Coastal upwelling limitation by onshore geostrophic flow in the Gulf of Guinea around the Niger River plume

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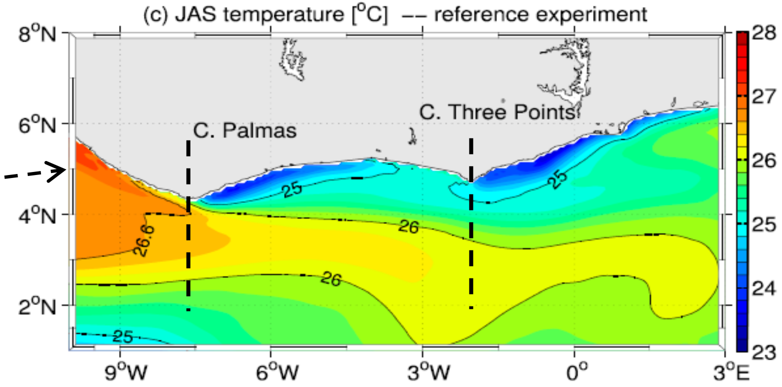
Regional context



- Summer upwelling off Côte d'Ivoire/Ghana driven by detachment of the eastward Guinea Current from the coast east of Cape Palmas and local wind east of Cape Three Points (*Djakouré et al., 2014, 2017*)
- Possible compensation by geostrophic downwelling (*Marchesiello & Estrade, 2010*) due to Niger river plume in the east?

Model, data, methods

Model

- NEMO 1/12° model tropical Atlantic configuration 2010-2017
- Forcing: DFS (based on ERAi) fluxes + *Dai &Trenberth* climatological runoff
- **Reference simulation (REF) + test simulation without rivers (noRIV)**

In situ data

- SST from PROPAO coastal stations
- SSS from **PIRATA**/EGEE + VOS TSG
- Currents from **PIRATA**/EGEE ship ADCP data
- T/S and derived geostrophic currents from WOA
- Currents from NOAA drifters

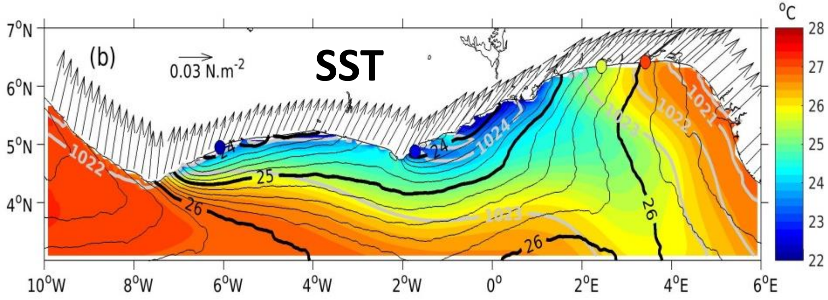
Satellite data

- SST MUR 0.01°,
- SSS SMOS ¼°
- SSH from CMEMS ¼°, X-TRACK
- Geostrophic currents CMEMS ¼°

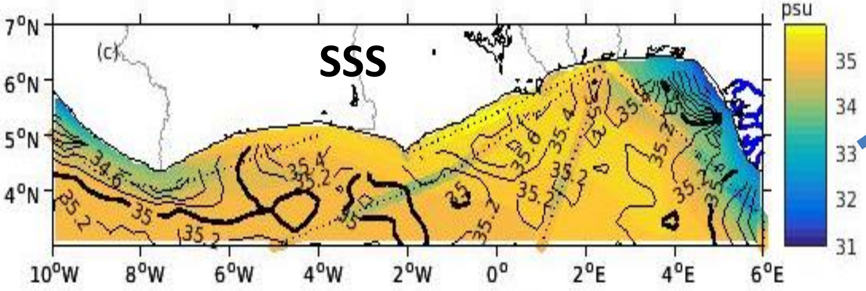
Methods

- **Climatological analysis with focus on summer** (JAS) season
- Ekman/geostrophic coastal upwelling indices from *Bakun (1973), Marchesiello & Estrade (2010)*
- Decomposition of steric sea level height contributions

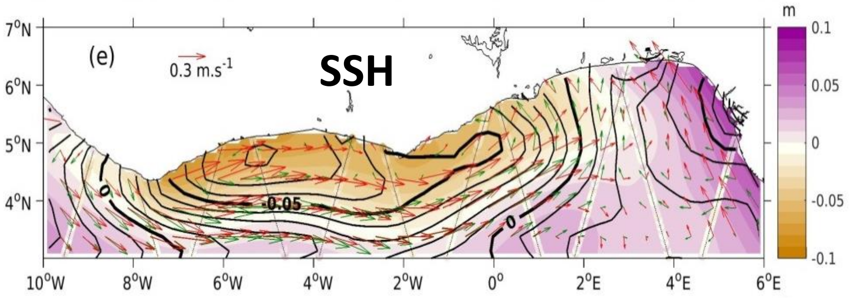
Upwelling surface signature



NEMO (colors) *vs* MUR (isolines) & PROPAO (dots)



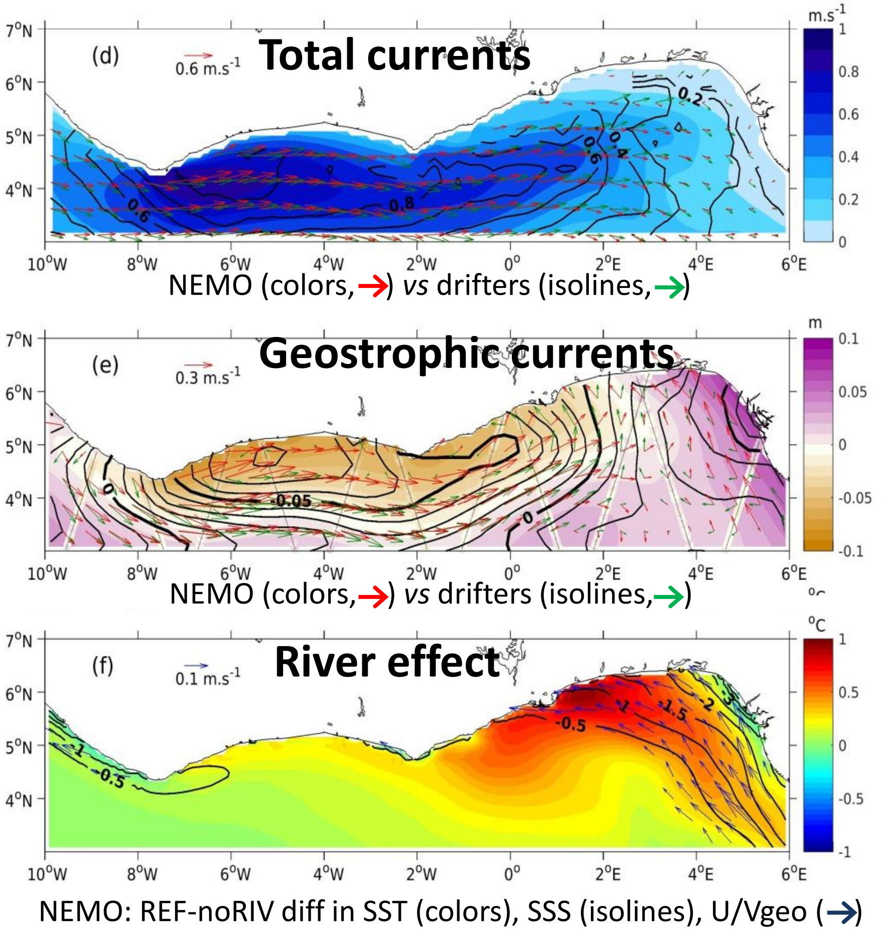
NEMO (colors) *vs* SMOS (isolines) & TSG (dotted lines)



NEMO (colors) *vs* CMEMS (isolines)

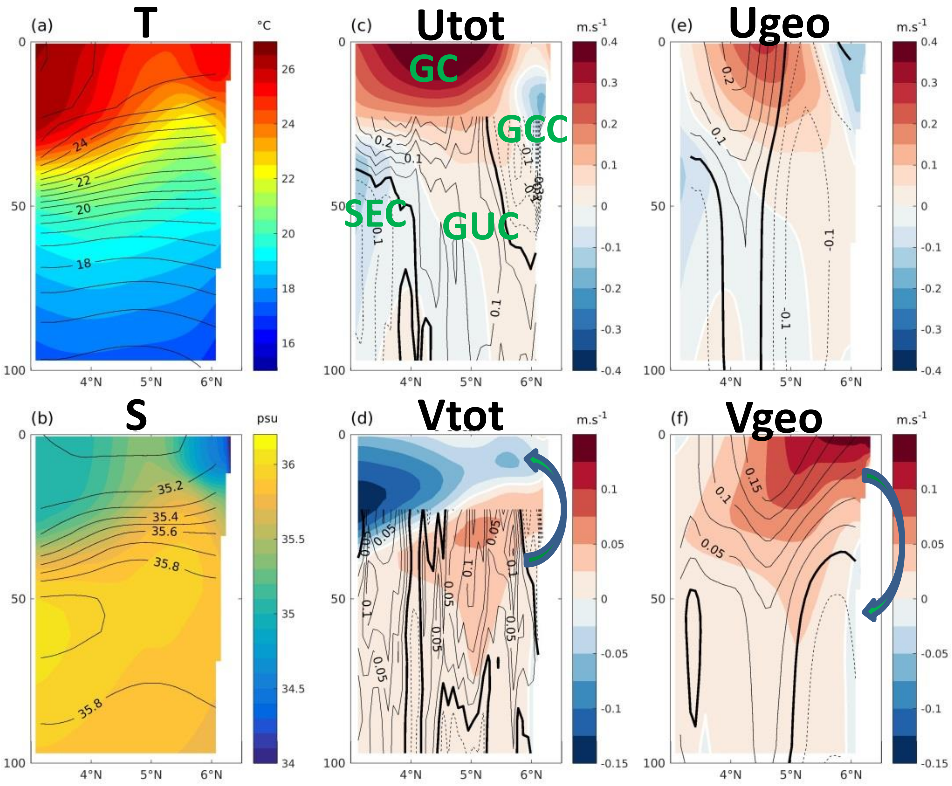
- Wind-driven upwelling → cool & salty tongue that extends southeastward
- Niger freshwater plume to the east
- 10 cm eastward increase of sea level at the coast

Surface currents

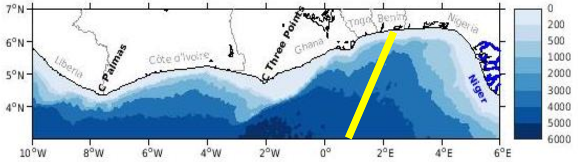


- Eastward flow dominated by the Guinea Current, largely geostrophic
- Geostrophic currents toward the coast between 0°E and 4°E
- Niger River plume contributes to onshore geostrophic currents and warms the upwelling tongue by ~1°C

Upwelling vertical cross-shore dynamics



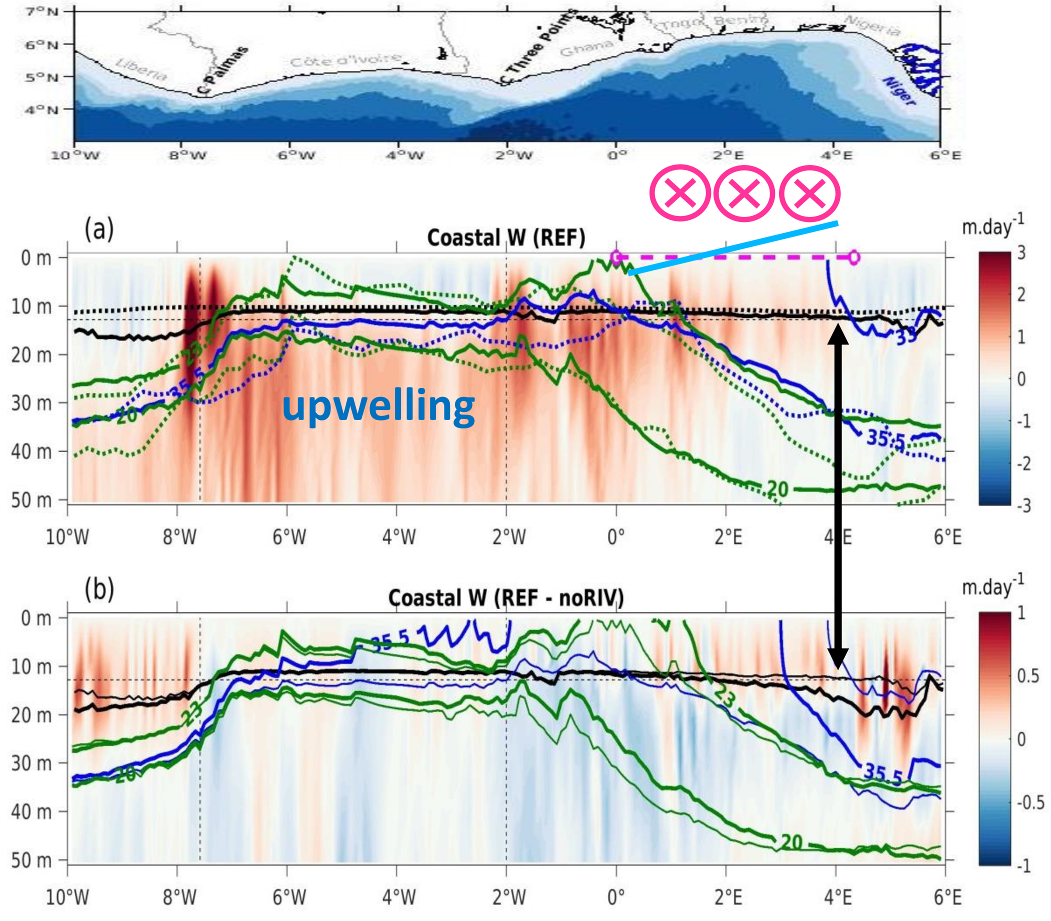
NEMO (colors) *vs* WOA T/S/U/Vgeo & PIRATA U/V (isolines)



GC: Guinea Current
GCC: Guinea Counter-Current
GUC: Guinea Under-Current
SEC: South Equatorial Current

- Coastal rise of isotherms/isohalines
- Main zonal flows simulated
- Upwelling cell in total current
- Geostrophic downwelling cell

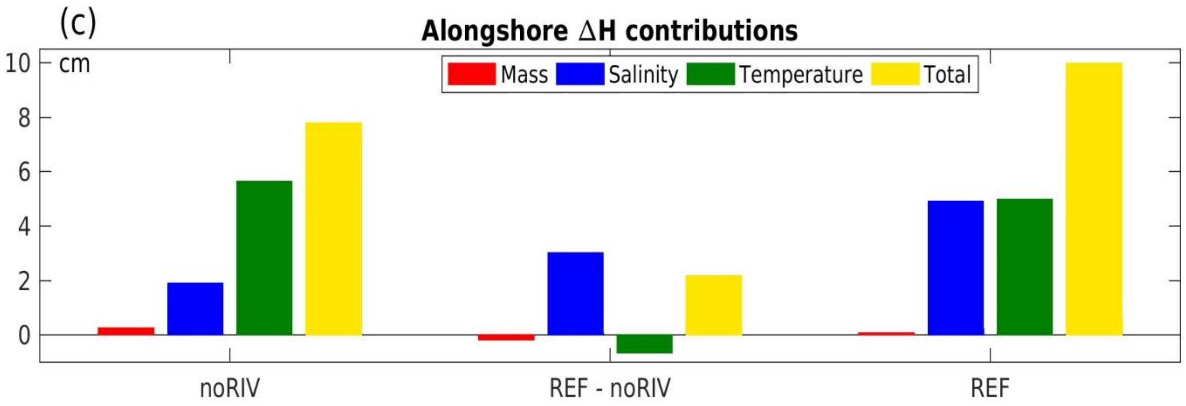
Upwelling vertical along-shore dynamics

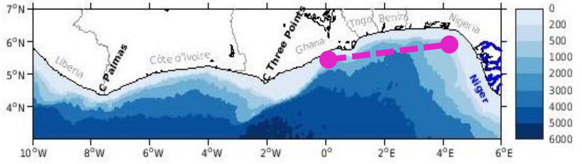


NEMO W (colors), iso-T (—) iso-S (—), MLD w/wo river (▬ /—)

- Upwelling strongest east of capes, weak east of 1°E
- Relatively small river-induced vertical velocities
- MLD reduced by river plume

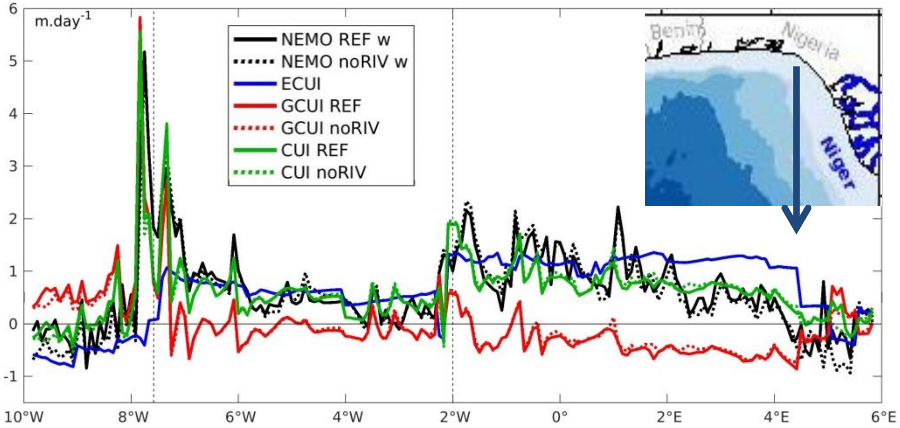
Steric contributions to coastal sea level slope





- Decomposition of 0°E-4°E sea level slope into thermosteric and halosteric components
- Slope equally driven by temperature and salinity coastal variations
- River: 60% of halosteric component but only 20% of total slope
- 40% of halosteric and all thermosteric component due to upwelling itself

Upwelling dynamical indices



Ekman Coastal Upwelling Index :

$$ECUI = \frac{\tau_{alongshore}}{\rho_o f L_u}$$

L_u : upwelling width (12 km)

Geostrophic Coastal Upwelling Index :

$$GCUI = -\frac{u_G D}{2L_U}$$

u_G : cross-shore

D : mixed layer depth (12 m)

CUI=ECUI+GCUI

- Good agreement between CUI and NEMO vertical velocity (*r=0,72*)
- ECUI gets stronger east of 2°W
- From 1°E to 5°E, geostrophy compensates Ekman transport by 30-50%
- Very small river effect on GCUI
- Sharp decrease of ECUI with coastline direction change

Conclusion & perspectives

- Coastal upwelling in the eastern part of northern Gulf of Guinea (Togo/Benin/Nigeria coasts) weakened by up to 50% due to geostrophic compensation
- Niger plume contribution to upwelling small due to a compensation of the enhanced onshore geostrophic flow by reduced MLD (almost no effect on near-surface transport)
- Geostrophic compensation associated with eastern upwelling front (negative retroaction), triggered by sharp change in coastline orientation that decreases Ekman transport
- Warming effect (+1°C) of river plume in upwelling region probably due to surface processes (heat budget required)
- Other influence of river on upwelling regions (Congo region)?

Alory et al., 2021, Frontiers in Marine Science