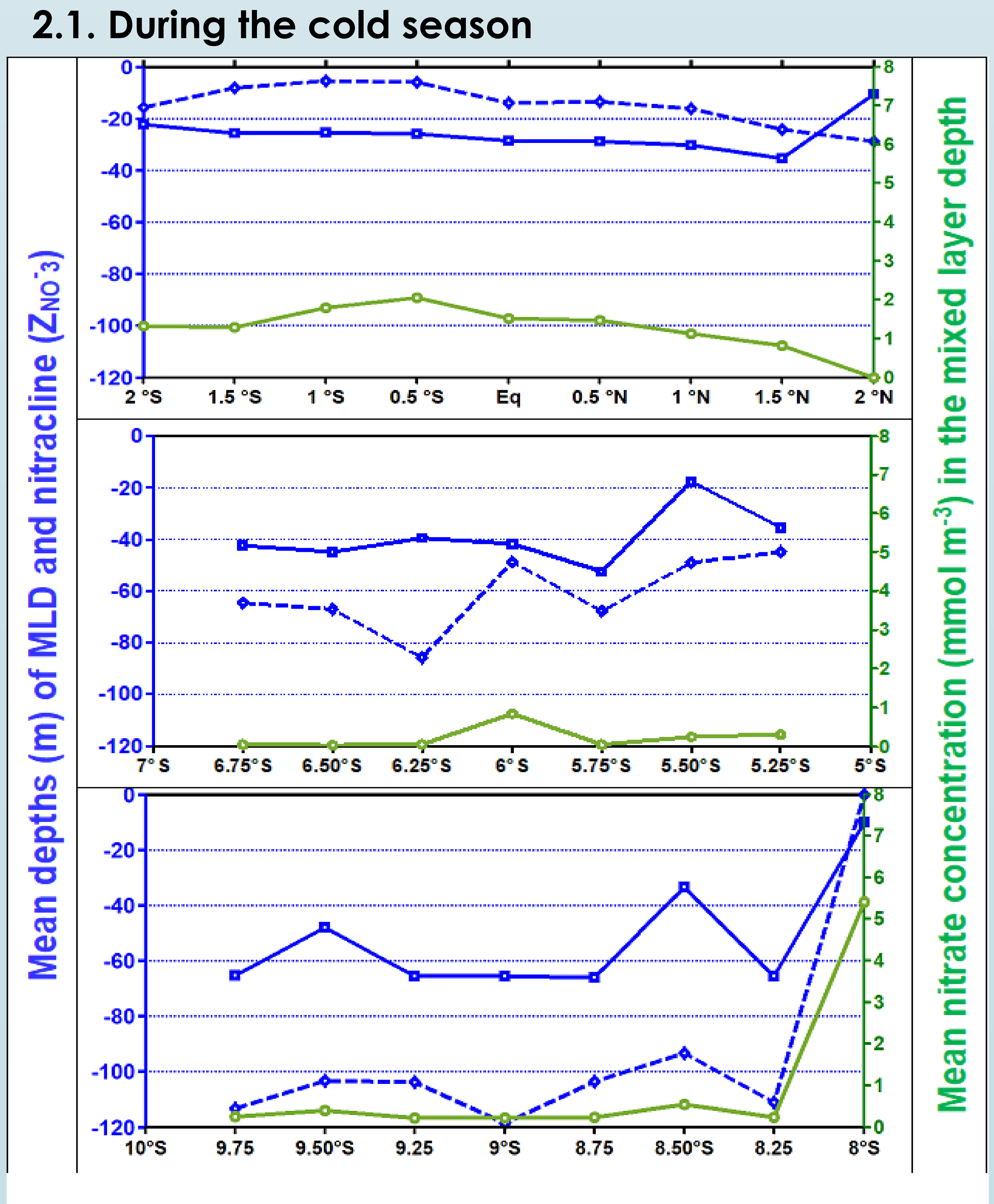
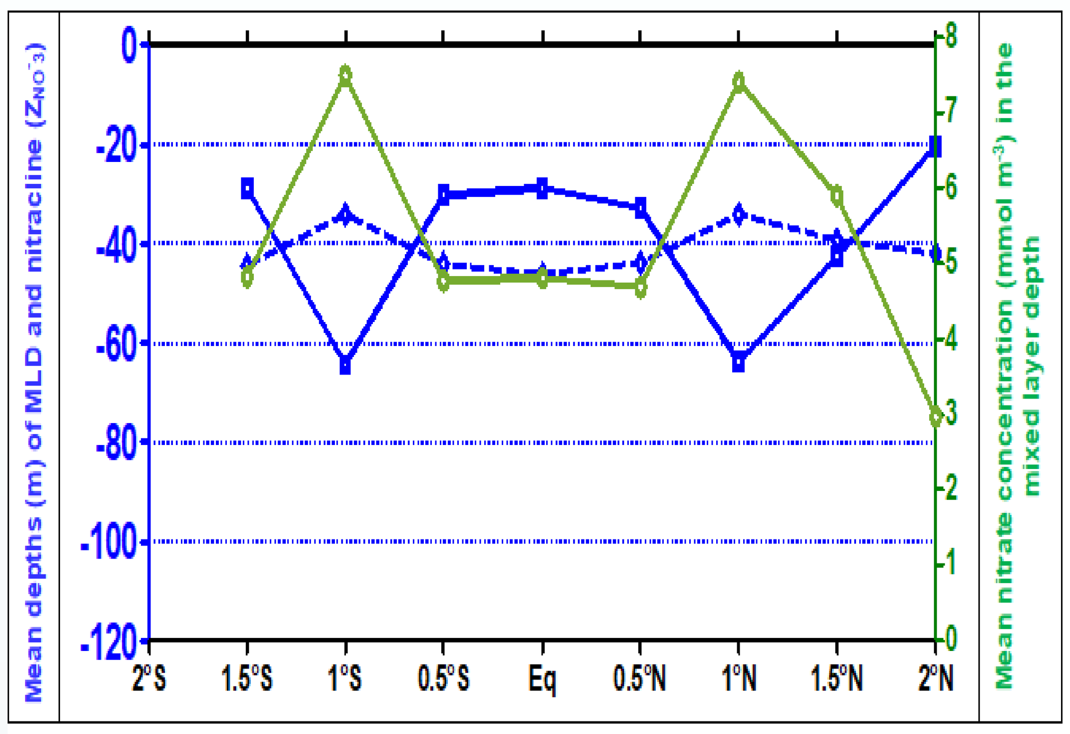


Fig.2 Spatial evolution of the average MLD (blue), nitracline (black) and the average nitrate concentration in the mixed layer (green), during the cold season at 10 °W. Top: in the equatorial zone, middle: in the 6 °S zone, bottom: in the 10 °S zone. Eq: means equator.

2.2. During the hot season



. **Fig.3** Spatial evolution of the mean MLD (blue), nitracline (black) and the mean nitrate concentration in the mixed layer (green), during the hot season at 10 °W in the equatorial zone. Eq: means equator

Cold season:

In the equatorial zone, the evolution of mixing layer depths is relatively weak and homogeneous over the whole area. Nitracline remains low above the mixed layer between 1.75 °N and 2 °S and remains below the MLD above 1.75 °N.The evolution of the average nitrate concentration in the MLD remains low and ranges from about 0 to 2.06 mmol m^{-3} in this area at 10 °W.

6° sud zone: In the 6 °S zone, the MLD varies weakly between 31 and 42.5 m. As for nitracline, it is below the MLD and varies between about 46 and 80 m.. . In this zone, nitrate concentrations in the MLD remain very low and are less than 1 mmol m^{-3}.

10° sud zone: a monotonic increase in the mixed layer from 10 to 65.5 m ranging from 8 to 10 °S on the water column

Hot season: The equatorial zone shows relatively large mixed layer thicknesses compared to the cold season, ranging from 20.5 to 64.5 m. As for nitracline, it has a slight variation between 42.12 and 44.14 m. Nitrate concentrations in the MLD range from 3 to 7.8 mmol m^{-3} at the equatorial zone.

V. CONCLUSION

The depths of nitracline, as well as the amounts of nutrients in the surface layers, are different between the equatorial zone and the southern zone of the equator. At equivalent depth of the MLD, the contribution of nitrates during the cold season to the surface layers is therefore greater in the equatorial zone than in the zone south of the equator. The results obtained confirm that the seasonal cycle of MLD largely constrains the variations in nutrient concentrations at the surface. In the equatorial zone, the deepening of the MLD is accompanied by the enrichment of the surface layer during the cold and hot seasons. In the southern zone of the equator, despite the deepening of the MLD, nitracline remains below the MLD and the surface layer remains depleted of nitrates with concentrations below 1 mmol m^{-3} throughout the cold season.

References

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