Shallow and Deep Eastern Boundary Currents in the South Atlantic at 34.5°S: Mean structure and variability

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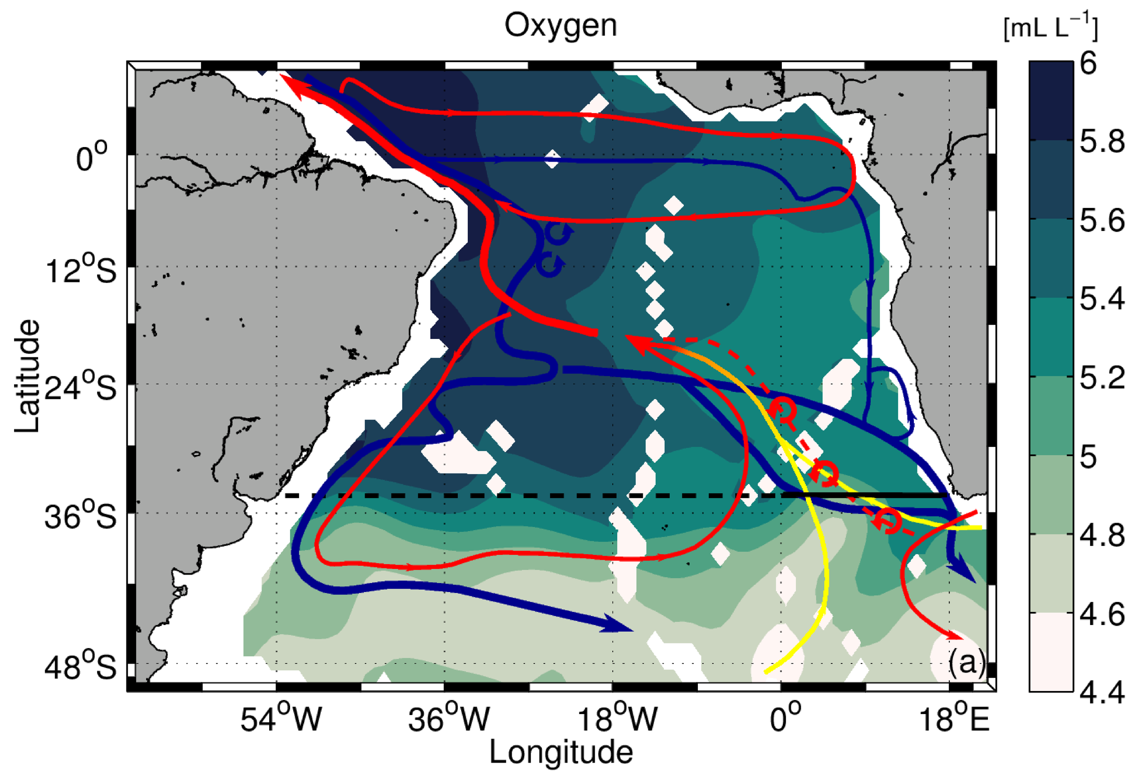
The Eastern Boundary Currents

- **The Eastern Boundary Currents (EBCs)** in the South Atlantic carry components of the **Meridional Overturning Circulation (MOC)** → Temporal and spatial variability affect the meridional heat and salt transports→ **Global climate system**
- **34.5°S** - Crucial latitude to understand the **MOC variability** and the impact of **inter-ocean exchanges**
- **Eastern part of the S**outh **A**tlantic **M**OC **B**asin-wide **A**rray (SAMBA) - **SAMBA-East**
- **The upper-EBCs** main gateway for surface and intermediate **Indian/Pacific waters → South Atlantic Ocean**
- **Southward flowing deep-EBCs**; **Origins:** branch of cold and salty waters coming from the basin interior, and/or a local deep re-circulation in the Cape Basin (*e.g.*, Arhan et al., 2003; Garzoli et al., 2015)



Schematic of the MOC
Oxygen concentrations (mL L^{-1}) [WOA annual climatology]

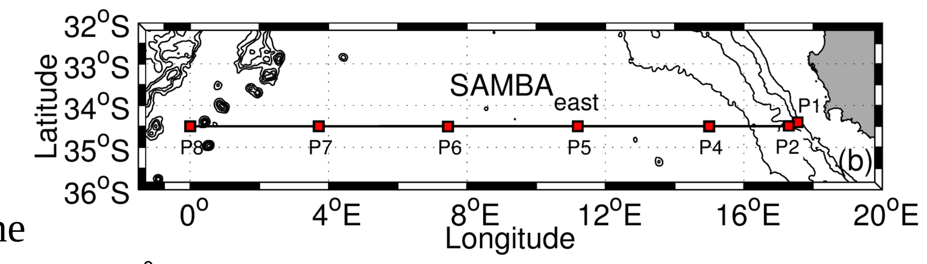
Objectives

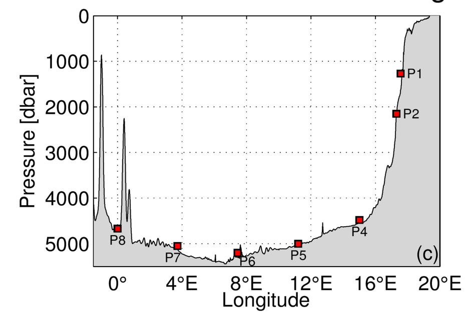
- Evaluate the **mean structure of the EBCs, the water mass properties** carried by these currents, and the associated **volume transport variability**
- **Comparison to other** available ***in situ* data sets** as well as to the output from an **ocean general circulation model**
- EBC flow **variability** on time scales ranging from a **few days to a few months**
- **Possible causes** for the largest observed upper and deep EBC variations

[Kersalé et al., 2018]

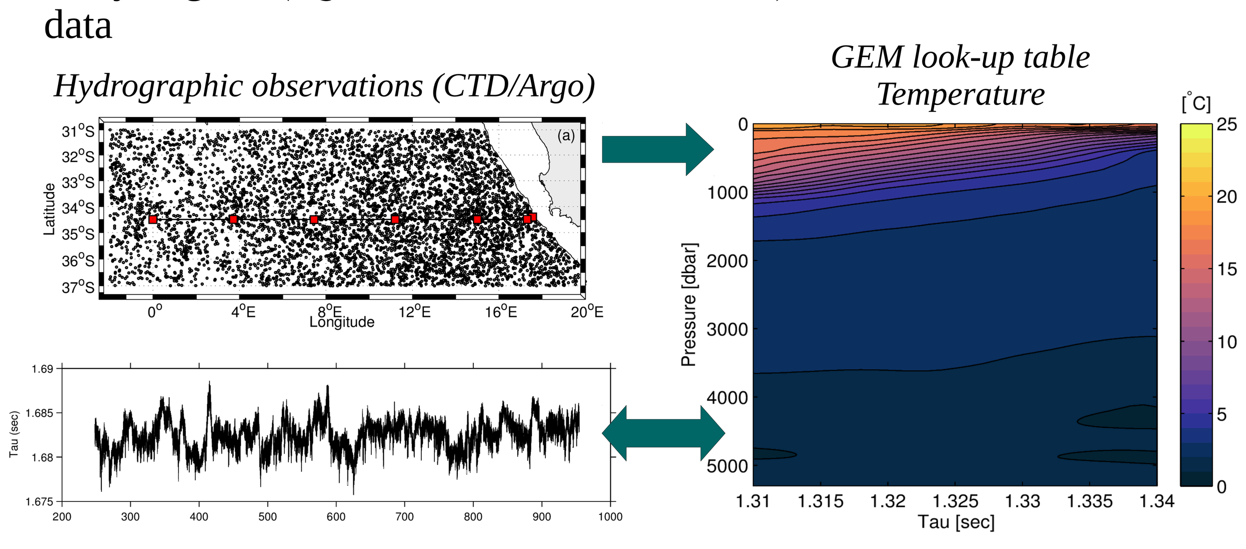
SAMBA-East CPIES measurements – GEM technique

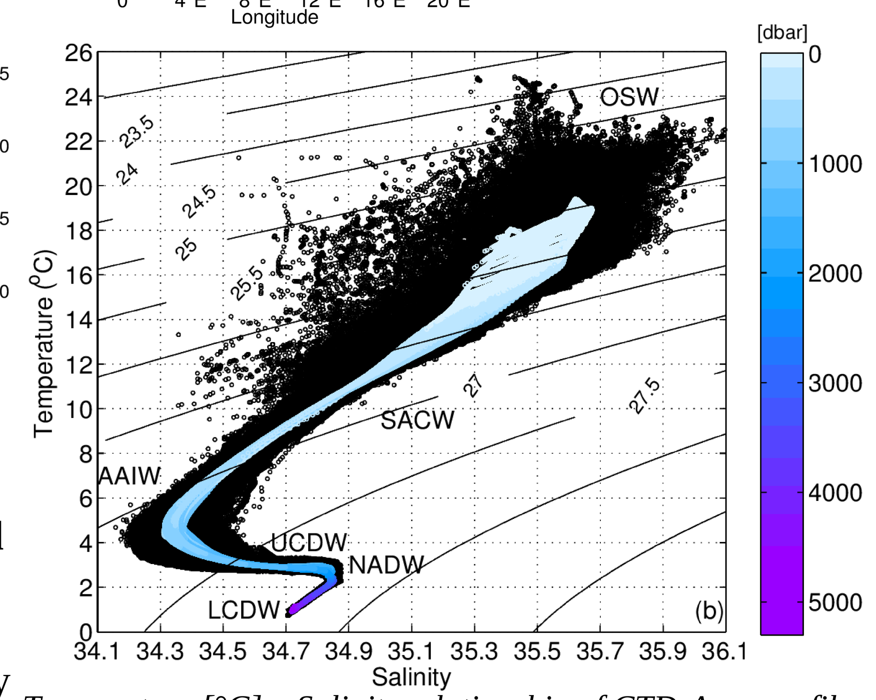
- First *in situ* **continuous full-water-column observations** of the EBCs at 34.5°S from September 2013 to July 2015 (**23 months**) from a line of seven **C**urrent and **P**ressure recording **I**nverted **E**cho **S**ounders (**CPIES**s) spanning the **Cape Basin**
- A **CPIES** measures **the current velocity** 50 m above the **bottom,** the **bottom pressure**, and **the round-trip time (tau)** for an **acoustic signal** to travel vertically from the bottom to the sea surface and back
- **Application** of the **G**ravest **E**mpirical **M**ode (**GEM**) technique for analyzing tau (*e.g.*, Meinen and Watts, 2000) to the SAMBA-East data





Horizontal and vertical positions of the CPIES





Temperature [°C] – Salinity relationship of CTD-Argo profiles (black dots) and PIES-GEM estimated fields (color shaded dots)

- Estimate the **full-water-column profiles of temperature, salinity, and density** → Quantify the **baroclinic** and **barotropic geostrophic flows**
- **Comparison of the T-S diagram**: GEM process has not created false water masses and contains all the structural features that are persistently and recurrently found in the region

Mean EBC structure and time variability

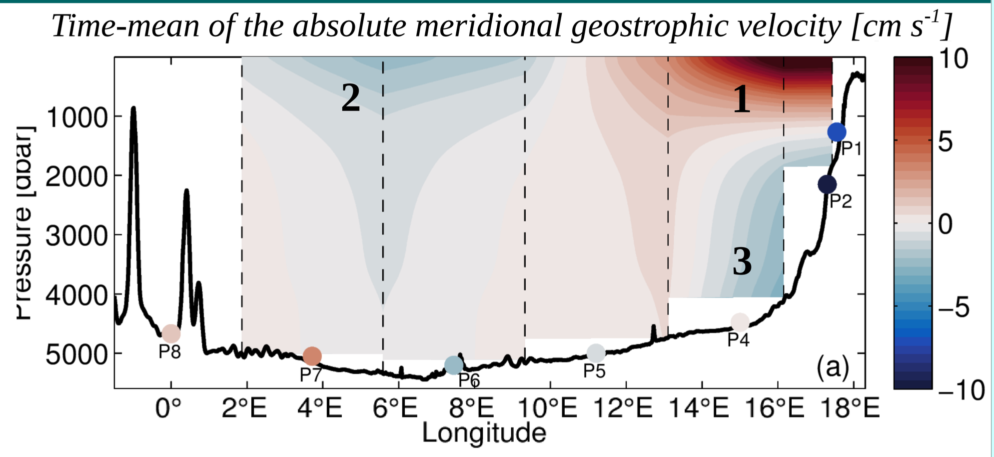
- **Time-mean** absolute geostrophic velocity **section** from the **CPIES** data at 34.5°S reveals:

  1- Benguela Current and a portion of the northward flowing **Cape Peninsula Jet** east of 11°E

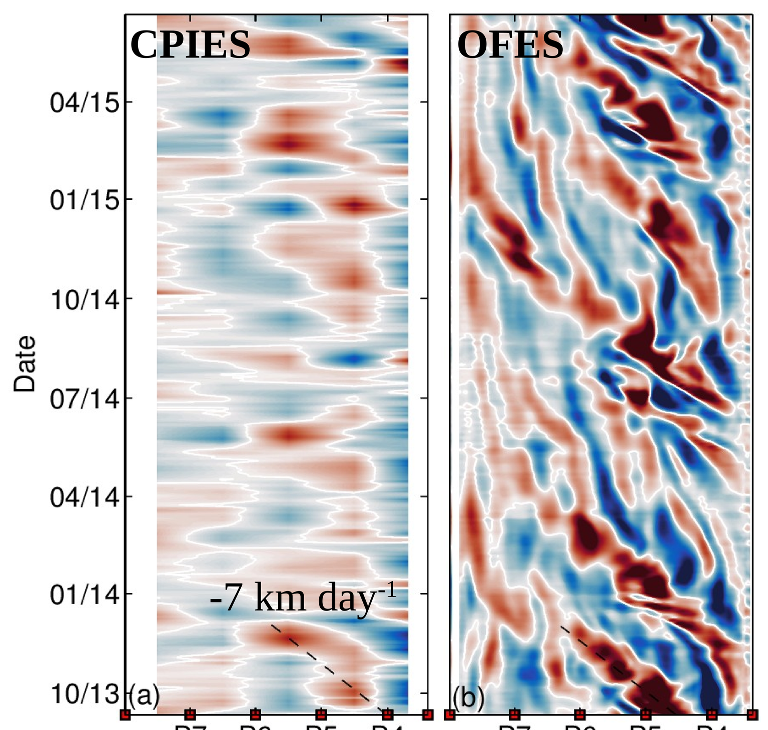
  2- Weak mean **southward current** influenced by transient **Agulhas Rings** west of 11°E

  3- Southward flowing deep-EBC adjacent to the slope associated with the presence of recently ventilated NADW water

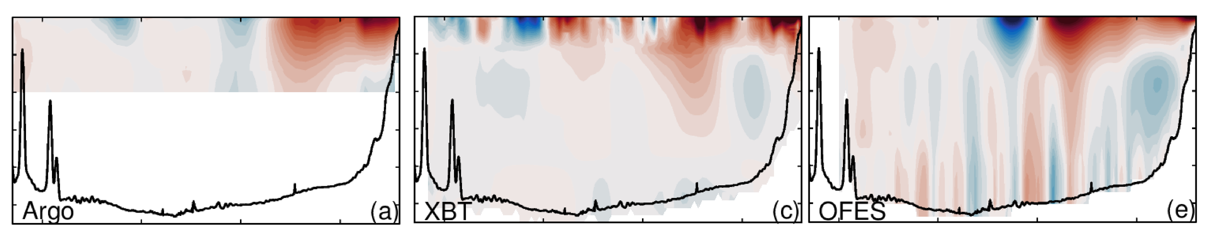
Time-mean of the absolute meridional geostrophic velocity [cm s^{-1}]



- **Similar** zonal and vertical mean structures from **Argo** and **XBT** products, and **OFES** model output with **finer horizontal scales**: two cores of the Benguela Current; offshore poleward surface flow; hints of deep-EBC



Hovmoller plots of meridional velocity at 2700 dbar



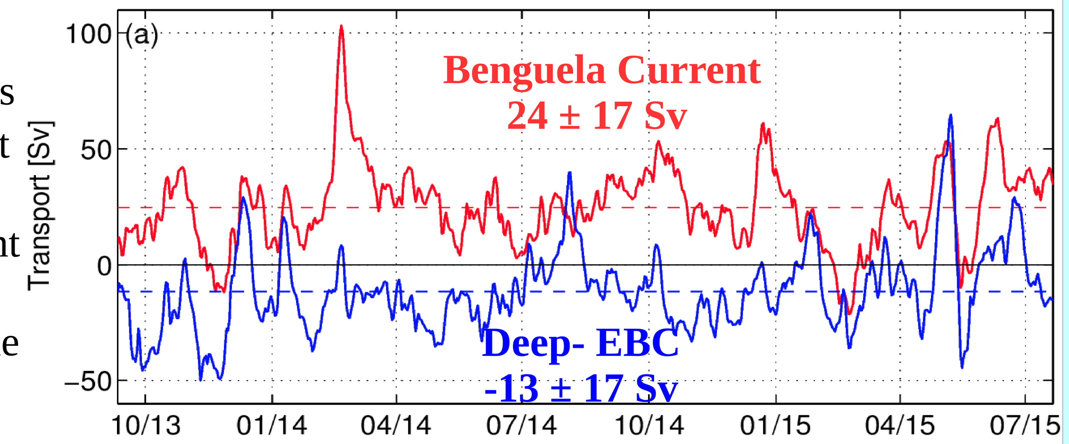
[Majumder and Schmid, 2018] *[Dong et al., 2014]* *[OFES - JAMSTEC]*

Dominant source of variability?

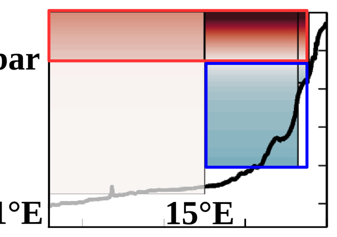
- Presence of **alternating bands of flow** associated with **Agulhas Rings** moving westward with **typical propagation speed of**
- Tendency to observe **strong southward flows** East of P4 at the times when Agulhas Rings are observed offshore
- Southward deep-EBC in the Cape Basin could be somewhat **intermittent,** and that variations in the DEBC flow might be **directly linked to the passing of Agulhas Rings** (van Sebille et al., 2012)

EBC Transport and Energy spectral distribution

- **Benguela Current** and **deep-EBC volume transports** demonstrate **strong variations** at a wide range of time scales
- **Robust relationship** between both time series **is not evident** (r=0.4)
- **Time-mean Benguela Current transport -** Good agreement from all data sets, model output and previous estimates
- **Strong variability** at high frequencies **is not captured** in the **other data sets**
- **Time-mean deep-EBC transport larger** than **historical estimate** (Arhan et al., 2003) and 54% larger than the model output → Presence of **recirculation cells**



Time series of absolute transport [Sv]



ARGO	25 ± 4	*n.a.*
XBT	26 ± 6	*n.a.*
OFES	21 ± 23	-7 ± 13

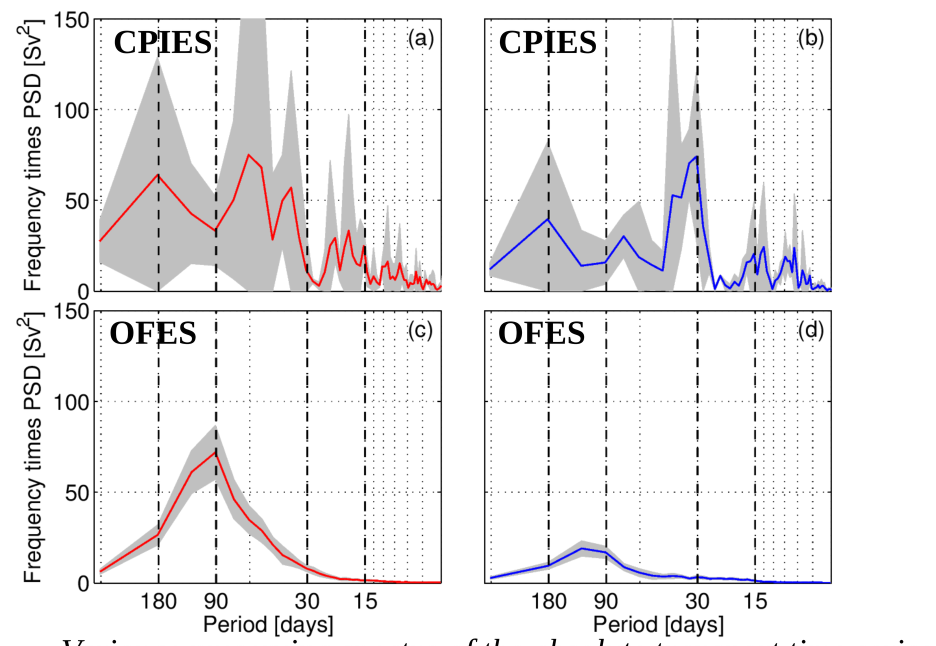
- **Spectral analysis** of the **Benguela Current** and **deep-EBC transport** time series from CPIES reveals:

  - 30 - 90 days: **Predominant variability** consistent with the propagation of **Agulhas Rings**

  - 180 days: Characteristic of **upwelling** time scale in the area; **Caution**: relatively short record (~2 years)

  - 2 - 15 days: Characteristic of poleward propagating **coastally-trapped waves** (typical period of 8.5 days)

- **Modeled** transport variability is **weaker** than the **observed at all time scales** except a peak at around 90 days in the upper part
- Consistent with Dong et al. (2014) - Artificially strong vertical density shear → **No transmition of energy to deeper levels**



Variance preserving spectra of the absolute transport time series

Conclusions

- First direct continuous *in situ* EBCs observations along 34.5°S over a 23 month period

  - CPIES data reveal the presence of the Benguela Current east of 11°E with a volume transport of **24 ± 17 Sv**
  - Time-mean transport **agrees** with other ***in situ*** data sets and **model** output **estimates**
  - **Daily observations** are essential to successfully resolve **the short time scale variability**

  - For the first time, the southward flowing **deep-EBC** is observed with a volume transport of **-13 ± 17 Sv**
  - **Presence support** by the direct deep **current meter** measurements and the OFES **model output**
  - **Recently ventilated NADW water** at the location of the deep-EBC consistent with an **interior pathway**

- Spectral analysis of the **Benguela Current** and **deep-EBC transport time series** reveals the predominant variability is at time scales between **30 and 90 days**, consistent with the expected time scales associated with the propagation of Agulhas Rings
- **Relative short records** length of the observation (**~23 months**) introduces **large uncertainties** at scales **larger** than **180 days**
- **Model output** must be used **with caution**, as the data suggests that the model is not allowing enough energy to penetrate to the deep ocean

Contribution of the EBCs to the MOC?

Historical **mean MOC** estimates at 34°S - 35°S → **14.7 − 18.4 Sv** (*e.g.*, Dong et al., 2014; Meinen et al., 2018)

22% of the lower MOC limb **feeds** the **deep-EBC** (Garzoli et al., 2015)

► Deep-EBC MOC transport ~ **-3.2 Sv − -4 Sv** // SAMBA-east deep-EBC transport ~ **-13 Sv**

► Significant portion of the observed deep-EBC must be recirculating within the Cape Basin rather than participating in the MOC

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Acknowledgments: The authors are very grateful to all the scientists, institutions, funding agencies, support from the NOAA Climate Variability Program (GC16-212) and research vessel crews from France, South Africa and United States involved in the SAMBA-East array