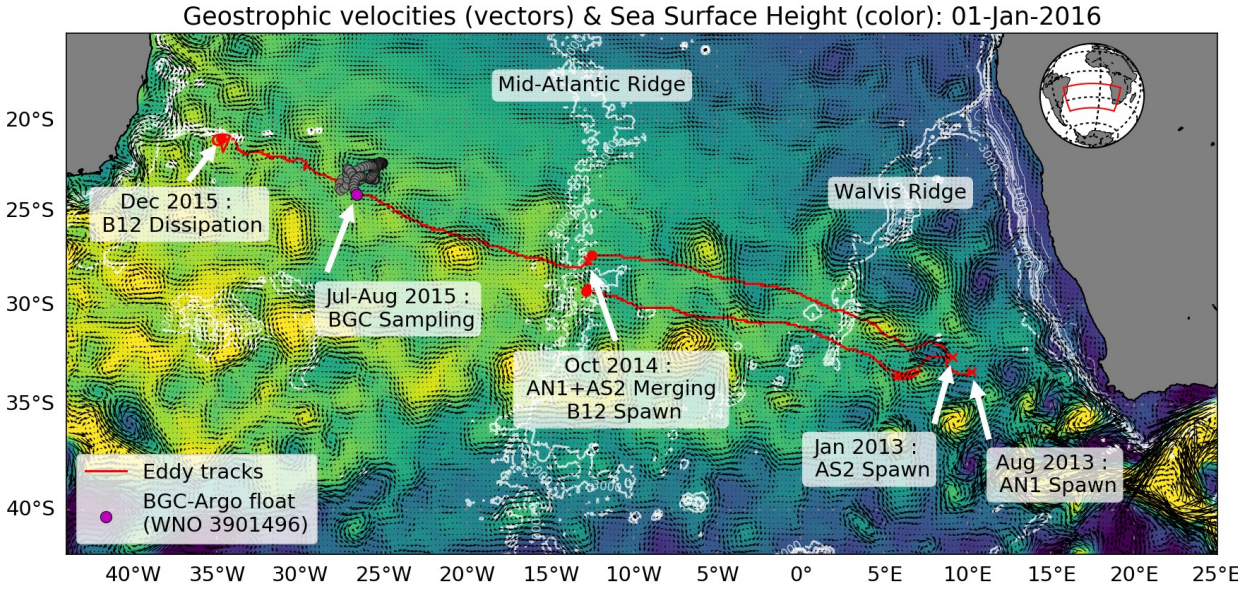
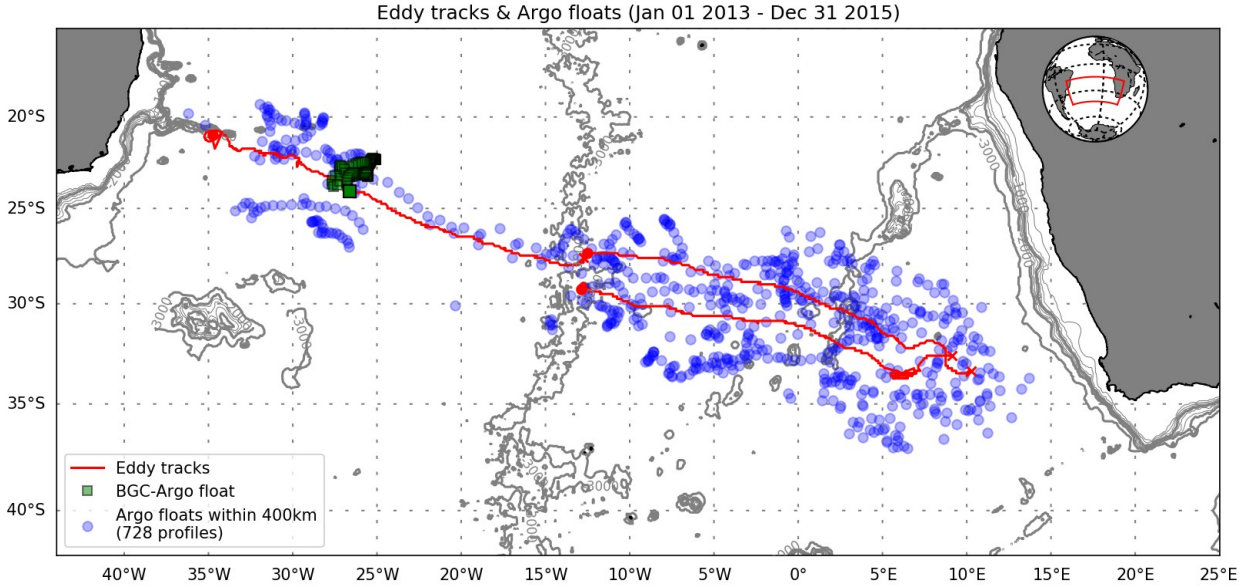
Agulhas ring transport efficiency from combined satellite altimetry and Argo profiles

Francesco Nencioli, Giorgio Dall'Olmo and Graham Quartly

PML | Plymouth Marine Laboratory





Nencioli et al., JGR-Oceans, 2018; doi: 10.1029/2018JC013909

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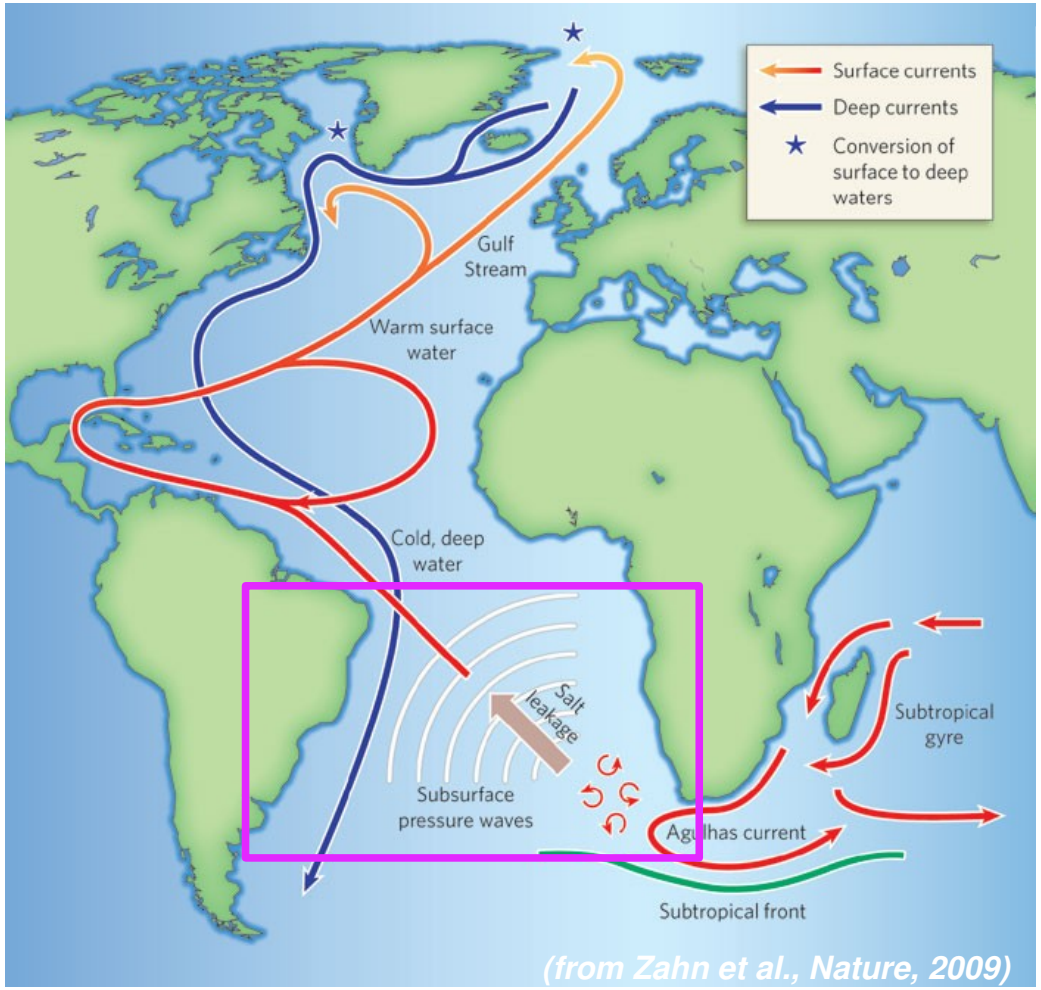
Motivation: AMOC and transport of Agulhas leakage

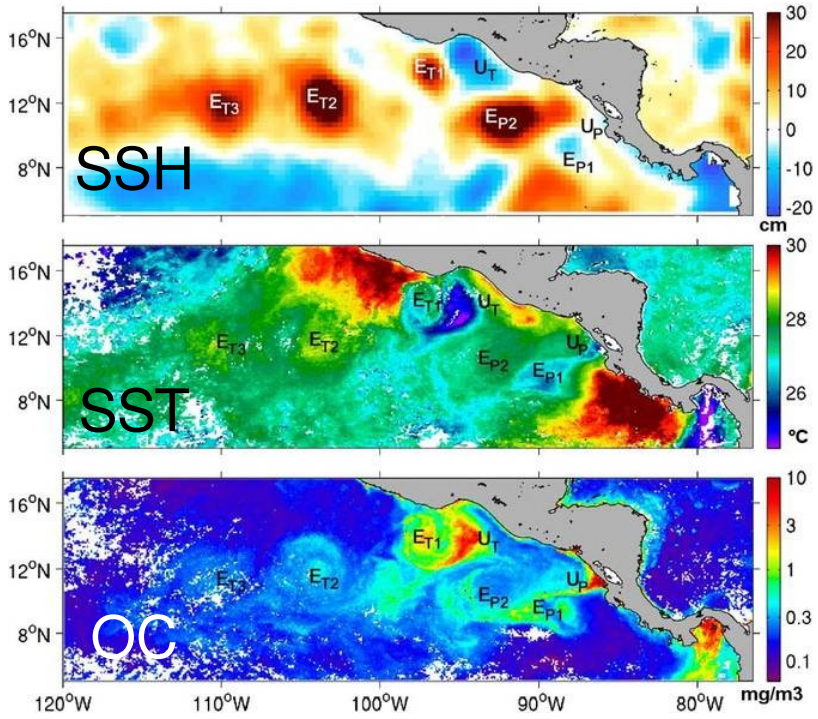


(from Zahn et al., Nature, 2009)

The Atlantic Meridional Overturning Circulation (AMOC)

- **Agulhas region key component of thermohaline circulation** (redistribution of heat and salt)
- **Agulhas leakage** feeds surface branch of **AMOC:**
  Connection between Indian and Atlantic basin
- Leakage transported across South Atlantic by **Agulhas rings**:
  - Mesoscale eddies
  - Large (>100 km radius)
  - Deep (~1000 m)
  - Long lived (>1 years)
- Efficiency of eddy-driven cross-basin transport still under debate

Observe the impact of mesoscale eddies



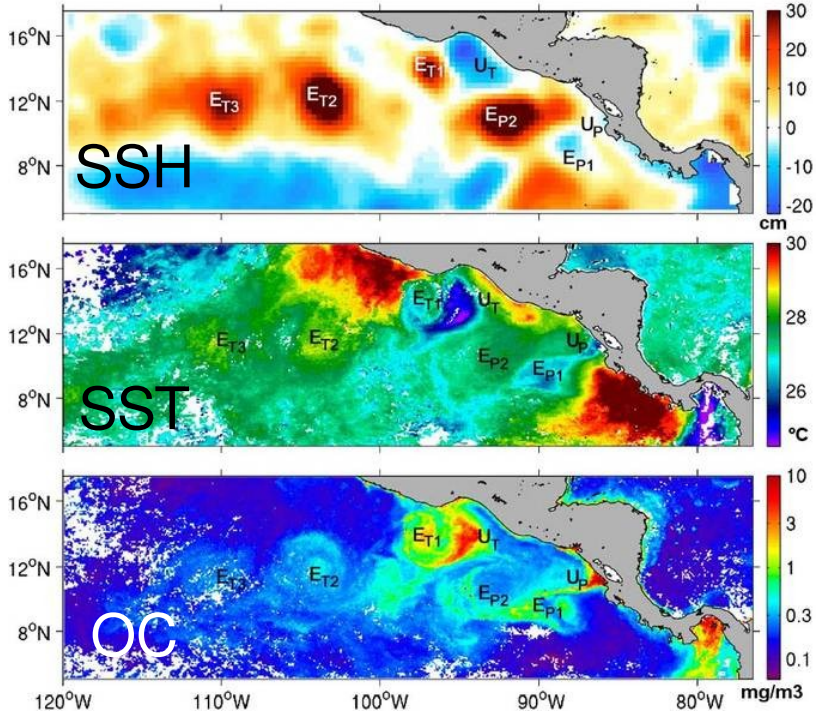
(from Palacios et al., 2006; courtesy of AVISO)

a) Remote sensing

Pros: Daily global coverage

Cons: **Surface only**

Observe the impact of mesoscale eddies



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a) Remote sensing

Pros: Daily global coverage

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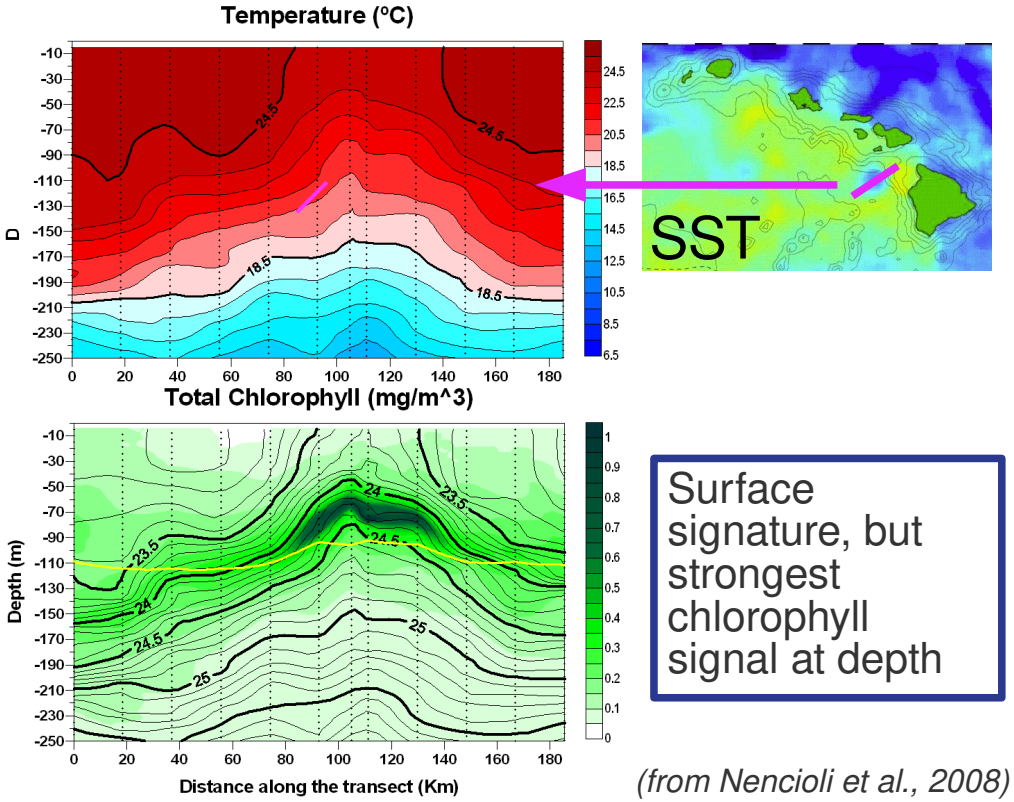
b) In-situ observations

Pros: **Subsurface information**

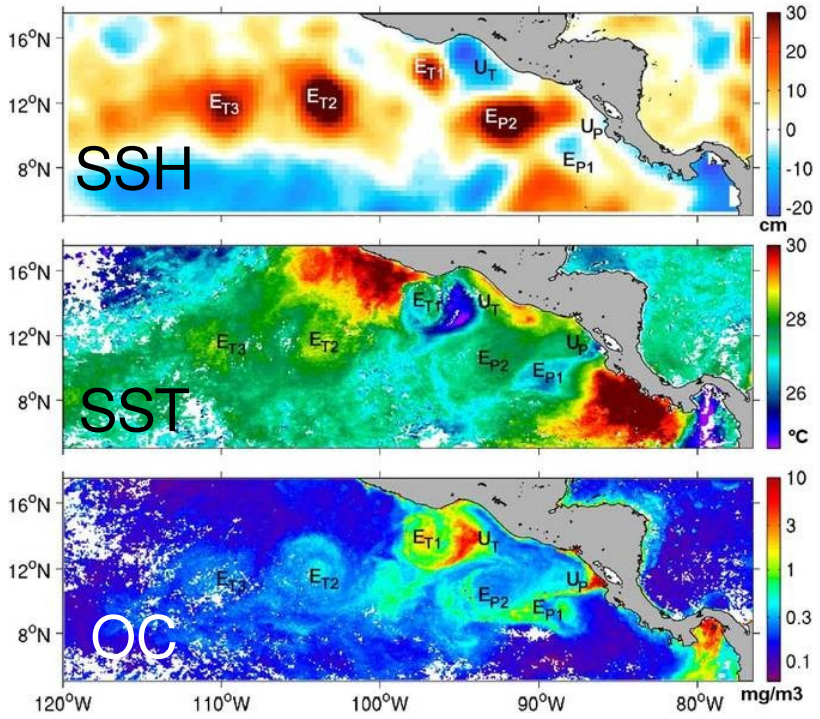
Cons: Spatio-temporally limited



Surface signature, but strongest chlorophyll signal at depth

(from Nencioli et al., 2008)

Observe the impact of mesoscale eddies



(from Palacios et al., 2006; courtesy of AVISO)

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+

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Pros: **Subsurface information**

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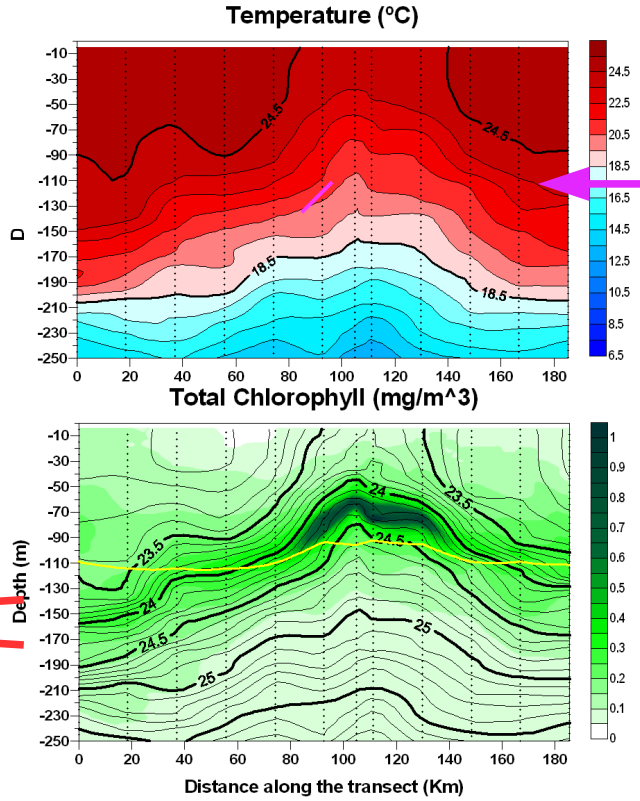

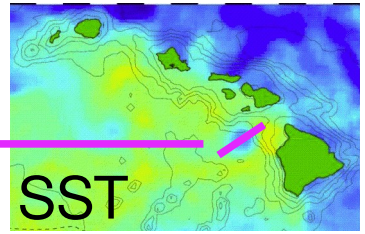

Surface signature, but strongest chlorophyll signal at depth

(from Nencioli et al., 2008)

Synergistic approach: combine the two to mitigate limitations

Main Aim: Understand Agulhas ring transport efficiency

Quantify the effective contribution of Agulhas rings to the Atlantic meridional overturning circulation (**AMOC**) from **remote sensing + in-situ observations**

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Main Aim: Understand Agulhas ring transport efficiency

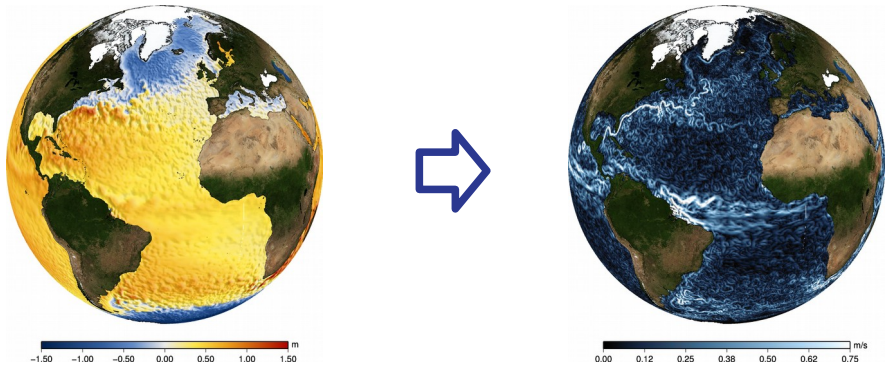
Quantify the effective contribution of Agulhas rings to the Atlantic meridional overturning circulation (**AMOC**) from **remote sensing + in-situ observations**

1. Remote sensing (surface)

Altimetry from AVISO (now at CMEMS)

- **Global**, **cloud-free** measurements of sea-level anomaly
- **Daily** maps at **1/4 degree** resolution by combining multiple altimeter observations

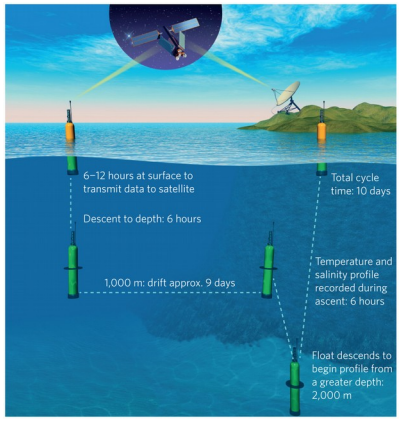
Absolute Dynamic Topography **Surface Geostrophic Currents**

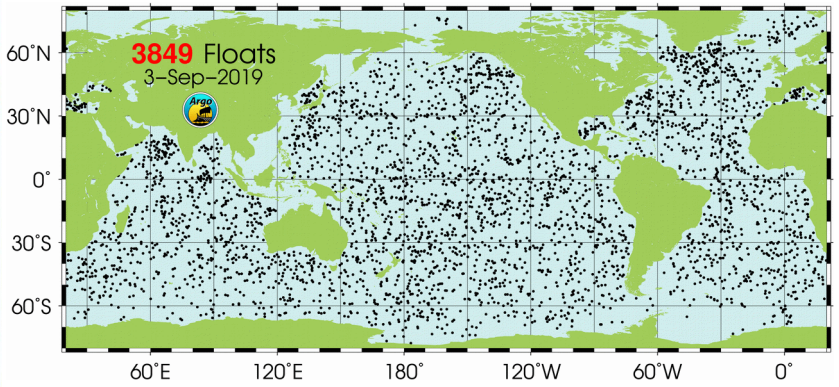


2. In-situ (sub-surface)

Observations from Argo

- **Global network** of >**3700** free-drifting profiling floats
- From each float **profiles of T and S** from **2000m depth** every **10 days**





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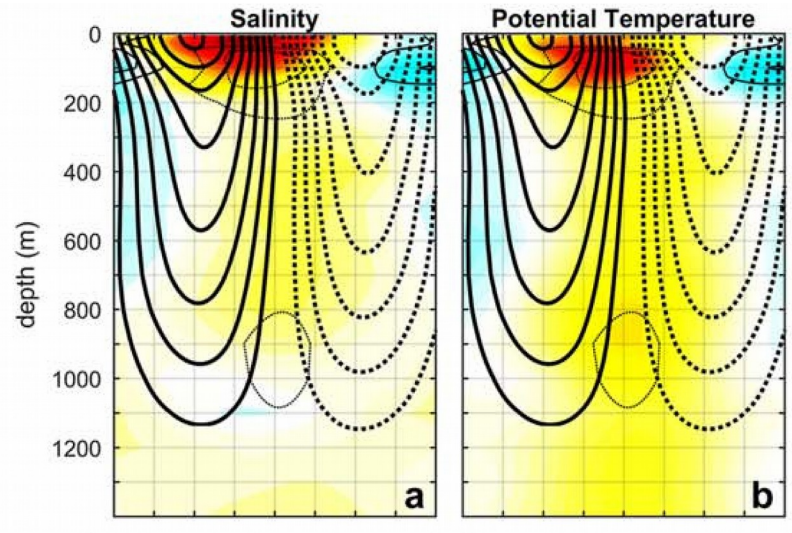
Previous studies: already adopted this synergistic approach
(Qiu & Chen, 2005; Chaigneau et al., 2011...)

- Combined Argo profiles **collected within several eddies…**
- **...**to **recontruct the average eddy section** for a given ocean region



(from Amores et al., 2017)

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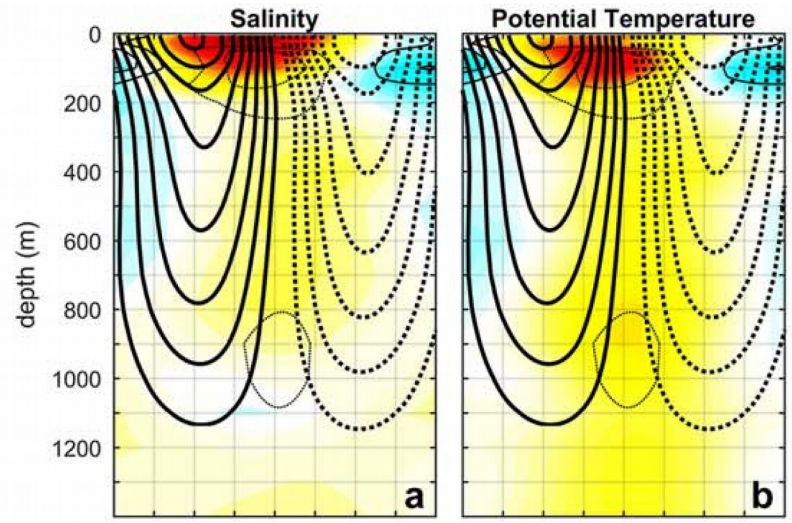


(from Amores et al., 2017)

Focus of this work:
Combine satellite and in-situ to investigate **evolution of a specific mesoscale feature**

Objectives

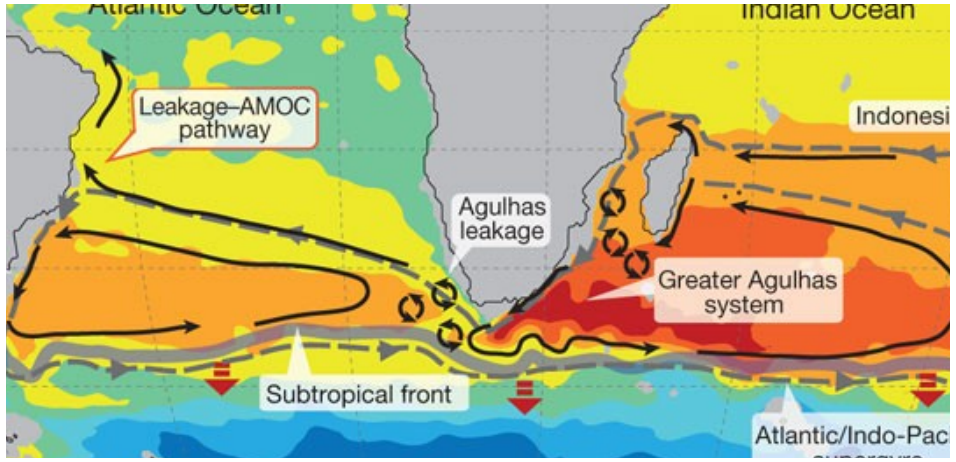
1. Quantify transport and exchanges

➔ **How much** and **how far** Agulhas water is transported by the eddy?

➔ **Where** do exchanges occur?

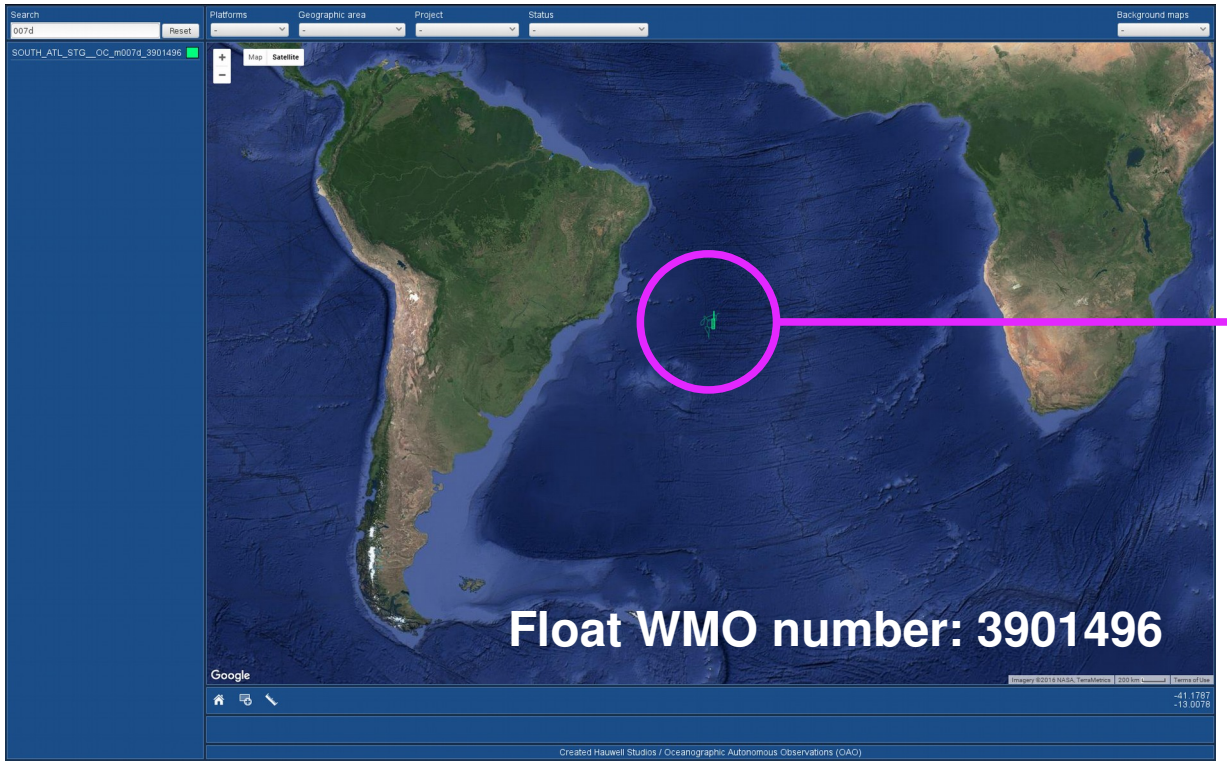
2. Identify pathways of exchanged waters

➔ **Where** do the exchanged waters go?

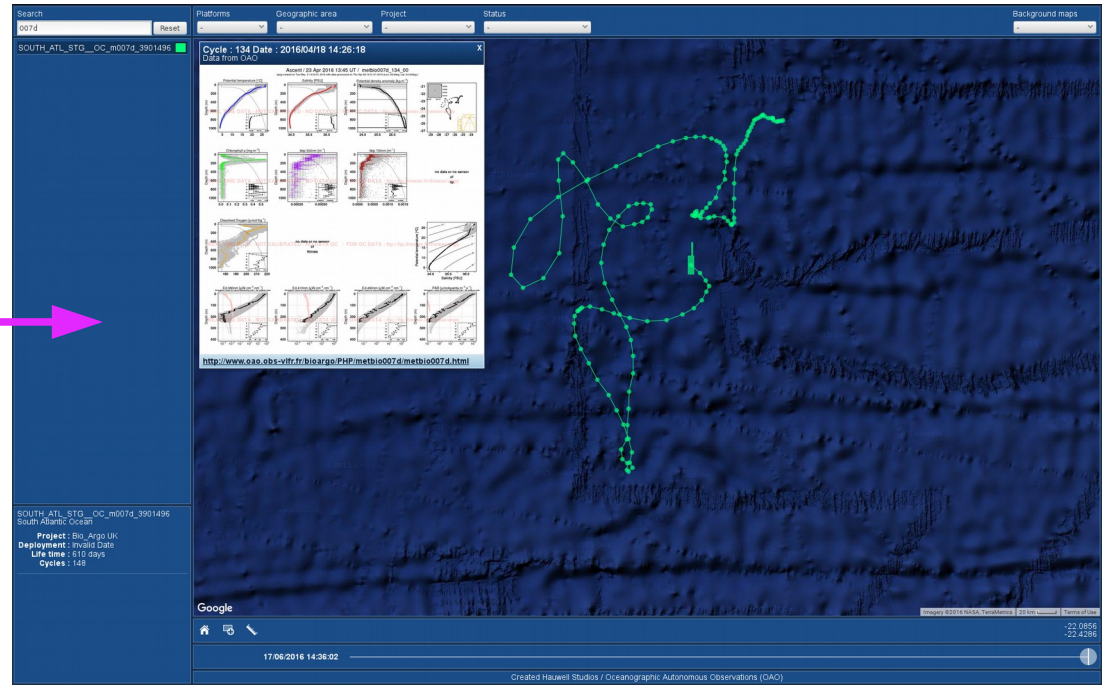


(from Beal et al., 2011)

Starting point: BGC-Argo float metbio007d



Float WMO number: 3901496



(from http://www.oao.obs-vlfr.fr/maps/en/)

➔Deployed in Oct 2014 during Atlantic Meridional Transect (AMT) 24

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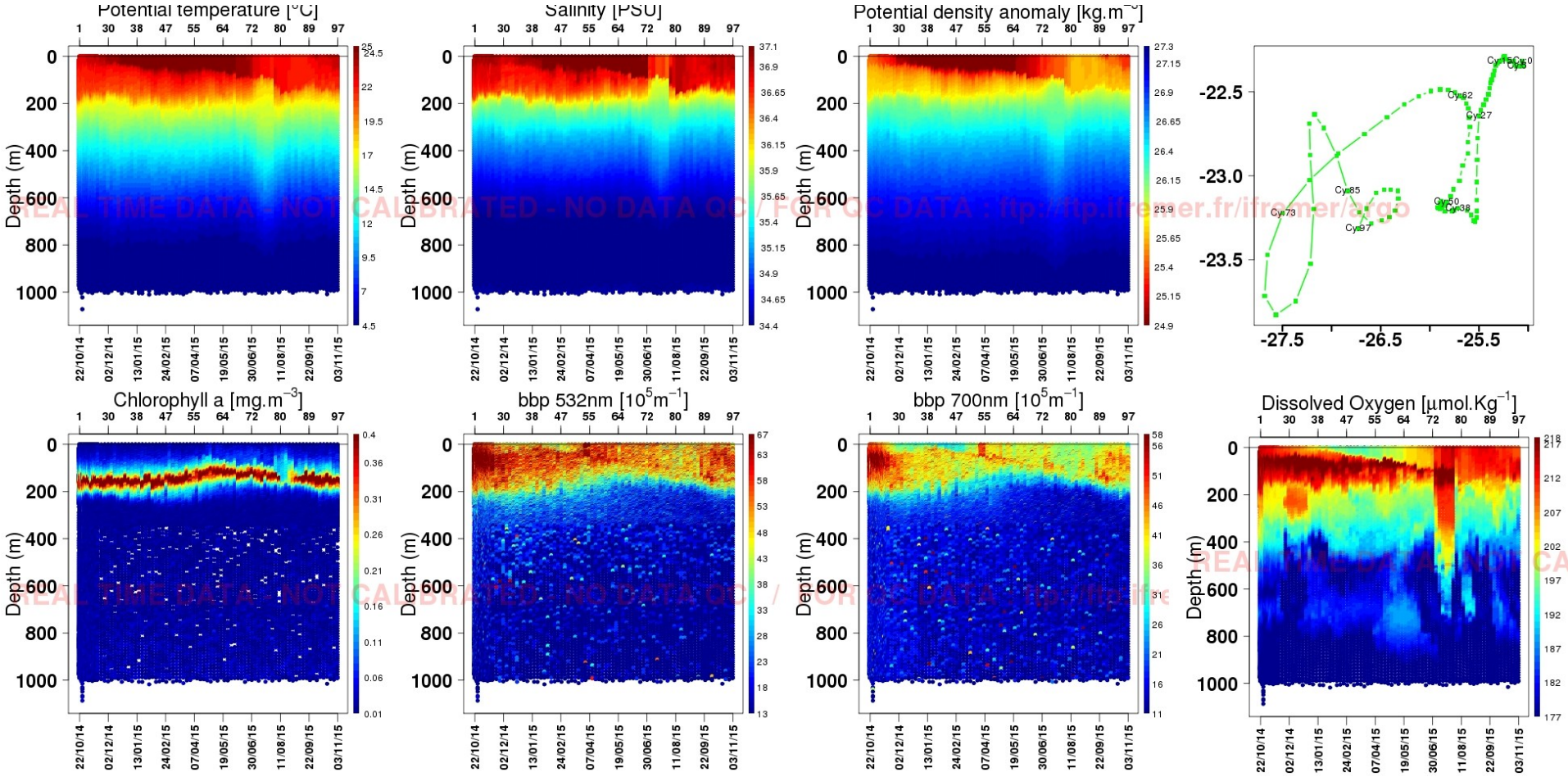

(from http://www.oao.obs-vlfr.fr/bioargo/PHP/metbio007d/metbio007d.html)

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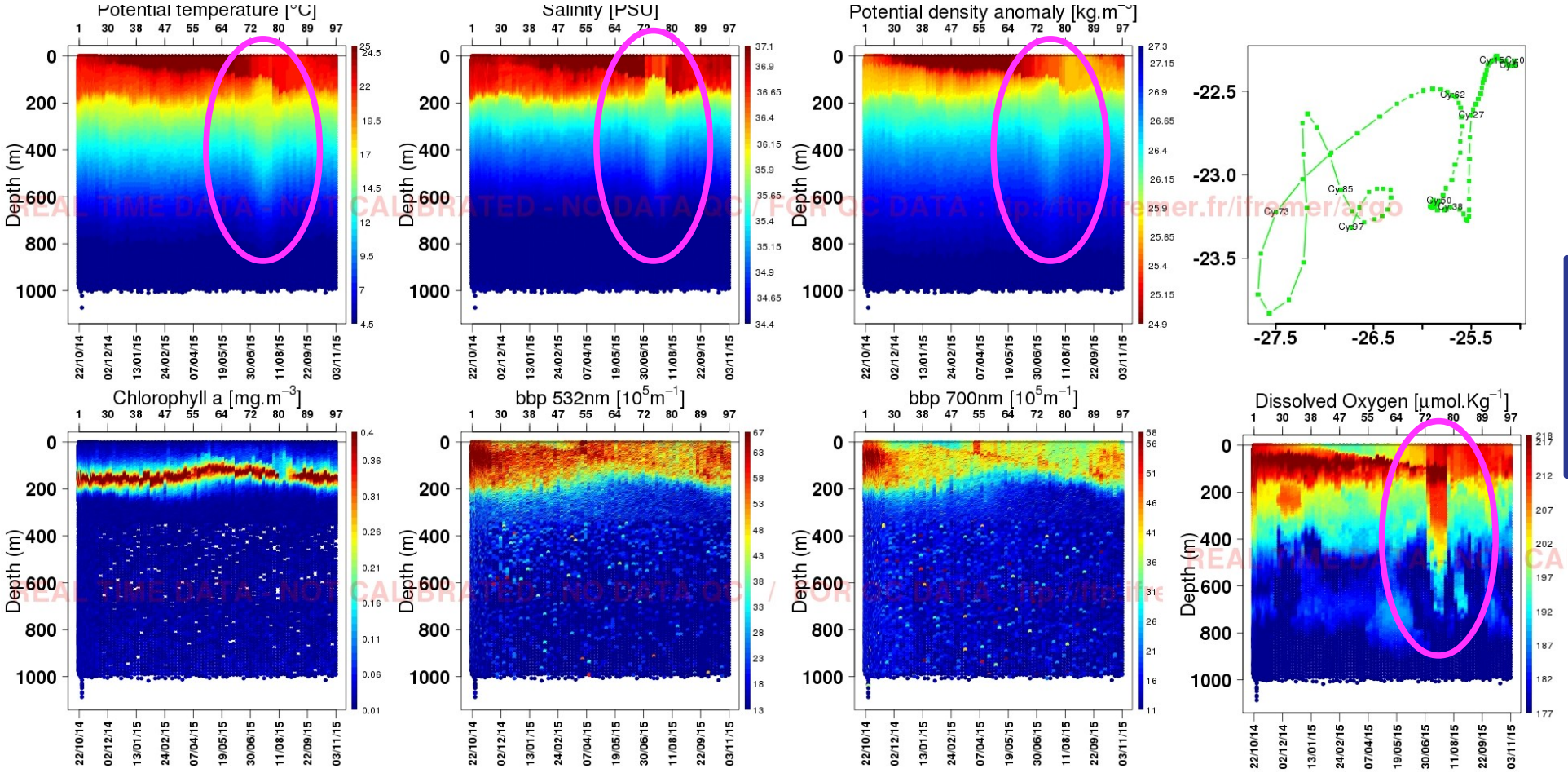
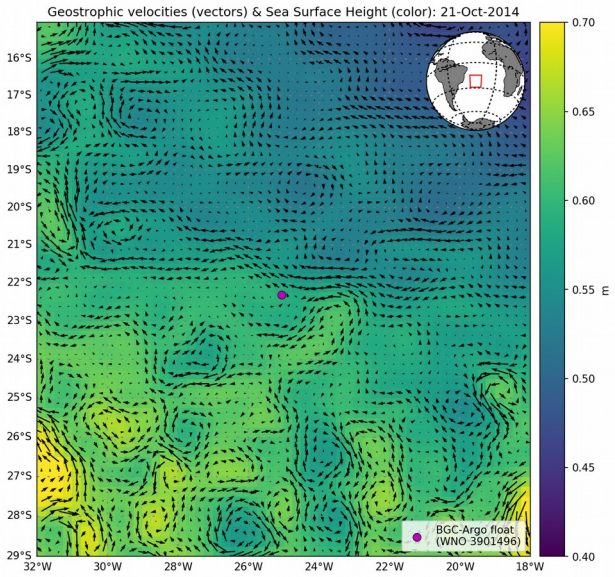


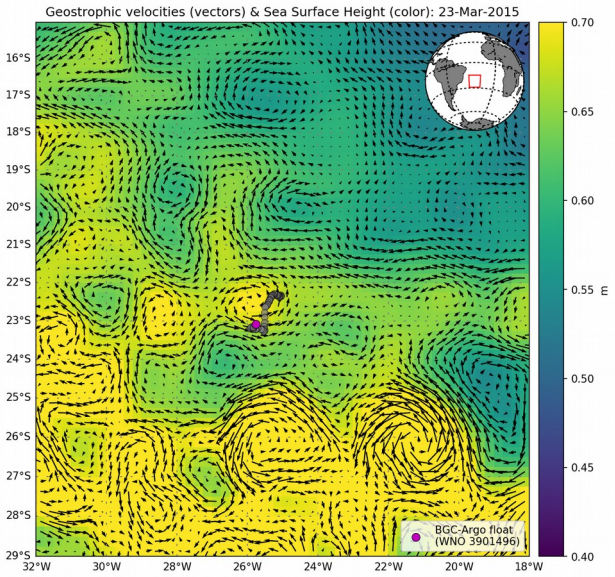
Strong **anomaly of physical and biogeochemical variables** in Jul-Aug 2015

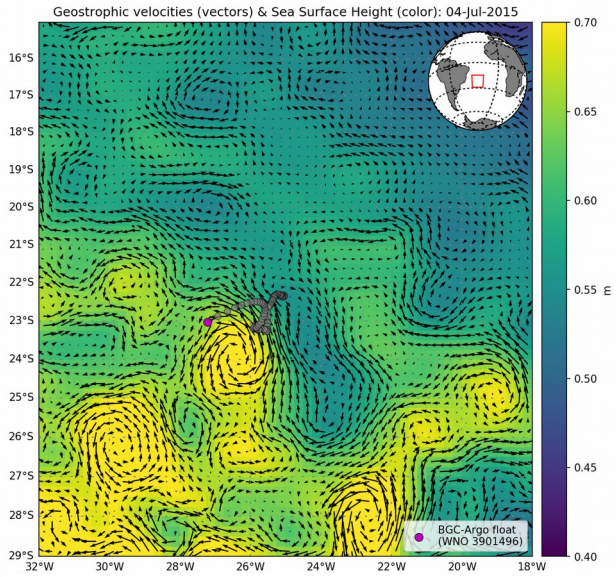
(from http://www.oao.obs-vlfr.fr/bioargo/PHP/metbio007d/metbio007d.html)

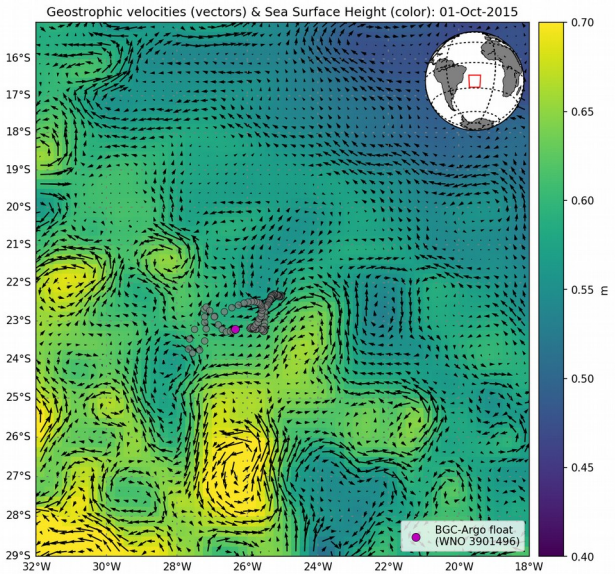
Zoom Out 1: Origin of the anomaly?

➔ BGC-Argo float position over altimetry-based surface velocities (AVISO product)









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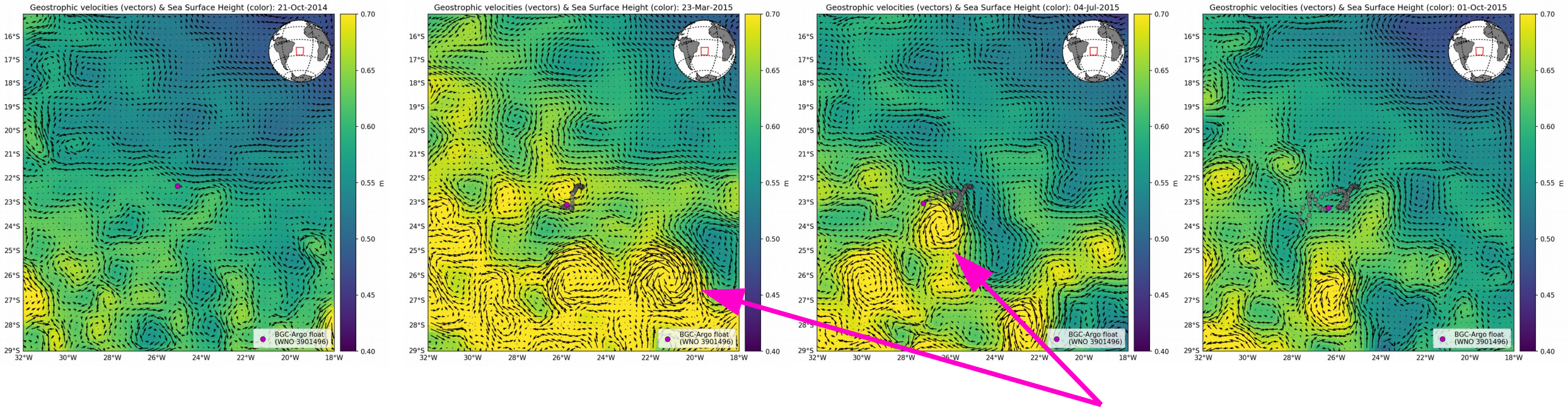
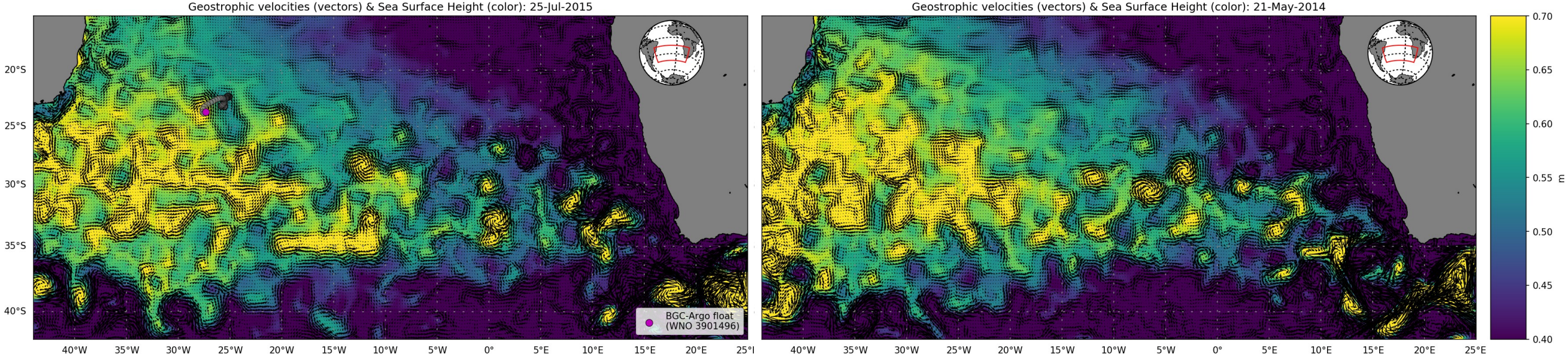


➔ Observed anomaly in O2, T and S is associated with **passage of a mesoscale eddy**

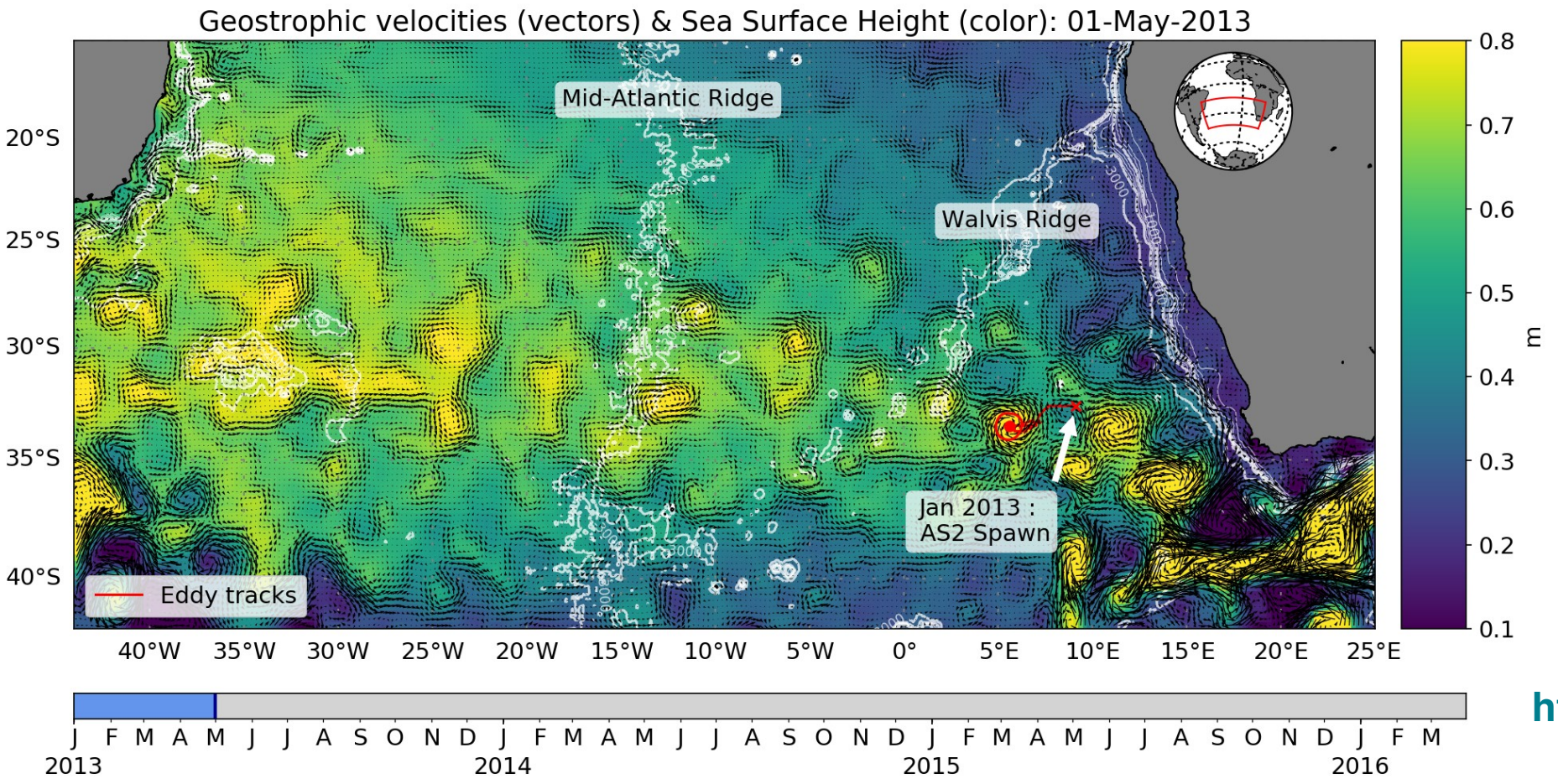
Zoom out 2: Origin of the eddy?

- ➔Where did it come form?
- ➔How old was it?
- ➔Which waters were transported?



Lots of eddy activity + long time-series ⇨ **Automated detection** (from Nencioli et al. 2010)

Zoom out 2: Origin of the eddy?



https://youtu.be/cq9qu0hmmSI

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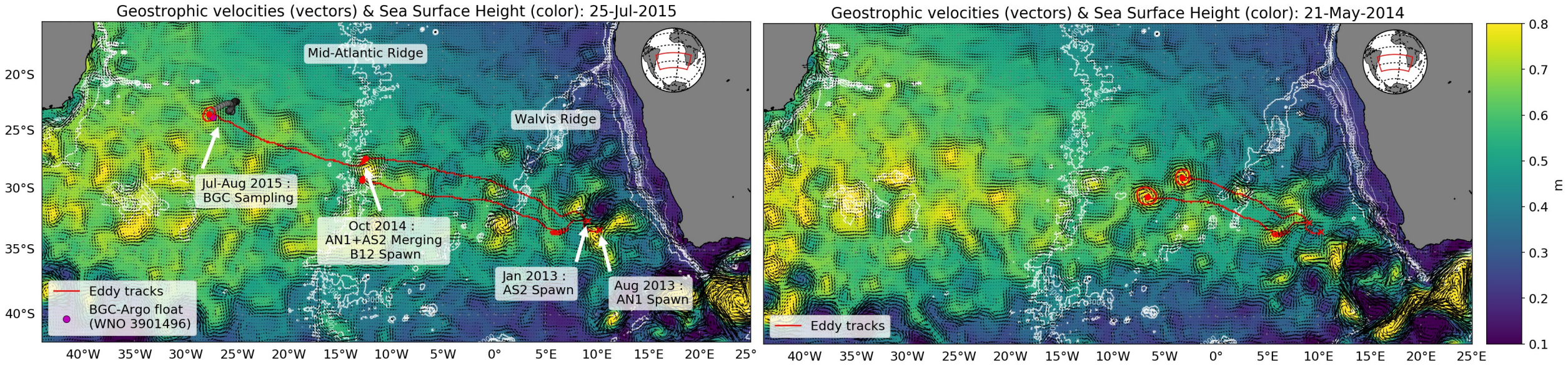
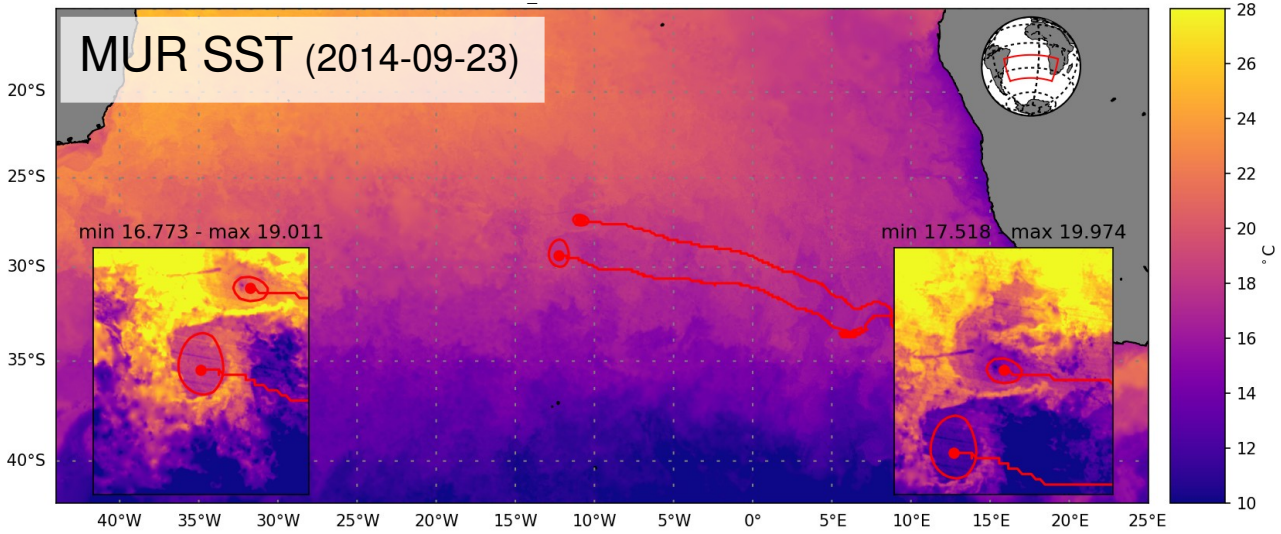
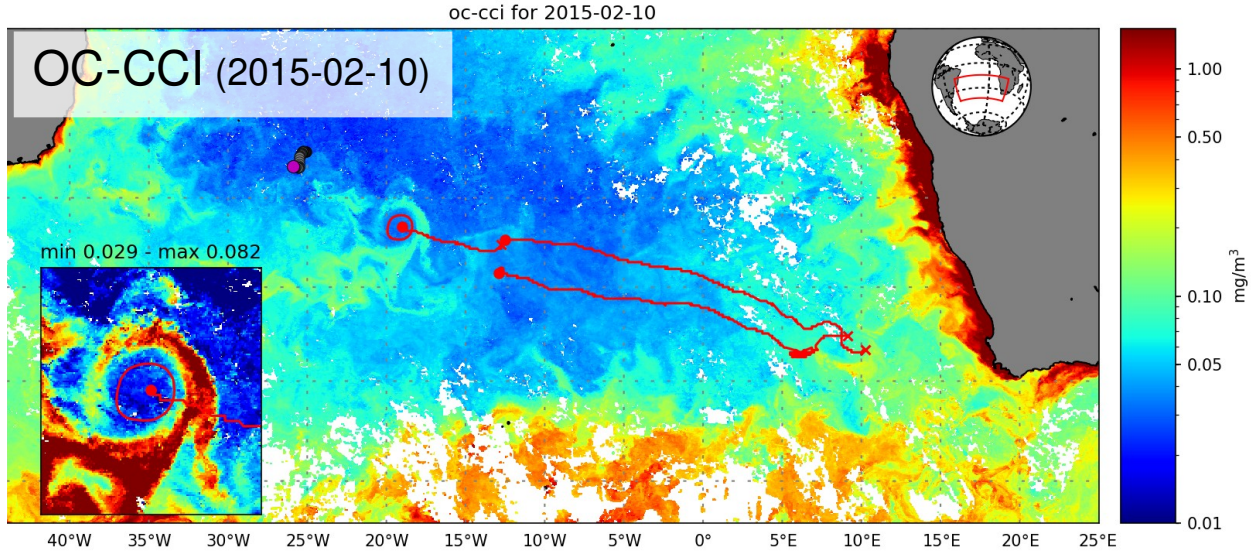


- ➔ Eddy sampled by BioArgo in Western South Atlantic on **Jul 2015**
- ➔ Originated by merging of two eddies from Agulhas region on **Oct 2014**
- ➔ Agulhas rings formed in Eastern South Atlantic on **Jan 2013**

Active transport of water?

Lagrangian vs Eulerian eddy detection: Eulerian methods do not guarantee eddy coherence (*Haller & Beron-Vera, 2013; Abernathey & Haller, 2018)*



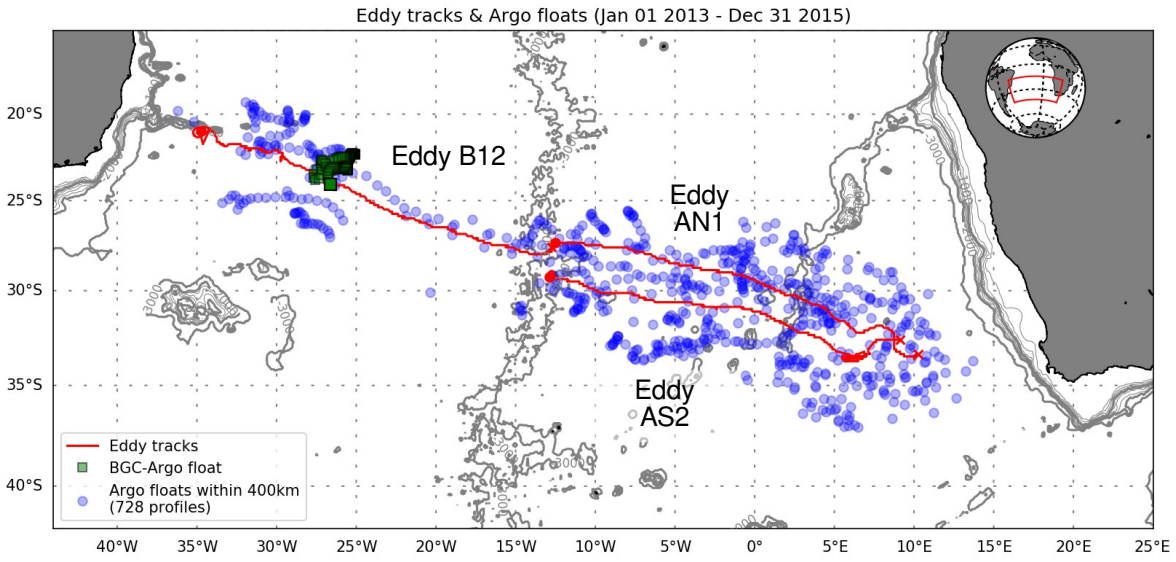


Evidence 1

➔Eddy cores with lower SST and chlorophyll-a concentrations

➔Advection of filaments of higher SST and chlorophyll-a concentrations around the cores

In-situ: Argo observations within the eddy



➔Retrieved Argo profiles within 400 km to the eddy centre along each eddy track

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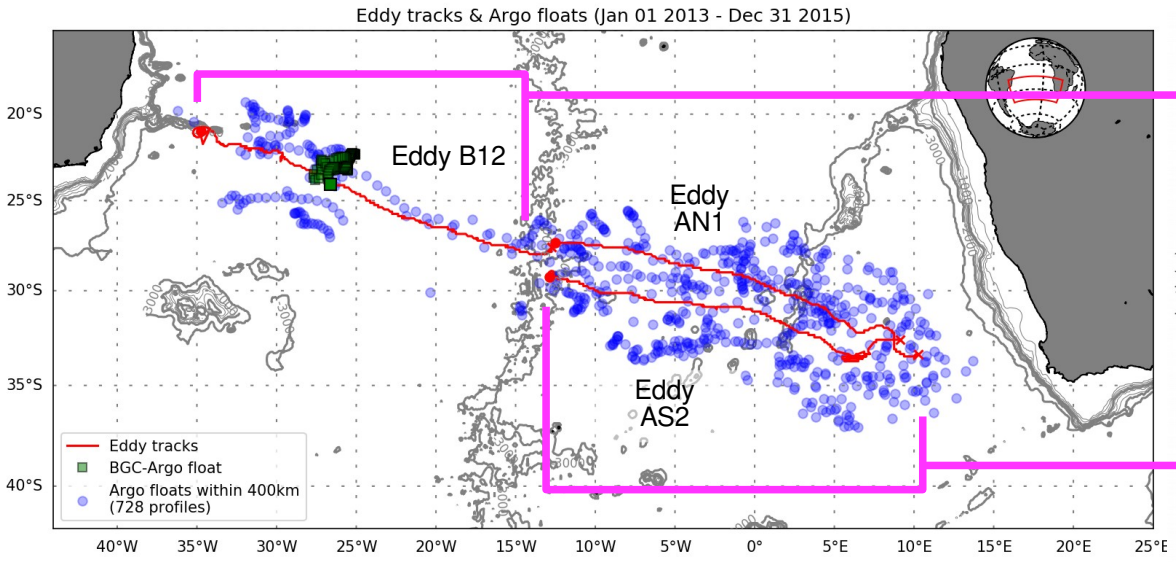
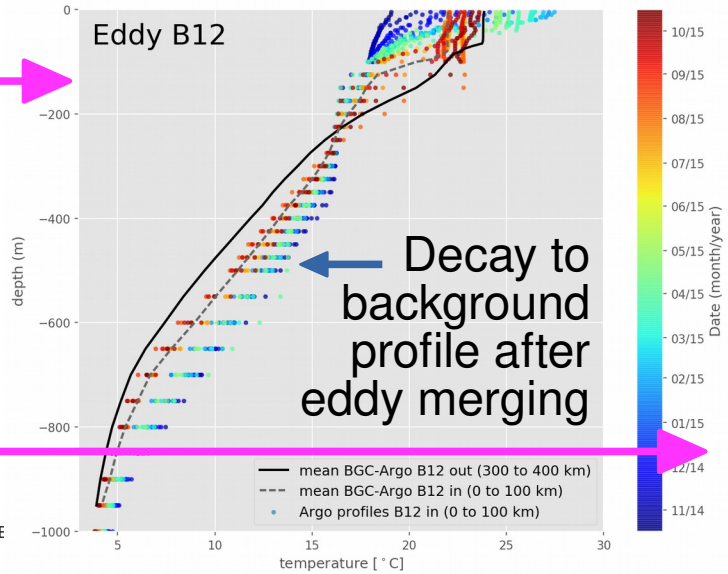
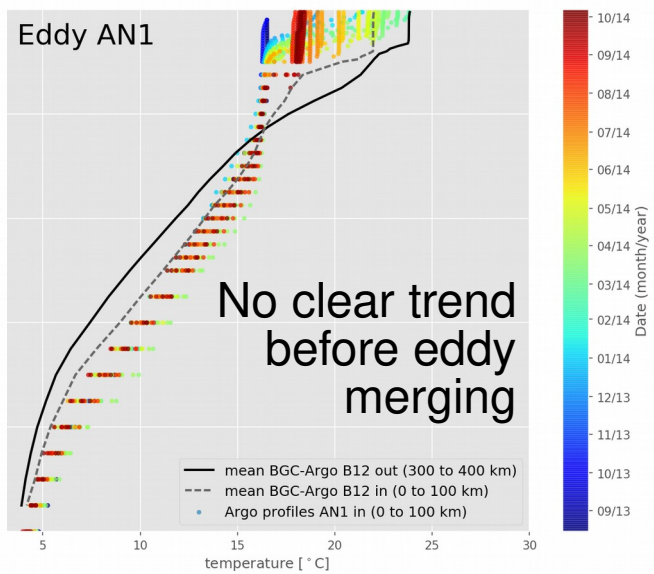






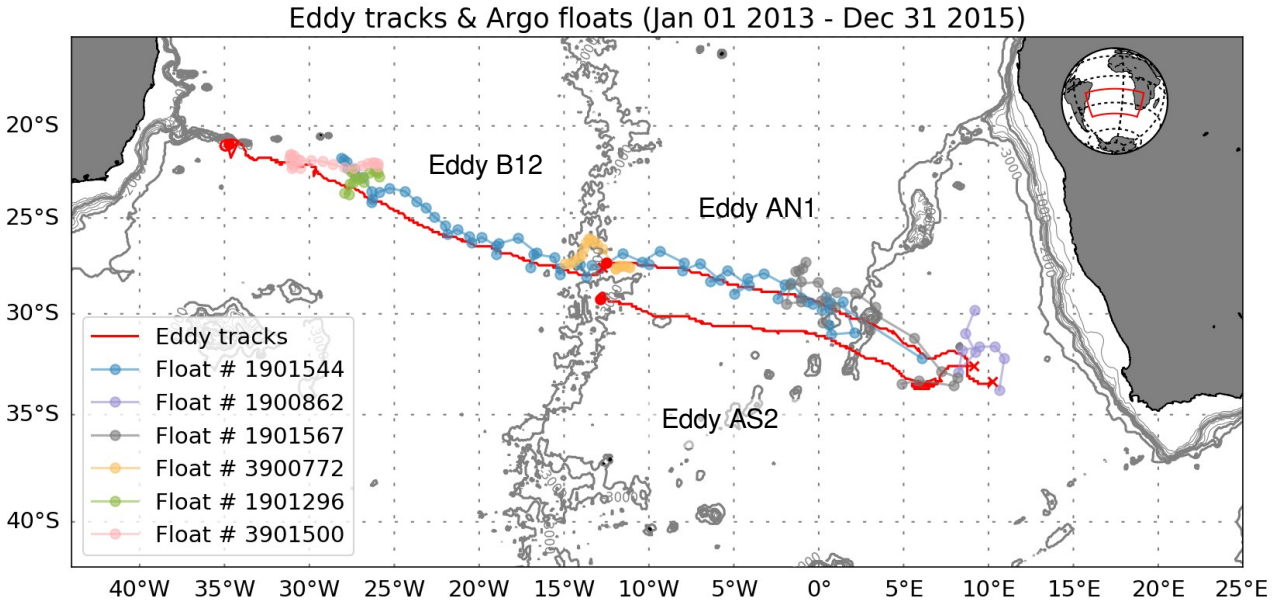
➔Retrieved Argo profiles within 400 km to the eddy centre along each eddy track

➔Temporal evolution of temperature profiles at eddy center (0 to 100 km)

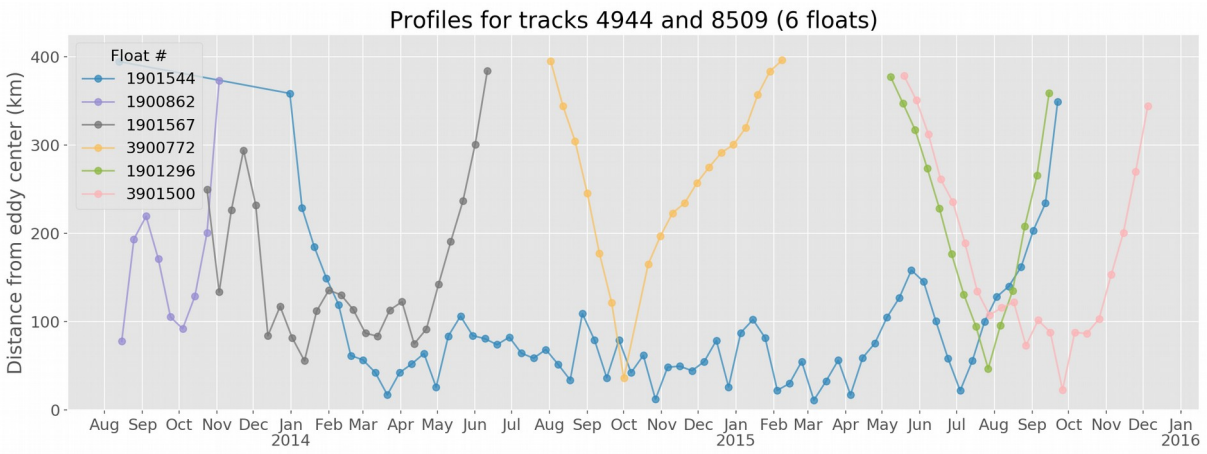
Evidence 2

➔Profiles within the eddy cores associated with anomaly

In-situ: Argo observations within the eddy



Profiles <100 km from eddy centers



Evidence 3

➔Float #1901544 within eddy core for **1.5 years** (Feb 2014 - Jul 2015)

Obj. 1: Agulhas ring transport and exchanges

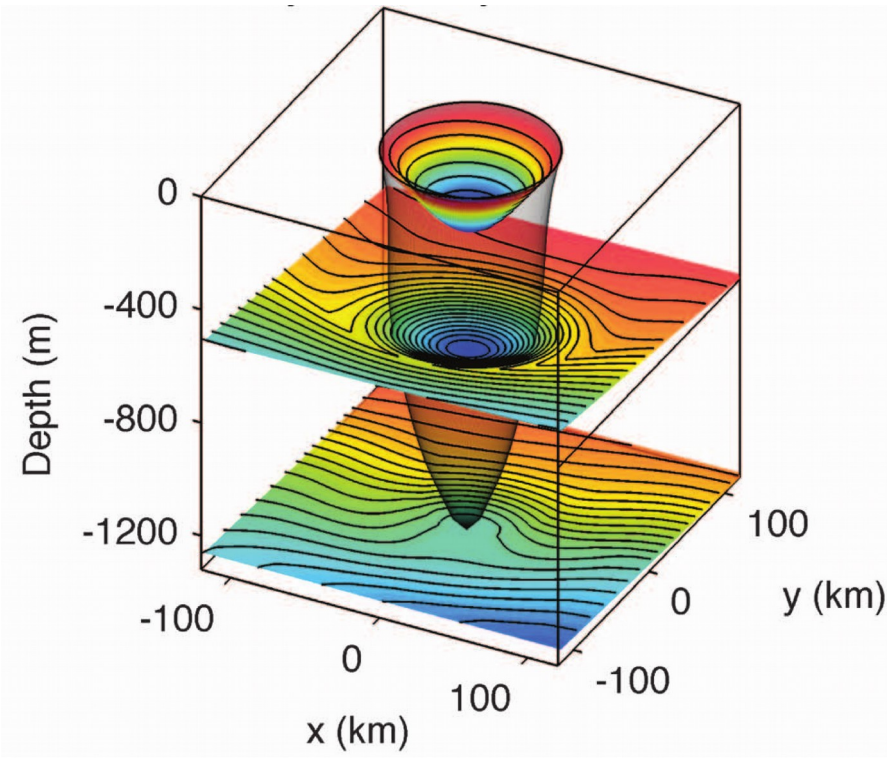
- ➔**How much** and **how far** Agulhas water is transported by the eddy?
- ➔**Where** do exchanges occur?

Reconstruct **volume** trapped within the Agulhas ring:

- ➔Satellite provides only surface information (eddy center)
- ➔3D structure reconstructed using Argo data

Eddy associated with a pressure anomaly

It can be approximated by a depth-varying Gaussian shape



(from Zhang et al., 2014)

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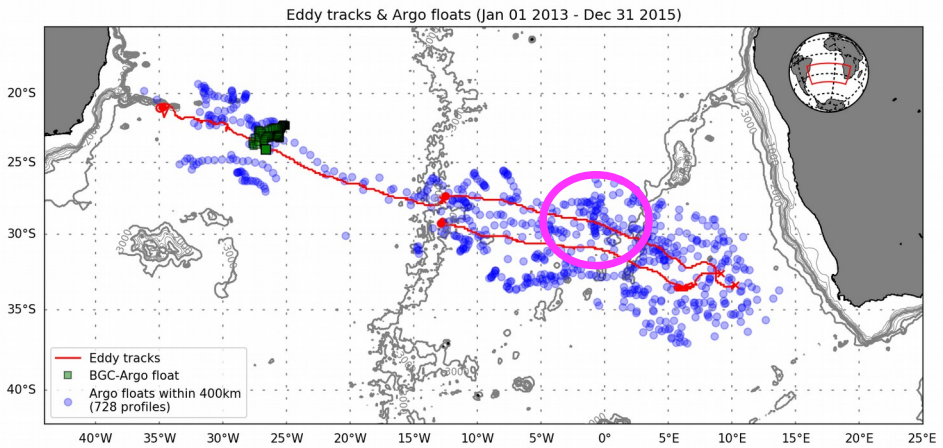

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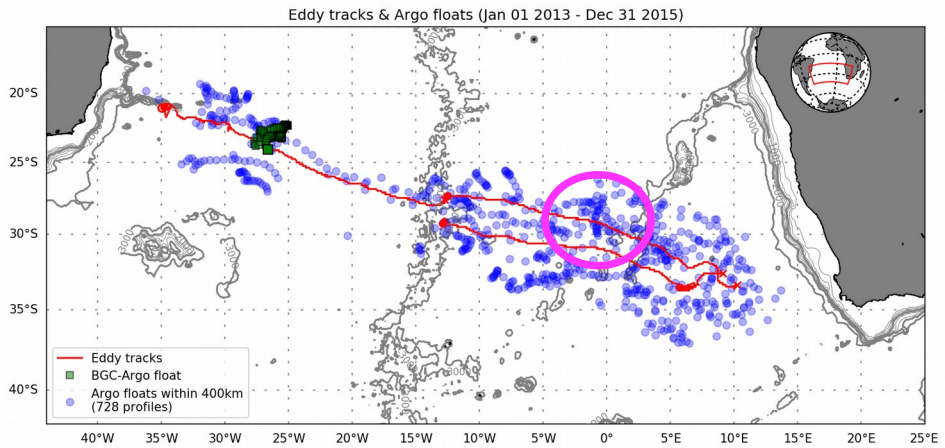

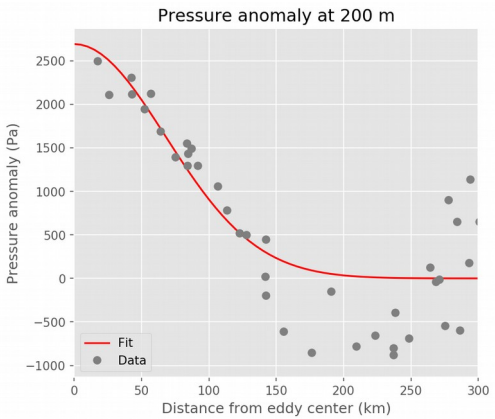

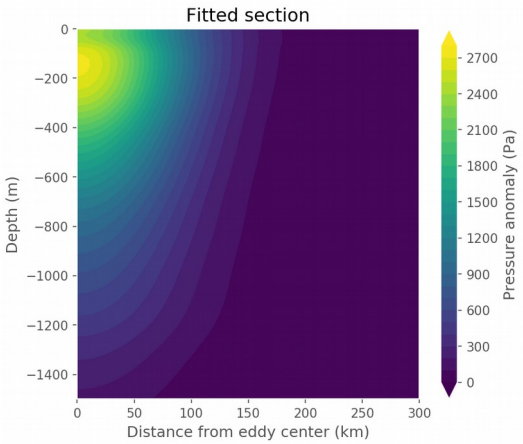

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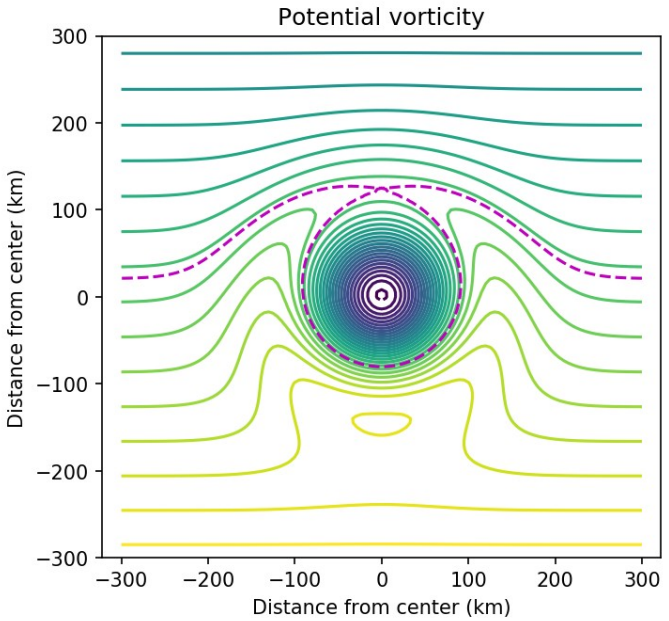
4. Define **eddy boundaries** at each depth based on **absolute vorticity**



$$v_\theta = \frac{1}{\rho f}\frac{\partial P}{\partial r} \Rightarrow \zeta = \frac{v_\theta}{r} + \frac{\partial v_\theta}{\partial r} \Rightarrow \eta = (f + \zeta)$$

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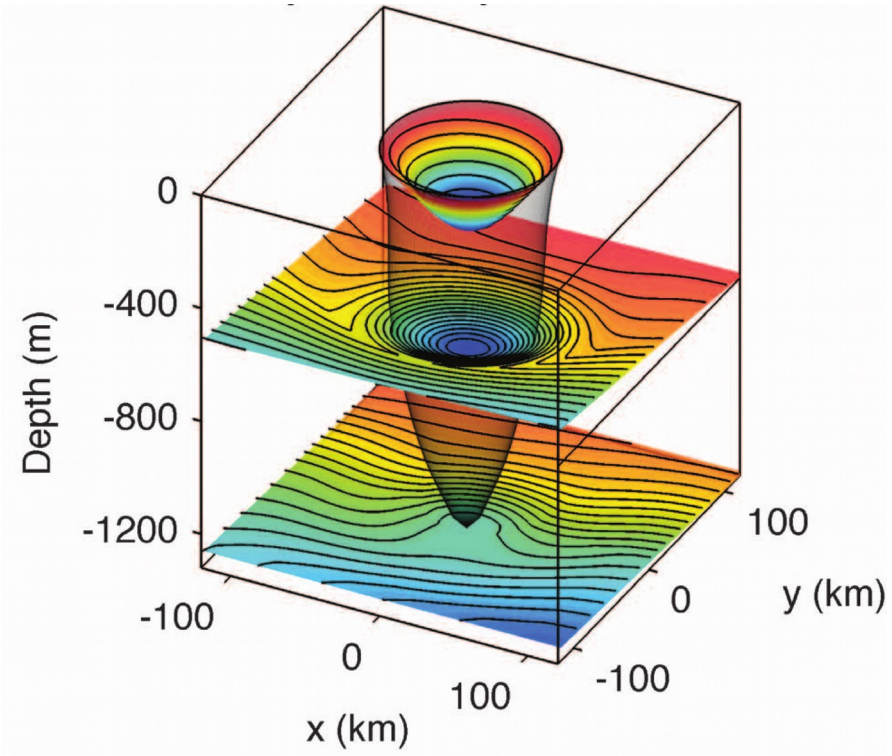
4. Define **eddy boundaries** at each depth based on **absolute vorticity**
5. Compute the **total eddy volume** by integrating the resulting volumes at each depth

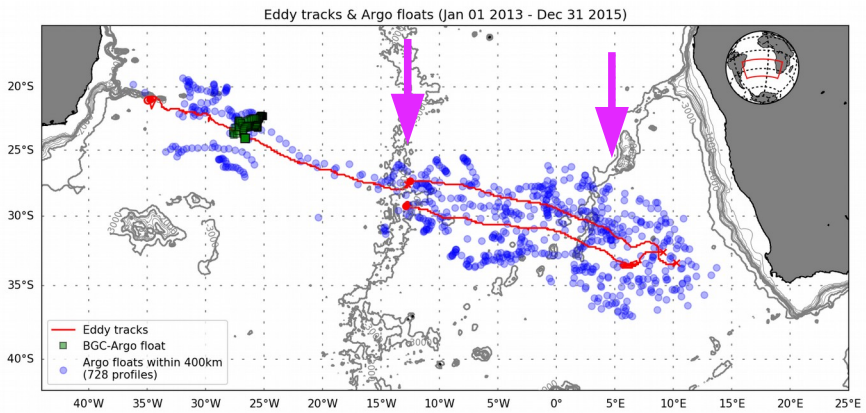


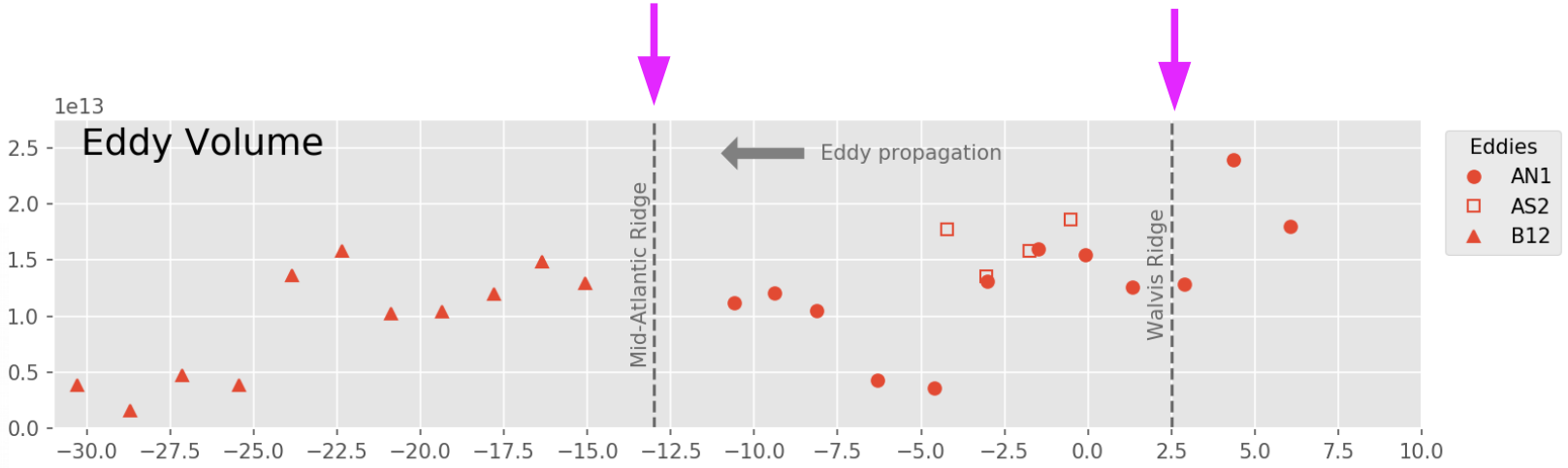
(from Zhang et al., 2014)

Results 1: Agulhas ring transport and exchanges

Time series of eddy volume

(Gaussian fit at various succesive months completely automated and unsupervised)





Results 1: Agulhas ring transport and exchanges

Time series of eddy volume

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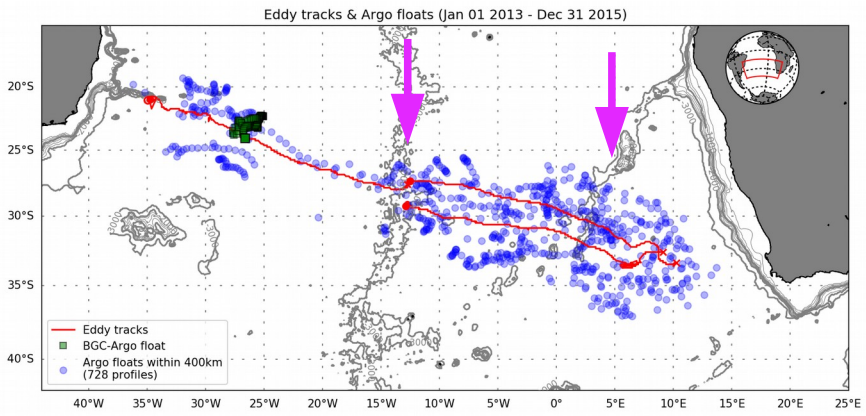

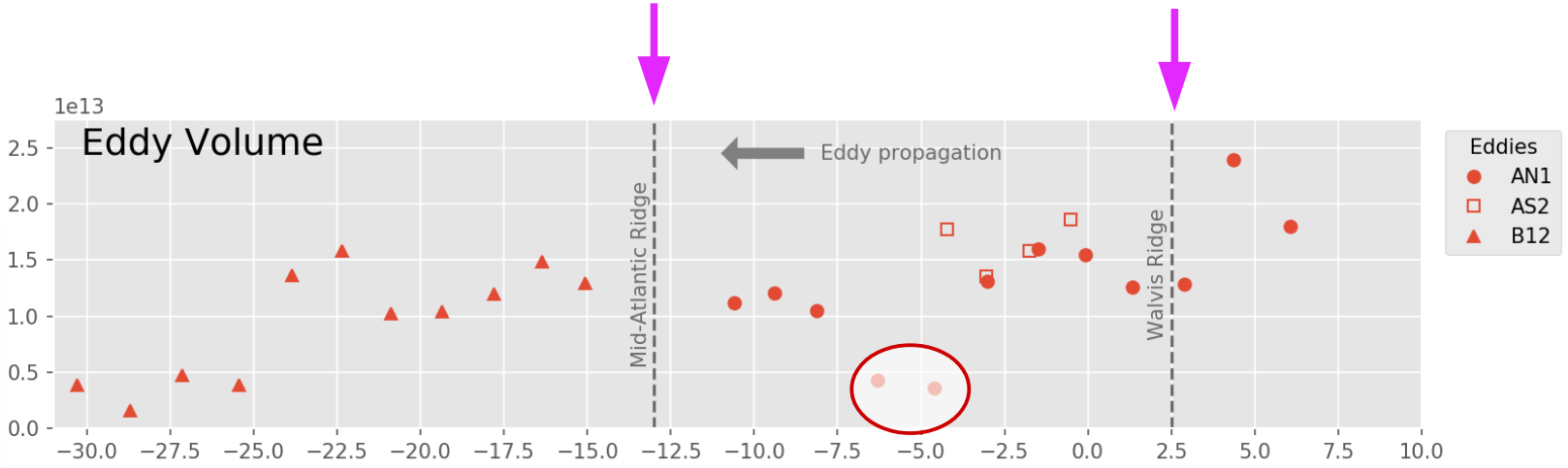

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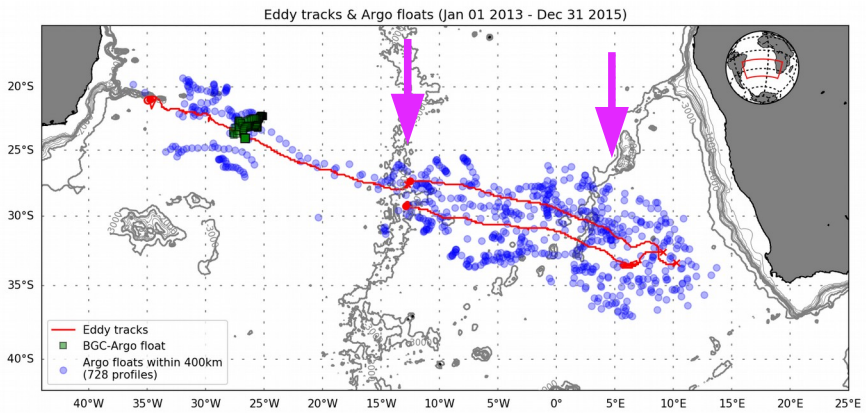

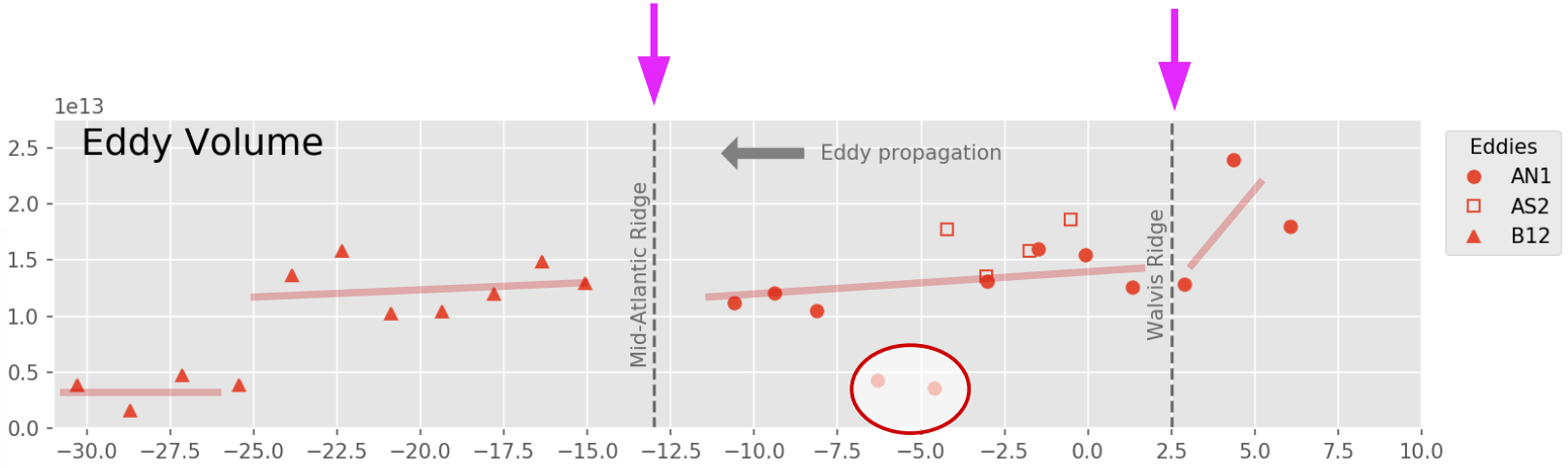

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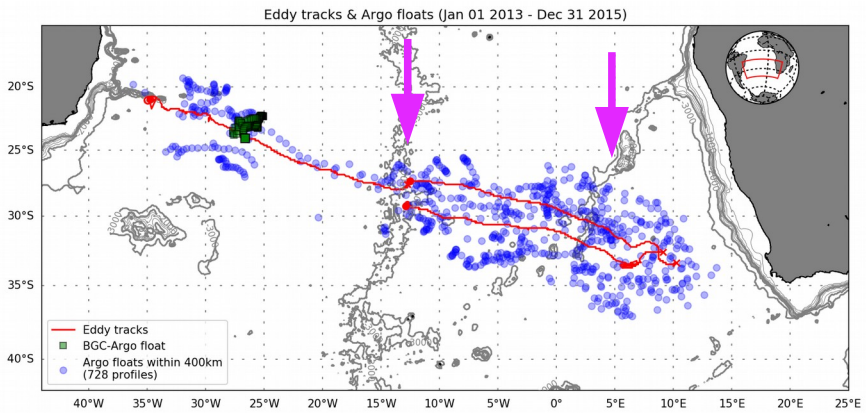

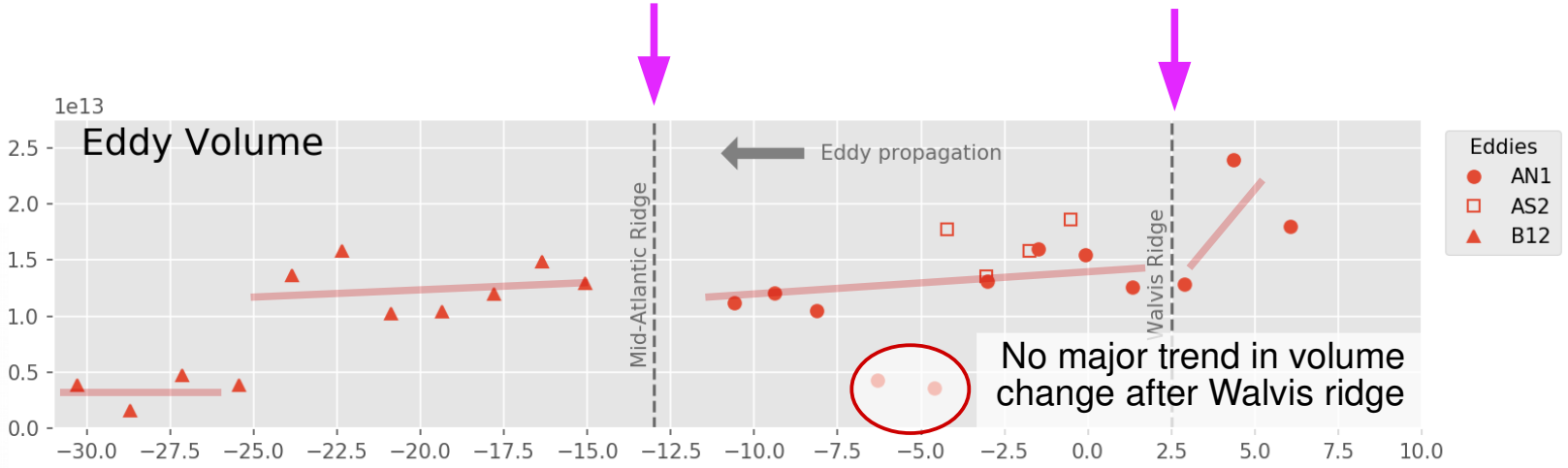

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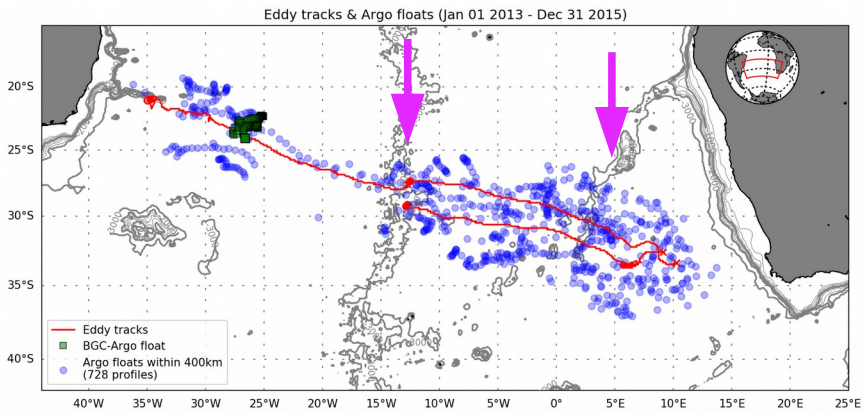

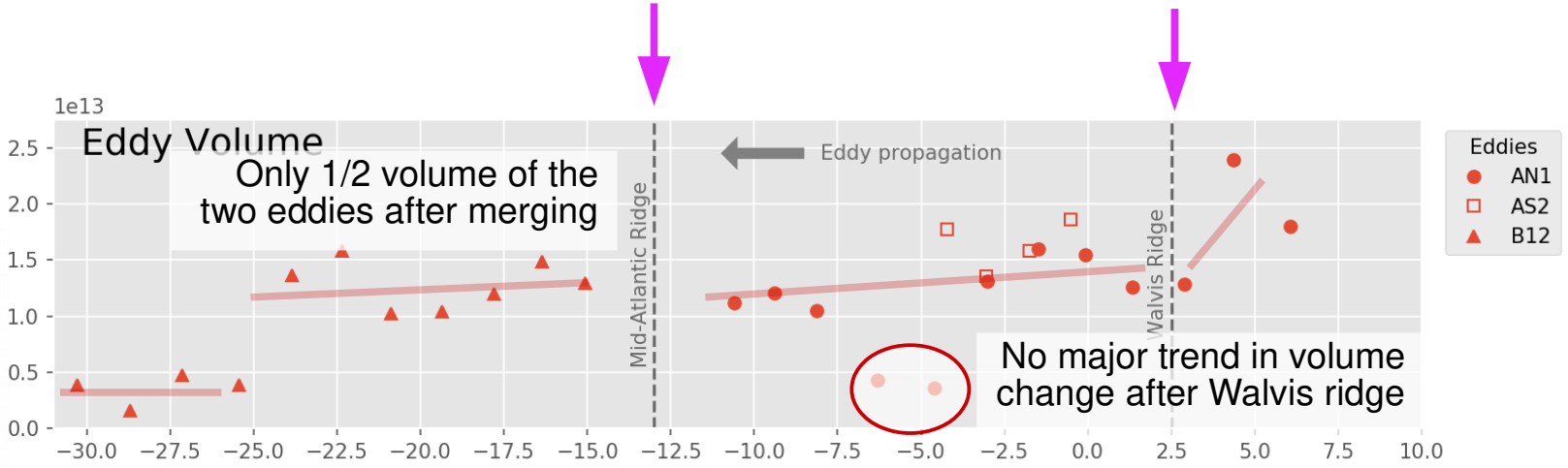

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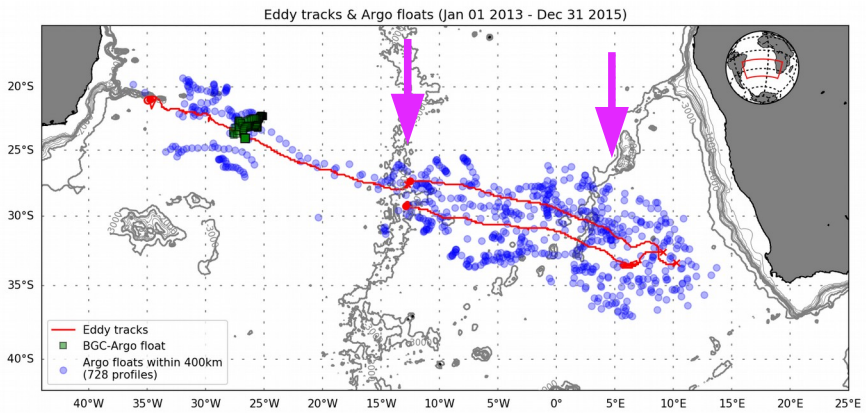

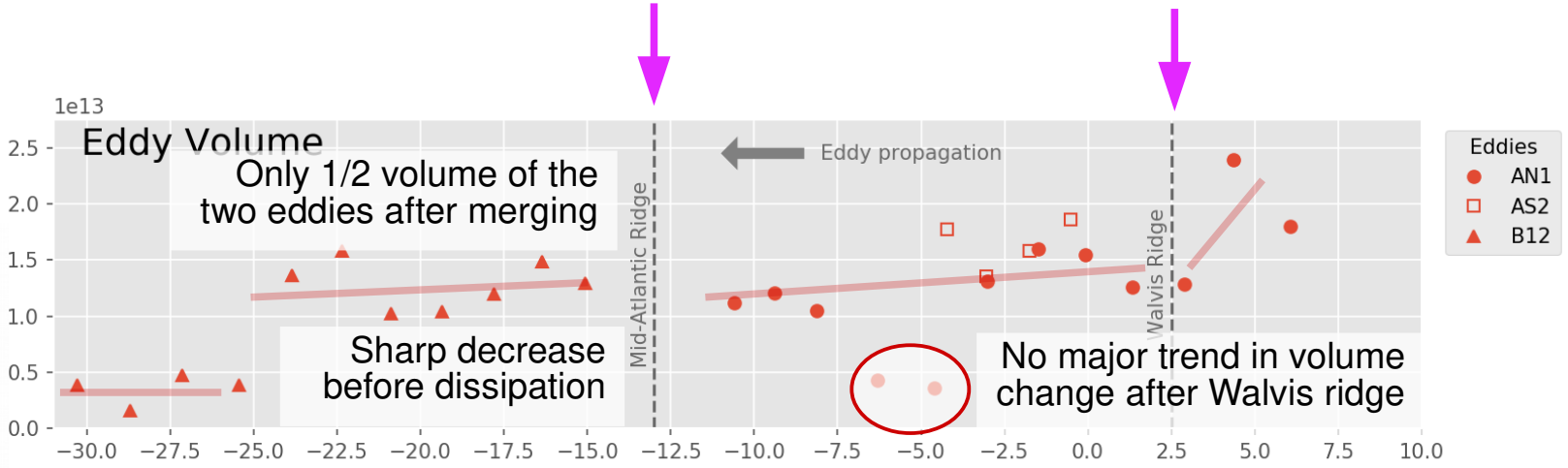

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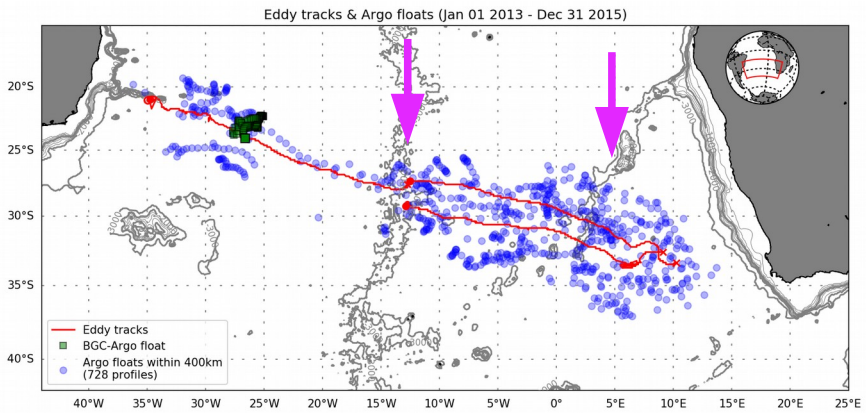

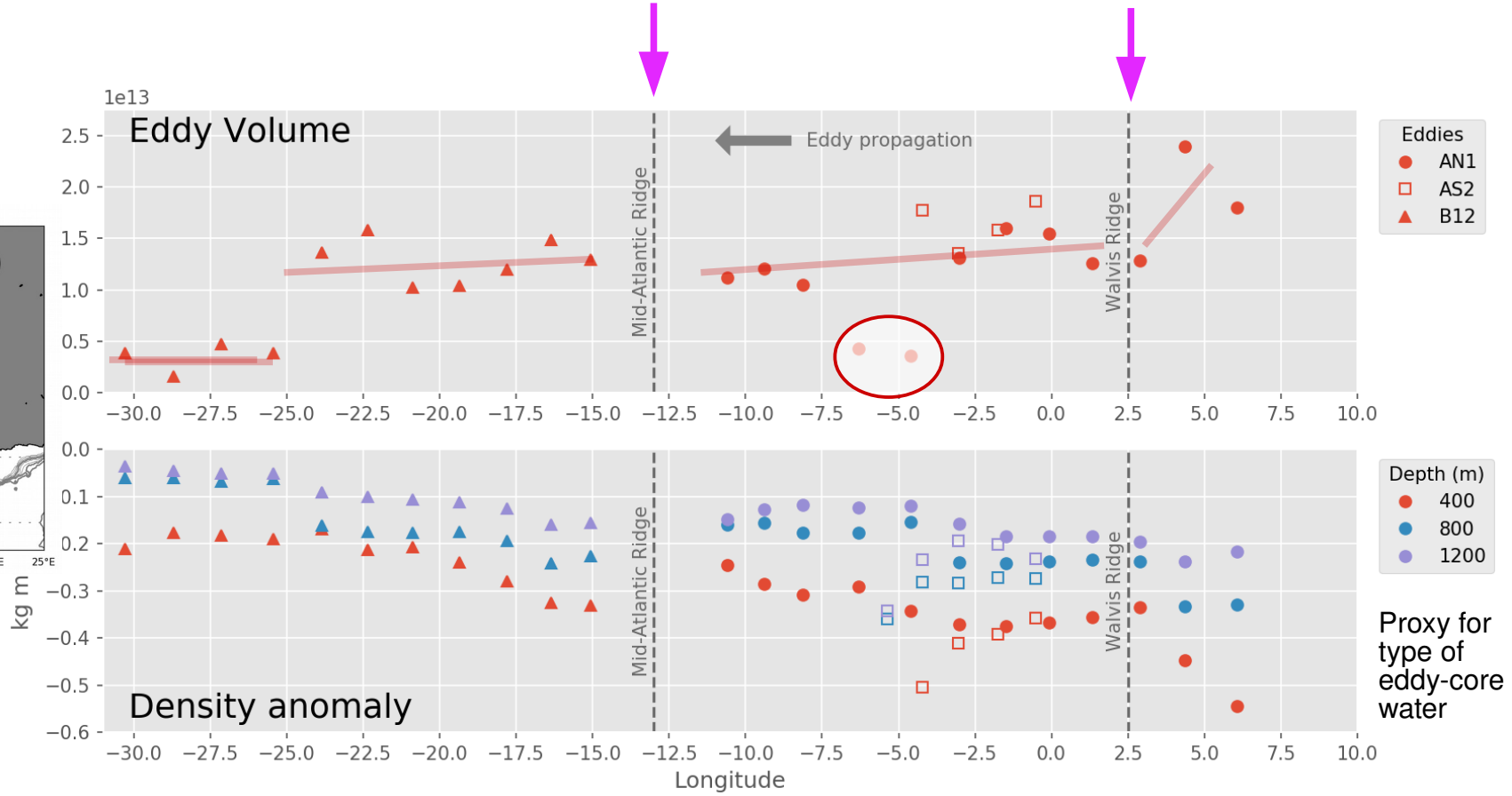

Proxy for type of eddy-core water

Results 1: Agulhas ring transport and exchanges

Time series of eddy volume

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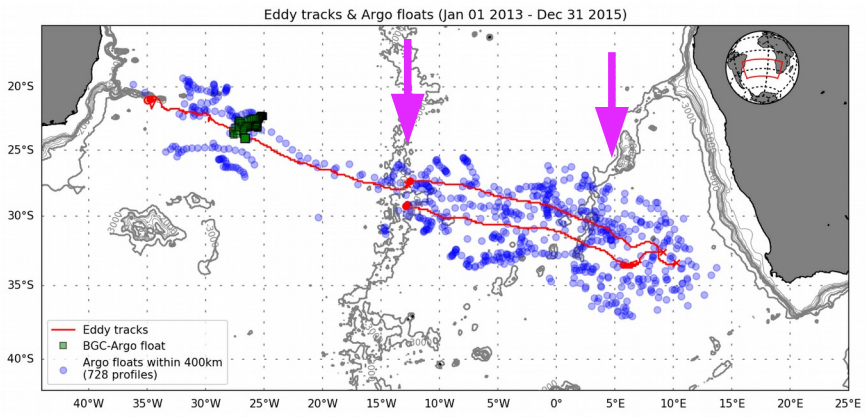

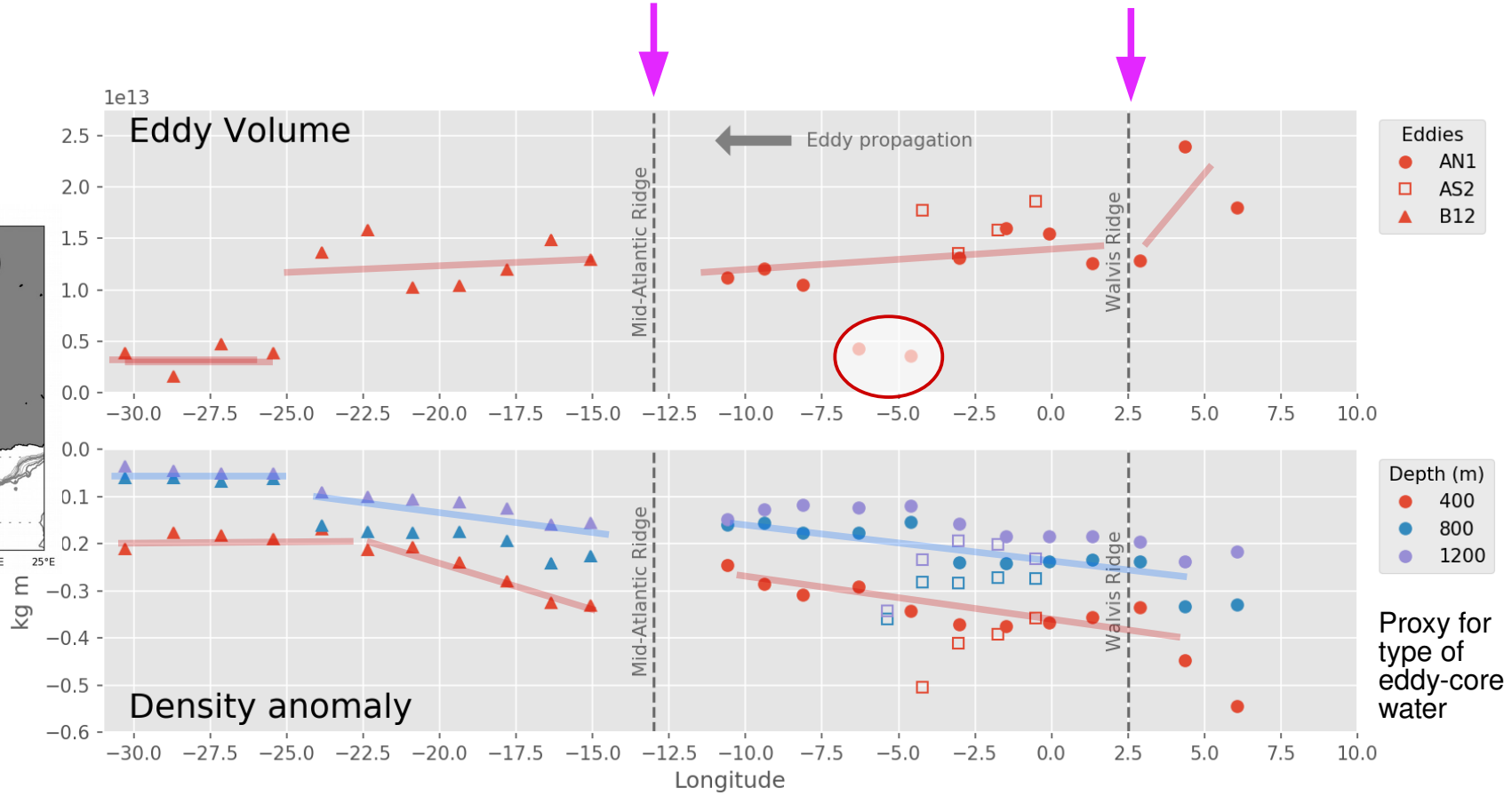

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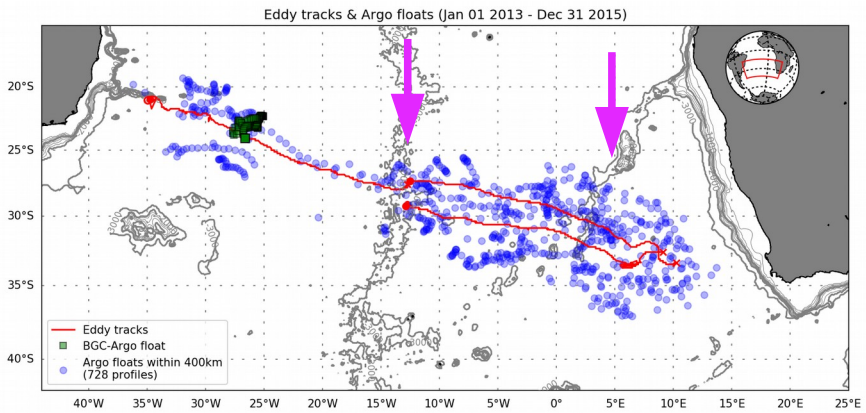

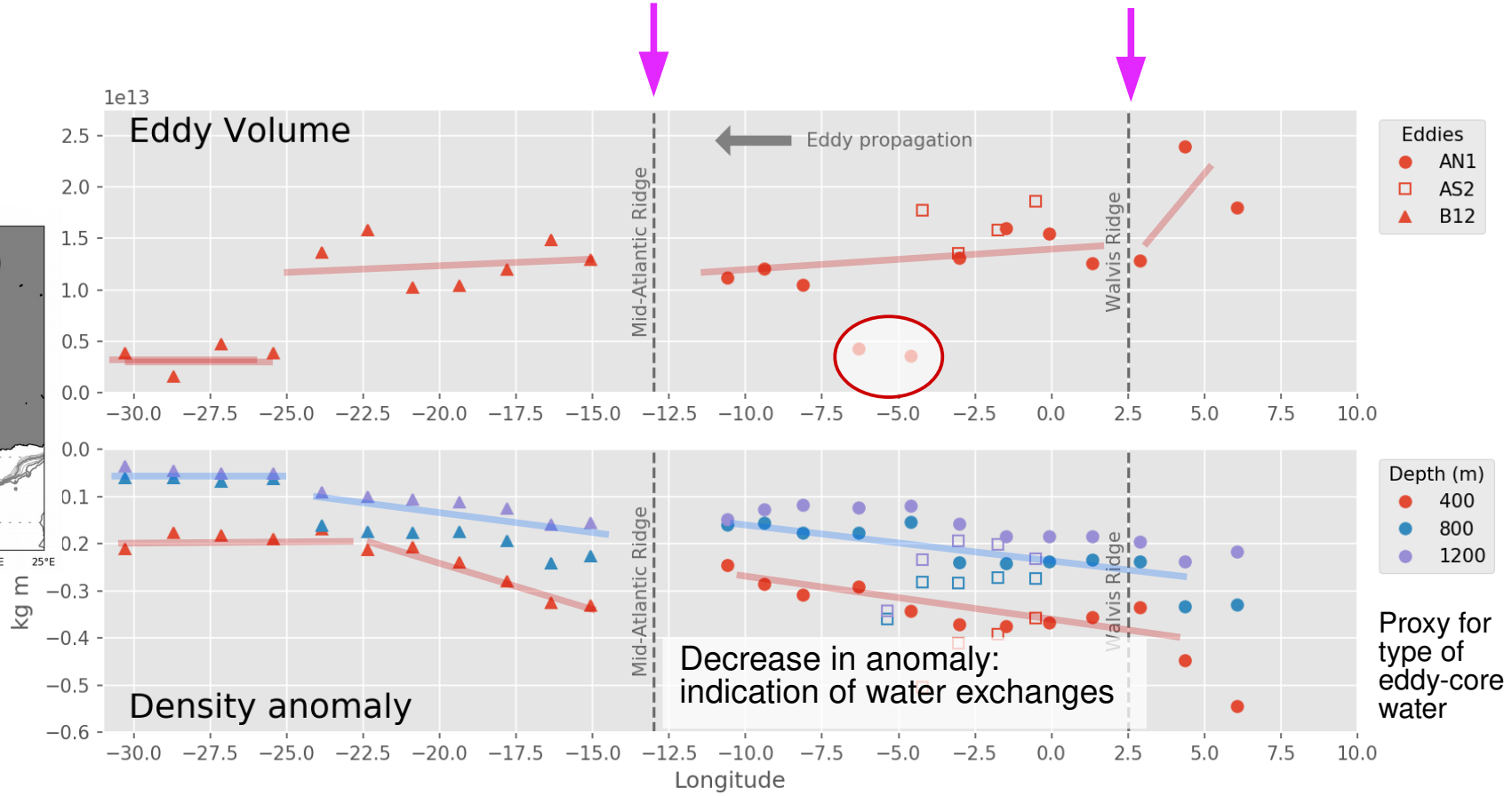

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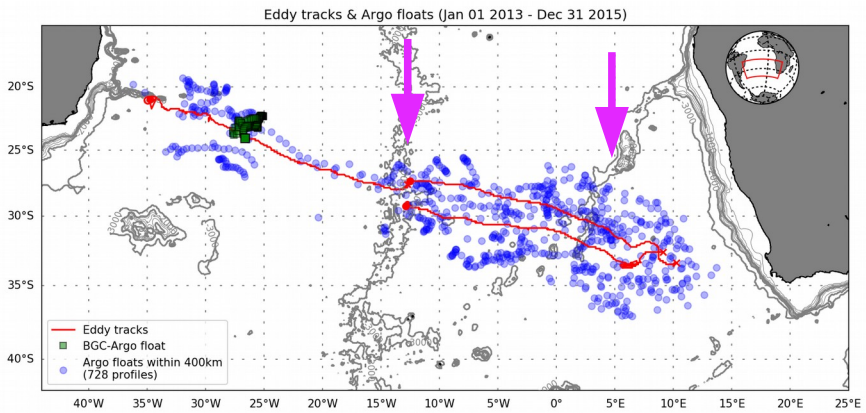
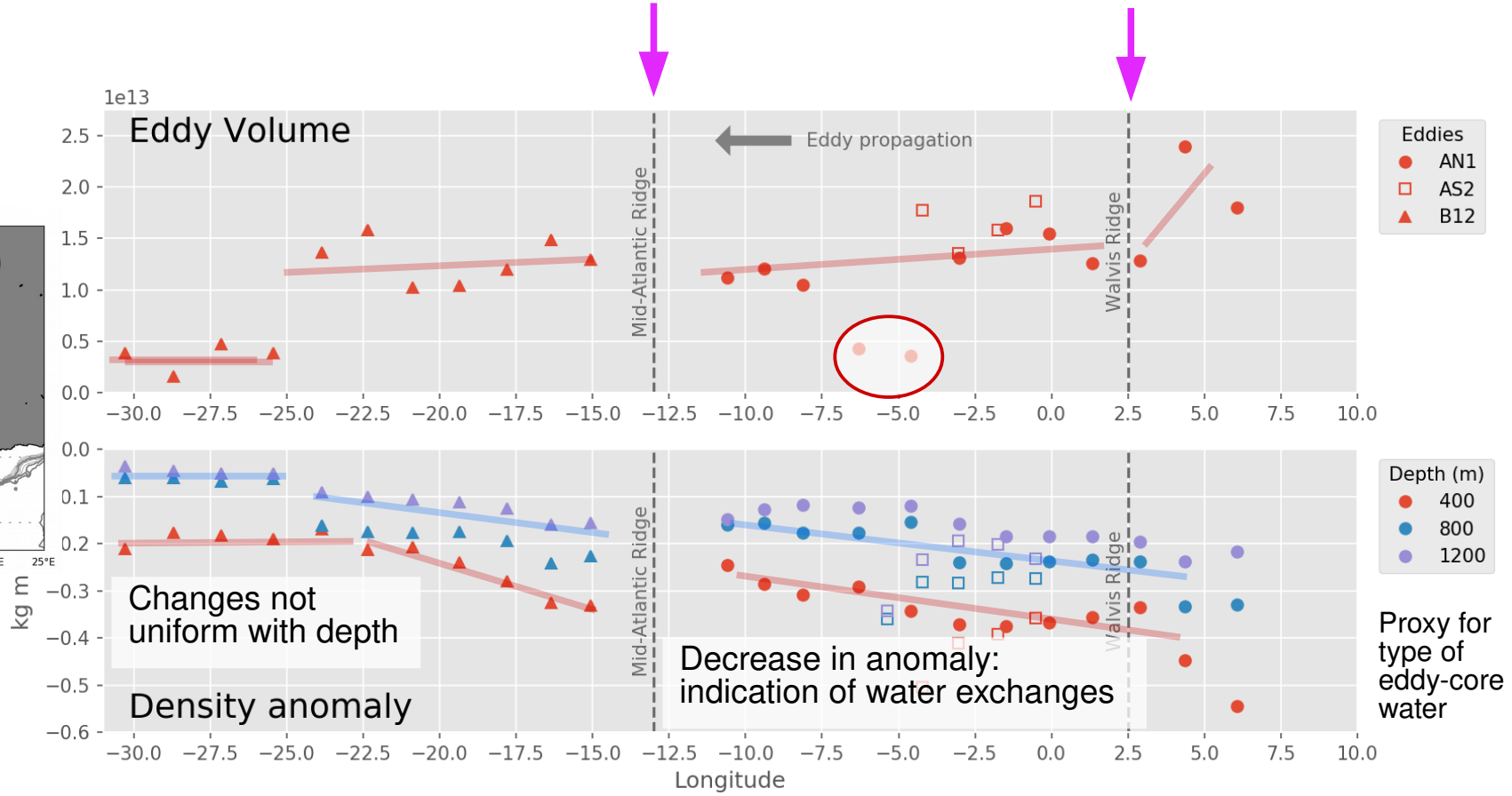




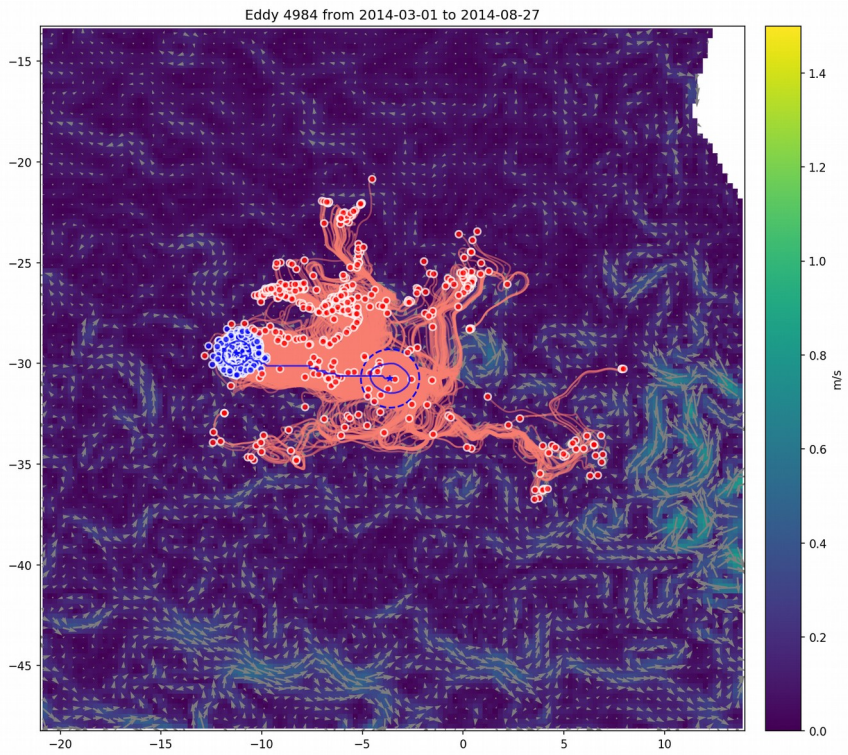
Proxy for type of eddy-core water

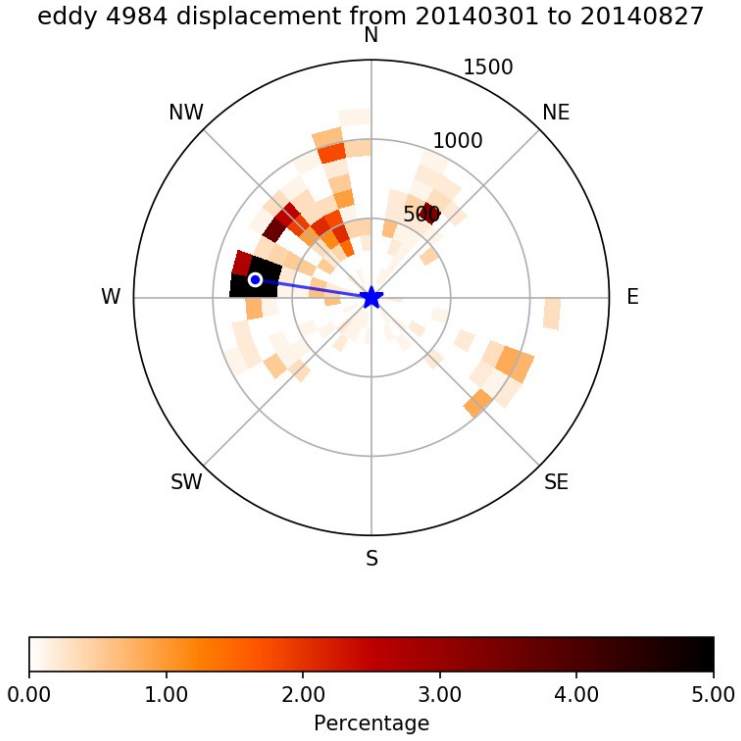
Objective 2: Fate of exchanged waters

➔**Where** do the exchanged waters go?

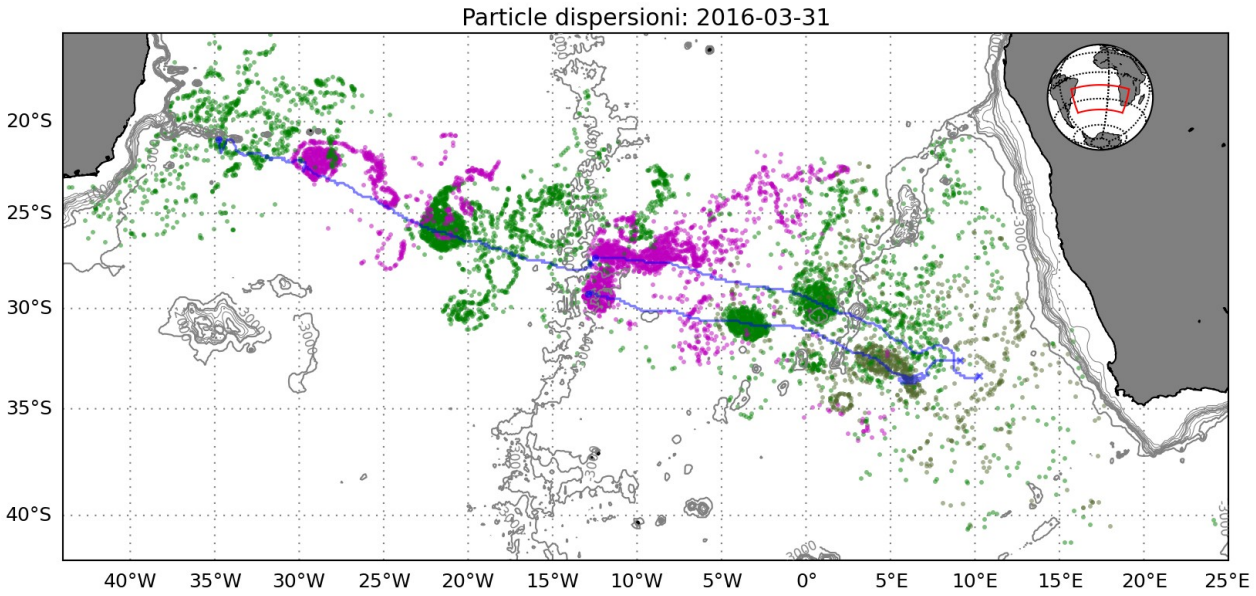
Lagrangian Analysis

- Each month **particles deployed within 150 km** from eddy center
- **Advected for 6 months**: AVISO velocity field + RK4 advection scheme
- Investigate **final dispersion patterns**



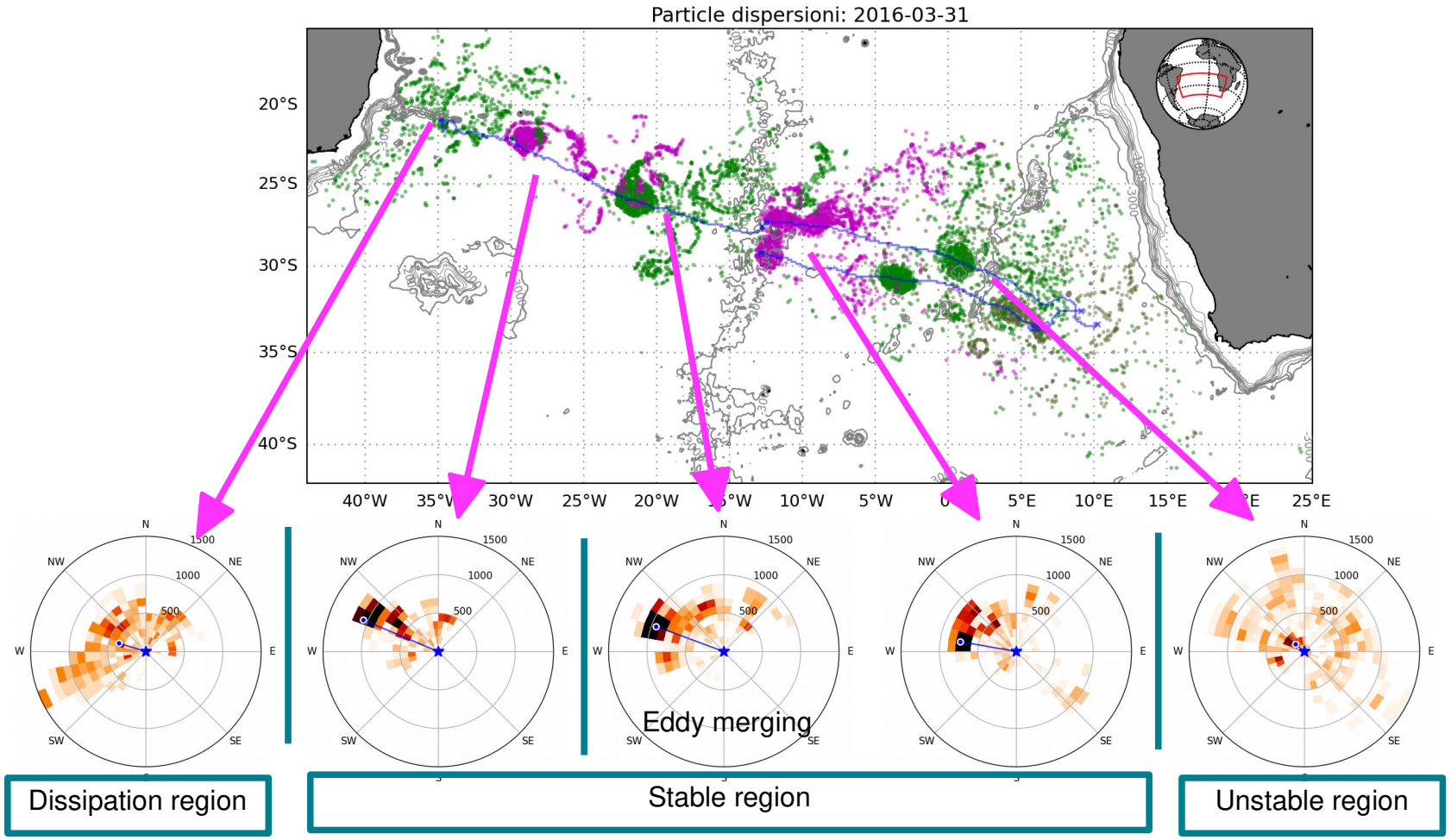


Results 2: Fate of exchanged waters



hhttps://youtu.be/_WkTloTrxUQ

Results 2: Fate of exchanged waters



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Nencioli et al., JGR-Oceans, 2018; doi: 10.1029/2018JC013909

Conclusions

- Eddy most efficient mechanism for westward transport (~0.5 10^{13} m^3 west of 30W)
- Major volume losses due to ridge interaction
  (~0.5 10^{13} m^3 lost at Walvis Ridge; and ~1.0 10^{13} m^3 lost at Mid-Atlantic Ridge)
- Volume almost entirely conserved within ridges
- However, constant exchanges with eddy core (diffusive-like processes)
- Water exchanges not uniform with depth (largest volume losses at depth)
- After mid-atlantic ridge (eddy merging) exchanged water keeps contributing to AMOC

Open questions

- What is the fate of the exchanged water at depth?
- How much heat and salt transport?
- How representative are the 3 observed eddies?