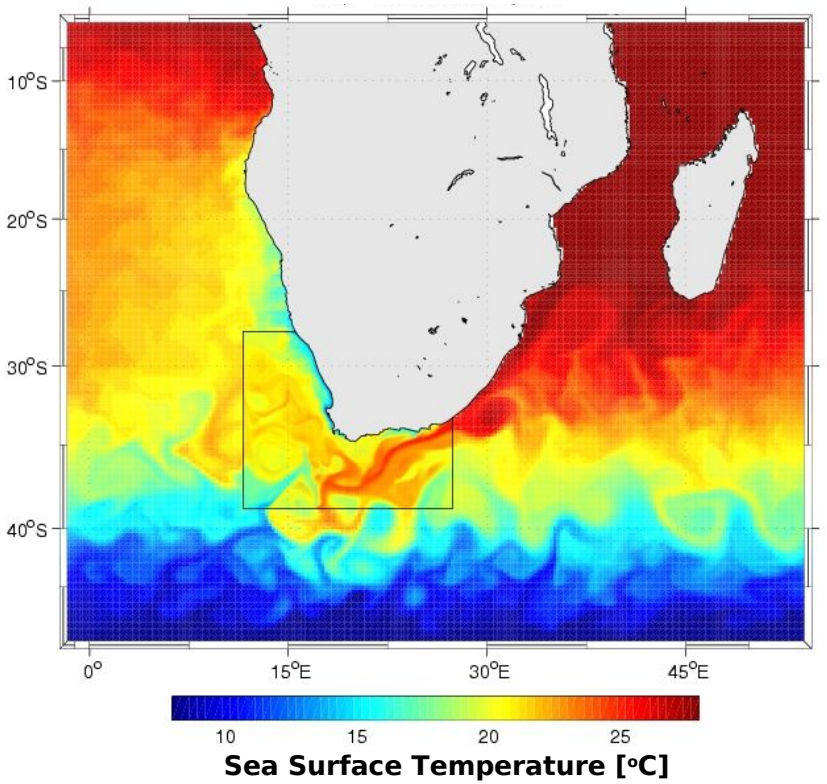
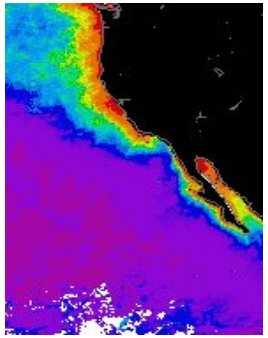
Regional ocean modelling around Southern Africa



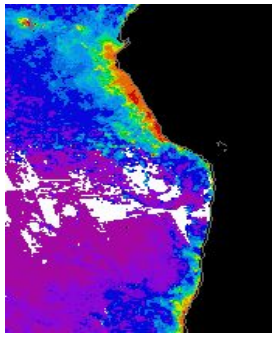
P. Penven[1], J. Veitch[2], N. Chang[2], M. Rouault[2], F. Shillington[2], B. Pohl[3].

[1] Laboratoire de Physique des Ocean (UMR 6523: CNRS, IFREMER, IRD, UBO), France.
[2] Department of Oceanography, University of Cape Town, South Africa.
[3] Centre de Recherches de Climatologie, Universite de Bourgogne, France.

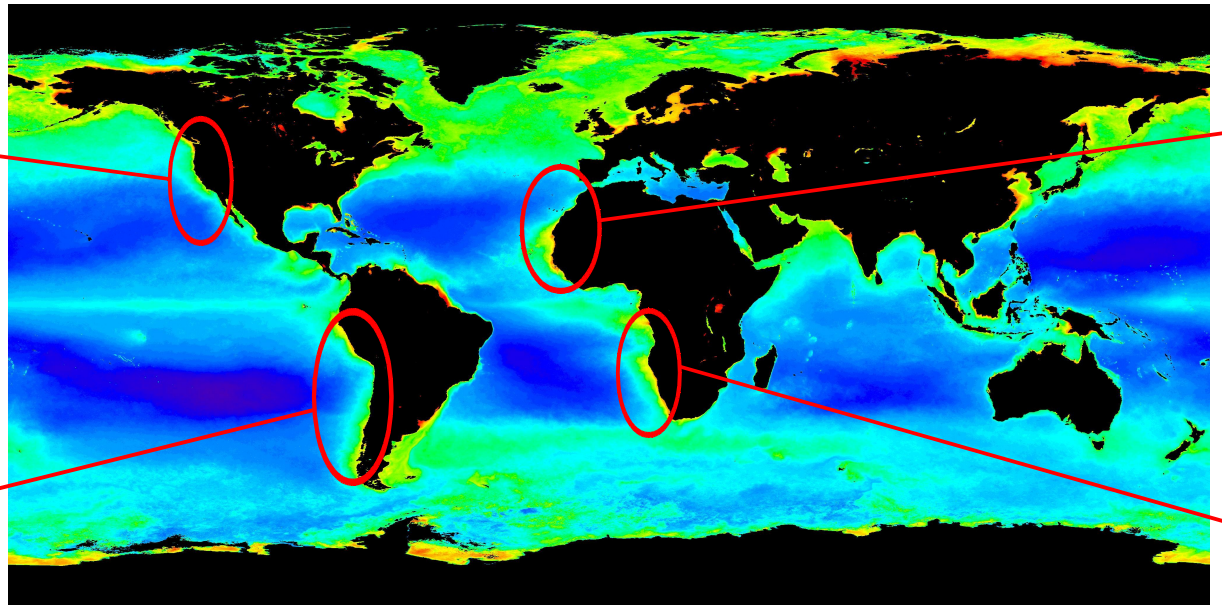
The Benguela Current,
1 of the major coastal upwelling ecosystems



California Current

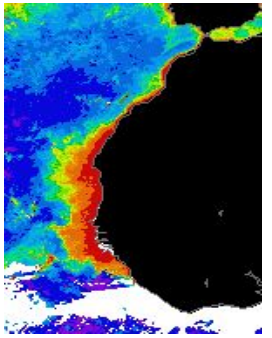


Humboldt Current

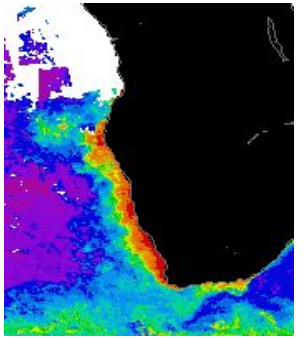


Surface chlorophyll concentration

(source SeaWiFS & CZCS, NASA/Goddard Space Flight Center)



Canary Current



Benguela Current

Maximum annual production in the Benguela Current (Carr, 2002).

Carr, M.-E., 2002. Estimation of potential productivity in Eastern Boundary Currents using remote sensing. *Deep-Sea Research II,* **49,** 59-80.

The Agulhas Current, the strongest western boundary current of the Southern Hemisphere

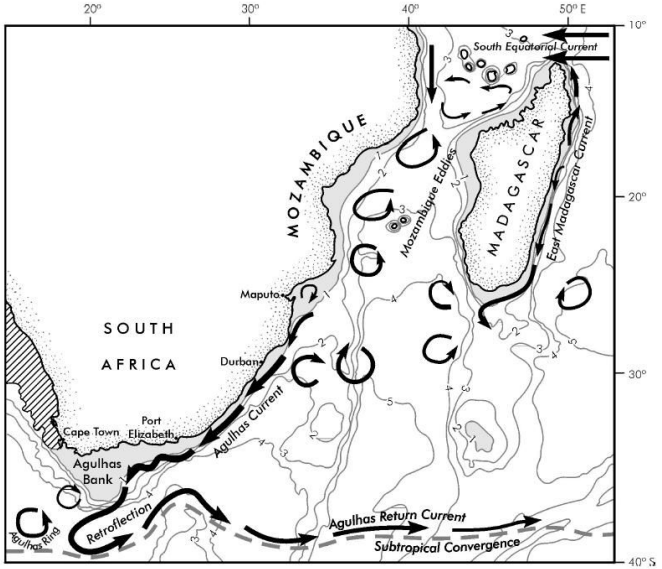
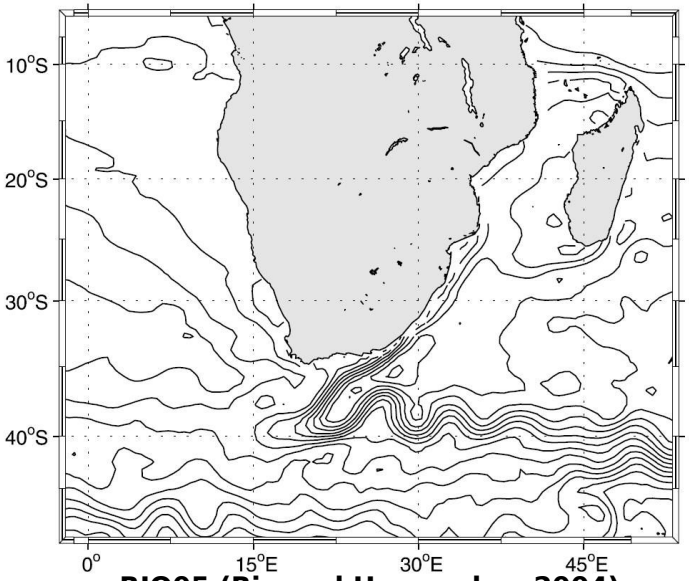
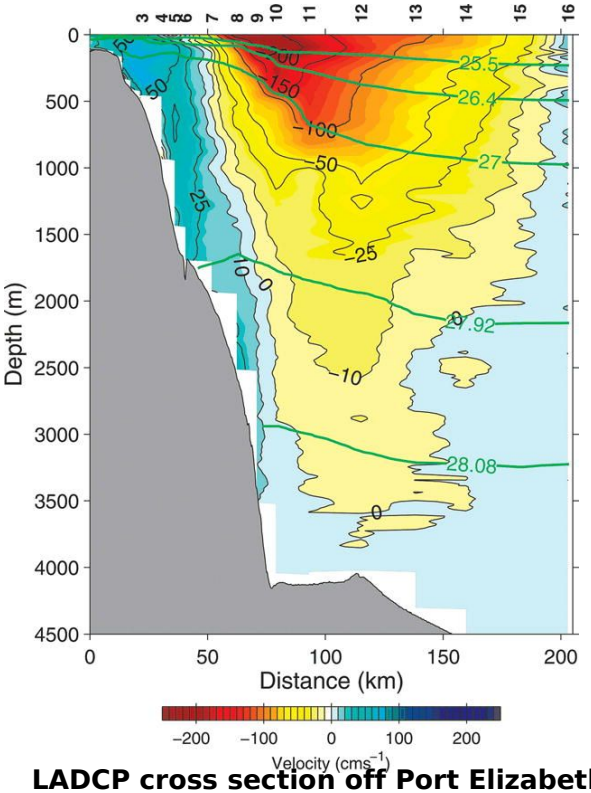


image source: Lutjeharms (2006).



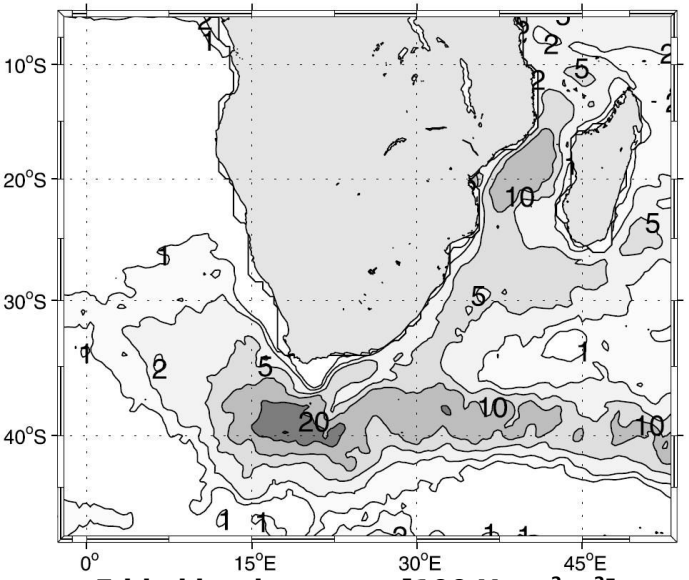
RIO05 (Rio and Hernandez, 2004) dynamic height [1 contour/10 cm].



LADCP cross section off Port Elizabeth
image source: Beal et al. (2006).

Agulhas Current:

- Velocities up to 2 m.s^{-1}
- 70 Sverdrups.
- Sources: South-Western Indian Ocean.



Eddy kinetic energy [100 X cm^2.s^{-2}] derived from AVISO altimetry.
image source: Penven et al. (2006).

Beal, L.M., T.K, Chereskin, Y.D. Lenn and S. Elipot, The Sources and Mixing Characteristics of the Agulhas Current, *J. Phys. Oceanogr.*, **36**, 2060-2074, 2006.

Lutjeharms, J.R.E., Three decades of research on the greater Agulhas Current, *EGU Ocean Sci. Discuss.*, **3**, 939-995, 2006.

Penven, P., J.R.E. Lutjeharms and P. Florenchie, Madagascar: a pacemaker for the Agulhas Current system ? *Geophys. Res. Lett.*, **33**, L17609, 2006.

Rio, M.-H., and F. Hernandez, A mean dynamic topography computed over the world ocean from altimetry, in situ measurements, and a geoid model, *J. Geophys. Res.*, **109**, C12032, 2004.

Agulhas Rings:
key elements of the global conveyor belt

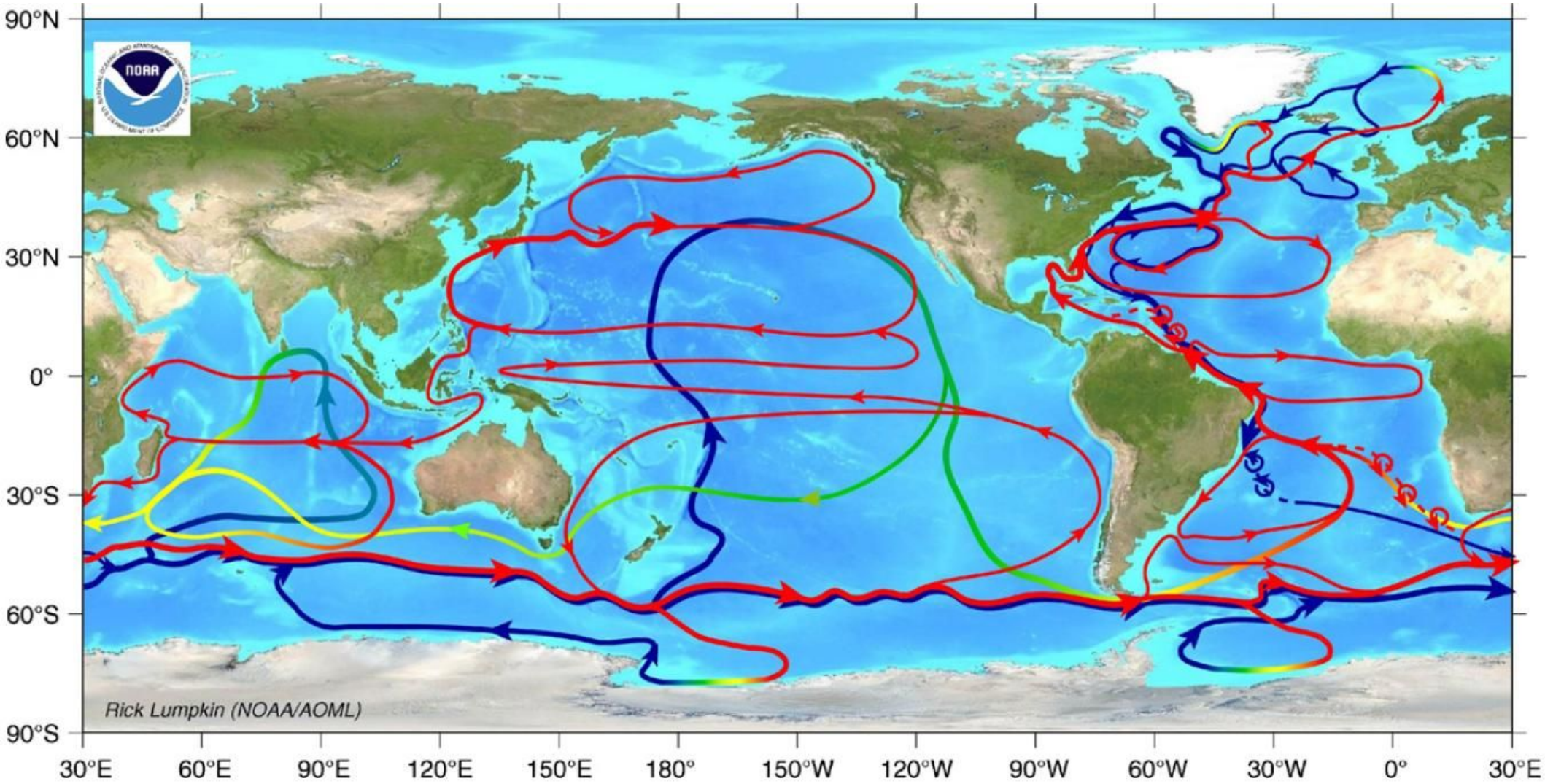
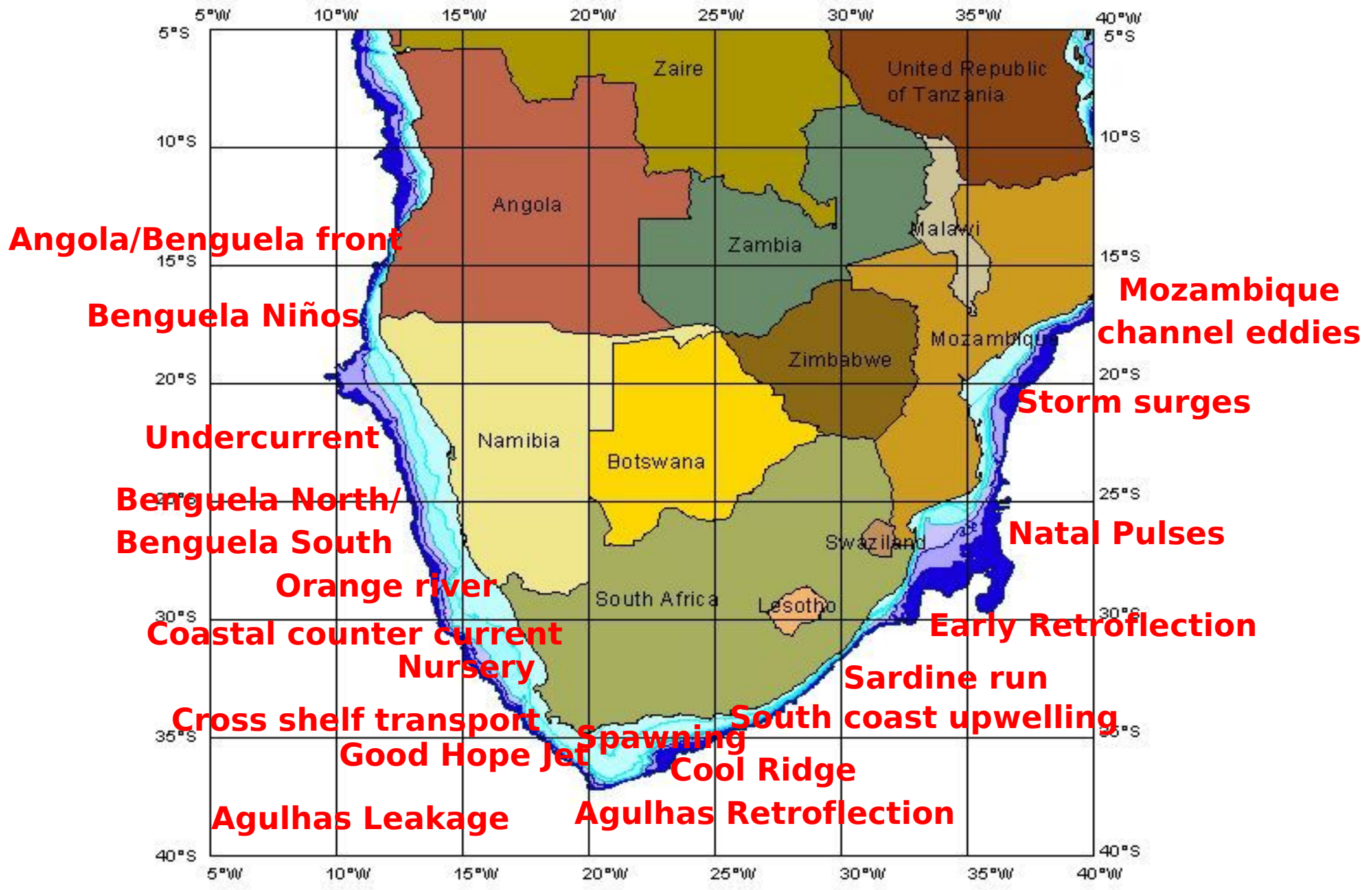


Image source: Richardson, P. L., On the history of meridional overturning circulation schematic diagrams, *Progr. Oceanogr.*, **76**, 466-486, 2008.

Several Questions at the regional/coastal scale



SAfE (Southern Africa Experiments) strategy:

- Parent model which resolves both the Agulhas (from its sources to the spawning of Agulhas Rings) and the Benguela.

- Coastal zooms depending on the scientific interest.

Larger region: intermediate resolution (1/4°) for the parent model.

→ easy to test new ideas or parameters (and for coupling with ecosystem models)

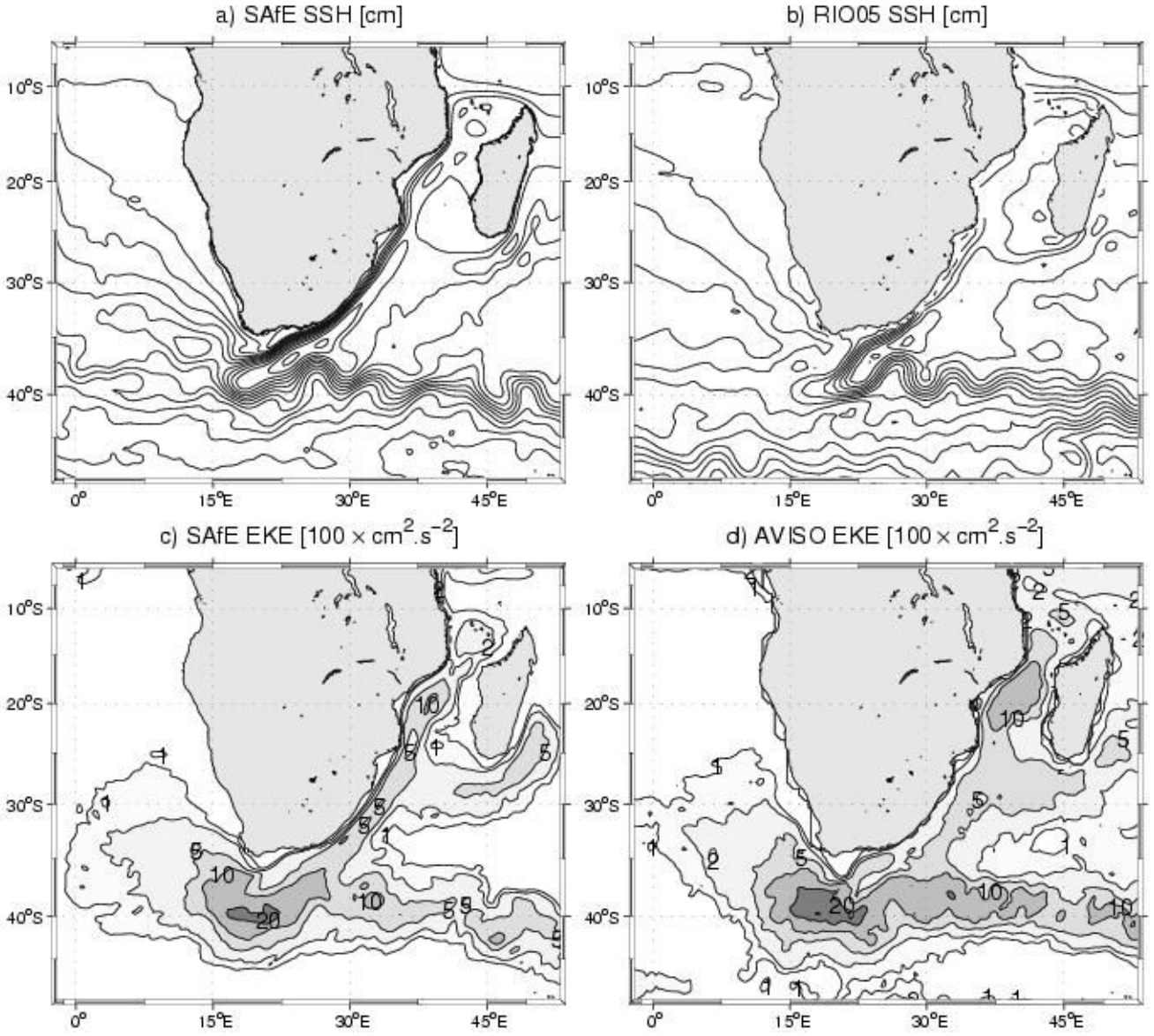
Climatology and/or inter-annual simulations depending on the scientific questions.

- Climatology experiments: QuikSCAT winds, DaSilva fluxes, WOA2005 initial and lateral boundary conditions.

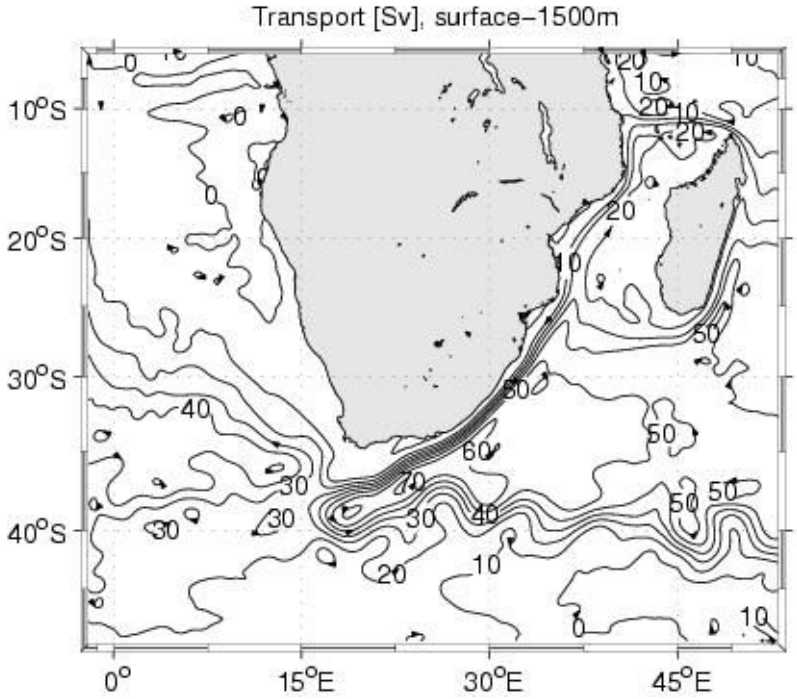
- Inter-annual experiments: NCEP atmospheric forcing, ECCO (1993-present) or SODA (1958-2001) initial and lateral boundary conditions.

http://www.brest.ird.fr/personnel/ppenven/SAfE/index.html

Large scale climatology experiments



Annual mean transport (1500m - surface)



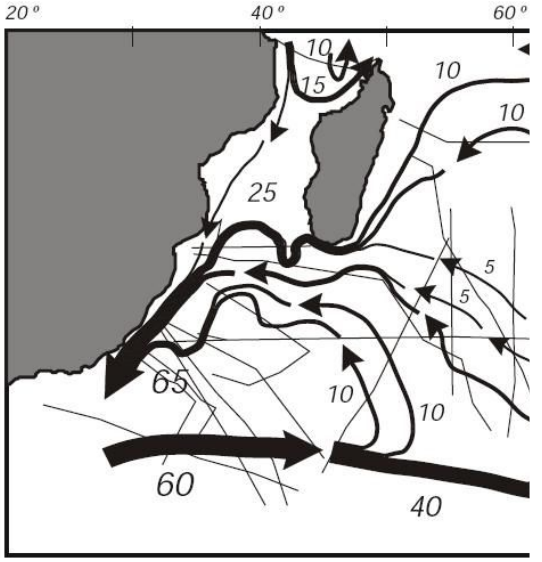
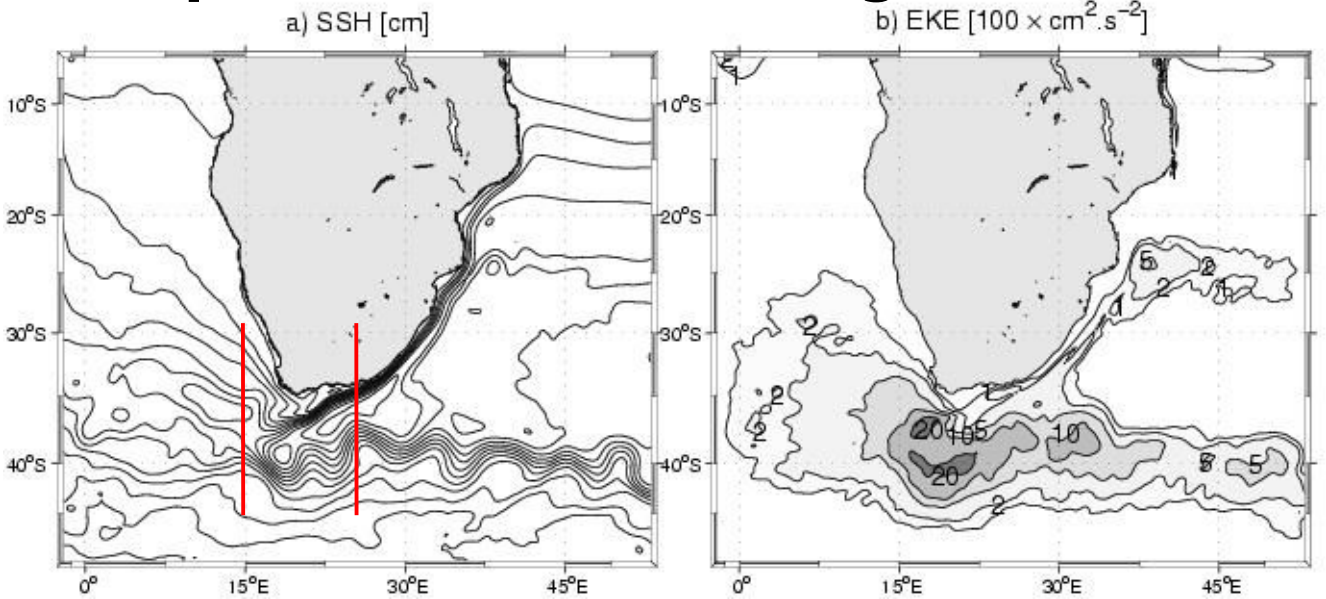
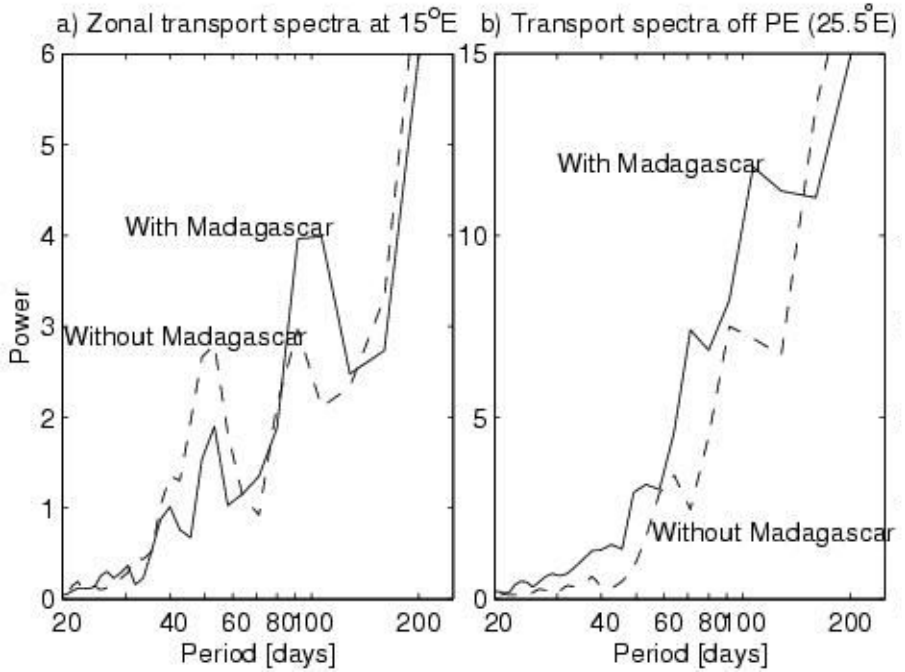


image source: J. Lutjeharms, 2006.

Madagascar: a pacemaker for the Agulhas Current System ?

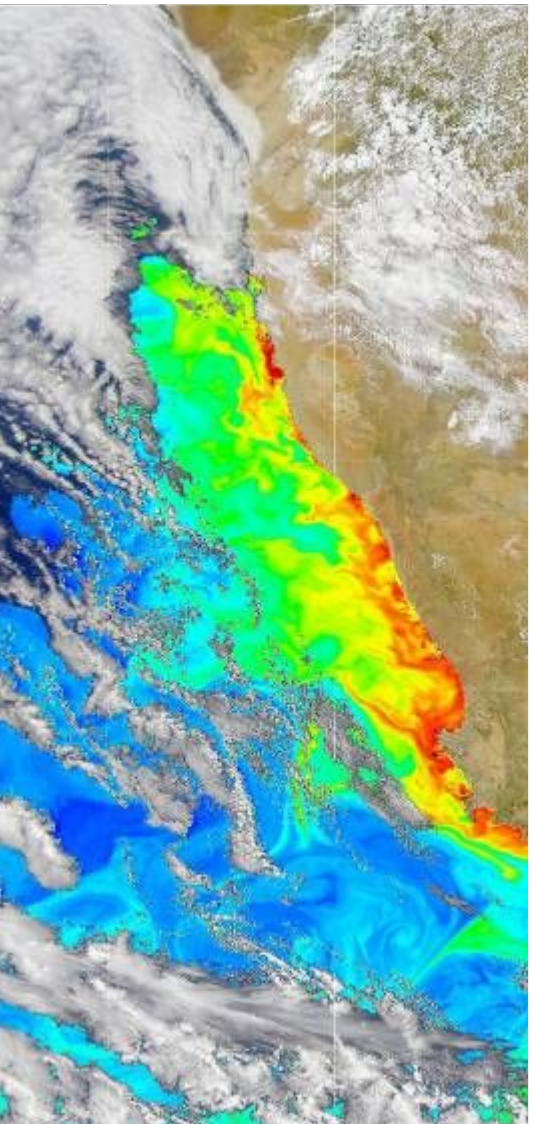




Penven, P., J. Lutjeharms and P. Florenchie, Madagascar: a pacemaker for the Agulhas Current system ? *Geophys. Res. Lett.*, 2006, **33**, L17609, doi:10.1029/2006GL026854.

Equilibrium dynamics of the northern and southern Benguela Current systems

Jennifer Veitch, PhD Thesis, UCT.

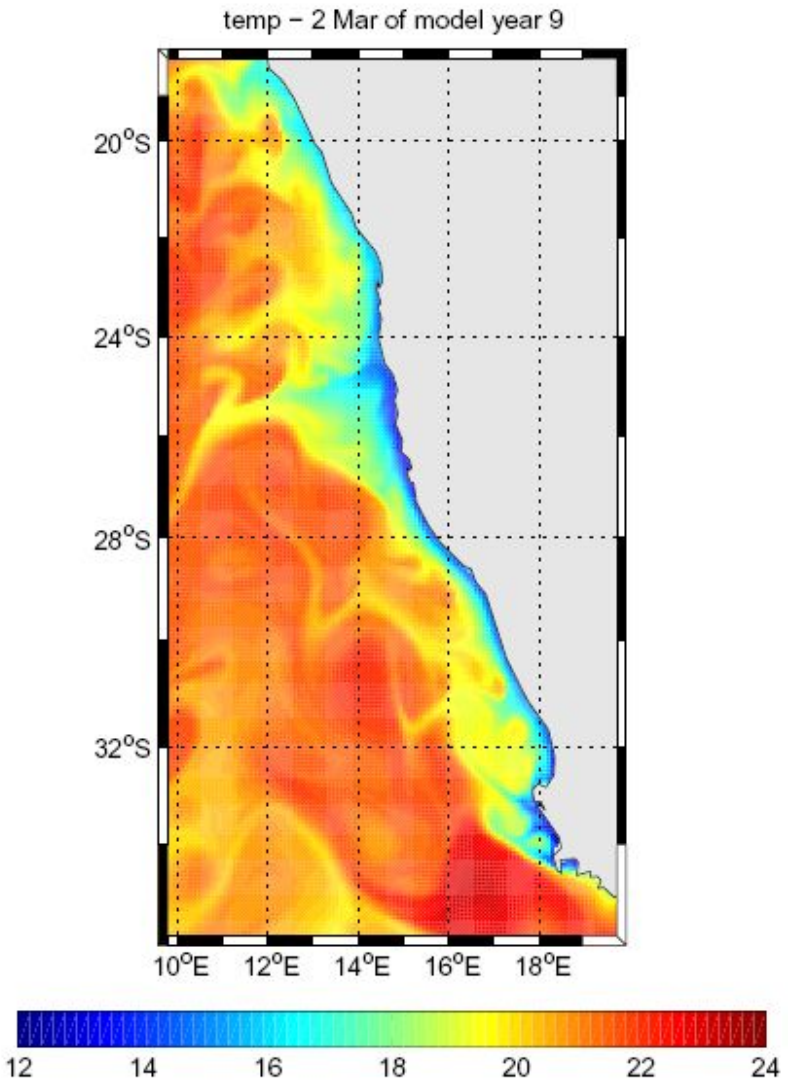


Equilibrium dynamics and seasonal cycle in the Benguela Current System:

- The seasonal cycle dominates in the south-east Atlantic.
- Equilibrium conditions are used as the 'benchmark' from which extreme events are measured.
- Investigate the impact of mesoscale variability induced by the Agulhas Current on the Benguela upwelling regime.
- A study of the entire system in a cohesive manner.

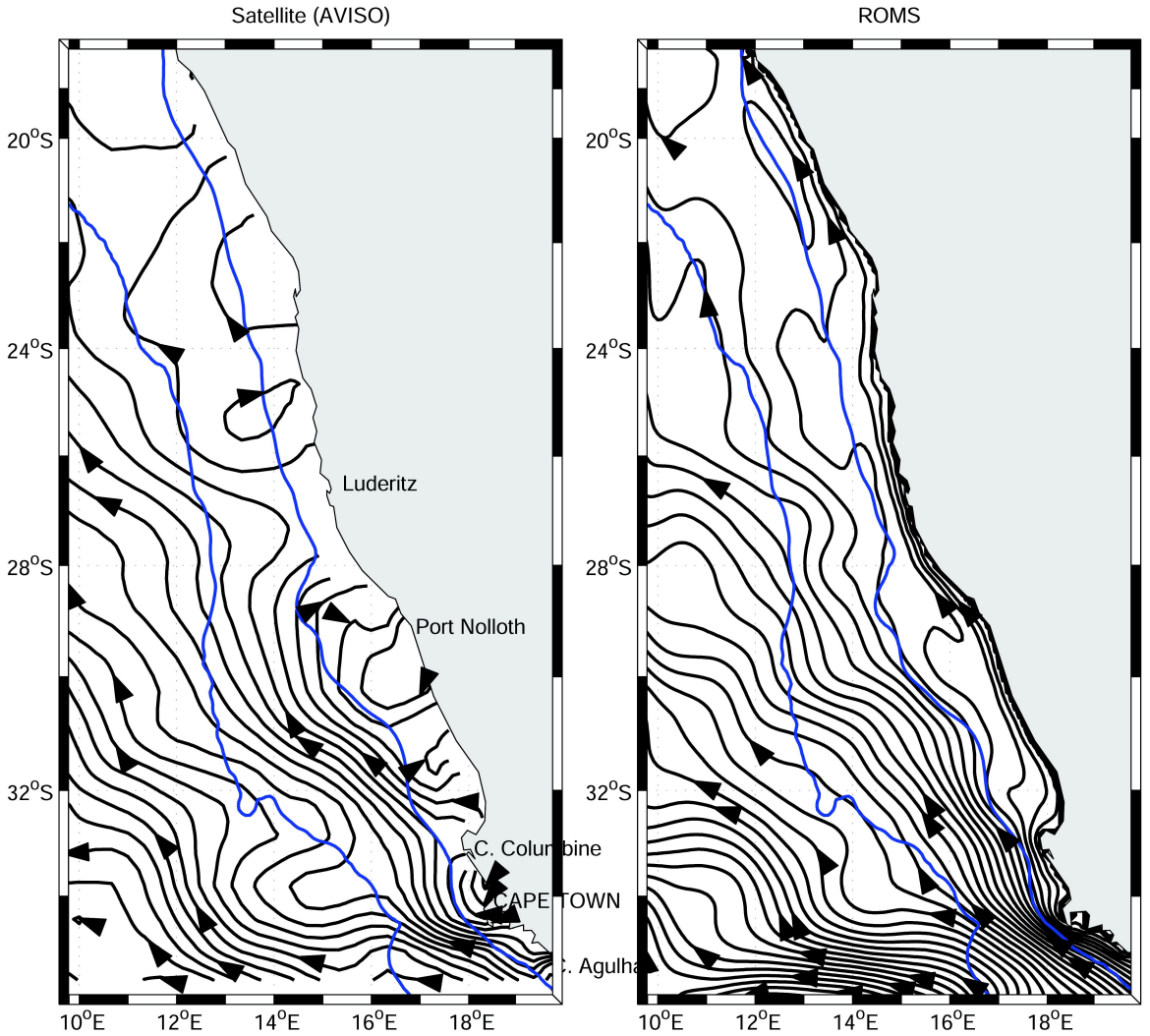
ROMS child domain for the Benguela

Domain:
18-35°S, 10-20°E
Horizontal resolution:
~9km (125x239)
Vertical resolution:
32 sigma levels
(0.31/0.51 m at top,
1.86/784 m at bottom)
Boundary conditions:
SAfE (1 way nesting using AGRIF)
Bottom topography:
GEBCO 1'



10 years (2 year spin-up) forced with 0.5° QuikSCAT climatological winds, COADS surface heat fluxes and fresh water fluxes.

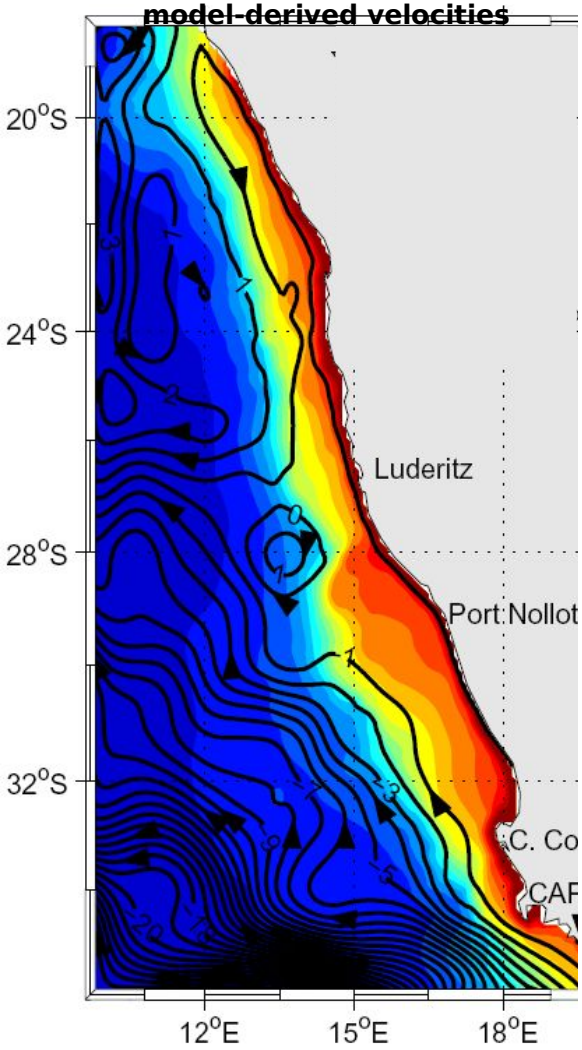
Mean surface geostrophic flow



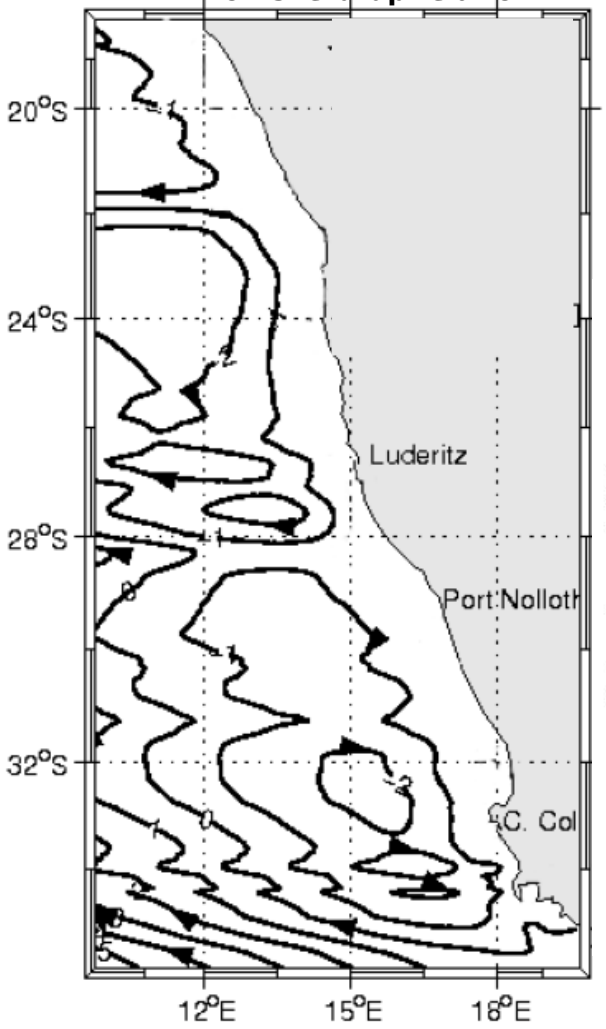
- Two streams of equatorward flow separated by cyclonic meander.
- Evidence of weak poleward flow in north at shelf-edge.
- Topographical control of equatorward flow in south.

Large-scale transport: 0-1000 m

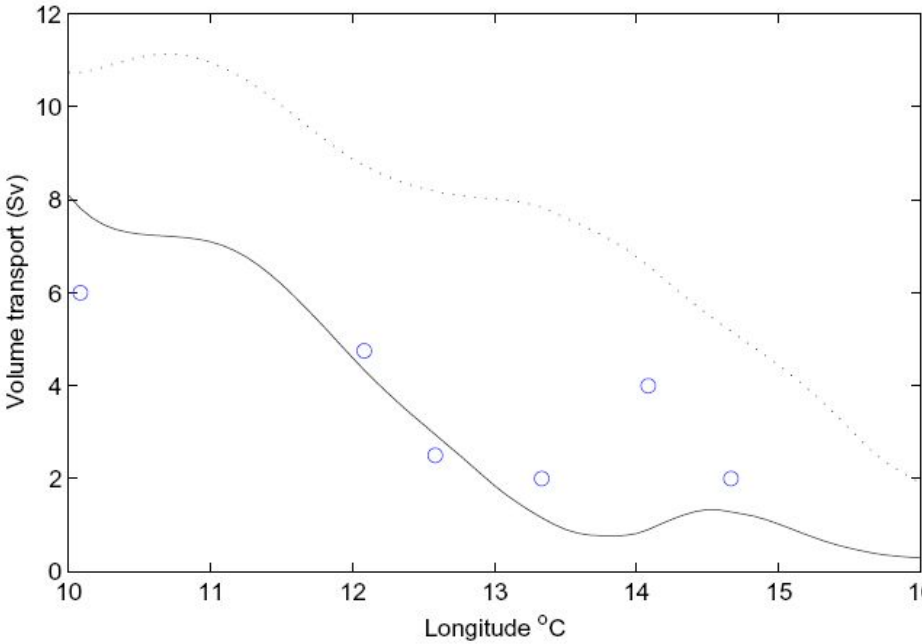
Transport streamfunction based on model-derived velocities



Transport streamfunction based on Sverdrup relation

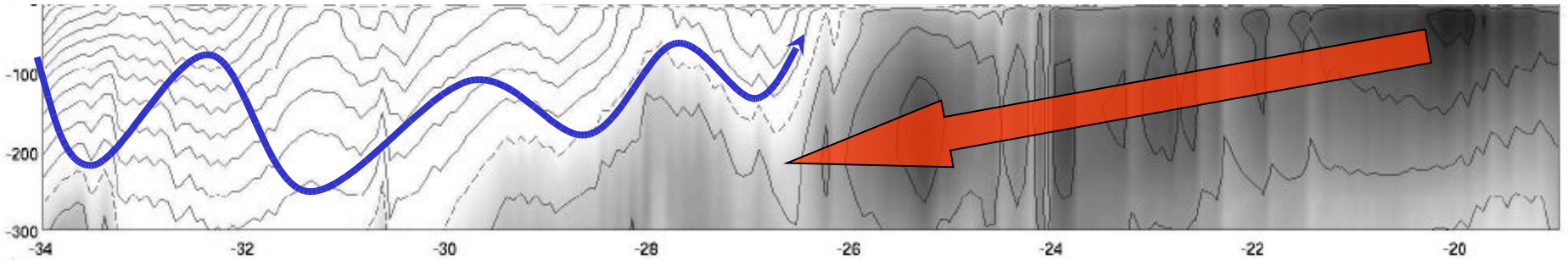


Benguela sources and transports (BEST,Garzoli and Gordon,1996) data (blue circles) and ROMS (solid line) across 30°S.

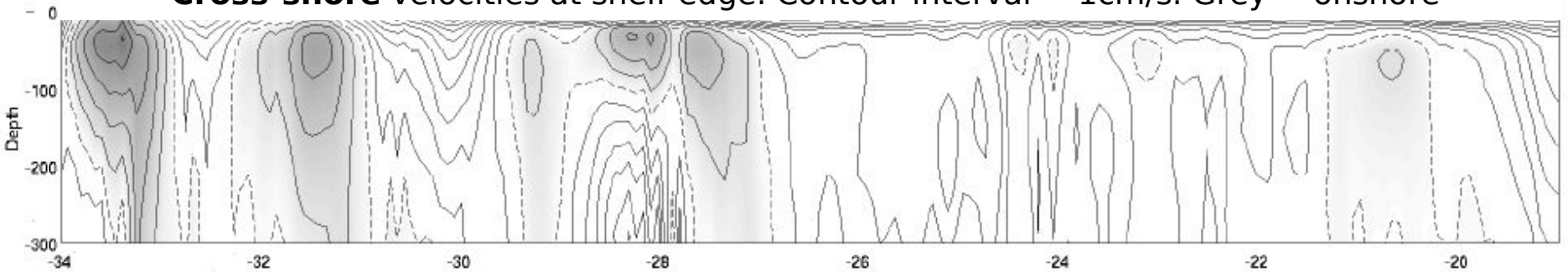


Shelf-edge velocities

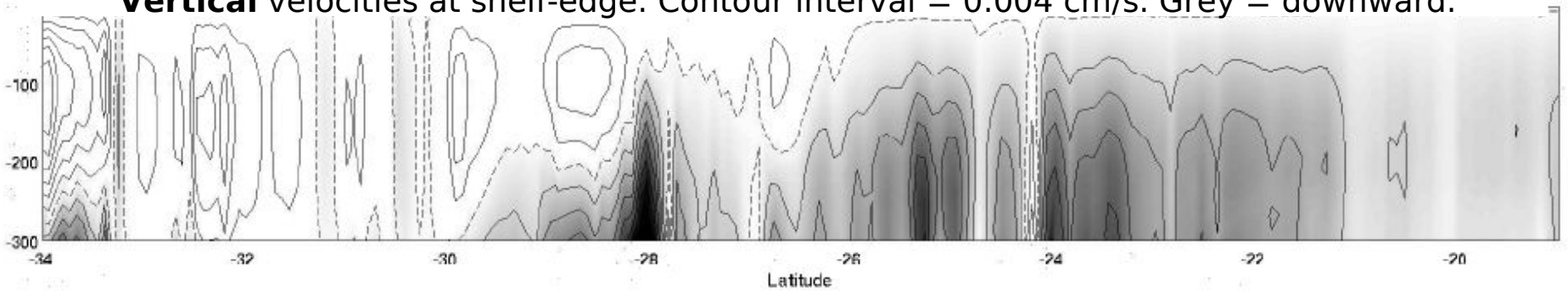
Alongshore velocities at shelf-edge. Contour interval = 2 cm/s. Grey = poleward.



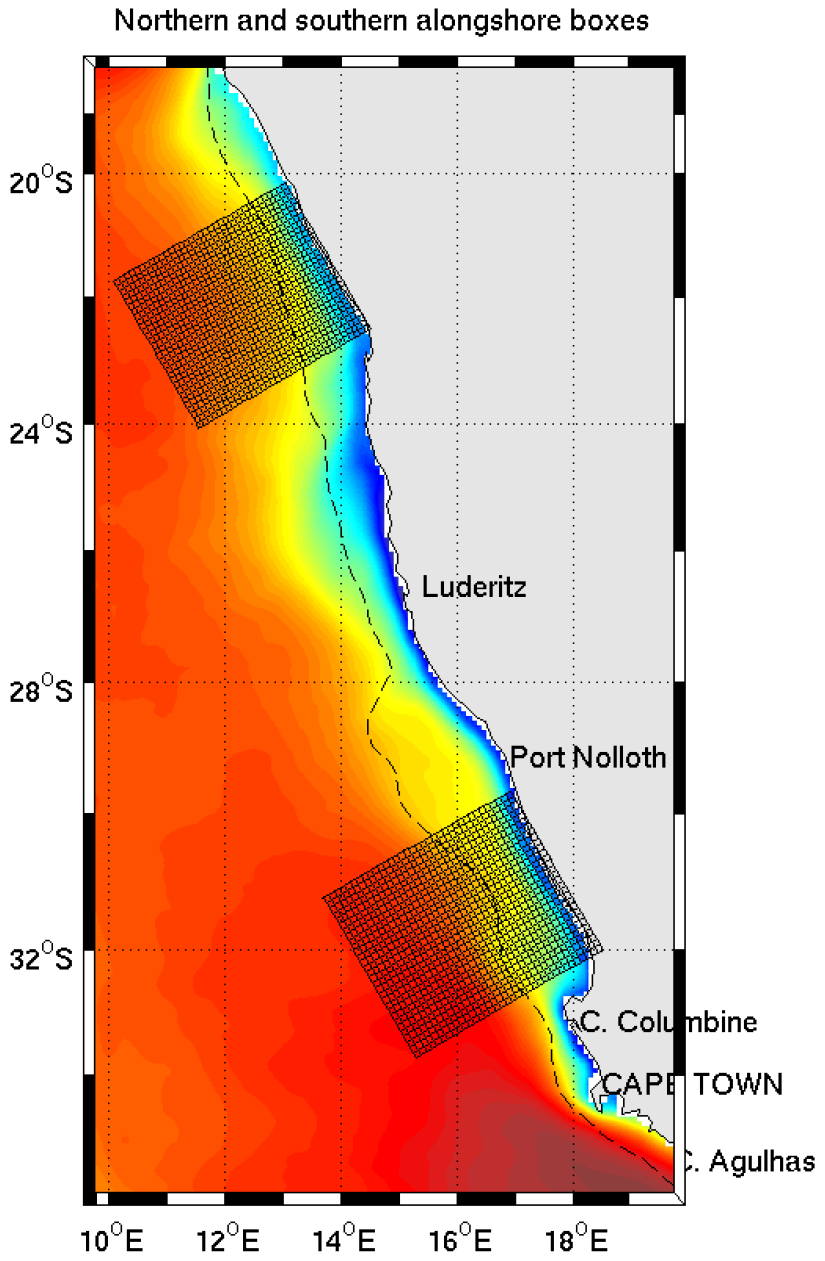
Cross-shore velocities at shelf-edge. Contour interval = 1cm/s. Grey = onshore



Vertical velocities at shelf-edge. Contour interval = 0.004 cm/s. Grey = downward.

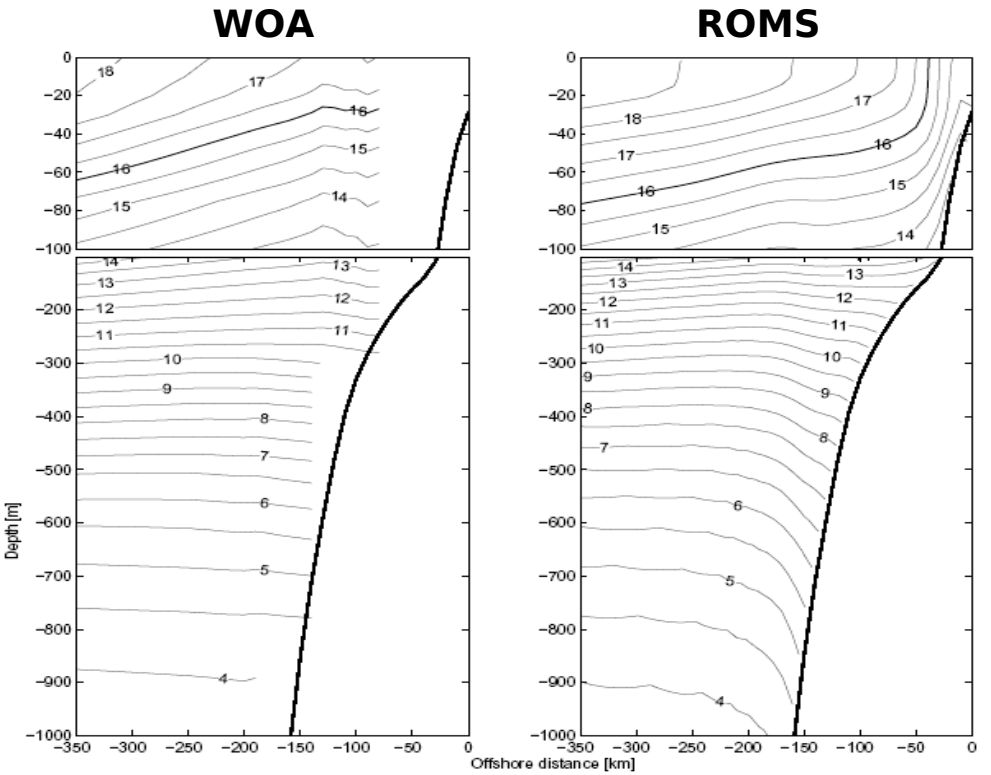


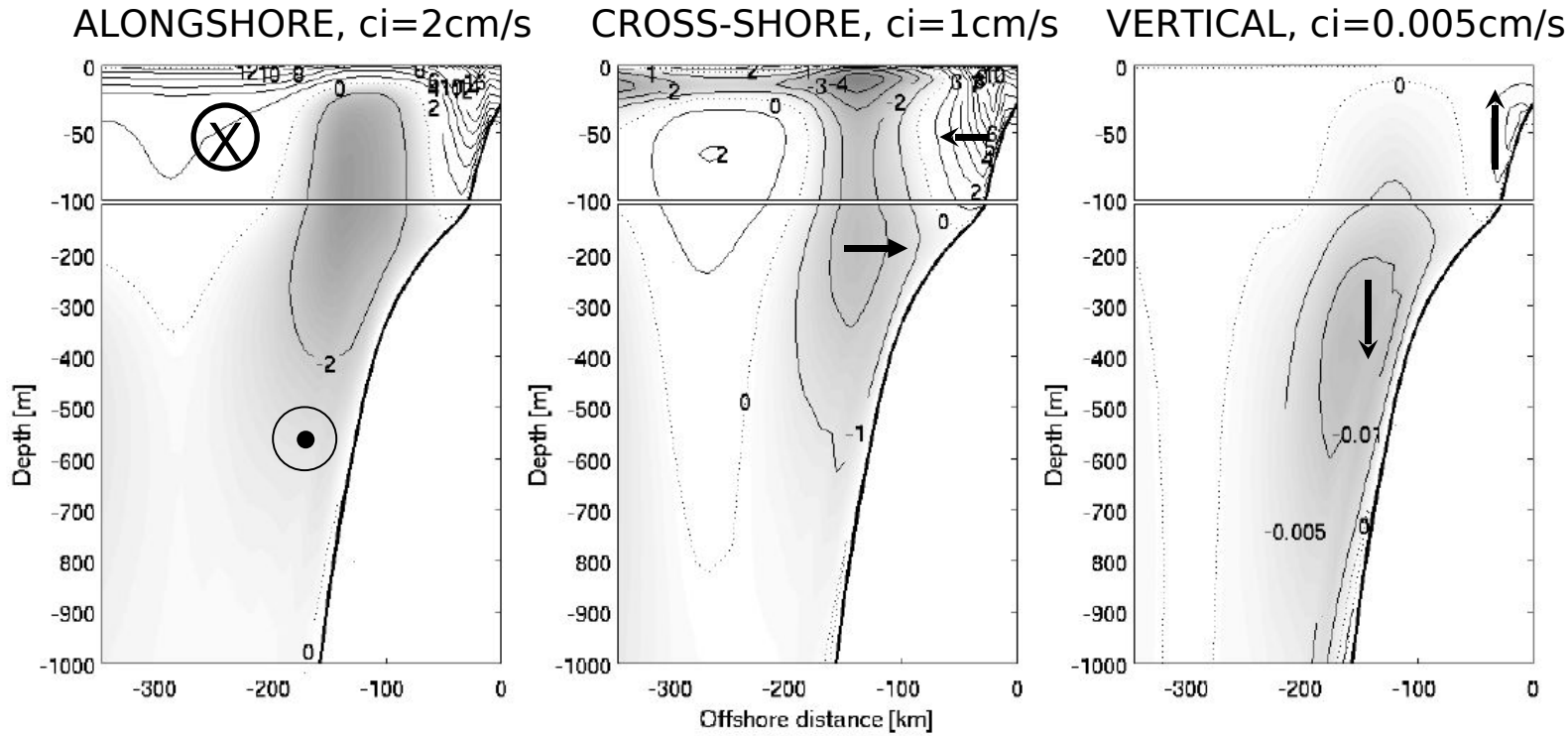
Northern Benguela / Southern Benguela



Northern Benguela:

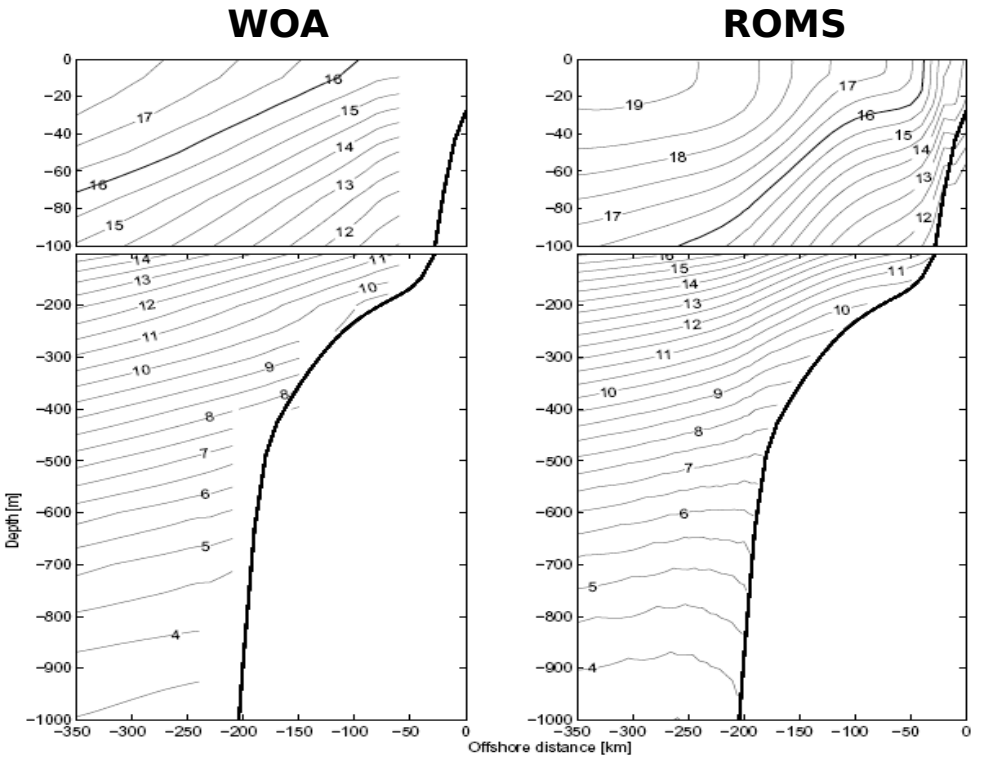
- Downward tilt of isotherms toward the coast associated with poleward flow over the shelf edge.
- Poleward flow coincident with downward velocities.
- Poleward flow strongest in spring and summer, associated with strong negative curl during these seasons.

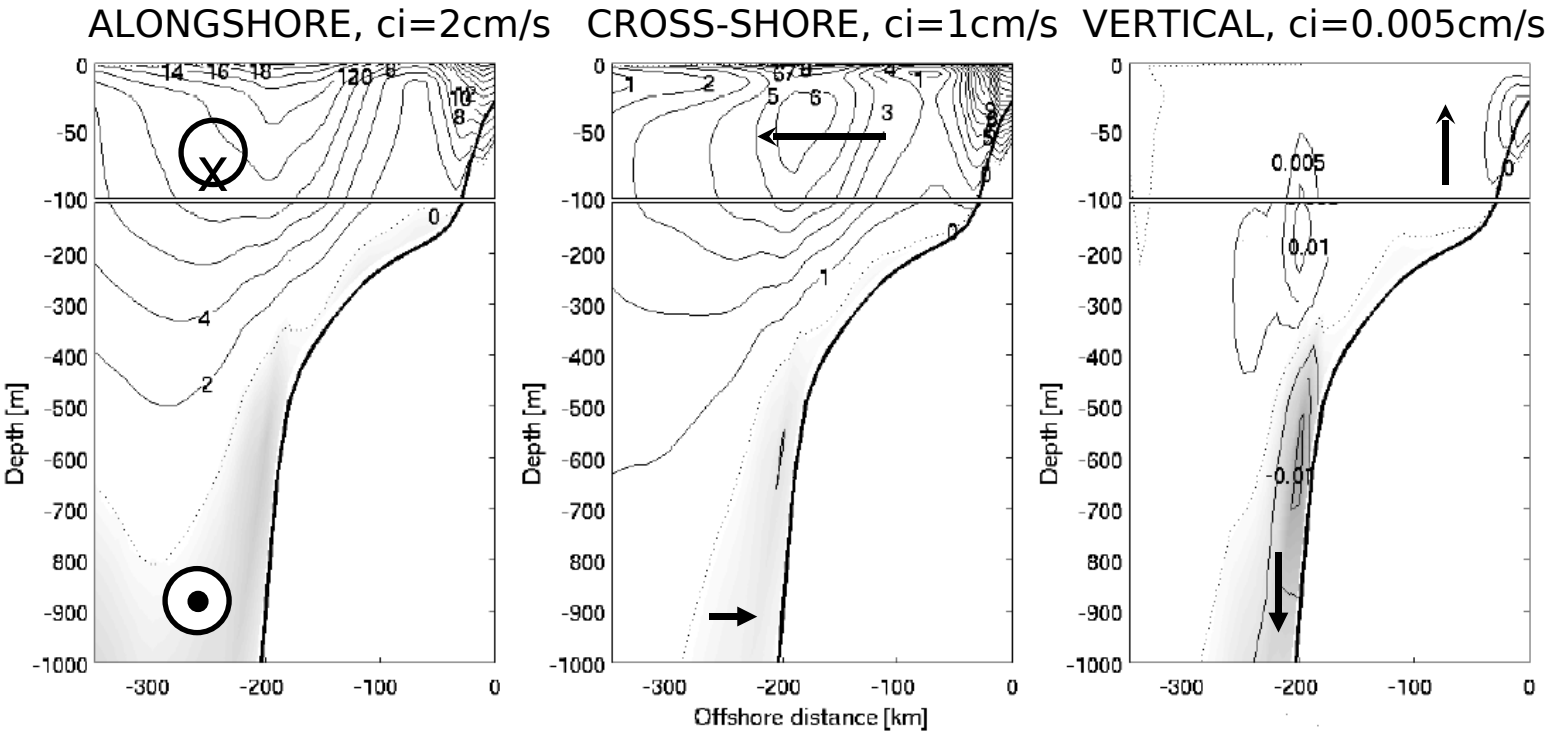




Southern Benguela regime

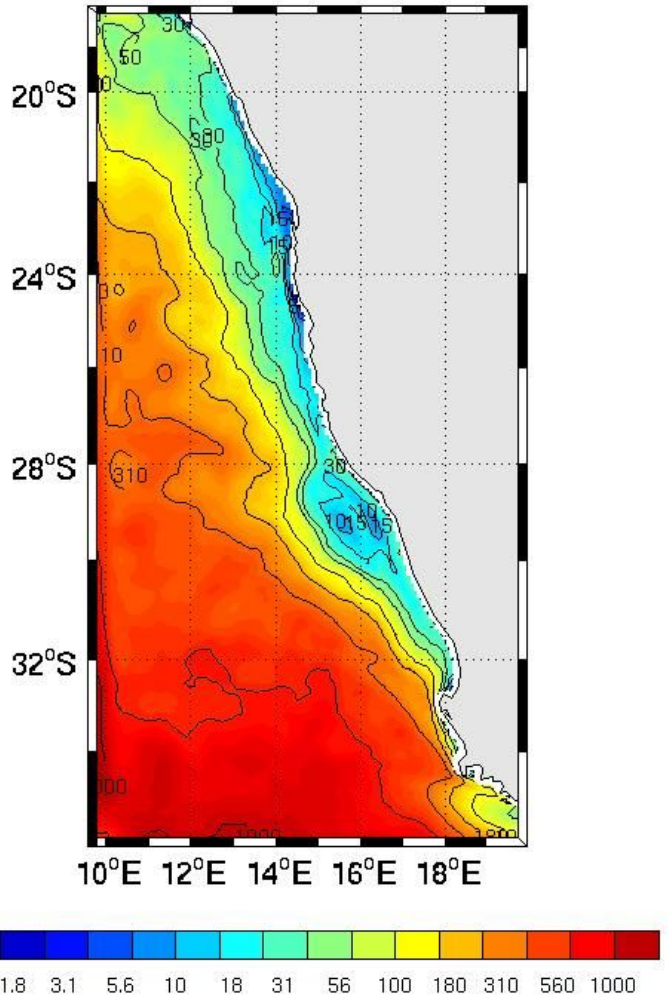
- Steep tilt of isotherms off the shelf and ‘flat’ on shelf.
- Deep poleward undercurrent at shelf break associated with downward tilting isotherms.
- Secondary upwelling at shelf-edge.
- No distinct seasonality evident in the Benguela Current.



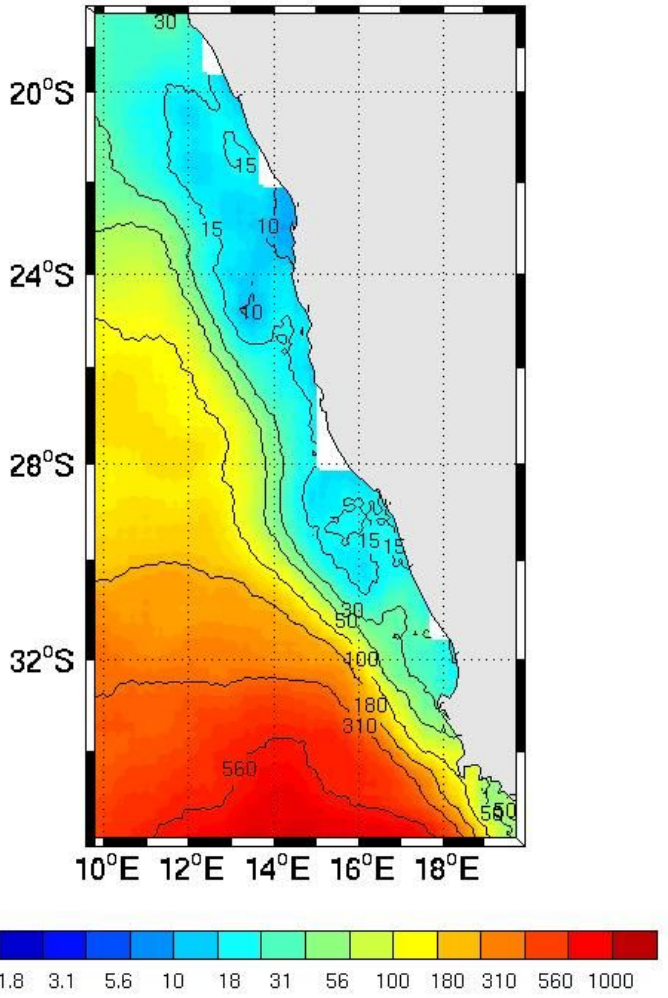


Mesoscale variability: eddy kinetic energy (EKE)

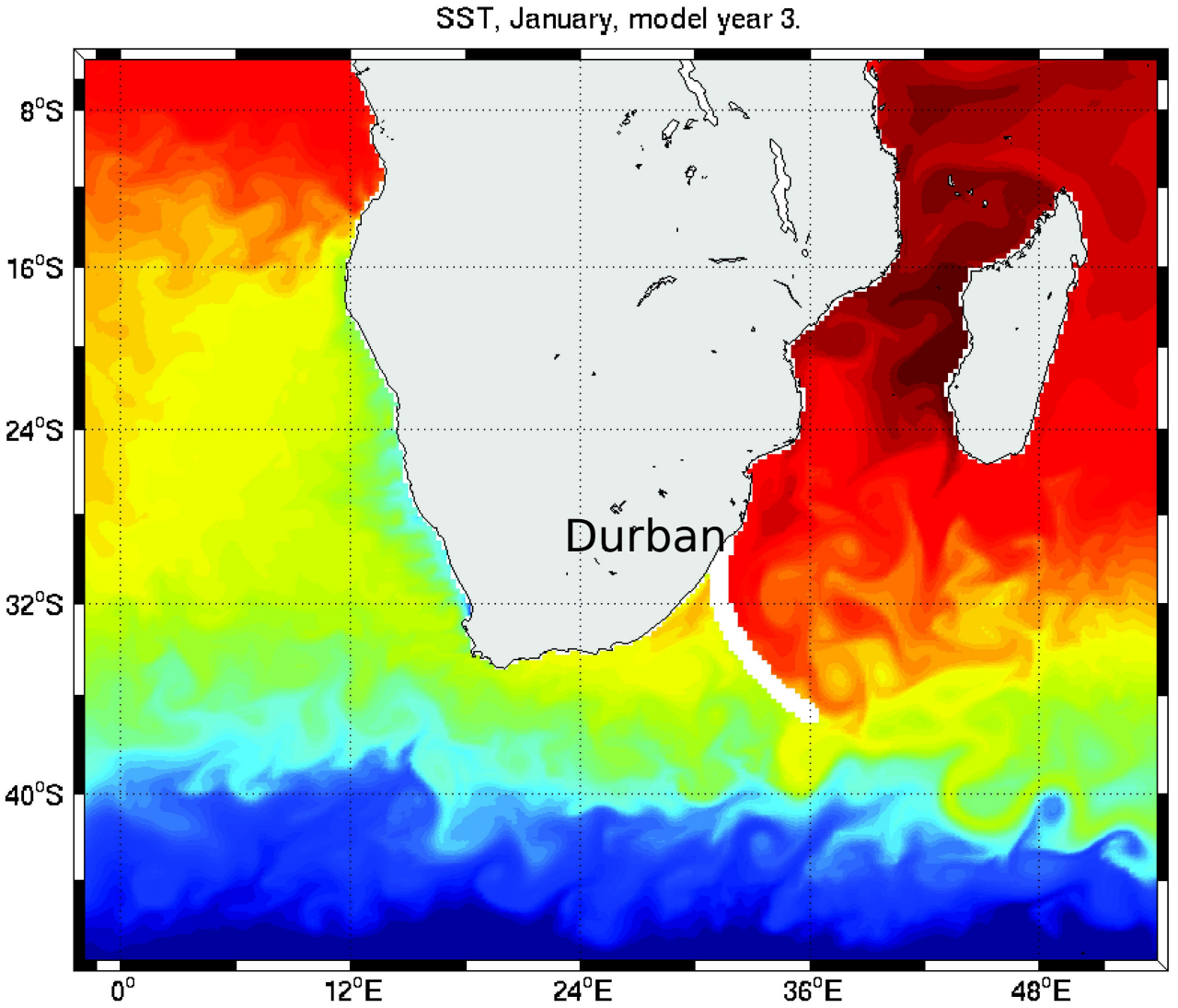
Model-derived geostrophic EKE



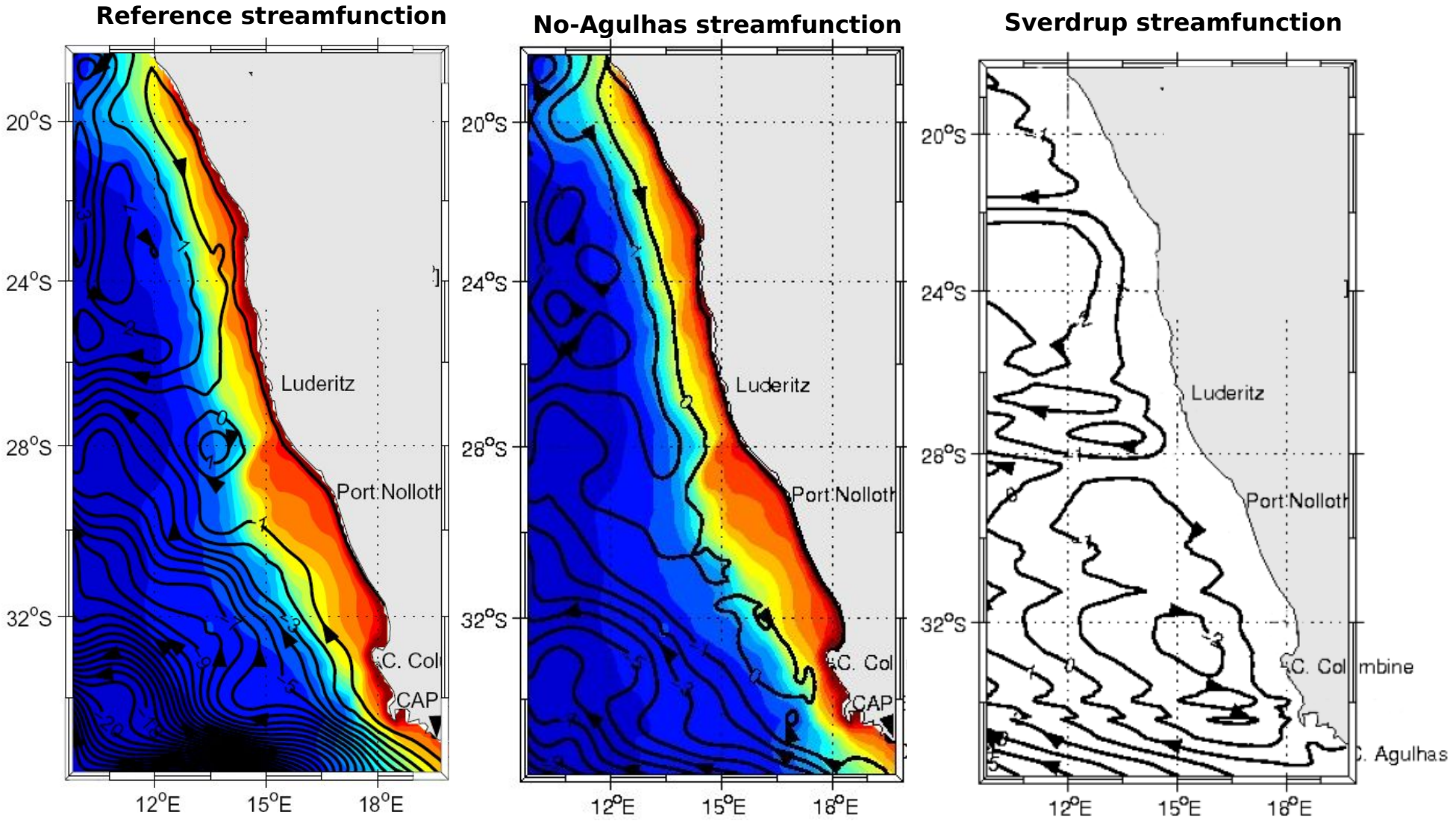
AVISO satellite-derived EKE



Testing the effects of the Agulhas Current: No-Agulhas Experiment

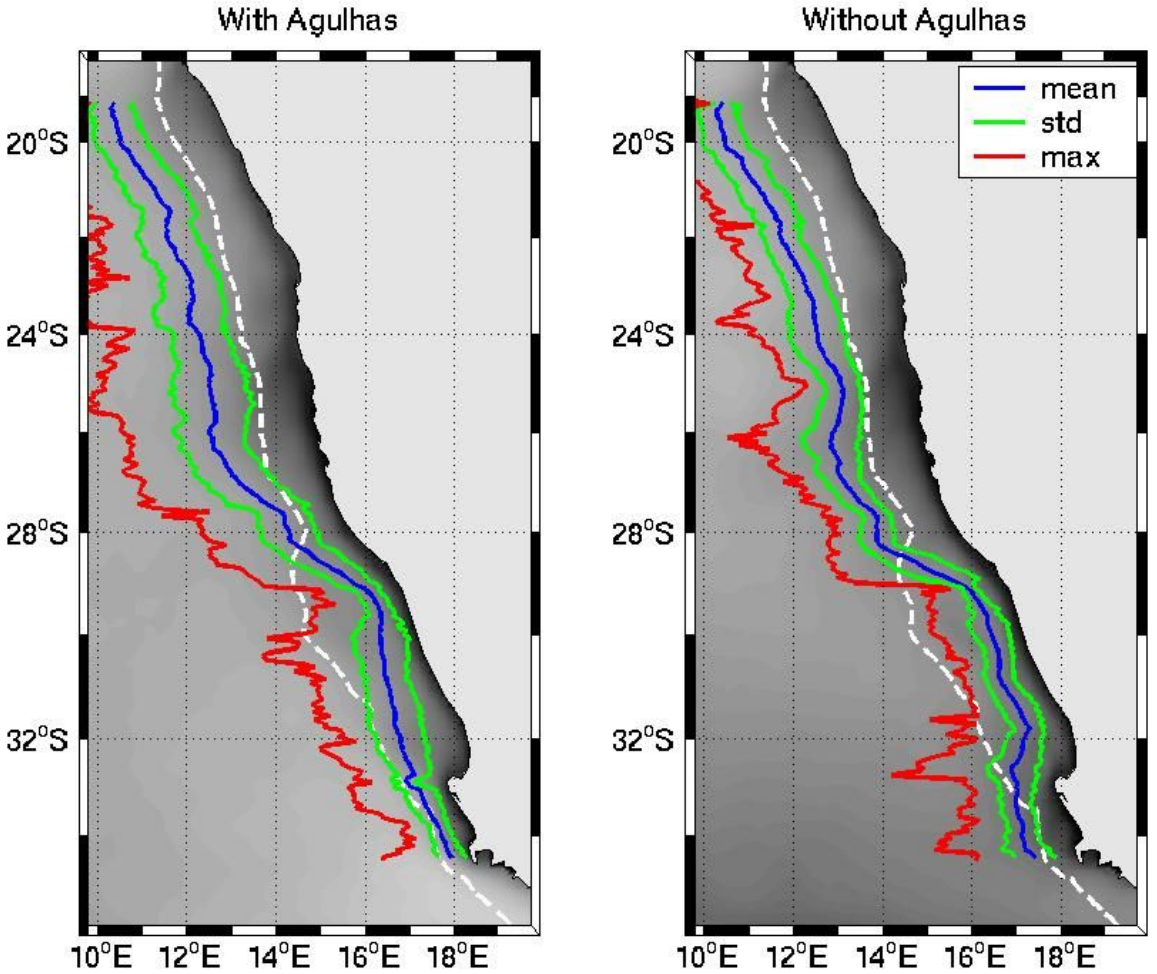


Large-scale transport: 0-1000 m



The summer upwelling front

Line following the frontal SST (Latitude) = 3/4 offshore SST + 1/4 coast SST



Northern Benguela:

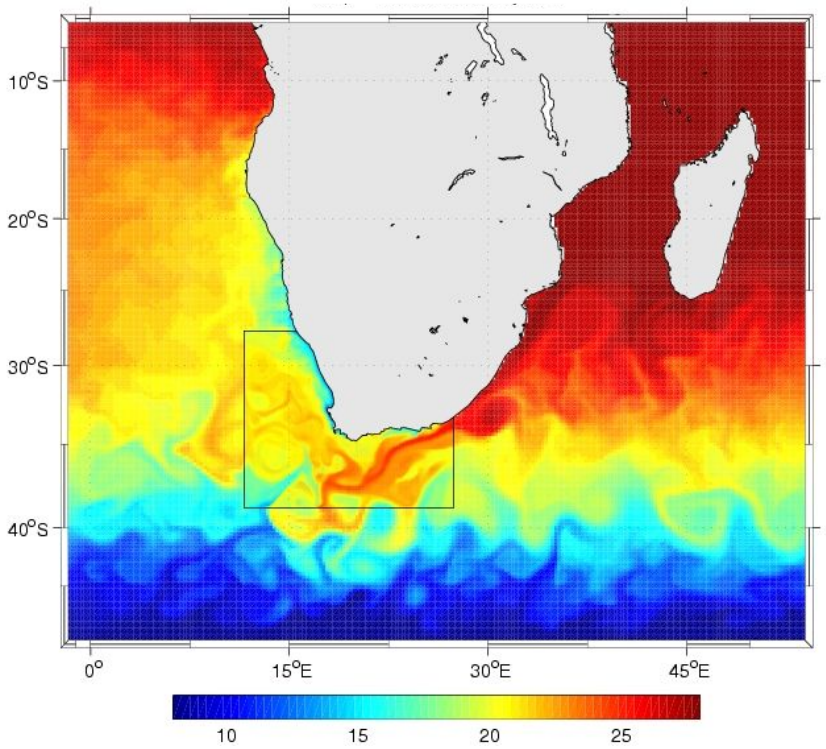
- Front offshore of the shelf break.
- No significant effect of Agulhas.
- Front slightly more inshore without Agulhas.

Southern Benguela:

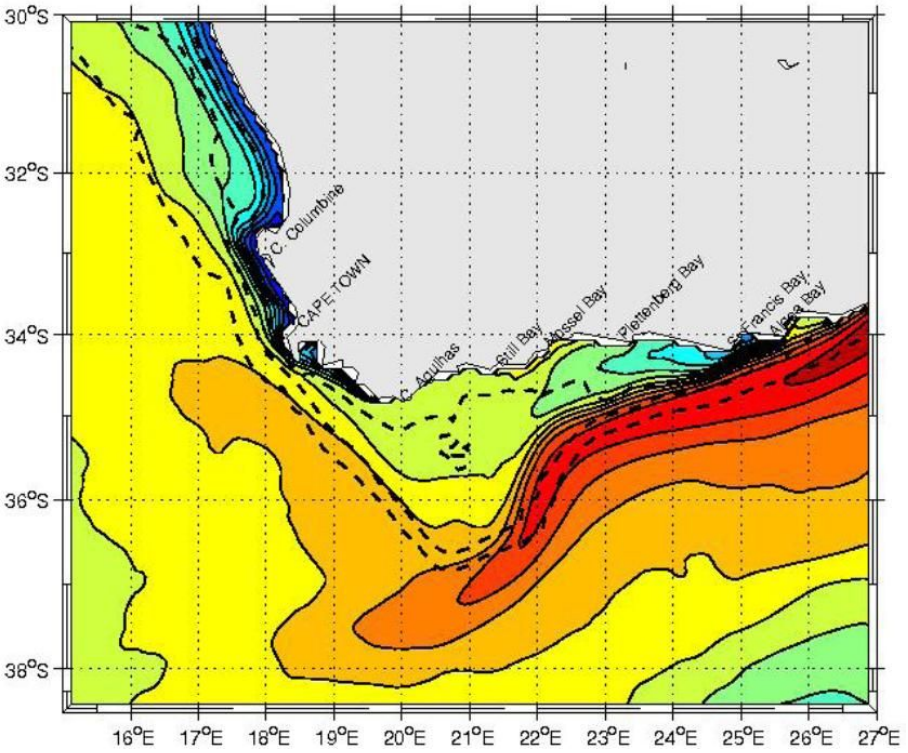
- Front following the topography.
- Cape Columbine - Luderitz: front more inshore without Agulhas.
- Cape Point - Cape Columbine : front more offshore without Agulhas.

The effect of the Agulhas Current on the Agulhas Bank

Nicolette Chang, PhD Thesis, UCT.

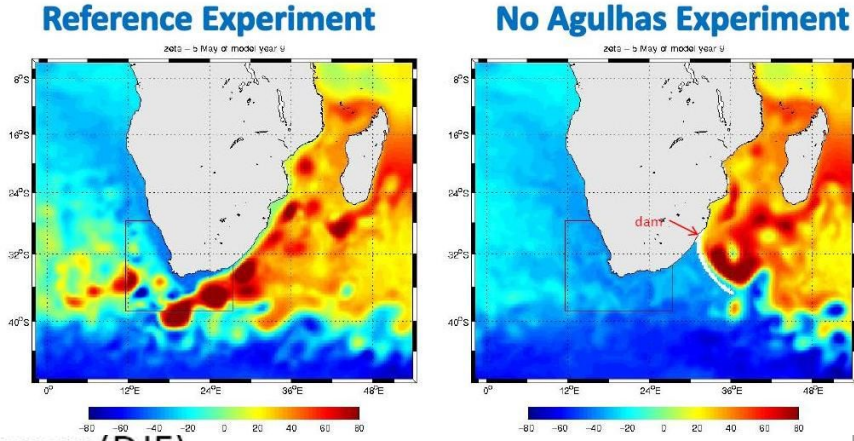


Sea Surface Temperature [°C]



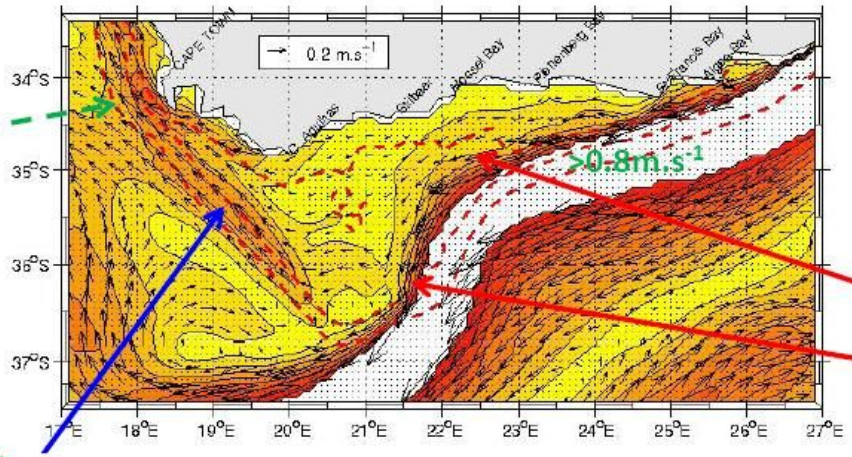
Mean summer SST [°C] for the zoom

No-Agulhas Experiment

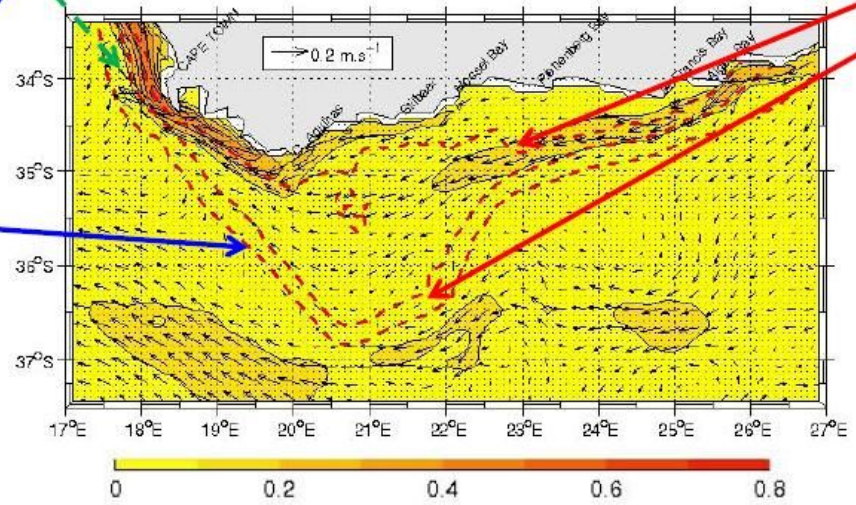


The **Good Hope Jet** is slightly faster in the Reference Experiment (0.5-0.6m.s^{-1}) compared to the No Agulhas Experiment (0.4-0.5m.s^{-1}) .

Reference Experiment - 10m Summer (DJF)



No Agulhas Experiment - 10m Summer (DJF)

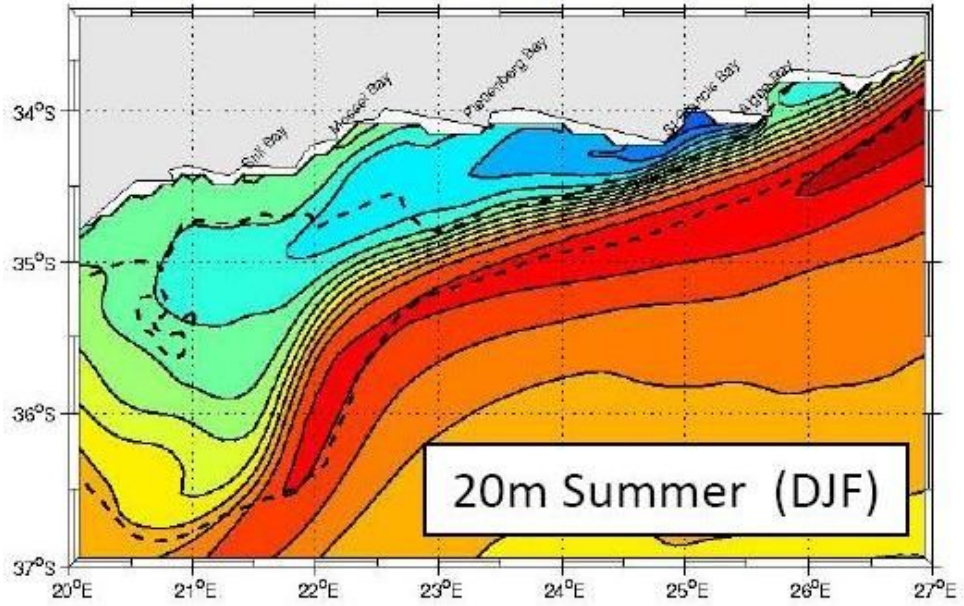


Agulhas Current / Agulhas filament drives northwestward flow on the outer West Agulhas Bank up to 0.4-0.5m.s^{-1}. In the No Agulhas Experiment flow is less than 0.1m.s^{-1}.

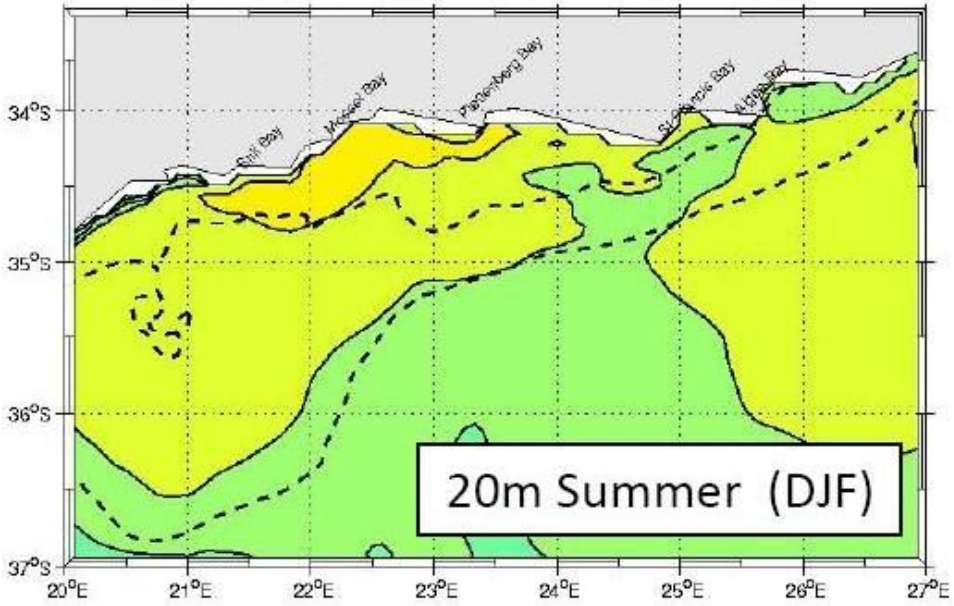
Currents on the outer East Agulhas Bank are related to the Agulhas Current. The No Agulhas Experiment shows relatively slower current speeds (<0.3m.s^{-1}).

The Agulhas Current drives the cool ridge

Reference Experiment

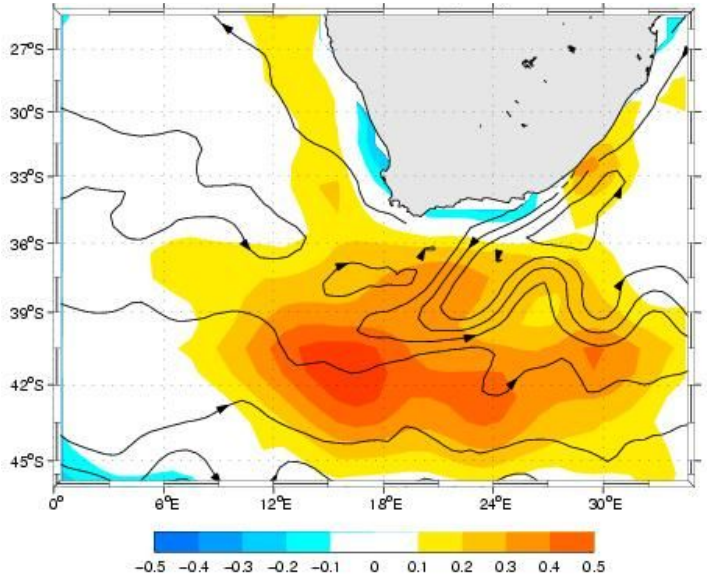


No Agulhas Experiment

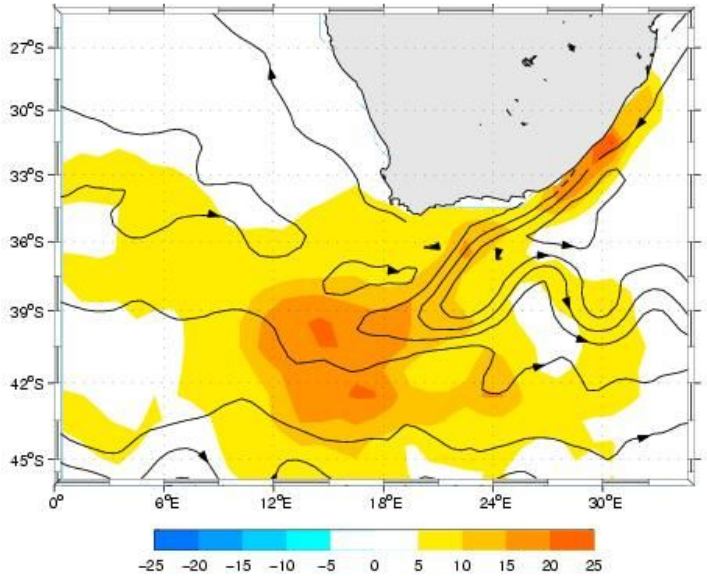


Recent increase of the flux of heat and salt from the Indian to the Atlantic Ocean

OI SST 1982-2008 decadal trend [°C/10 years]

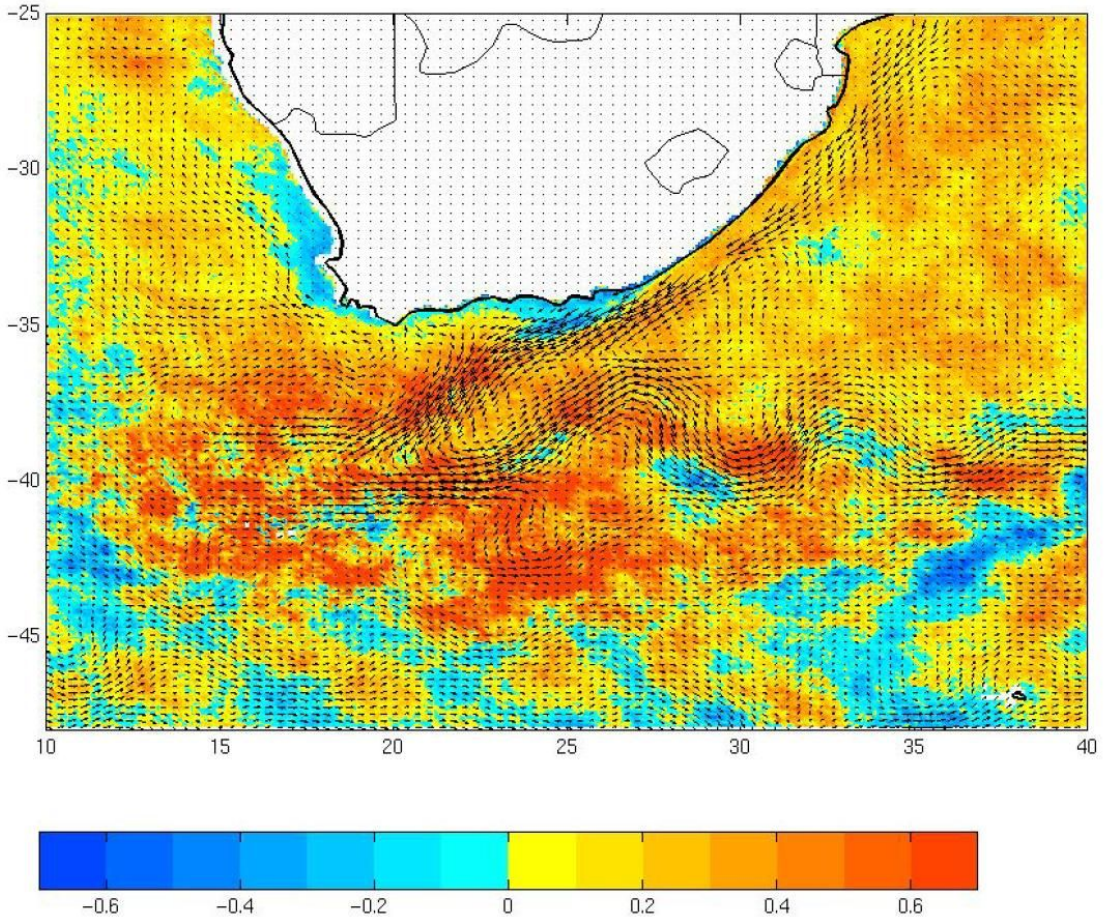


OA flux 1982-2008 decadal trend [W.m^{-2}/10 years



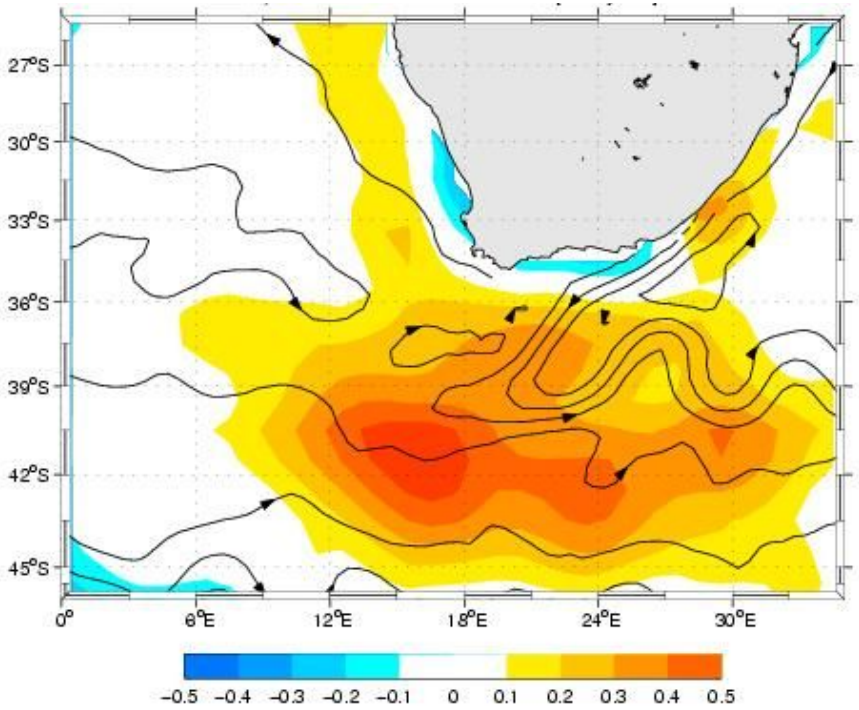
Warming in the Agulhas Retroflection region

AVHRR SST 1985-2006 decadal trend [°C/10 years]



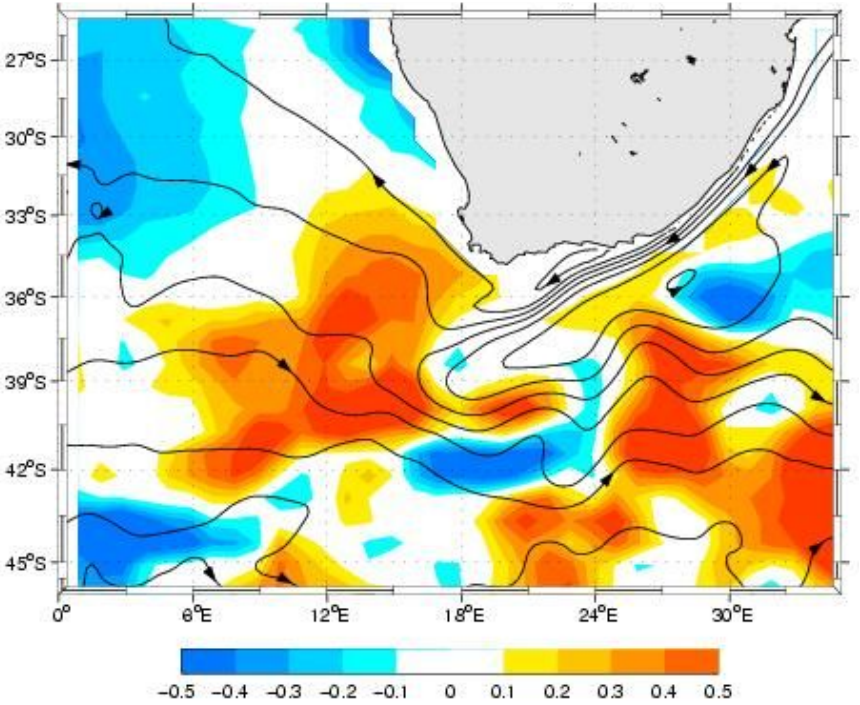
Rouault, M., P. Penven, and B. Pohl, Recent increase of the flux of heat and salt from the Indian to the Atlantic Ocean, corrected and resubmitted.

OI SST 1982-2008 decadal trend [°C/10 years]

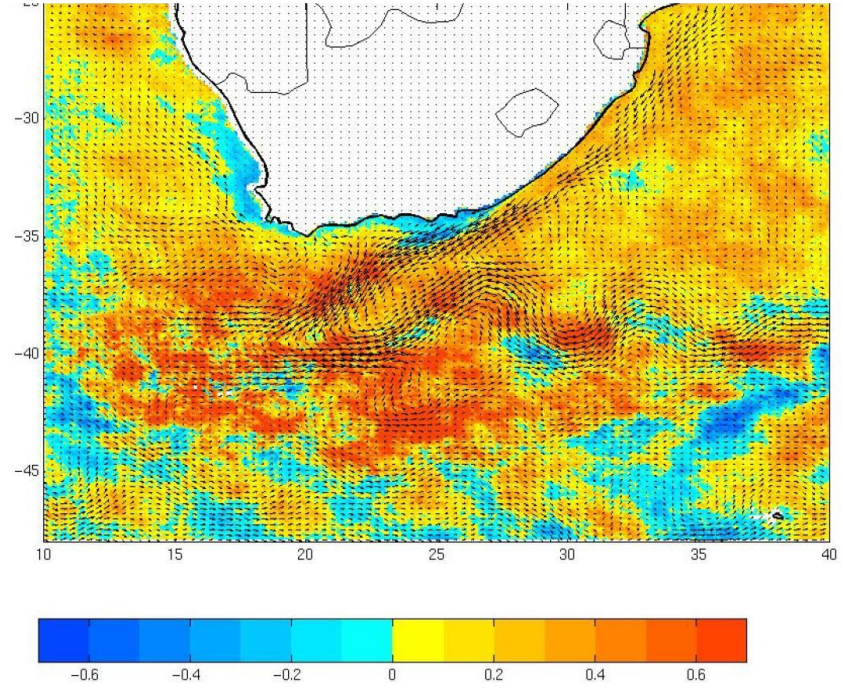


Signal present in the model

SAfE SST 1982-2001 decadal trend [°C/10 years]

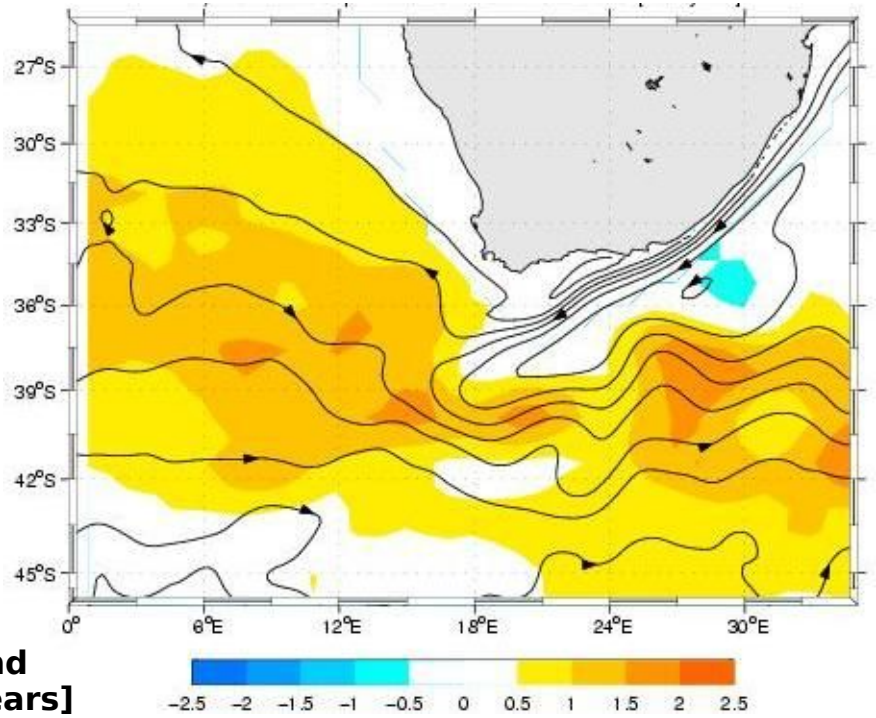


AVHRR SST 1985-2006 decadal trend [°C/10 years]

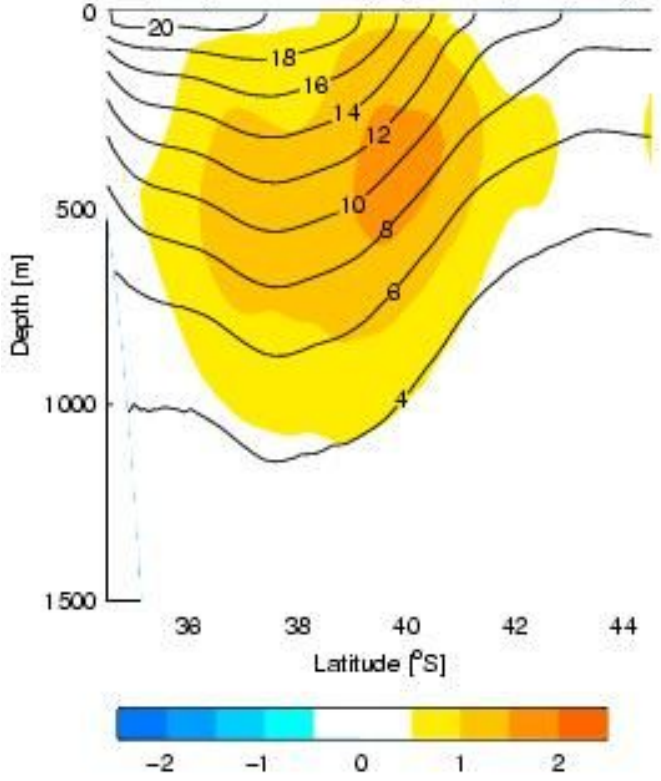


Strong signal at depth in the model

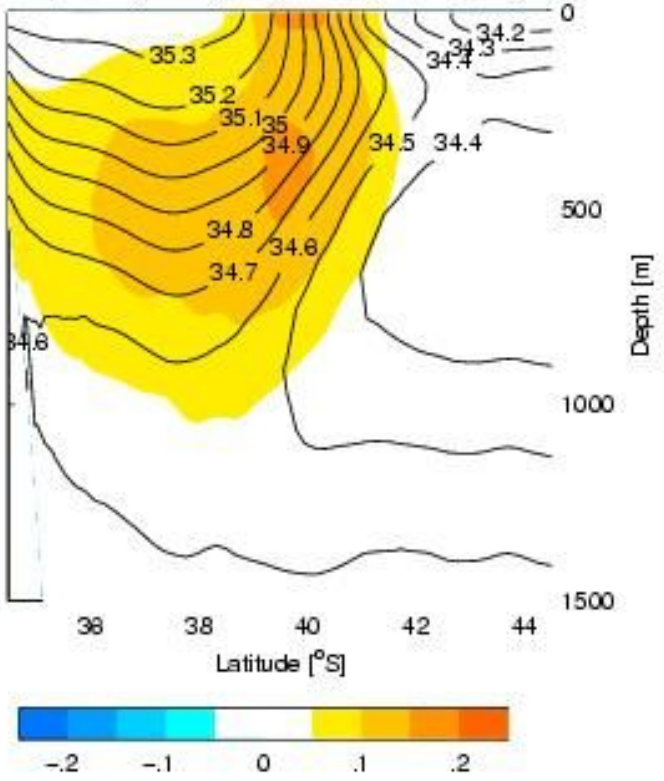
SAfE 500m temperature 1982-2001 decadal trend [°C/10 years]



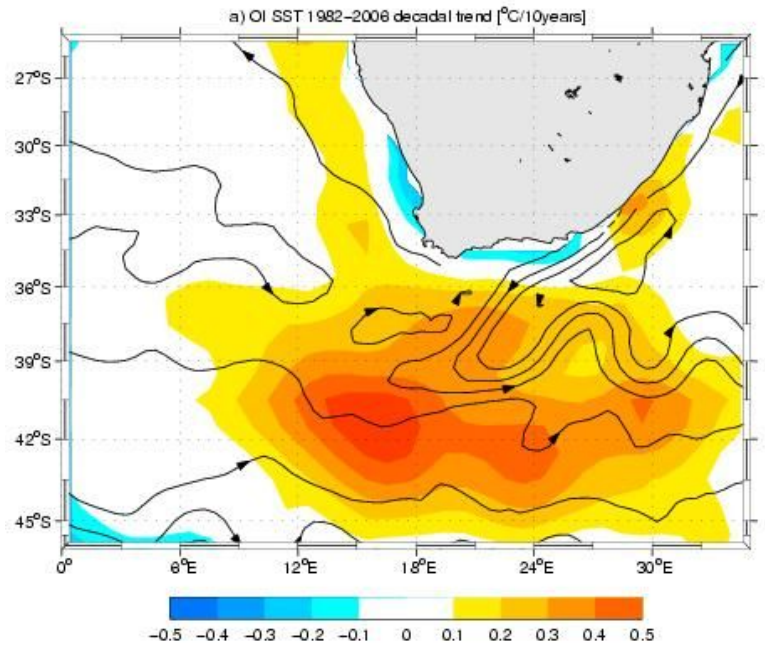
Temperature mean [°C] and decadal trend [°C/10 years]

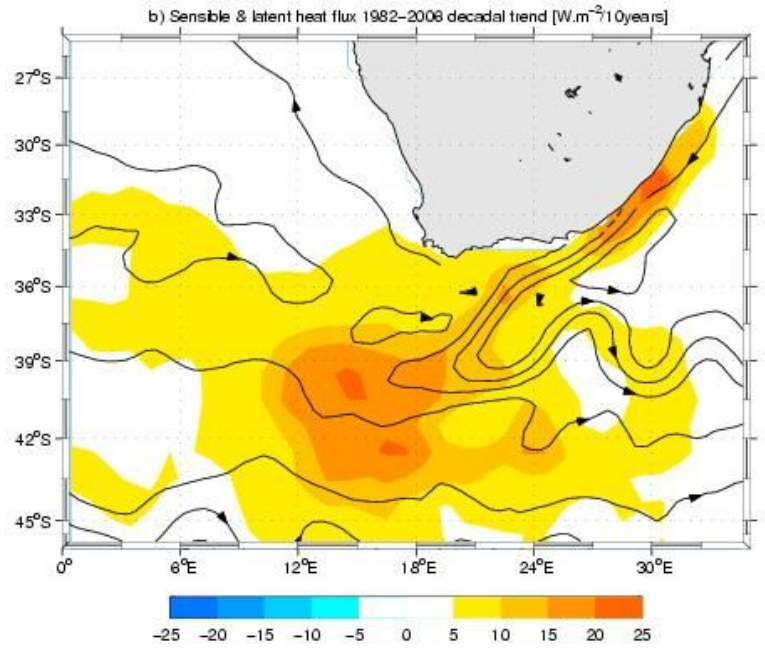


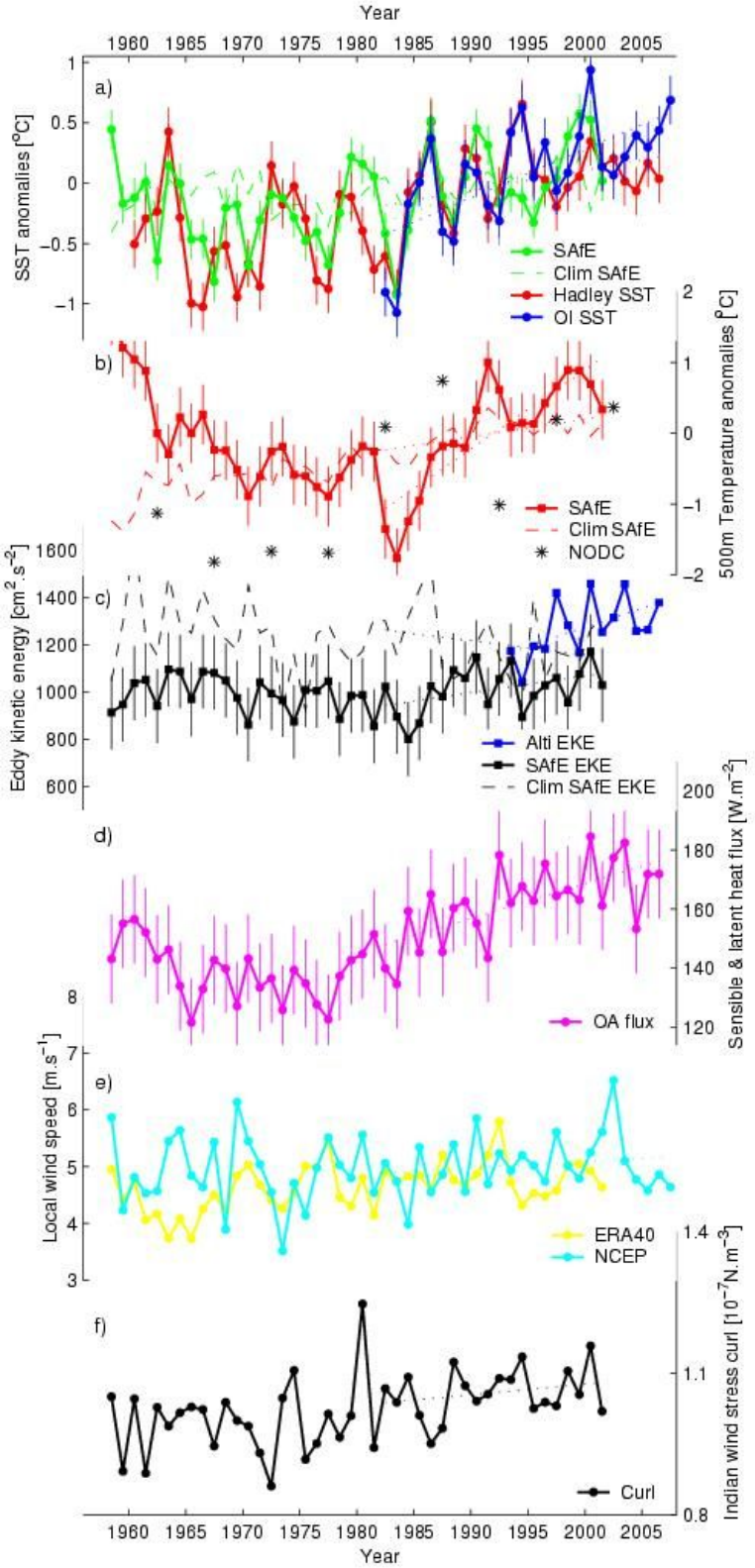
Salinity mean [PSU] and decadal trend [PSU/10 years]



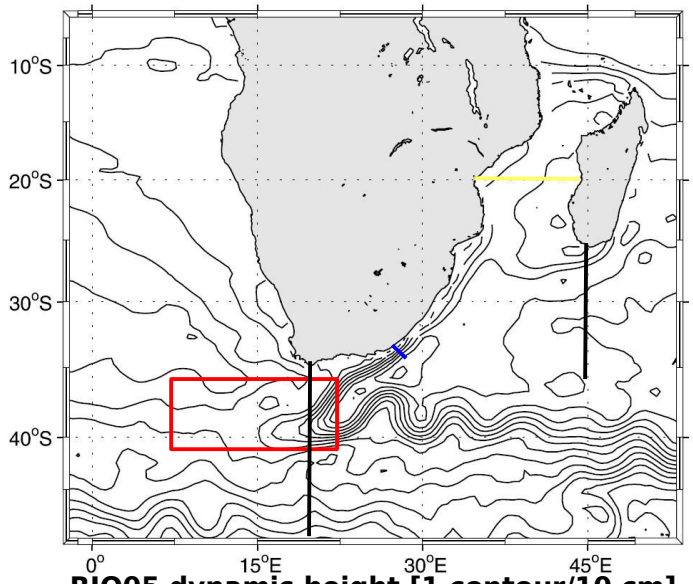
Average on 36°S-41°S; 10°E-20°E:







Causes and consequences of the recent changes in the Agulhas Current System



RIO05 dynamic height [1 contour/10 cm].