Fine scale structures observed by SWOT satellite in the Gulf of Guinea

H., M. Aguedjou[1], I. Dadou[1], Y. Morel[1], G. Alory[1], **F. Hernandez[1]**, C. Cardot[1], A-K. Thiam[1], A. Chaigneau[1], D. Napolitano[2], R. Ngakala[3], C. Le Goff[4], G. Morvan[1], J. Jouanno[1], S. Illig[1], P-E Brilouet[1], F. Gasparin[1], Y. Krien[1], F. Lyard[1]

[1] **LEGOS,** Université de Toulouse, CNES/CNRS/IRD/UPS, Toulouse, France.
[2] **LOPS**, Université de Brest, CNRS/IRD/UPS, Brest, France.
[3] **CIPMA/UAC**, Université d'Abomey-Calavi, Cotonou, Bénin.
[4] **eOdyn**, Plouzané, France.

1- SWOT-GG and new SWOT-ETAO projects

We study the **meso/submesoscale dynamics in the Gulf of Guinea (GG) and the Eastern Tropical Atlantic Ocean** (**ETAO**, Fig.1) using the **altimetry nadir missions** (multi-mission product, single missions: T/P, Jason, SWOT, etc.) and the new **SWOT 2D data with other remotely sensed data, high-resolution models** (1/36,1/60°)**, in situ data** (PIRATA, surface drifters, TSG, etc.) as well as **AIS data** in the **SWOT-GG project (2020-2024) and the following new SWOT-ETAO project (2024-2027).**

Our main results for the SWOT-GG project are **: 1) Observability of the mesoscale eddies in the altimetry data (TAO) :** seasonal cycle and barotropic instabilities (Aguedjou et al., 2019), isopycnal properties of eddies and generation processes with Argo data (Aguedjou et al., 2021), imprint of the mesoscale eddies on air-sea fluxes (Aguedjou et al., 2023), **2) small eddies with sea level signature and generated processes in the GG coastal area** (Assene et al., 2020), especially in the North GG coastal upwelling (Thiam, et al., 2024, prep.), in the Congo plume (Cardot et al., 2024, prep.) **3) sub-surface large anticyclonic eddies in the GG (with no surface signature)** associated with the Equatorial undercurrent recirculation (Assene et al., 2020 ; Napolitano et al., 2022) **4) Potential Vorticity diagnostics** to better study mesoscale dynamics (Morel et al., 2019 ; 2023).

The main objective of the **new SWOT ETAO project** is to **evaluate the improvement brought by the 2D SWOT data to describe and study the 2D meso-submesoscale dynamics in the Eastern Tropical Atlantic Ocean (ETAO, Figure 1).** We will address the following issues in the ETAO region :1) Evaluate the "Observability" of 2D meso-submesoscale activity with SWOT from the coastal regions to the open ocean in this equatorial region (WP1), 2) Study this high-resolution meso-submesoscale activity in the coastal ETAO area along the African coast and islands (WP2), 3) Study the meso-submesoscale and wave dynamics in the open equatorial ocean of ETAO (WP3) with SWOT data.

Our first results with the new 2D SWOT data for the meso/submesoscale dynamics in the GG and ETAO are presented in this poster.

2- Data and methods

- We used daily L3 SWOT (cal/val) version v0.3 at 2km resolution and DUACS sea level anomalies (SLA) at ~25 km resolution, sea surface temperature and salinity (SST, SSS) from MUR and SMOS products, respectively to study meso/submesoscale structure signals in the Gulf of Guinea (GG)
- We automatically detected and tracked mesoscale eddies from DUACS SLA maps (2022-2023), using the algorithms of Chaigneau et al. (2008; 2009) and Pegliasco et al. (2015) and applied to the TAO by Aguedjou et al. (2019).
- We high-pass-filtered SST and SSS data, both in space and time using a 6° × 6° longitude/latitude and 120 days Hanning filter (Delcroix et al., 2019) to obtain mesoscale signals, and then collocated the obtained signals with detected eddies to determined their induced anomalies.
- We computed the mean wave-number power spectral density (PSD) using SWOT (cal/val) SLA from the swath N°3 (Fig.1) in the GG in different latitude bands. PSD were first computed for each longitude pixel along the SWOT swath and then averaged.
- We only considered latitude pixels along the SWOT swath with a maximum of 5 consecutive missing data (~ 10 km), to compute the PSD, after completing them with a linear interpolation.

3- Results

3.1- Comparison of SWOT with DUACS SLA and SLA spectrum

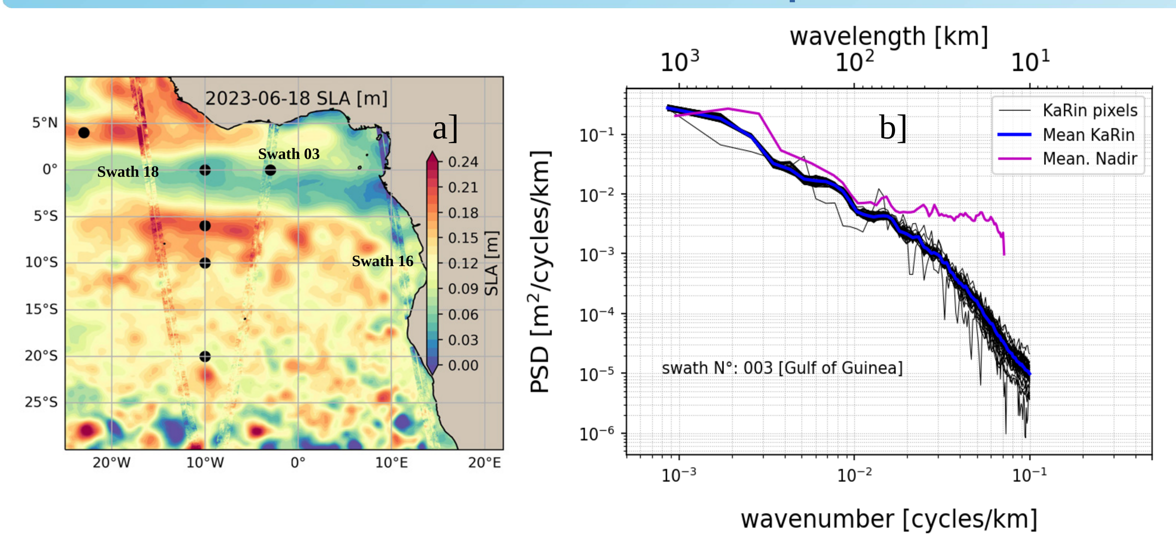
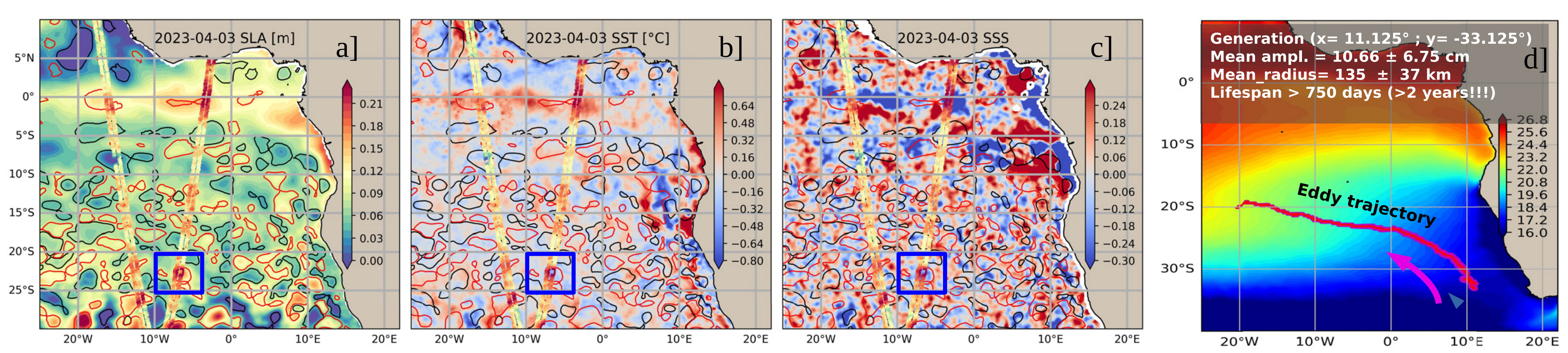


Figure 1: a] DUACS SLA superimposed with SWOT SLA. Black dotes are the PIRATA mooring stations and b] SLA spectrum for SWOT KaRin swath and nadir for the latitude band between 0-30°S.

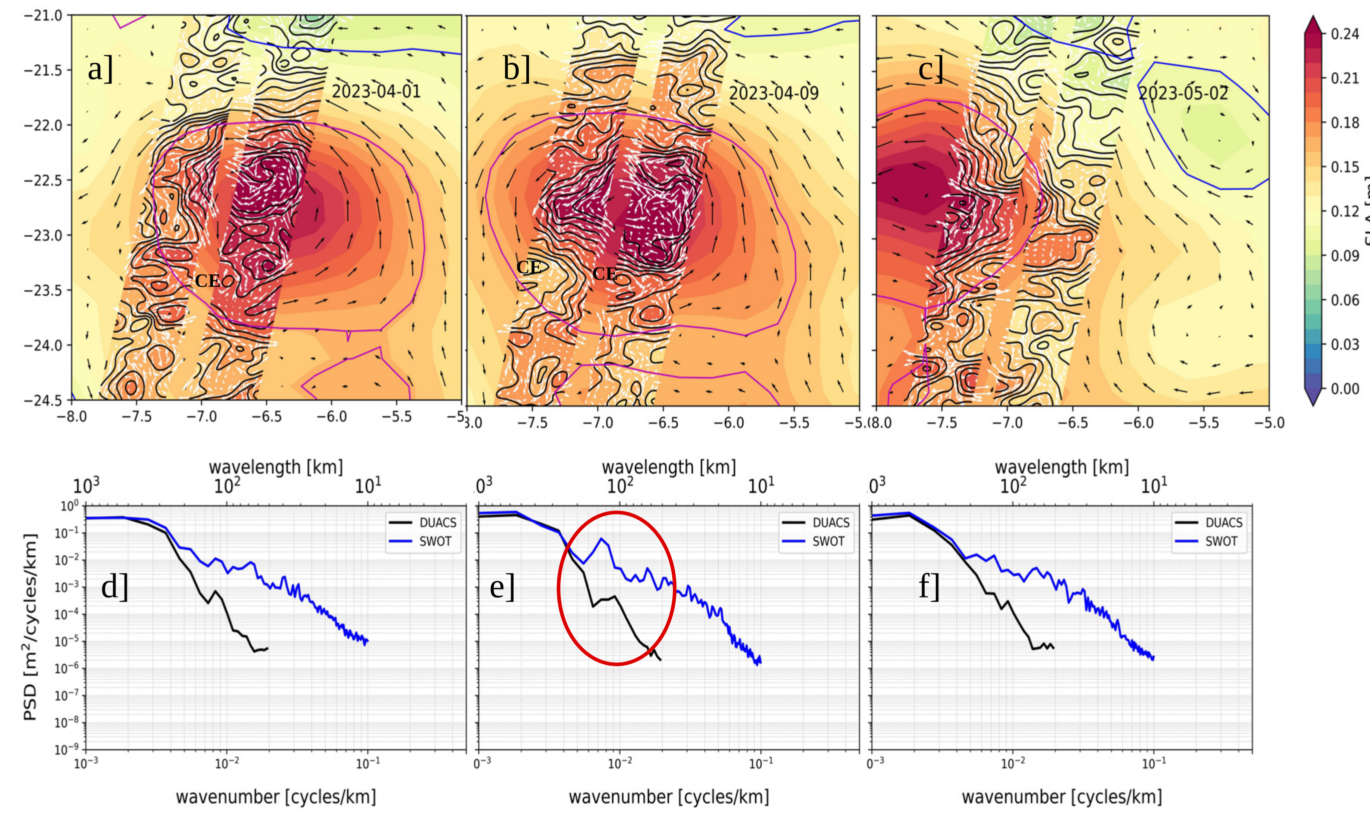
- SWOT cal/val SLA signal is similar to DUACS SLA in the GG with high intensity.
- SWOT nadir SLA exhibits a slight more energetic spectrum than the mean KaRin SLA spectrum
- The SLA spectrum maintains a constant mean slope from large to small scales.
- The same spectrum slope is observed for nadir SLA between 100 and 600 km wavelengths

3.2- Mesoscales eddies observed in SWOT and DUACS SLA maps



The detected eddy in SWOT and DUACS SLA maps (blue box Fig.2a) is also identified on SST and SSS maps and exhibit at the detected time a negative SST and SSS signature. The time evolution of SST ans SSS signature are shown in Figure 4.

Figure 2: a] Detected mesoscale eddies in DUACS SLA maps, b] SST anomalies, c] SSS anomalies for a specific date (2023/04/03) and d] a particular anticyclonic eddy trajectory sampled by SWOT (blue box in a]) advecting cold water from Agulhas retroflection region.



- Stronger geostrophic velocities in SWOT compared with DUACS (Fig. 3A-c).
- A mesoscale anticyclonic eddy with small scale structures are observed in SWOT swath in the same area as the detected mesoscale anticyclonic eddy in DUACS SLA maps.
- Some of the small scale structures exhibit a cyclonic circulation (denoted by CE in Fig.3a-b) in opposite rotation of the mesoscale anticyclonic eddy.
- SWOT SLA spectrum exhibit two major peaks of energy around 60 and 120 km (Fig.3 d-f), possibly due to the mesoscale eddy propagation at this time (Fig.3e)

Figure 3: top panel] Three different phases of a detected mesoscale anticyclonic eddy passage through SWOT KaRin swath ; bottom panel] corresponding KaRin and DUACS SLA spectrum. DUACS SLA is first interpolated on SWOT grid to compute the spectrum. Geostrophic velocities are represented in white and black arrows for SWOT and DUACS respectively.

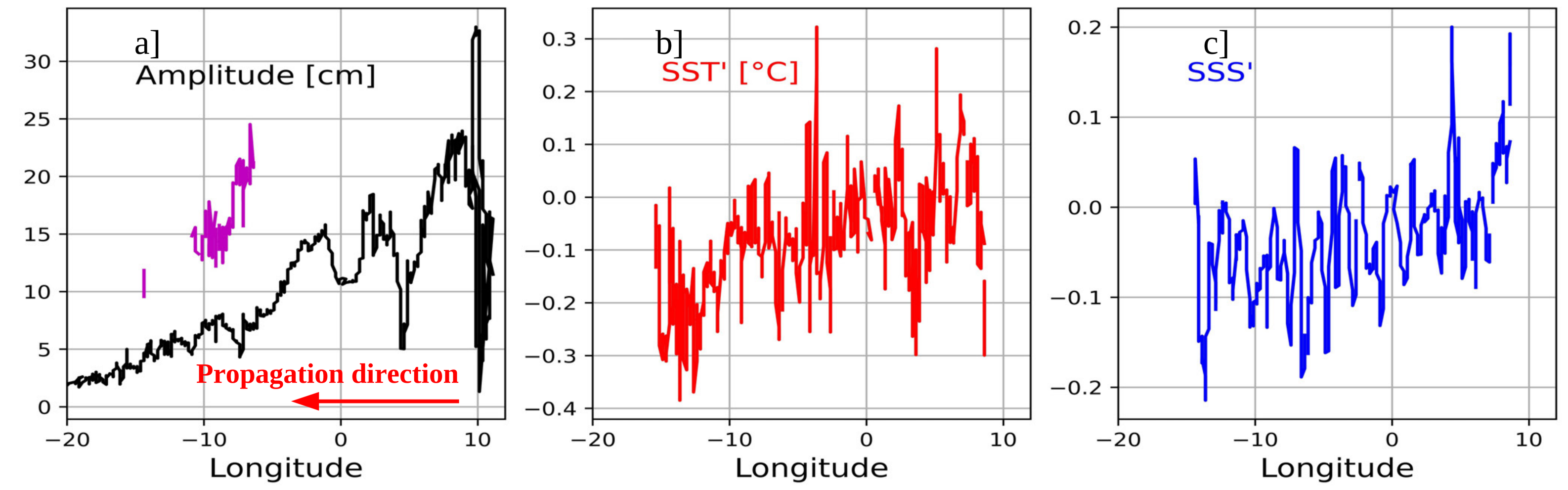


Figure 4: Time change of the the tracked eddy a] SLA amplitude, b] mean SST anomaly and c] mean SSS anomaly in the eddy during its westward propagation. The purple curve represents the maximum SWOT SLA within the DUACS detected eddy during its passage through the SWOT swath.

- The observed mesoscale eddies in the SWOT swath in April 2023 was generated, two years or more before (Fig.2d) from the Agulhas current retroflection which is an area of high turbulence, and then it propagates westward (Fig. 2d)
- The eddy amplitude largely fluctuates between 1 and 30 cm and decays during the eddy propagation until its disappearance.
- The eddy SST and SSS anomalies fluctuate from positive to mostly negative values during its propagation. The mostly negative SST anomaly signature observed during the eddy propagation is mainly due to the eddy propagates throughout a large scale SST gradient, from a cooler coastal water region to a warmer offshore region as shown in Figure 2.d

3.3- SWOT SLA spectrum within different latitude bands

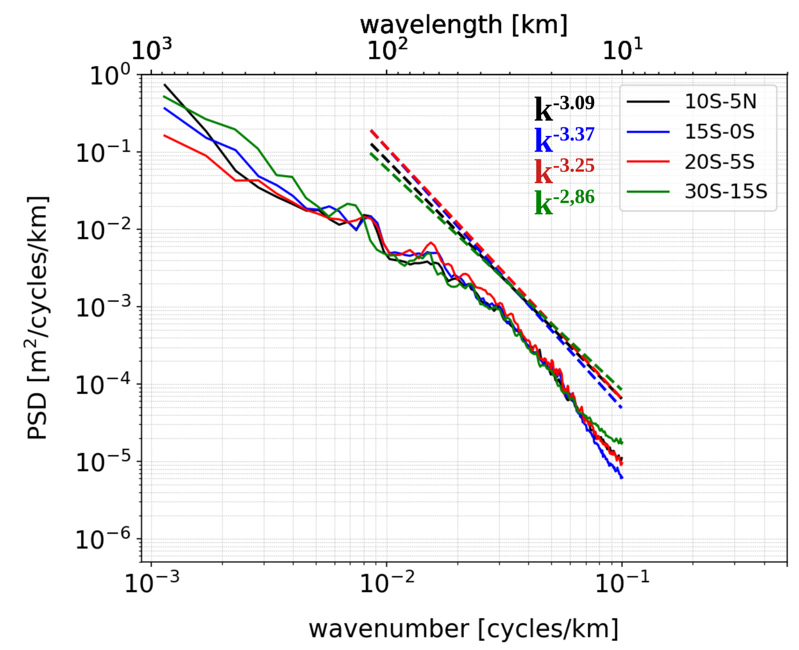


Figure 5: SWOT KaRin SLA spectrum for swath N°3 in different latitude bands in the gulf of Guinea.

- SWOT SLA spectrum computed within four latitude bands between 30°S and 5°N, exhibit similar average energy spectrum for all latitude bands ; specifically from 10 to 120 km wavelengths, with mean slopes varying from $k^{-3.09}$ to $k^{-2.86}$. Peaks of energy are observed around 60 and 120 km wavelengths (Fig.5).
- At larger wavelengths, energy levels are different.
- The peaks of energy observed around 60 and 120km wavelengths might be due to internal waves or to meso/submesoscale eddies as observe in Figure 5.

Conclusion

- Some robust mesoscale eddies where observed both in DUACS and cal/val SWOT SLA maps as well as in other maps such SST and SSS. More over, SWOT reveals small scale structures with opposite polarity that are embedded in the mesoscale anticyclonic eddy detected in DUACS SLA with a lifetime more than 2 years..
- Contrary to the plateau observed in the SWOT nadir SLA wave number PSD, KaRin SLA PSD exhibit a slope of k-3.2 between ~10 – 100 km wavelengths.
- In the Gulf of Guinea, analysis of the swath N°3 of SWOT SLA seems to indicate the same submesoscale turbulence. However, internal wave signals remain to be analyzed and isolated in the SWOT data.

References : Aguedjou et al., 2023 mprint of mesoscale eddies on air-sea interaction in the tropical Atlantic Ocean. Remote Sensing, 15(12), 3087 ; Aguedjou et al, 2019. Eddies in the Tropical Atlantic Ocean and Their Seasonal Variability. Geophys. Res. Lett. 2019, 46, 12156–12164 ; Aguedjou et al., 2021. What Can We Learn From Observed Temperature and Salinity Isopycnal Anomalies at Eddy Generation Sites? Application in the Tropical Atlantic Ocean. J. Geophys. Res. Ocean. 2021, 126, 1–27. Assene et al. 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. Fluid, 5(3), 147 ; Chaigneau et al., 2009. Eddy activity in the four major upwelling systems from satellite altimetry (1992–2007). Progress in Oceanography, 83(1–4), 117–123 ; Chaigneau et al., 2008. Mesoscale eddies off Peru in altimeter records: Identification algorithms and eddy spatio-temporal patterns. Progress in Oceanography, 79(2–4), 106–119Pegliasco et al., 2015. Main eddy vertical structures observed in the four major Eastern boundary upwellingsystems. Journal of Geophysical Research: Oceans, 120, 6008–6033 ; Delcroix et al. 2019. Eddy-Induced Salinity Changes in the Tropical Pacific. J. Geophys. Res. Ocean. 2019, 124, 374–389 ; Morel et al. ; 2019 A. (2019). Potential vorticity diagnostics based on balances between volume integral and boundary conditions. Ocean Modelling, 138, 23–3 ; Napolitano et al., 2022. Influence of the Gulf of Guinea Islands on the Atlantic Equatorial Undercurrent Circulation. JGR Oceans,127, e2021JC017999. Thiam et al., 2024. Mesoscale dynamics and its interaction with coastal upwelling in the northern Gulf of Guinea. To be submitted in Frontiers in Marine Science. Cardot et al., Mesoscale dynamics offshore off Congo river in the gulf of Guinea and its impact on coastal-open ocean water exchange (2024). To be submitted in Journal of Geophysical Research.