

THE DISTRIBUTION OF NUTRIENTS IN EQUATORIAL ATLANTIC :
VERTICAL MOTION, VERTICAL TURBULENT MIXING AND ZONAL ADVECTION

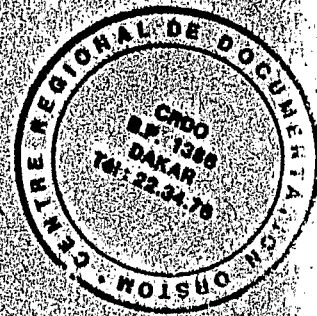


C. Oudot^{*} and P. Morin[†]

(*) Centre ORSTOM B.P. 1386 Dakar Sénégal

(†) L.O.C. U.B.O. 6, Av. Le Gorgeu 29283 Brest Cedex France

*Symposium UNESCO
Paris, Mai 1985, communication.*



Fonds Documentaire ORSTOM



010014477

Fonds Documentaire ORSTOM

Cote: **B4477** Ex: **1**

Bx

19845

THE DISTRIBUTION OF NUTRIENTS IN EQUATORIAL ATLANTIC :
VERTICAL MOTION, VERTICAL TURBULENT MIXING AND ZONAL ADVECTION

C. Oudot* and P. Morin†

(*) Centre ORSTOM B.P. 1386 Dakar Sénégal

(†) I.O.C. U.B.O. 6, Av. Le Gorgeu 29283 Brest Cedex France



ABSTRACT

In the Gulf of Guinea (4°W), the equatorial upwelling, generated by the divergence of surface current meridional components, appears only in northern summer (June to September) south of the equator and exhibits a respectable enrichment in nitrate and phosphate at the sea surface. But at the equator properly so-called, the surface layer is enriched also in nutrients by the vertical mixing by vertical shear between the Equatorial Undercurrent and the surface Equatorial Current. The zonal advection from the african coastal zone, put forward to explain the equatorial fertility, does not agree with the observed surface distributions of nitrate.

In the western equatorial Atlantic (35°W), the seasonal surface nutrient enrichment does not appear in July and the surface layer seems to stay impoverished in nutrients throughout the year. There the thermocline is deeper and the upwelling does not seem sufficiently strong to bring up the nutrients to the lighted surface layer : then the activity of the primary biological producers is reduced. The deepening of the thermocline occurs between 22 and 24°W.

1 - INTRODUCTION

For a long time the distribution of the nutrients is used in hydrological studies to show the vertical motions in the surface layer of the ocean. Their distribution within the ocean first set by the biochemical processes (consumption - regeneration) can be afterwards modified by the physical ones (vertical and horizontal advection - vertical turbulent mixing).

In tropical regions the production cycle is continuous throughout the year and the thermocline is permanent contrary to what it happens in mid latitude regions. Nevertheless the surface circulation induced by the trade winds is subject to seasonal variations. For a long time these seasonal variations in the equatorial area of the Atlantic Ocean, particularly in its eastern part, were unknown, because one continually referred to the Equalant 2 cruise (August 1963), which afterwards appeared to be carried out in abnormal conditions for the season. For a decade it seems well established that the equatorial Atlantic area undergoes seasonal variations (Hisard, 1973). The R.V. CAPRICORNE cruises carried out in the eastern equatorial Atlantic between August 1978 and January 1980 (CIPREA Program of the ORSTOM/France and Ivory Coast, contribution to FGGE) and more western as far as the South America between July 1982 and August 1984 (FOCAL Program of the ORSTOM/France and Senegal, joint to SEQUAL) allow to improve the knowledges on the variations of the nutrients distributions and to precise the part of the different physical processes in these distributions.

2 - SEASONAL VARIABILITY

It is an accepted fact for a long time that in the three oceans, the equatorial belt subject to the effects of the divergence of surface current meridional components is the centre of a vertical upward transport, called upwelling. This upwelling firstly distinguished oneself by a cooling of the surface layer, which is more or less pronounced according to the season and the longitude. In the Gulf of Guinea, the equatorial upwelling appears usually in northern summer (Mazeika, 1968 - Merle, 1978). Between April and August at 4°W (see map on Fig. 4) the surface

Fonds Documentaire ORSTOM

Cote: BX 14477 Ex: 1

CRDO - DAKAR	
date	22/16/88
n°	5944
cote	ABP

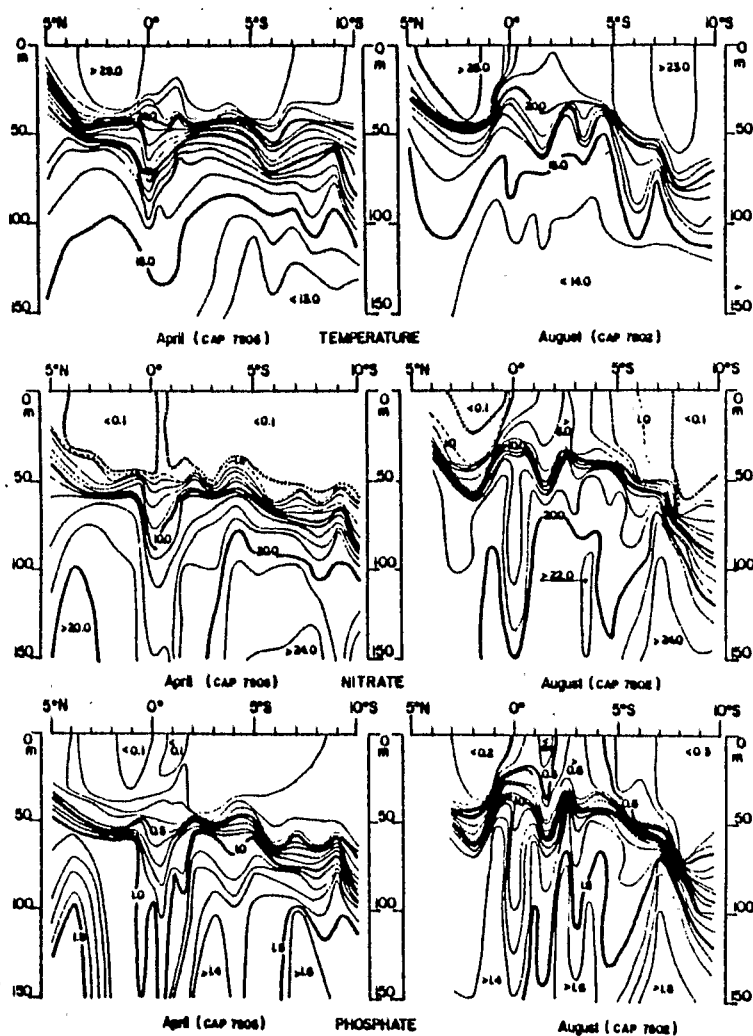


Fig. 1. Meridional distributions along 4°W, in August 1978 and in April 1979 of temperature (°C), nitrate ($\mu\text{mol.l}^{-1}$) and phosphate ($\mu\text{mol.l}^{-1}$).

ked that there is no seasonal variations at 30°W. Yet the mixed layer seems more exhausted in nutrient in July than in January : note that in July the thermocline is slightly deeper than in January.

Along the 4°W meridian, at the equator properly so-called in subsurface, that is to say at the level of the Equatorial Undercurrent (about 50-60 m at 4°W), the seasonal variation of the nitrate and phosphate vertical distributions is quite so clear (Fig. 1) : in August the Undercurrent is carrying waters much richer in nutrient than in April. This enrichment is important from an ecological point of view because it affects the euphotic layer and it is different from the previously described : it should be due to the vertical mixing in the vertical shear between the Equatorial Undercurrent and the surface Equatorial Current which is intensified in summer by the increase of the vertical gradient of the horizontal speed of current (Hisard et al., 1977).

The five CIPREA cruises performed between August 1978 and January 1980 allow to specify the degree of nutrient enrichment of the mixed layer according to the time of the year and to estimate how long lasts the enrichment period (Oudot, 1983). Considering only the sea surface (Fig. 3) the nitrate enrichment period of the surface layer by upwelling would last from June to September. If one takes as an enrichment criterion the form of the subsurface isopleths up to $4,0 \mu\text{mol NO}_3 \cdot \text{l}^{-1}$ to consider also the action of the vertical mixing by vertical shear, one notices that the strict equatorial enrichment which proceeds from this latter process would last more long (June to January) than the former. Thus we can confirm at 4°W the Kaiser

temperature drops from more 28°C to less 22°C in the band 0°-5°S. (Fig. 1 at the top). The cooling of the equatorial belt 0°-5°S is accompanied by a nitrate and phosphate pronounced enrichment of the surface layer above the thermocline (Fig. 1) : in this band the superficial concentration of nitrate, inferior to $0,1 \mu\text{mol.l}^{-1}$ in warm season, is exceeding $2,0 \mu\text{mol.l}^{-1}$ in cold season (with a maximum value higher than $6,0 \mu\text{mol.l}^{-1}$), whereas the phosphate one is increasing from 0,1 to $0,4 \mu\text{mol.l}^{-1}$. Thus at the 4°W longitude, the area cooled and enriched in nutrients is completely south of the equator, contrary to that happens generally more western where this area overlaps the equator (Fig. 4). In accordance with the qualitative model proposed by Cromwell, the southeasterly trade winds, which are the usual rule in this area, are generating a divergence and consequently an upwelling south of the equator.

On the west (35°W), in front of the Brasil, there is no seasonal cooling of the sea surface followed by a nitrate and phosphate enrichment of the surface layer (Fig. 2). There no difference appears really between January and July in the meridional distributions of temperature, nitrate and phosphate. Recently Kaiser and Postel (1979) remarked

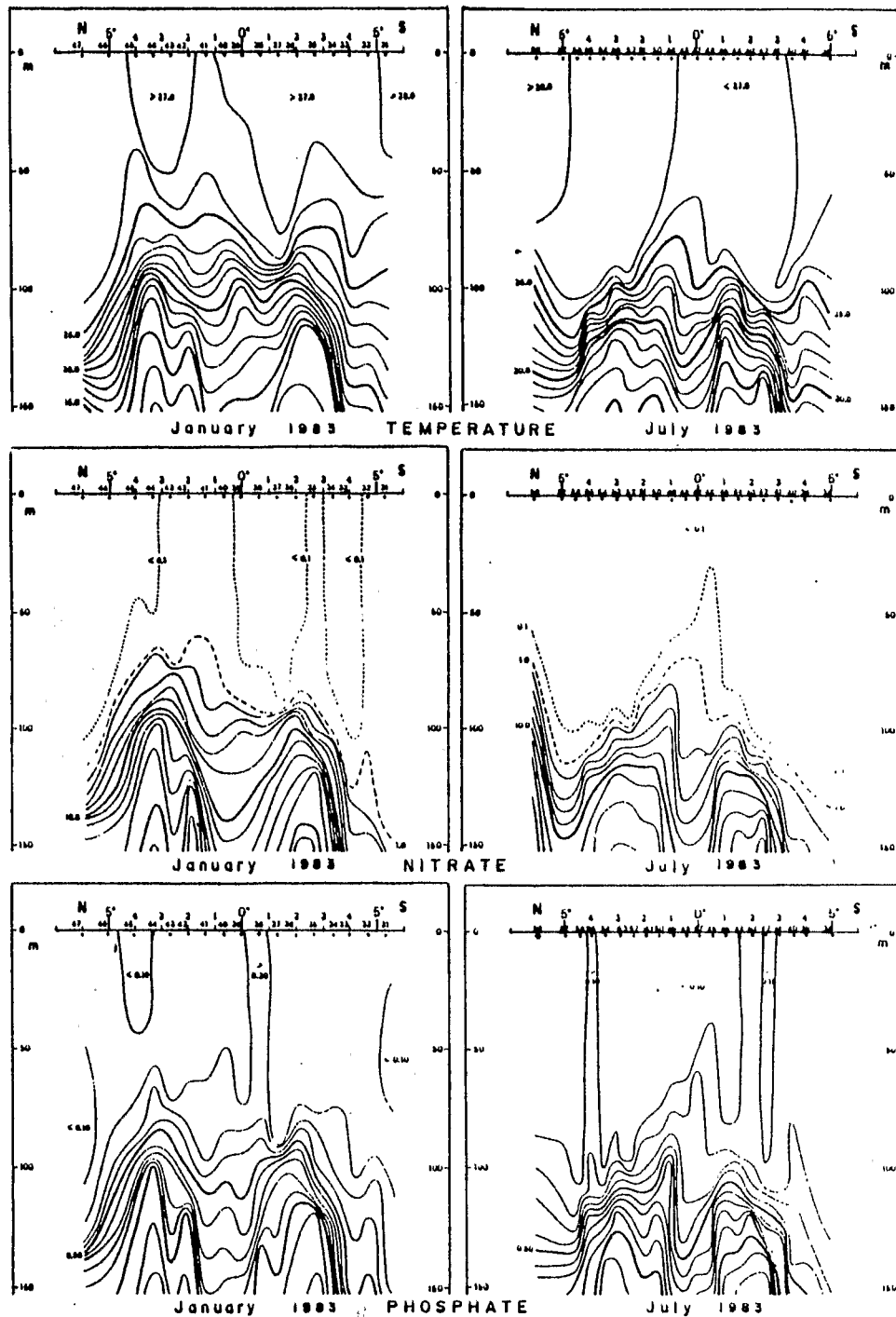


Fig. 2. Meridional distributions along 35°W, in January and July 1983 of temperature (°C), nitrate ($\mu\text{mol.l}^{-1}$) and phosphate ($\mu\text{mol.l}^{-1}$).

and Postel (1979) proposal more western (30°W) of the leading part of the vertical mixing on the vertical advection in the process of enrichment of the equatorial euphotic layer : the superimposition of these two mechanisms leads to observe the maximum enrichment of the equatorial belt in August and the minimum one in April.

3 - ZONAL EXTENSION OF THE EQUATORIAL NUTRIENT ENRICHMENT

The maps of the nutrient distribution at the surface of the oceans show most of the time a continuous decrease of the concentrations along the equatorial belt from the eastern boundary, that is to say an area of coastal upwelling. Therefore the zonal advection from the rich coastal zone is often put forward to explain the equatorial fertility. The observations collected with the R.V. CAPRICORNE (Fig. 4) as

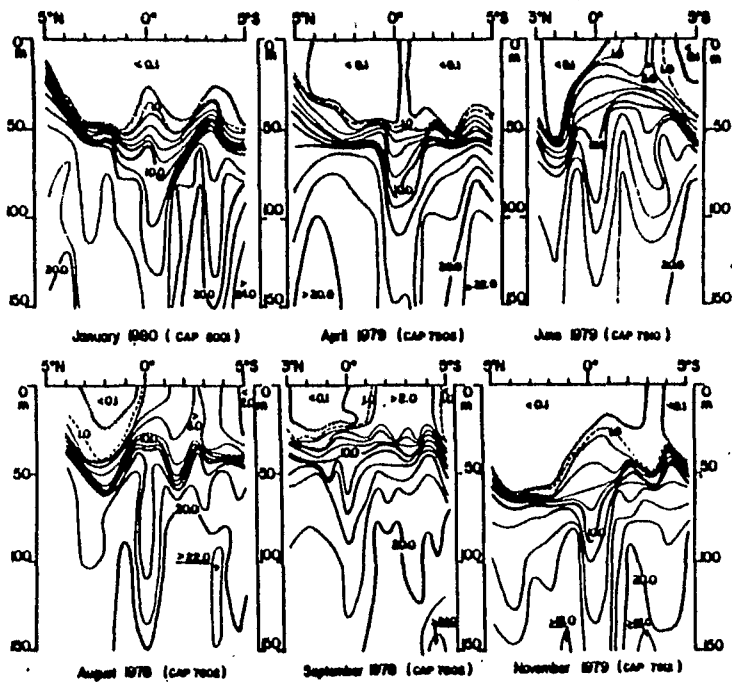


Fig. 3. Meridional distributions of nitrate ($\mu\text{mol.l}^{-1}$) along 4°W in six different months of the year.

longitude and due to the upwelling has an effect on the primary production of this area. Considering the quantity of chlorophyll a integrated in the water column as a criterion of the biological productivity, we find that at 4°W the equatorial upwelling zone is barely richer in July-August ($27 \text{ mg Chl.a.m}^{-2}$) than in January-February ($26 \text{ mg Chl.a.m}^{-2}$) (Fig. 5 on the right). Herbland et al. (1983), according to the CIPREA data, underlined previously the "paradox" of the equatorial zone of which the global production is not increased during the upwelling season. On the other hand note the large increase in the coastal upwelling area just in front of Abidjan

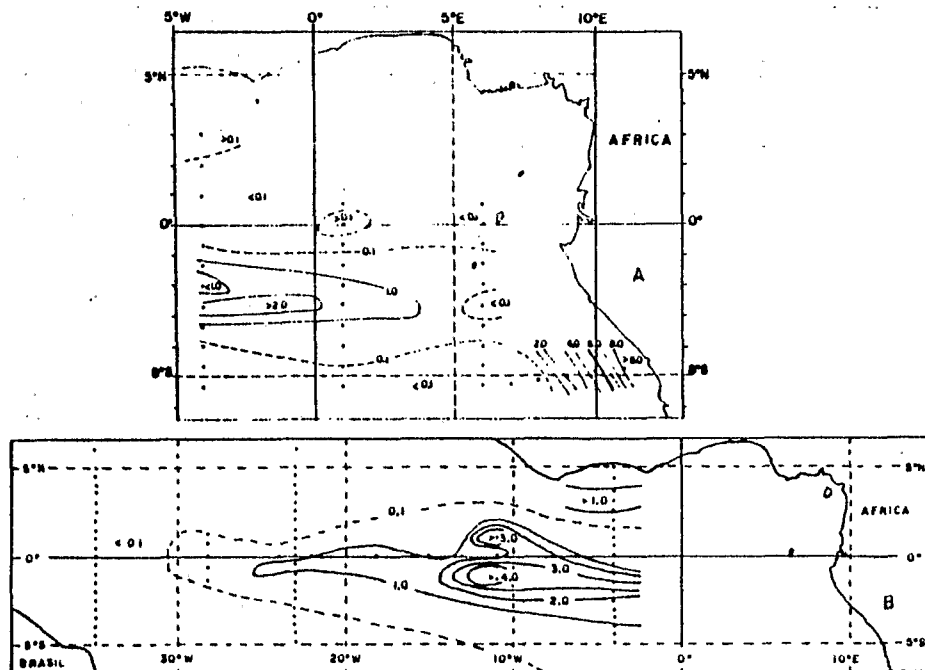


Fig. 4. Horizontal distributions of nitrate ($\mu\text{mol.l}^{-1}$) at the sea surface in June-July 1979 (A) and in July-August 1983 (B). Note that for the upper drawing the scale is about two times smaller than the one for the lower drawing.

well in the eastern part of the Guinea Gulf (CIPREA cruise : A) as in the central Atlantic (FOCAL cruise : B) do not show such a continuous decrease westwards : in 1979 (A) the surface nitrate concentration is higher at 4°W than at 6°E and in 1983 (B) at 10°W than 4°W . The increases of nitrate concentration westwards follow most of the time a cooling of the sea surface which seems to be a local process.

If we take as a reference the isopleth $0.1 \mu\text{mol NO}_3 \cdot \text{l}^{-1}$ (figure 4 B) which marks the exhaustion of the surface layer, we can establish that the equatorial nutrient enrichment was stretching westwards to about 30°W in summer 1983.

4 - EQUATORIAL NUTRIENT ENRICHMENT AND PRODUCTIVITY

It is important to see if the seasonal nutrient enrichment observed south of the equator at the 4°W

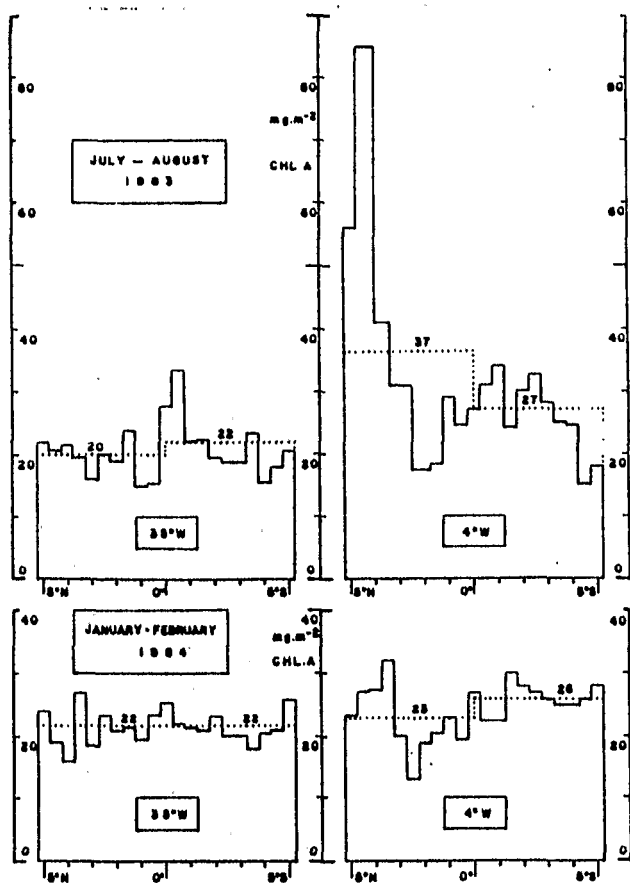


Fig. 5. Meridional distributions of the integrated values of chlorophyll a (mg. m^{-2}) at 4°W (on the right) and 35°W (on the left) in July-August 1983 (at the top) and in January-February 1984 (at the bottom).

deepening of the thermocline and the nitracline decrease the upward nutrient flux in the euphotic layer and the primary production is reduced.

REFERENCES

- Herbland, A., Le Borgne, R., Le Bouteiller, A., Voituriez, B. (1983) Structure hydrologique et production primaire dans l'Atlantique tropicale orientale. Océanogr. trop., 18, 249-293.
- Hisard, P. (1973) Variations saisonnières à l'Equateur dans le Golfe de Guinée. Cah. ORSTOM, sér. Océanogr., 11, 349-358.
- Hisard, P., Citeau, J., Voituriez, B. (1977) Equatorial undercurrent influences on enrichment processes of upper waters in the Atlantic Ocean. GATE Workshop, Miami, March 1977.
- Kaiser, W., Postel, L. (1979) Importance of the vertical nutrient flux for biological production in the Equatorial Undercurrent Region at 30°W . Mar. Biol., 55, 23-27.
- Mazeika, P.A. (1968) Mean monthly sea surface temperatures and zonal anomalies of the tropical Atlantic. In : Serial Atlas of the marine environment, Folio 16, American Geographical Society.

(Ivory Coast).

In the western part (Fig. 5 on the left) the quantity of chlorophyll a is less ($22 \text{ mg Chl.a.m}^{-2}$) than in the eastern part and maintains the same value all the year round. There the deepening of the thermocline and the nitracline seems to affect the productivity of the euphotic layer.

According to the vertical distributions of the temperature and the nitrate concentration in July-August along the equator (Fig. 6), it is between 22 and 24°W that the thermocline and the nitracline deepen. This zone corresponds to a sharp decrease of the nitrite concentration (Fig.6 below). Following Voituriez and Herbland (1977), who assign the nitrite production to the nitrate reduction by the phytoplankton, we can admit that the disappearance of the nitrite is an indication of the decrease of the phytoplankton activity above-mentioned in the western equatorial area.

5 - CONCLUSIONS

The onset of the equatorial upwelling in summer in the eastern Atlantic does not seem to have an effect on the global production in this area. The fertility of this region, constant all the year long, should be rather ascribed to the vertical turbulent mixing reinforced at the equator by the vertical shear between the surface Equatorial Current and the Equatorial Undercurrent. In the western Atlantic, the

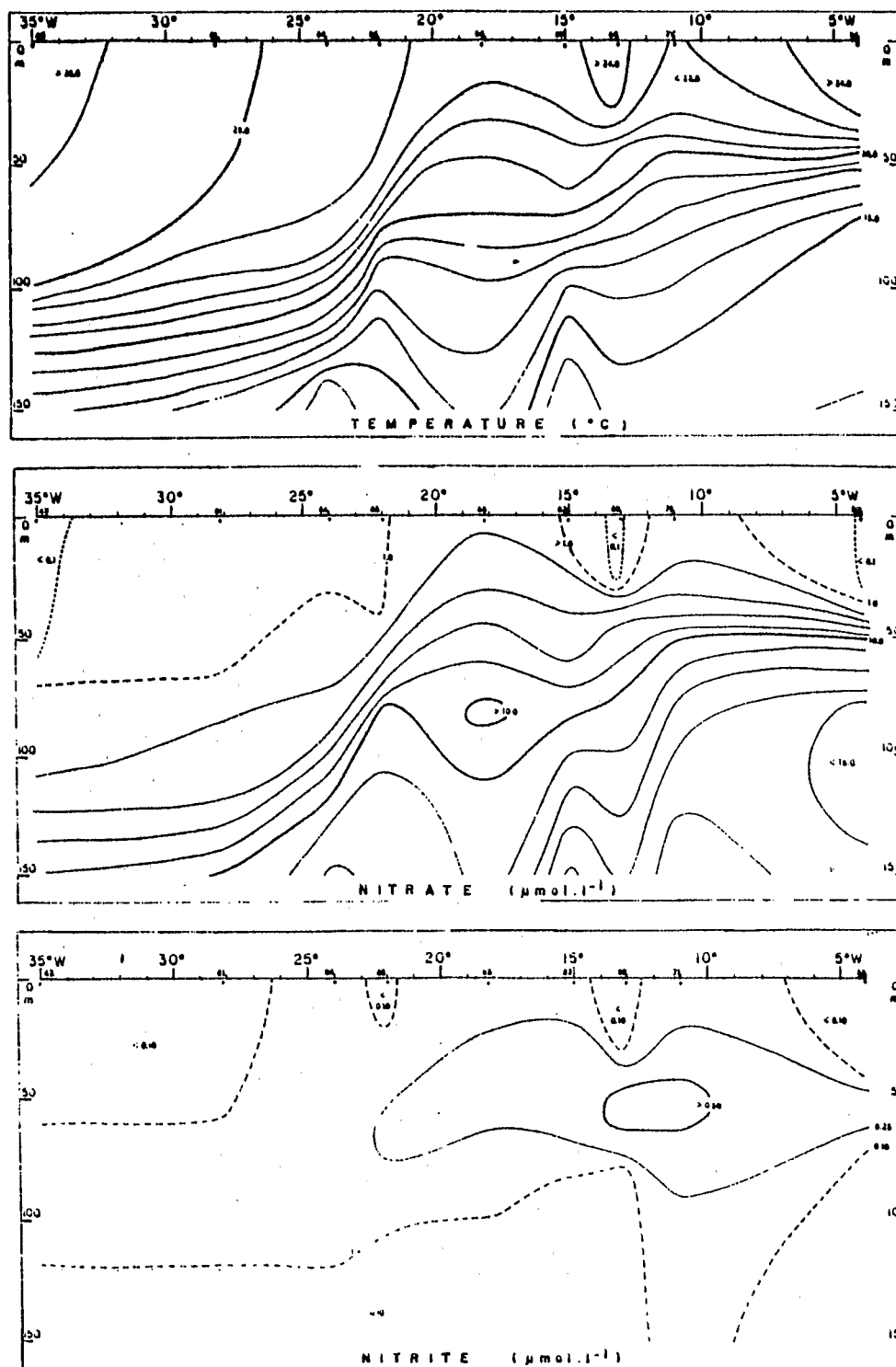


Fig. 6. Zonal distributions along the equator of the temperature ($^{\circ}\text{C}$), the nitrate ($\mu\text{mol.l}^{-1}$) and the nitrite ($\mu\text{mol.l}^{-1}$) in July-August 1983.

Merle, J. (1978) Atlas hydrologique saisonnier de l'Océan Atlantique intertropical. Trav. Doc. ORSTOM, 82.

Oudot, C. (1983) La distribution des sels nutritifs (NO_3^- - NO_2^- - NH_4^- - PO_4^- - Si O_3) dans l'Océan Atlantique intertropical oriental (région du Golfe de Guinée). Océanogr. trop., 18, 223-248.

Voituriez, B., Herbland, A. (1977) Production primaire nitrate et nitrite dans l'Atlantique tropical, 2, Distribution du nitrate et production de nitrite. Cah. ORSTOM, sér, Océanogr., 15, 57-65.