OSTST Project: « Alti-ETAO »

Characterization and analysis of circulation and mesoscale dynamics in the Eastern Tropical Atlantic Ocean using altimetry data

OSTST-AO2016 2017-2020

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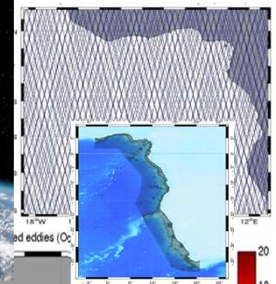
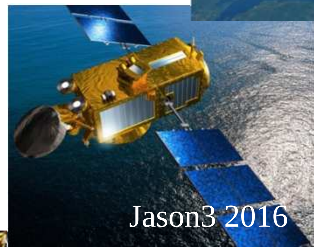
and other collaborators (LOPS, LOCEAN, European and African laboratories/universities)

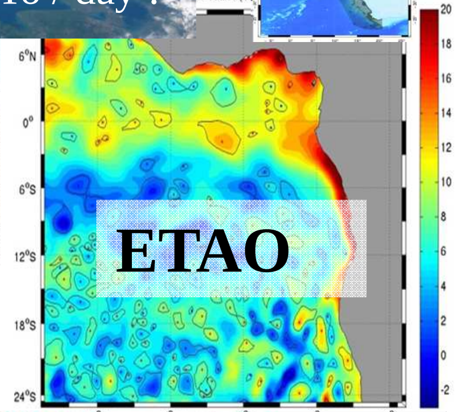
Altimetry : toward high resolution (mesoscale)

Main objective of Alti-ETAO OSTST project: study of the **dynamics of the Eastern Tropical Atlantic Ocean at mesoscale from intraseasonal to interannual timescales using the altimetry missions** (single mission: along track data and gridded products) combined with other satellite (SST, ocean colour, SSS, wind) and in situ (tide gauge, cruises, mooring, floats) data and high-resolution models.

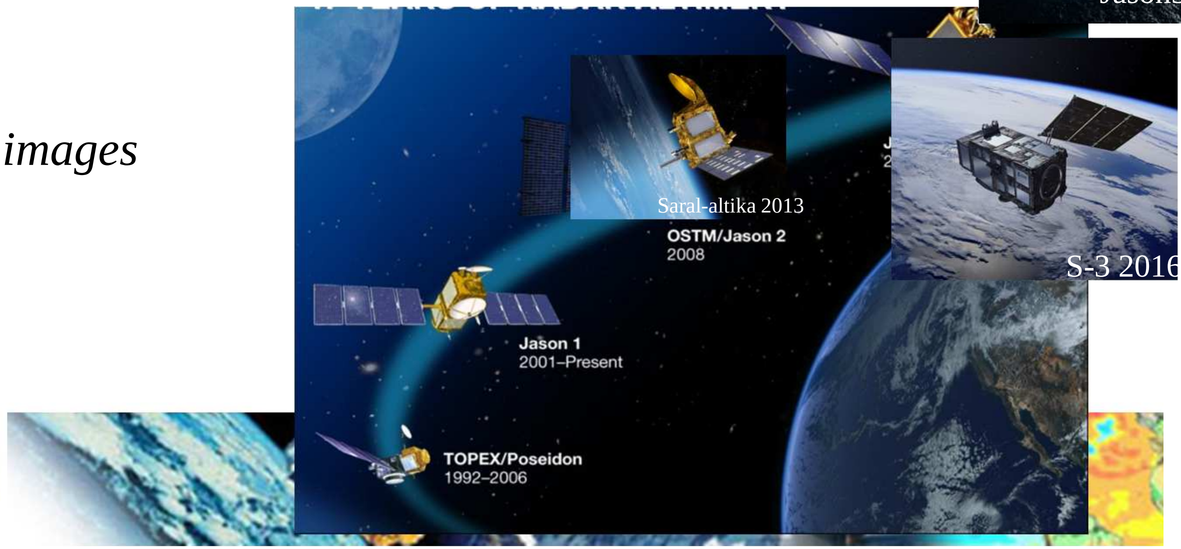
Altimetry

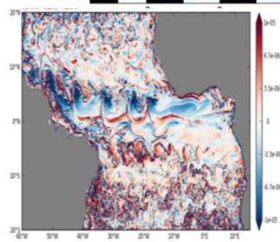




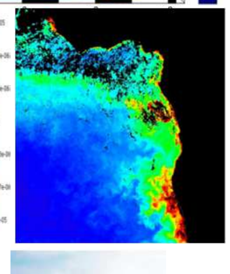


CNES images





Models (NEMO /ROMS/T-UGOm)



Other Satellite and in situ data

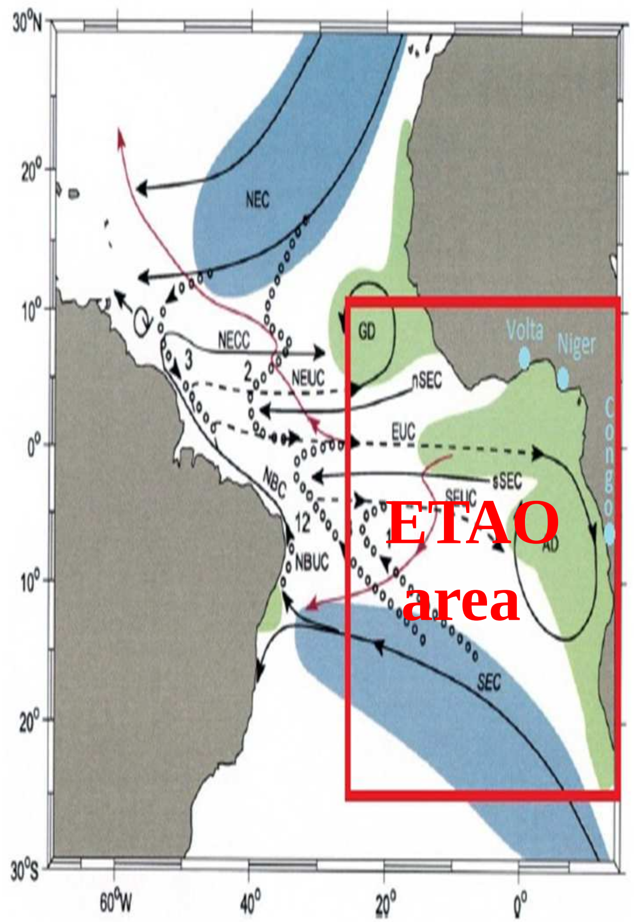
4 issues in the Alti-ETAO OSTST project

- I- Main characteristics of the **mesoscale activity (especially eddies)** and **new diagnostics ;** **PhD thesis 2018-2021 (IRD/SCAC) Result summary + 4 Slides**

- II- Influence of **the large scale current variability (equatorial, tropical), the equatorial waves** and the **coastal dynamics** (coastal currents, transient and permanent upwelling systems, trapped waves and internal tides); **Result summary – 4 Slides**

- III-Investigate the role of mesoscale on the overlying atmosphere, biogeochemistry and the regional oceanic circulation, in particular for the **transport from coastal regions to the open ocean**. **Result summary – 4 slides**

- IV- Improve **coastal altimetry data with new high frequency/space corrections for ETAO** (tides, dynamic atmospheric correction) **Result summary - 1 slide**



from Stramma (2014)

I/ General characteristics of mesoscale dynamics and eddy detectability using satellite data

(Aguedjou et al., 2019; Morel et al., 2019; Assene et al., 2020)

Result summary - 1 slide

Seasonal cycle from altimetry (AVISO+)
and vertical structure from altimetry/ARGO
4 slides

Main results

1) 60% more eddies are found in the tropics compared to the equatorial zone;

2) Vortices (eddies) form in the eastern part of the basin and propagation westward (faster speed at the equator) with vortex lifetimes of up to 140 days in tropical areas;

3) Waves represent 10% of the structures detected by applying a vortex/wave criterion

4) Eddy seasonal cycle amplitude can reach up to ± 50% of the mean value for the eddy properties (radius, EKE) and linked to the ocean circulation seasonal cycle

5) Vortices are generated mainly by barotropic instability to the east of the North Brazil current retroflexion, along the North Equatorial Counter-Current, according to a newly defined criterion based on altimetry and validated by academic modeling;

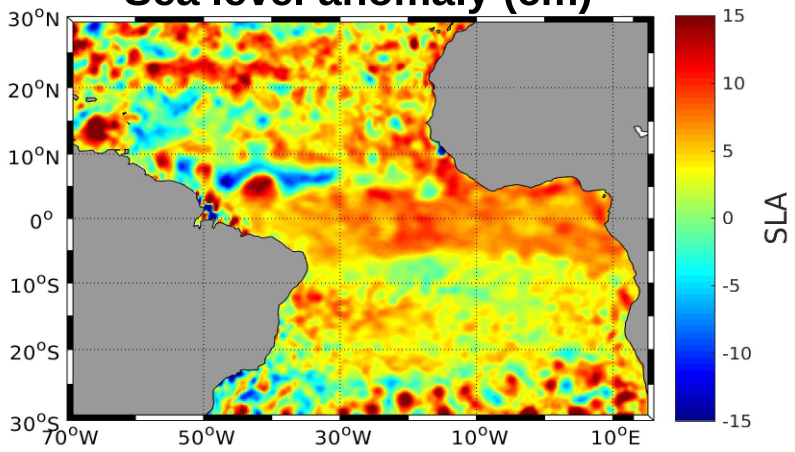
6) Vortices present Temperature/salinity eddy anomalies at the surface in the equatorial zone and in subsurface in the tropical zones;

7) In equatorial zone (beta plane), vortices are much easier to follow with potential vorticity (PV) rather than with SSH (realistic and academic modeling);

8) Based on PV, vortices were classified in 3 types in the Gulf of Guinea: surface vortices detectable by SSH and subsurface eddies with either short or long lifetime without detectable signature in satellite data.

1/4- DATA & METHODS

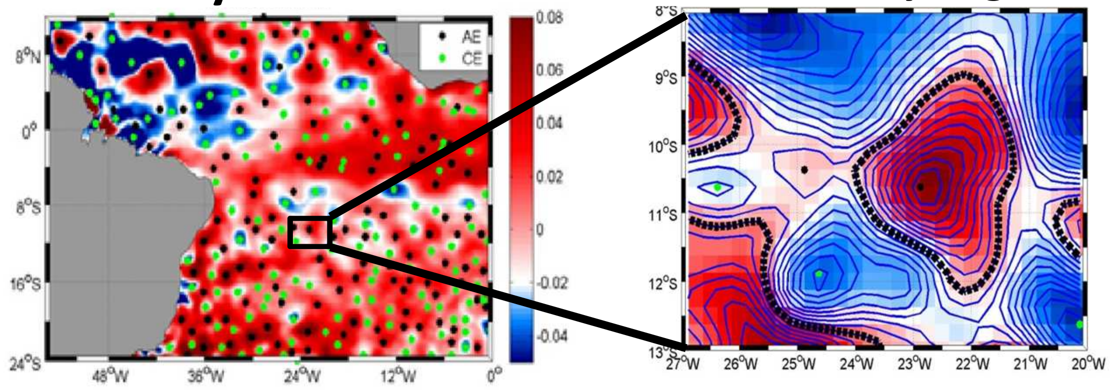
Sea level anomaly (cm)



Daily SLA (0.25°x0.25°) from 1993 to 2015

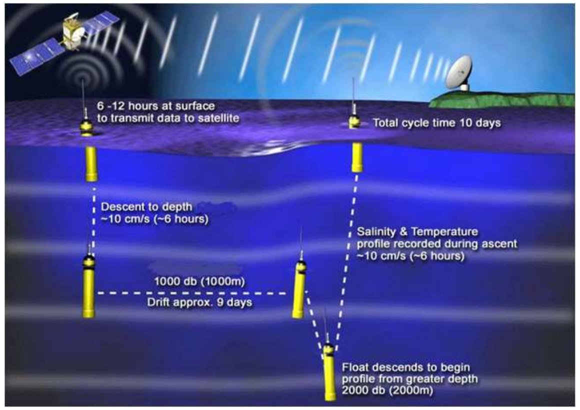
https:marine.copernicus.eu/

Eddy centers **One eddy edge**



Eddy detection and tracking algorythms

(Chaigneau et al. 2008 et 2009 ; Pegliasco et al. 2015)



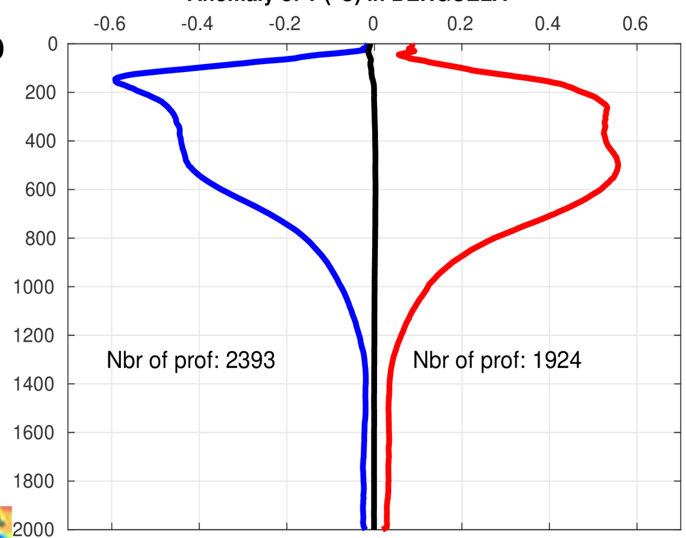
https://www.coriolis.eu.org

Eddy Colicalization with Argo profiles

$$T'(z) = T(z) - T_{clim}(z)$$

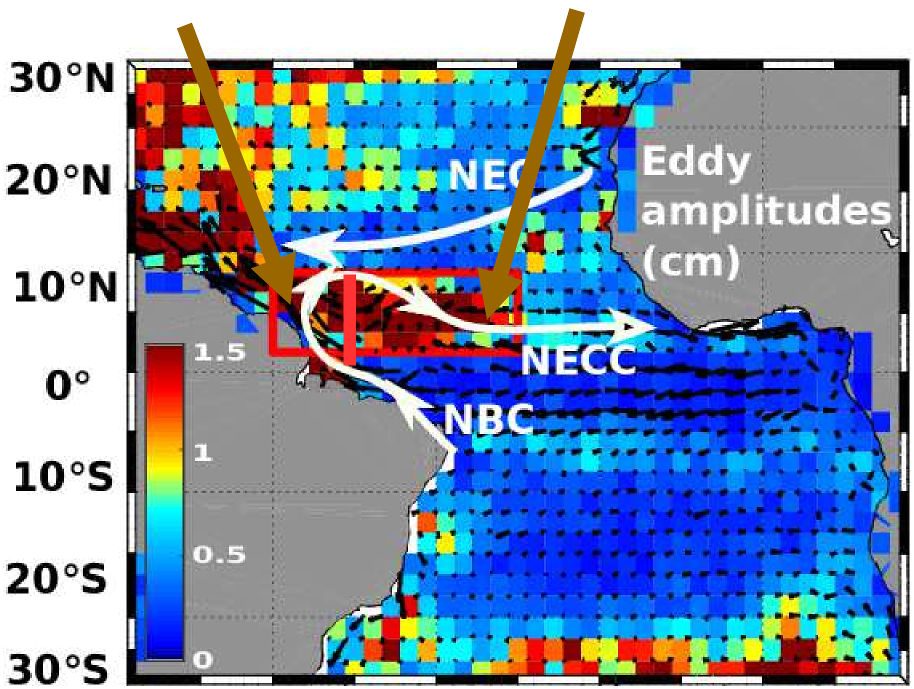
$$S'(z) = S(z) - S_{clim}(z)$$

Aguedjou et al., 2020

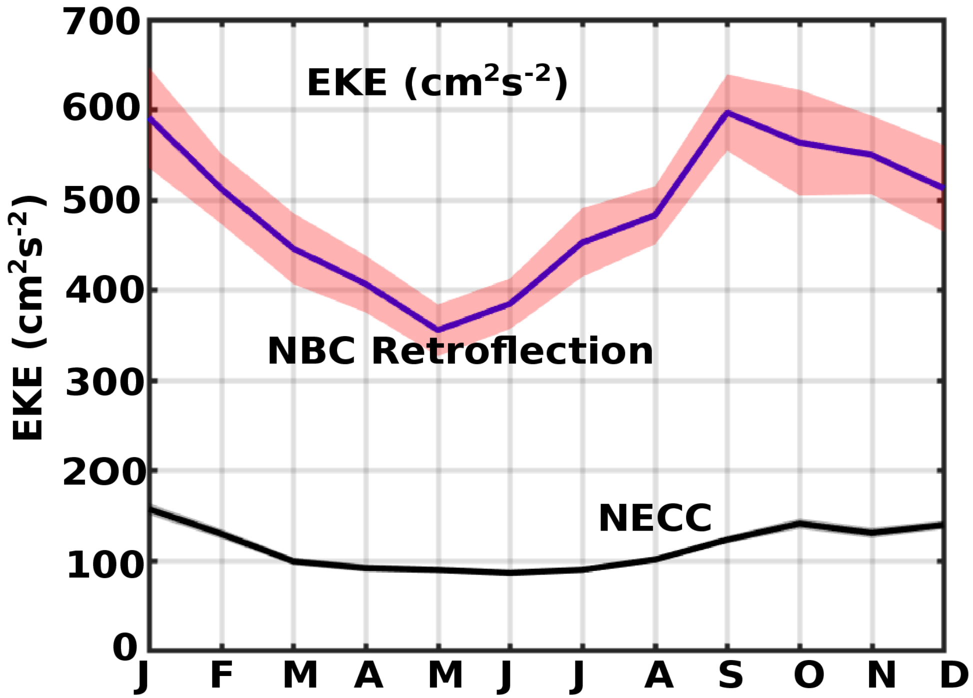


Temperature anomaly profiles

2/4 - Seasonal cycle of eddy properties



Amplitude of the seasonal cycle of the eddy amplitudes (cm)



Seasonal cycle of EKE (cm²/s²) in NECC and NBC boxes

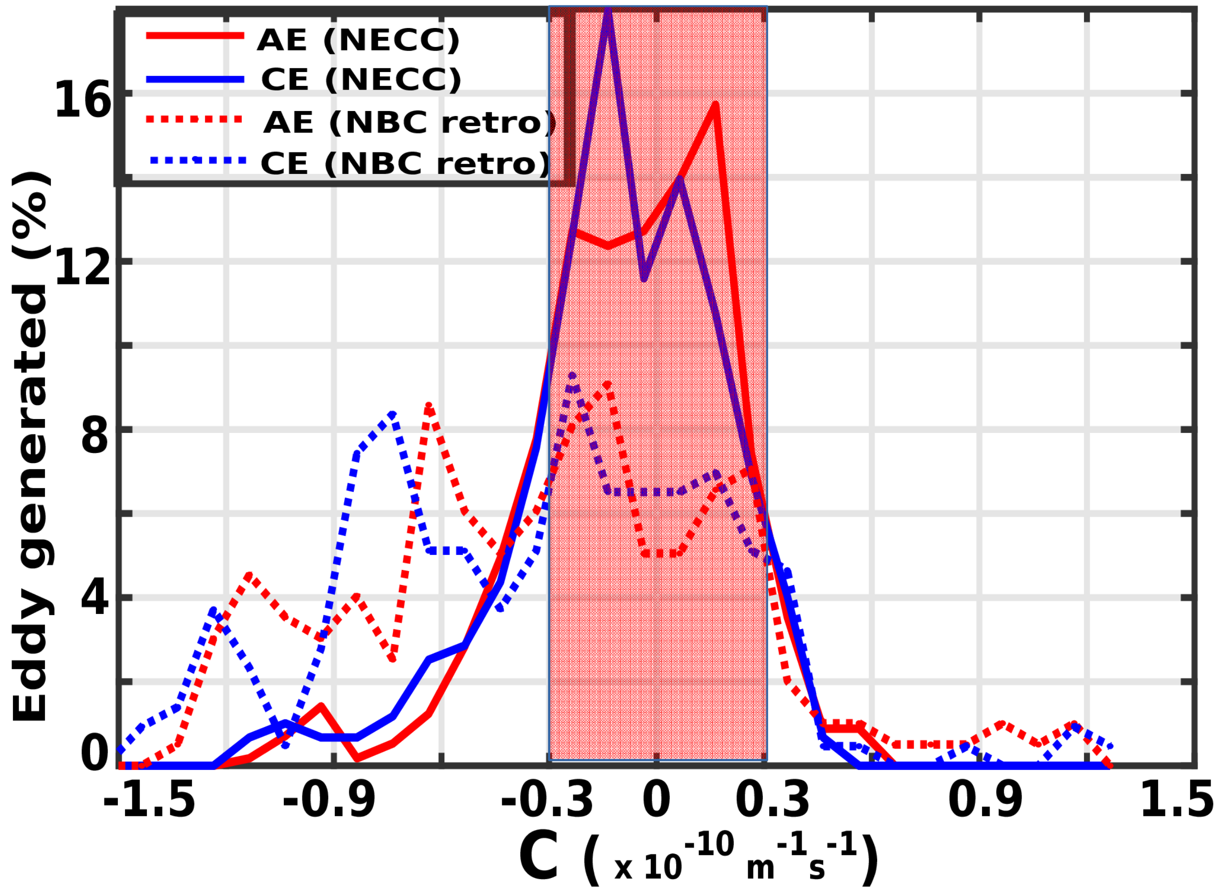
Eddy seasonal cycle amplitude can reach up to ± 50% of the mean value for the eddy properties in the North Brazil Current retroflection and North Equatorial Counter Current and are linked to the NBC and NECC seasonal cycle

Aguedjou et al. (2019)

3/4 - Eddy generation mechanism

$$C = \vec{\nabla}(f + \zeta).\vec{n}$$

Charney-Stern's (1962)
Drazin and Howard (1966)

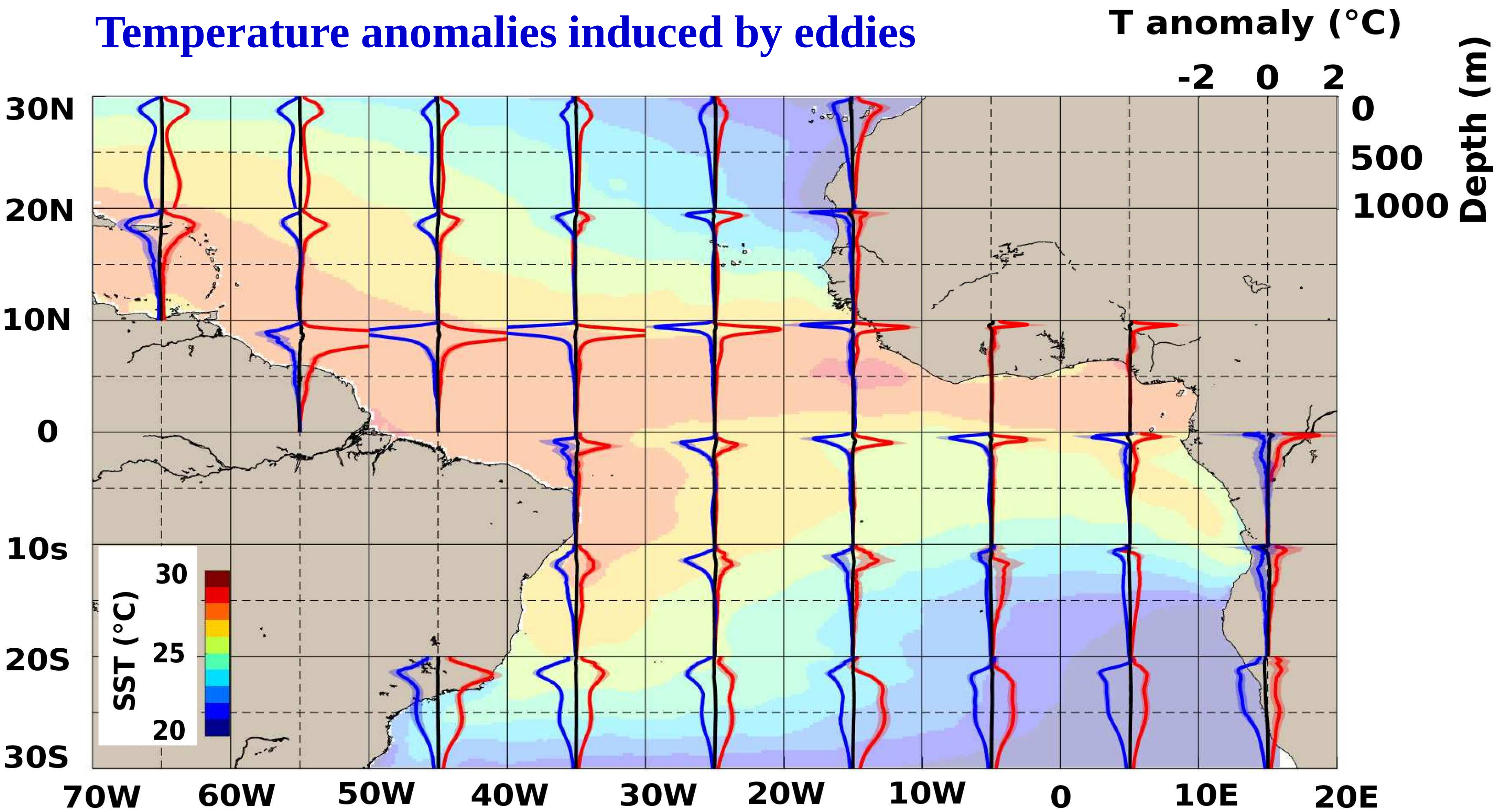


Aguedjou et al. (2019)

When C is close to zero, eddies are mostly generated by barotropic instability so **Barotropic instability probably the main mechanism of eddy generation in the NECC area.**

4/4- Mean vertical eddy properties

Temperature anomalies induced by eddies



Temperature/salinity eddy anomalies at the surface in the equatorial zone and in subsurface in the tropical zones

Aguedjou et al., 2020

II/ Currents, equatorial waves and coastal dynamics variability and mesoscale dynamics

(Awo et al., 2018;Assene et al., 2020)

Result summary - 1 slide

PV diagnostics and different types de vortices
(open ocean and coastal ocean)
4 slides

Main results:

1) Sea Surface Salinity signature of the tropical Atlantic interannual modes of variability in the equatorial band and around the plumes of large rivers, visible by SMOS, and identified driving processes (satellite data and realistic modeling).

2) A theoretical model of the dynamics of equatorial Kelvin waves successfully applied to the Atlantic to explain the SLA and SST anomalies observed in July-October 2009, with strong consequence on the African Monsoon

3) Close to the Equator, the strong zonal surface currents and undercurrents stirred and destroyed vortical structures but presence of long-life equatorial subsurface vortices (especially anticyclonic eddies) without satellite signature (realistic modeling and PV diagnostics);

4) The inter-annual variability of eddies lower than the seasonal cycle and linked to large-scale ocean circulation (altimetry data).

1/4 Tropical Atlantic ocean realistic modeling : configuration

NEMO / configuration *Jouanno et al, 2016-2017, Hernandez et al, 2017*

Initial+ C.L. : MERCATOR – GLORYS2V4 reanalysis

Atm forcing DFS5.2 : ERAinterim reanalysis + CheapAML *(Deremble 2013)*

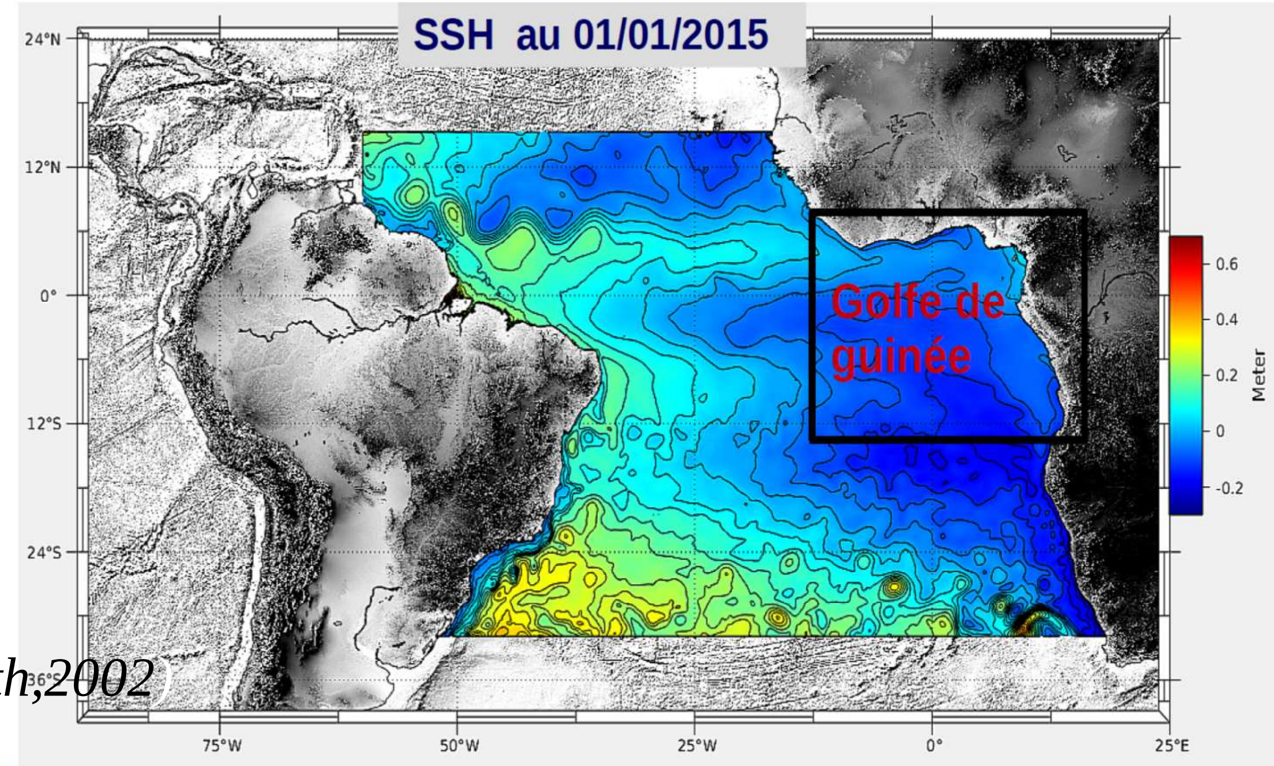
Resol : 1/12°

75 vertical levels

Mixing: GLS ~ K–ε

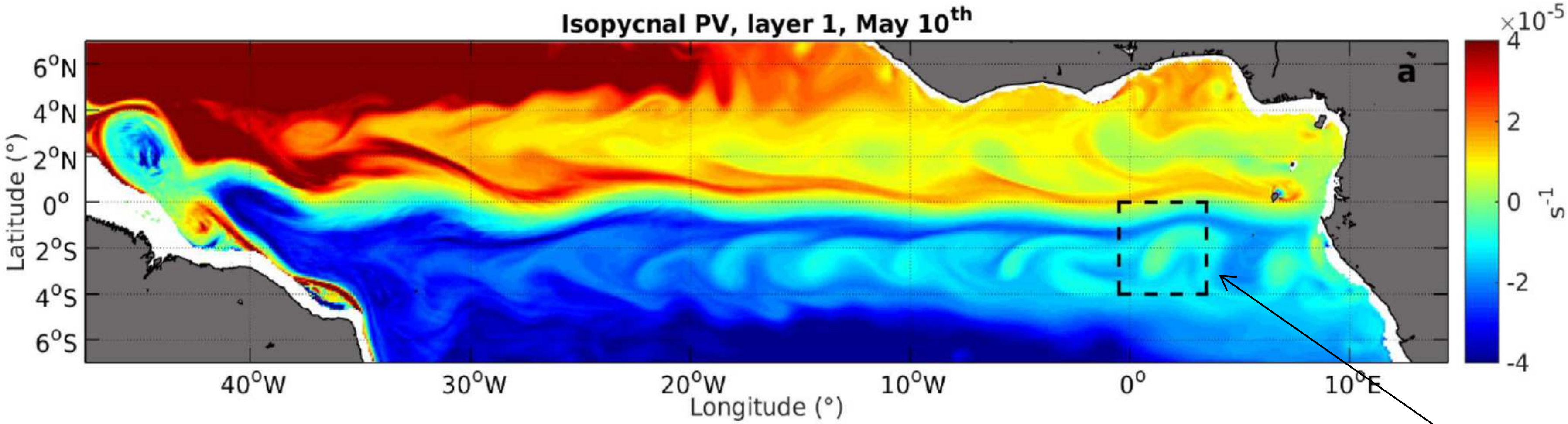
Years : *spinup +1995-2015*
PV diagnostics for the year 2015

River discharge *(Dai et Trenberth,2002)*



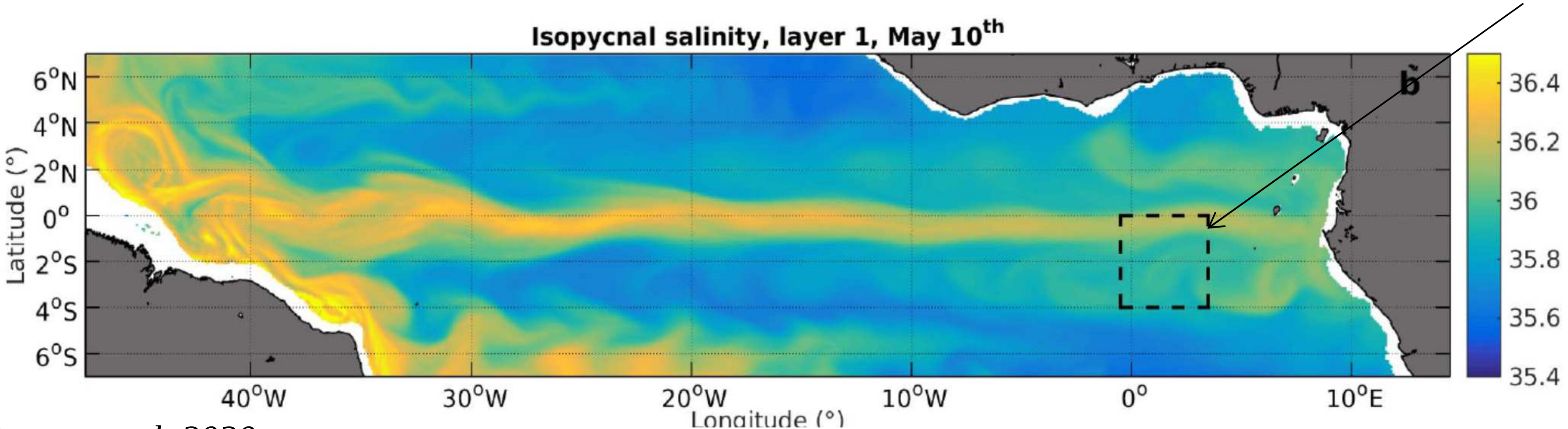
Internship M2 2019 : F. Assene

2/4 Tropical Atlantic ocean realistic modeling : PV diagnostics



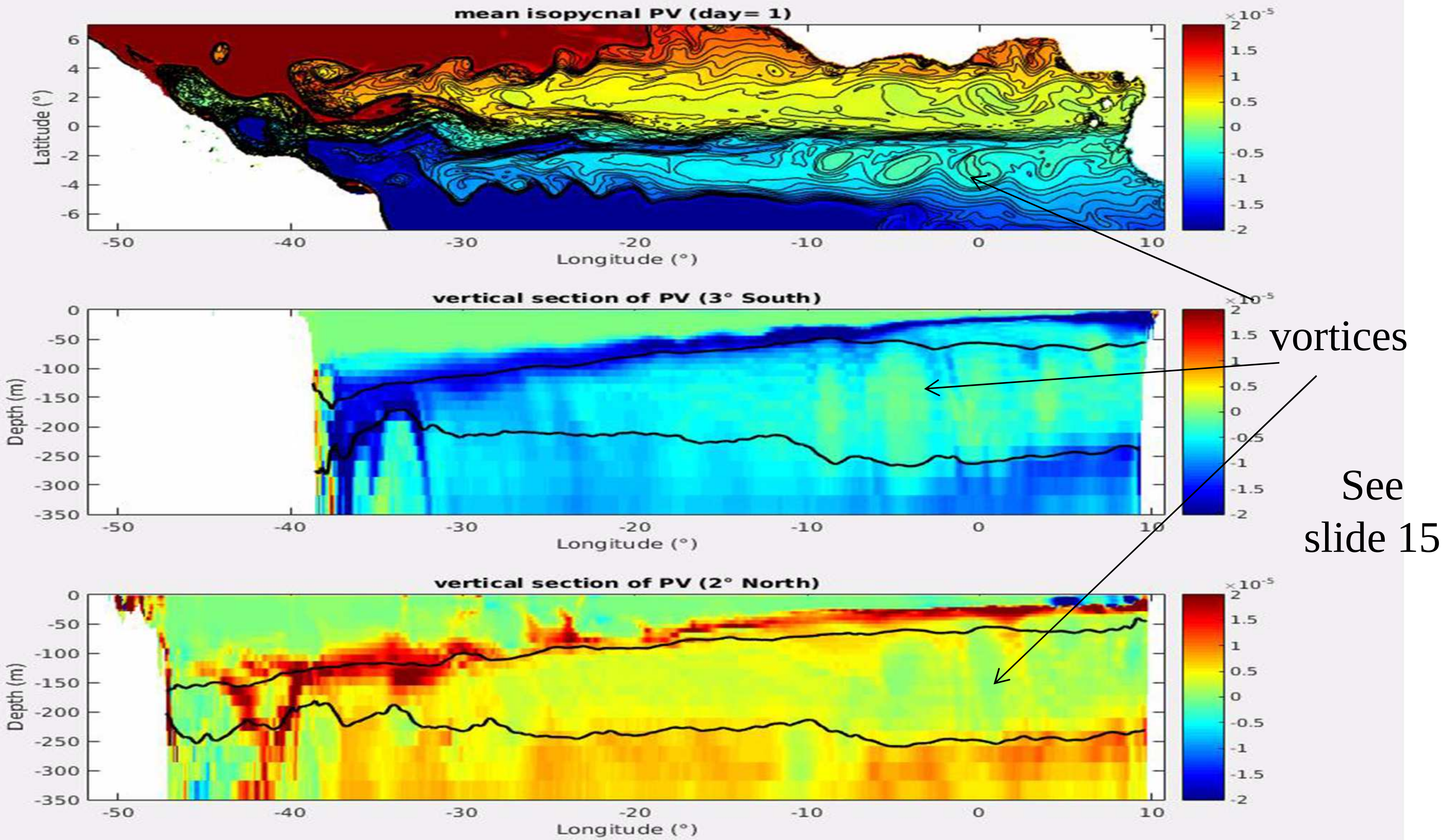
Potential vorticity and salinity in isopycnic layer (depth ~50-100 m)

Eddy (see slide 15)



Assene et al, 2020

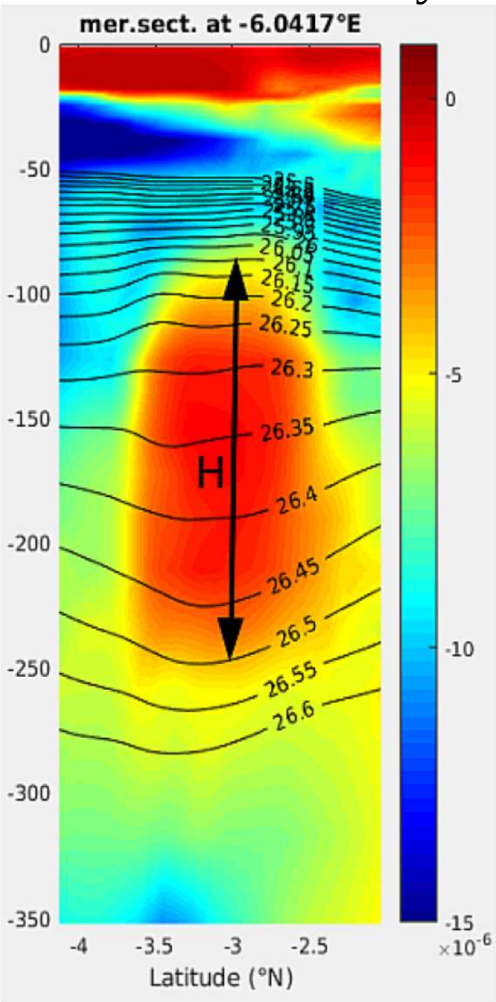
3/4 Tropical Atlantic ocean realistic modeling : PV diagnostics

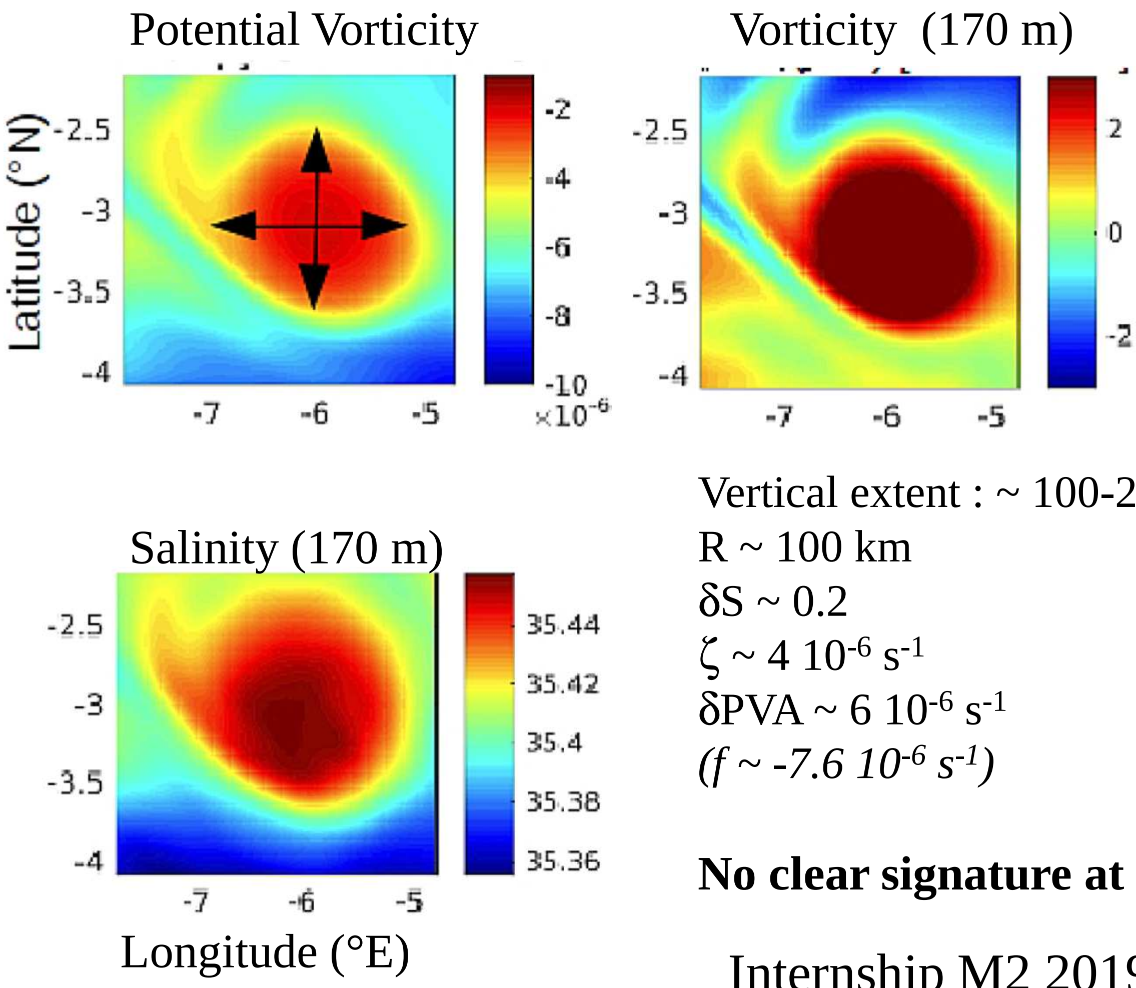


MOVIE see Assene et al. (2020)

4/4 Tropical Atlantic ocean realistic modeling : structure and open ocean vortices

Potential Vorticity





Vertical extent : ~ 100-250 m

R ~ 100 km

$\delta S \sim 0.2$

$\zeta \sim 4\ 10^{-6}\ s^{-1}$

$\delta PVA \sim 6\ 10^{-6}\ s^{-1}$

($f \sim -7.6\ 10^{-6}\ s^{-1}$)

No clear signature at surface!

Internship M2 2019 : F. Assene

III- Coastal dynamics, coastal-open ocean transport and mesoscale dynamics in the ETAO (Alory et al., 2020; Le Goff et al., 2020; Assene et al., 2020)

Result summary - 1 slide

Upwelling and river discharge areas 4 slides

Main results:

1) **Coastal upwelling in the northern Gulf of Guinea:**

- weakened by about 50% due to onshore geostrophic flow in its eastern part
- surface geostrophic flow due to coastline curvature and equally controlled by steric effects related to temperature and salinity
- Niger river enhances geostrophic currents and stratification with no net effect on onshore flow, but warms by 1°C the upwelling tongue

2) **Congo river and coastal circulation:**

- Validation of the eOdyn (AIS data) with in situ data and reconstruction of the courant (Geostrophy + Ageostrophy).
- Inertial current and secondary circulation – high near the river mouth
- Geostrophy stronger in austral summer (JFM) with maximum of the Congo discharge
- Ageostrophy stronger in austral winter (JAS) with the maximum of wind intensity

-3) Vortices in the coastal area of the Gulf of Guinea:

Small vortices in the surface layer close to the coast with small radius (~ 50 km) and short lifespan (~ 1 month) in relation with the coastal dynamics (currents, upwelling, ect.) in the northern part of the Gulf of Guinea

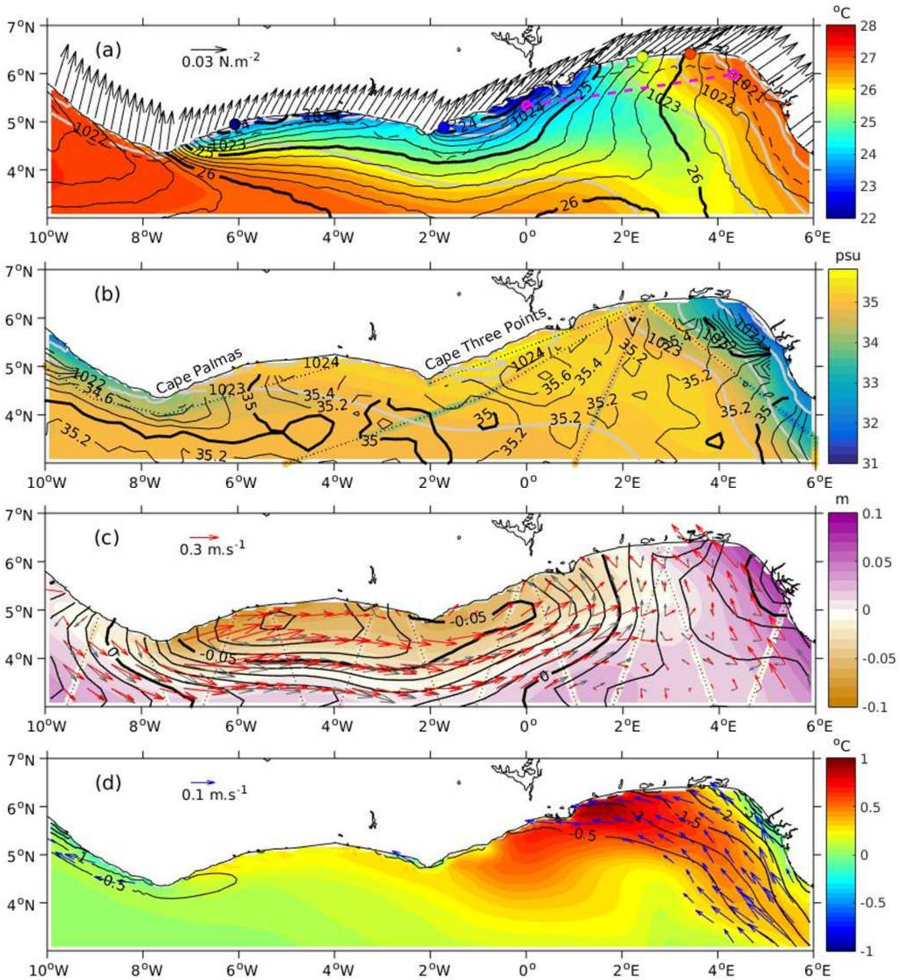
1/4 Coastal upwelling in the northern Gulf of Guinea: Mean summer (JAS) conditions in NEMO 1/12°

SST + wind
NEMO *vs* MURSST

SSS
NEMO *vs* SMOS/TSG

SSH + Vgeos
NEMO *vs* X-TRACK/ CMEMS

SST/SSS + Vgeos
NEMO : REF – noRIV



Wind-driven eastern upwelling tongue

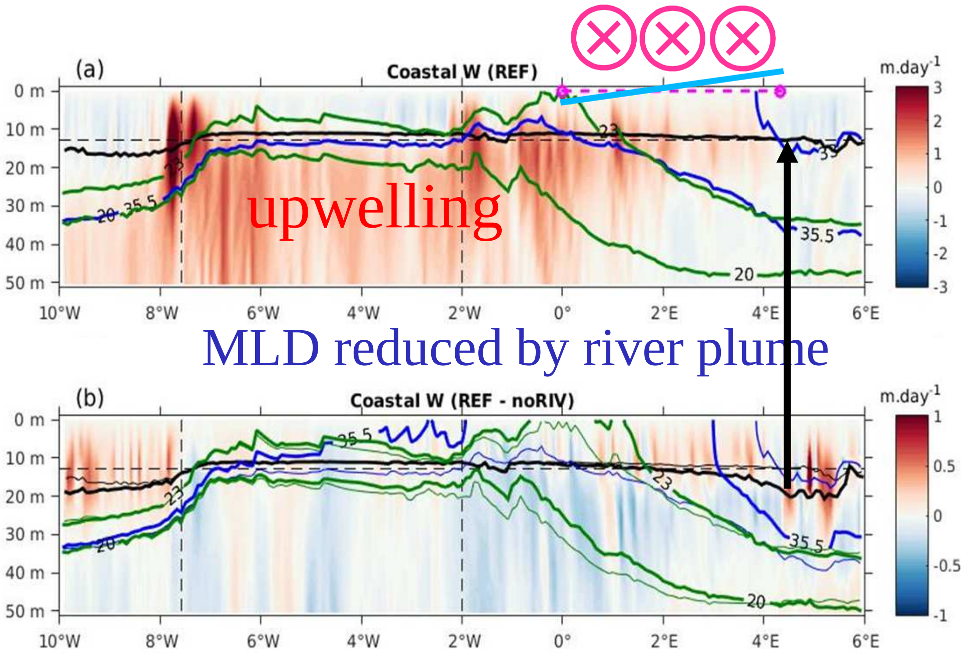
Salty upwelling tongue *vs* Niger plume

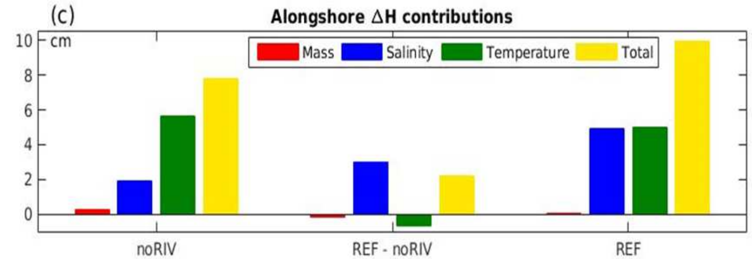
- Strong Guinea Current
- Onshore flow (0-5°E)

River-induced 1°C warming & onshore flow

Alory et al.,in revision

2/4 Coastal upwelling : geostrophic compensation



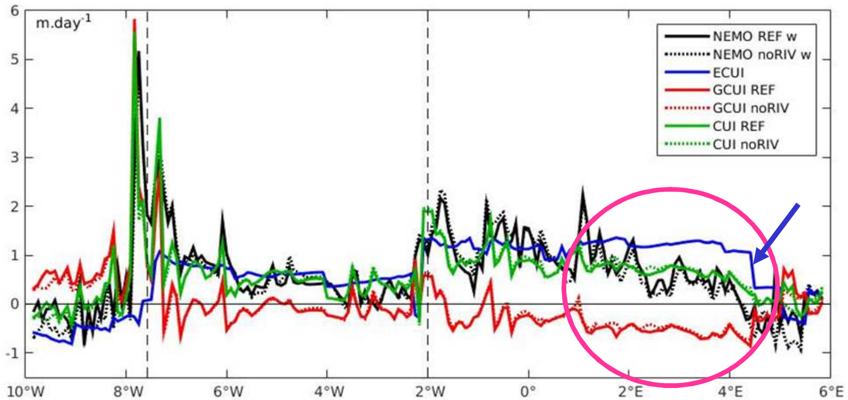


Alongshore SSH slope contributions

50% thermosteric

50% halosteric

River : 60% of halosteric but only 20% overall



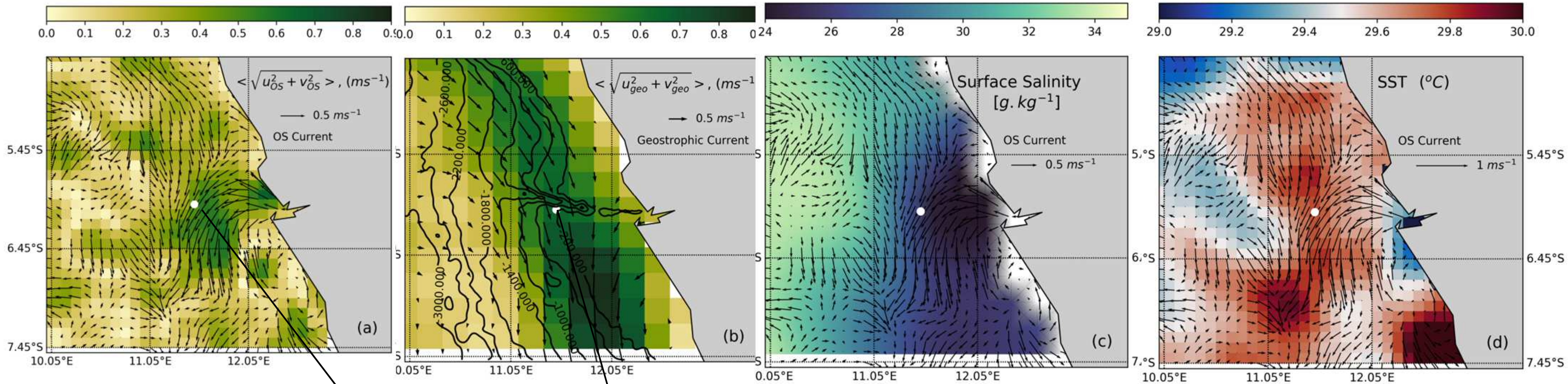
Alory et al.,in revision

Upwelling indices:

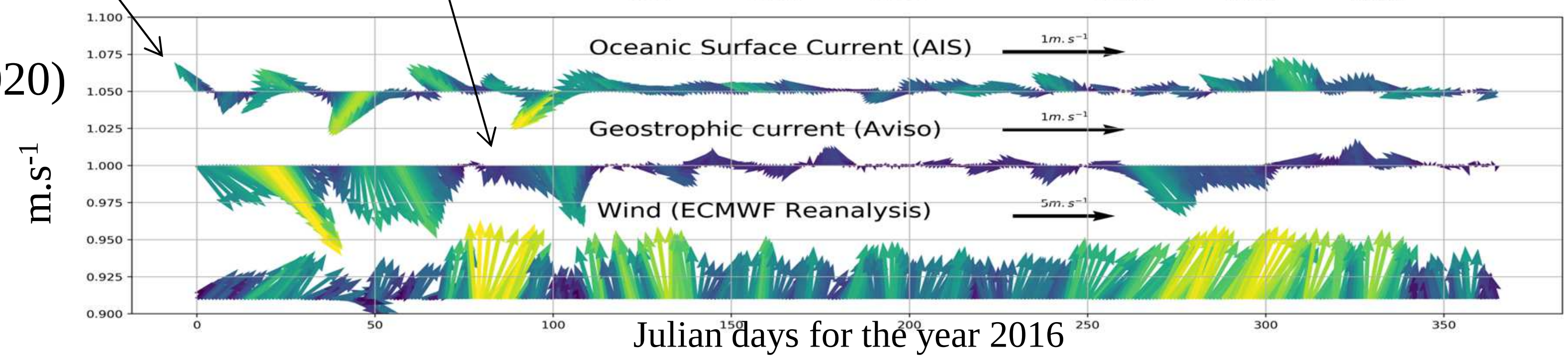
$\mathbf{W}_{\mathbf{Ekman}} + \mathbf{W}_{\mathbf{geos}} = \mathbf{W}_{\mathbf{total}}$ *vs* $\mathbf{W}_{\mathbf{NEMO}}$

- Can explain upwelling variations (r = 0,72)
- Small river contribution (in transport)
- 50% geostrophic compensation in the east triggered by coastline curvature
- River-induced warming : horizontal advection?

3/4 Impact of Congo river on the coastal circulation



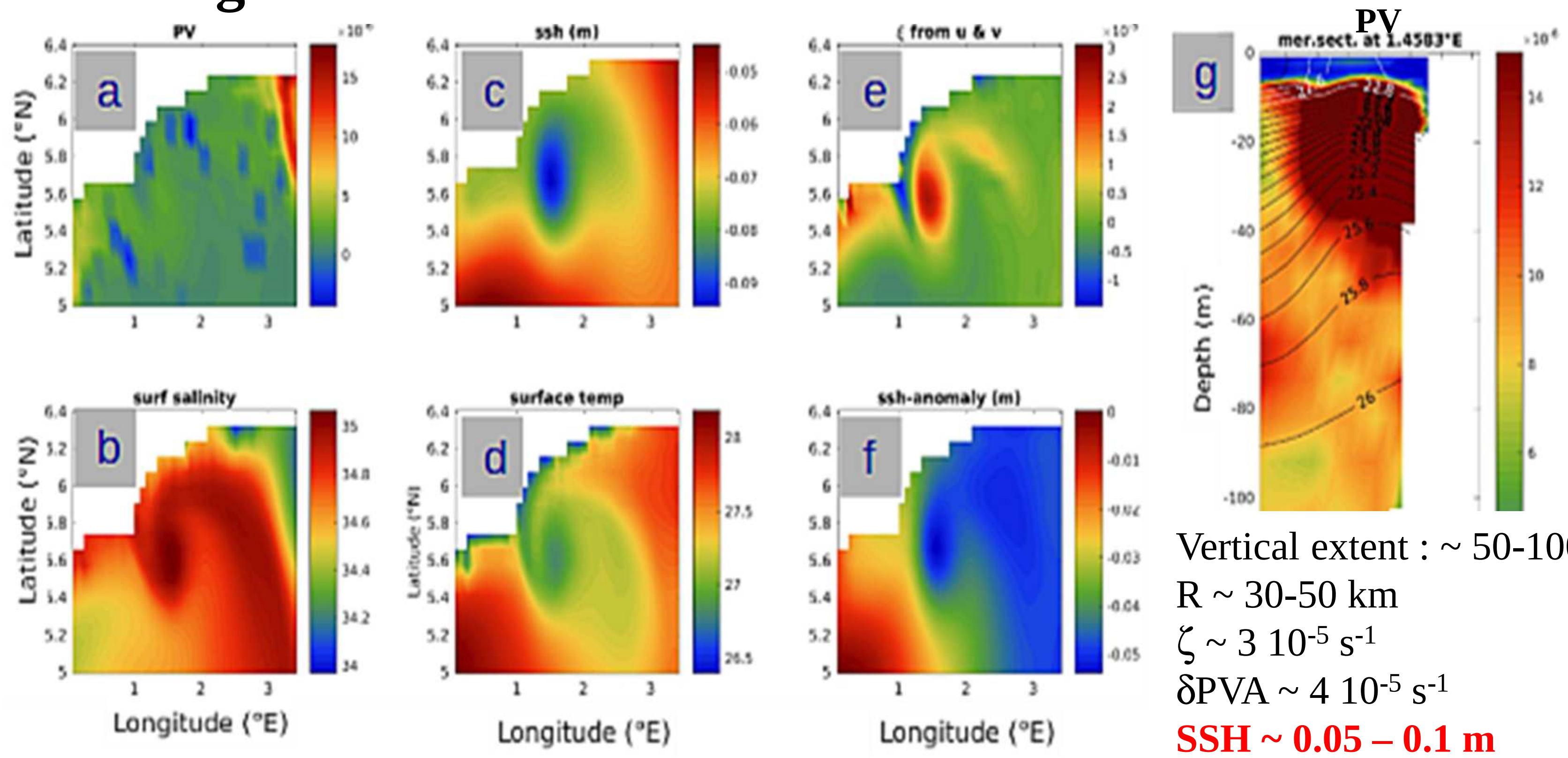
Le Goff et al. (2020) using AIS and satellite data



- Inertial current and secondary cross-shelf circulation – high near the river mouth, stronger in JFM
- Geostrophy stronger in austral summer (JFM) with maximum of the Congo discharge (30-50% of the total current instead of 20-30% for the other months)
- Ageostrophy stronger in austral winter (JAS) with the maximum of wind intensity (60-80% of the total current instead of 50-60% in JFM).

Internship M2 2019: A. Bourgeois (using AIS/in situ/satellite data and realistic modeling with and without Congo river discharge)

4/4 Vortices in the coastal area of the Gulf of Guinea: realistic modeling



Vertical extent : ~ 50-100 m
R ~ 30-50 km
ζ ~ 3 10^{-5} s^{-1}
δPVA ~ 4 10^{-5} s^{-1}
SSH ~ 0.05 – 0.1 m
δSSS ~ 0.2
Lifespan ~ 10 – 30 days

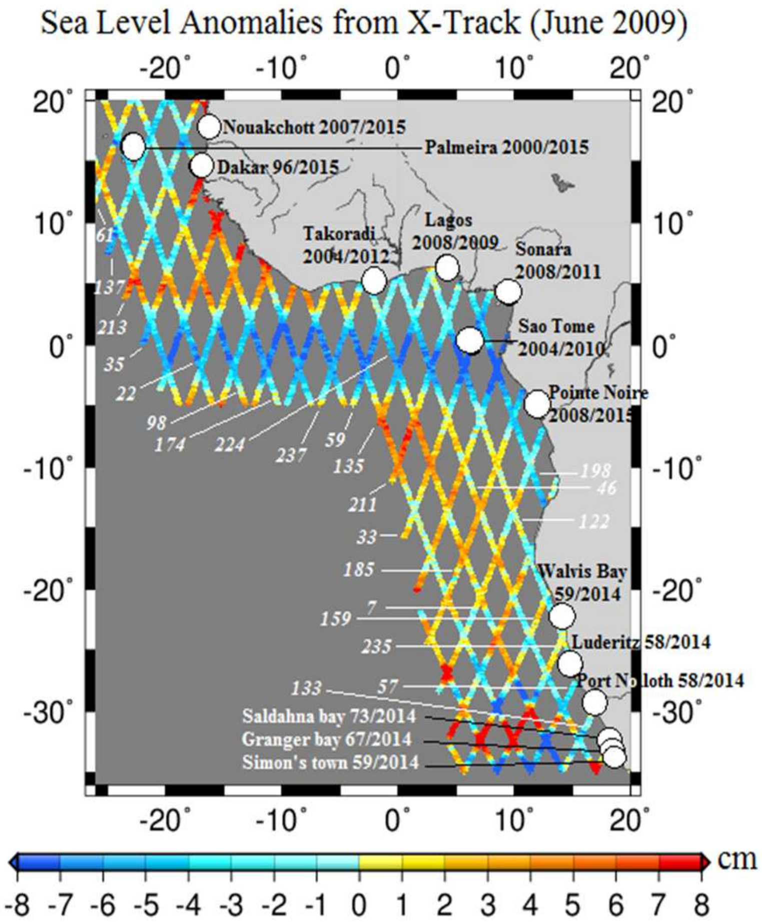
Small vortices exist in the surface layer close to the coast with small radius (~ 50 km) and short lifespan (~ 1 month) in relation with the coastal dynamics (currents, upwelling, ect.) in the northern part of the Gulf of Guinea

Internship M2 2019 : F. Assene

IV- Coastal Altimetry in the ETAO region
(Dieng et al., 2019)

1 slide

Main results:



Dieng et al. (2019)

1) Coastal altimetry validation XTRACK – comparison with in situ data, AVISO, model : *1)* XTRACK version 2017 (SLA,SSH, courant) *2) :* XTRACK 20Hz v2019 & ALES+XTRACK 20Hz v2019 & NEMO Model (1/4°, 1/12°) & CMEMS DT2018 v2018 1/4°

2) Valorization of validated XTRACK data with frequency content study and coastal processes (see Dieng et al., 2019)

3) Tests for improvement of corrections : Tides and DAC (Dynamic Atmospheric Correction) with the T-UGOm model (Benguela area) (*2020*)

4) Multi-sensor analyzes and multi-sensor product development (HR) : SST, ocean color, SSS, wind+ altimetry (XTRACK, AVISO+) and new mesoscale diagnostics. (*2020*)

Publications of the projet OSTST Alti-ETAO (2017-2020)

- Alory G., C. Y. Da-Allada, S. Djakouré, I. Dadou, J. Jouanno and D. P. Loemba (2020). Coastal Upwelling Limitation by Onshore Geostrophic Flow in the Gulf of Guinea around the Niger River Plume. In revision in Frontiers in Marine Science.

-Assene, F., Morel, Y., Delpech, A., Aguedjou, M., Jouanno, J., Cravatte, S., F. Marin, C. Ménesguen, A. Chaigneau, I. Dadou, G. Alory, R. Holmes, B. Bourlès and A. Koch-Larrouy. (2020). From Mixing to the Large Scale Circulation: How the Inverse Cascade Is Involved in the Formation of the Subsurface Currents in the Gulf of Guinea. Fluids, 5(3), 147.

- Awo F. M., G. Alory, C. Y. Da-Allada, T. Delcroix, J. Jouanno, E. Kestenare and E. Baloïtcha (2018). Sea surface salinity signature of the tropical Atlantic interannual climatic modes. Journal of Geophysical Research: Oceans, doi: 10.1029/2018JC013837

-Aguedjou, M., I. Dadou, A. Chaigneau, Y. Morel, G. Alory (2019). Eddies in the Tropical Atlantic Ocean and their seasonal variability, Geophys. Res. Lett, https://doi.org/10.1029/2019GL083925

- Aguedjou, M., A. Chaigneau, I. Dadou,, Y. Morel, C. Pegliasco, C. Da-Allada and E. Baloïtcha (2020). Mesoscale eddies isopycnal structure and generation mechanism in the tropical Atlantic ocean. In prep., Journal of Geophysical Research

- Dieng, H.B., Dadou, I., Léger, F., Morel, Y., Jouanno, J., Lyard, F., Allain, D. (2019) Sea level anomalies using altimetry, model and tide gauges along the African coasts in the Eastern Tropical AtlanticOcean: inter-comparison and temporal variability, Advances in Space Research (2019), doi: https://doi.org/10.1016/j.asr.2019.10.019

-Le Goff, C., Dadou, I., Morel, Y., Dieng, H., Bourgeois A. Monitoring the Congo River Plume with the Oceanic currents derived from the AIS messages. OS meeting, San Diego, CA, USA, 16-21 February 2020 and paper in prep.

-Morel, Y., S. Thual, T. Delcroix, N. Hall, G Alory (2018). A theoretical model to analyze the Central to Eastern Pacific El Nino continuum. Ocean Modelling, 130, 140-159, DOI:j.ocemod.2018.07.006

-Morel Y., J. Gula, A. Ponte (2019). Potential Vorticity diagnostics based on balances between volume integral and boundary conditions. Ocean Mod., 138, 23-35, 10.1016/j.ocemod.2019.04.004.

-Ohde T, Dadou I (2018) Seasonal and annual variability of coastal sulphur plumes in the northern Benguela upwelling system. PLoS ONE 13 (2): e0192140. https://doi.org/10.1371/ journal.pone.0192140