Ocean Eddies: Hot spots for air-sea intercations and water masses (trans)formations

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Abstract

Mesoscale eddies are ubiquitous in the ocean, and typically exhibit different characteristics to their surroundings, allowing them to transport properties such as heat, salt and carbon around the ocean. This takes place everywhere in the world's ocean and at all latitude bands. Most of mesoscale eddies energy is generated by instabilities of the mean flow, and by air-sea interactions. Mesoscale dynamics can feed energy and momentum back into the mean flow and help drive the deep ocean circulation. Their suspected importance in transporting and mixing water properties as they propagate in the ocean, play a significant role in the global budgets of these tracers and climate. Increasing evidences point out at intense air-sea interaction at smaller scale than synoptical, especially in the extratropics that can strongly affect the Troposphere. However we do not have yet neither a global quantitative assessments nor a theoretical understanding of these processes. We will present new results from a recently developed eddy-atlas (ToEddies) that includes eddies merging and splitting. In particular, we will discuss properties of Agulhas Rings in the South Atlantic derived from satellite altimetry and the colocalization of these eddies with Argo floats. Our results show that these eddies are, in the South Atlantic, associated with strong thermal and haline anomalies. These are essentially due to Mode Waters (Agulhas Rings Mode Water: ARMW) formed in the core of the rings in the southeastern Cape Basin, just west of the Agulhas Retroflection, after intense air-sea interactions that can last for more than an entire season. These eddies are then advected in the South Atlantic and are responsible of an important flux of heat and salt into this basin (Laxenaire et al. 2018a,b). We corroborate such findings with full depth hydrography of selected eddies and very high-resolution modelling studies.

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Introduction

Mesoscale eddies are ubiquitous in the ocean, and typically exhibit different characteristics to their surroundings, allowing them to transport properties such as heat, salt and carbon around the ocean. This takes place everywhere in the world's ocean and at all latitude bands. Most of mesoscale eddies energy is generated by instabilities of the mean flow, and by air-sea interactions. Mesoscale dynamics can feed energy and momentum back into the mean flow and help drive the deep ocean circulation. Their suspected importance in transporting and mixing water properties as they propagate in the ocean, play a significant role in the global budgets of these tracers and climate. Increasing evidences point out at intense air-sea interaction at smaller scale than synoptical, especially in the extratropics that can strongly affect the Troposphere. However we do not have yet neither a global quantitative assessments nor a theoretical understanding of these processes.

Methods

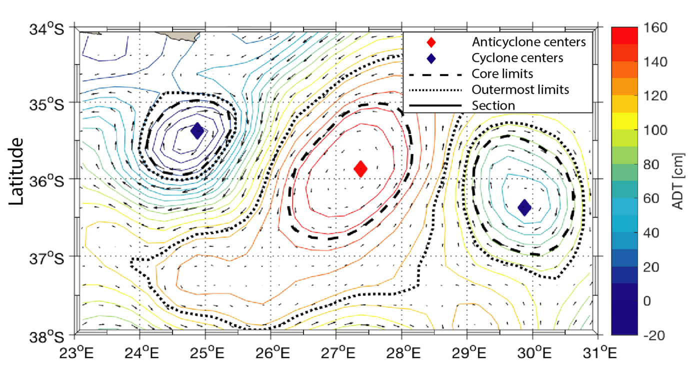
- New eddy detection and tracking method [Laxenaire et al. 2018] modified from Chaigneau et al. [2008].
- ROMS-UCLA-AGRIF High Resolution Ocean simulations of the south-east Atlantic region.

Data

- AVISO Ssalto-Duacs/CMES daily satellite Absolute Dynamic Height maps
- BONUS/GoodHope ocean and atmosphere observations
- *In situ* ocean data from the international Argo floats programme
- Various Ocean-Atmosphere products (merged SST, OA fluxes, ...). In particular *Yu et al.* (2018) WHOI fluxes.
- HR ocean numerical simulation

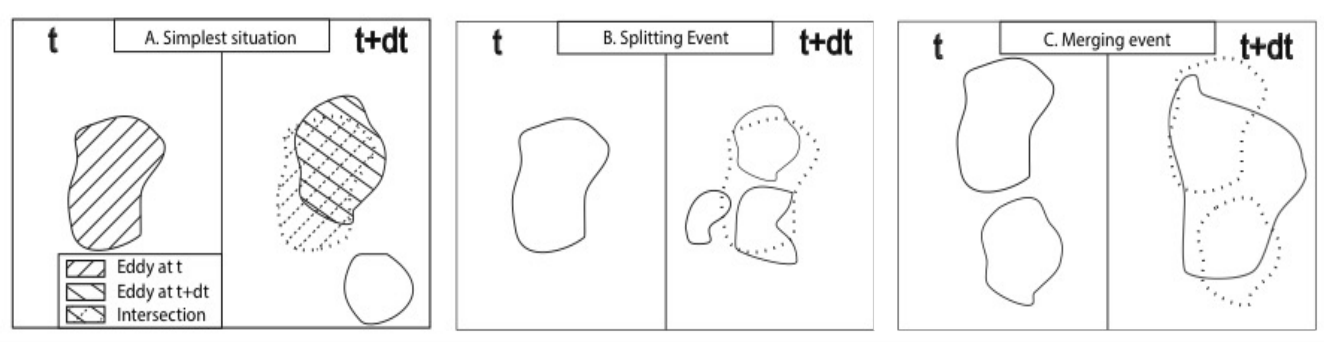
The *TOEddies* detection algorithm (applied on AVISO ADT):

Based on closed contour of ADT:

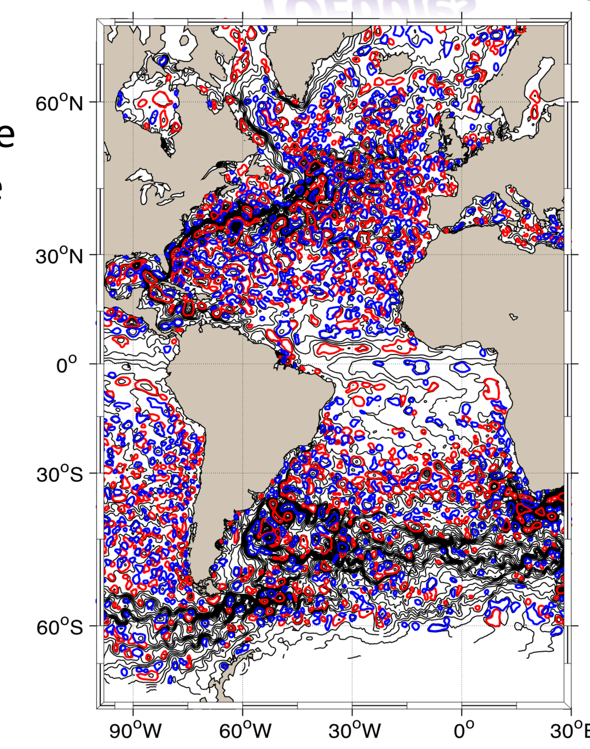


- Core limits associated to contour of maximum geostrophic velocities
- Outermost limits associated to the largest close contours of ADT encompassing a local extreme
- We use superposition of surface between two days to associate eddies. Both merging and splitting events are identified.

Tracking between successive maps :



A *TOEddies* daily snapshot

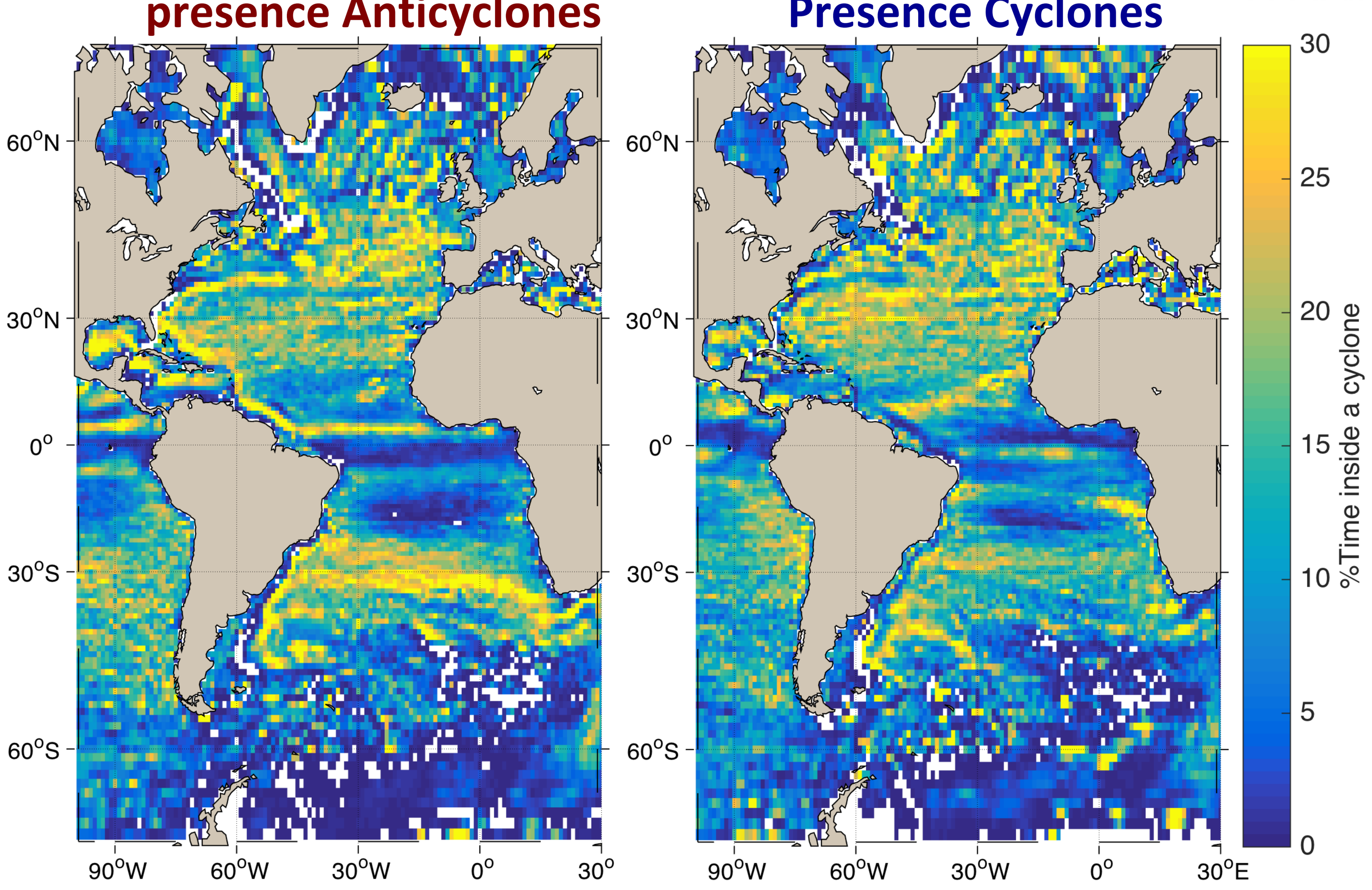


- TOEddies lead to detect an enourmous number of eddies that fill the upper South Atlantic ocean from 15° poleward.
- The subtropical and subpolar gyres large-scale structure is hidden under this rich mesoscale activity.

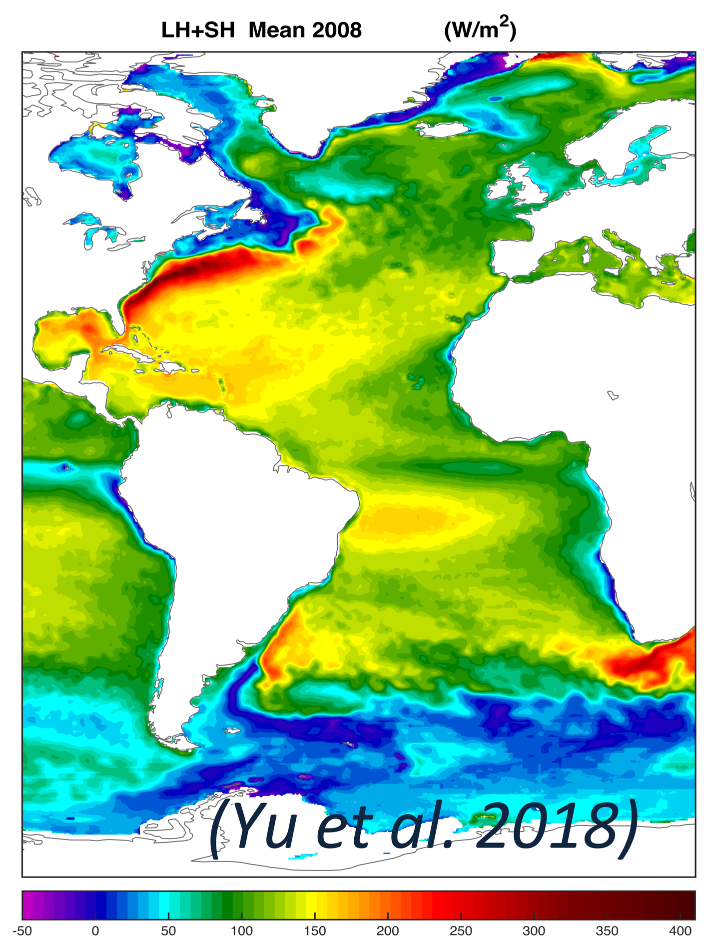
An Atlantic Ocean filled by eddies

Atlantic Mesoscale Eddies Persistence

1°x 1° % Time of presence Anticyclones | 1°x 1° % Time of Presence Cyclones

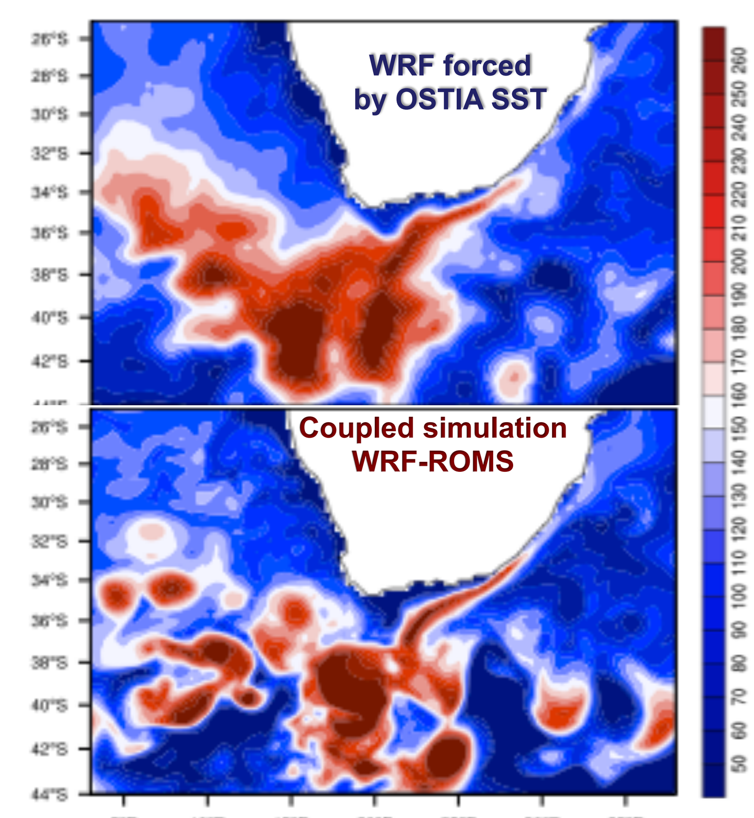


Latent + Sensible Heat fluxes Mean for 2008 OA-HR WHOI Fluxes



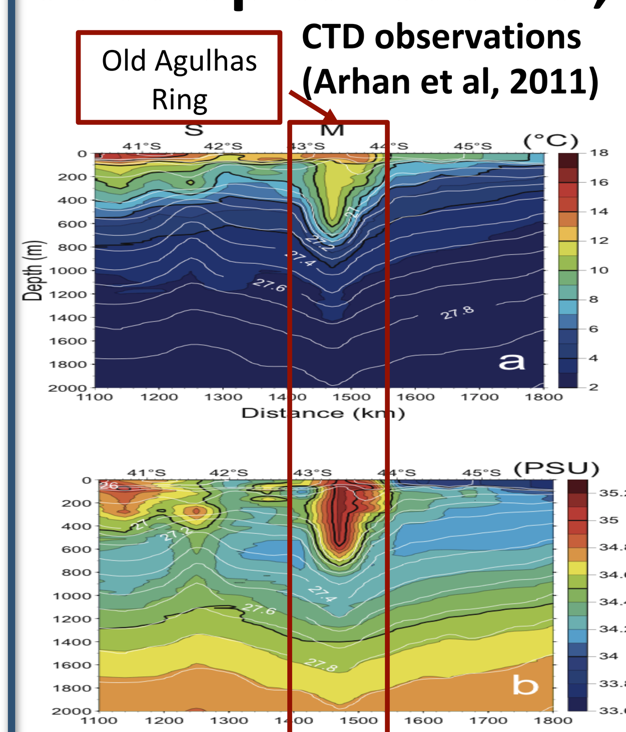
Latent Heat fluxes: Forced & Coupled atmospheric model *(Le Bars et al., 2010)*

- Intense air-sea heat fluxes that coincide with regions or paths of high-eddy presence.
- In particular, intense ocean heat losses in highly energetic regions associated with anticyclonic eddies (South-west of Africa, the Brazil Current andt Zapiola gyre, the North Equatorial Current and the Gulf Stream)
- This is particular evident in mesoscale resolving OA coupled model (right, bottom panel): ocean eddies are the hotspots of air-sea exchanges compared to an atmospheric model forced by observed SST (upper panel). In this case the Latent Heat fluxes are distributed over a large diffused area



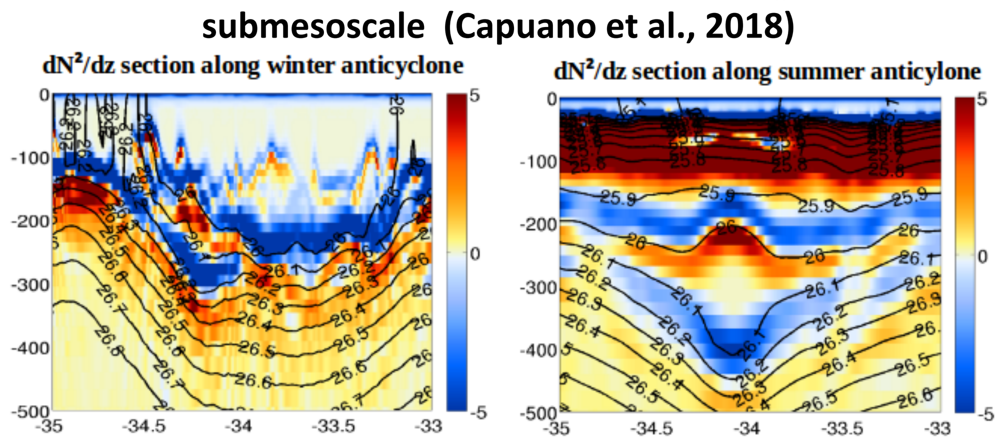
Subtropical eddies , air-sea interactions, Mode Water formation, subduction and ocean ventilation: example of Agulhas Rings

CTD observations (Arhan et al, 2011)



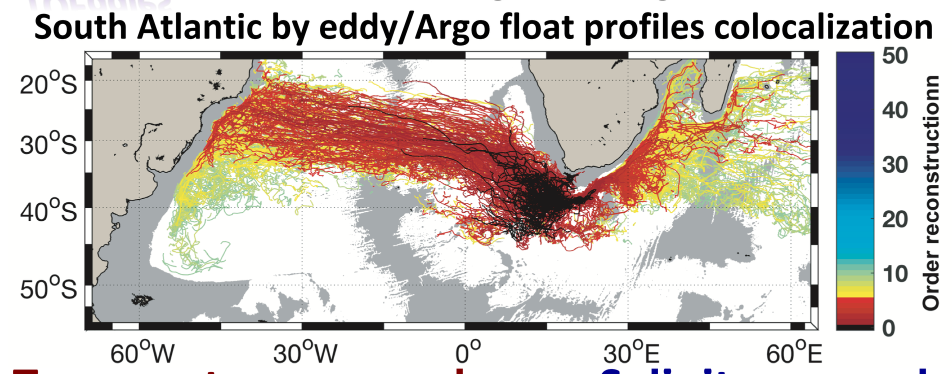
Full depth hydrography shows that Agulhas Rings develop, just after spawning by the Agulhas Current, very deep (200-600) mixing layer before entering the South Atlantic

HiRes ROMS Ocean Numerical Model resolving the ocean submesoscale (Capuano et al., 2018)

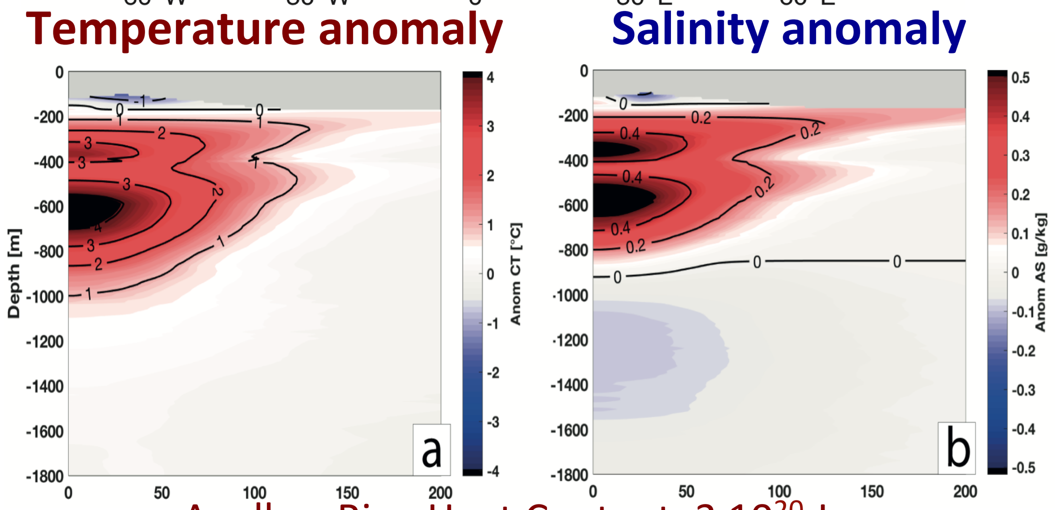


Model simulations that are at sufficient resolution to resolve a large part of the submesoscale dynamics spectrum (0.9 km x 0.9 km and 100 vertical levels) shows important mixing layers in the core of Agulhas Rings in winter. In summer, subduction of the winter mixing layer . This creates cores of Mode Water within the Agulhas Rings upper thermocline. We have named these water *Agulhas Rings Mode Waters* (ARMW).

TOEddies reconstruction of Agulhas Rings structure in the South Atlantic by eddy/Argo float profiles colocalization



Temperature anomaly | **Salinity anomaly**



Agulhas Ring Heat Content: $3\ 10^{20}$ J

Agulhas Ring Salt Content: $7\ 10^{15}$ Kg

- We used the *TOEddies* Atlas to track Agulhas Rings (together with their splitting or merging with other eddies) in the South Atlantic.
- We then colocalized these eddies with Argo floats profiles paying attention that every of such profile falls in the core of each eddy to be representative of the eddy and not of the external environment
- This allowed us to account for the thermal and haline anomaly that characterize these eddies in the South Atlantic, far from their spawning regions.
- The reconstructed Agulhas Rings South Atlantic thermohaline structure shows that Mode Waters formed in the core of these eddies in the Cape Basin, just west of the Agulhas Retroflection, are advected in the South Atlantic and are responsible of an important flux of heat and salt into this basin (*Laxenaire et al. 2018a,b*).

SUMMARY AND OUTLOOK

- The global ocean is filled with mesoscale eddies that, as a consequence, should have a strong impact on the ocean circulation. These eddies are very efficiently detected and tracked (including their splitting and merging with other eddies) with the newly *TOEddies* algorithm developed at LMD-IPSL.
- The Atlantic Ocean show a very organized structure of eddies paths (both anticyclonic and cyclonic) that seem to cross zonally the subtropical and tropical regions and follow the western boundary currents.
- Observations and coupled modelling experiments suggest that these eddies have a strong imprint in ocean-atmsophere exchanges of heat. We show that this is in particular true for Agulhas Rings that once spawned from the Agulhas Retroflection strongly interact with the atmosphere. These interactions induce the formation of very deep mixing layer in the core of Agulhas Rings. This water successively subduct and fill large pouches of (Agulhas Rings) Mode Water in the eddy cores. This water is subsequently advected in the South Atlantic interior transporting a strong heat and salt anomaly.

REFERENCES: Arhan et al. 2011, J. Geophys. Res., doi:10.1029/2011JC007140 Capuano et al., 2018, J. Geophys. Res., In press. . Laxenaire et al. , 2018 a,b J. Geophys. Res., Under review. Le Bars, 2010, Master Thesis, Univ. Bretagne Occidentale, France, under the supervision of S. Speich and C. Messager. Lyu et al., 2018, Under preparation.