Impacts of changes in the Thermohaline Circulation on the climate and variability of the Tropical and Subtropical South Atlantic

Numerical Simulations with a coupled Ocean Atmosphere Model

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Grupo de Estudos do Oceano e do Clima
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Repercussões dos trabalhos do grupo

O GEOCLIM congrega especialistas brasileiros em interação oceano-atmosfera e circulação oceânica em grande escala, e foi criado para coordenar os esforços desenvolvidos país no estudo do papel dos oceanos nas mudanças globais.

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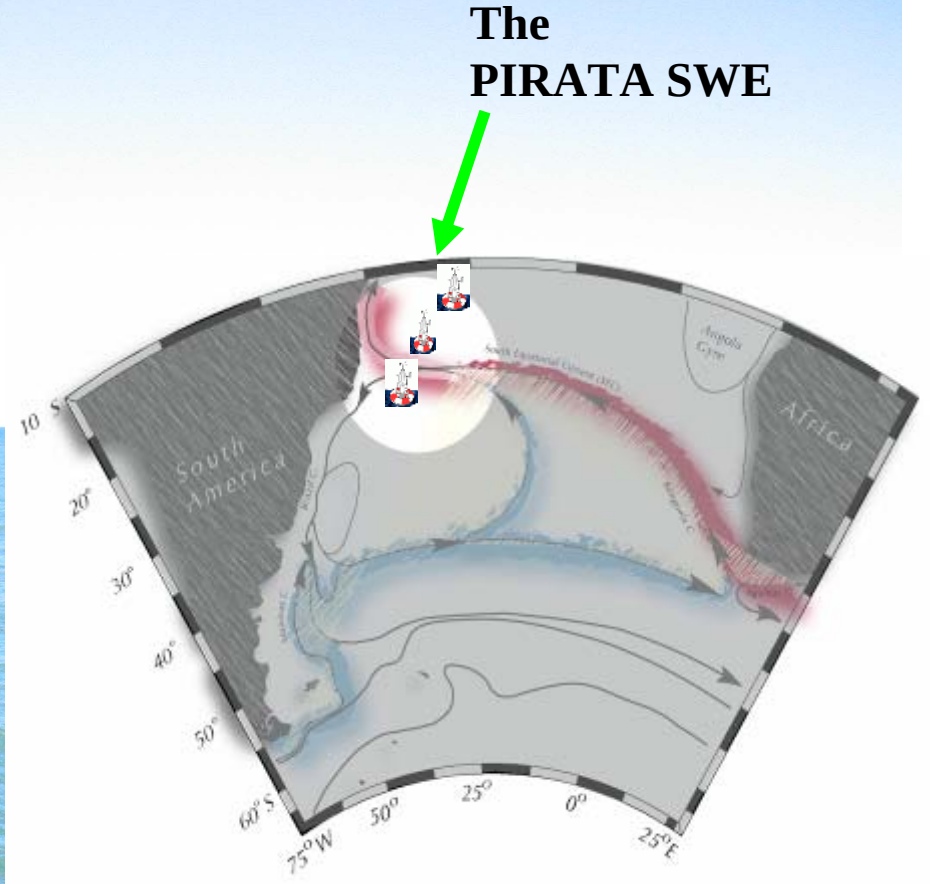
Outline

1. Motivation
2. The modes interannual variability in the Tropical Atlantic
3. The THC and the Atlantic MOC
4. The “Agulhas Leakage”
5. The Numerical Experiments
6. Conclusions

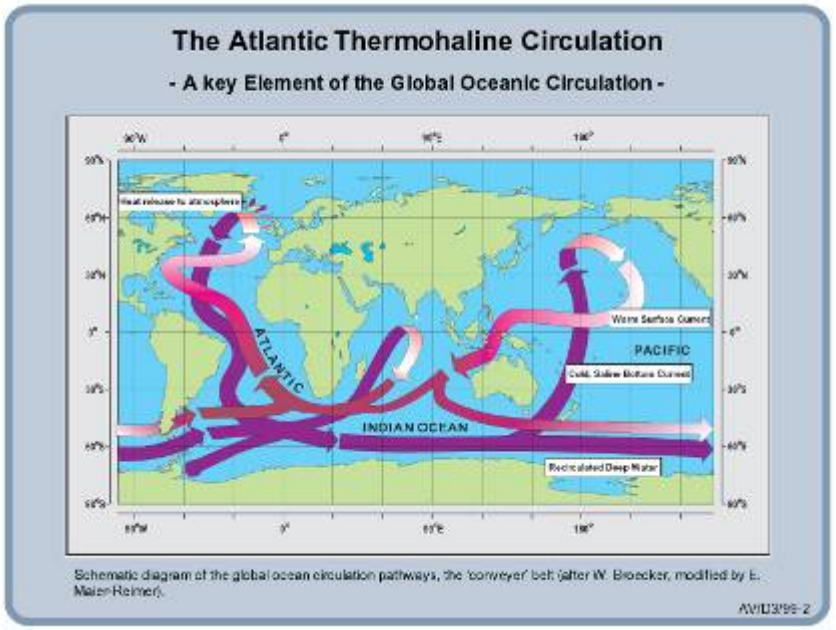
Motivation

The South Atlantic receives considerable inflows from the Pacific, through the Drake Passage, and from the Indian Ocean by means of the rings shed at the Agulhas Current retroflection.

The resulting water mass is part of the upper limb of the Atlantic Meridional Overturning Circulation (MOC)



Modeling studies with coupled climate models suggest that major changes in the strength of the THC significantly affect the atmospheric and oceanic circulation on a global scale.



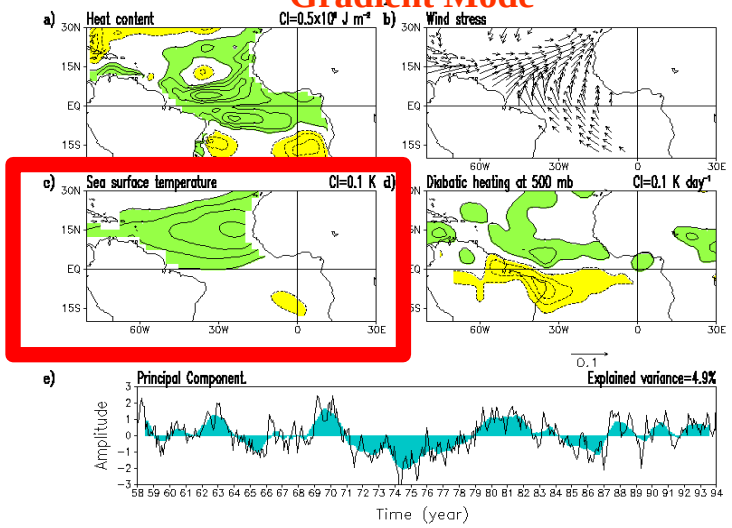
Because the seasonal cycle and interannual variability are strongly linked to the climatological mean state, it is expected that they also be affected by a weakened THC.

The Modes of Variability of the Tropical Atlantic

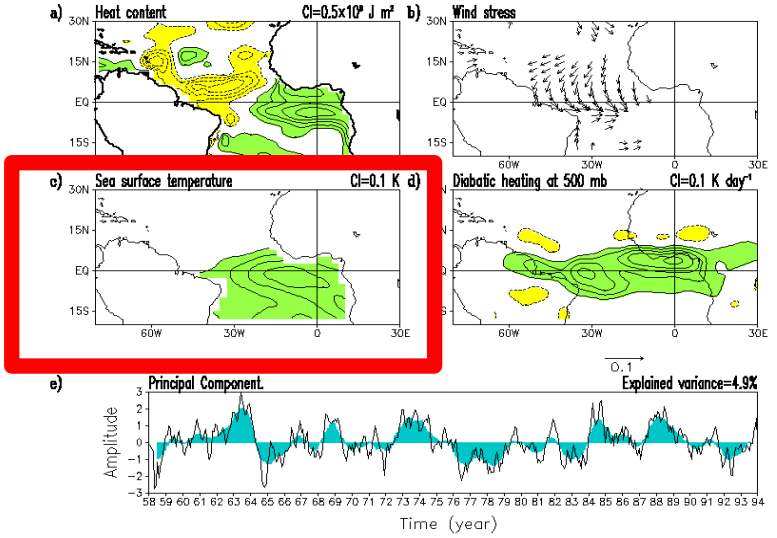
The interannual variability in the Tropical Atlantic is dominated by two modes of variability: **The Equatorial or Cold Tongue Mode and the Gradient Mode (former dipole)**

The Gradient Mode is a decadal mode of variability, in which the equatorial North Atlantic is warmer (positive phase) or cooler (negative phase) than the average.

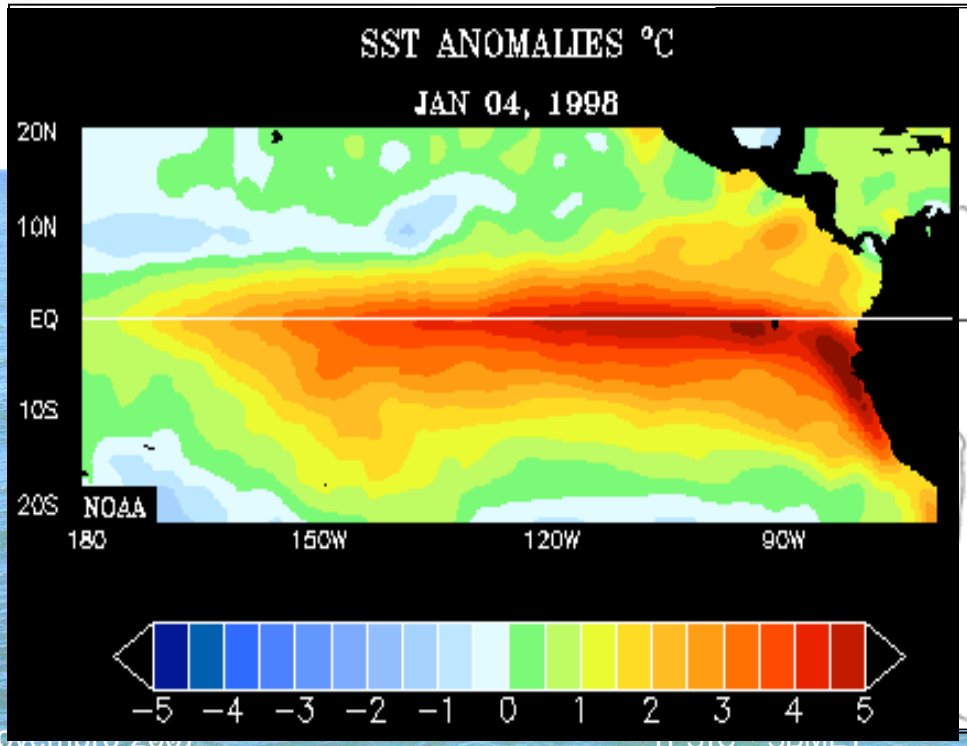
Gradient Mode

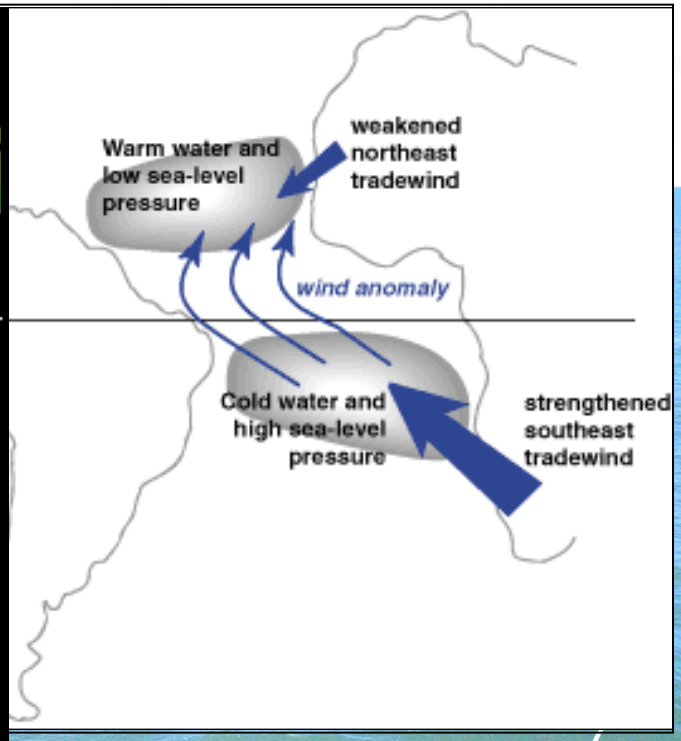


Cold Tongue Mode (El Nino type)

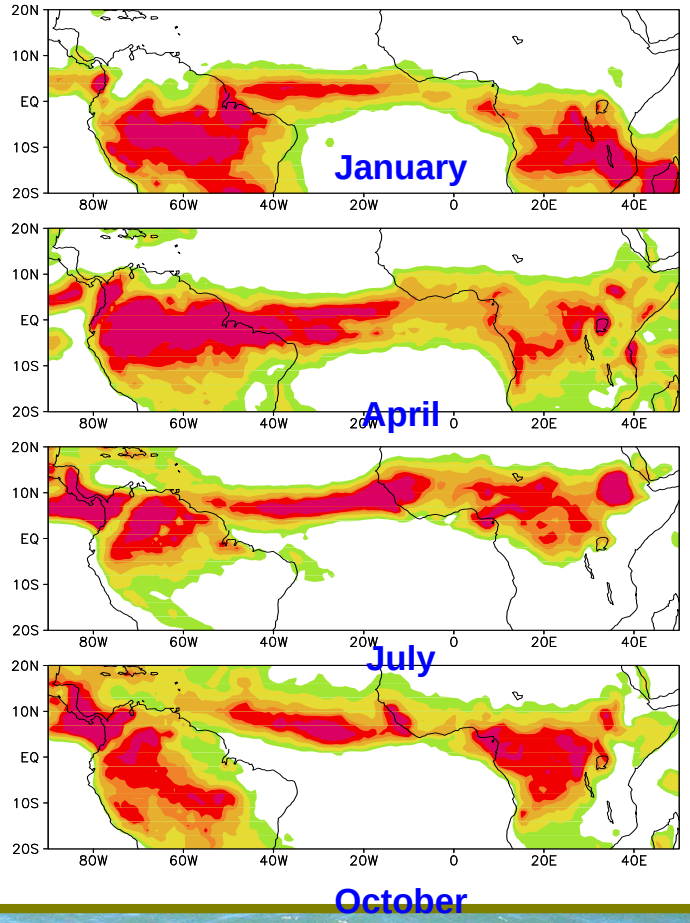


The climate in the east Amazon and NE Brazil is strongly affected by the combined effect of both the Pacific ENSO and Atlantic interhemispheric SST gradient modes.

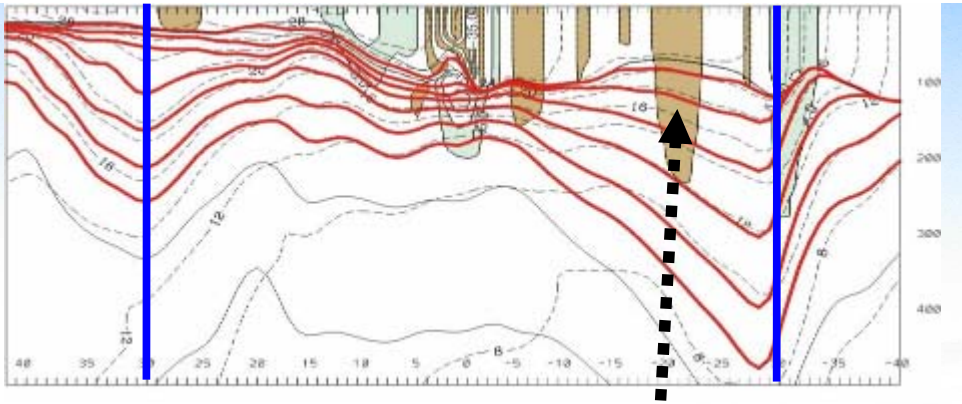


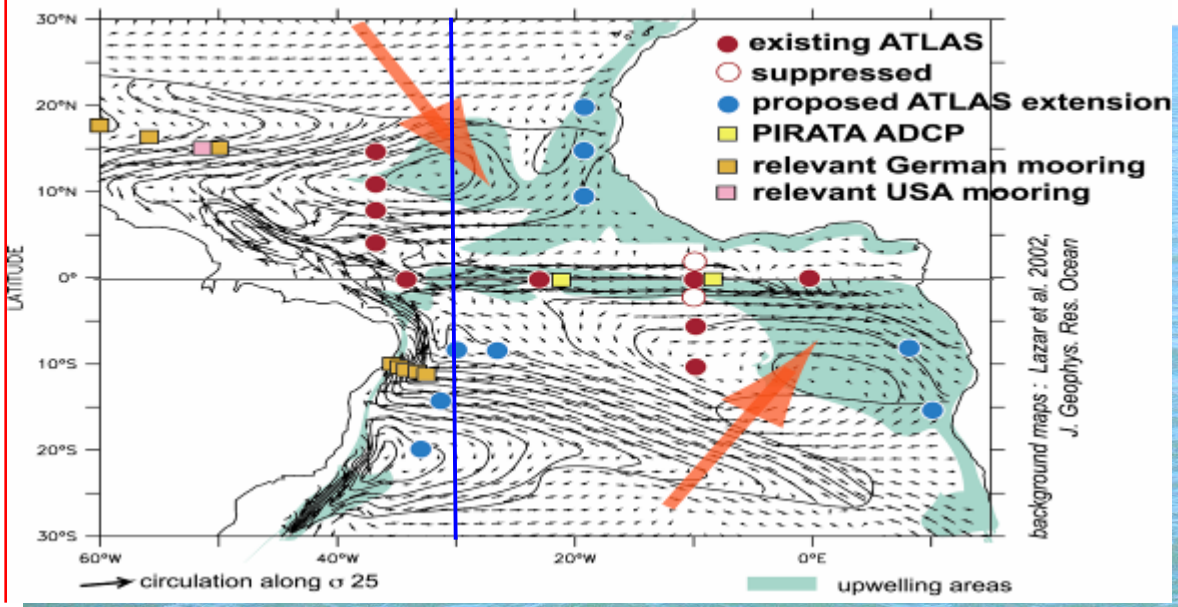


East Amazonian (EA), NE Brazil and the African Sahel rainfall is associated with the position of the Intertropical Convergence Zone (ITCZ), which in turn is strongly linked to the meridional gradient of sea surface temperature (SST) anomalies in the Tropical Atlantic.



The thermocline circulation in the South Atlantic



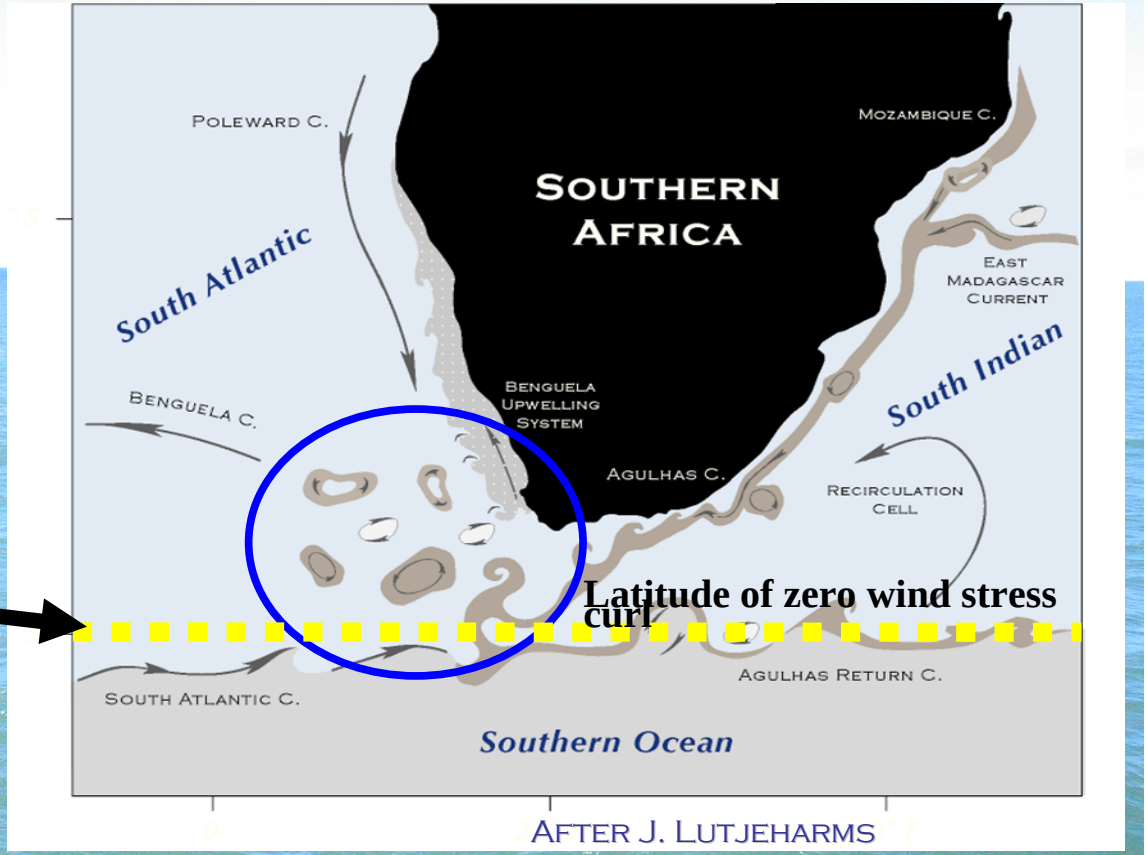


sigma=25.

The Agulhas leakage is formed by an average number of 6 rings per year, each transporting between 0.5 and 1.5 Sv.

A northward shift of the zero wind stress curl line could interrupt the Agulhas leakage

The "Agulhas leakage"

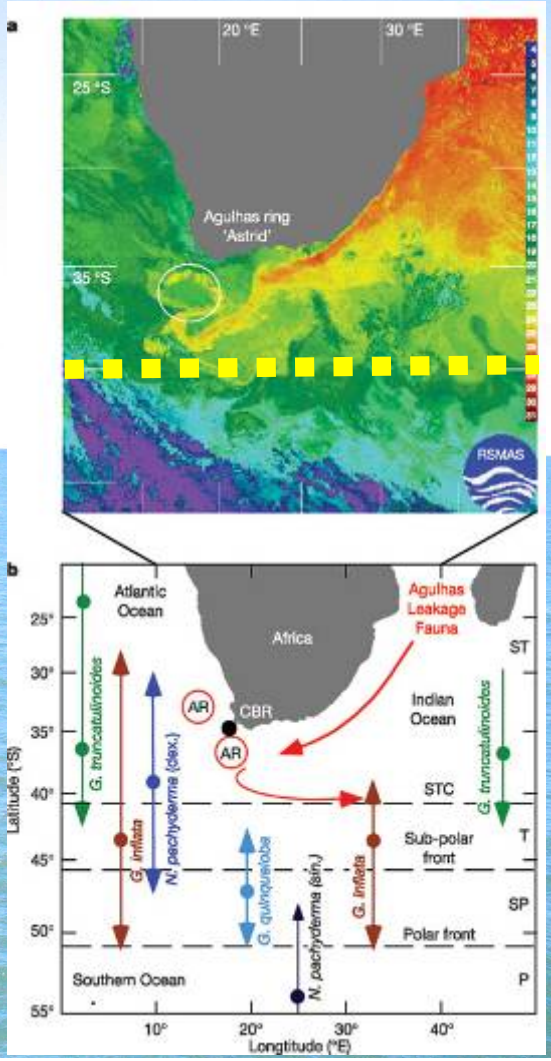


After J. Lutjeharms

Past evidences of interruption of the Agulhas Leakage

Paleoceanographic records indicate that the Agulhas leakage might have been interrupted during the last glacial period.

Events of extinction and reappearance of foraminifera species in the S. Atlantic seems to be associated with the closing and reopening of the Agulhas connexion



Peeters et al., Nature 430, 661-665 (2004)

The effects of changes in the THC on tropical Atlantic climate and variability was investigated using an atmosphere-ocean coupled model.

Influence of the Meridional Overturning Circulation on Tropical Atlantic Climate and Variability

NOMOC

Reindert Haarsma[1], Edmo Campos[2], Wilco Hazeleger[1], Camiel Severijns[1]

J. of Climate, 2007 (accepted)

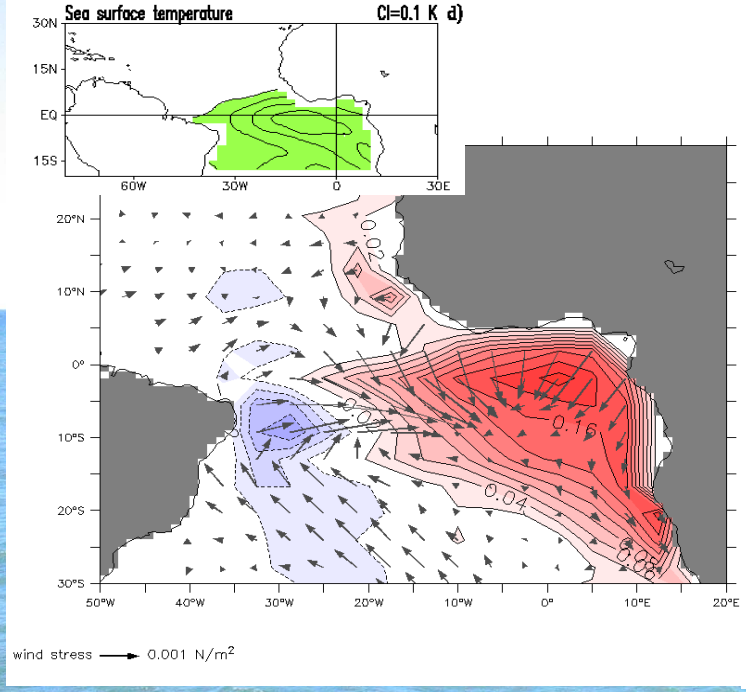
Impacts of shutting off the Agulhas leakage on the tropical Atlantic in a coupled ocean-atmosphere model

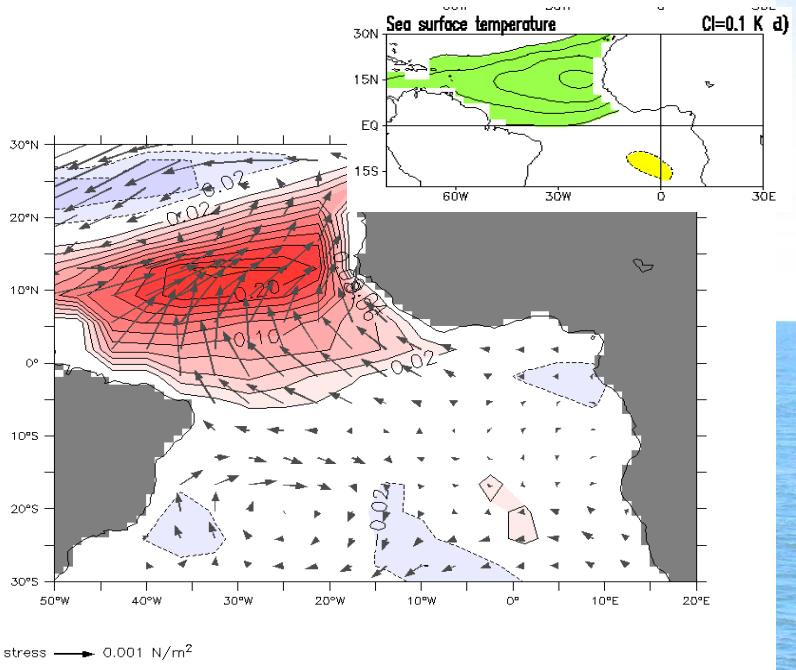
NOAGU

Edmo J. D. Campos[1], Reindert J. Haarsma[2], Wilco Hazeleger[2], Camiel Severijns[2] and Sybren Drijfhout[2]

In preparation. To be submitted to J. of Climate.

The CONTROL Experiment
(present day conditions)





The CONTROL run simulates realistically the tropical Atlantic variability including the gradient mode and the cold tongue mode.

Experiment 1

Total collapse of MOC

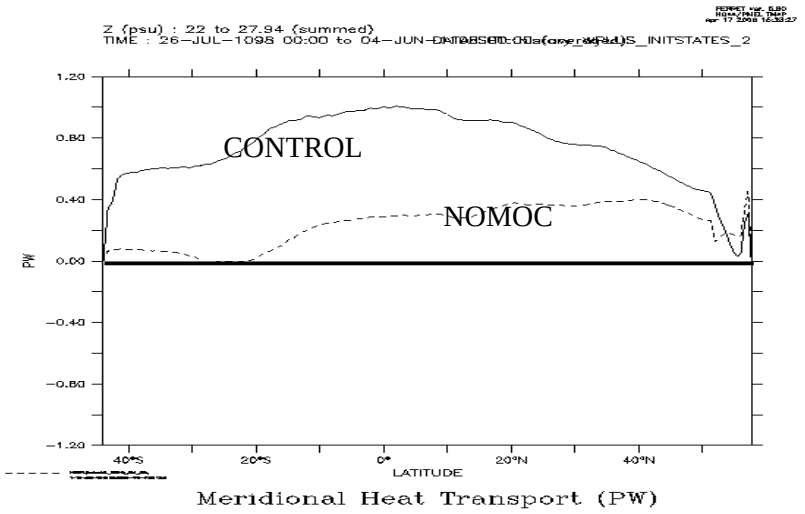
Ocean open boundary conditions are taken from global run with no MOC (NoMOC).

Results (NoMOC)

The meridional overturning circulation of the CONTROL experiment is about 18 Sv. The meridional heat transport is about 1 Pw. These values are approximately in agreement with the observations.

The MOC is collapsed and the circulation becomes dominated by two STCs of 4 and 6 Sv in the South and North Atlantic respectively.

The meridional heat transport is reduced to 0.3 Pw, implying that about 70 % of the ocean heat transport is due to the MOC.

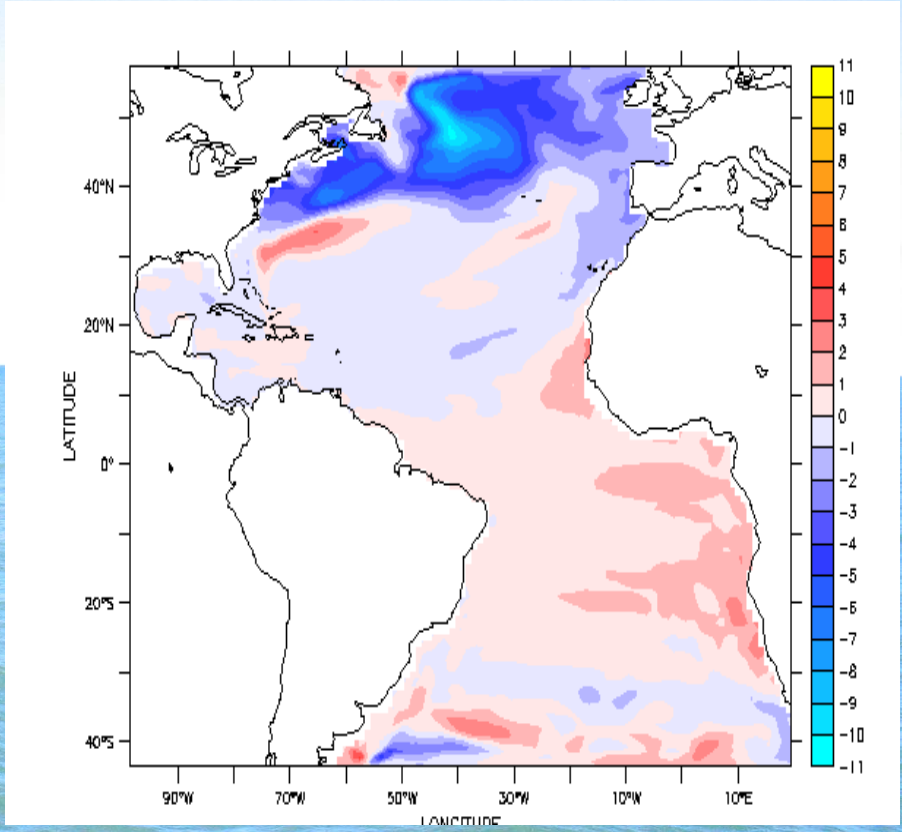


Meridional heat transport (Pw)

SST differenceannual mean

NO-MOC minus CONTROL

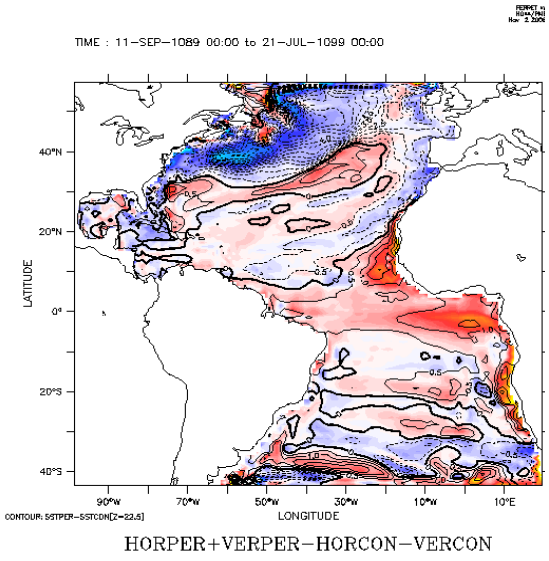
The change in the Atlantic circulation strongly affects the temperature and salinity distribution.



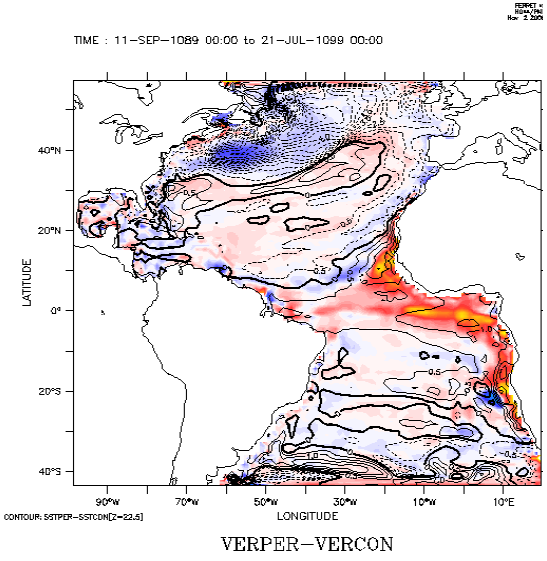
The SST anomaly reveals a dipole pattern with a cooling in the North Atlantic and warming in the tropical and South Atlantic.

NoMOC leads to cooler North Atlantic and Warmer Topical and South Atlantic!

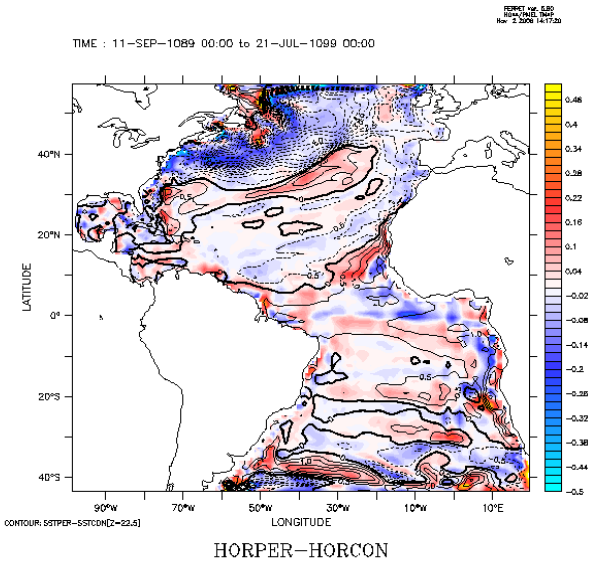
Most of the changes in the mixed layer temperature are due to changes in the ocean heat transport.



HORPER+VERPER-HORCON-VERCON



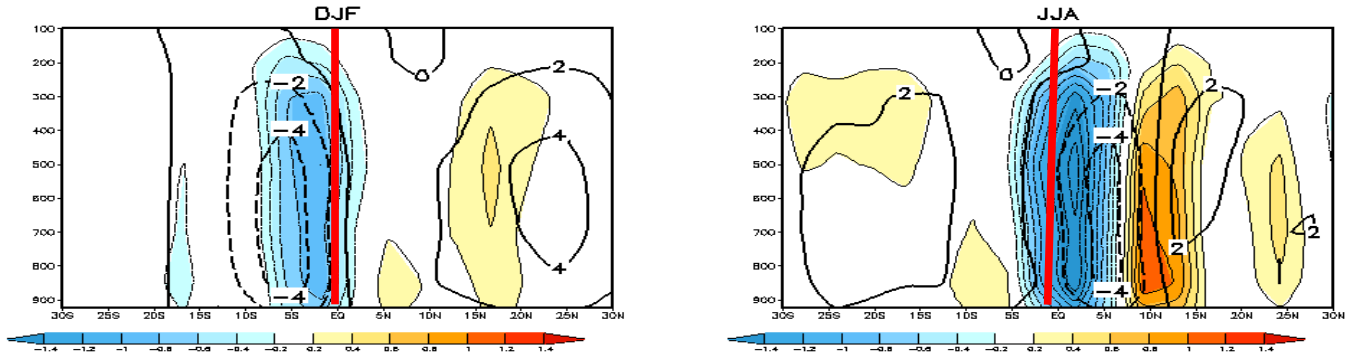
VERPER-VERCON



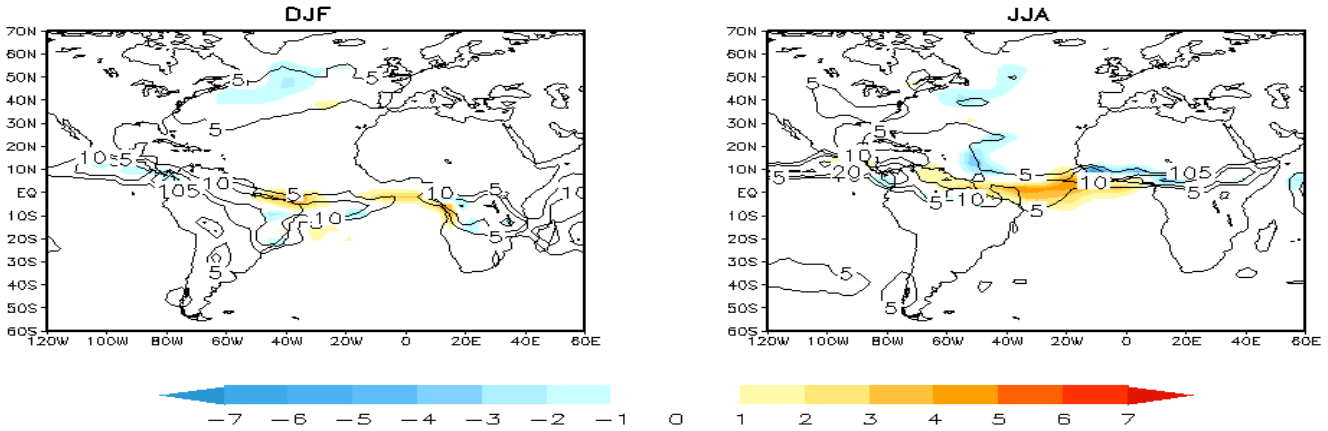
HORPER-HORCON

Cooling in the NW Atlantic is due to changes in horizontal ocean heat transport, caused by the reduction of the western boundary current.

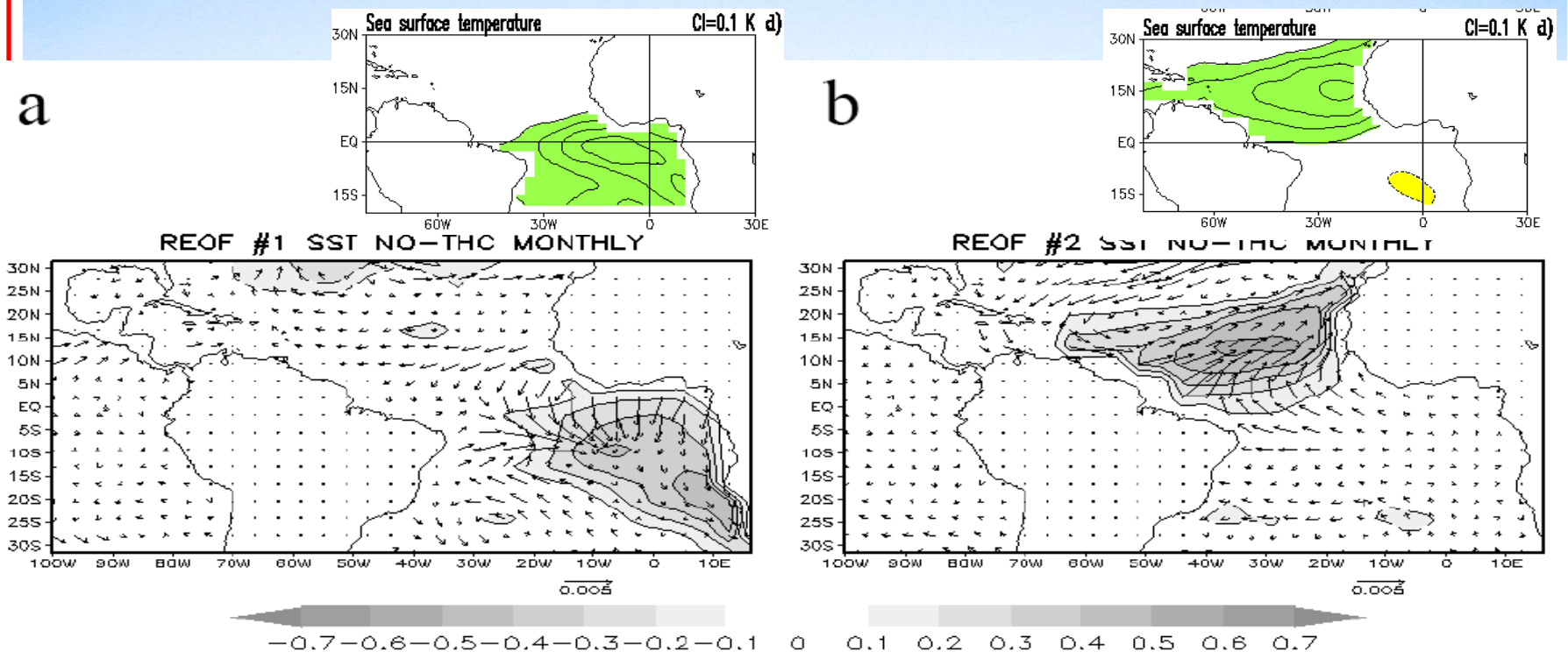
In the tropical Atlantic the warming is due to reduction of the oceanic cooling due to vertical entrainment.



- The warming of the tropical Atlantic enhances the Hadley circulation, mainly in the boreal summer when the increase of tropical SSTs is largest.
- In addition to the strengthening there is a southward shift of a few degrees during the boreal summer when the Hadley circulation is at its northernmost position.
- The change in strength of the Hadley circulation is less during DJF because the changes in SST are less.



The largest changes in rainfall occur during JJA and are in the order of 5 mm/day. During this season the ITCZ is shifted southward, whereas it is shifted northward during DJF

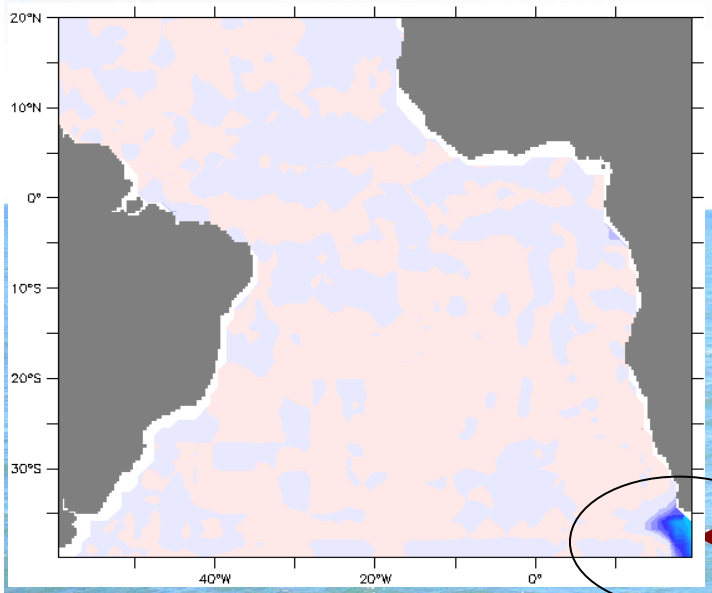


The Cold Tongue mode weakens and the dominant variability shifts to the Benguela region.

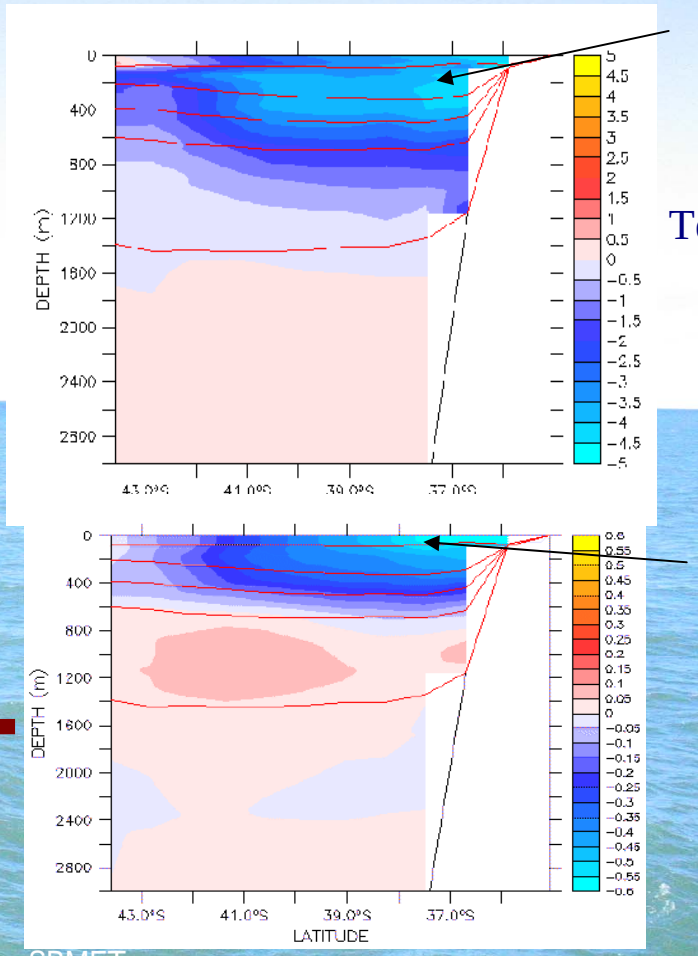
Experiment 2

The No Agulhas Leakage Experiment NoAGU

Change only the boundary conditions in the South Eastern corner of the MICOM-Atlantic basin.



NOAGU minus CONTROL, for salinity, one month after start-up.



~ -3º to -5º C

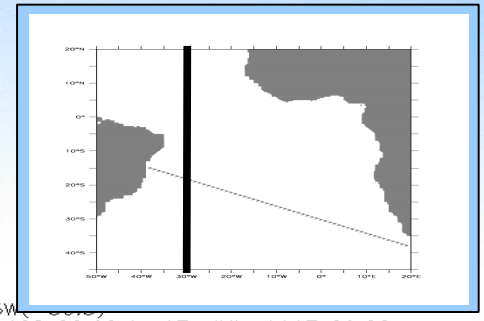
Temperature

~ -.4 to -.6

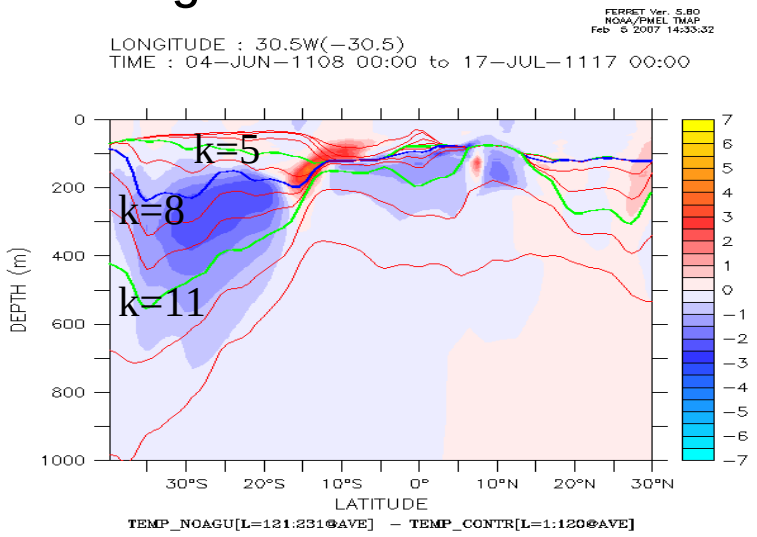
Salinity

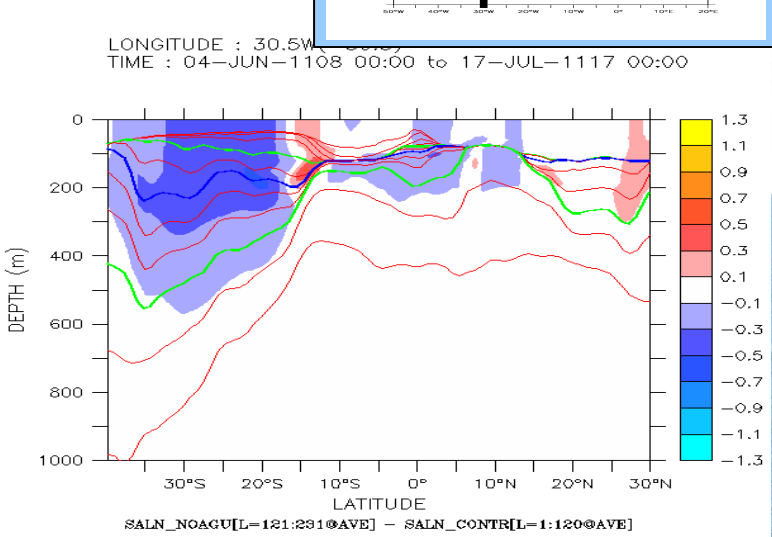
Differences between mean values of NOAGU and CONTROL

NO_AGULHAS minus CONTROL



Difference of averaged temperature and salinity profiles along 30W





Across 30°W, only the salinity anomalies appear in the mixed layer. This is because the temperature signal is damped out more quickly by exchanges with the atmosphere.

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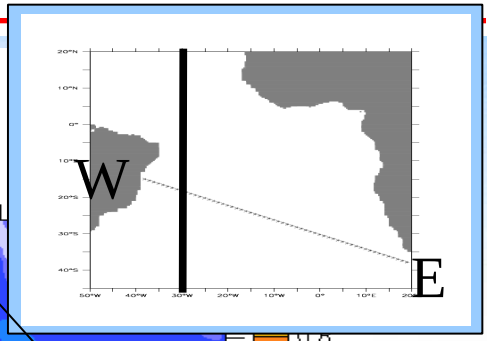
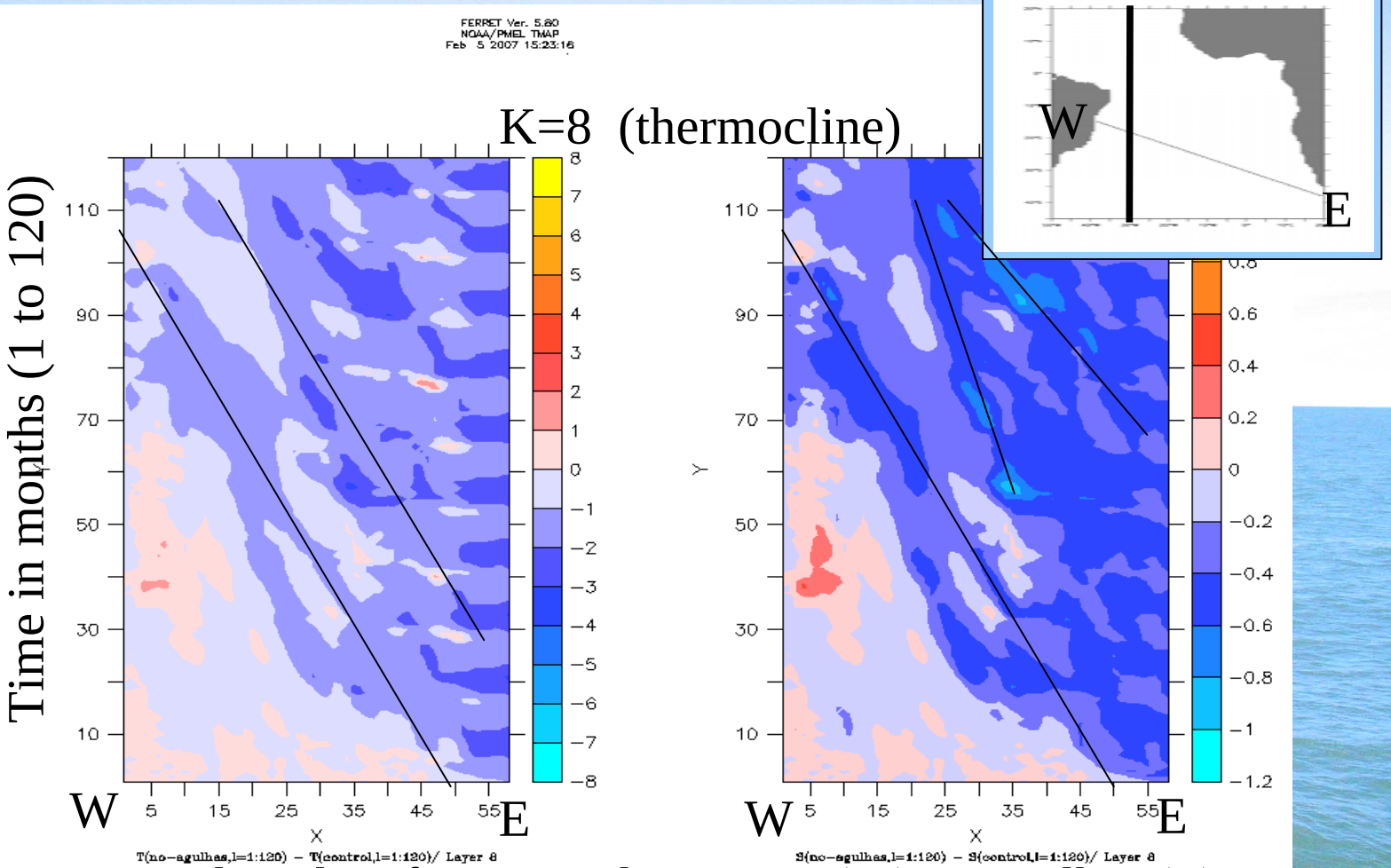
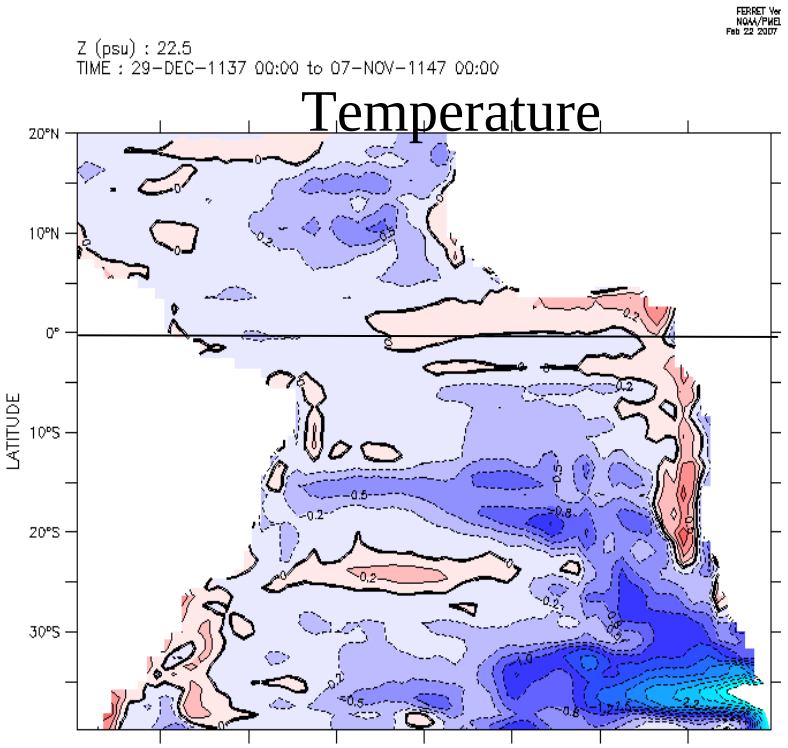
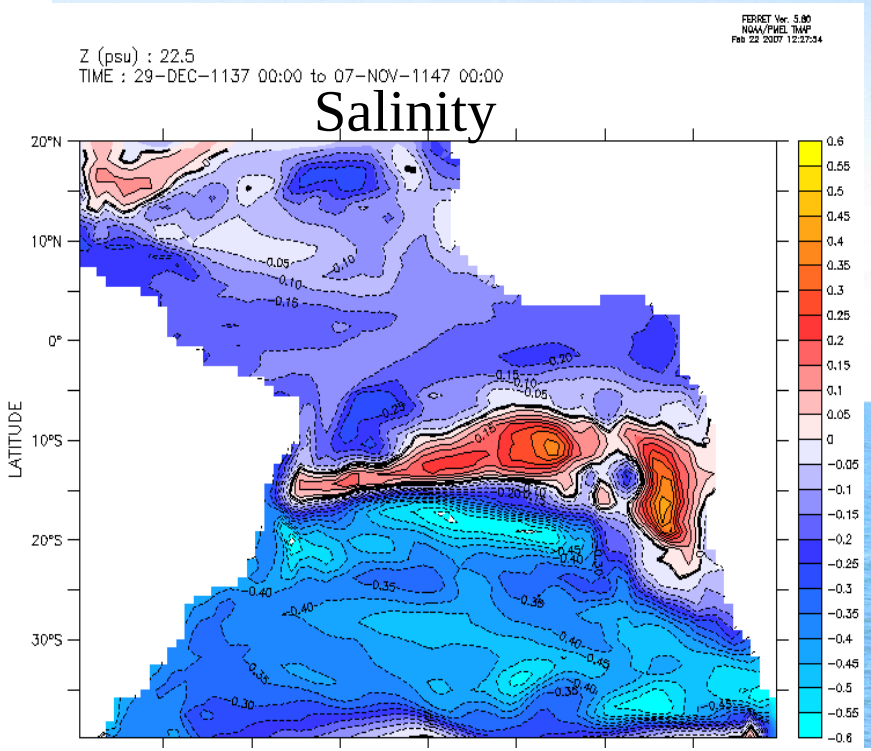




Points along line from Brazilian Coast (W) to Agulhas (E)

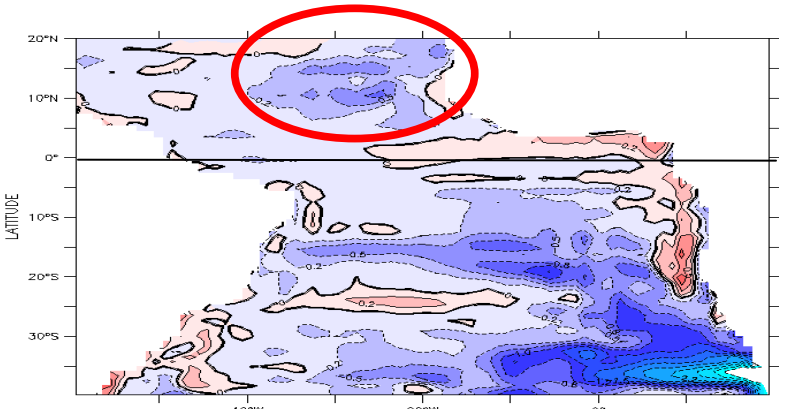
Surface Mixed Layer

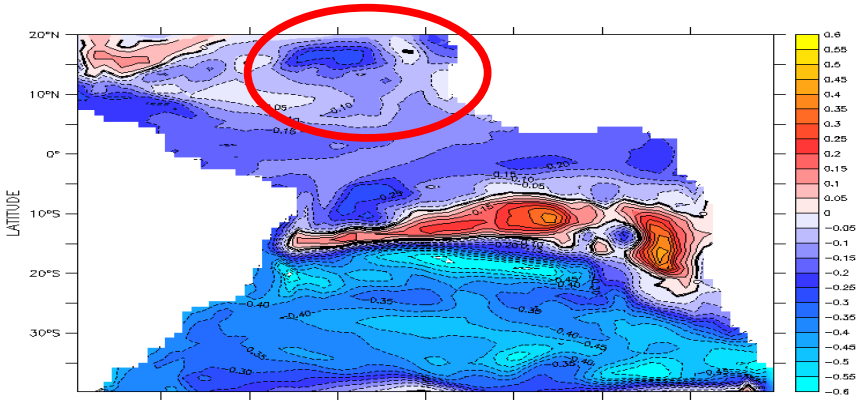




After 50 years run, the differences between the NOAGU averages and the CONTROL climatology show a cooler and fresher SA, and a strong increase in salinity in the southern tropical region. This is due to the northward shift of the ITCZ.

Mixed Layer





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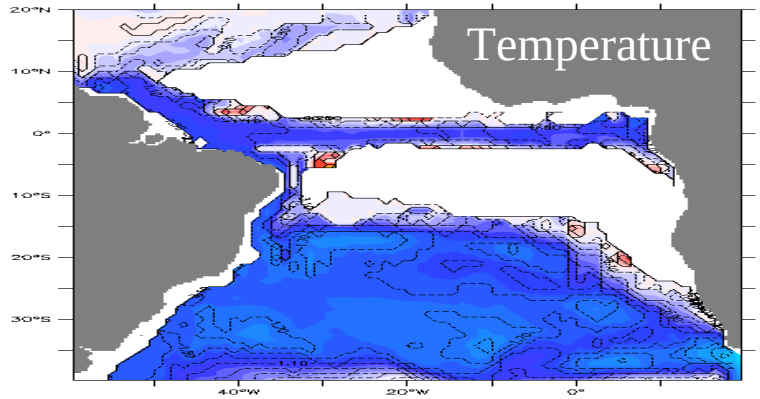
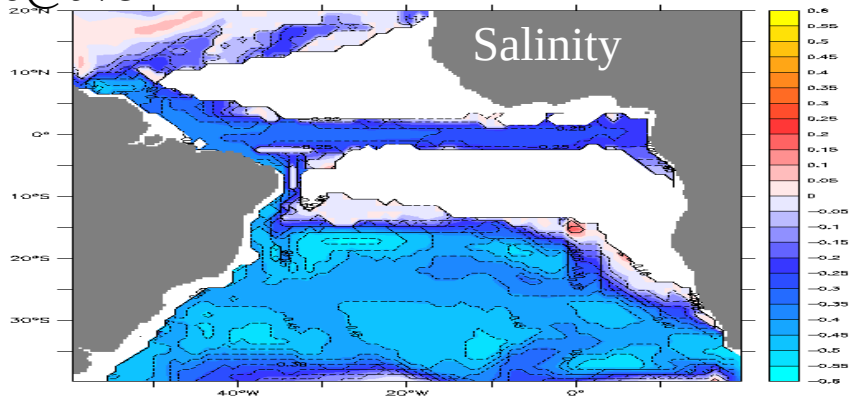


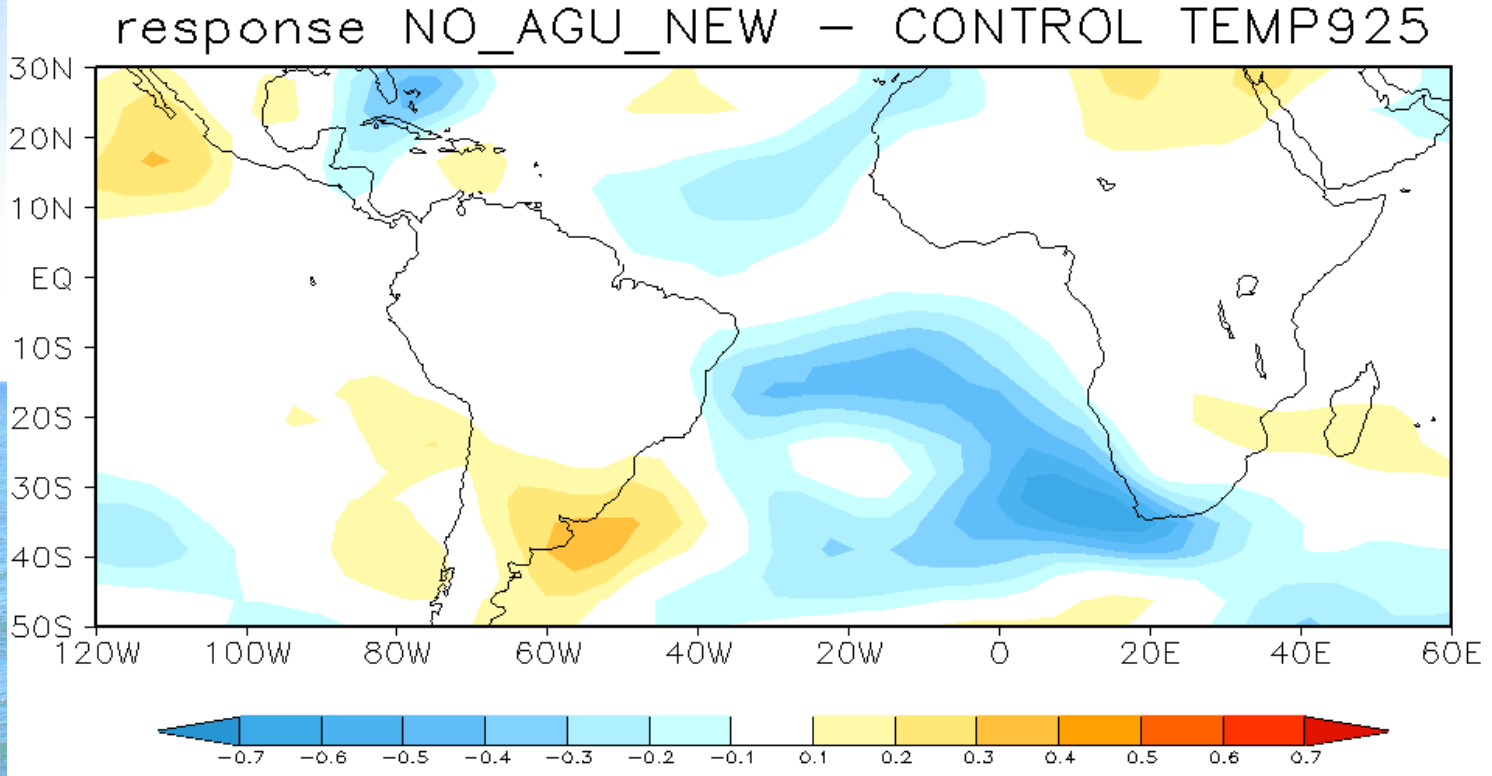


Isopycnal Layer 8 - sigma=26.18

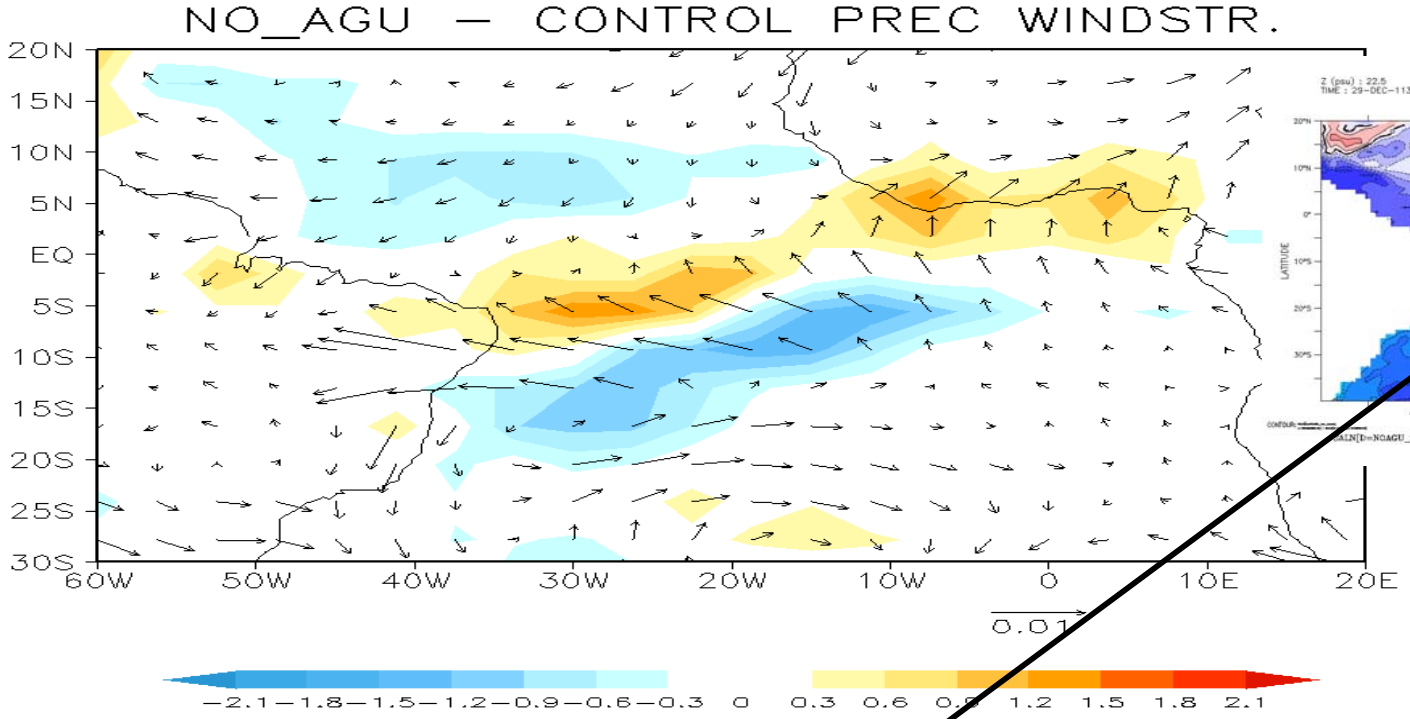
At the surface (top panels), the temperature anomaly does not reach the equatorial region, which shows a sligh warming up in the eastern side of the basin. There is, however, a freshening of the equatorial mixed layer.

Within the thermocline (lower panels), both T and S signals reach the EUC and are advected eastward.

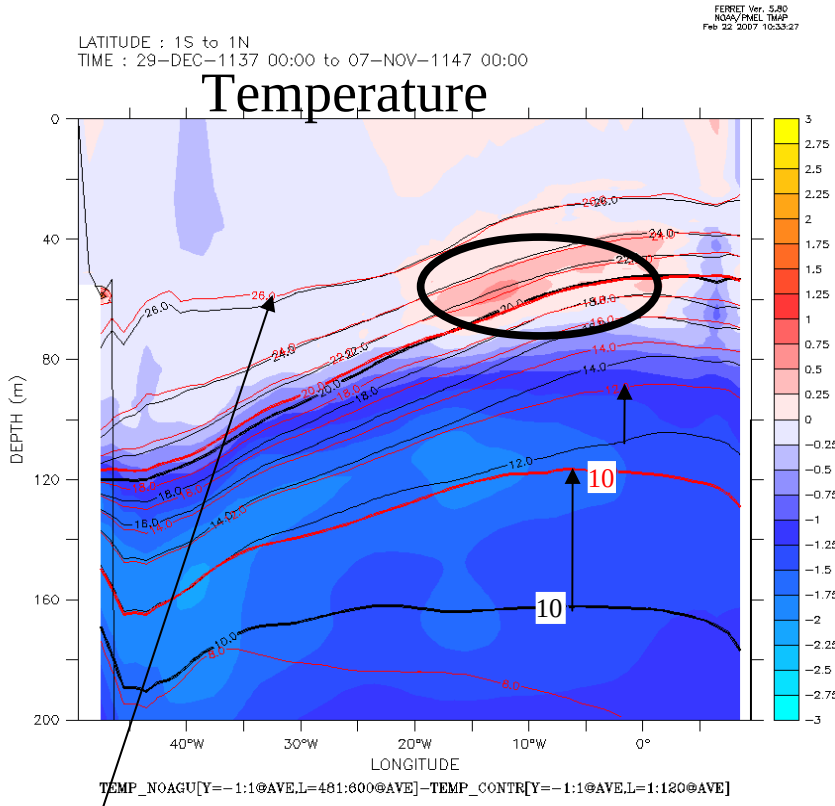
Air Temperature anomaly (NOAGU-CONTROL) at 925 hPa

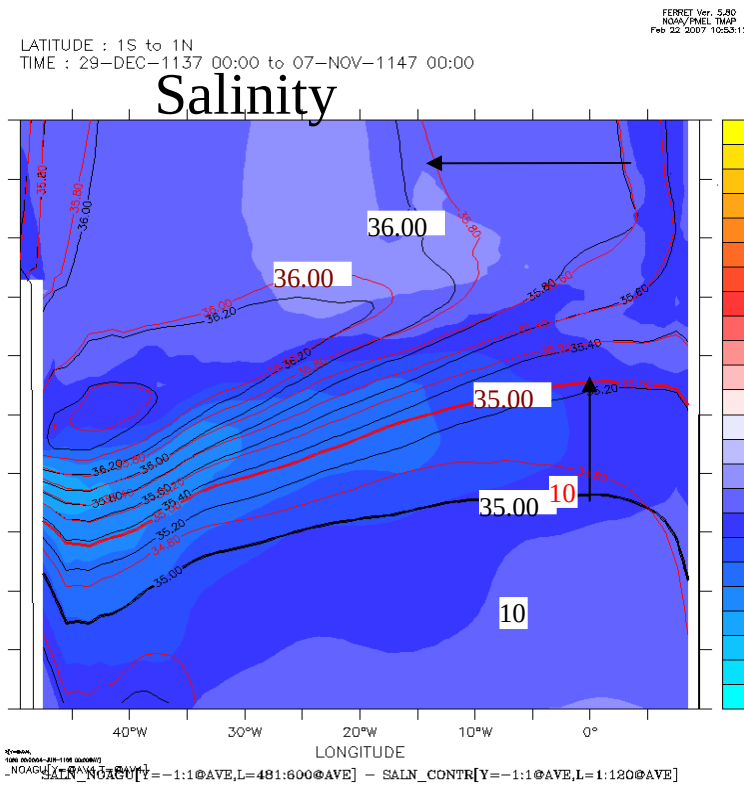


The atmosphere is cooled down over the Agulhas Region, due to the NOAGU cold anomaly. The colder air is then advected northwestward by the anticyclonic atmospheric circulation over the South Atlantic.



The northward shift of the ITCZ, due to the cooler South Atlantic, causes a decrease in precipitation in the tropical South Atlantic. This leads to an increase in salinity in the mixed layer.





Along the Equator, the thermocline gets cooler and fresher. The mixed layer is also freshened in the NOAGU experiment. However, the mixed layer hardly changes.

A slight warming up is observed in the bottom of the mixed layer in the eastern Atlantic. **Why???**

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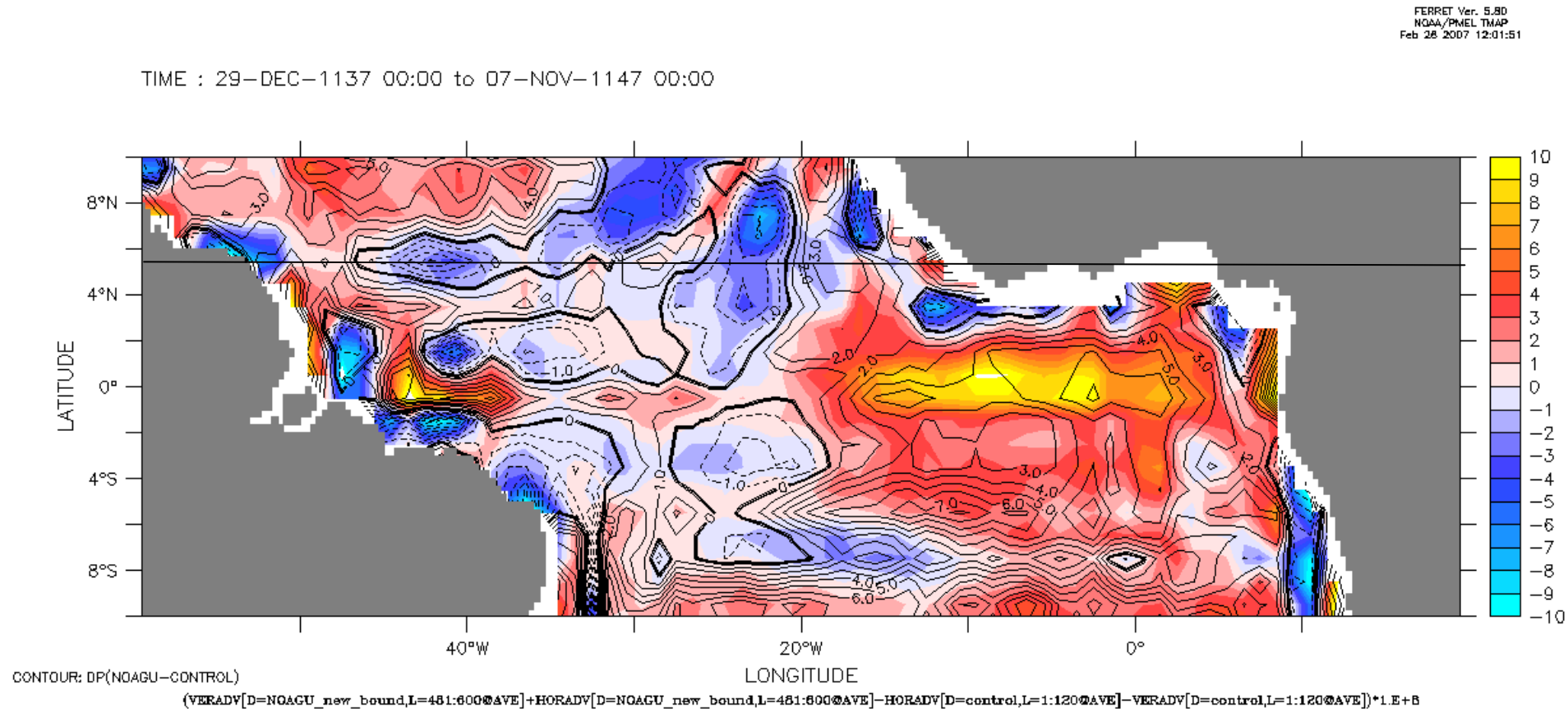
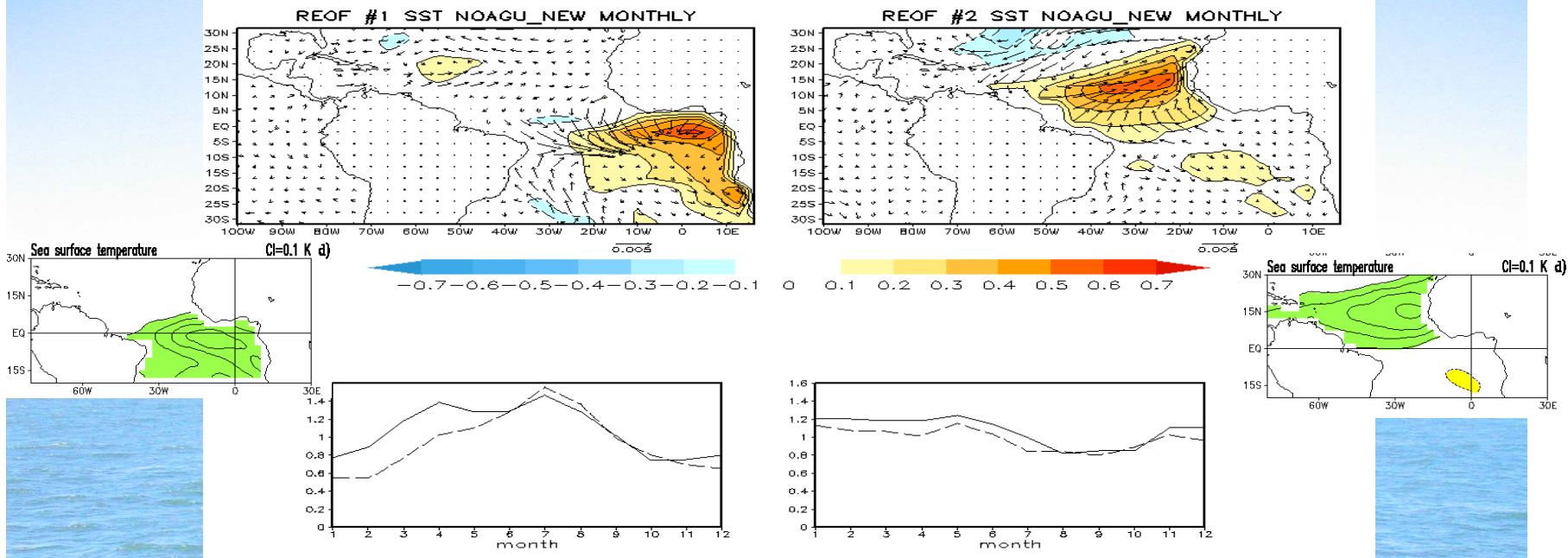


HORADV+VERADV and Relative change in depth of mixed layer (%)



The closing of the Agulhas leakage seems to have no significant impact on the Atlantic Equatorial and Gradient modes.

3. Conclusions

Closing of Agulhas leakage experiment:

- **Cooling and freshening of South Atlantic**
  Possible cause: advection of cooler and fresher water due to shutdown of the warm water path into the Atlantic
- **Limited impact on equatorial climatology and variability**
- **Northward shift of ITCZ**
- **Anomalies advected by the EUC reach and affect the Guinea Dome region**
  Possible cause: increased stability of eastern equatorial mixed layer

NO MOC experiment:

- **Equatorial thermocline becomes warmer and more saline**
  Cause: Weaker MOC advects less cold and fresh water from the midlatitudes into the equatorial region.
- **Large impact on equatorial climatology**
- **Disappearance of cold-tongue mode**
- **Enhancement and southward shift of tropospheric jet in the N. Atlantic**


FIM