Tracking Mesoscale Eddies within a Regional Model of the Cape Basin

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PROJECT GOALS

- identifying mesoscale eddies with an objective method,
- time-tracking these eddies and
- evaluating their properties and the water mass they transfer.

Wavelets **A**nalisys for **T**ime-tracking **E**ddies in **R**egional model**S**

http://www.ifremer.fr/lpo/adoglioli/WATERS/

Acknowledgments
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This study is also a contribution to InterUp, a project funded by the French Programme national Atmosphère et Océan à Multiéchelles (PATOM).

This study is part of a project that deals with the analysis of the out put of numerical models.

This project is founded by the French Navy and it aims at identifying mesoscale eddies with an objective method, time tracking these eddies and evaluatimg their properties and the mass they transfer.

We mantain web pages about the projet at this address.

Ocean Model - *Configuration*

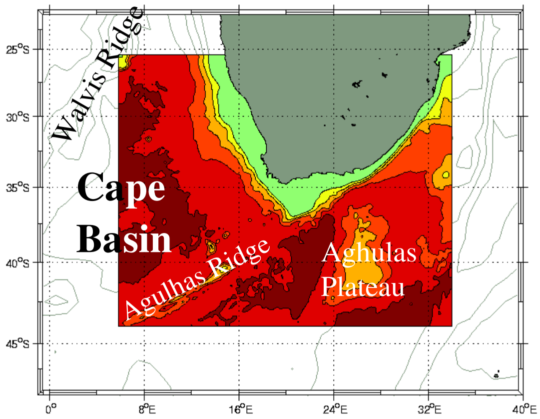
ROMS code

IRD version with
ROMSTOOLS [Penven, 2003]

Horizontal resolution: 1/10°

8-year run

Output :
2-day average



Climatologies		
Open boundaries	*Wind forcing*	*Heat & Fresh water fluxes*
OCCAM 1/4°	QuikSCAT	COADS 1/2°

A numerical model of the ocean region around the South of Africa has been developed on the basis of the ROMS code.

Here shaded colours show the bathymetry of the model domain.

The horizontal resolution is one tenth of degree and allows a good reproduction of mesoscale variability.

The model solution is started from rest and calculated for height years.

Model outputs are averaged and stored every 2 days of simulation.

The model forcing was derived from different climatologies:

open boundaries conditions are calculated from OCCAM model,

wind forcing from Quickscat satellite data,

and heat and fresh waters fluxes from the atlas COADS *cohomprensive Ocean-Atmosphere Data Set.*

Wavelet Analysis – *Eddy identification*

Decomposition of an horizontal slice of relative vorticity

Research Area
128 x 128 [gridcells]

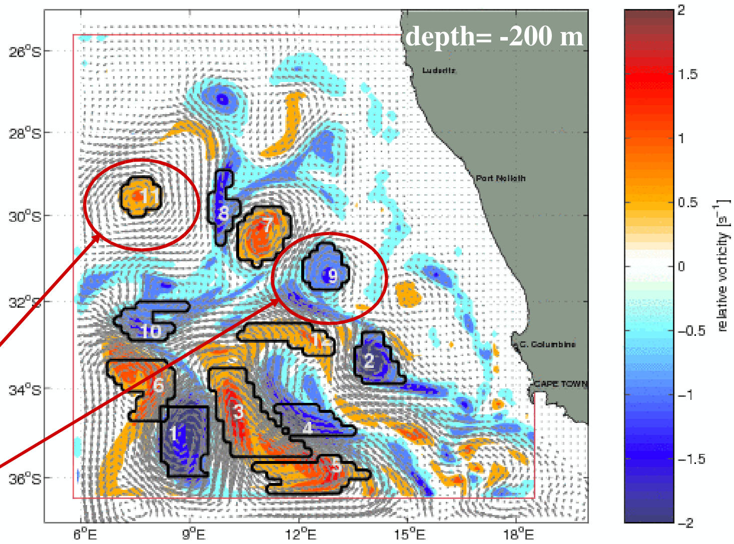
Center definition

$$\max(|\zeta|) \ \mathit{or}$$

$$\min(|u^2 + v^2|)$$

Numbering and Naming
Anticyclone PANORAMIX
Cyclone ASTERIX

MATLAB tools using **Wavelab** library [http://www-stat.stanford.edu/wavelab/]



In oder to identify mesoscale structures, horizontal slices of relative vorticity are decomposed with the wavelet technique following a classical approach in image processing.

To do this we use the Wavelab library for Matlab.

As shown here in a fixed area of the model domain, the wavlets allow to identify several structures.

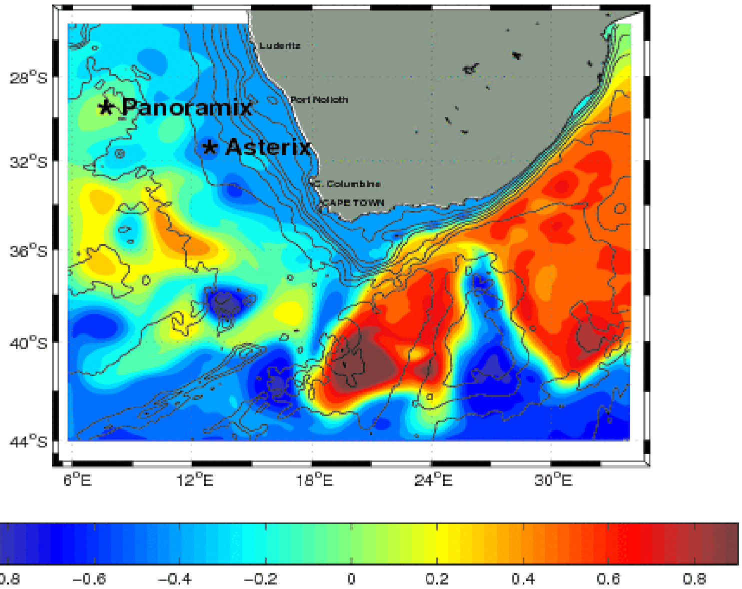
For each structure the center is defined as the point of maximum relative vorticity or minumum velocity.

The criterion is chosen to allow the longest possible tracking.

Some structures are superimposed, a few others are not eddies but rather filaments or meanders.

On the other hand structures as numer 9 an number 11 are well defined cyclonic and anticyclonic eddies and in the following I will show you that we are able to track them.

Wavelet Analysis – *Eddy identification*



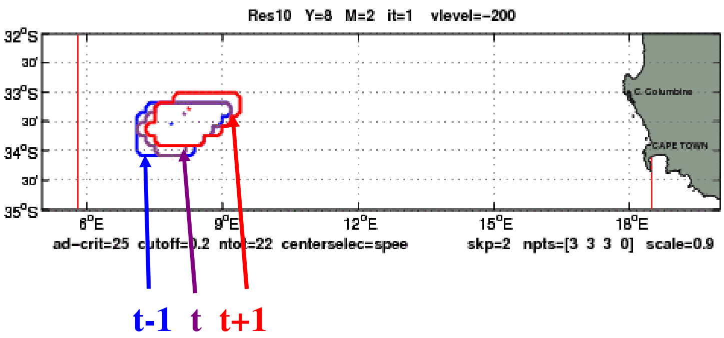
Sea surface height [m]

The wavelets method has been accurately tested with sensitivity analysis and comparison with other criteria for eddy identyfication.

Here I show you the free surface field of the entire domain of the model and you can observe the signature in the elevation due to the two eddies previously detected.

Wavelet Analysis – *Time tracking*

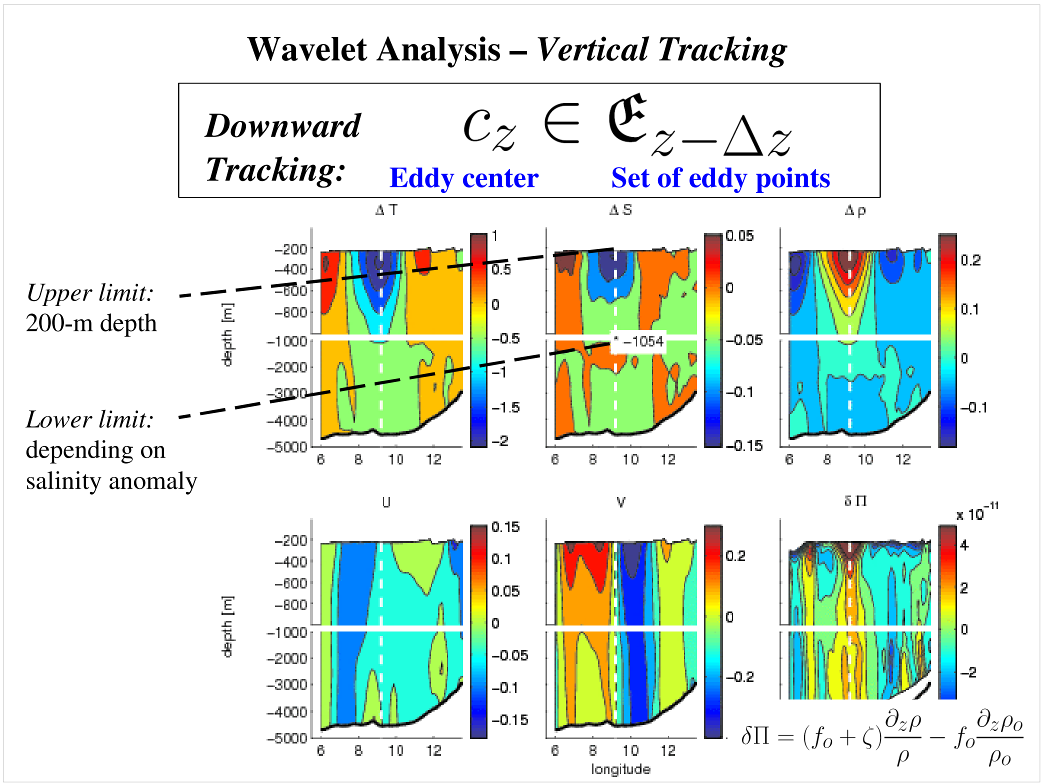
Backward Tracking:	$c_t \in \mathfrak{E}_{t-\Delta t}$
	Eddy center **Set of eddy points**



To track in time the identified eddies, we fixed this criterion, that is in backward direction the eddy center at the time t has to belong to the set of points of the eddy at the previous time.

Here I show you an example of successful tracking: the dot representing the center is alwais surronded by the eddy contour.

The backward direction presents the advantage of a simplier initialization.



To establish the vertical extension of an eddy, we adopted a criterion analogous to time tracking.

At each level eddy center must belong to the set of the point of the upper level.

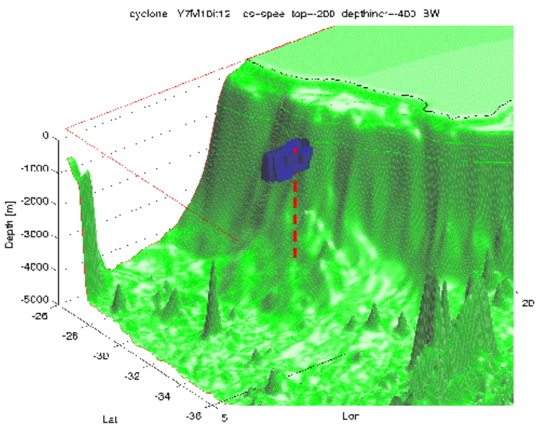
The eddy upper limit is fixed to 200m in oder to cut off the model superficial levels, strongly influenced by the boundary condition.

Lower limit istead is fixed on the basis of the position of the salinity anomaly.

In this way at each timestep we know the 3D structure of the eddy.

Wavelet Analysis – ***4D tracking***

Cyclone Asterix



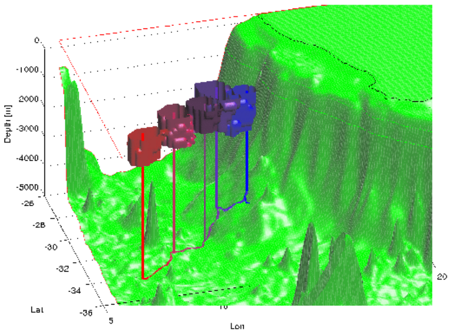
In this movie I show you the cyclone Asterix.

It initially moves northward and its shape is streatched.

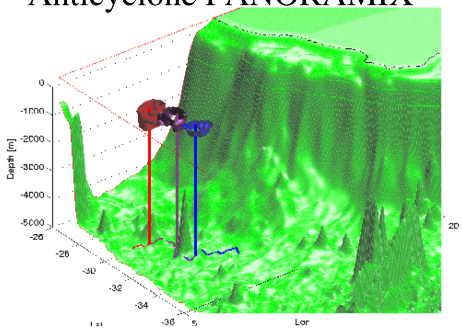
Then it assumes a circular shape and starts to move west-southwestward until it reaches the western boundary of the model.

Wavelet Analysis – *4D tracking*

Cyclone ASTERIX



Anticyclone PANORAMIX



September to February (spring/summer)

Vel = 0.08 [ms^{-1}]

Diam= 179 [km]

Vol=15.8 10^{12} [m^3]

July to October (winter/spring)

Vel = 0.11[ms^{-1}]

Diam = 147[km]

Vol=5.9 10^{12} [m^3]

	Boebel et al, 2003		Van Ballegooyen et al.,1994	
	Cyclones	Agulhas Rings	Cyclones	Anticyclones
Diameter [km]	120	200	160	190 – 320
Velocity [m/s]	0.036	0.038	0.046	0.04 – 0.09
Volume [1012m^3]	-	-	-	11.2 - 33.8

Divergent pathways
[Morrow et al., 2004]

Here I resumed the anlysis of the two eddys we tracked.

The volume is shown each month.

On the bottom is reported the eddy center trajectory.

Color represents the time, in blu young eddies, in red old eddies.

In little bit more than five months the cyclone moves westward with a mean velocity of heigth centimeters per second.

Its mean diameter is   and mean volume is

The anticyclone is followed little less then four months.

It moves northwestward going around the Vema seamount.

Doing this the eddy interacts with the sponge layer at the western boundary of the model.

Consequently analysis is less accurate.

In any case, the estimated mean velocity is

Its mean diameter is   and mean volume is

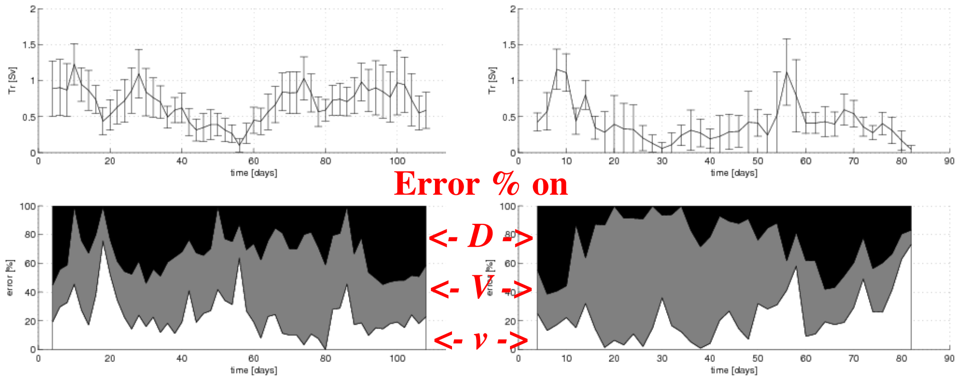
This values are compatible with field data.

Also the divergence in eddies pathways is observed in satellite and drifter data.

Wavelet Analysis – *Transport*

$$Tr = v \cdot V \cdot D^{-1}$$

Cyclone ASTERIX | Anticyclone PANORAMIX



<Tr>=0.69±0.44 [Sv] | <Tr>=0.41±0.42 [Sv]

Knowing velocity, volume and diameter, we can calcuate an istantaneous transport of the eddy with this formula.

Time series od istantaneous eddy transport show modulations in time mainly driven by the changes in velocity.

Cyclone transport is always larger than anticyclone one.

For Asterix the error is equally distributed on the three varibles used to derive transport.

For Panoramix insted the error is mainly due to the poor extimation of the volume during central period, when eddy interct with the seamount.

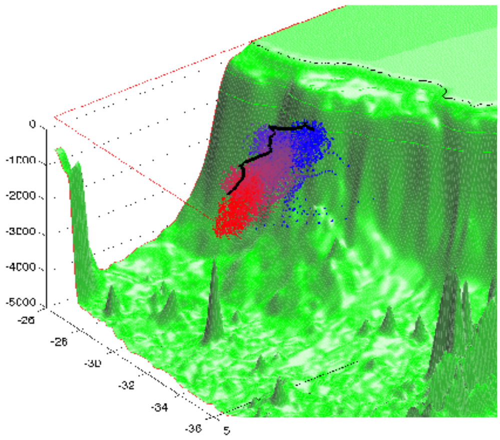
Time averaged transport is o.69 SV for cyclone and 0.41 for anticyclone.

Lagrangian particles - *Coherent eddies*

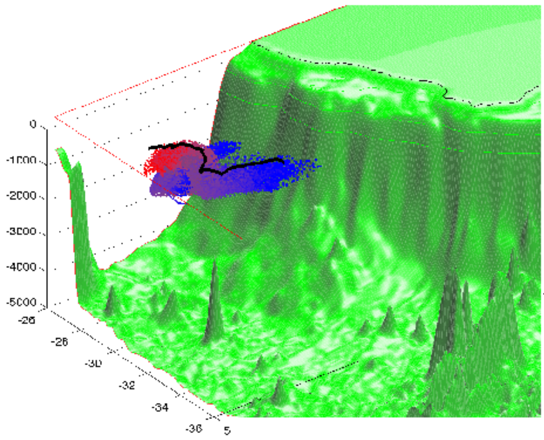
ARIANE ***http://www.univ-brest.fr/lpo/ariane***

Backward time integration

Cyclone ASTERIX
- 120 days
- 9920 particles (4particles/gridcell every 50m)



Anticyclone PANORAMIX
- 90 days
- 3984 particles (4particles/gridcell every 25m)



Knowing the volume of the eddy, we can disseminate it with lagrangian particles using ARIANE toolkit.

We integrated backward in time.

The trajectory show that particles are trapped within the eddy and follow the trajectory as the one detected with the wavelet analysis, here represented by the blak line.

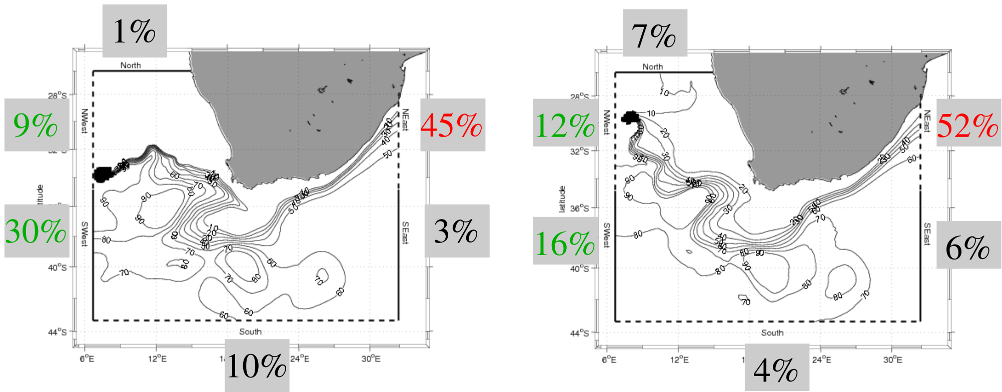
This is a robust validation of the ability of the wavelets analysis to track eddy cores within the time.

Lagrangian particles - *Remote Origins*

3-year backward time integration

Cyclone ASTERIX

Anticyclone PANORAMIX



Integration lagrangian particles trajecotries for 3 years we obtain an estimation of remote origins of water trapped in eddies.

Here isolimes correspond to the general features of the movement of all particles. About 45% of the cyclone particles come from Agulhas current, while about 40% come from Atlantic.

Fort the anticyclone the percentage of particles originating from the Agulhas current increases, while Atlantic water contribution decreases.

The differences between this two different origins partially explain the cold and fresh anomaly of the cyclone as well the warm and salty asignal carried by the anticyclone.

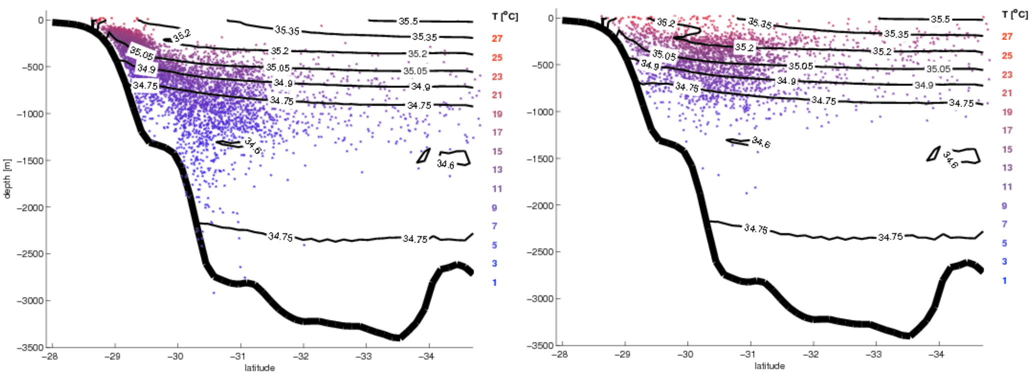
Nevertheless the high percentage of Agulhas origin is surprising.

Lagrangian particles - *Remote Origins*

Agulhas origin

Cyclone ASTERIX
<*t*> = 427 days
<*z*> = 670 m
<*T*> = 10.2°C
<S> = 34.85 psu

Anticyclone PANORAMIX
<*t*> = 361 days
<*z*> = 478 m
<*T*> = 13.2°C
<S> = 35.01 psu



Thus we studied in more details the Agulhas origin.

We founded that the anticyclone particles are the fastes to connec the agulhas current to the western domain.

In fact, the mean age of the cyclone particles is 427 days against 361 days for the anticyclone.

So, the cyclone particles spend more time in the Cape Cauldron mixing with the ambient water.

Futhermore cyclone particles in the Agulhas current are deeper, colder and fresher than anticyclone ones.

SUMMARY

- the wavelet analysis proved successful in tracking eddies;
- tracked model mesoscale eddies present realistic dynamics;
- wavelets+lagrangian diagnostics offer estimates of eddy mass transport and origins;
- warning!: narrow domain; OCCAM drift.

Poster:
Speich, S., Blanke, B., Arhan, M., Dencausse, G., Lutjeharms, J., *Ocean dynamics and exchange of water properties in the Cape Cauldron from regional sensitivity studies and altimetry.*

Reference:
Doglioli, A.M., Blanke, B., Speich, S., Lapeyre, G. (2005), *Tracking eddies in a regional model of the Cape Basin off South Africa*. J. Geophys. Res., Submitted.

In summary we can say that

the wavelet analysis proved successful in tracking eddies;

tracked model mesoscale eddies present realistic dynamics;

wavelets+lagrangian diagnostics offer estimates of eddy mass transport and origins;

Despite the robustness of our result we have noted two warnings:

our model domain was too narrow and eddies too soon interacted with western boundary.

Furthermore the OCCAM open boundaries conditions doesn't represent perfectly the temperature and salinity distribution.

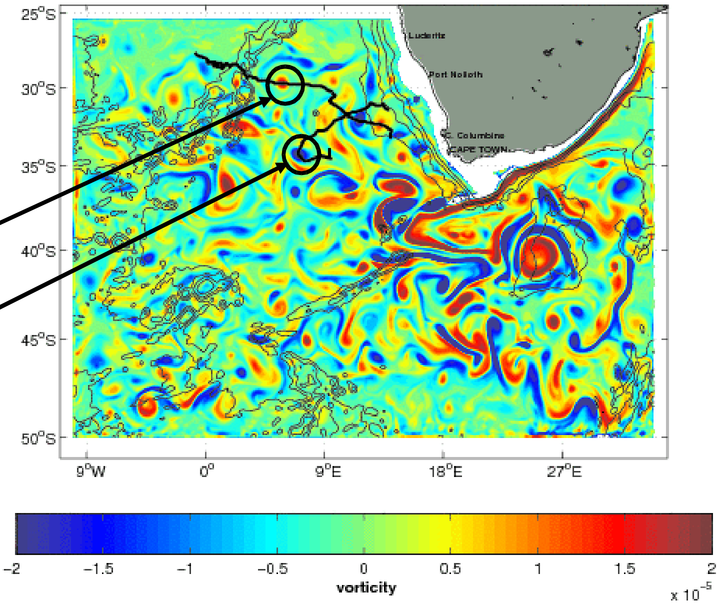
OUTLOOK

New Runs

- larger domain
- 11-year run
- new b.c.

Anticyclone
11-month tracking

Cyclone
7-month tracking



To resolve these problems we have now new runs with a larger domain, extendig in longitude until 10 degree west, and a new open boundary conditions.

Recently we have already tracked 2 veri nice eddies.

One anticyclone tracked for 11 months and a cyclone tracked for 7 months.

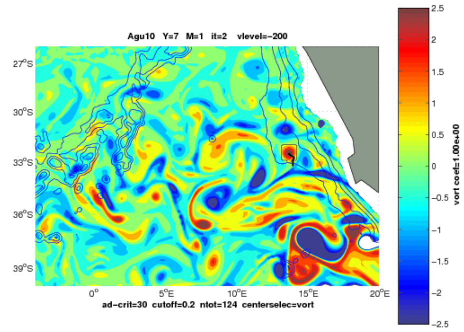
OUTLOOK

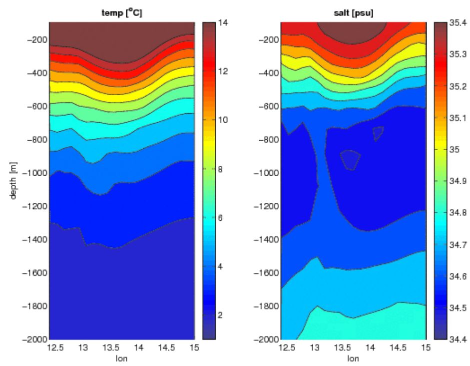
very realistic stratification with respect to measurements by Schmid et al., 2003.

What mixing with the surrounding waters?

Which interaction with other mesoscales features?

What happens at the Walvis Ridge?





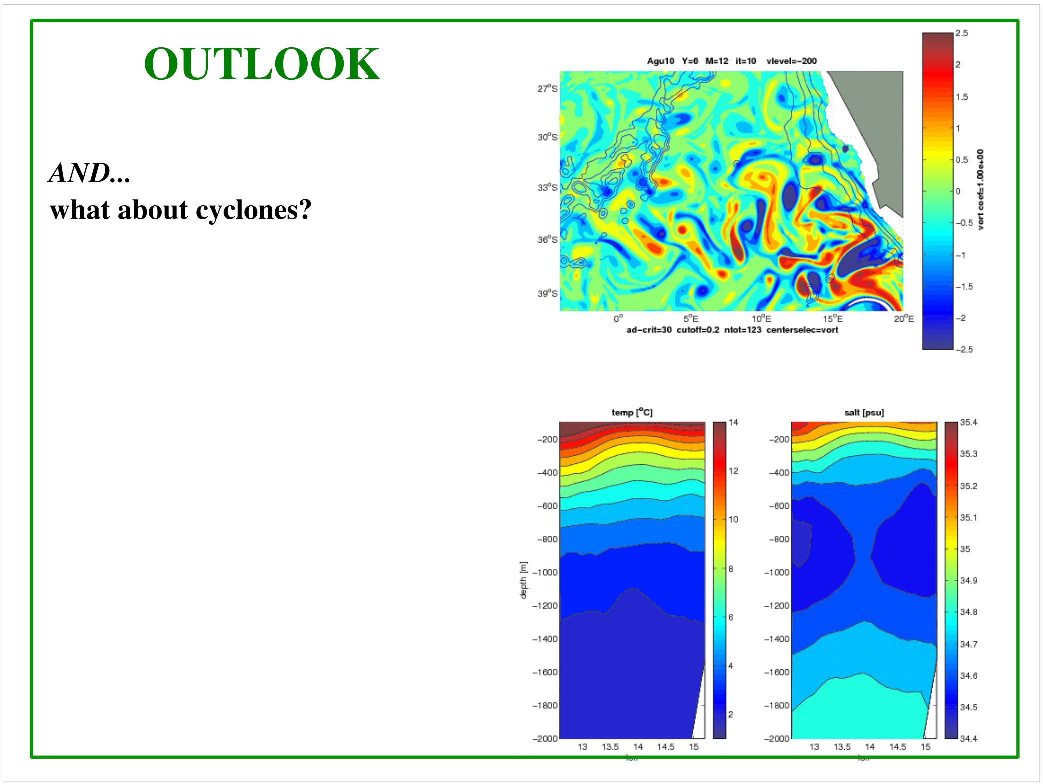
A quick look at the anticyclone shows a very realistic stratification with respect measurements effectued by schimd et al.

So, analysing this data, we hope to answer to several questions such as

Which mixing with the ambient
waters?

Which interaction with other
mesoscales features?

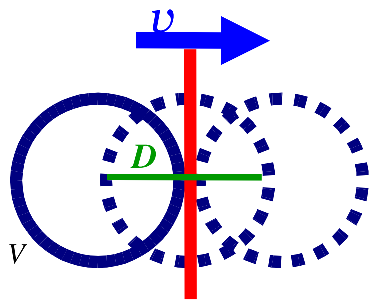
What happens at the Walvis Ridge?



And what abbout cyclones that are less known.

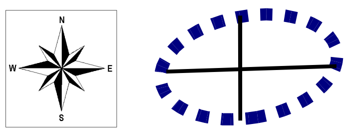
Wavelet Analysis – *transport*

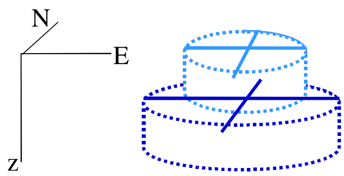
$$Tr = V \cdot \Delta t^{-1}$$



$$Tr = v \cdot V \cdot D^{-1}$$

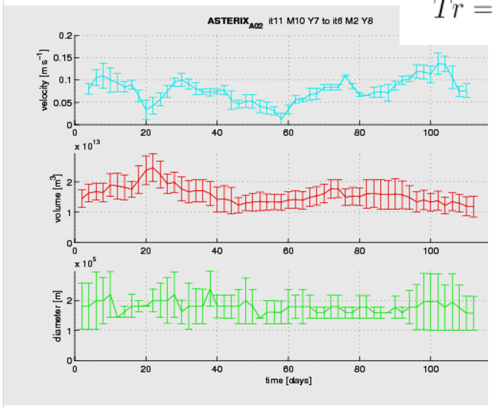
$$D = \max\left\{\max_z\{D^{EW}\}; \max_z\{D^{NS}\}\right\}$$

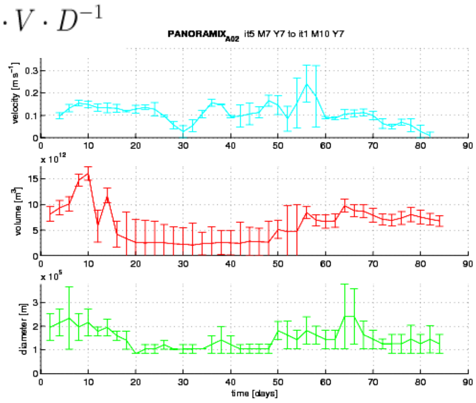




Wavelet Analysis – *transport*

$$Tr = v \cdot V \cdot D^{-1}$$

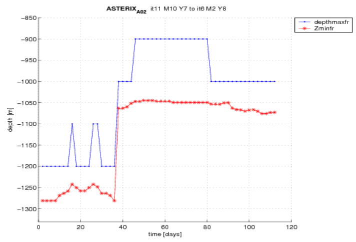




Relative errors

$$v_{err} = \frac{\sigma_z(u)}{v} \qquad D_{err} = \frac{\max_z\{D^{EW}\} - \max_z\{D^{NS}\}}{D}$$

$$V_{err}(t) = \underbrace{\frac{(z_L - iz_L) \cdot A_L}{V}}_{\text{vertical}} + \underbrace{\frac{4\Delta x \Delta z \sum_{k=1}^{iz_L} A_k D_k^{-1}}{V}}_{\text{horizontal}}$$



Lagrangian particles - *Remote Origins*

Inflow Atlantic

Cyclone ASTERIX

Anticyclone PANORAMIX