On the formation of thermohaline stratification off Congo River plume

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SCAN ME

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MOTIVATION **:**

The thermohaline stratification within the ocean superficial layers plays a key role on the air-sea interactions by modulating heat flux exchanges and vertical mixing, which have a great implication on climate. The global warming has induced fundamental changes in temperature and salinity fields of the oceans, with impacts on the near-surface stratification that substantially increased of about 5.3% over the most recent decades (1960-2018), ~71% of which occurring within the upper 200m (Li et al., 2020; Yamaguchi & Suga, 2019). In the southeastern Gulf of Guinea (GG), temperature and salinity of the surface layers are strongly influenced by the Congo River runoff. The impact of the Congo River plume on the 3-dimensional thermohaline structure in this region is still poorly documented due to the scarcity of in situ data. Using the recent Sea Surface Salinity product from ESA's Climate Change Initiative (CCI+SSS), and the available in situ and remote sensing measurements, the impacts of the Congo River plume on the thermohaline stratification in the southeastern GG are presented and analyzed. Typical structures of the thermohaline stratification off Congo River plume are characterized. The mechanisms controlling the thermohaline layering are investigated, with a focus on the stepped thermohaline stratification above the main thermocline.

DATA**:**

CTD and ADCP profiles from PIRATA FR – Argo profiles – surface currents from GLORYS Mercator Ocean data – SSS from ESA's CCI database – OI-SST from NOAA database.

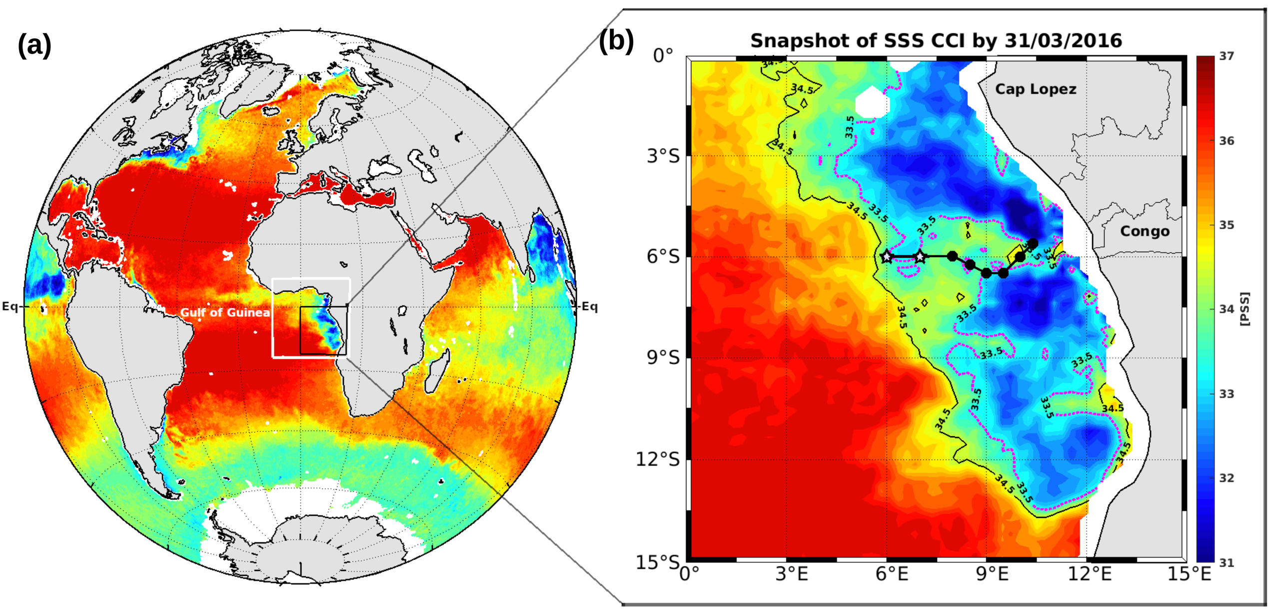


Fig.1. Snapshot SSS from CCI+SSS by 31/03/2016 : (a) global view and (b) zoom of southeastern of the GG. Black points and starts are CTD profiles stations across the freshwater plume

Objectives

Low salinity patterns (SSS<34.5pss) are found in the southeastern Gulf of Guinea due to the Congo River Runoff (Fig.1). What is the influence of the Congo River plume on the thermohaline stratification within the upper layers of the ocean? What are the mechanism associated with freshwater plume stratification at intra-seasonal scale?

1.Thermohaline stratification across the region under the influence of Congo River runoff (Fig. 1b and Fig.2)

The potential density of the top layer of 0 to 30-m layer under the influence of the Congo River plume is strongly stratified: N^2>3.10-4/s² (Fig. 2a, black contours). Within this top layer, density, salinity and temperature homogeneous double-layer structures are observed (far from 270 km of the coast, Fig.2 a.b.c). The density-homogeneous double layer structure are dictated by the vertical salinity gradient: N^2_S shown up the same structure like N^2 (Fig.2 a.b.c). Below ~30-m depth, the density stratification is controlled by the temperature vertical gradient.

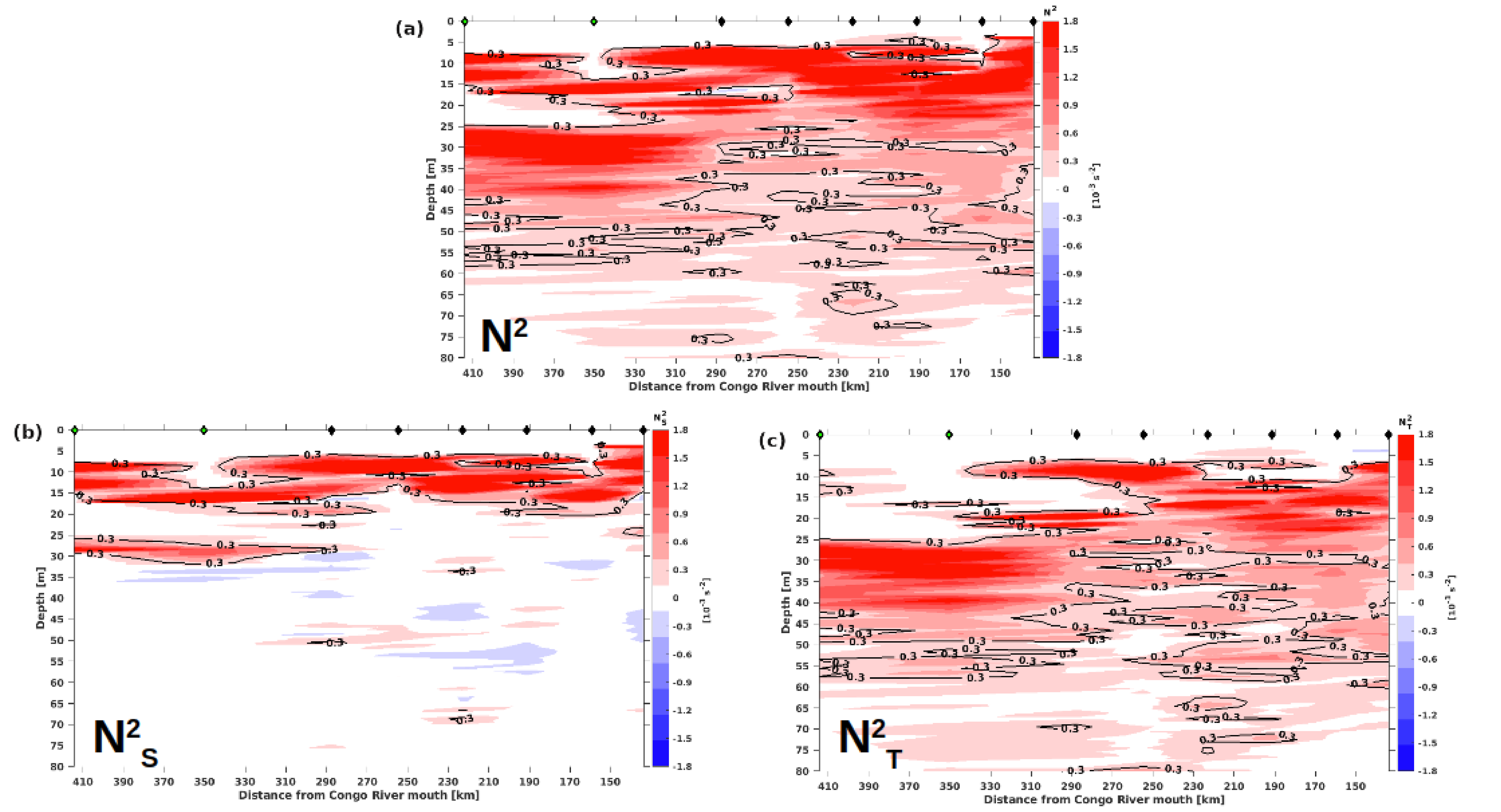
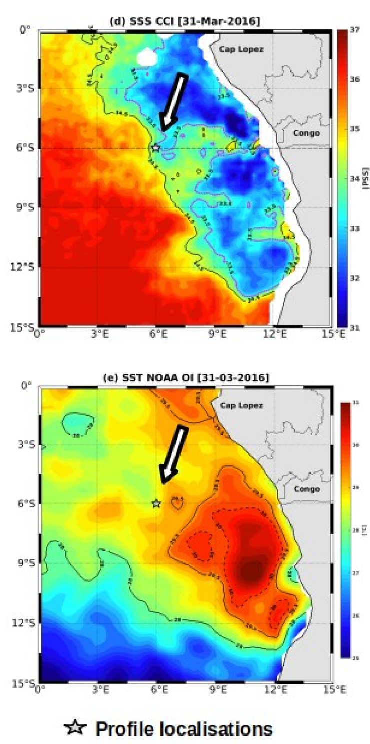


Fig. 2. Vertical sections in function of the distance from the coast of (a) N^2 : Brunt Vaïsäla frequency, (b) N^2_S and (c) N^2_T across the freshwater plume (see Fig. 1b). N^2_S and (c) N^2_T are the contribution of salinity and temperature vertical gradient of density stratification (N^2) respectively

2.The thermohaline stratification of water column within SSS ans SST fronts zone

In the SSS ans SST fronts zones (fig. 3d.e), double mixed layer structure with density gradient interface (0-20m), like "Thermohaline staircase" is observed : $\Delta_z S$ = 0.3 pss/m; $\Delta_z\theta$ = -0.1°C/m; $\Delta_z\sigma_\theta$ = 0.2 kg/m³ per m over 7m layer thickness (8-15m depth, Fig. 3 a.b). There is a potential salty fingering process under 30m depth: within and below the thermocline layers (Fig. 3 a.b.c)



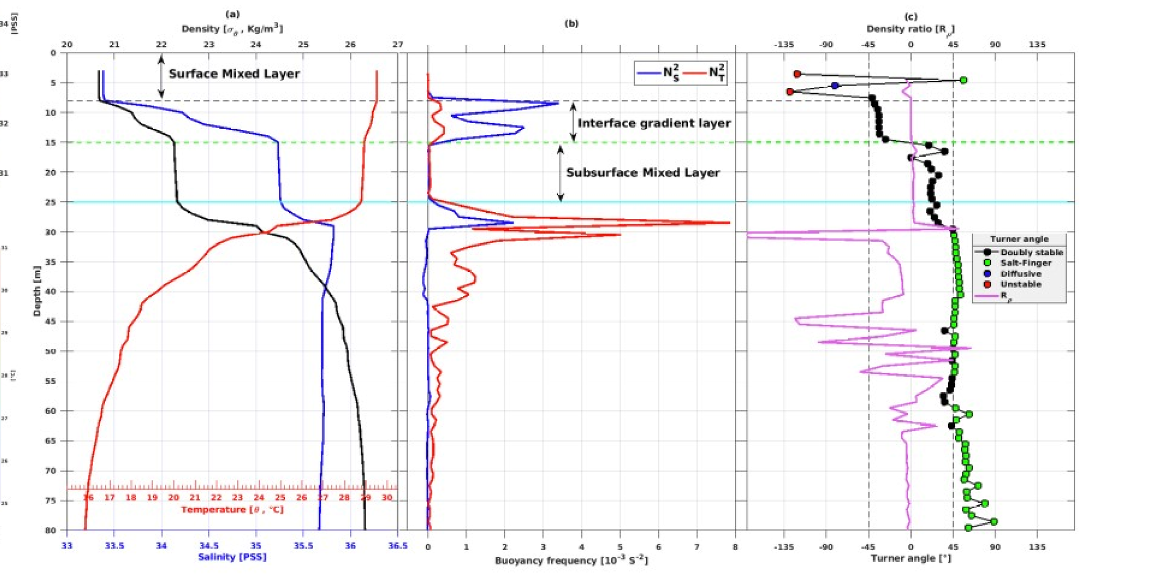
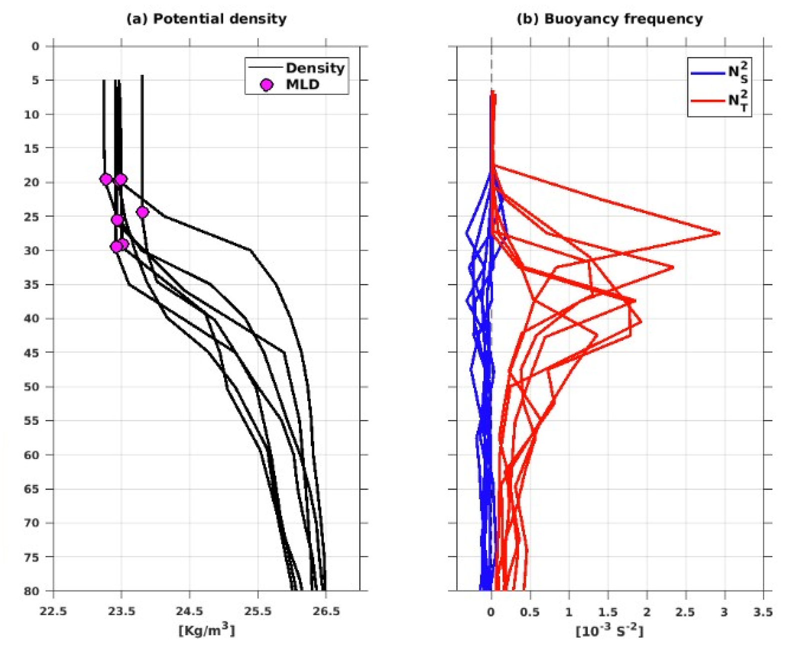


Fig. 3. Vertical profiles of (a)T,S and ρ; (b) N^2_S and N^2_T ; (c) Turner angle and density ratio; snapshot of (d) SSS and (e) SST off Congo

3.The thermohaline stratification out of the Congo River plume influence zone

Out of the Congo River freshwater plume (SSS>34.5pss, see starts in Fig. 4.c) , denser water mass with deeper density mixed layer of 30m thickness are observed (Fig. 4.a). The temperature vertical gradients mainly control the density stratification.



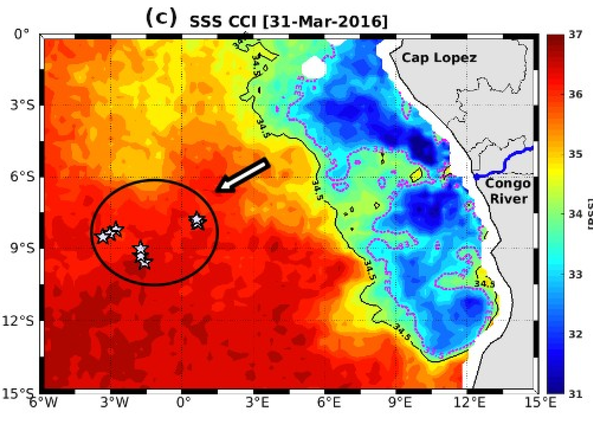


Fig. 4. Vertical profiles of (a) ρ; (b) N^2_S and N^2_T ; (c) SSS off Congo River plume Starts represent the positions of profiles in (a) and (b).

4.Dynamics of the surface circulation in the southeastern Gulf of Guinea freshwater plume

Southwestward advection of negative salinity anomalies of -0.3pss associated with the offshore SSS front displacement is observed (Fig. 5a). The decomposition of total surface currents shows opposite dynamics between surface Ekman wind driven currents and geostrophic currents (Fig. 5 c.d). The surface Ekman currents are oriented North-Westward within the freshwater plume (Fig. 5c) while the geostrophic currents (with fronts) are directed southeastern the region of the observed stepped thermohaline stratification. Profiles of the total currents shows strong vertical shear between the surface and the subsurface layers: I) ~0-15m : Northward currents and ii) ~15-35m: Intensified North-eastward currents (Fig. 5b).

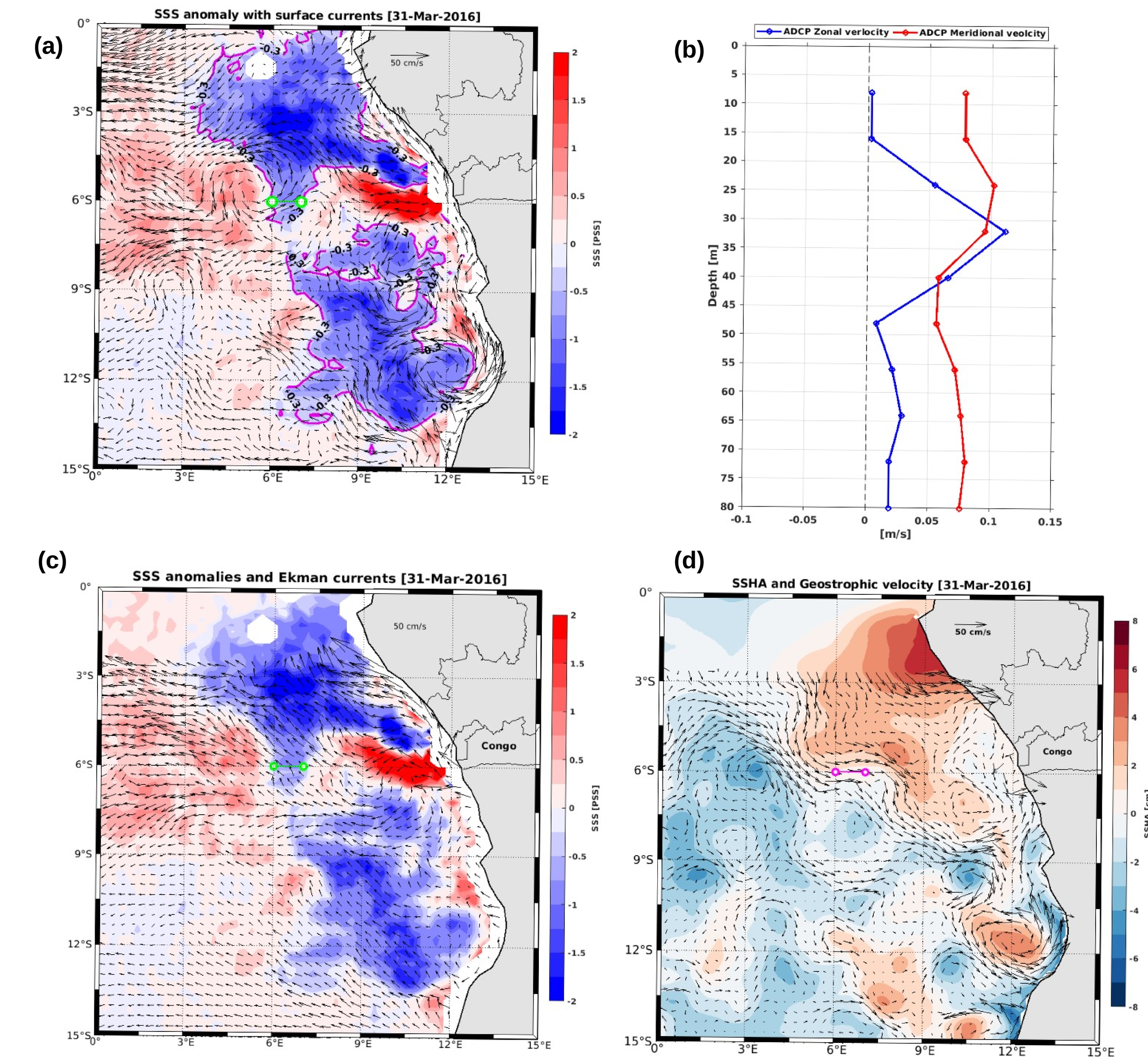
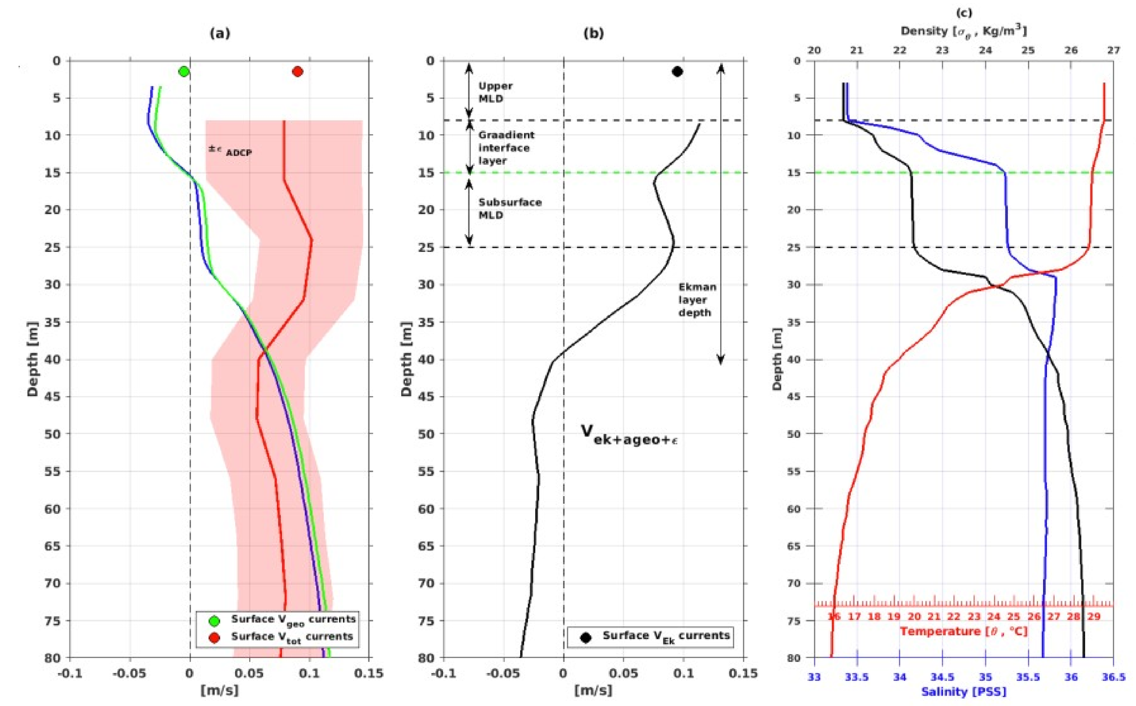
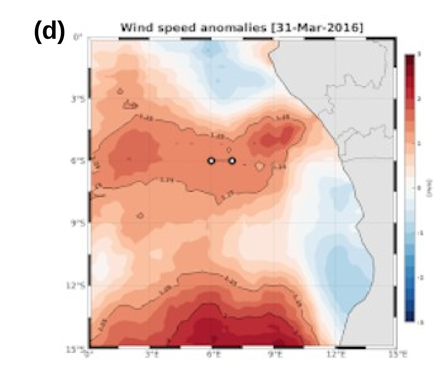


Fig. 5. (a) SSS anomalies (background color, CCI+SSS). The arrows are the total surface currents from GLORYS Mercator Ocean; (b) Vertical profiles of ADCP zonal and meridional currents; (c) SSS anomalies (background color) with the surface Ekman currents (arrows) and (d) Sea surface Height Anomalies, SSHA (background color) with the geostrophic currents (arrows) from GLORYS Mercator Ocean.

5.Vertical profiles of meridional currents : geostrophic and wind-driven Ekman currents

Staircases density structures are associated with sheared ageostrophic currents within the surface layers (Fig. 6a.b). Strong density and salinity vertical gradients interface are associated with the dominant sheared Ekman wind-driven currents (Fig. 6 b.c). The stepped thermohaline stratification is also associated with positive wind speed anomalies (Fig. 6d).

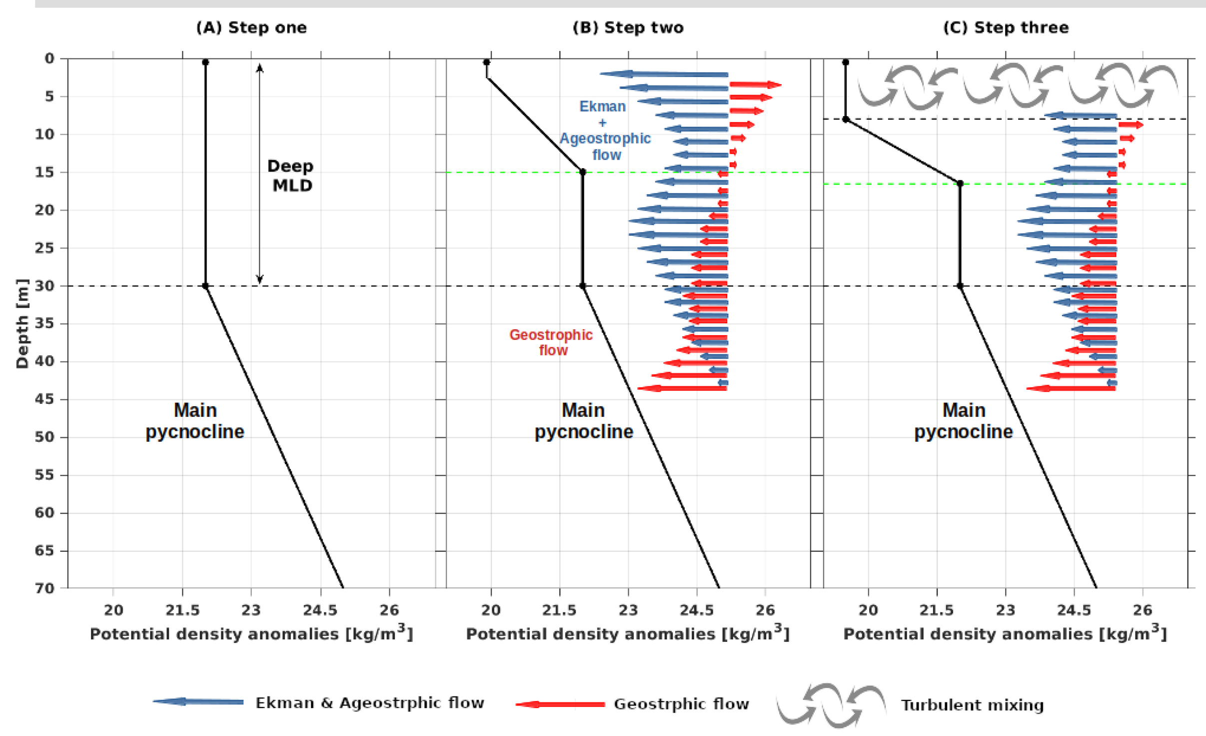




Positive wind speed anomalies of 1.25 m/s

Fig. 4. Vertical profiles of meridional (a) geostrophic currents (blue and green); ADCP currents (red); Ekman (ageostrophic) currents from in situ measurements; (c) same as in the figure 3a; (d) surface wind speed anomalies from GLORYS Mercator Ocean.

6.Mechanism of formation of the stepped thermohaline stratification



The mechanism of the formation could be splitted into three steps

1. Deep mixed layer (A);
2. Interface density gradient associated with sheared ageostrophic currents (B) and
3. Upper turbulent mixing due to positive wind speed anomalies (C)

SUMMARY:

During spring 2016, we found that the water masses off the Congo River plume are associated with a strong halocline of 0.43 pss/m within the top layer of 0-15m depth. At the intra-seasonal scale, the mesoscale dynamics (filamentation) of the freshwater plume is well observed from satellite L-Band SSS. The observed SSS and SST fronts are associated with doubly stable sequences of mixed layers separated by steep-gradient interfaces, with interface gradients of ~0.3pss/m and ~-0.1°C/m for ~7-m layer. Our findings suggest that the observed stepped thermohaline structures is associated with strong shear of the upper horizontal currents likely dominated by the surface Ekman currents and ageostrophic dynamics. Subsurface goestorphic flow (below 50 m depth) is associated with denser and saltier water masses.

PERSPECTIVE:

Investigate the seasonal variability of: i) the surface thin layers structures and ii) the thermohaline staircases structures in the Gulf of Guinea. What are the linkage between thermohaline staircases and the SST in this region? Data: Argo profiles (2000 – 2021) – ADCP & CTD PIRATA/EGEE (2005-2020)