Atlantic Ocean surface currents

G. Reverdin (LOCEAN, Paris)

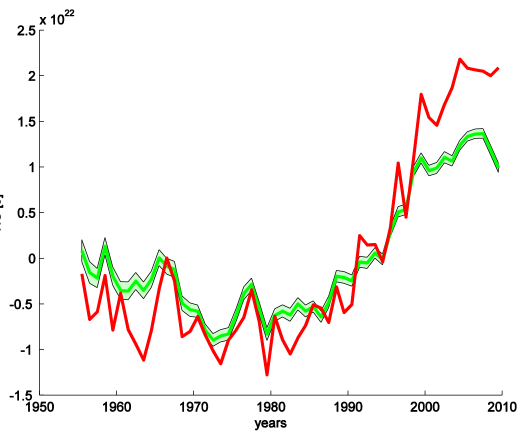
With contributions from

Bernard Barnier (LEGI),Nicolas Ferry (Mercator-Ocean), Rick Lumpkin (NOAA/AOML), Marie-Hélène Rio (CLS), Sabrina Speich (LPO), Anne-Marie Tréguier (LPO)

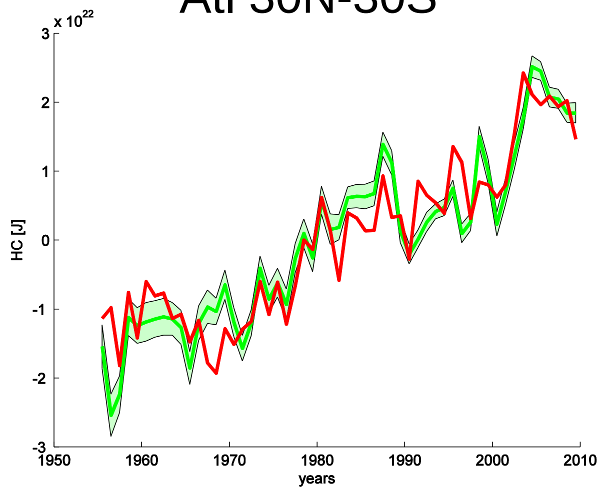
Collège de France, March 2012

Large recent heat content / steric changes in the upper ocean

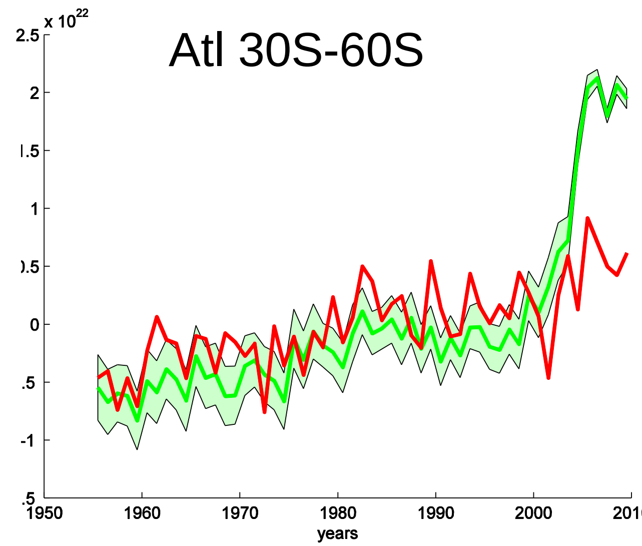
Atl 30N-60N

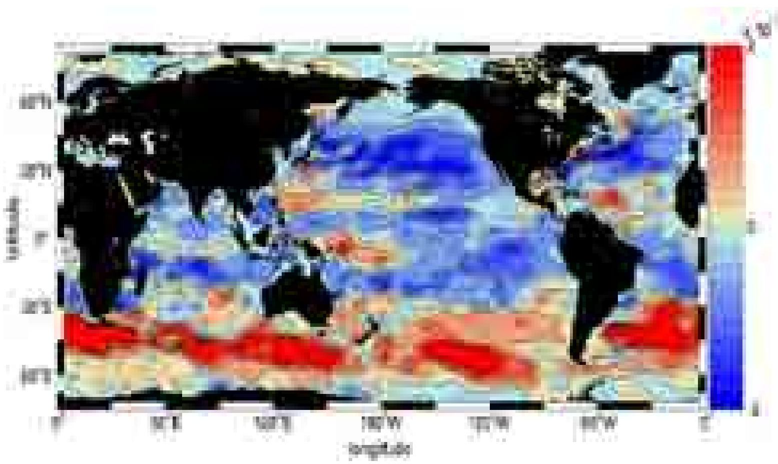


Atl 30N-30S



Atl 30S-60S



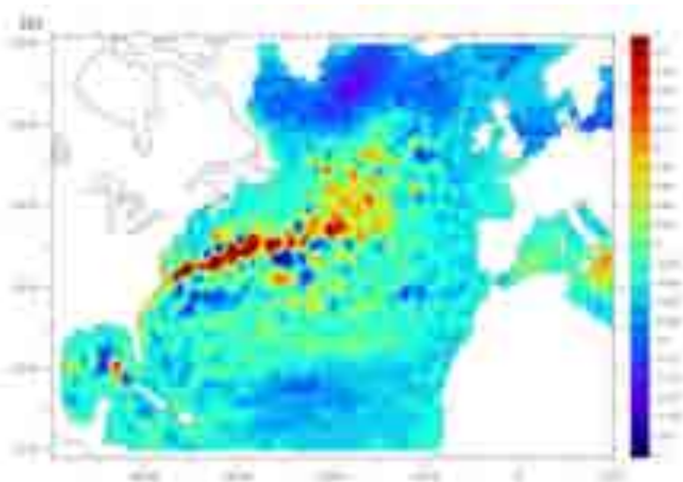


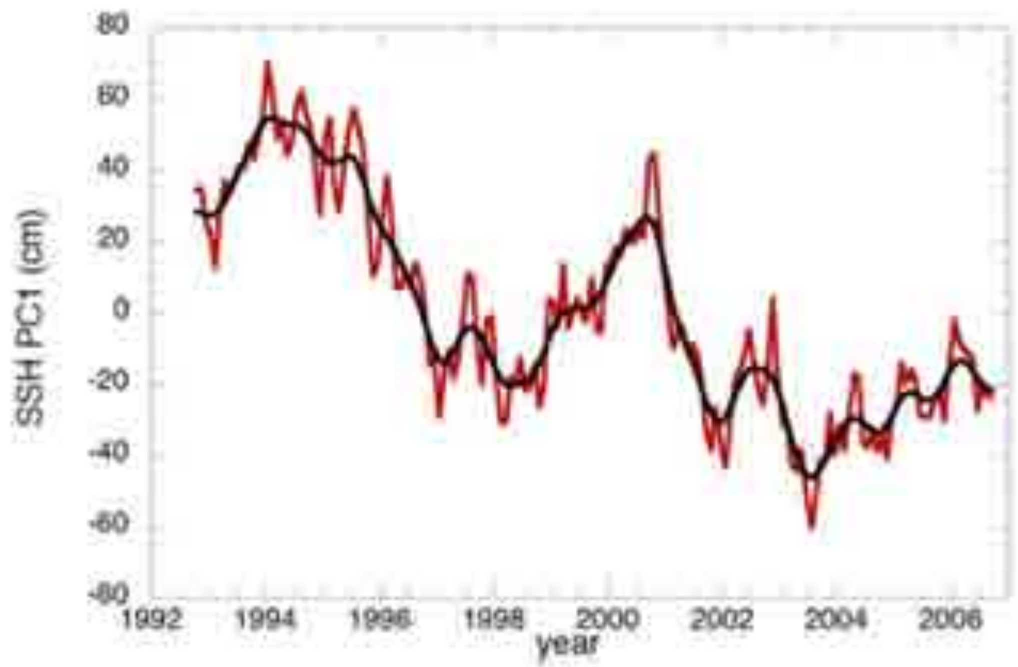
These 0-700m heat content/steric changes present meridional contrast
Is there redistribution of heat involving changes in ocean circulation? Or through changes in atmospheric circulation/transport?

M. Hamon 2012

Variability of the North Atlantic heat/steric content/geostrophic circulation

From Hakkinen and Rhines, 2009:
Increase of subpolar SSH after 1994, linked with NAO index



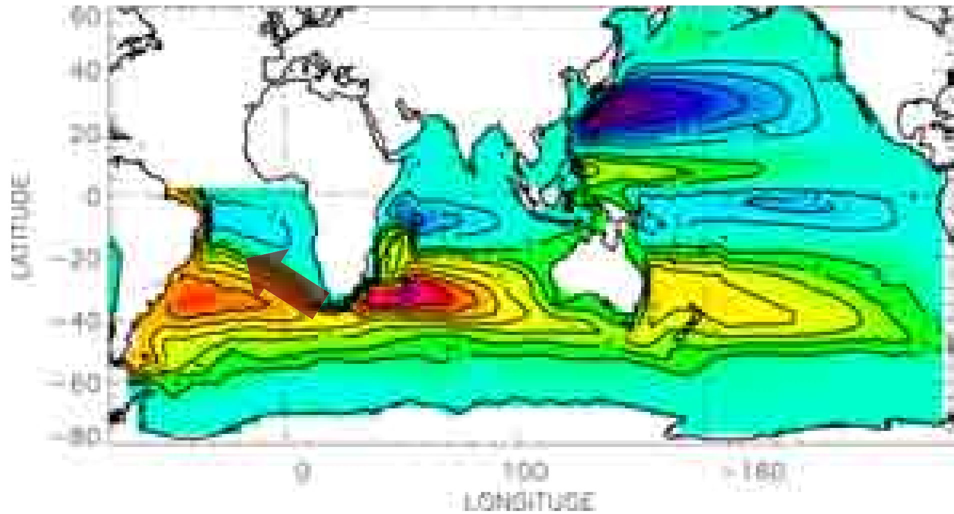


Regional ocean variability usually fairly well explained by local ‘forcings,
but does it connect to more global circulation variability and on which time scales

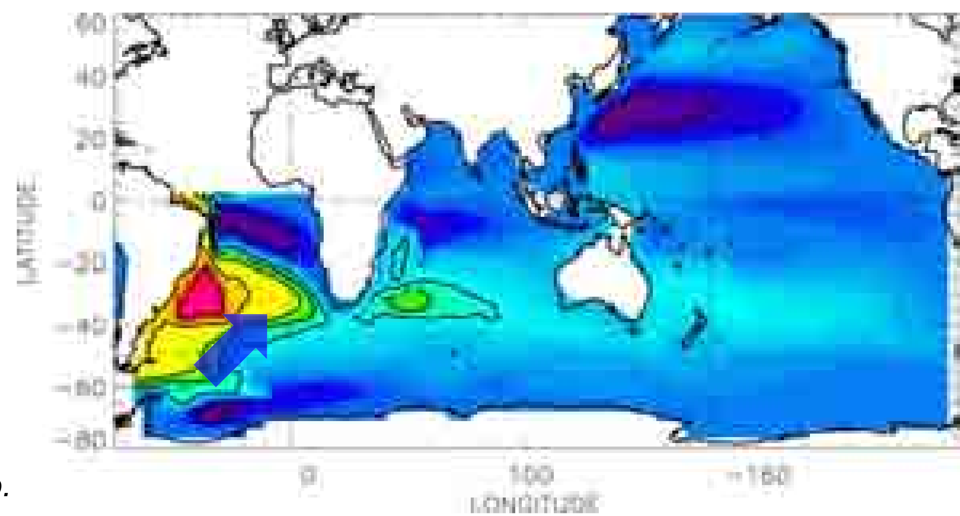
Climate models suggest large changes In ocean circulation (but over long climate time scales)
They also present weak variability
Over decadal-centenial time scales? Is it observed?

MODERN CLIMATE

Strong link between the North Atlantic and the global ocean via the Southern Ocean & the Supergyre

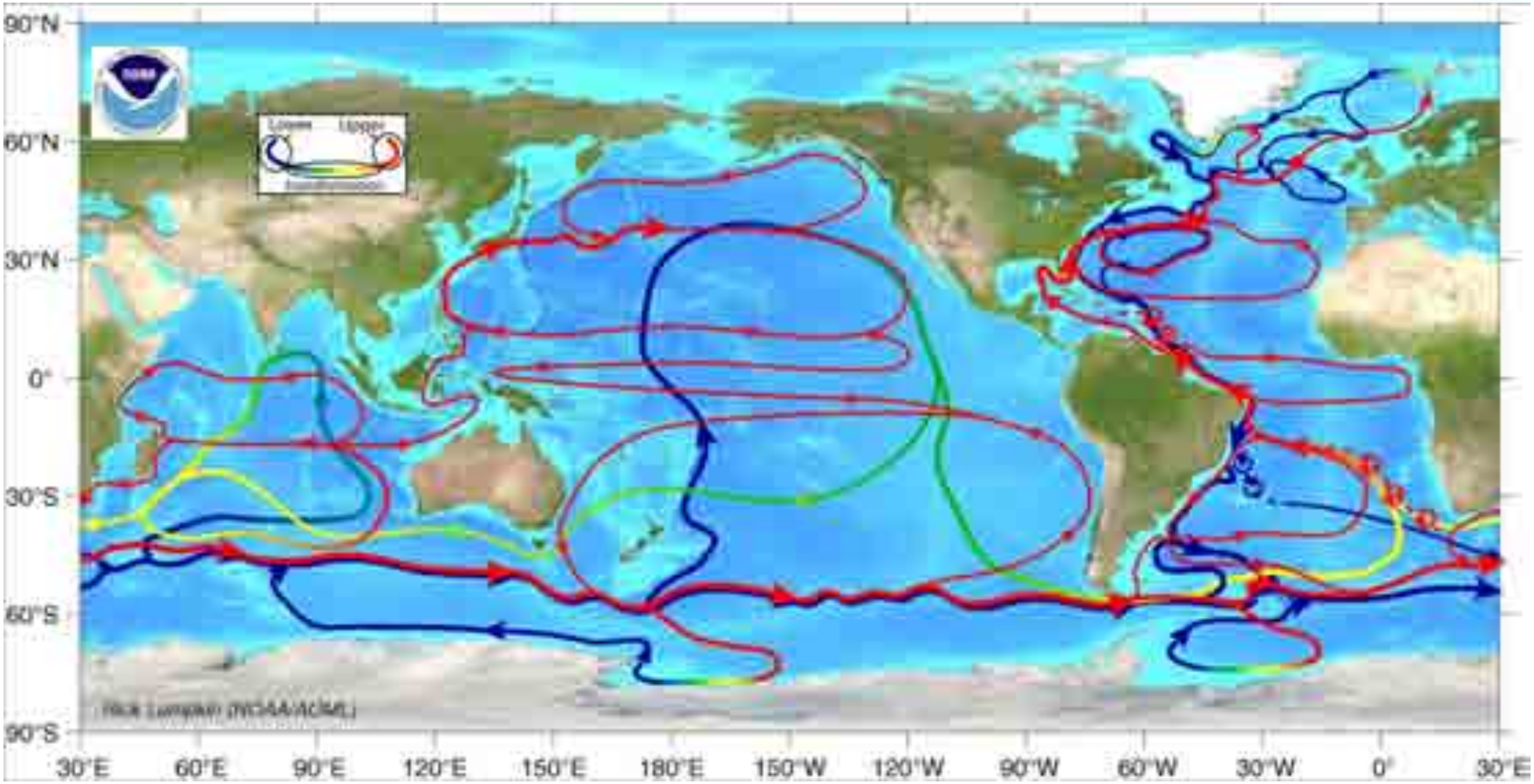


Last glacial maximum
A weak supergyre and an Atlantic meridional overturning circulation Mostly confined in the Atlantic



Speich et al., 2006; *Speich et al., in prep.*

Classical description (hydrography) of an upper ocean circulation in the upper 500-1000 m



This is mostly a long term view (decades)
Wind-forced gyres + western boundary + MOC
Can we say something more precise about its variability?

The upper layer

- In this layer, it is near the surface that we have the most useful observations to map variability (mostly for the last 20-30 years)

- Geostrophy to estimate currents just below a surface layer, thus sea level measurements from satellite altimetry can be used
- Drifts of surface objects (ships, drifters...)

But surface layer recieves an input of momentum from the wind, thus is sheared (and surface waves/direct slippage), which renders combining data more challenging

- A fairly good set of assimilated or ‘free’ numerical simulations for the recent climate *(‘free’ may include some relaxation to imposed surface conditions*)

Outline

What are our tools to describe recent circulation and follow/analyze its variability. Are these variations just regional or global?

Examples of variability
Certain large scale features
Eddies
Transports

(from south to north)

Ship drifts

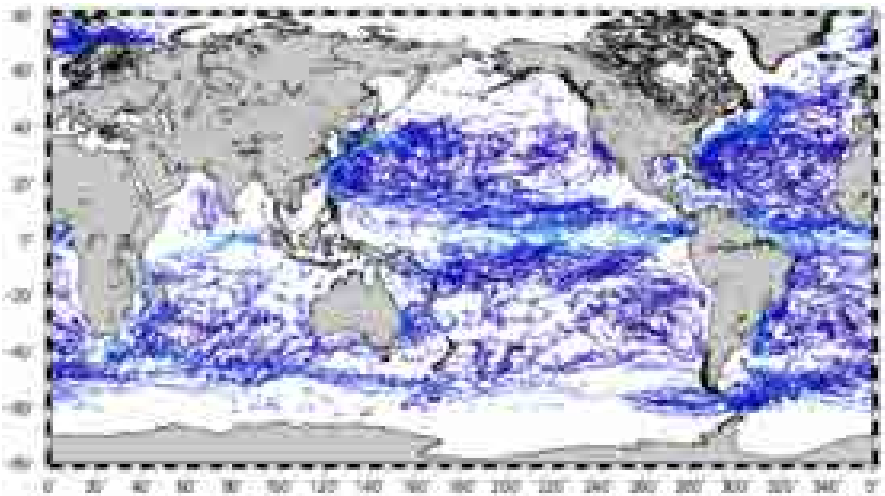
Benjamin Franklin’s
1769-1770 Gulf Streammap
(P. Richardson, 1980)

Systematic use of ship drifts
(Maury’s 1840s... To 1970s)
Bottles at sea
(late 19th century, WWI)
Prince Albert I of Monaco)

Accuracy: 20 cm/s

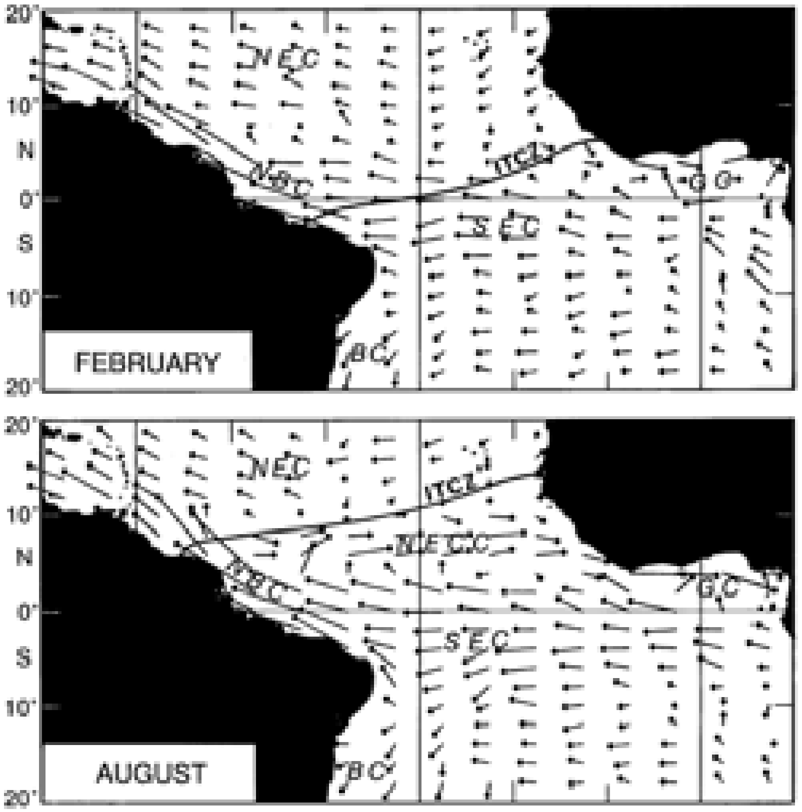
SVP drifters (15m currents)

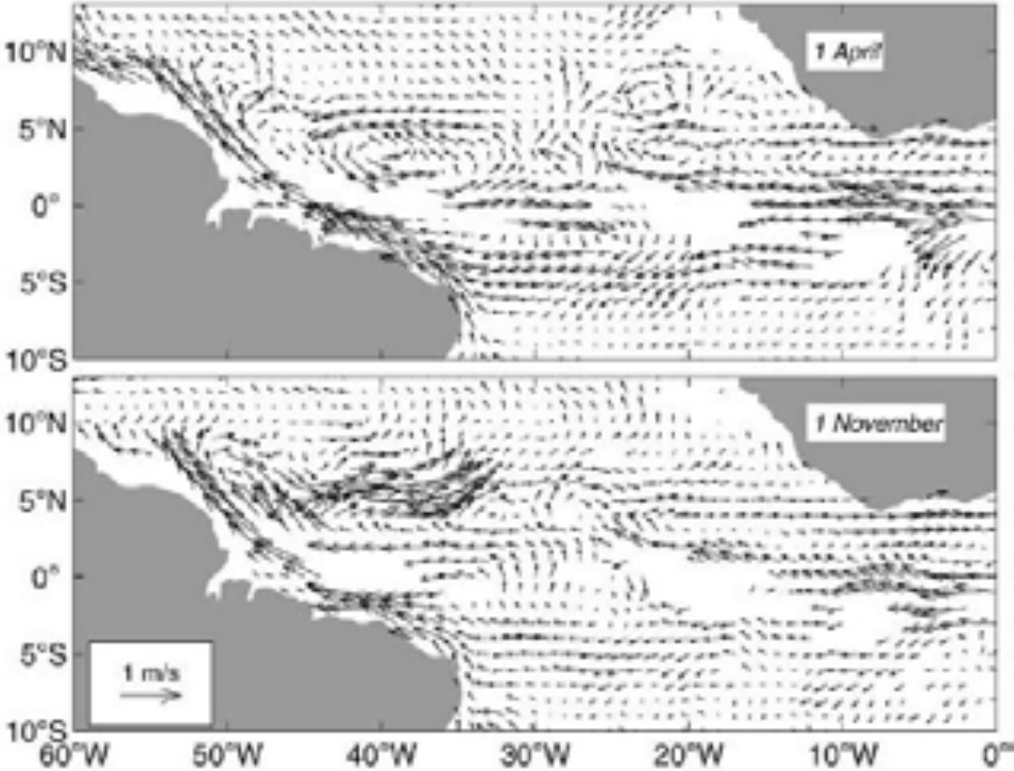
Trajectories January 2009-February 2010



Potential to estimate currents (from drift) at 15m to within 1 or 2 cm/s.

Ship drifts/versus drifters

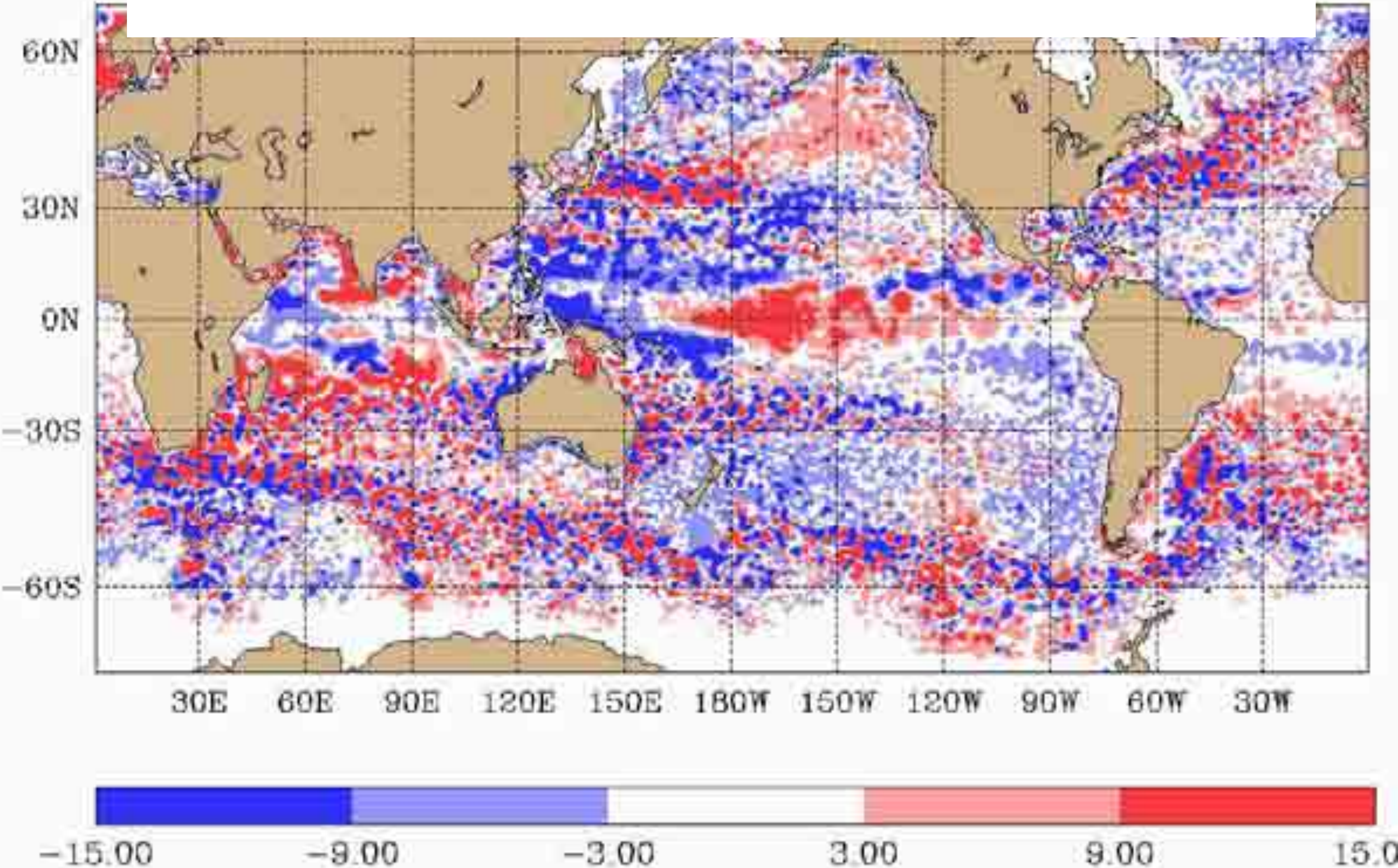




Stramma and Schott (1999)
Based on ship drifts

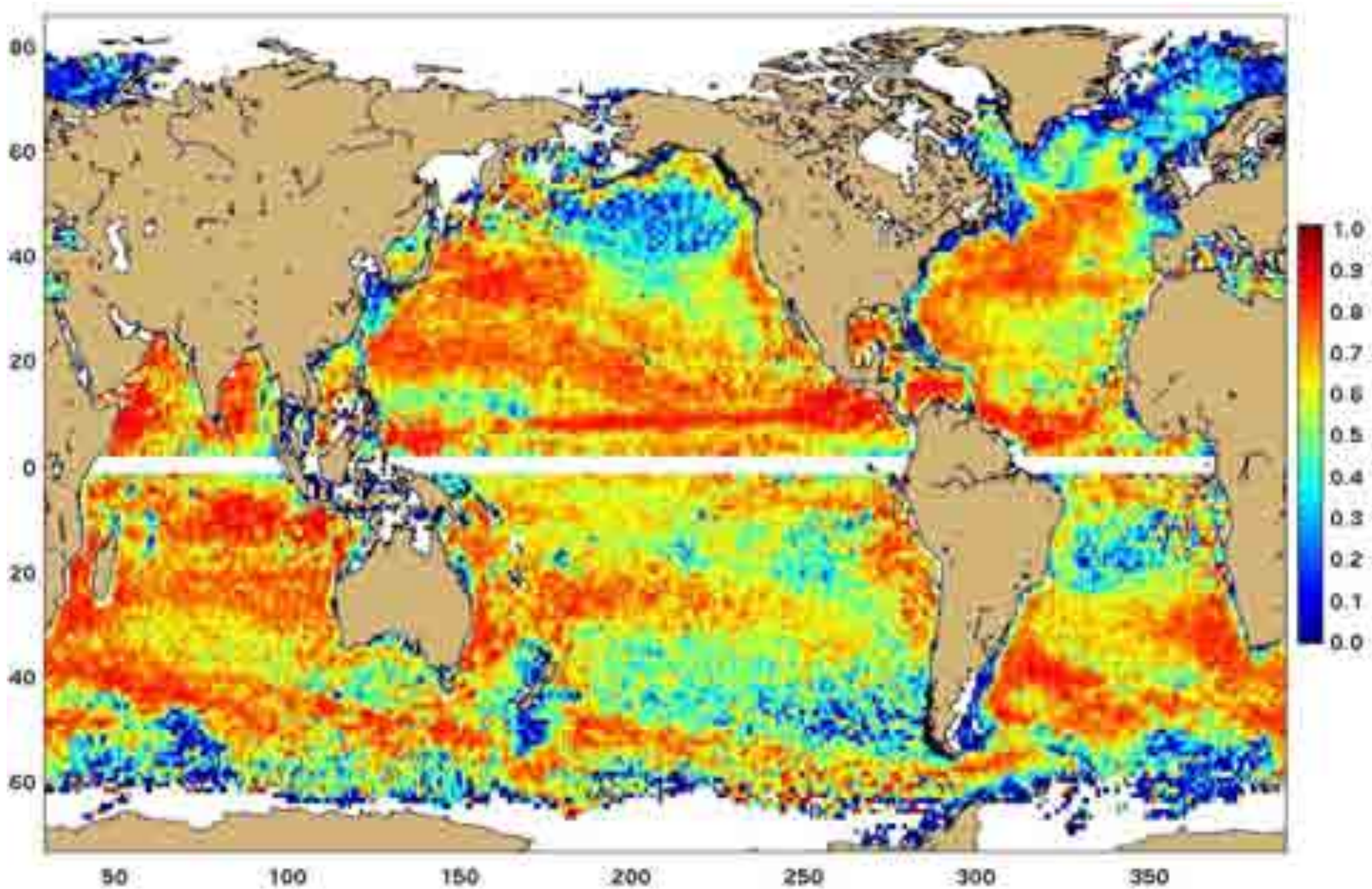
Lumpkin and Garzoli (2005)
Based on drifters

Sea level anomalies from T/P+ERS (10-day snapshot) (M. Juza)



Ubiquity of eddies in the ocean from satellite observations.

Drifters + altimetry, cont.



Correlation between drifter speeds (anomalies, Ekman-removed) and altimetric geo.vel.anomalies (N. Maximenko)

Combining drifters + altimetry

In-situ **drifter observations** are sufficient to construct high-res seasonal climatology.

However, they are inhomogeneous in space and time, and insufficient to resolve interannual variations except for particularly well sampled periods (in particular 2005-2010).

Altimeter: more homogeneous in time, but not *in-situ*.

Approach: combine the two (Niiler et al., 2003) for synthetic currents:

Geost. Vel. Unbiased mean

$$\vec{v}_{geo} = A\vec{v}'_{SLA} + \vec{v}_C$$

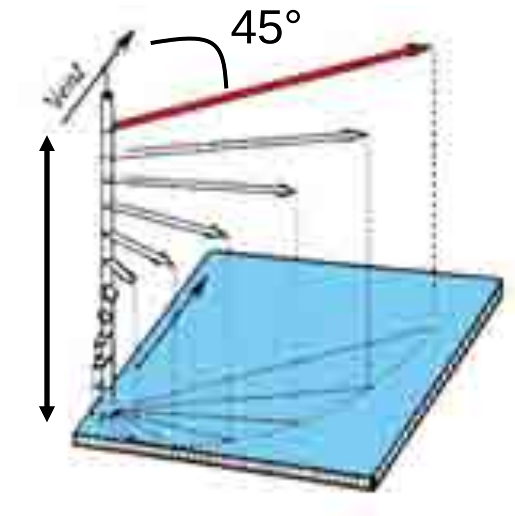
Gain coefficient from AVISO

$\vec{v}_C$ and *A* calculated to minimize

$$E = \sum_{i=1}^{n} (\vec{v}^{\,i}_{geo} - \vec{v}_{drifter})^2.$$

But drifters drogued at 15 m in layer where momentum input from wind still felt

Relative to deeper currents, shear+rotation in surface (Ekman model)



Interest to better understand/modem this component
Before combining data

Model retained for 15m currents

Rio and Hernandez, 2003

$$\vec{u}_e = \frac{\beta}{\sqrt{f}} \vec{\tau} e^{i\theta}$$

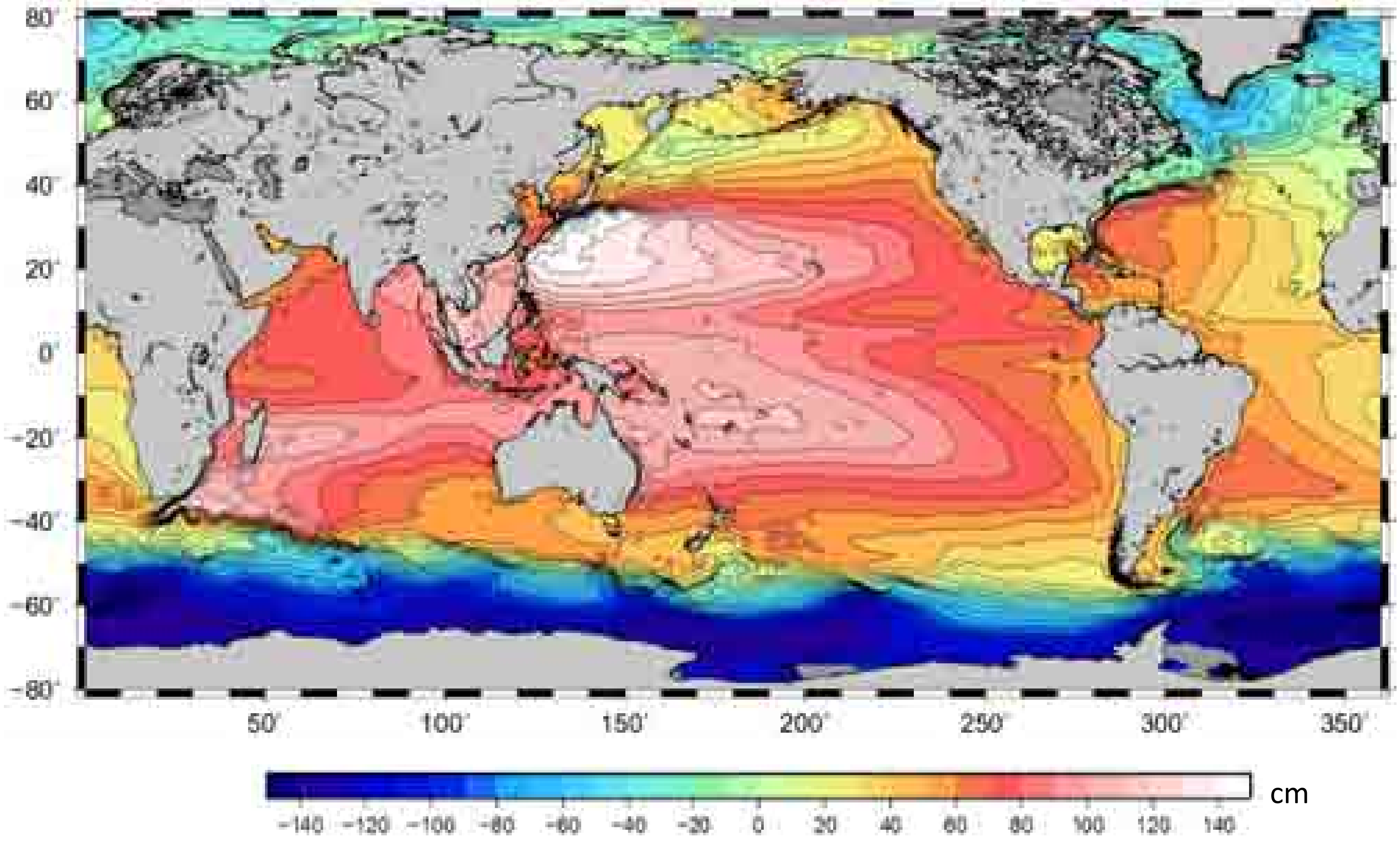
Udrifter-ualti
Filtered between 30h and 20days

Wind stress from ERA INTERIM

1 β et θ estimated by least squares in 5° and seasonally

New average absolute topography combining GRACE, altimeter and in situ data

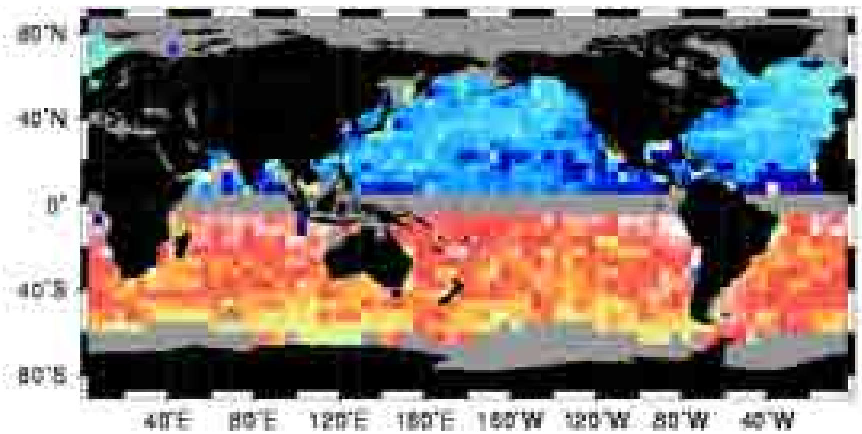
M-H Rio



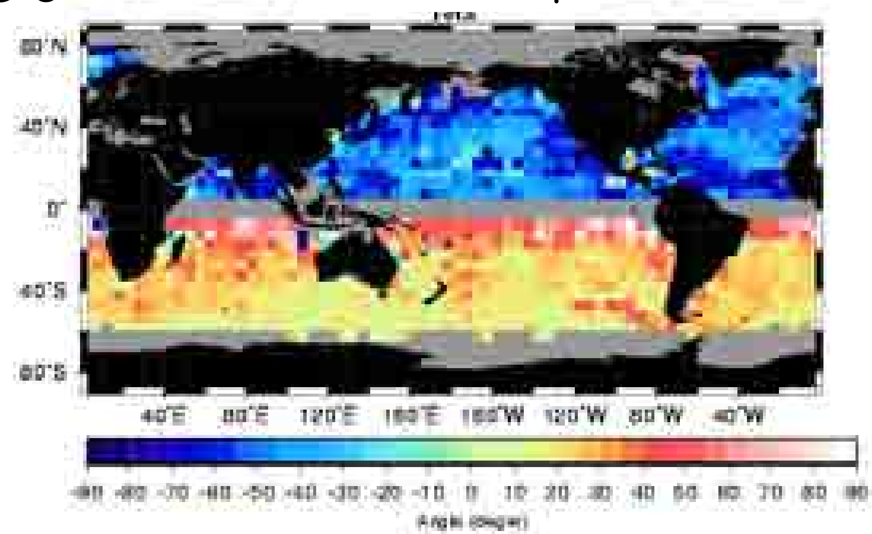
Model of 15m currents from drifters (wind part ; M.-H. Rio))

Paramètre θ

Jan-Fev-Mars

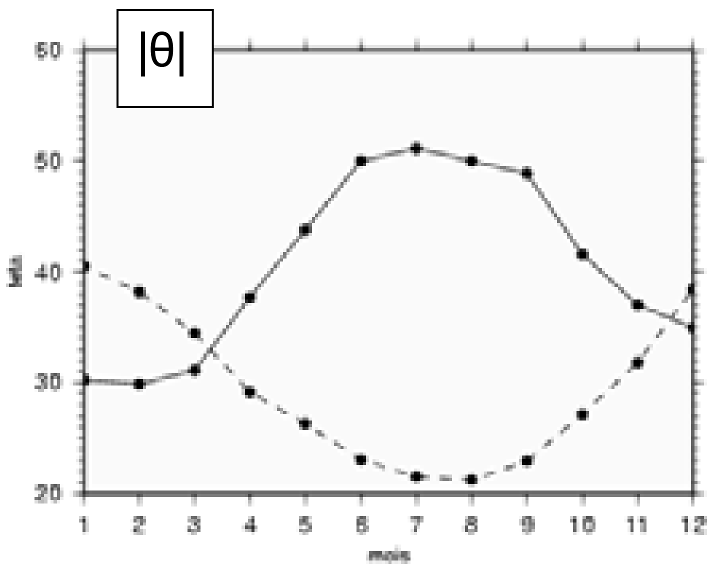


Jui/Aou/Sep



hémisphère
- ——— nord
- – – – sud

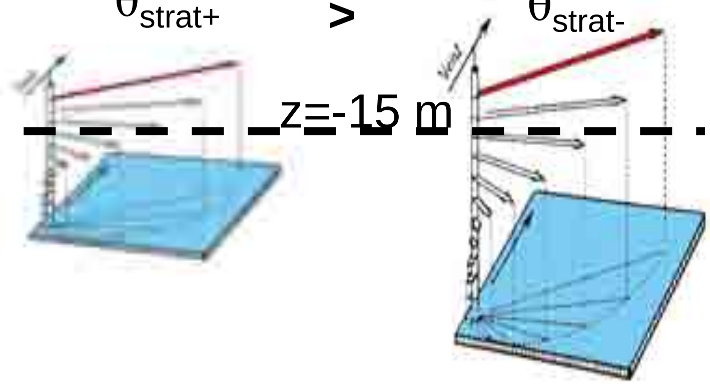
|θ|



In summer hemisphere, more stratified layer => De diminishes

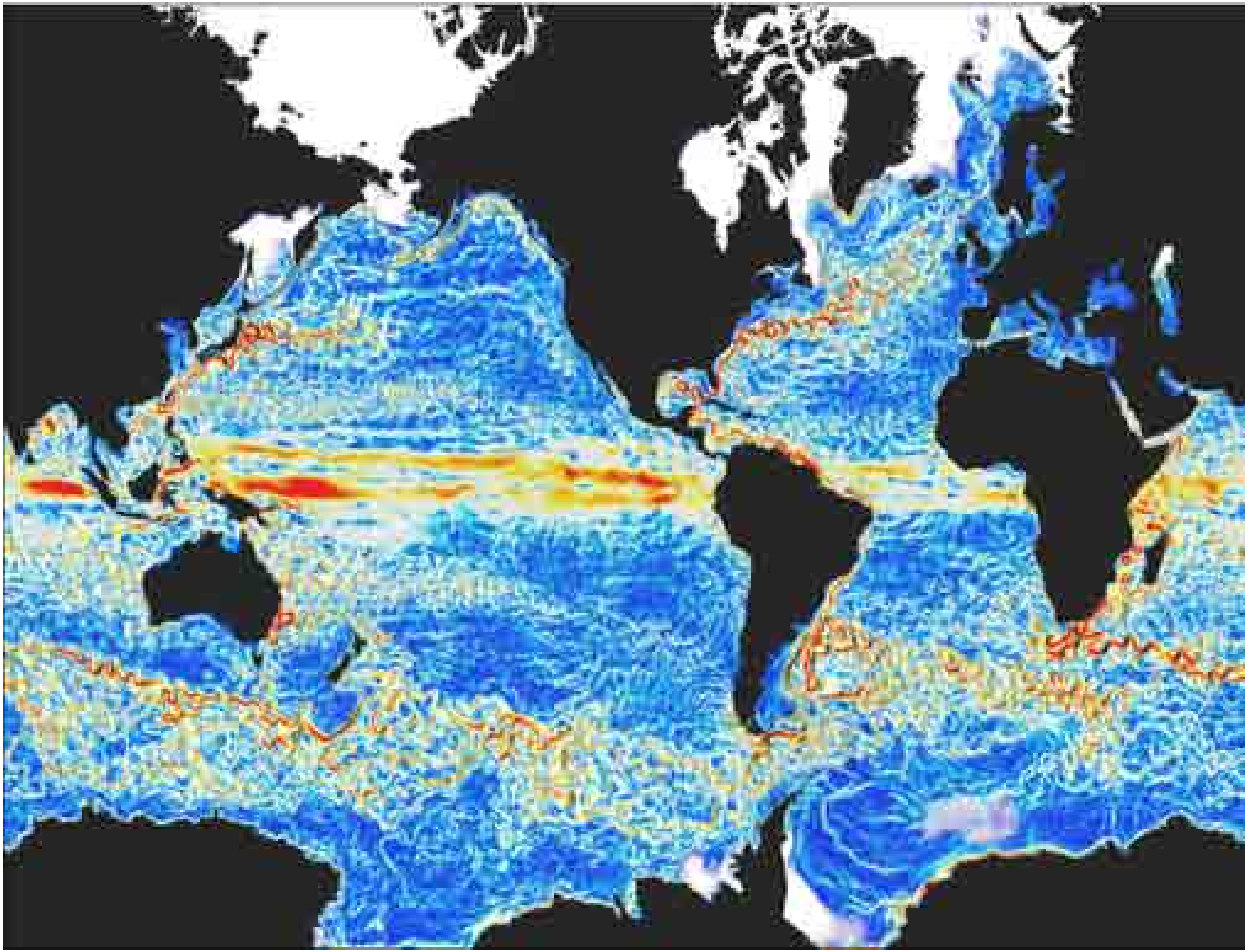
$$|\theta| = \left(\frac{\pi}{4} + \frac{15}{D_e}\right)$$ => θ increases

θ_{strat+} > θ_{strat-}



ORCA12: the surface currents

Eddies!!!

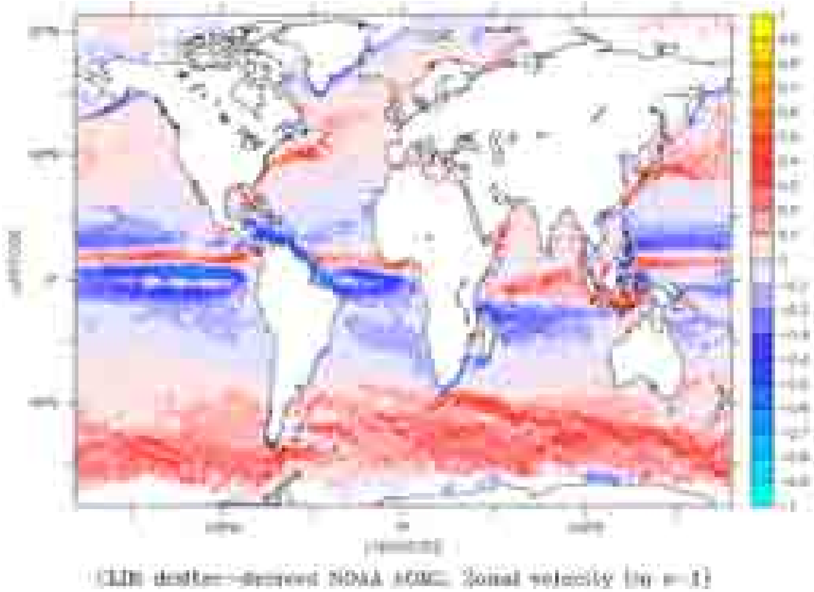


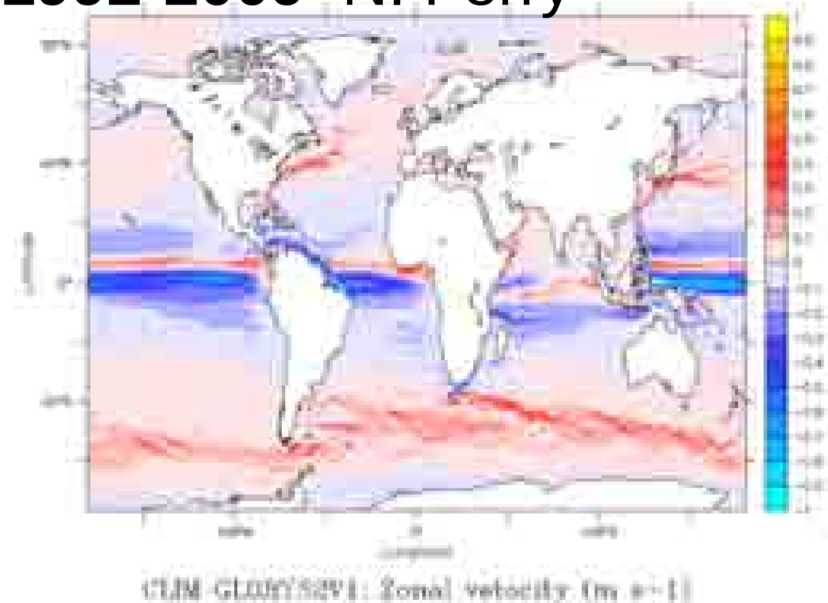
Results: GLORYS2V1 reanalysis : 1992-2009 N. Ferry

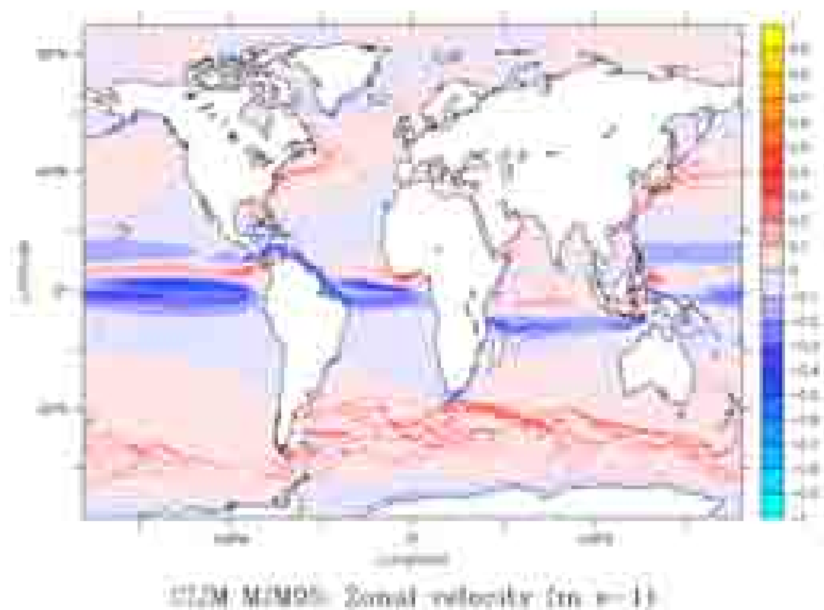
CLASS1 metric - difference with climatology

SVP drifter velocities are biased
Grodsky et al. GRL 2011

15 m zonal velocity



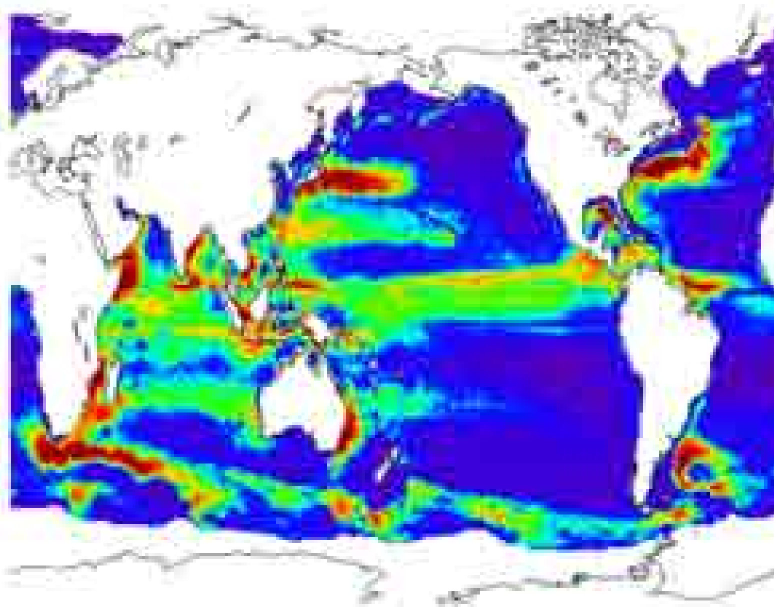




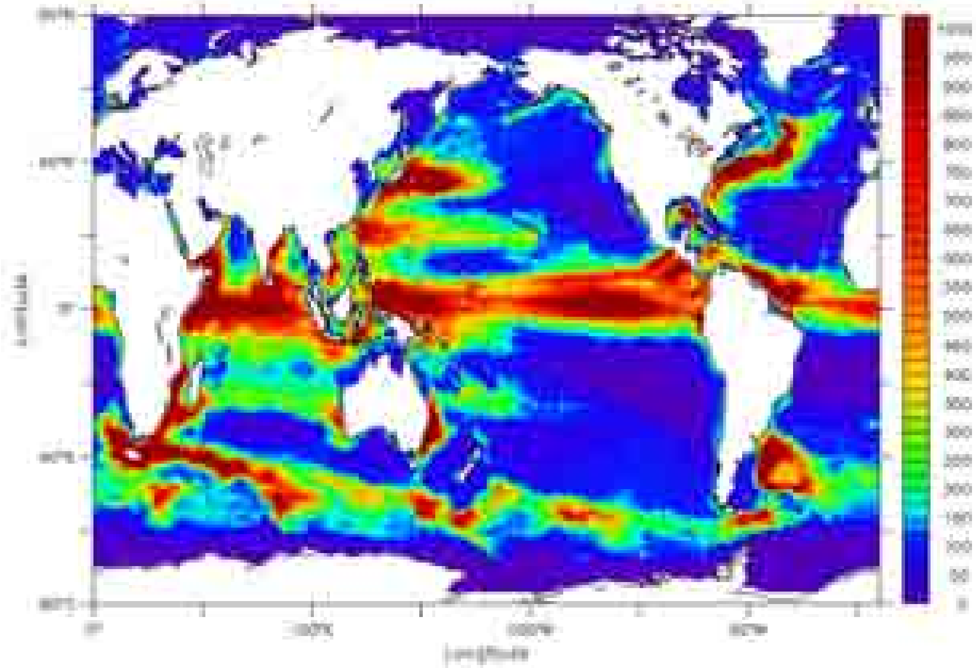
Still major flaws in the representation of equatorial undercurrents (the FREE RUN is far better)

Surface EKE (N. Ferry)

SURCOUF



GLORYS1



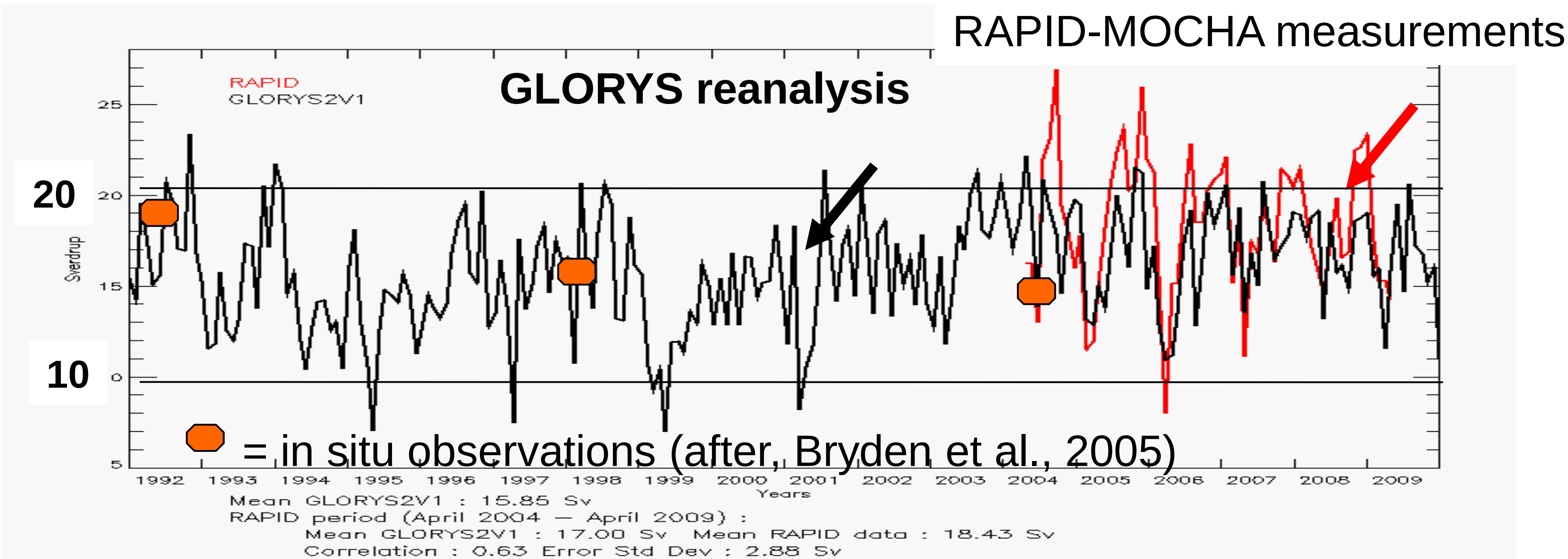
Mesoscale eddies are generated by the instability of the large scale flows:

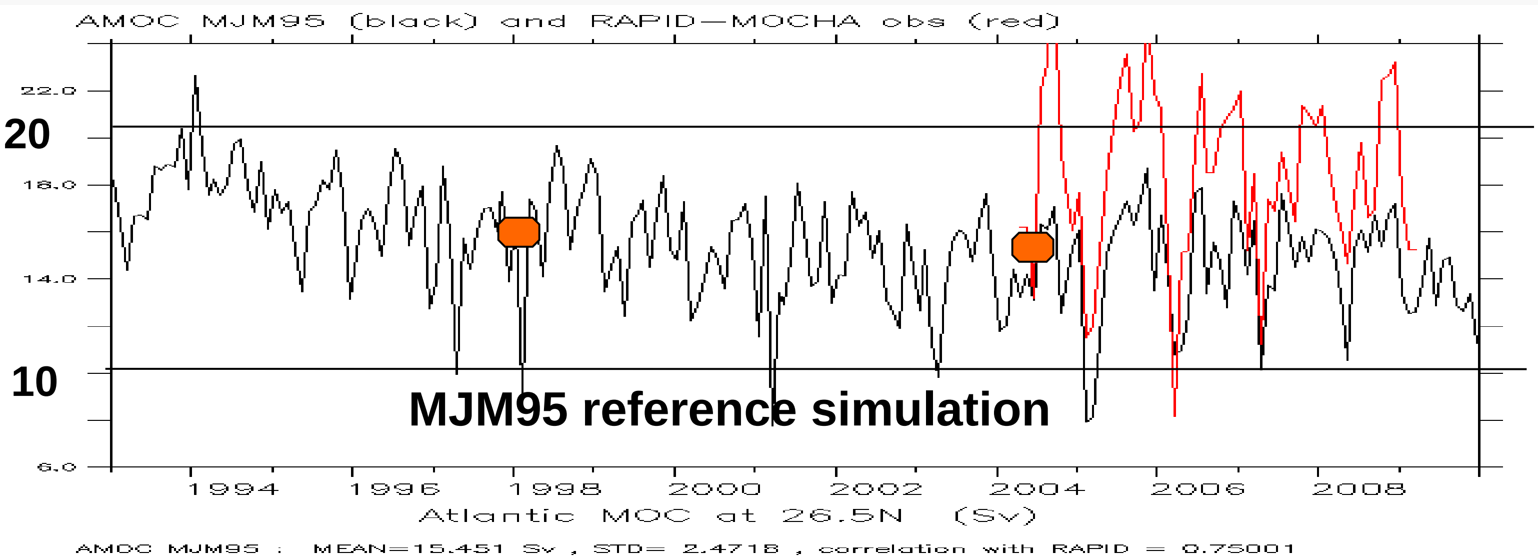
- Baroclinic instability (vertical shear) which is ubiquitous in the ocean (1st baroclinic mode)
- Barotropic instability (hz shear) in strong currents.

Mesoscale eddies are <u>strongly coupled to the general circulation</u>

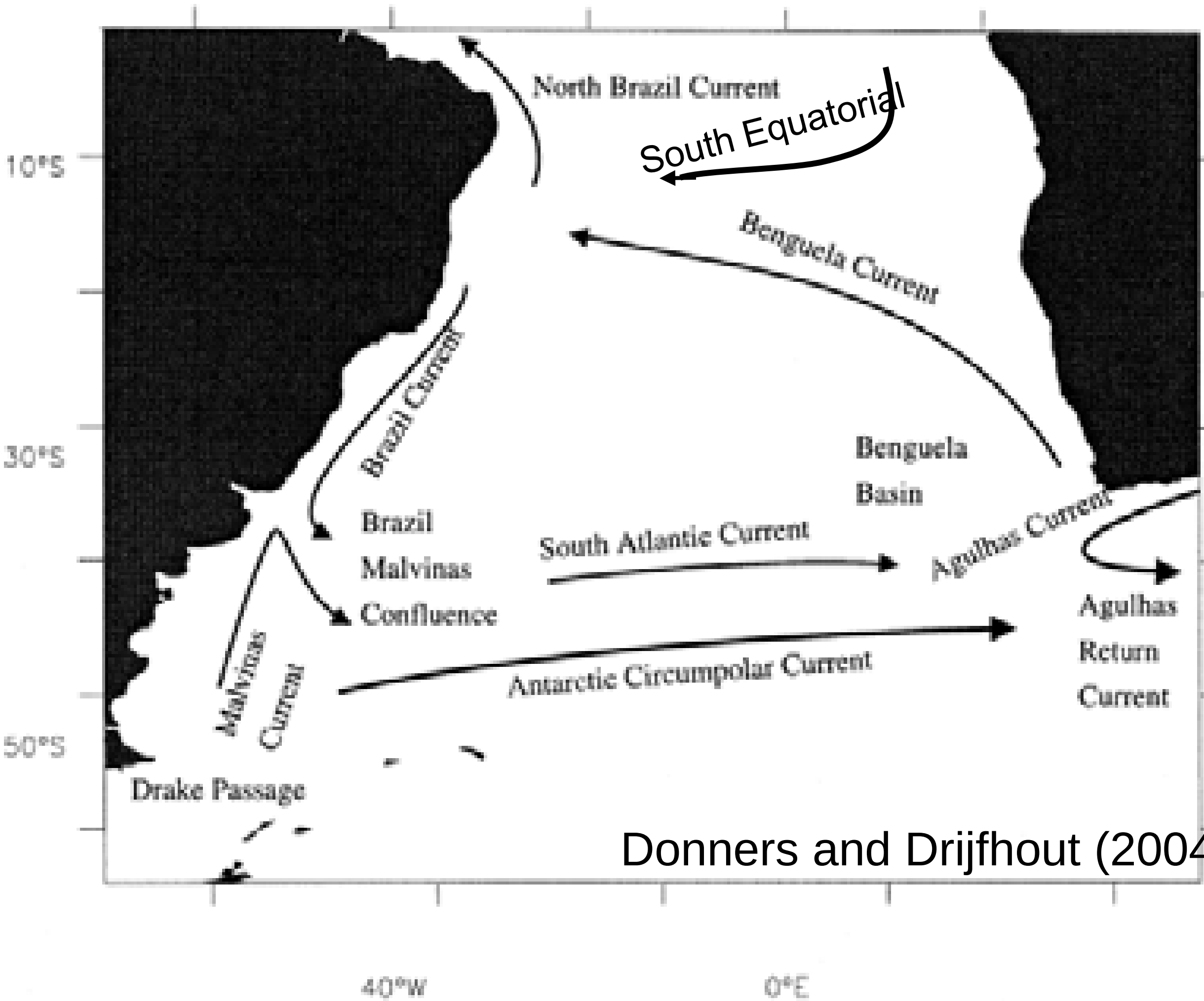
Results: GLORYS2V1 reanalysis : 1992-2009

Maximum Atlantic MOC at 26.5°N





South Atlantic circulation

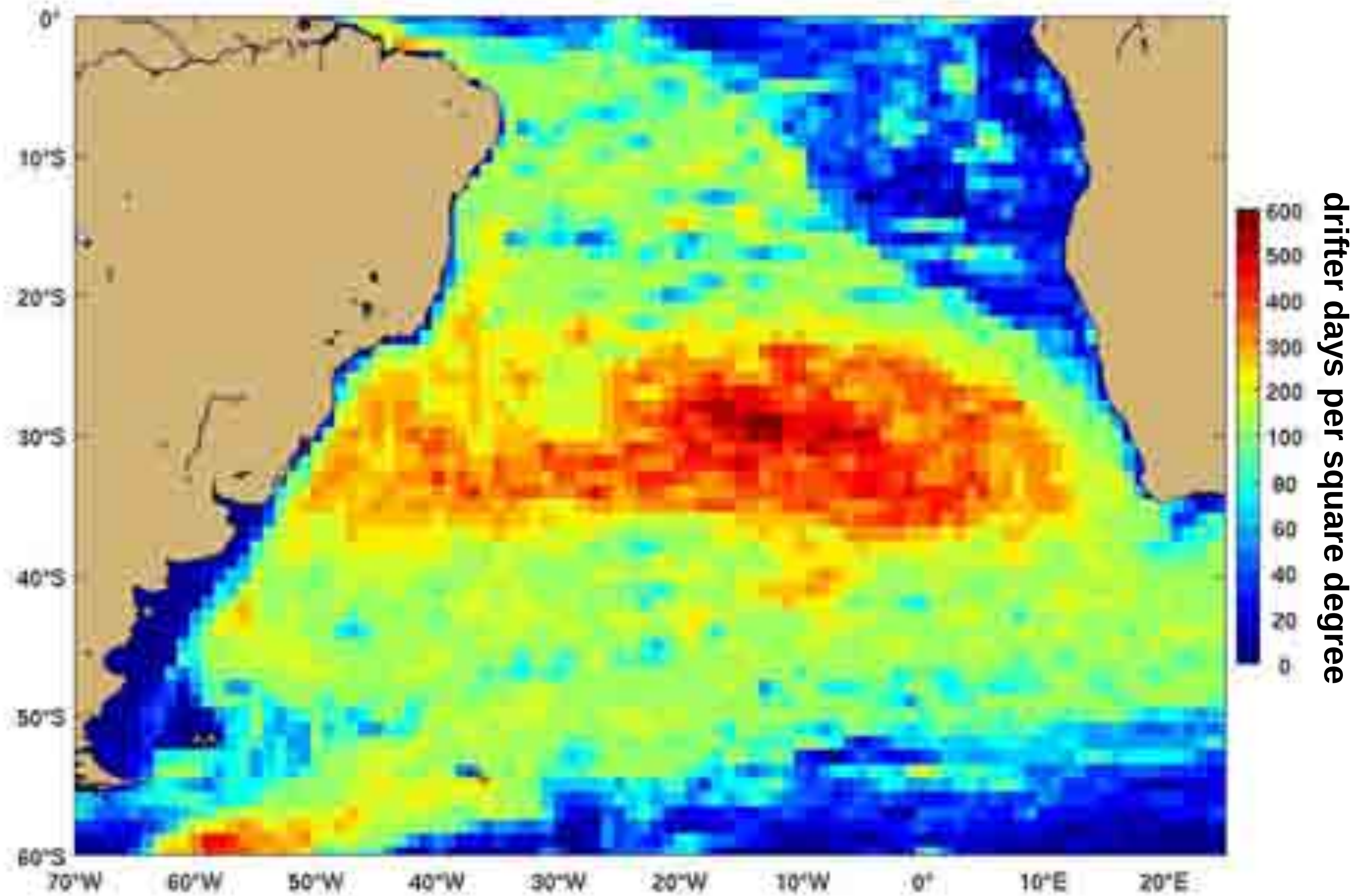


Donners and Drijfhout (2004)

“Warm” route: Agulhas leakage into South Atlantic along Benguela pathway.

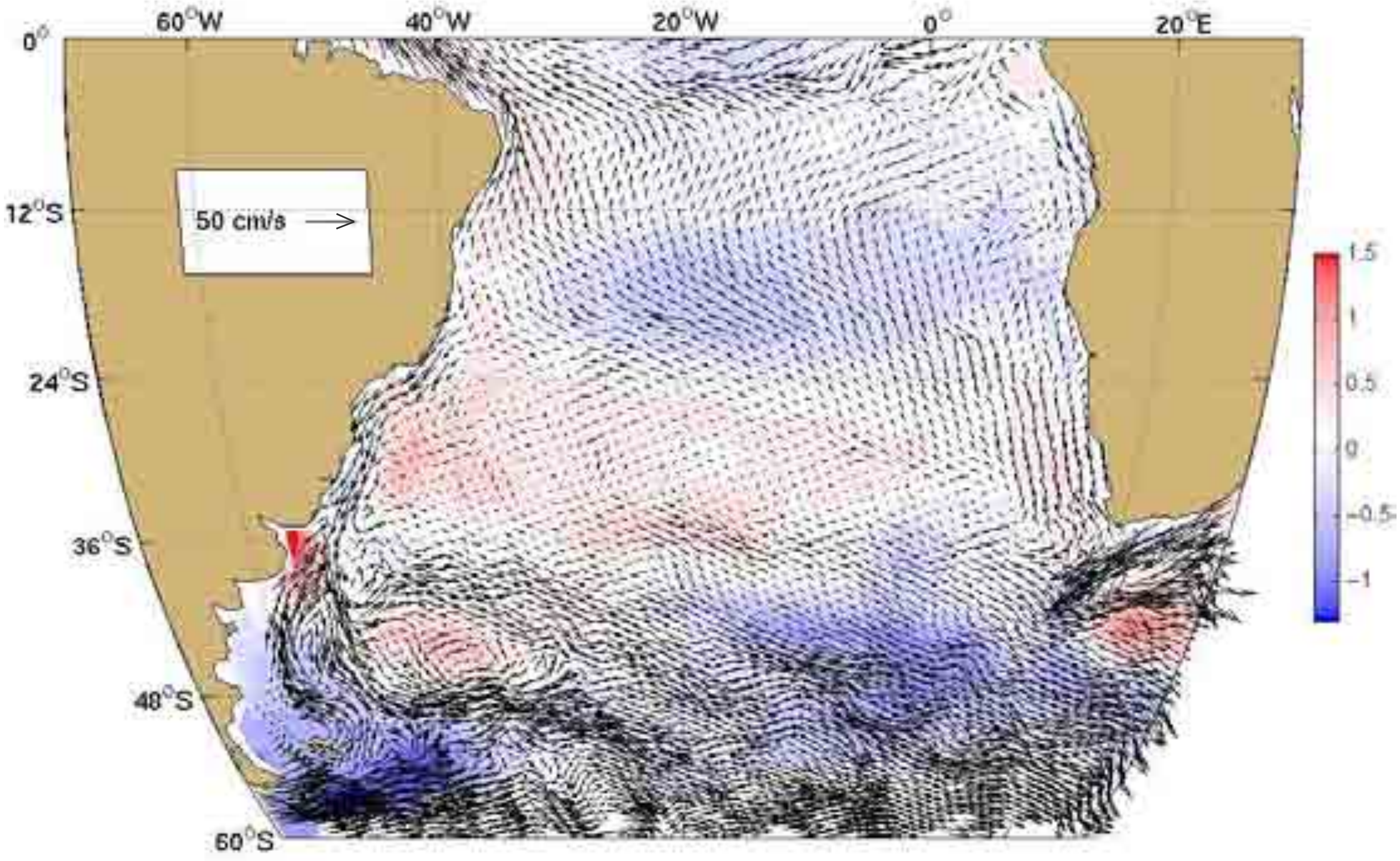
“Cold route” (AAIW): sensitive to dynamics of Subtropical Front, possibly including its location.

Drifter observations in the South Atlantic



R. Lumpkin

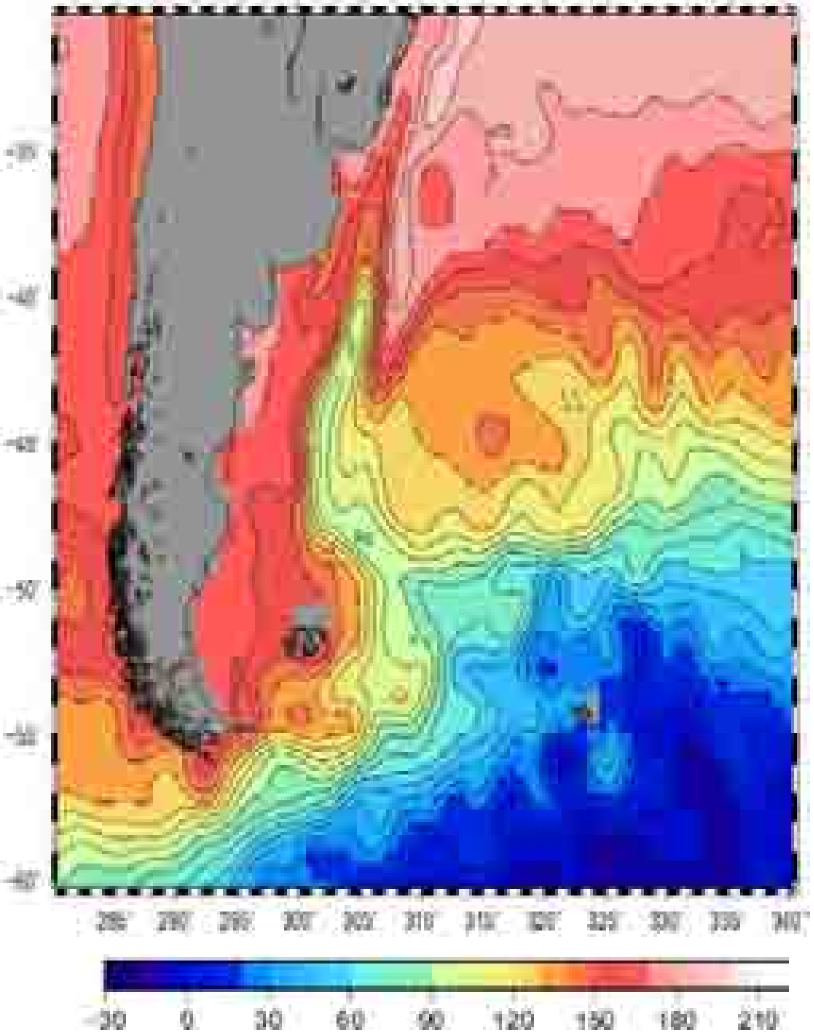
Time-mean South Atlantic circulation from drifters



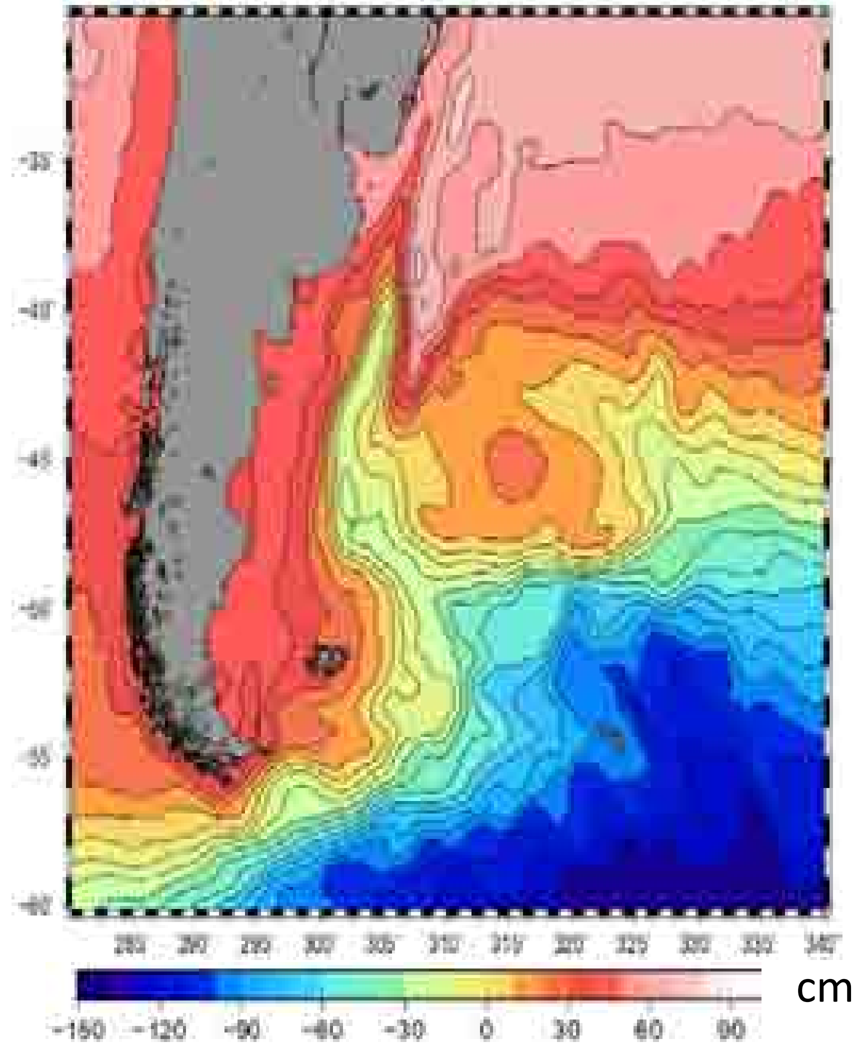
Shading: SST trend, 1993—2002 (°C/decade) from NCEP/NCAR.v2 (R. Lumpkin)

Confluence region

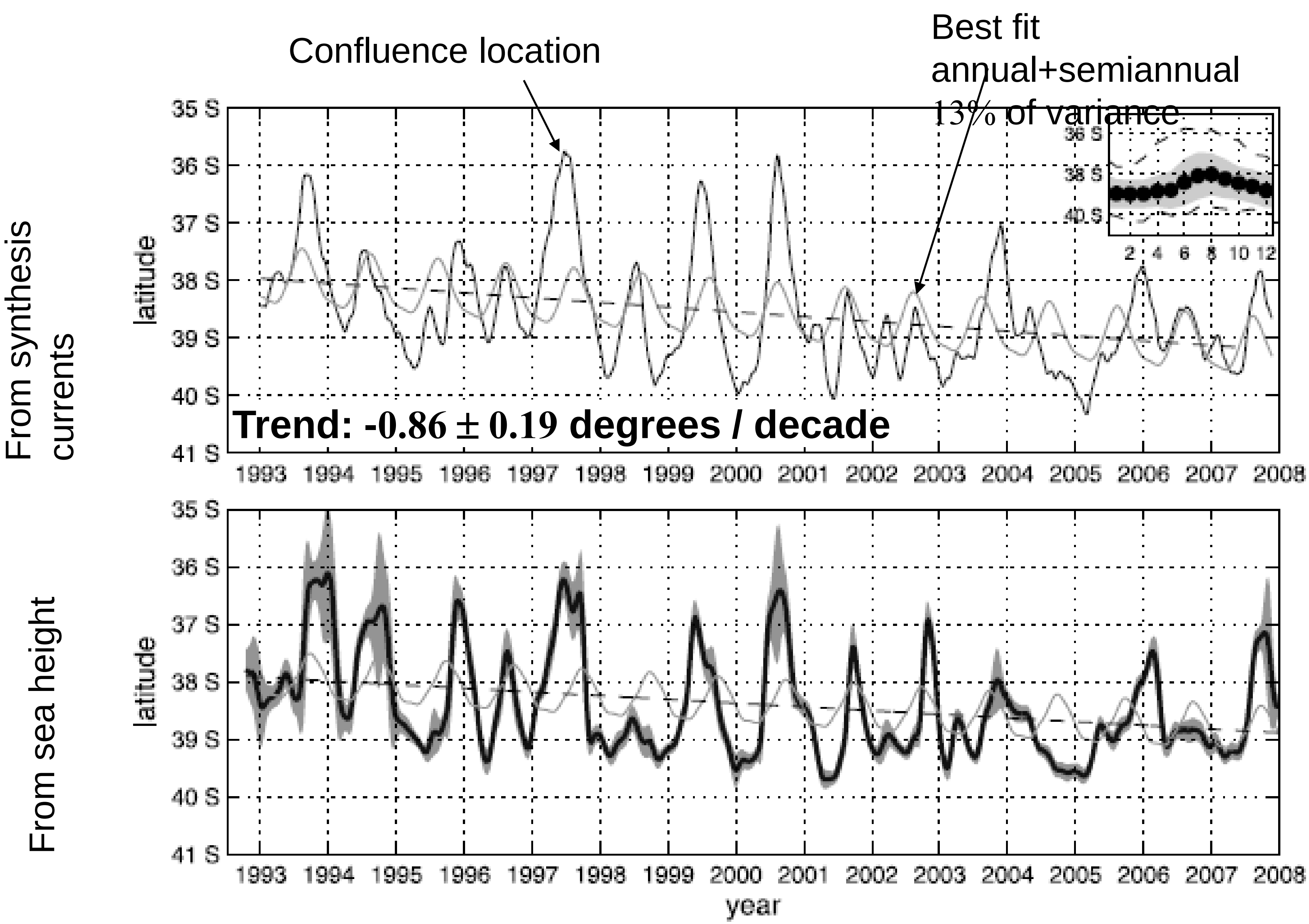
CMDT RIO05



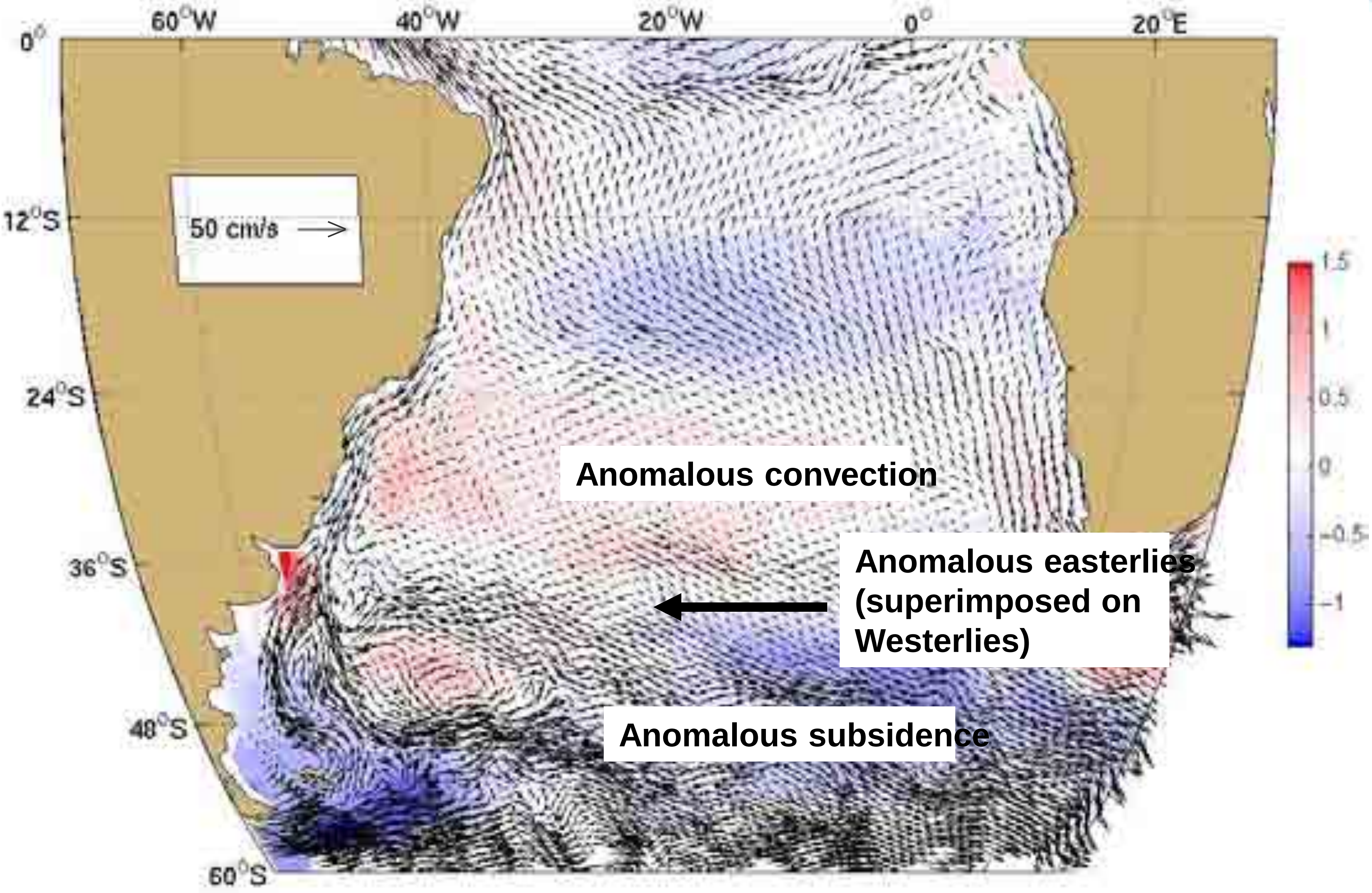
CMDT CNES-CLS09



Temporal variations (R. Lumpkin)



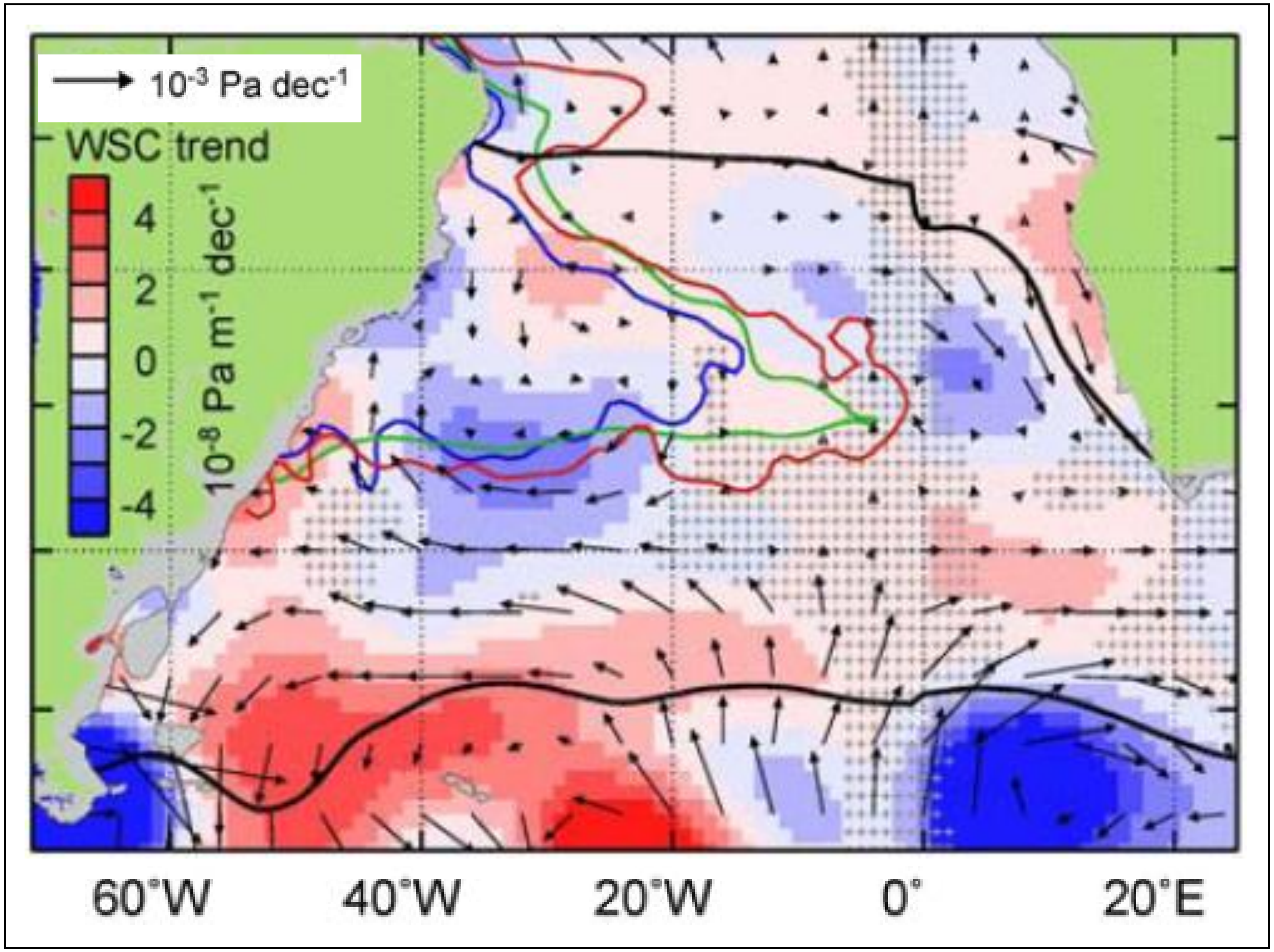
South Atlantic SST trend



Shading: SST trend, 1993—2002 (°C/decade) from NCEP/NCAR.v2

Variations in wind stress curl $\nabla\times\boldsymbol{\tau}$

Wind (arrows) and $\nabla\times\boldsymbol{\tau}$ (shading) trend, 1993—2006.



135 cm dynamic height, June 1993

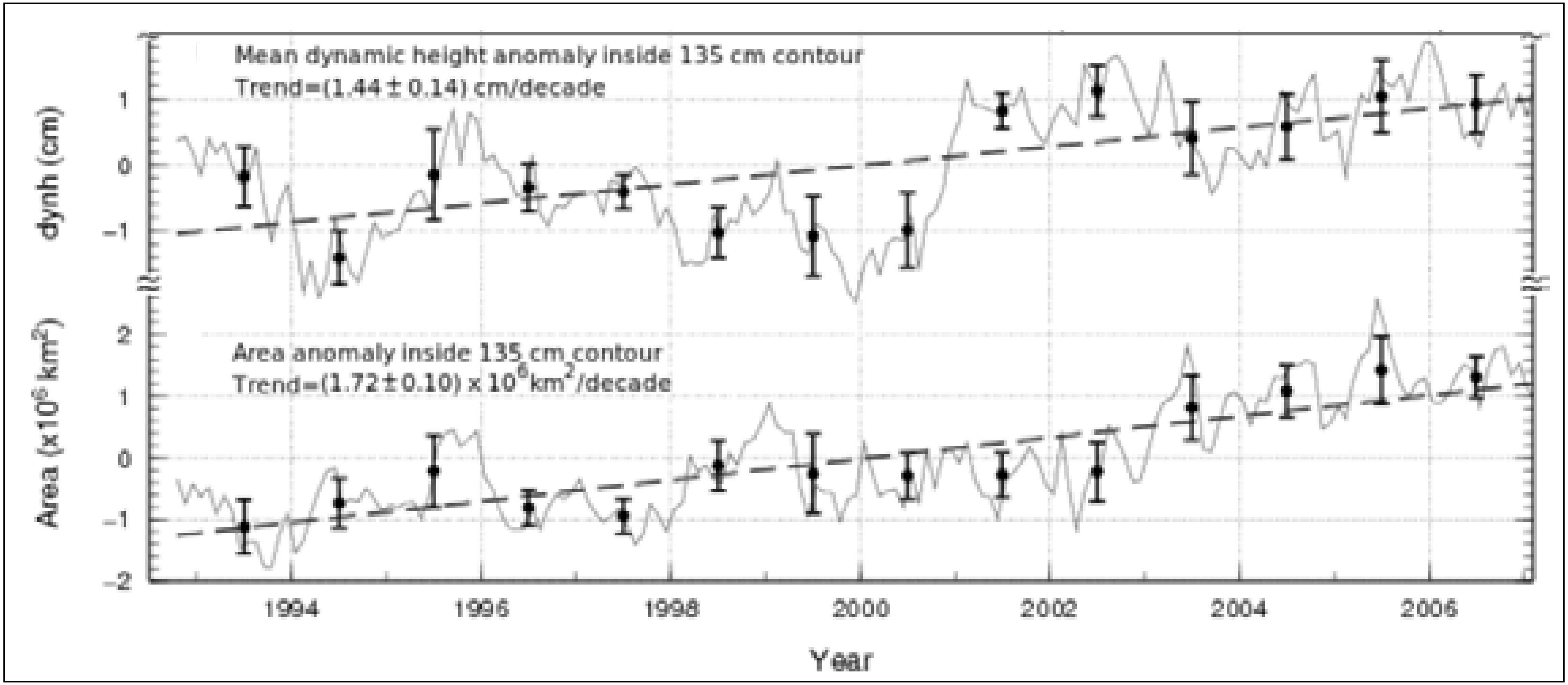
135 cm dynamic height, time-mean

135 cm dynamic height, June 2006

Climatological $\nabla\times\boldsymbol{\tau}=0$

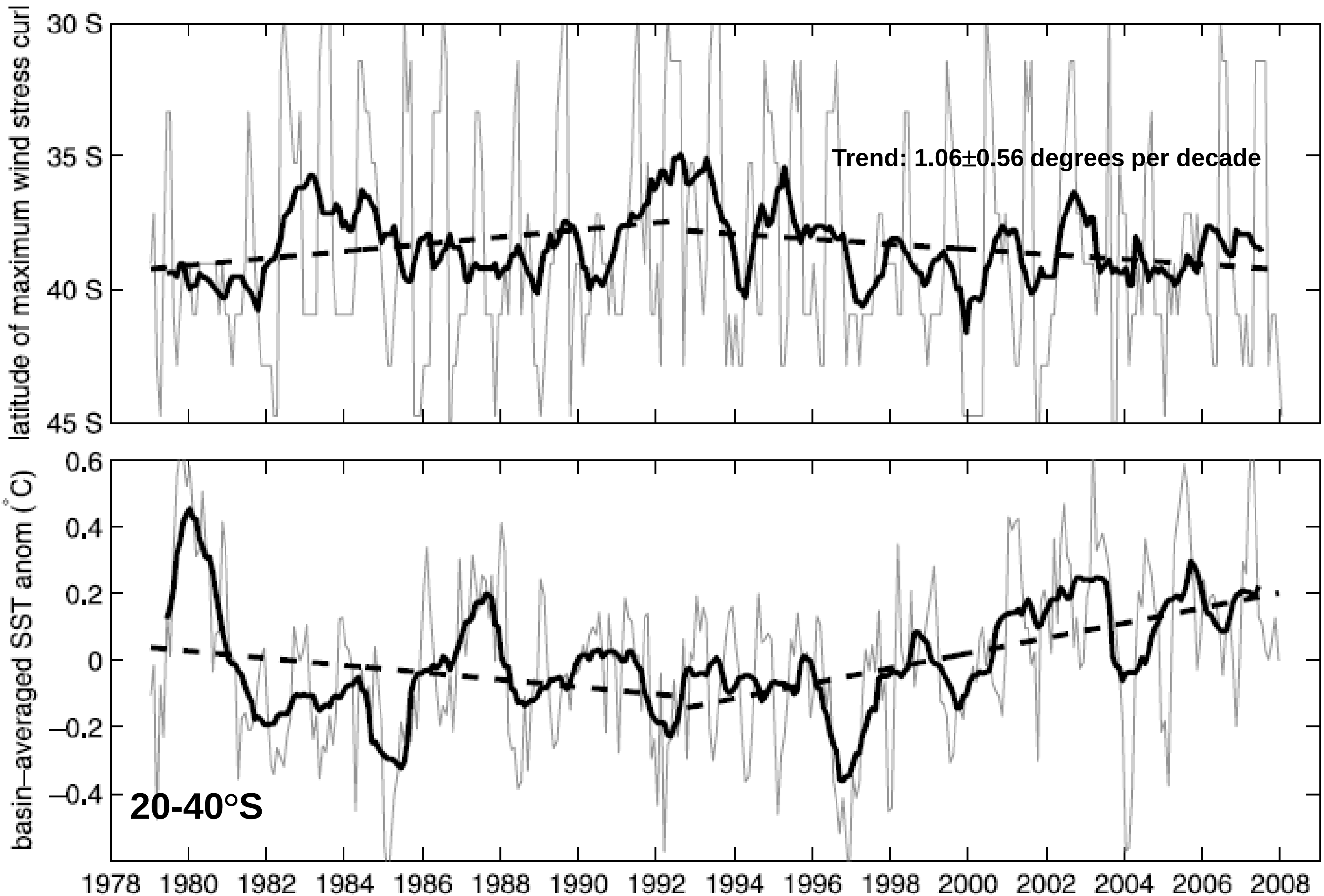
From Goni *et al.* (2011).

Growth of the subtropical gyre



From Goni *et al.* (2011).

Using $\nabla \times \boldsymbol{\tau}$ as a proxy for Confluence location

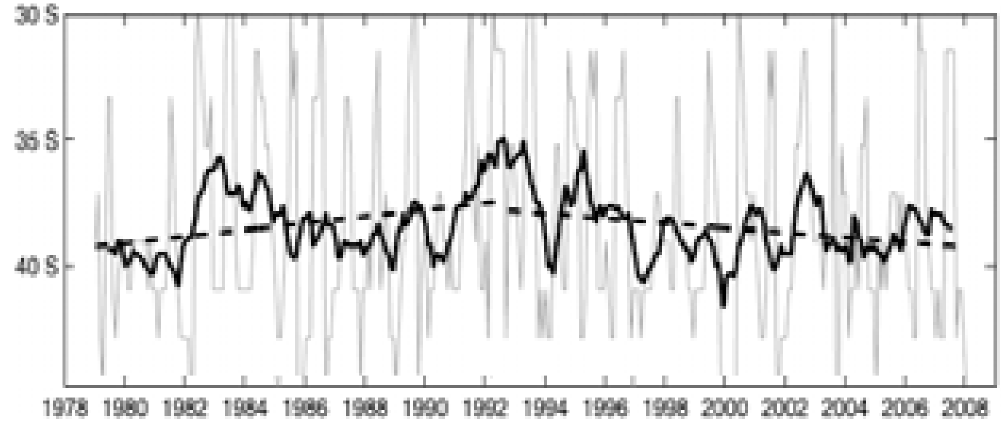


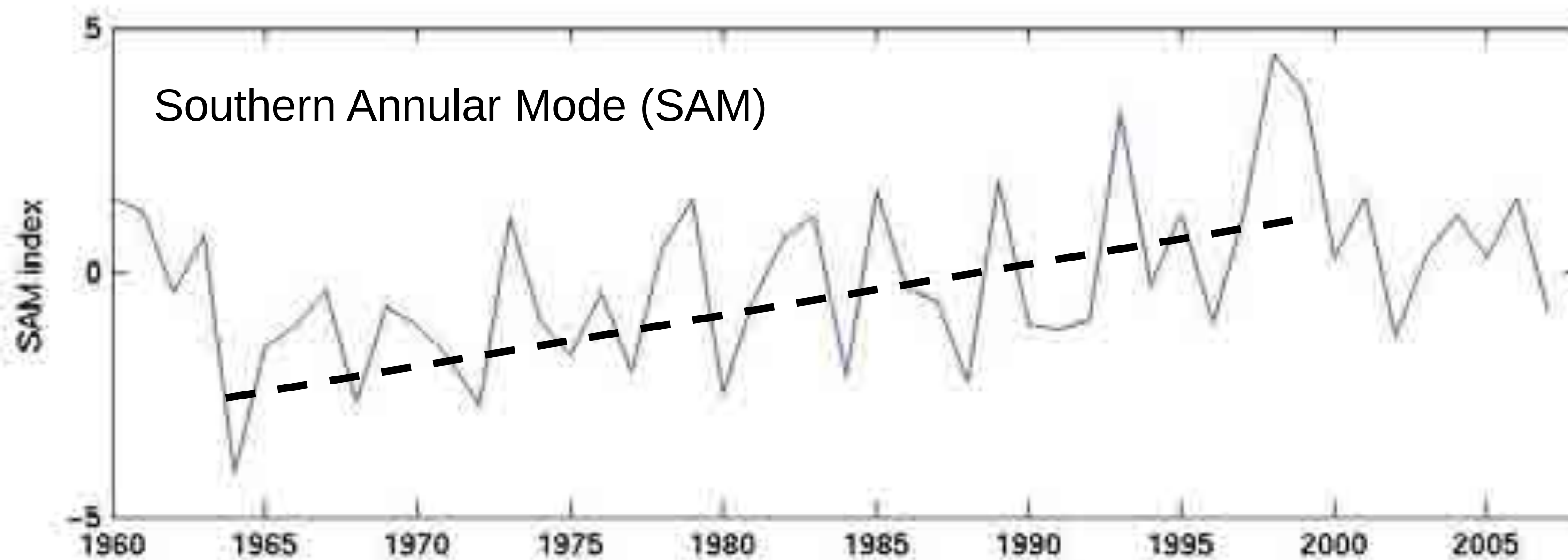
R. Lumpkin

Confluence Front and SAM

(R. Lumpkin)

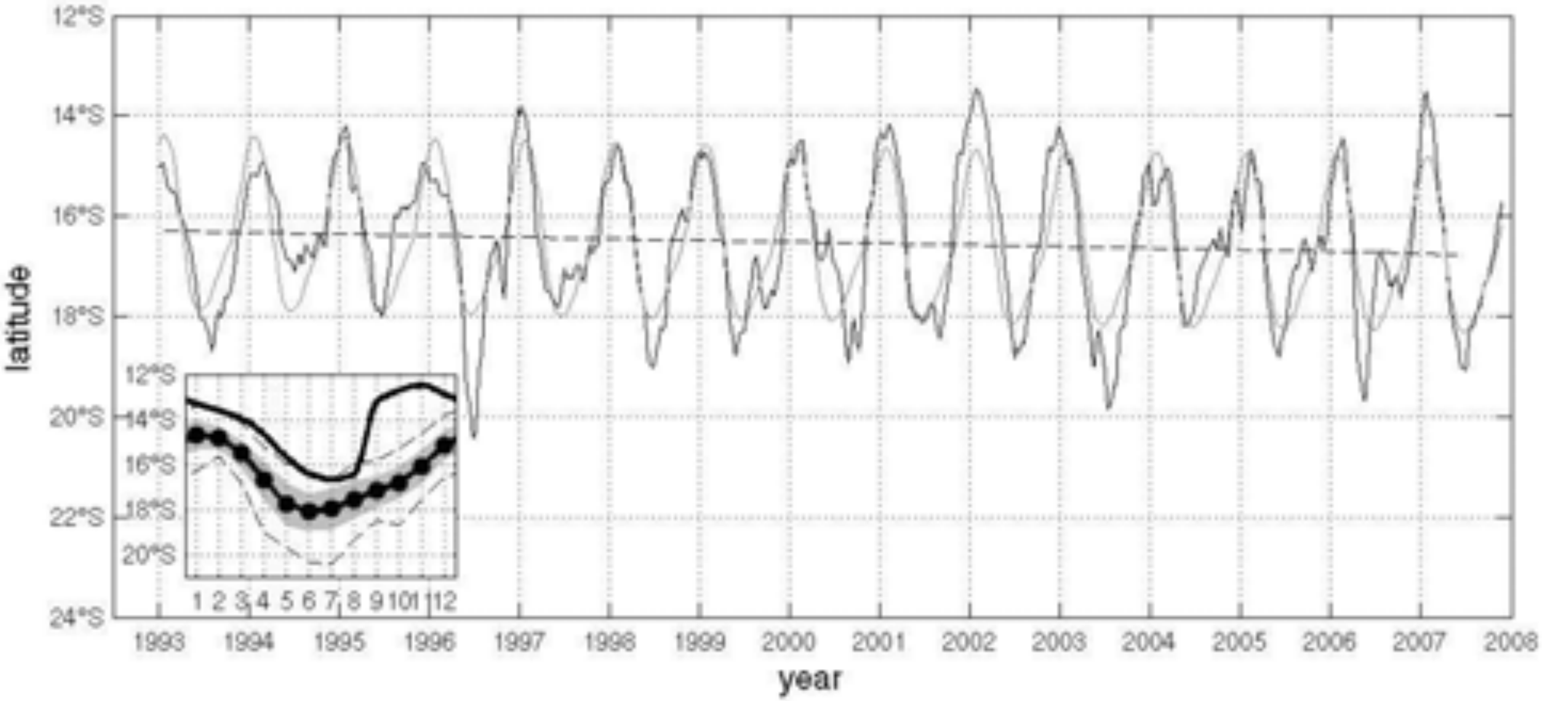
Confluence Location
(wind stress proxy)





Bifurcation of the SEC

(R. Lumpkin)

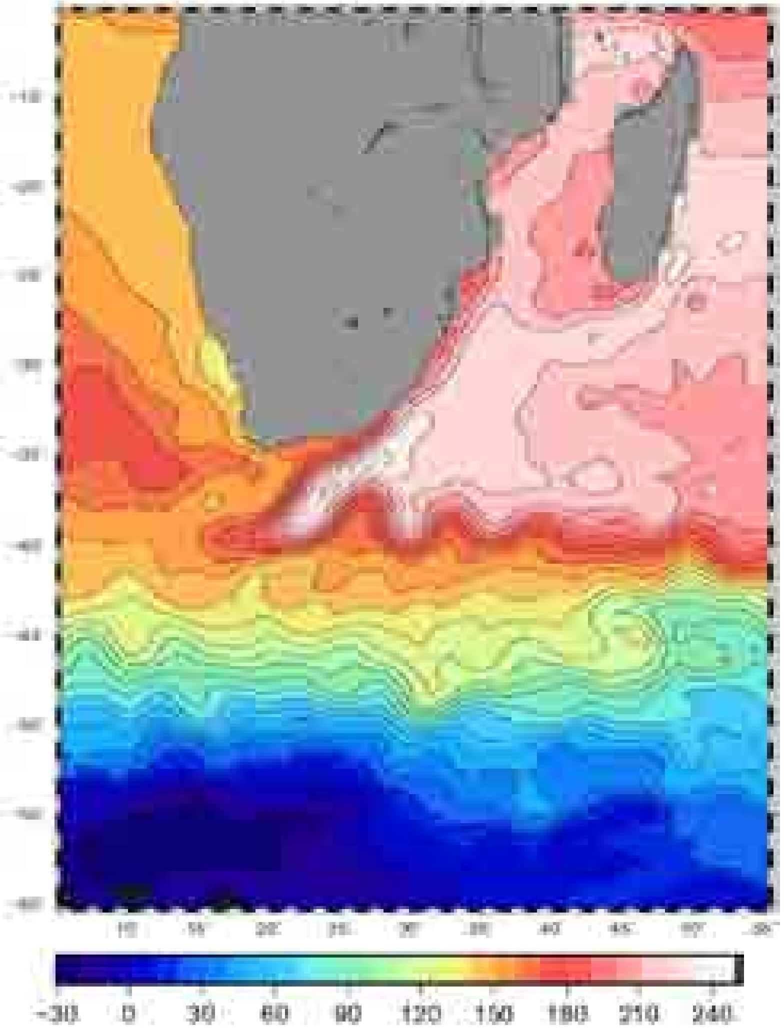


No evidence of long-term trend: asymmetric expansion of the South Atlantic subtropical gyre

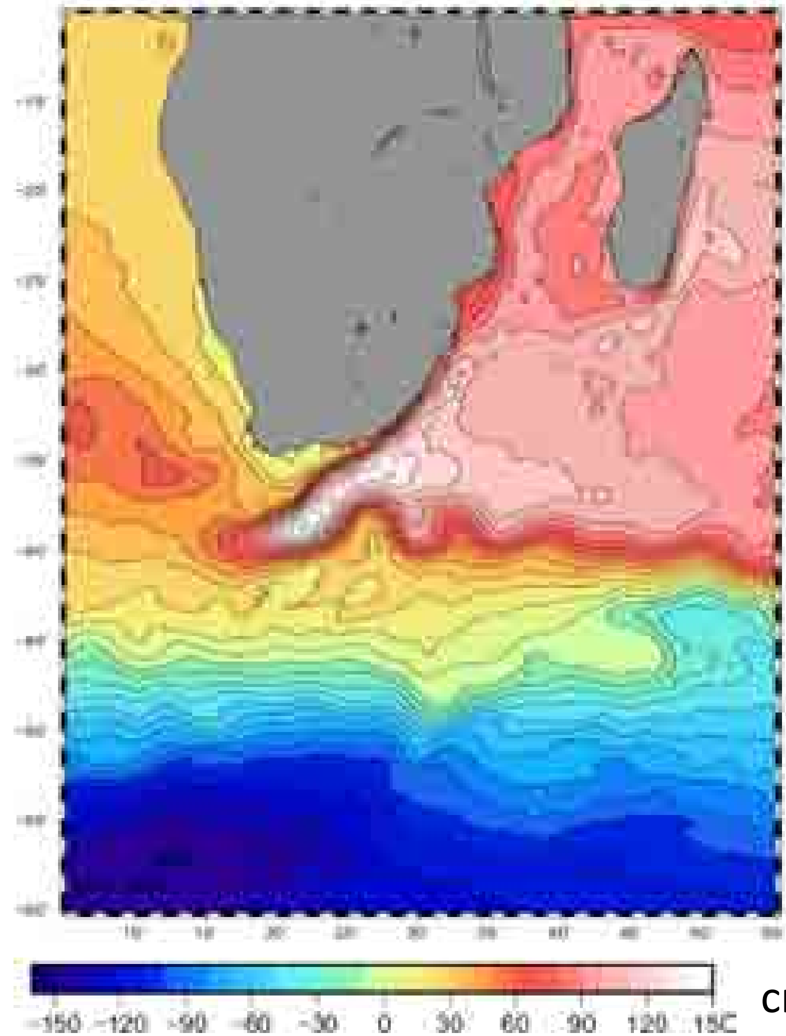
Average circulation (M.-H. Rio)

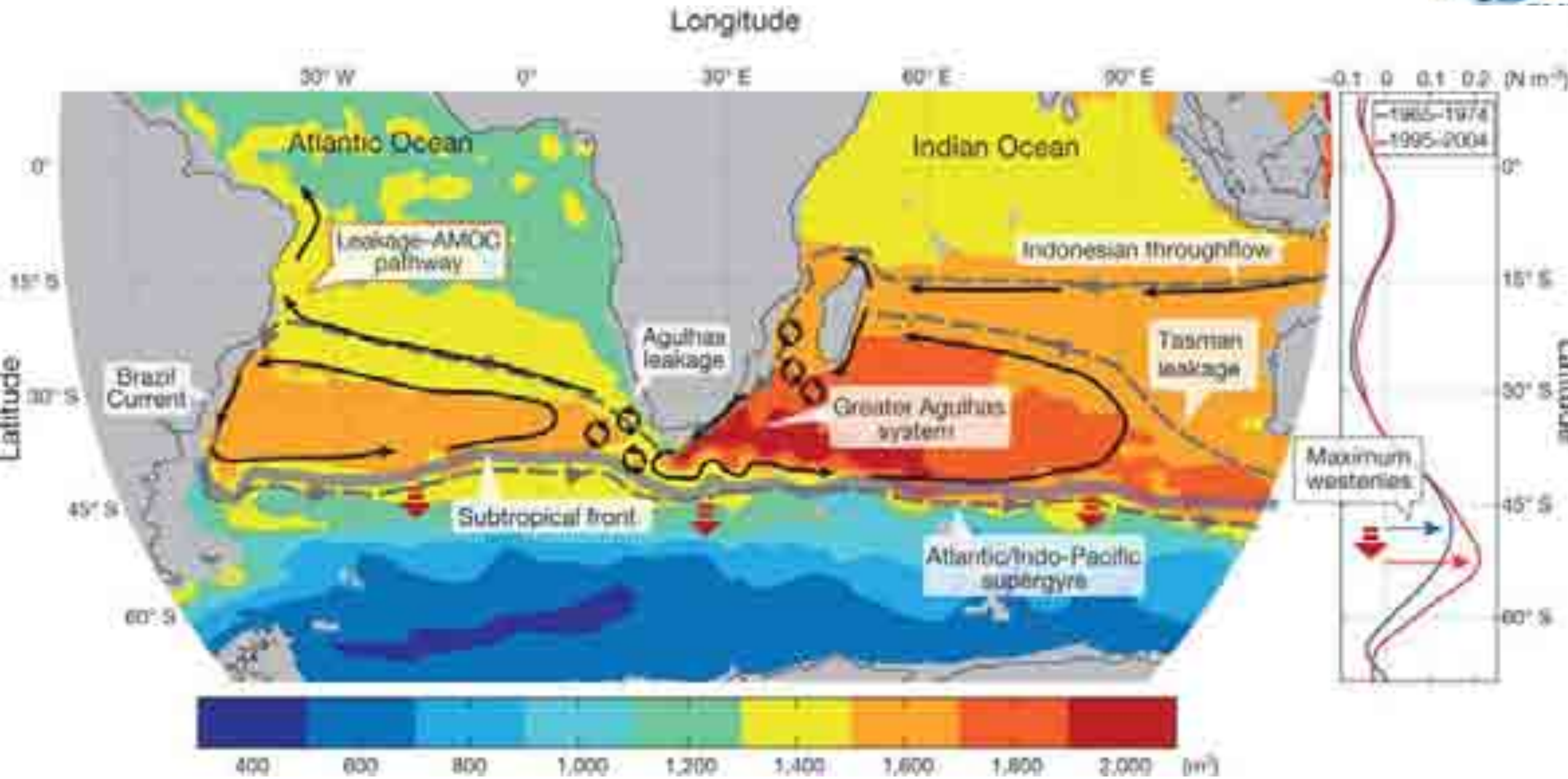
Agulhas Current

CMDT RIO05



CMDT CNES-CLS09

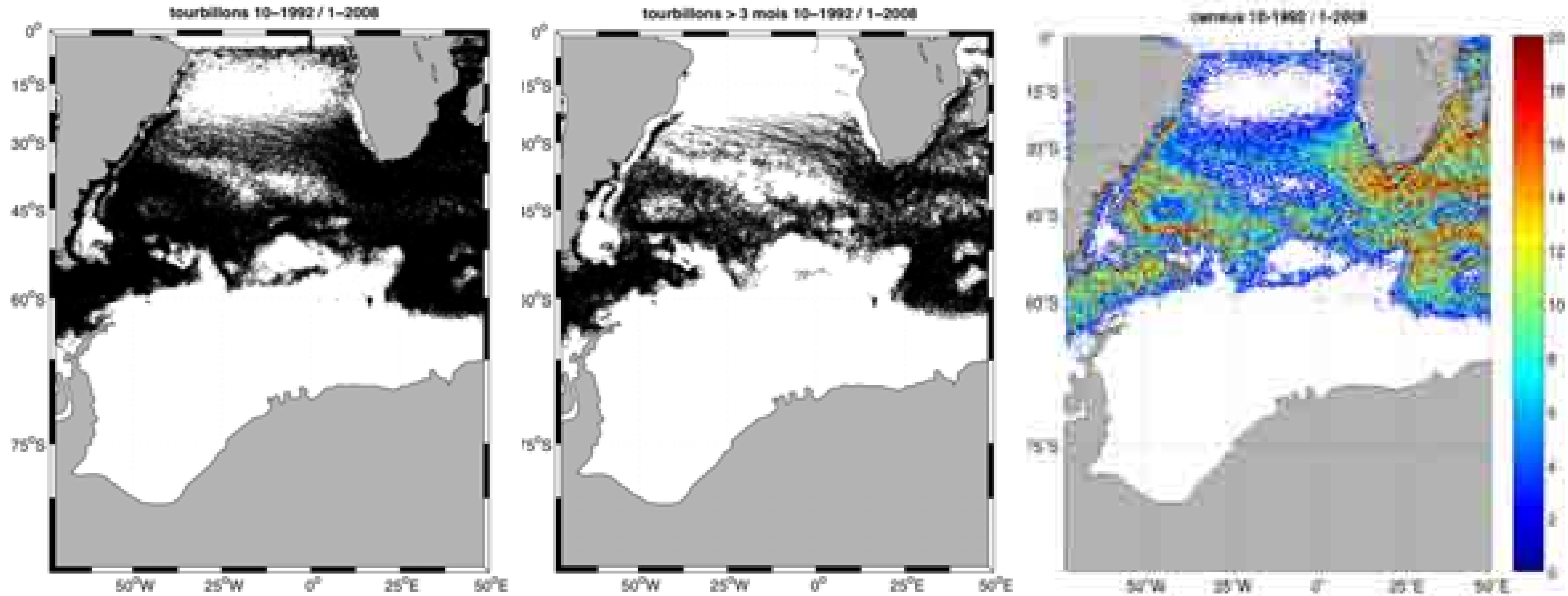




Biastoch *et al*. (2009), Beal *et al*. (2011): Agulhas leakage increasing with southward shift of wind field. Based on satellite data, far-field hydrographic data and hindcast simulations (no long-term *in situ* observations of Agulhas leakage). Three-decade trend related to anthropogenic forcing in simulations.

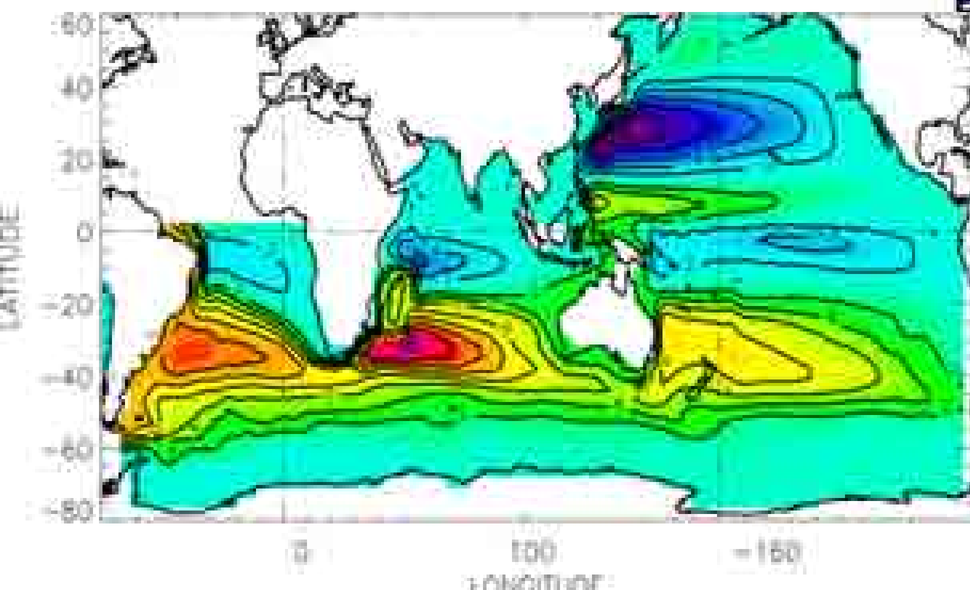
Tracking of global eddies trajectories from MADT AVISO
Focus on the South Atlantic

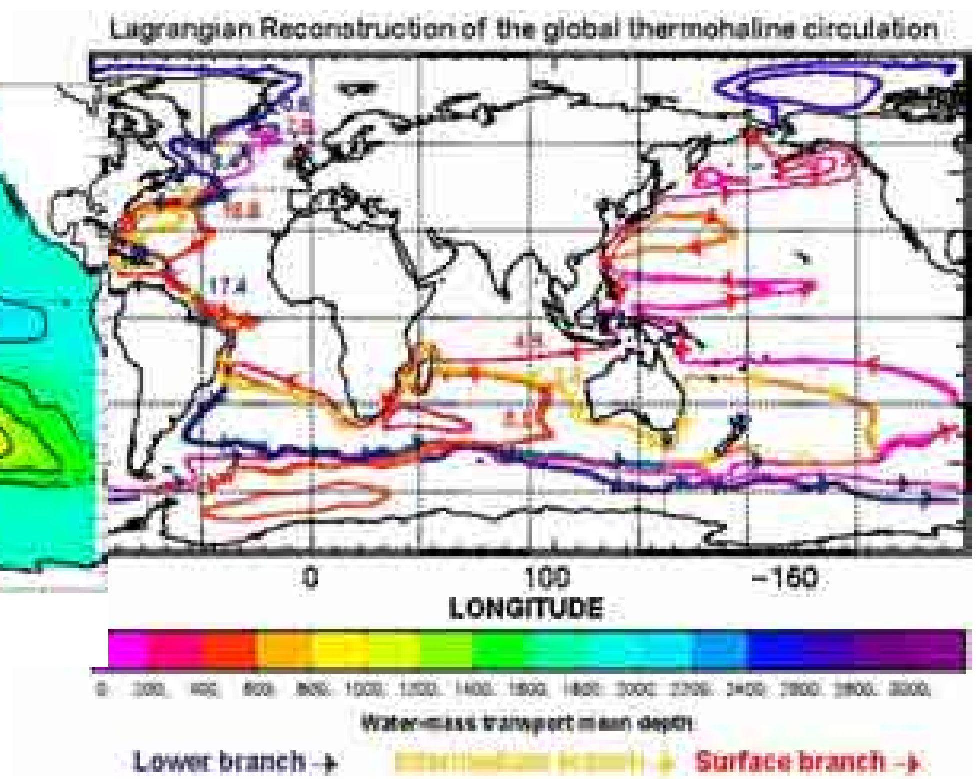
Frontal dynamics and properties exchanges by mesoscale and submesoscale ocean structures



PhD of Arnaud David

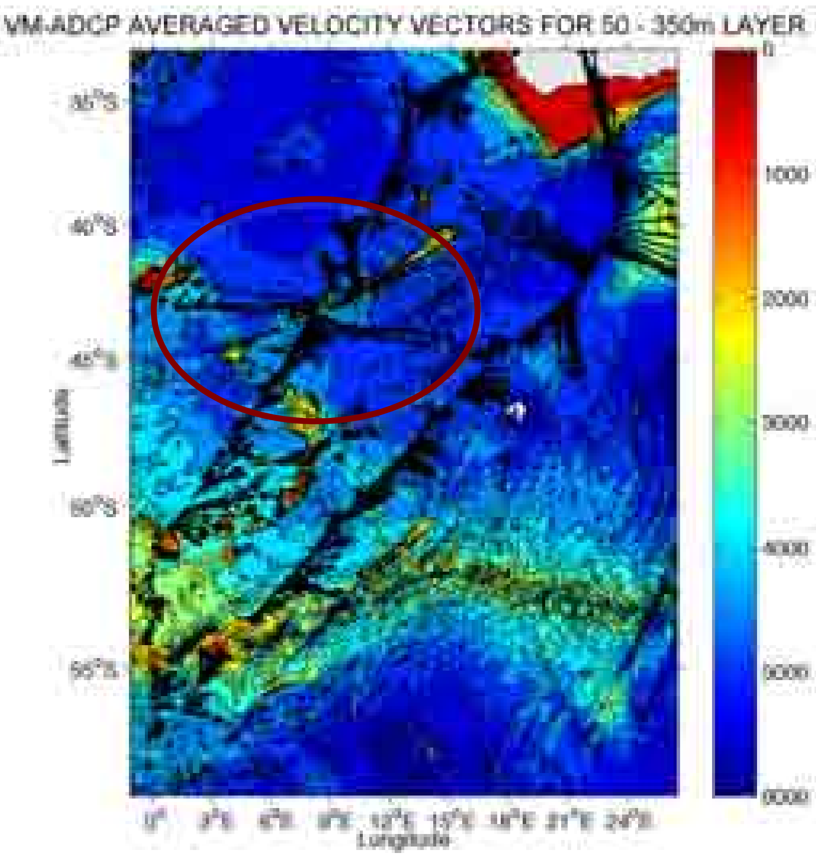
Model analyses : The Lagrangian view

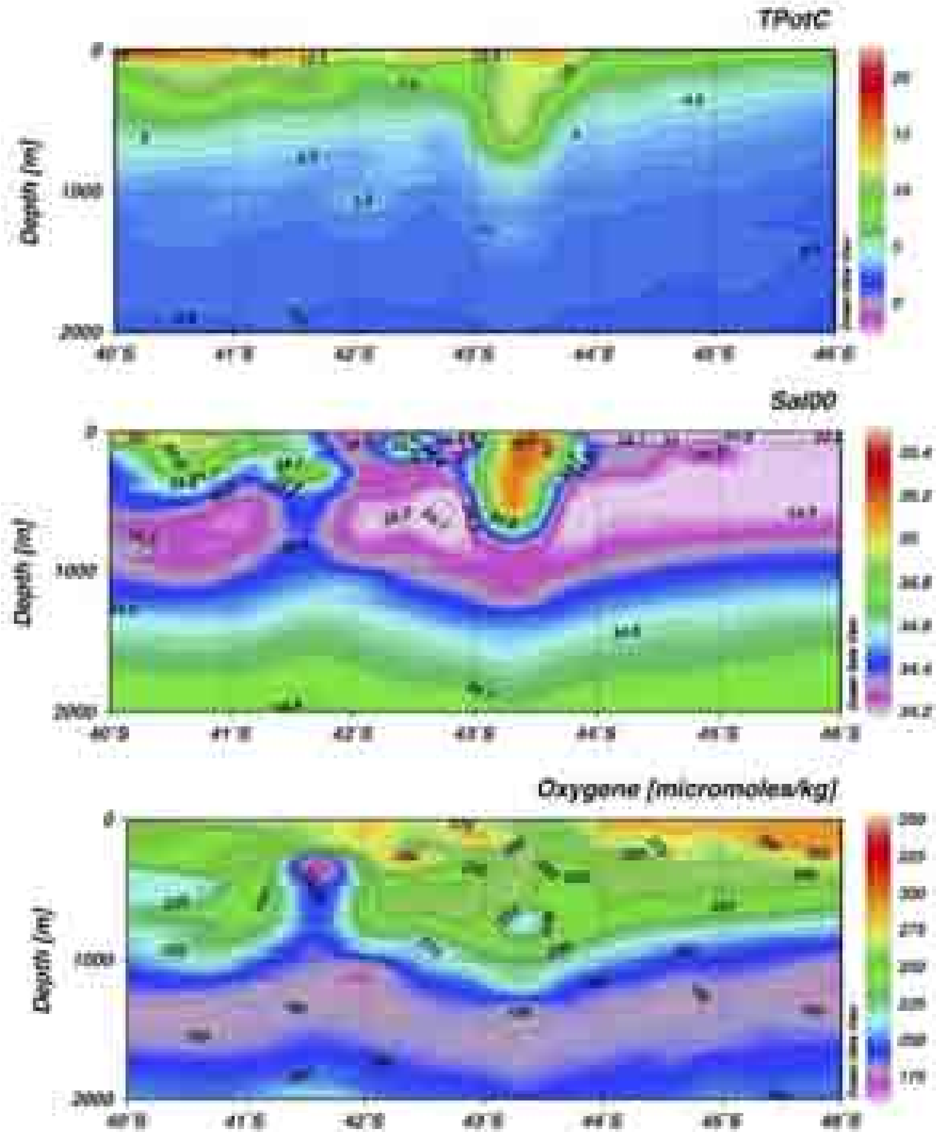




Speich et al., 2002 & 2007

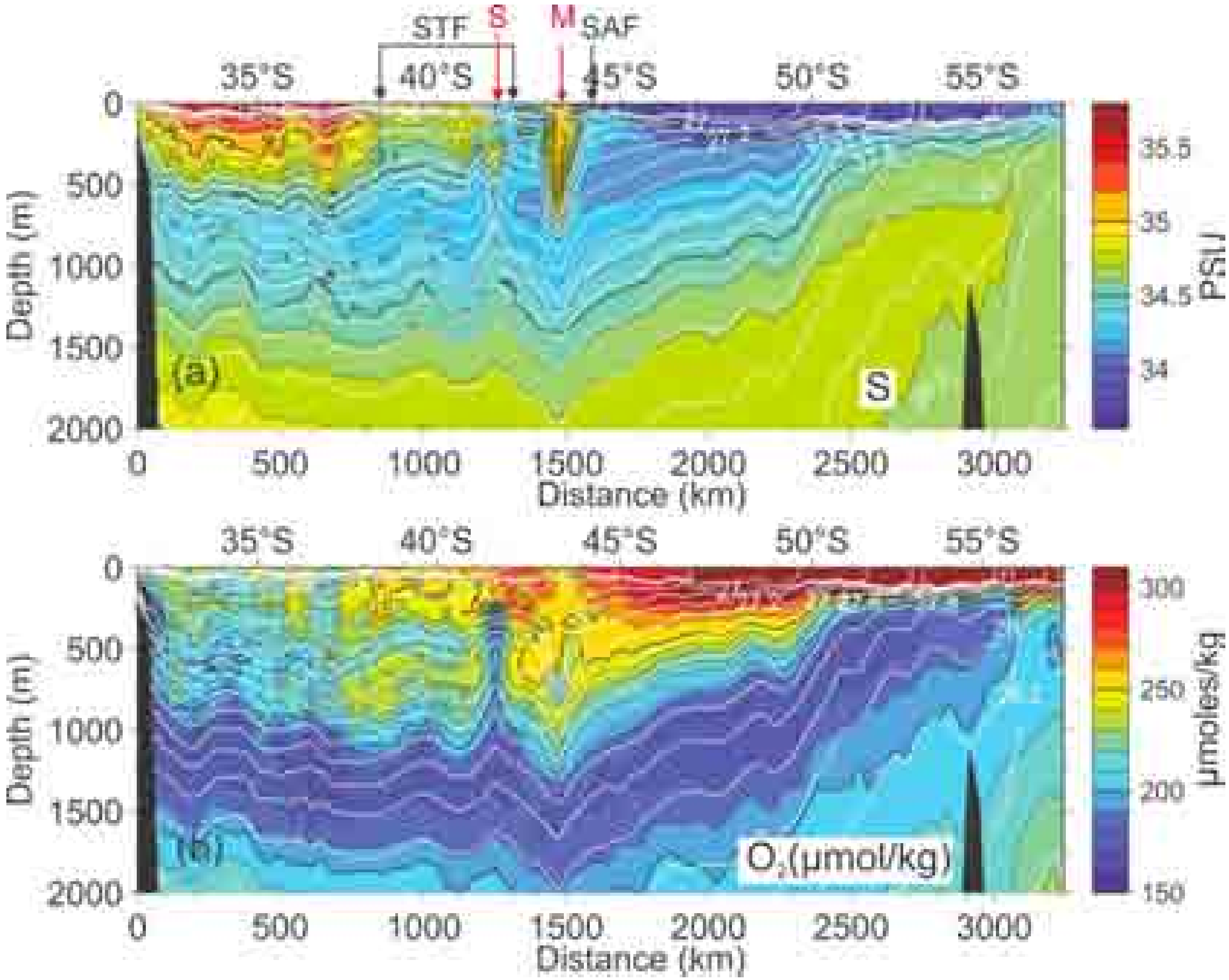
Bonus-Goodhope cruise: example of eddies (S. Speich)





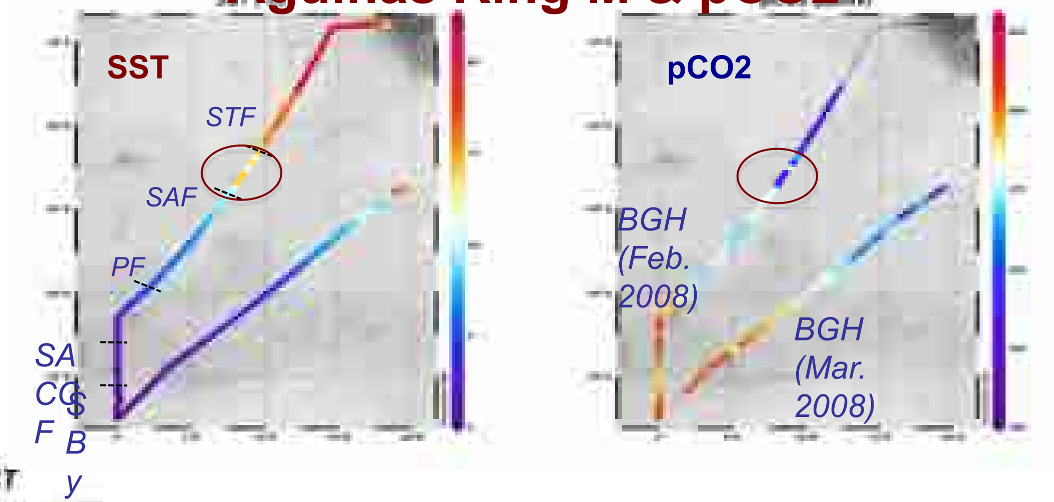
Zooming on Eddies

(S. Speich)

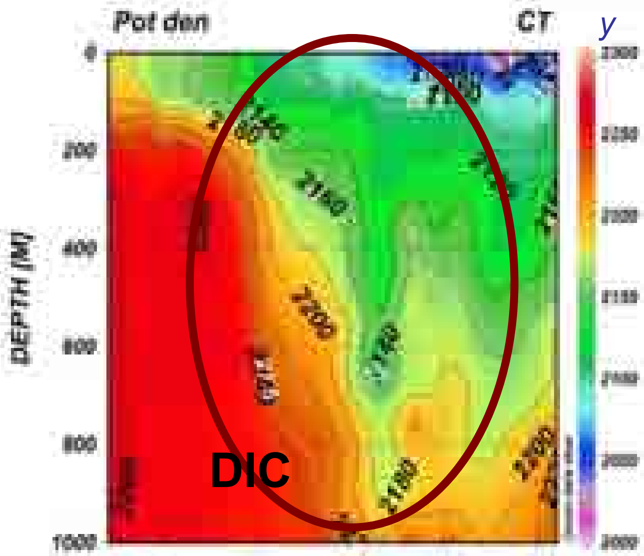


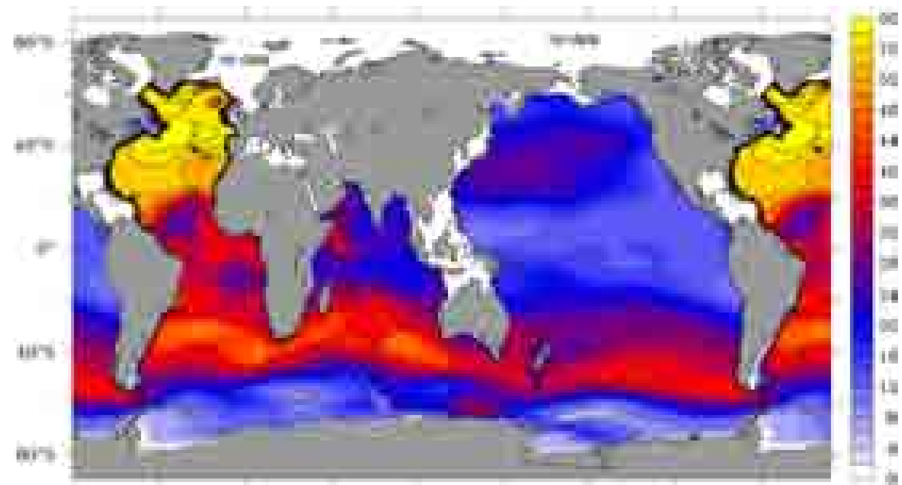
Mesoscale dynamics, air-sea Interaction & Biogeochemistry

Agulhas Ring M & pCO2



Agulhas Ring M
4 Mtons of C

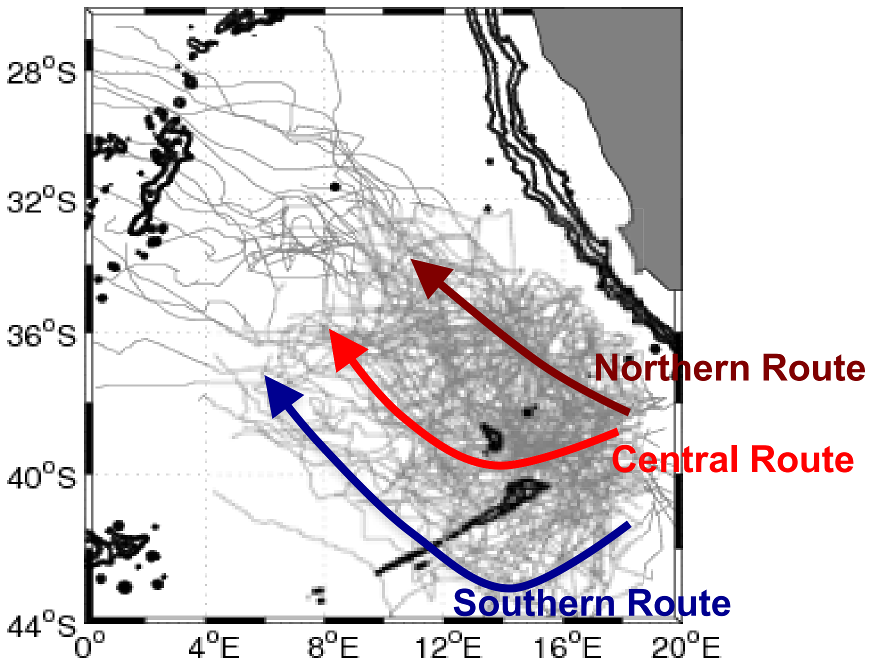




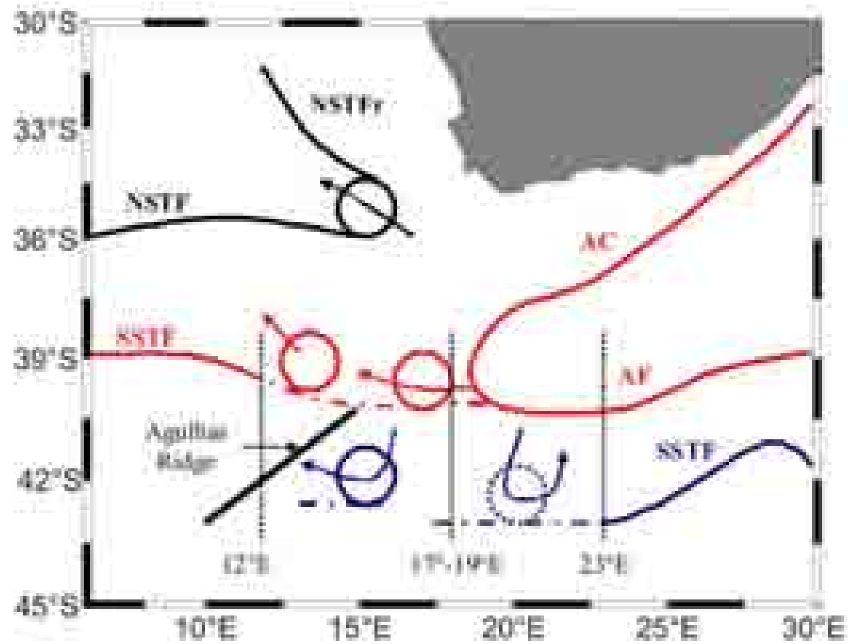
Data from Sabine et al. (2004)

Gonzalez-Davilla et al. in preparation

Trajectories of Agulhas Rings from AVISO MADT



Mesoscale dynamics and front structure



3 principal routes

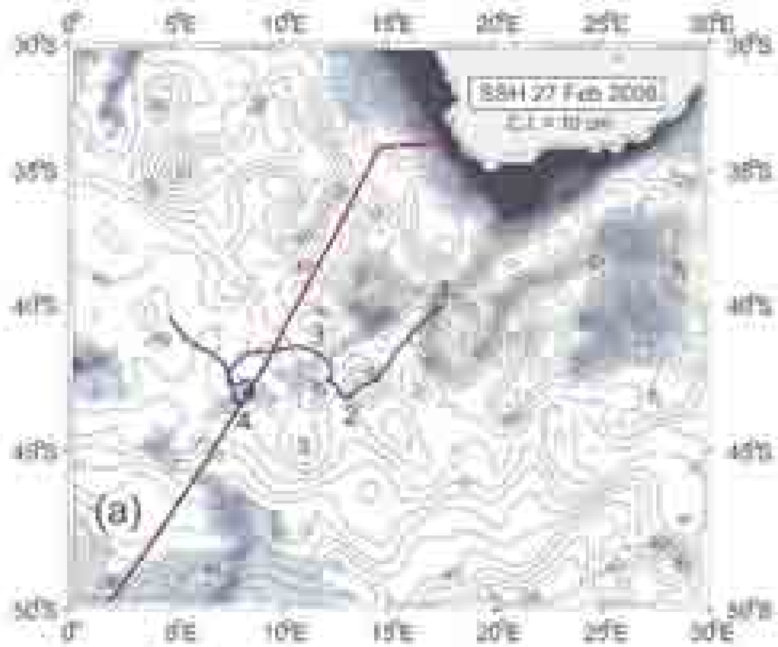
The S-STF south of Africa is not continuous but made of interacting eddies

Ring trajectories derived from altimetry (MADT-UPD) with WATERS wavelet based method (described in Doglioli et al. 2007)

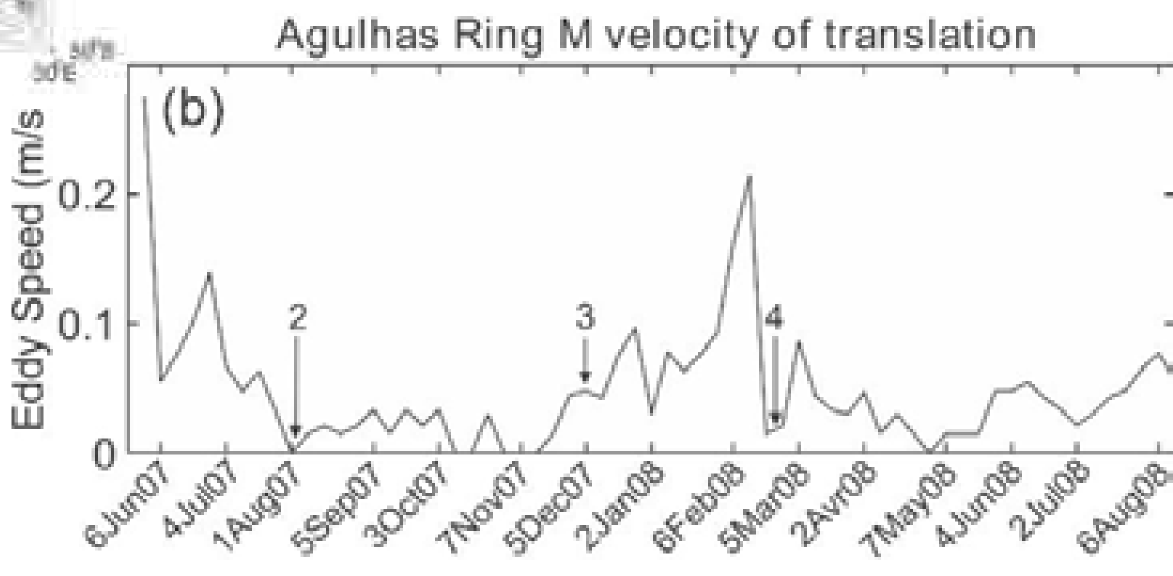
Dencausse, G. M. Arhan, S. Speich, Deep Sea Res. 2010a, b & c

Zooming on Eddies

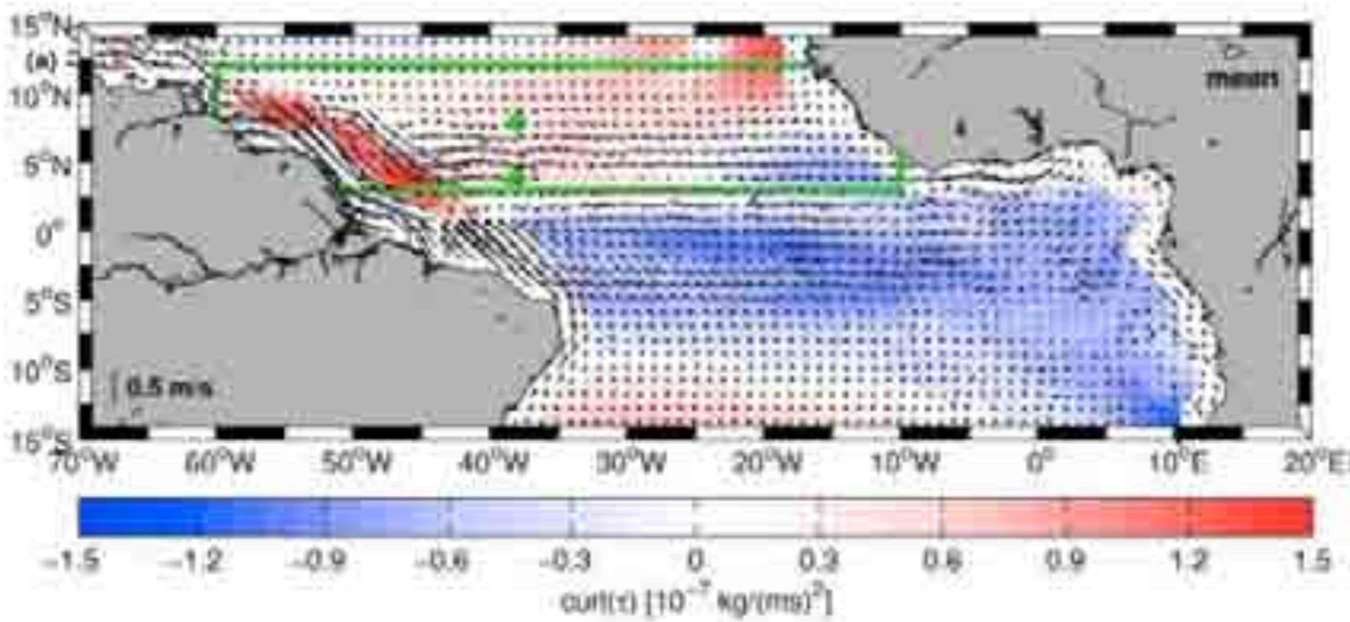
(S. Speich)



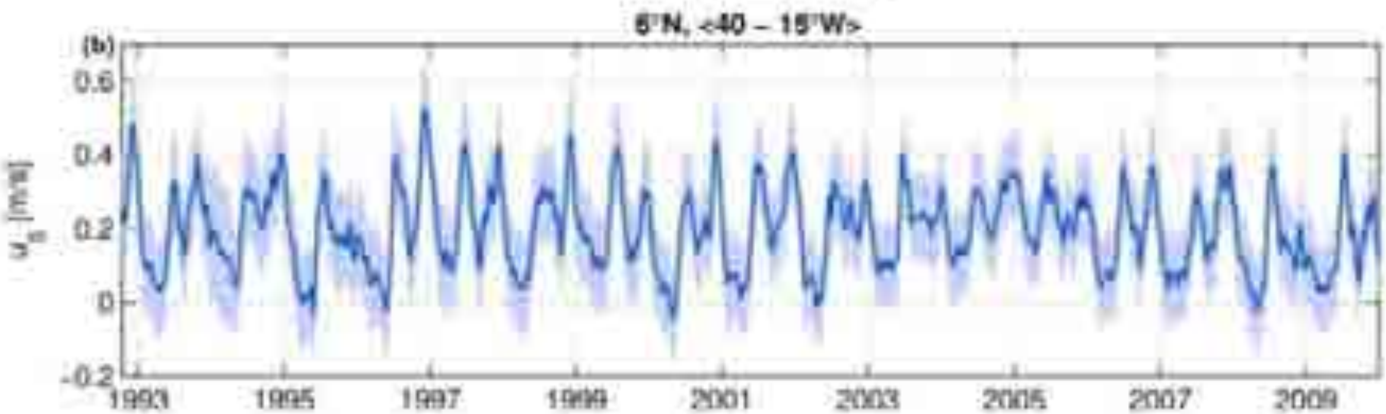
- Ring M: 9.5 months old
- Subducted in the S. Atlantic 5 months later
- Strong interaction with topography, SAF and other mesoscale structures



Variations of the NECC
(Hormann, Lumpkin and Foltz, 2011, in preparation)

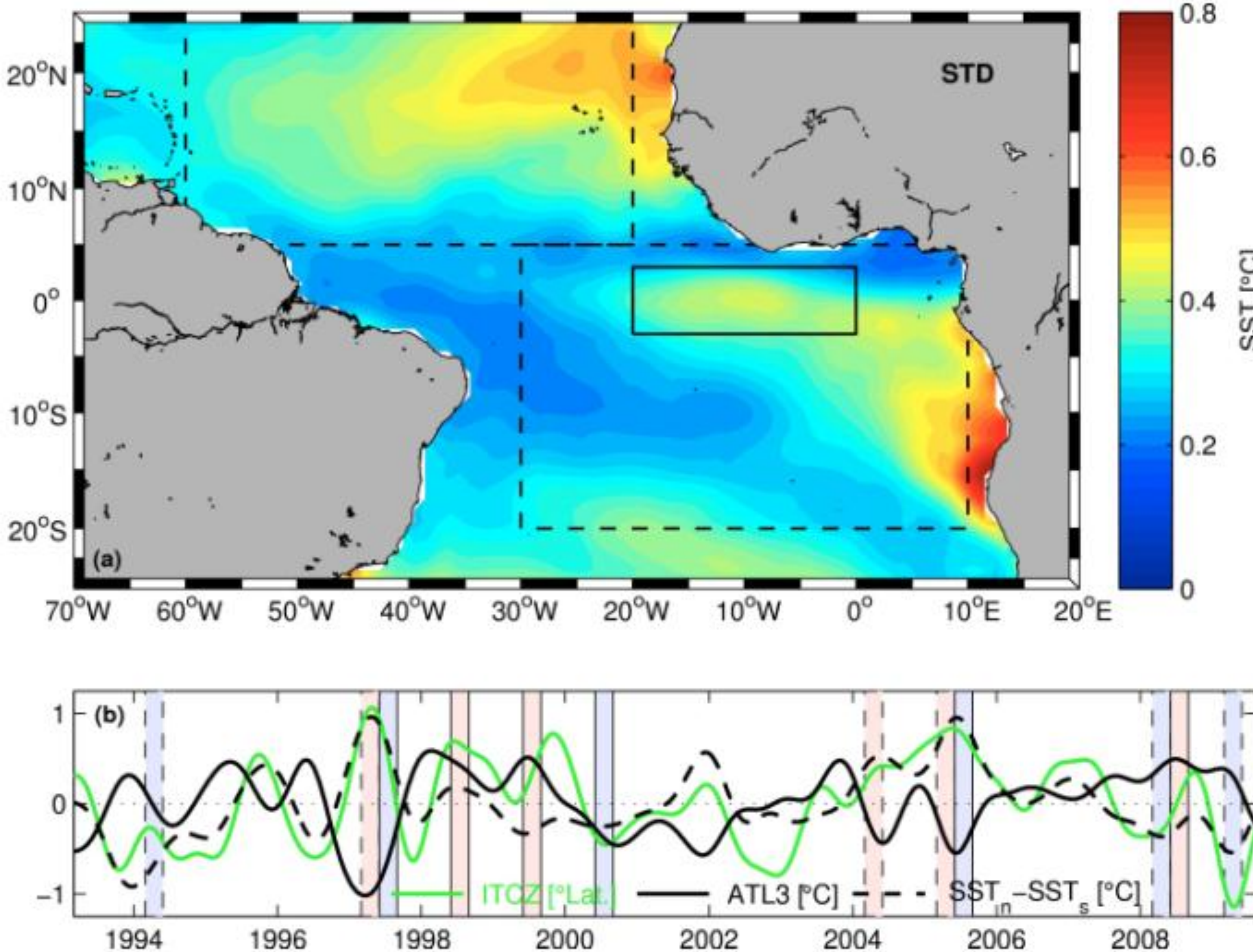


Arrows: time-mean geostrophic circulation from drifter/ altimetry/ wind synthesis.
Shading: wind stress curl.
Green box: “NECC region”. Diamonds: PIRATA moorings.



Time series of zonal geostrophic speed at core latitude of NECC, with error bars.

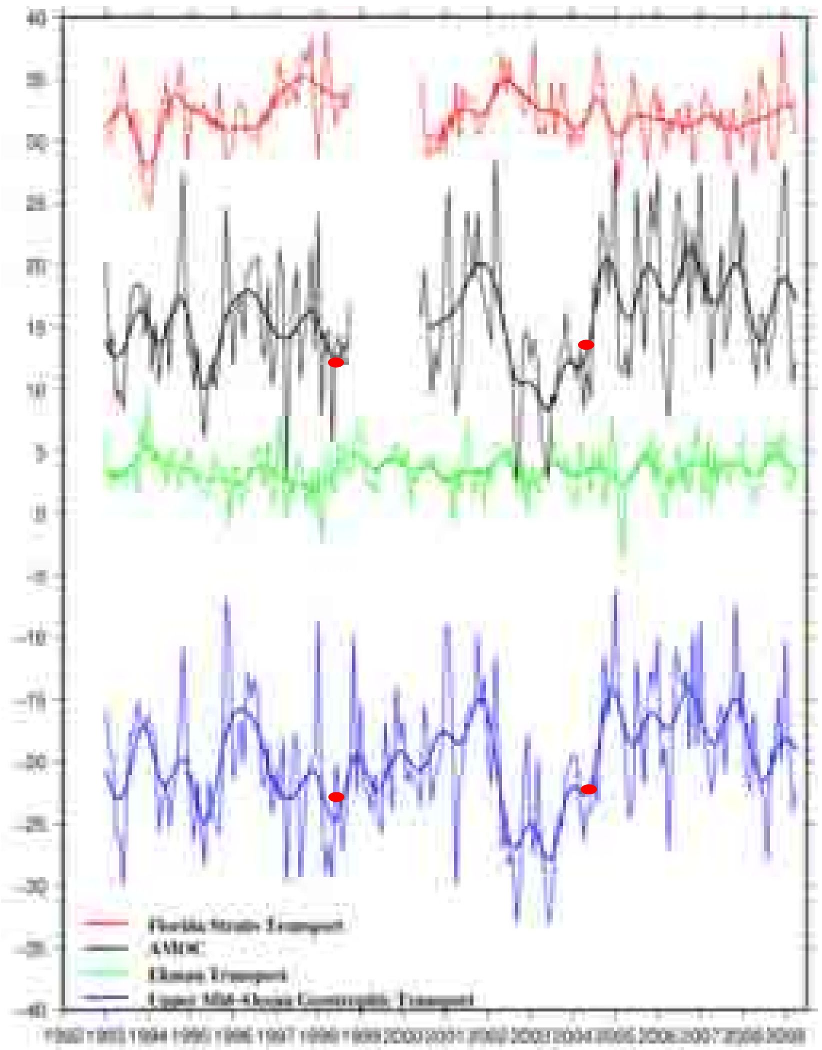
Relationship with tropical Atlantic climate modes



(a) Standard deviation of interannual SSTA. Black lines mark ATL3 region (solid) and northern/southern boxes (dashed). (b) ATL3 (black solid), SST_n - SST_s (black dashed), interannual ITCZ position anomalies (green). Peak seasons with largest

Surcouf3D - AMOC variability at 25°N

- Comparison with Bryden et al, 2005 (section at 24.5° from Africa to 73°W and at 26.5°N off Baha



(Bryden et al,2005)

Florida Strait Transport from electrical cable

AMOC = Geost + Ekman + Florida
(**Surcouf3D**, **Bryden et al., 2005**)

Ekman Transport from wind stress ERAInterim

Geostrophic Transport **from 75°W to 15°W** and **from the surface to 1000m**
(**Surcouf3D**, **Bryden et al., 2005**)

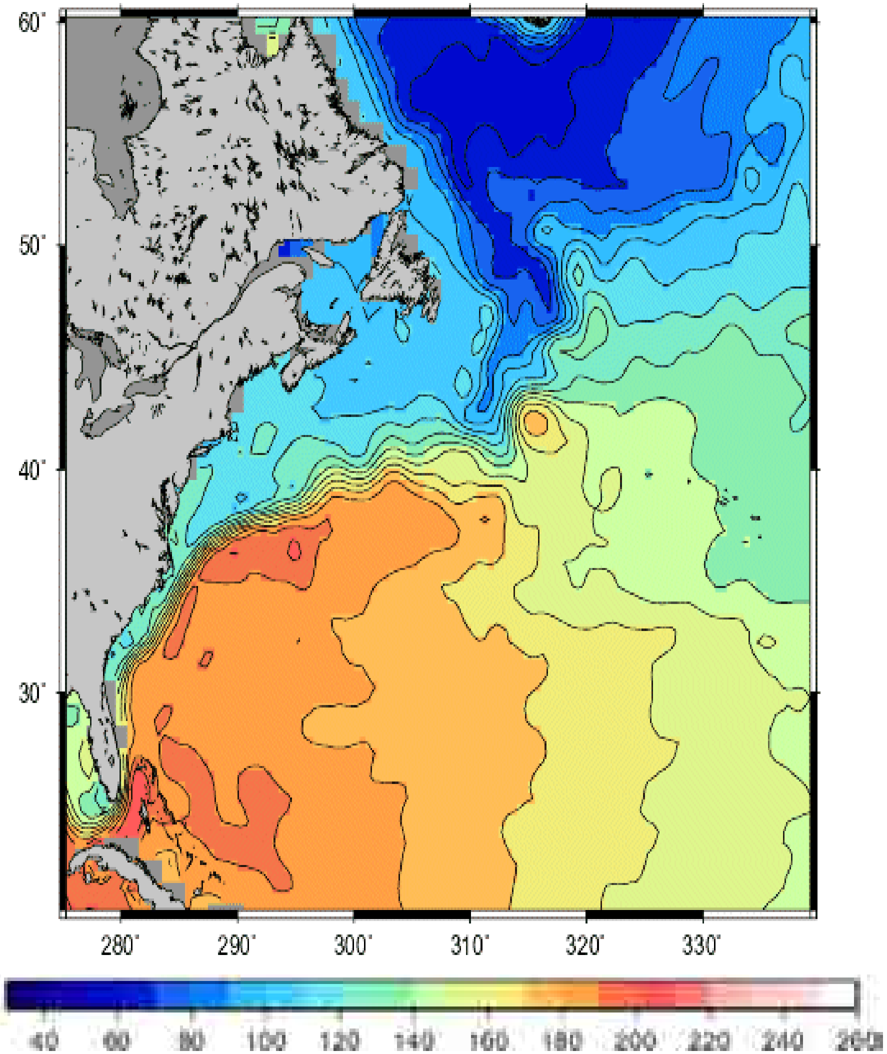
➔ consistent with Bryden et al, 2005
➔ High inter-annual variability
➔ Hard to distinguish a long-term trend

Gulf Stream

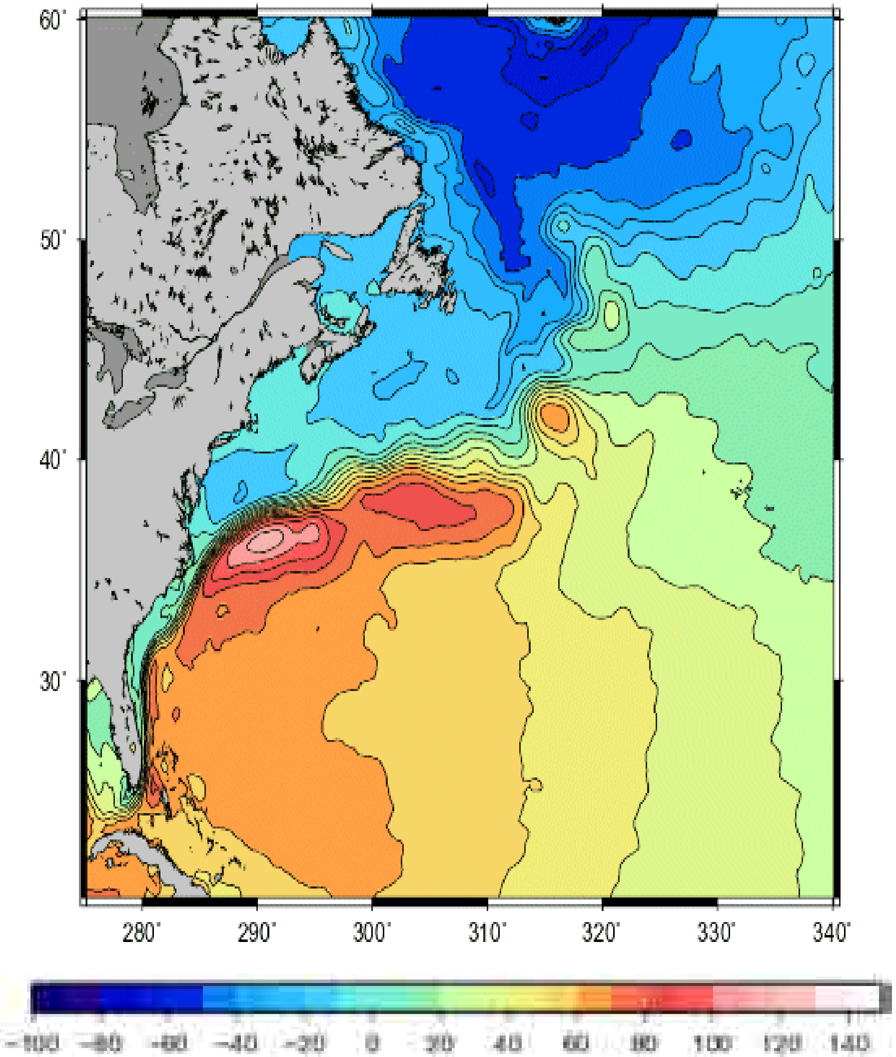
VALIDATION

(M.-H Rio)

CMDT RIO05

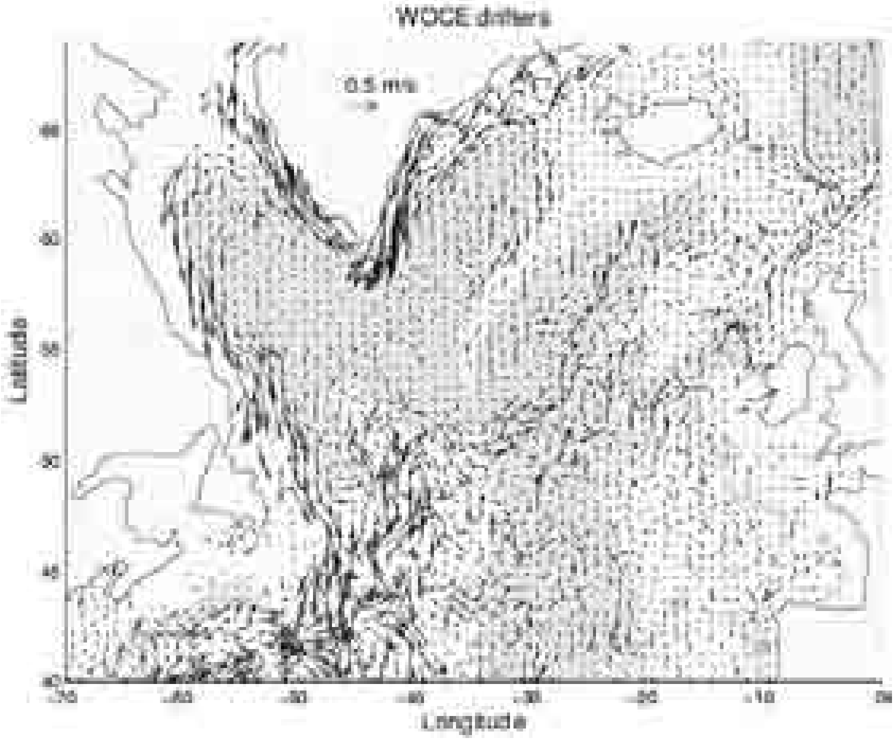


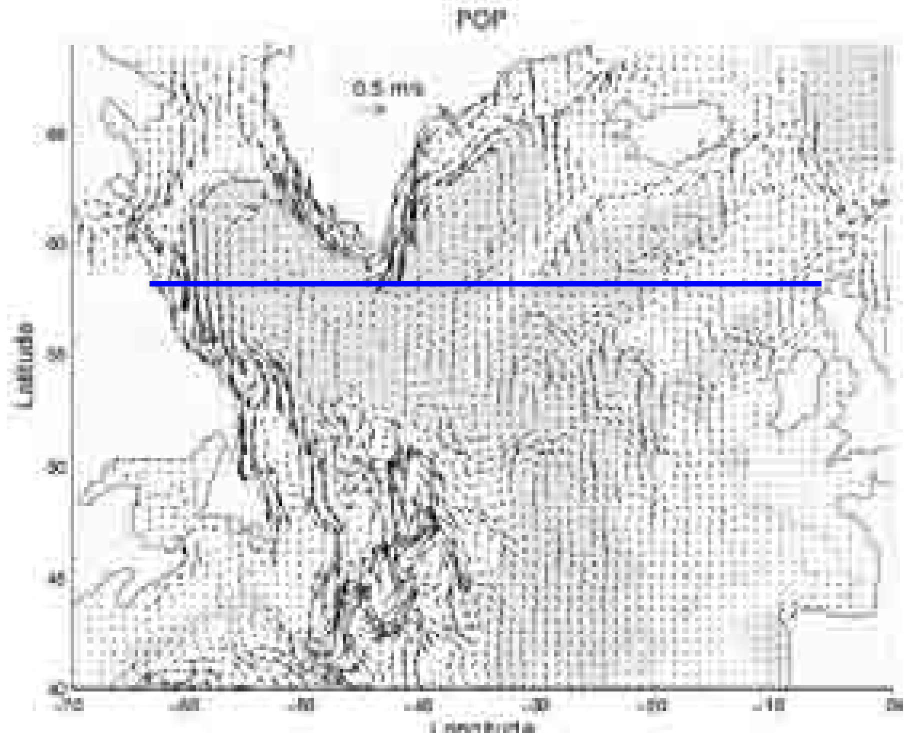
CMDT CNES-CLS09



Modelling the subpolar circulation

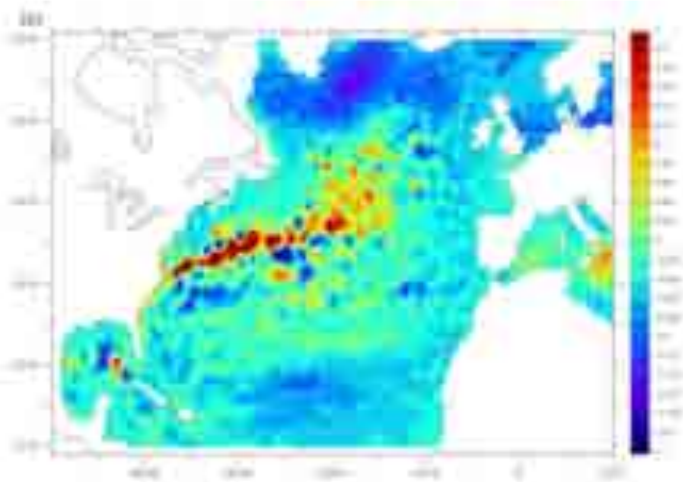
(A.-M. Tréguier)

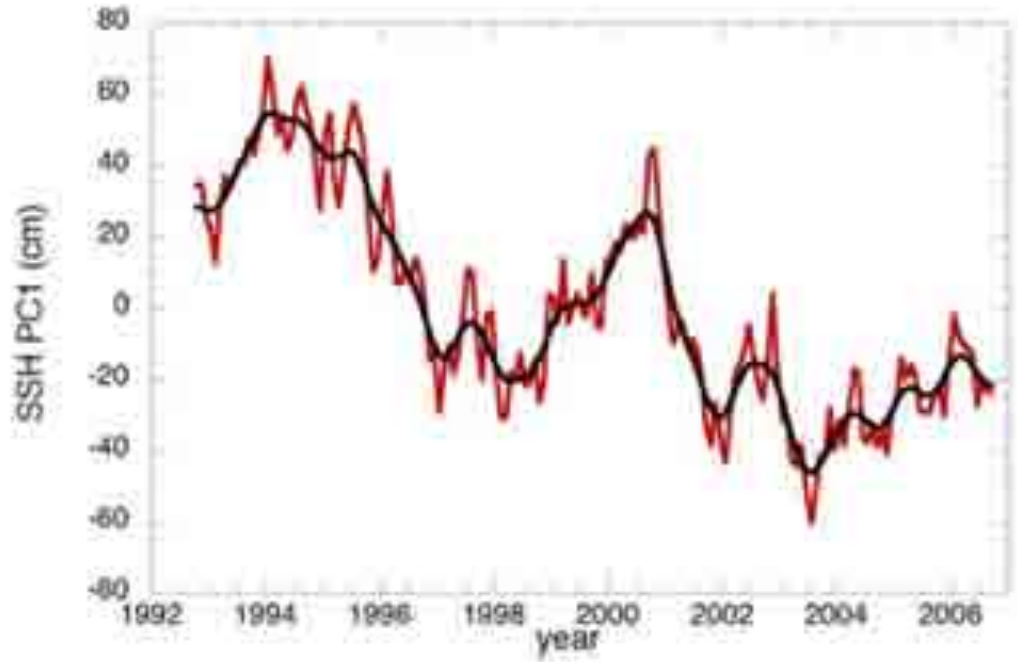




Variability of the subpolar Atlantic circulation

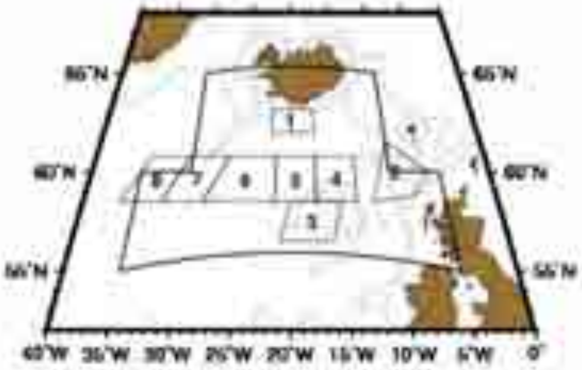
From Hakkinen and Rhines, 2009:
Decline of SSH after 1994, linked with NAO index

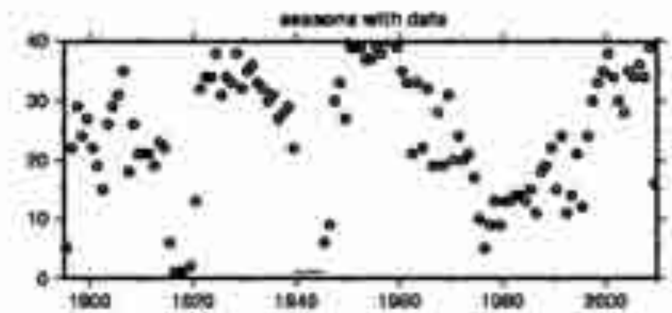


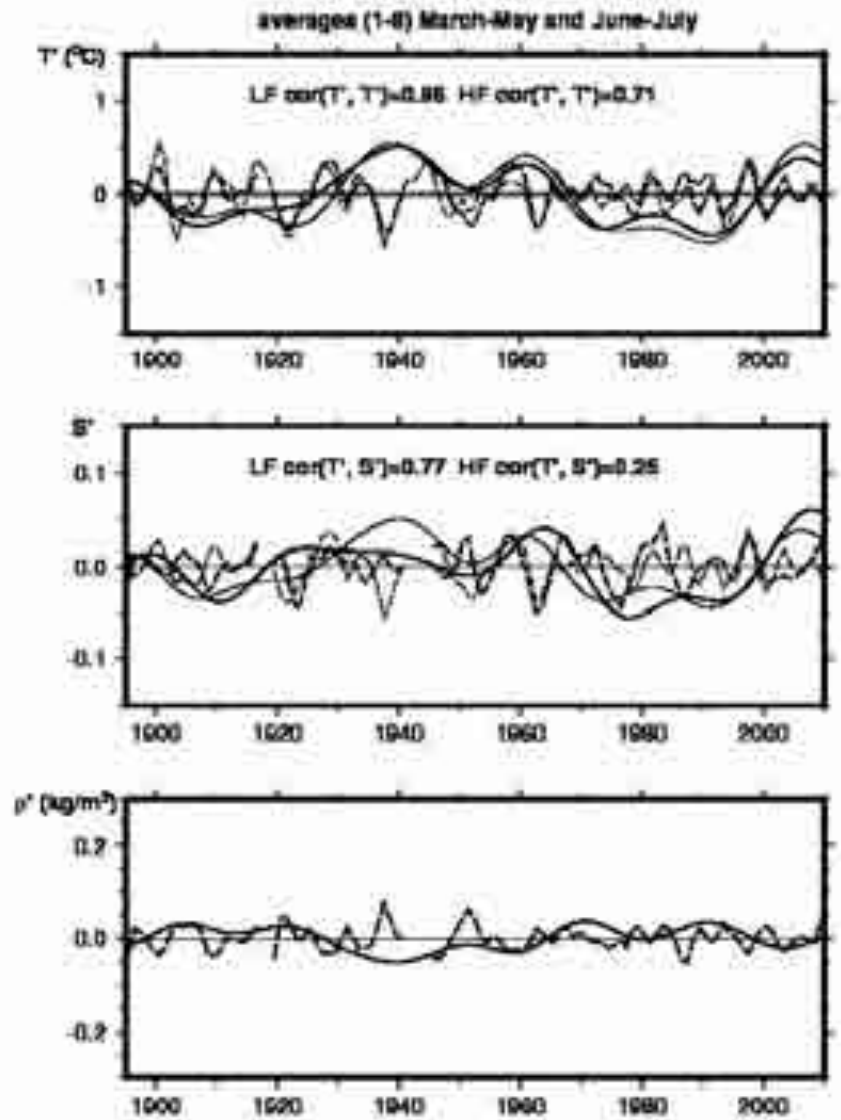


Shift of GS
Weakening of subpolar gyre
Cross-gyre transport? Not to be seen from this EOF, but water masses, floats...

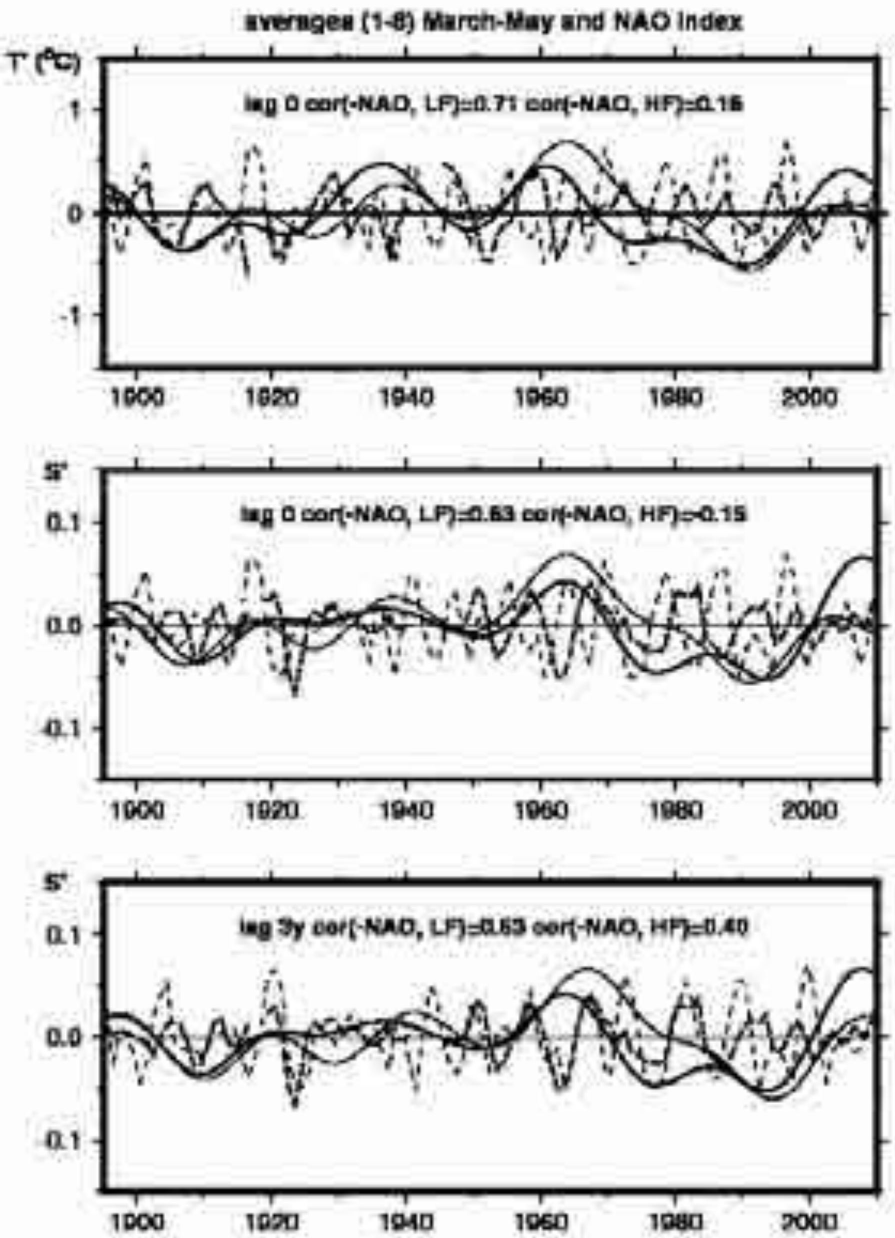
Surface hydrology in eastern subpolar gyre







LF T and S correlated (most seasons)
Probably indicative of changes
In eastern extension of North Atlantic
Subpolar gyre
(Reverdin, 2011)



Related to NAO?
S lags NAO (and T);
Compatible with gyre adjustment
response time (a few years)

Conclusions

We have :

- tools to observe well upper ocean circulation, with altimeter and drifters (and mean flow) , but less than 20 years to observe them except in a few key places
- Model simulations to interpret them:

either forced or ‘free’ (ocean only, but also

coupled ocean-atmosphere), at high resolution

Perspectives

Recent changes:

- Do they correspond to signature of natural variability , typical of the holocene?
- Or are they to some extent a result of anthropogenic changes
- Link with thermohaline changes?
- Role of eddies and modification of eddies in a changing circulation (saturation of ACC regime? Intensification of eddy transports?)