The fate of the Atlantic Deep Western Boundary Current

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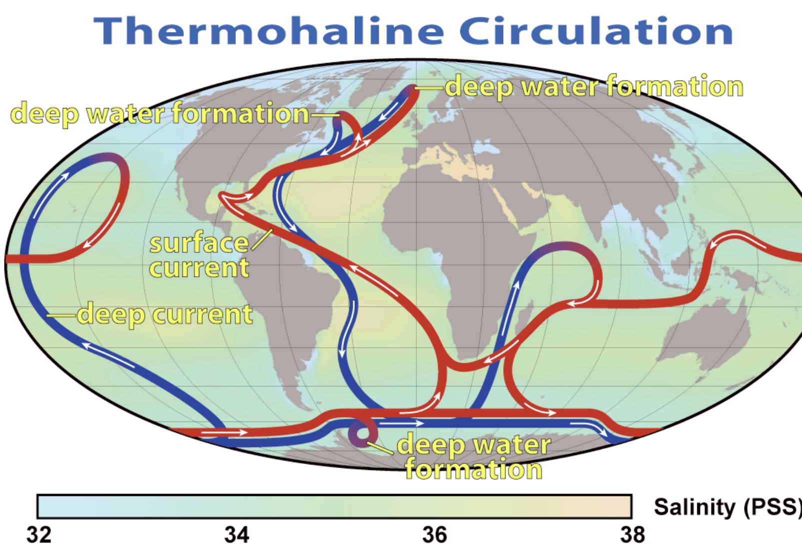
Motivation

The role of the Deep Western Boundary Current as a primary pathway for the cold, lower, limb of the Meridional Overturning Circulation has been well documented in the North Atlantic Ocean.

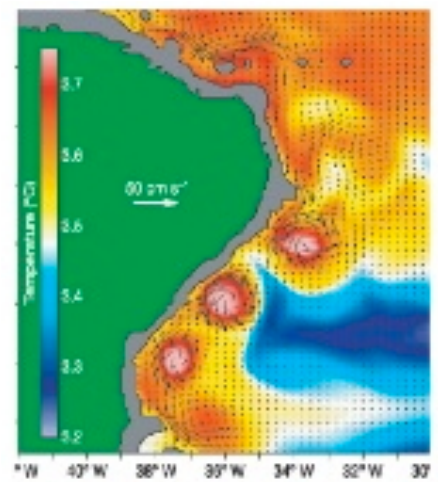


However the pathways and variability of the DWBC in the South Atlantic Ocean are less well known.

Near 8°S the DWBC appears to break up into rings as it flows southward

Break-up of the Atlantic deep western boundary current into eddies at 8° S
M. Dengler, F. A. Schott, C. Eden, P. Brandt, J. Fischer & R. J. Zantopp
Nature **432**, 1018-1020 (23 December 2004)

"…the Atlantic deep western boundary current breaks up at 8° S. Southward of this latitude, the transport of North Atlantic Deep Water into the South Atlantic Ocean is accomplished by migrating eddies, rather than by a continuous flow. Our model simulation indicates that **the deep western boundary current breaks up into eddies at the present intensity of meridional overturning circulation. For weaker overturning, continuation as a stable, laminar boundary flow seems possible**."

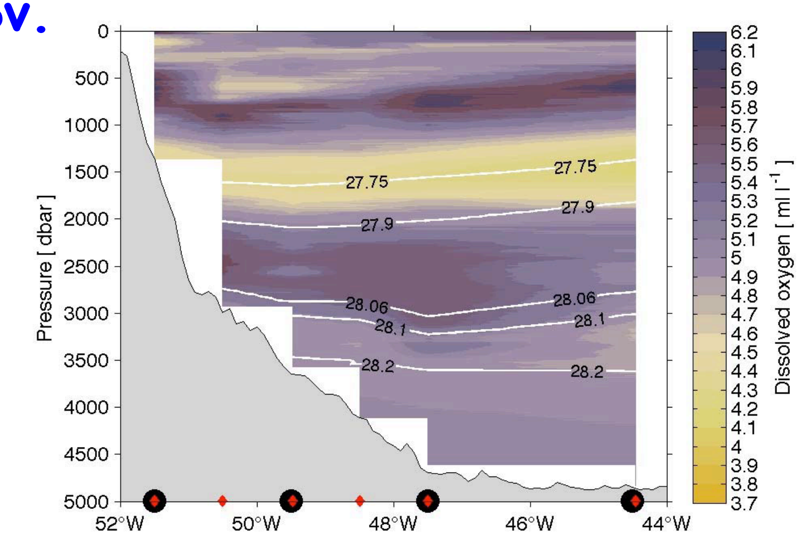


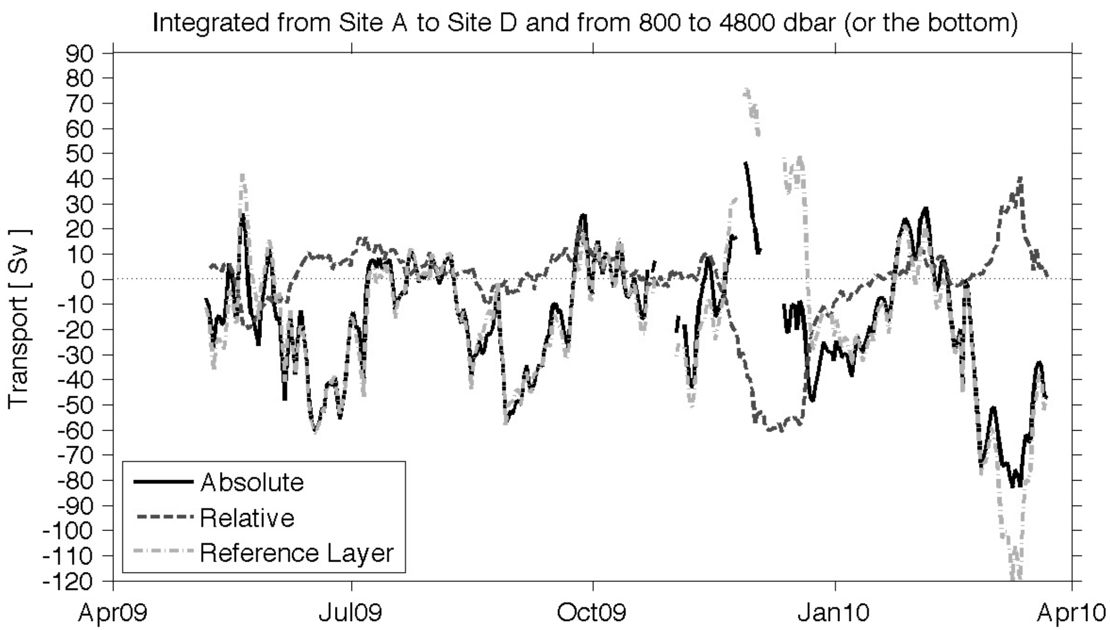
Flame 1/12°, 0 to 14S

The Shallow and Deep Western Boundary Circulation of the South Atlantic at 5°–11°S
Schott et al, 2005
"A mean DWBC exists at 5°S, while the situation is quite different **at 11°S, because the DWBC dissolves into a sequence of deep eddies between both latitudes**."

Preliminary results from a pilot array at 34.5°S shows the presence of NADW flowing southward, with a large variability and an estimated mean transport of 17 Sv.

Dissolved oxygen section collected along the PIES/CPIES line during July 7-11, 2010 on the Argentine research vessel Puerto Deseado. Red diamonds along bottom axis indicate locations of the CTD profiles, and black dots indicate the PIES/CPIES sites. White contours with labels indicate neutral density surfaces.

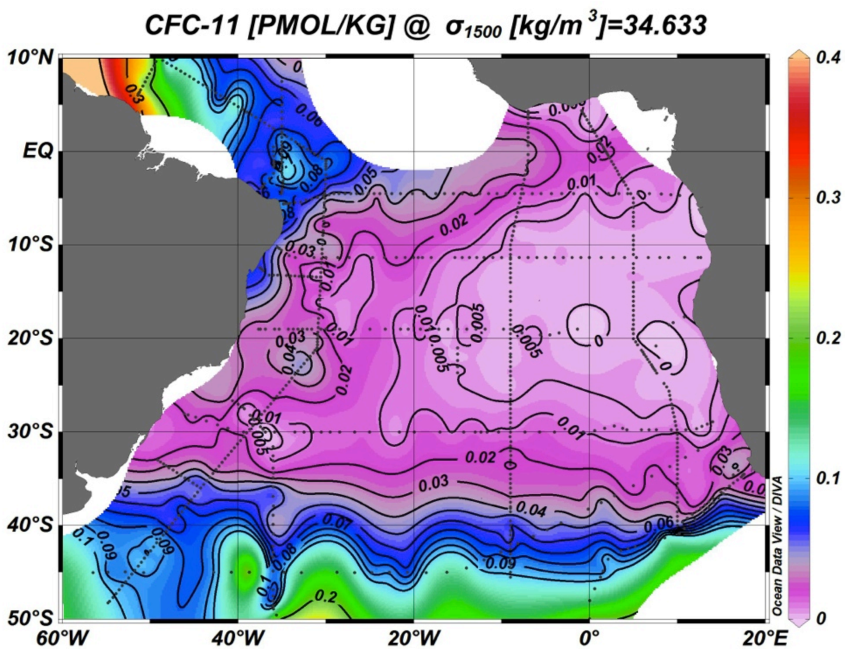


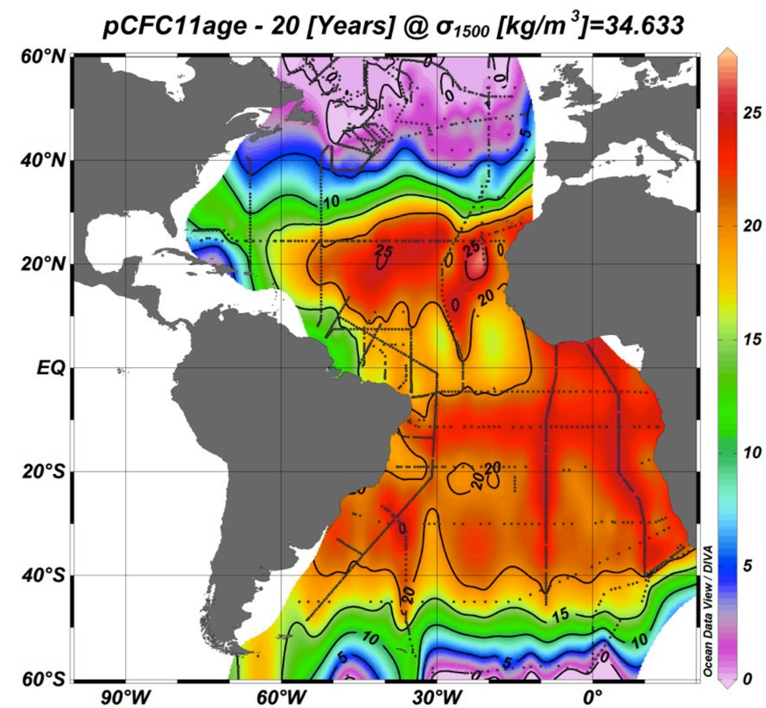


Absolute transport (black line) integrated across the entire SAM array within the nominal DWBC layer (800–4800 dbar). Also shown are the components of the absolute transport associated with velocity relative to an assumed level of no motion at 800 dbar (dark gray dashed) and with the absolute velocity actually observed at the level of no motion reference layer (light gray dash-dot).

(*Meinen et al. 2012*)

Maps of CFC concentrations and age show LSW (~1700-2000 m) spreading eastward between 10° and 25°S.





Map CFC-11 concentrations on 34.633 $\sigma_{1.5}$ from WOCE era data 1992-1997 shows high concentrations of CFC-11 along the western boundary in the North Atlantic, along the equator, and into the South Atlantic at the western boundary. In the recent CLIVAR data (not shown), CFCs are observed southward to 25°S. However, on the WOCE era map, relatively high concentrations are found along the western boundary to only 12°S. There is a tongue of measurable CFC-11 concentration >0.005 pmol/kg (blank level) spreading eastward between 10°-20°S to nearly 10°W. **The eastward extent of measurable CFCs on the WOCE era map could be limited by the fact that waters with high CFC concentrations have not yet arrived further east, or they could be confined to the western basin by mid-Atlantic Ridge.**

Maps of CFC ages with relic age removed for Labrador Sea Water (LSW) shows youngest waters from the high latitude source regions have an effective equatorward spreading rate of 1-2 cm/sec along the western boundary, eastward along the equator and into the South Atlantic along the western boundary.

The OFES Lagrangian Experiment

- **Floats were released off line in the OFES model along a grid at 5°S** whenever the local instantaneous transport within the grid cell is southward.
- The grid spans the full width of the South Atlantic **between 1000 m and 3500 m** depth and has 100 m vertical spacing.
- For a total of **5 years**, one float was released **every 3 days**.
- The vast majority of these floats were within **the NADW layer**.
- Each float was assigned a transport equal to the volume flux (velocity times area) through the grid cell in which it started.
- After release, the floats were tracked with a fourth order Runge Kutta scheme using snapshots of the OFES velocity fields with 3-day resolution.
- Advection of a float was terminated when the float rose above 500 m depth or when the float left the region north of 5°S, south of 45°S, or east of 17°E.

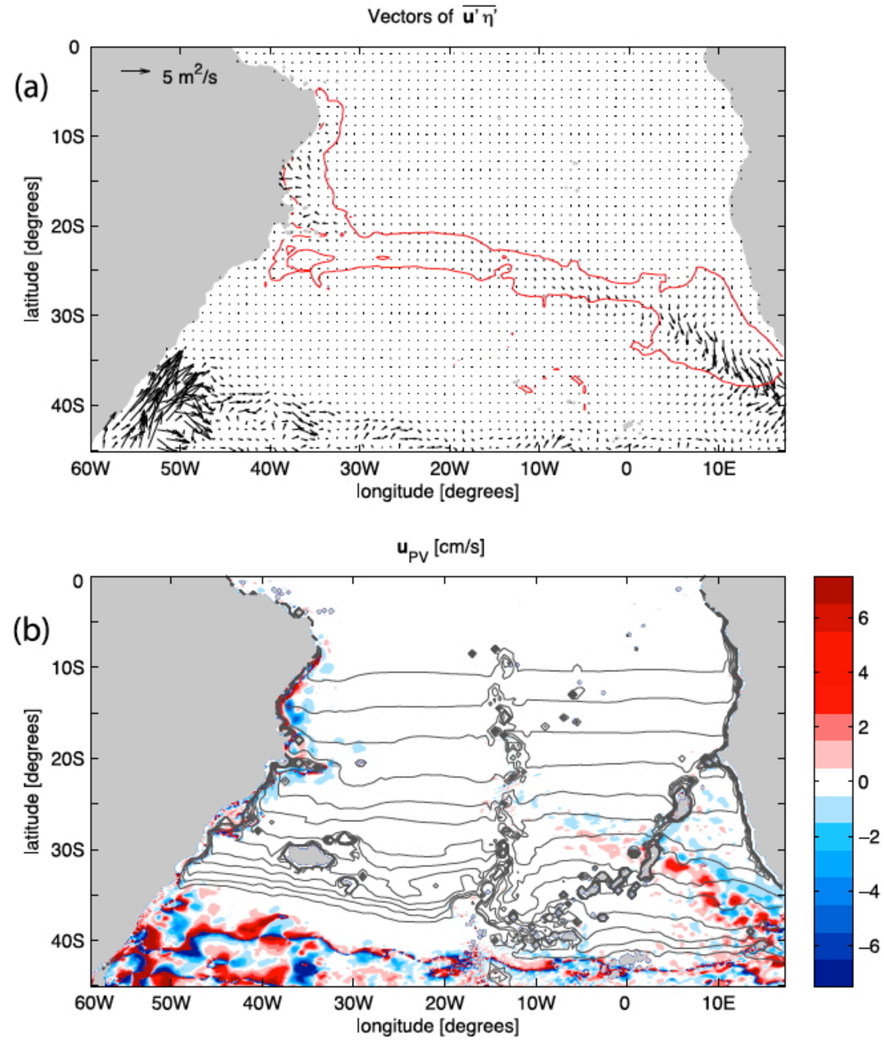
Van Sebille et al. (2012)

Van Sebille et al. (2012) found a significant pathway of DWBC waters crossing eastward through the South Atlantic at about 20°S underneath the Agulhas Ring corridor.

An analysis of the potential vorticity balance in the OFES model indicates **that the depression of the upper NADW interface by Agulhas rings results in a vertical vorticity transfer associated with the eddy thickness flux. This eddy thickness flux drives the flow of NADW across isolines of potential vorticity within the Cape Basin.**

By analyzing the velocity and density fields in the model, they found that **the decay of these rings, and their forward tilt with depth, results in a southward velocity, across isolines of planetary vorticity, of 1 to 2 cm/s in the deep waters.**

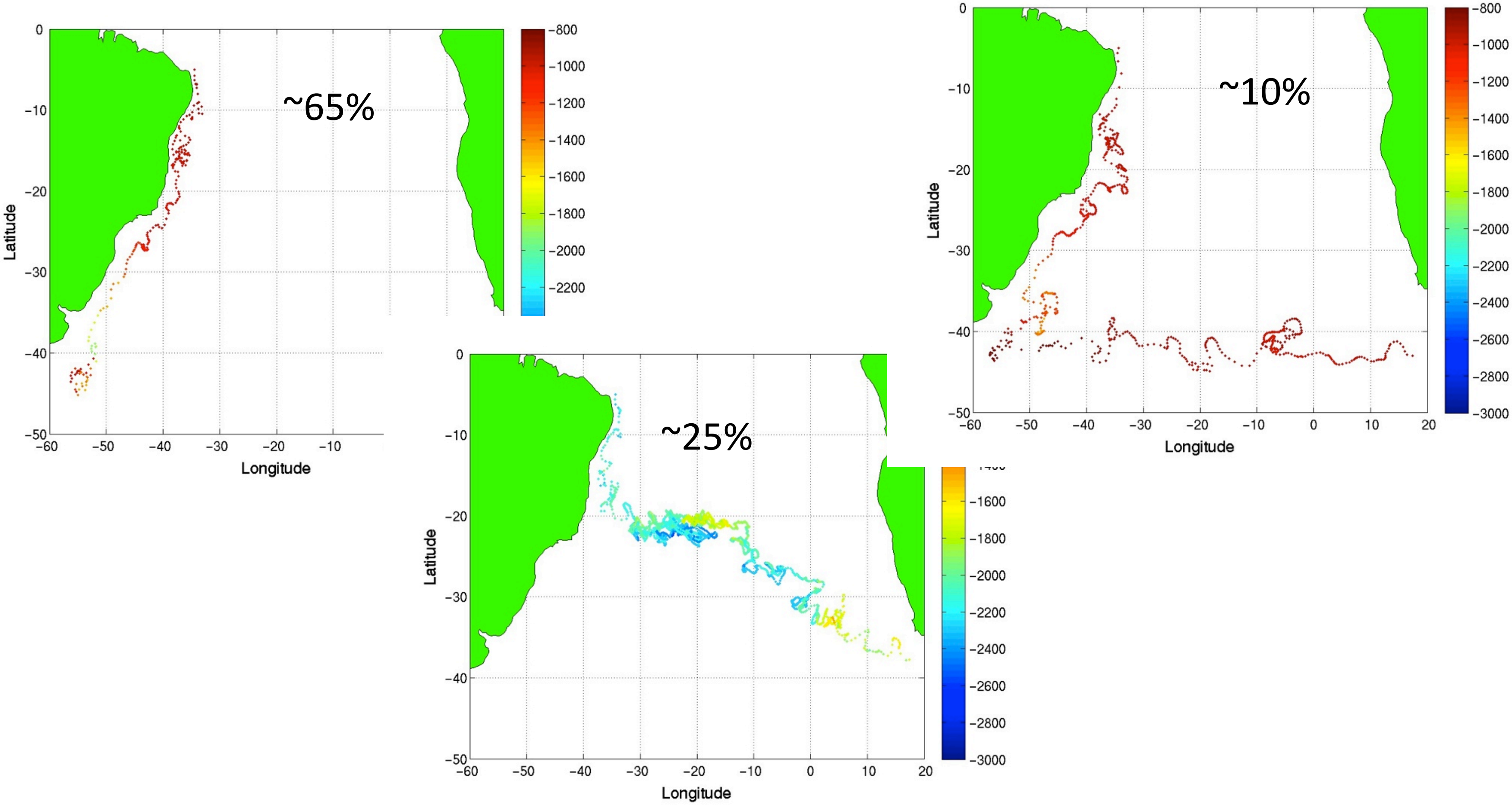
The associated stream function pattern yields a deep circulation transporting 3-4 Sv of NADW from the DWBC at 25°S to the southern tip of Africa.

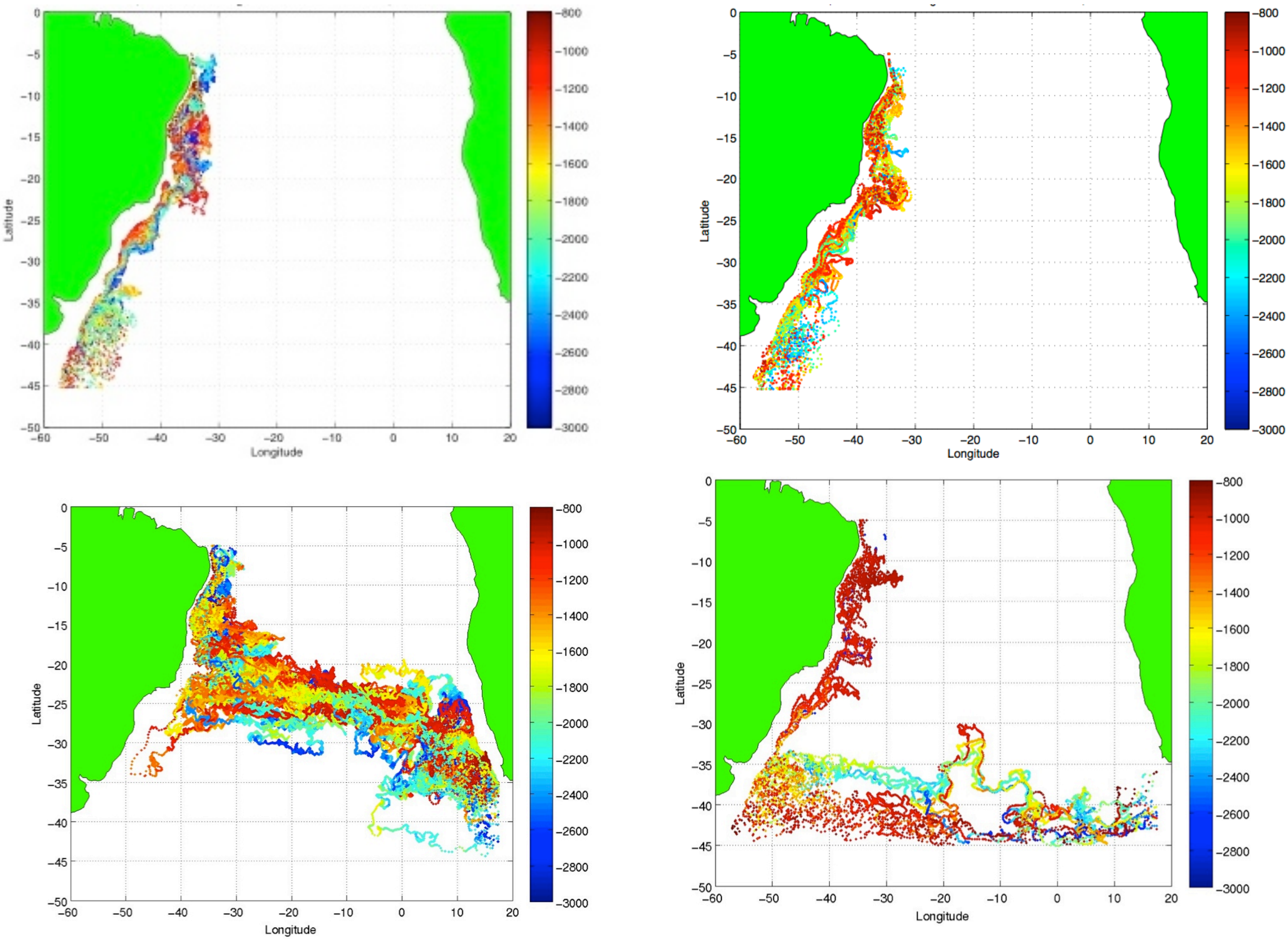


*Maps of (a) vectors of eddy thickness flux and (b) the eddying component of the flow of NADW across the mean potential vorticity gradient (**u_{PV}**) in the OFES data. The red lines in the top panel are the 0.50 Sv isolines of connectivity (the transport-weighted number of crossings of the Lagrangian floats launched at 5°S that reach the Agulhas section at 17°E), showing the location of a significant pathway for NADW. The black lines in the lower panel are lines of constant **f/h** for the NADW layer. The color bar is the magnitude of the **u_{PV}** in cm/sec.*

Further analysis of the Lagrangian product

Further analysis of these trajectories as part of this new study indicates that, while some flow does cross the South Atlantic interior near 20°S, the dominant pathway of the DWBC returns to the continental slope of South America. This is confirmed by simulated floats tracked both forward from 5°S and backwards from 17°E South of Africa to determine the origin of the flow exiting the basin.





Latitude
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-10
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10
20
-800
-1000
-1200
-1400
-1600
-1800
-2000
-2200
-2400
-2600
-2800
-3000

Transports from the Lagrangian trajectories:

• 15 Sv are transported South across 5°S. Tracking of the particles backward: Of the floats that crossed 34.5°S, 95% crossed 5°S west of 30°W.

• 10 Sv crosses 45°S after flowing parallel to the coast.

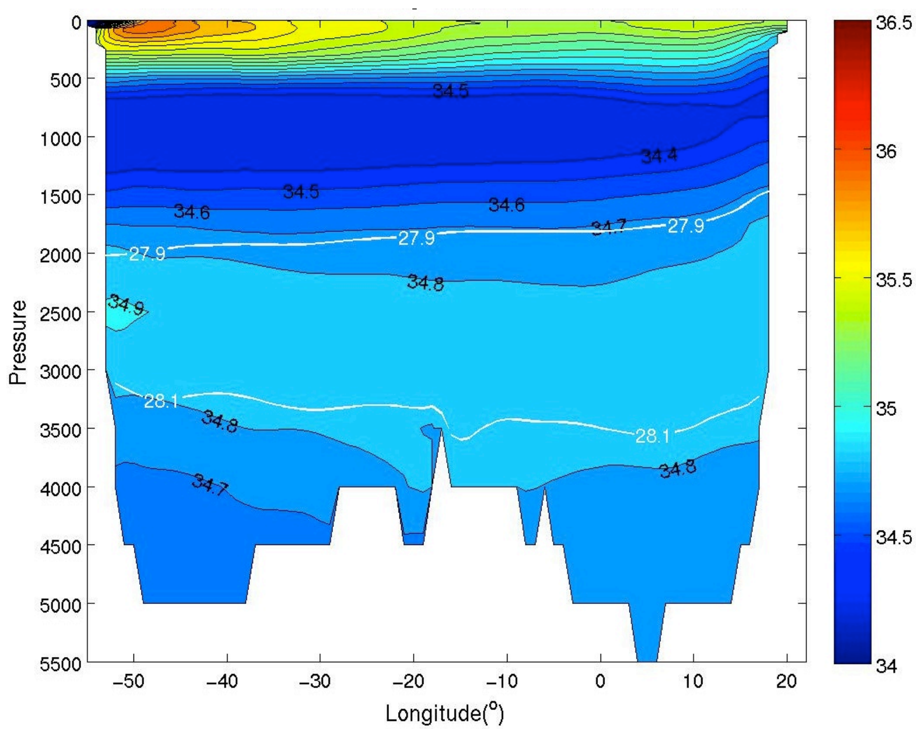
• 3.5 Sv crosses the Atlantic between 20°S and the tip of South Africa. The flow is turbulent and eddy like.

• There is a third pathway that follows the eastward meandering of the Malvinas Current with a transport of 1 Sv.

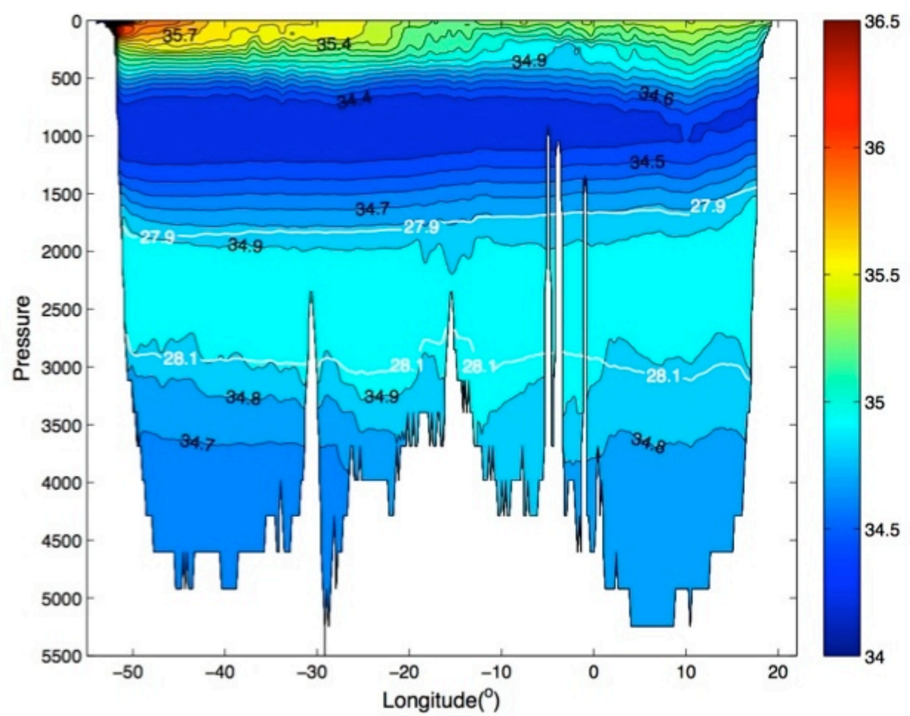
Eulerian analysis

Salinity section at 34.5°S

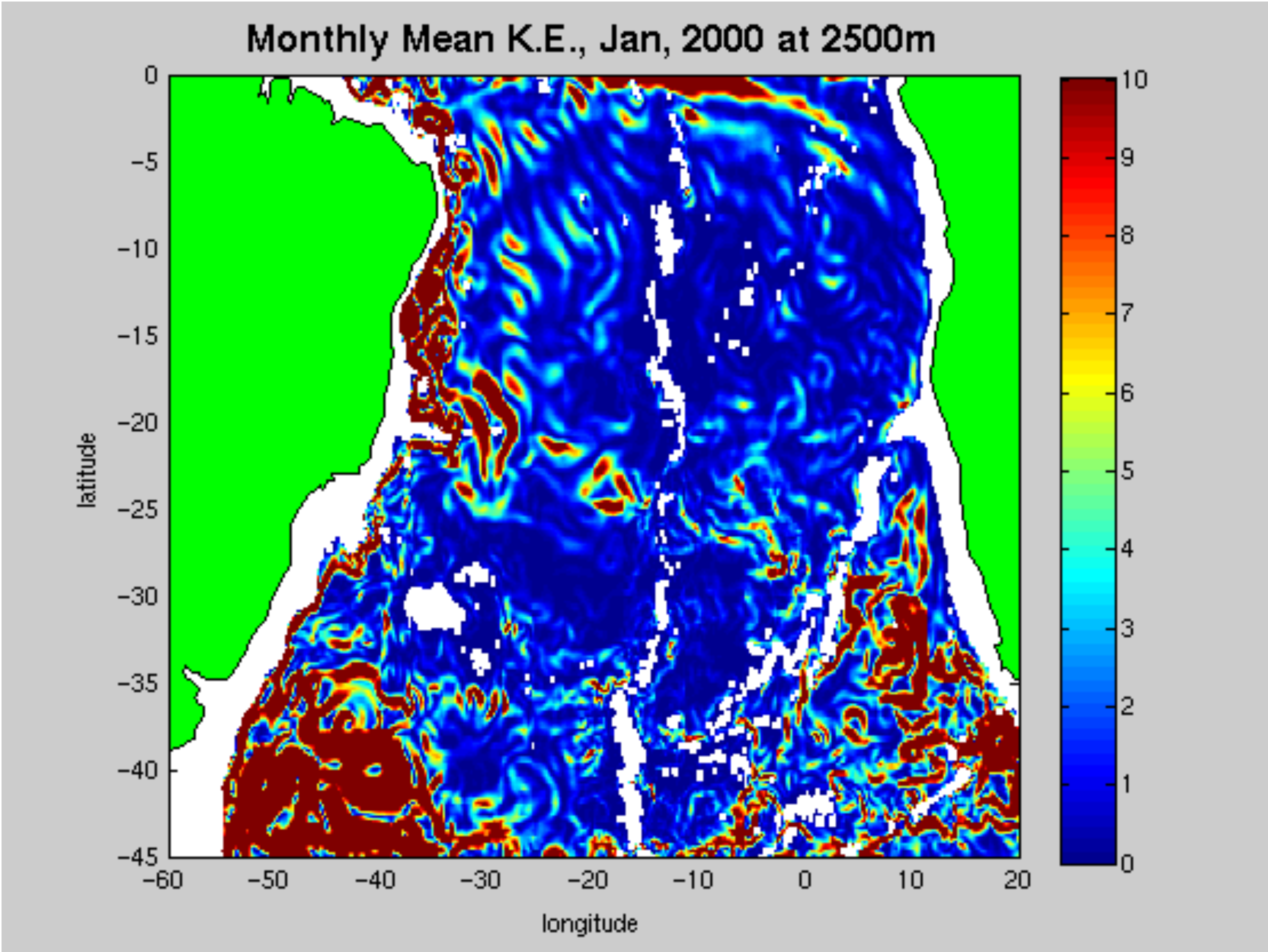
Neutral density 27.9 and 28.1 (NADW)



WOA 2009



OFES


Monthly Mean K.E., Jan, 2000 at 2500m
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longitude
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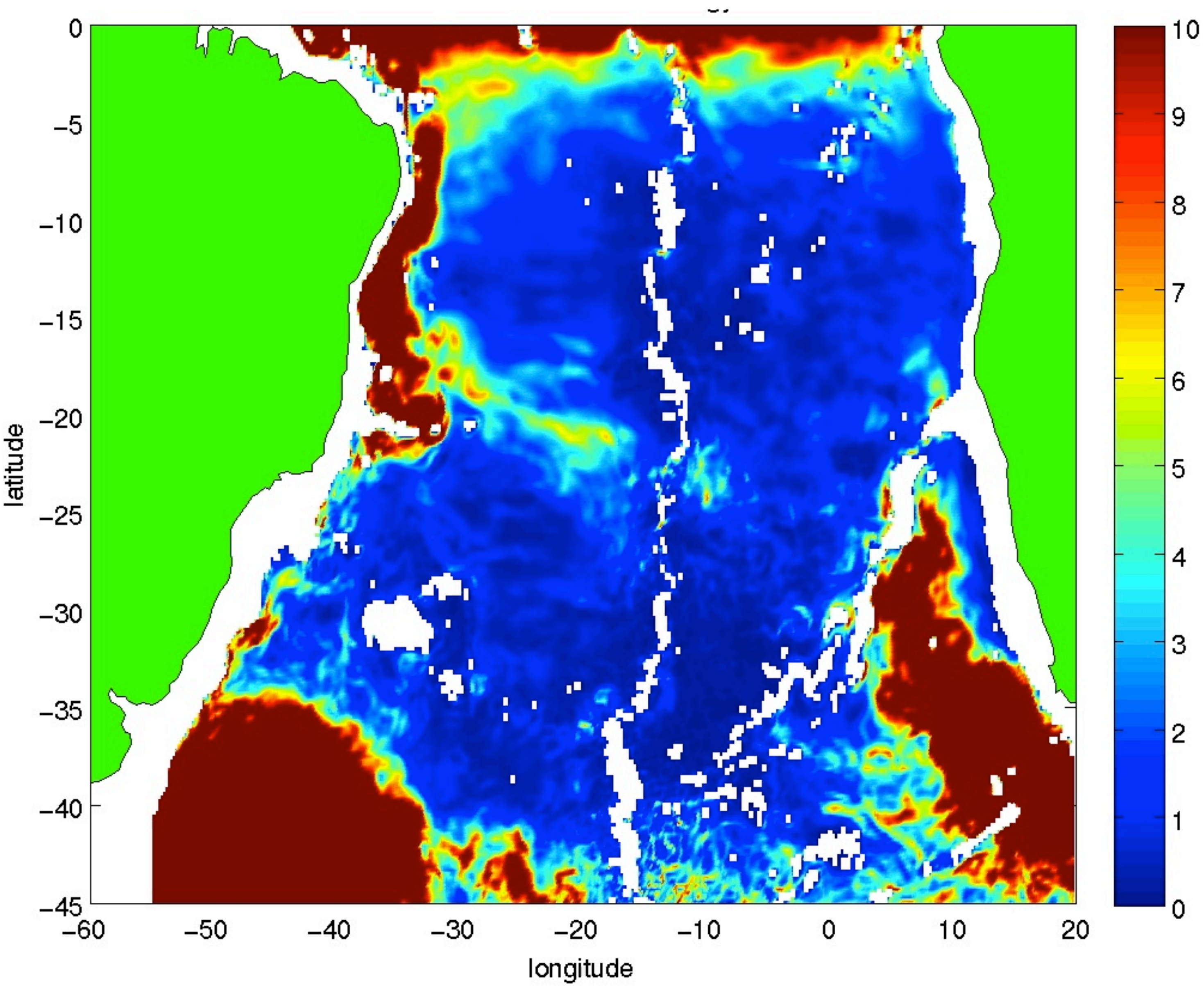

latitude
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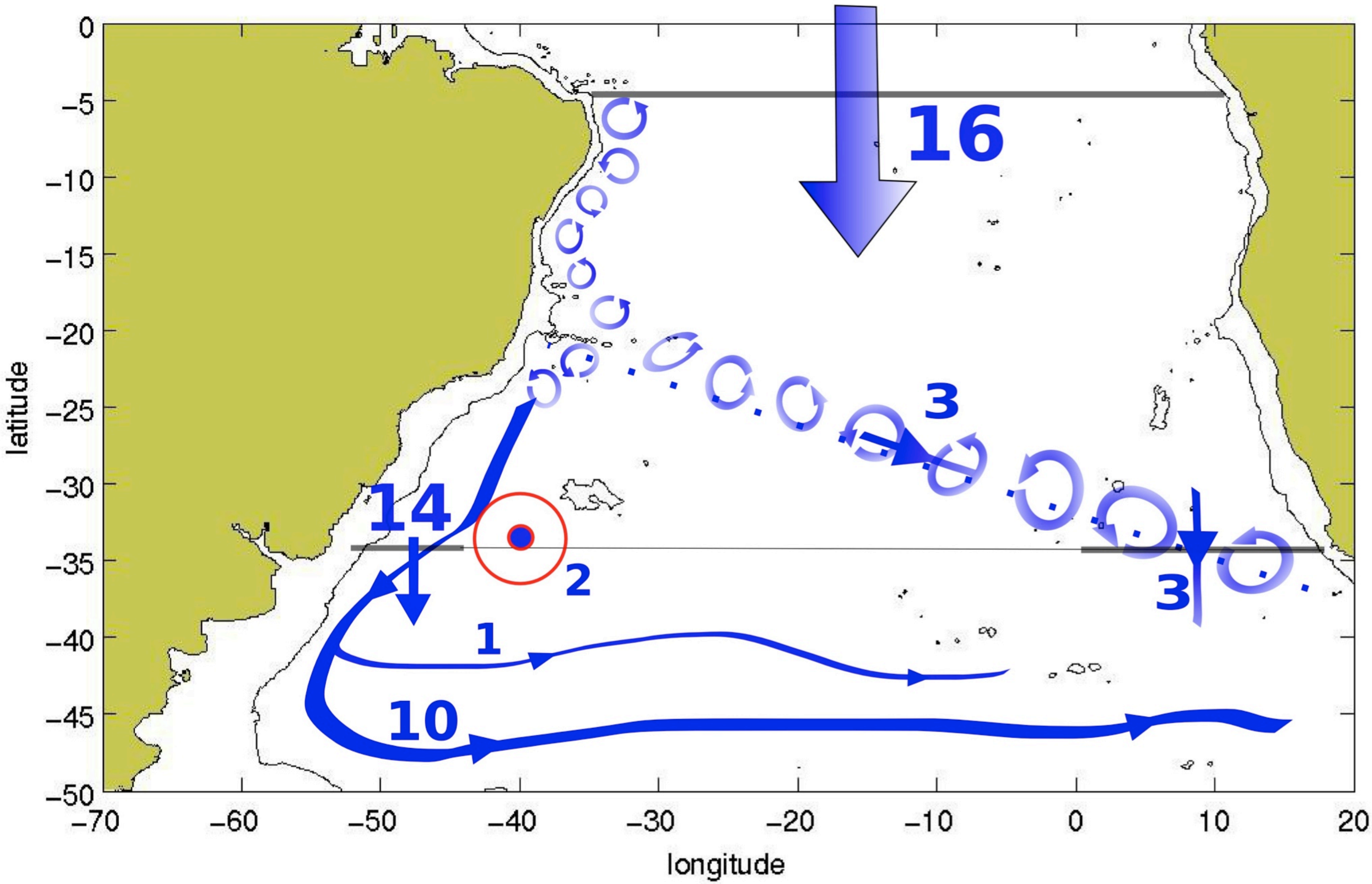
Eulerian analysis

Transports are also estimated in an Eulerian frame of reference using the same OFES velocity fields. Transports are calculated across four key sections noted in the table below. Transports are also calculated both in layers defined by density and depth.

	Eulerian	Eulerian	Lagrangian
	Neutran density 27.9 to 28.1 ~1700 to 3000 m	by depth 1000 to 3500 m	Floats deployed between 1000 to 3500 m
Across 5°S	-14.0 Sv	-16.5 Sv	-15.0 Sv
34.5°S Sam line 44.5 W to 51.5°W	-5.0 Sv	-14.0 Sv	-5.3 Sv
34.5°S from 40.0 W 51.5W coast	-6.3 Sv	-16.2 Sv	-10.0 Sv
34.5°S, from 0°E to coast	-4.1 Sv	-2.9 Sv	-2.9 Sv
Sam PIES results Integrated 800-4800 dbar transport: -17.2 Sv (this analysis: -17.0 Sv)			

Schematic of the results



Transport numbers are rounded

Conclusions from the analysis of the OFES model

- Approximately ~16 Sv crosses 5°S at the NADW depths/neutral density levels. Lagrangian particle tracking indicates that most of this south-southeastward flow originates west of 30°W (90% of the total virtual floats).

- In OFES, the DWBC flow along the coast of South America breaks into rings between 5° and 8°S, a region where the flow is mostly "non-stationary", consistent with earlier observations.
- This "ring-dominated" flow continues southward along the western boundary to the Trindade Ridge (20°S), where the flow splits into a branch flowing into the interior, and another branch, returning along the Trindade Ridge to the coast and flowing southward. Preservation of potential vorticity may be the cause of the the branching in this area (from a simple two layer model, Zangenberg and Siedler,1998.).

- Approximately 25% of the NADW at ~20°S (3 to 4 Sv) flows eastward into the interior Atlantic, and this flow continues towards the Cape Basin directly beneath the Agulhas ring corridor. The remainder of the NADW flow at 20°S returns to the continental slope as a more steady flow, forming the main branch of the southward DWBC.

- At 34.5°S the DWBC flow is about 14 Sv in the model, of which only about 10 Sv continues south to cross 45°S and then flow eastward with the ACC. After crossing 34.5°S, a small amount (about 1 Sv) of NADW flows towards the east at the latitude where the Malvinas Current turns offshore.

- Conservation of mass indicates that about 2 Sv of NADW does not leave the Atlantic as NADW. This is consistent with previous modeling and observational results (Garzoli and Matano, 2011) that found that in the Confluence region approximately 2.6 Sv transforms from NADW to AAIW.

- The model and tracer estimated mean velocity of the DWBC flow along the South American continental slope is ~2 cm sec^{-1}.

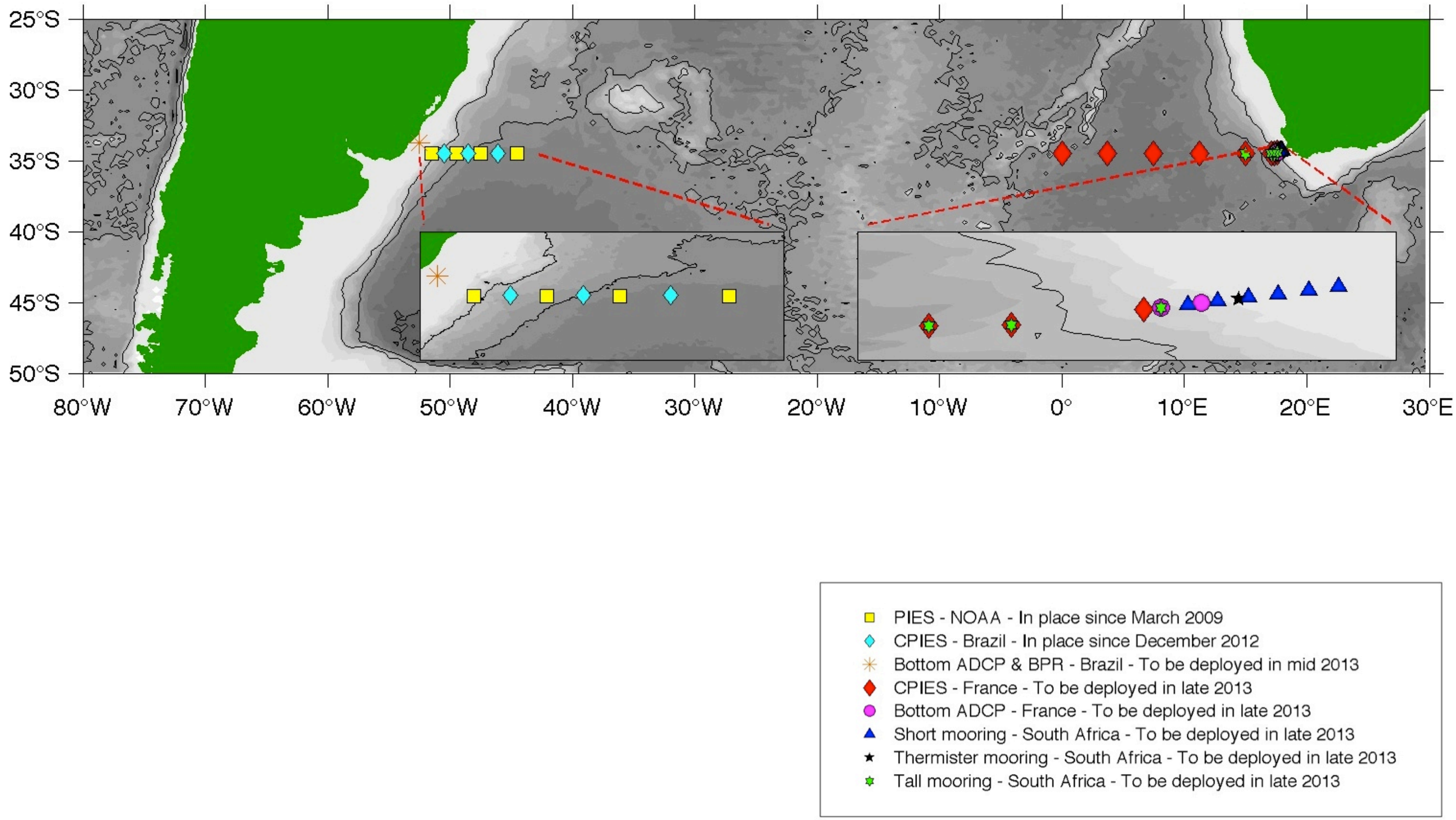
Other conclusions….

Still an open question: **What are the mechanisms that determine that the flows reconstructs after the Trindade Ridge? How? Why? Is this related to a lower intensity of the AMOC?**

To answer this question:

- **Further theoretical and model analysis** (Some will be performed as part of a newly funded NOAA proposal)
- **Further observations at the western boundaries. Process study based on a reinforcement of the existing western boundary observations.**
- **A real float study launching real Lagrangian floats at 5°S west of 30°W**

SAMOC line was designed at the right place (34.5°S)



Thank you