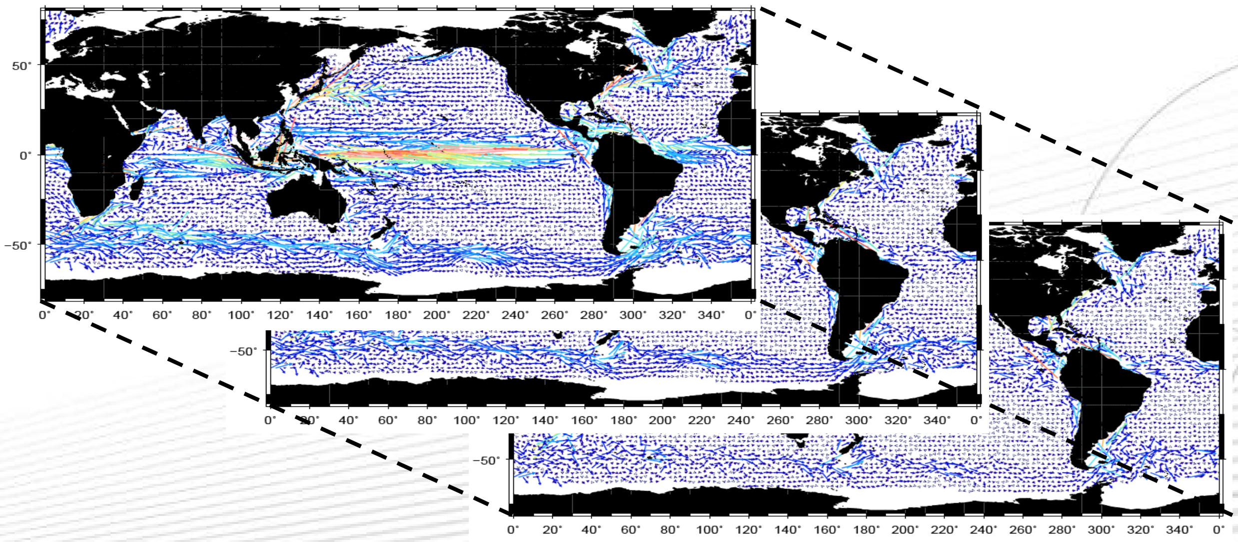
# A new estimate of the global ocean 3D circulation from altimetry, SST and in-situ measurements

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M.-H. Rio
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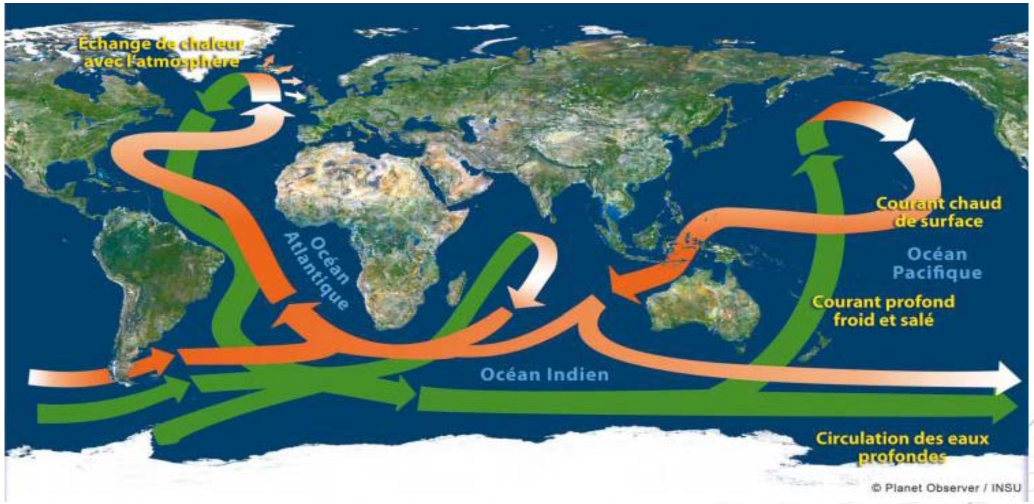
A. Mignot
G. Larnicol

# Contexte

Oceanic circulation regulates the climat: warm upper waters flow from the tropics to the Poles and cold deep waters flow from high to low latitudes




Global warming = change in **M**eridional **O**verturning **C**irculation (MOC) ?

# Contexte

Different ways to monitor the MOC:

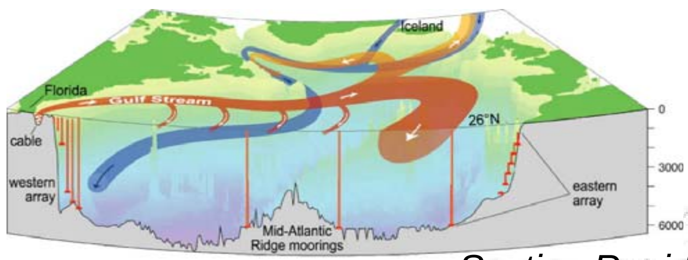
- Models :

- GLORYS (Global Ocean ReanalYses and Simulations, reanalysis from Mercator-Ocean)
- SODA (Simple Ocean Data Assimilation, university of Maryland)
- ECCO (Estimating the Circulation and Climate of the Ocean)

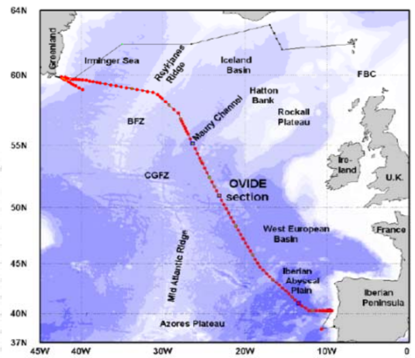
*Cabanes et al, 2008* : MOC variability is correlated with the NAO index

- *In situ* data:

- Ovide,
- RAPID-MOCHA



*Section Rapid*



*Section Ovide*

*Cunningham et al. 2007* : decrease pointed out by *Bryden et al. 2005* is questionnable (due to high frequency variability of the MOC ?)

- Combinaison of satellite and *in-situ* observations

Surcouf3D: observed product of global 3D currents

# A new estimate of the global ocean 3D circulation from altimetry, SST and in-situ measurements

- Method to compute Surcouf3D and AMOC strength at 25°N
- Validation of Surcouf3D (1993/2007)
- AMOC variability at 25°N
  - Comparison with *Bryden et al, 2005*
  - Comparison with GLORYS and RAPID-MOCHA
- Conclusions and perspectives

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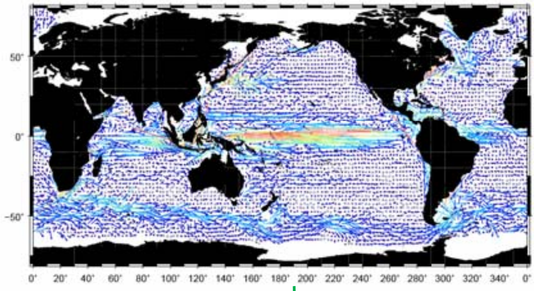
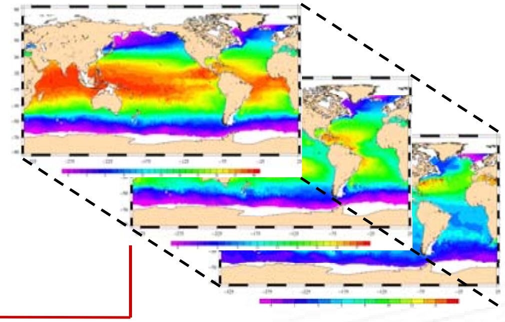
# The method to compute Surcouf3D

Surcouf :
Map of geostrophic surface currents
daily ; 1/3°

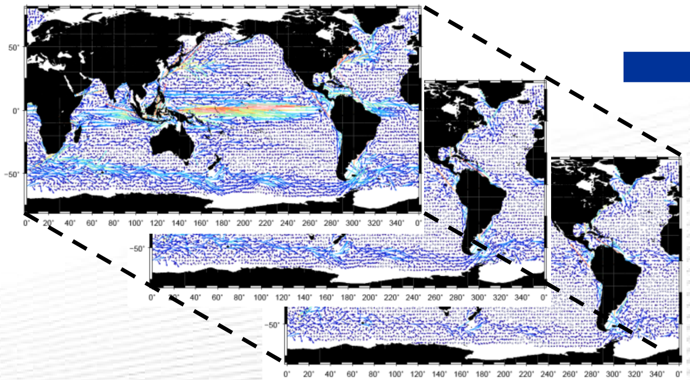
Armor3D :
3D thermohaline field
weekly ; 1/3° on 24 Levitus levels
from 0 to 1500m





$$u(z=z_i) = u(z=0) + \frac{g}{\rho f}\int_{z=0}^{z_i} \frac{\partial}{\partial y}\rho'(z)\,dz$$

$$v(z=z_i) = v(z=0) - \frac{g}{\rho f}\int_{z=0}^{z_i} \frac{\partial}{\partial x}\rho'(z)\,dz$$



Surcouf3D
3D geostrophic current field
weekly(1993-2007)
1/3° on 24 Levitus levels from 0 to 1500m

# The method to compute Surcouf3D

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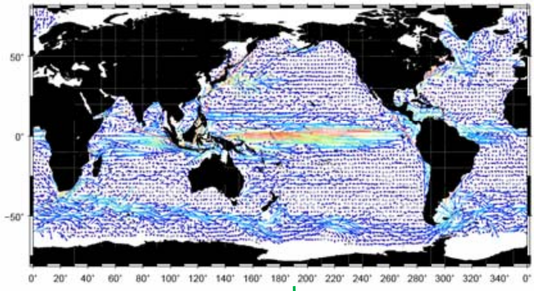

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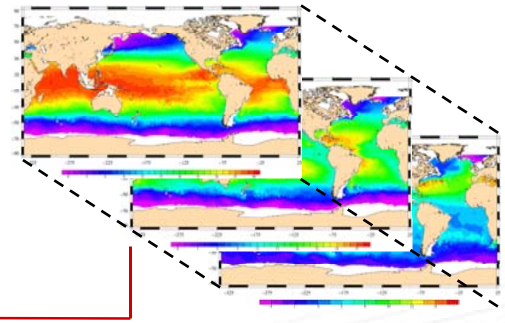

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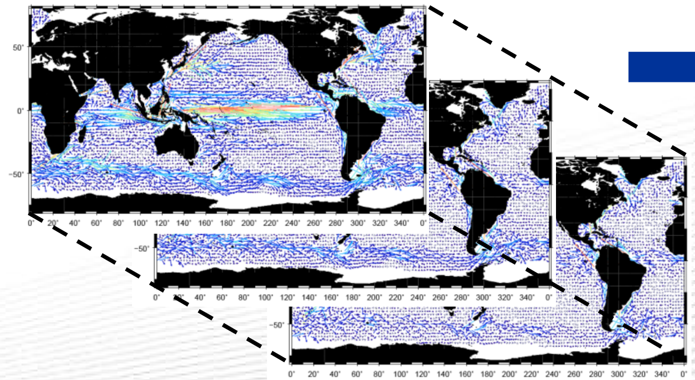
**Armor3D speed relative to 1500m:**

$$u_{/1500}(z=z_i) = \frac{g}{\rho f}\int_{z=1500}^{z_i} \frac{\partial}{\partial y}\rho'(z)dz$$

$$v_{/1500}(z=z_i) = -\frac{g}{\rho f}\int_{z=1500}^{z_i} \frac{\partial}{\partial y}\rho'(z)dz$$



Surcouf3D
3D geostrophic current field
weekly(1993-2007)
1/3° on 24 Levitus levels from 0 to 1500m

# Method to compute the AMOC at 25°N

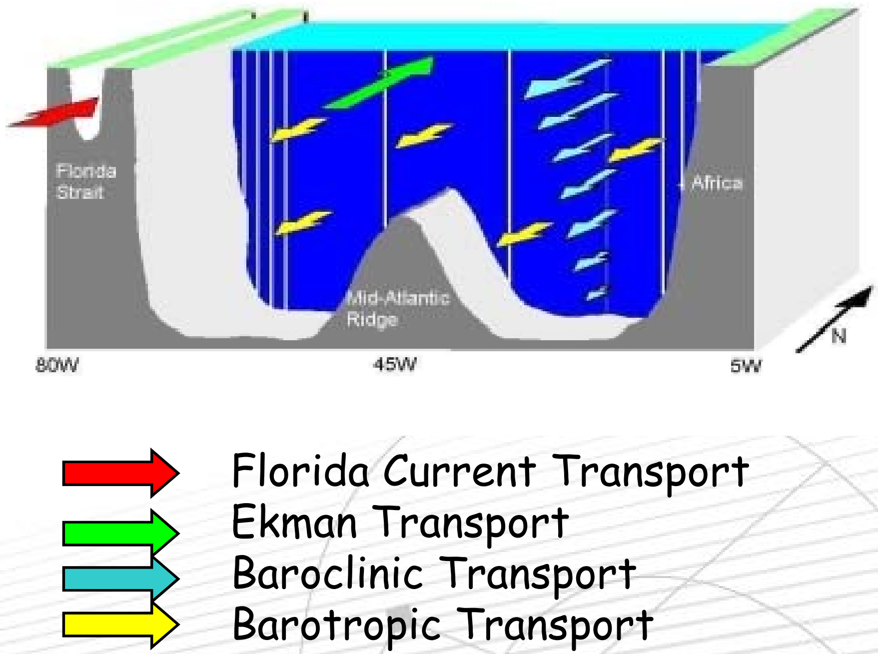
- Transport at 25°N can be divided in 3 components (*Hirschi et al, 2003*) :
  - Florida Current Transport $T_{fc}$
  - Ekman Transport $T_e$ (integrated from Bahamas to Africa)

$$U_{Ek} = \int_{-d}^{0} u\, dz = \frac{\tau_y}{\rho_0 f}$$

$$V_{Ek} = \int_{-d}^{0} v\, dz = -\frac{\tau_x}{\rho_0 f}$$

wind stress ERAInterim

  - Geostrophic Transport (integrated from Bahamas to Africa)
    - Baroclinic Transport $T_{bc}$
    - Barotropic Transport $T_{bp}$




- $(MOC)_{max} = T_{fc} + T_e + (T_{bc} + T_{bp})_{0\text{-}1000m}$ (*Bryden et al, 2005*)

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- **Validation of Surcouf3D (1993/2007)**

- AMOC variability at 25°N
  - Comparison with *Bryden et al, 2005*
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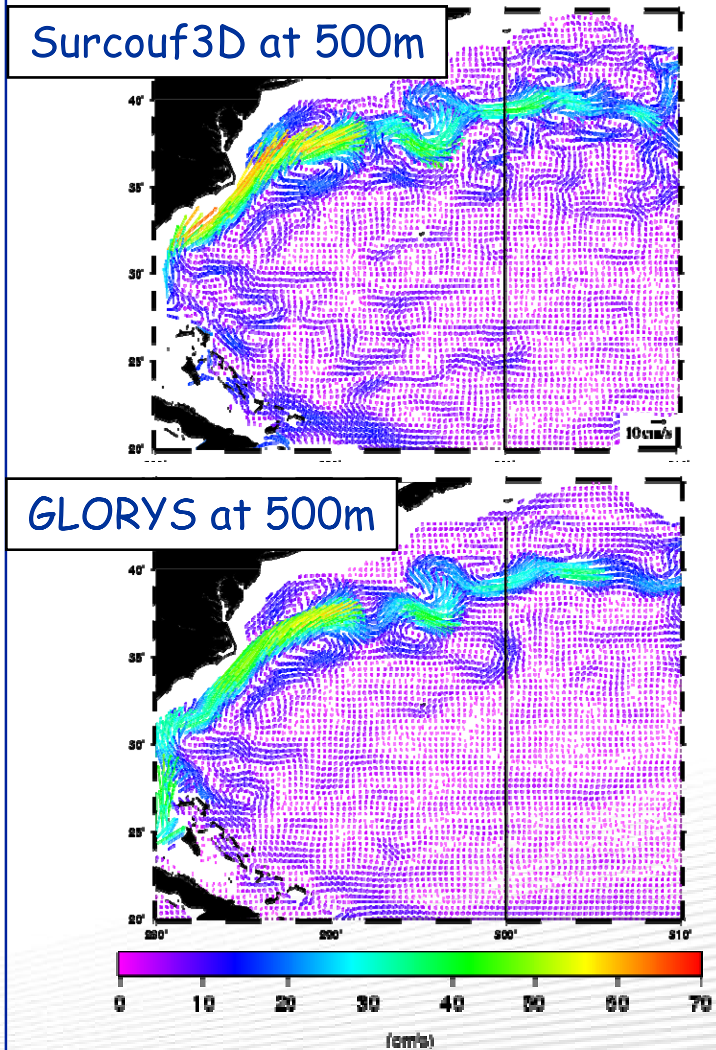
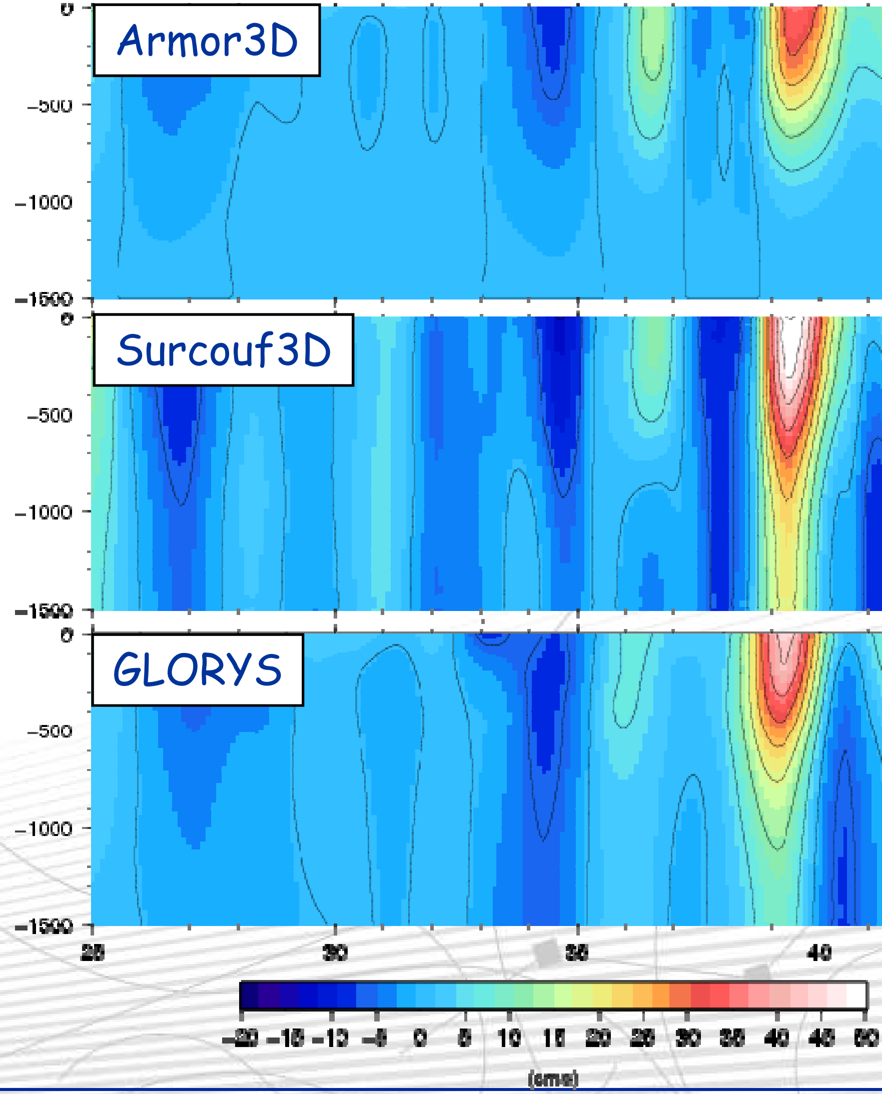
# VALIDATION – Comparison with GLORYS

- Vertical profile in 2006 at 60°W



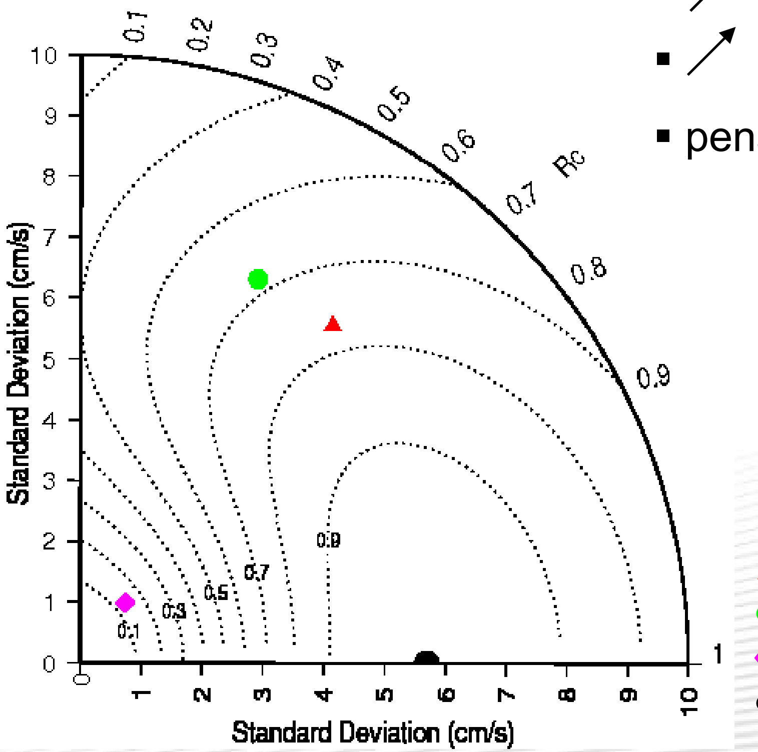



# VALIDATION – Comparison with Argo floats

❑ Global statistics over the Atlantic outside the equateur (10°S-10°N)
Comparison beetween the **meridian components** of 3 different methods (Surcouf3D, GLORYS, Armor3D) and *in-situ* observations (ANDRO) at **1000m** over the **2006/2007 period** *(Taylor, 2001)*

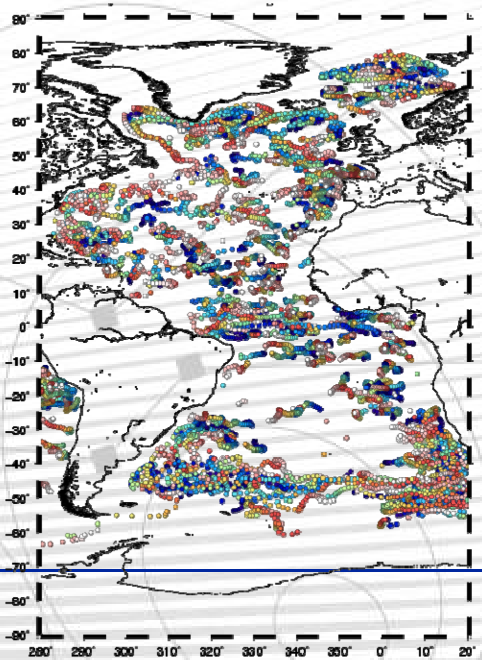
**Taylor's skill score:**

- ↗ if correlation (Rc) ↗
- ↗ if *standard deviation method – standard deviation observation* ↘
- penalizes method with smooth variability




▲ Surcouf3D (weekly, 1/3°)
● GLORYS (weekly, 1/4°)
♦ Armor3D (weekly, 1/3°)
● ANDRO (≈10days, ≈50/100km)

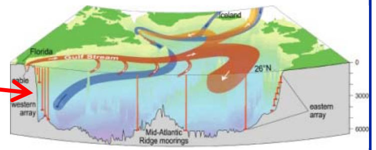
**Argo floats**

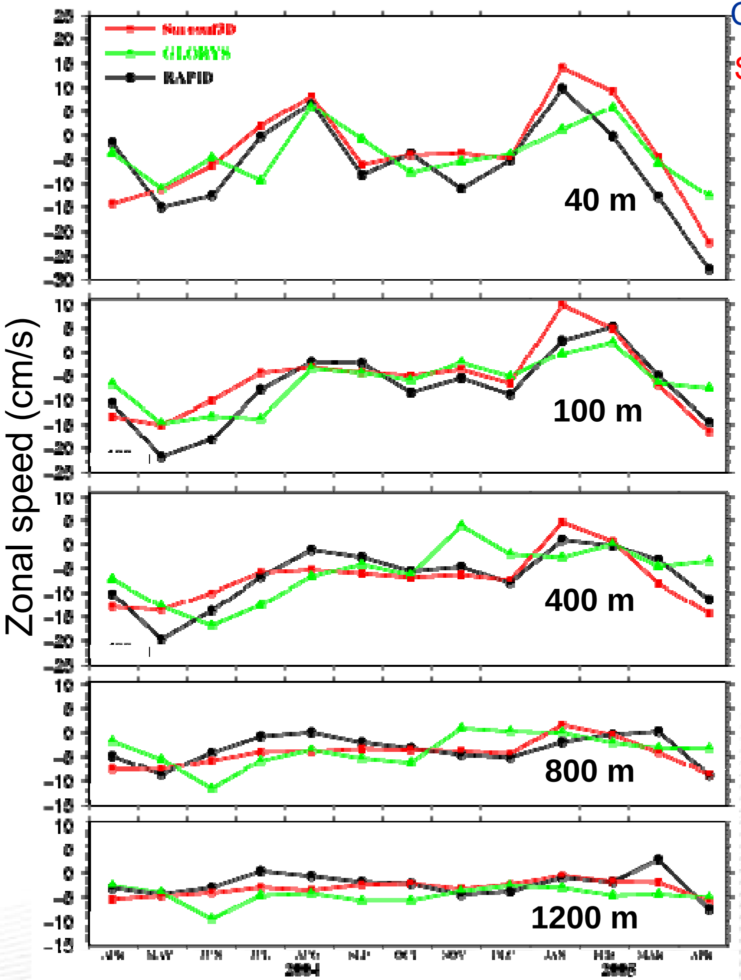


# VALIDATION – Comparison with RAPID-MOCHA

- Comparison with RAPID current-meters in the Western Boundary Current off the Bahamas from April 2004 to April 2005

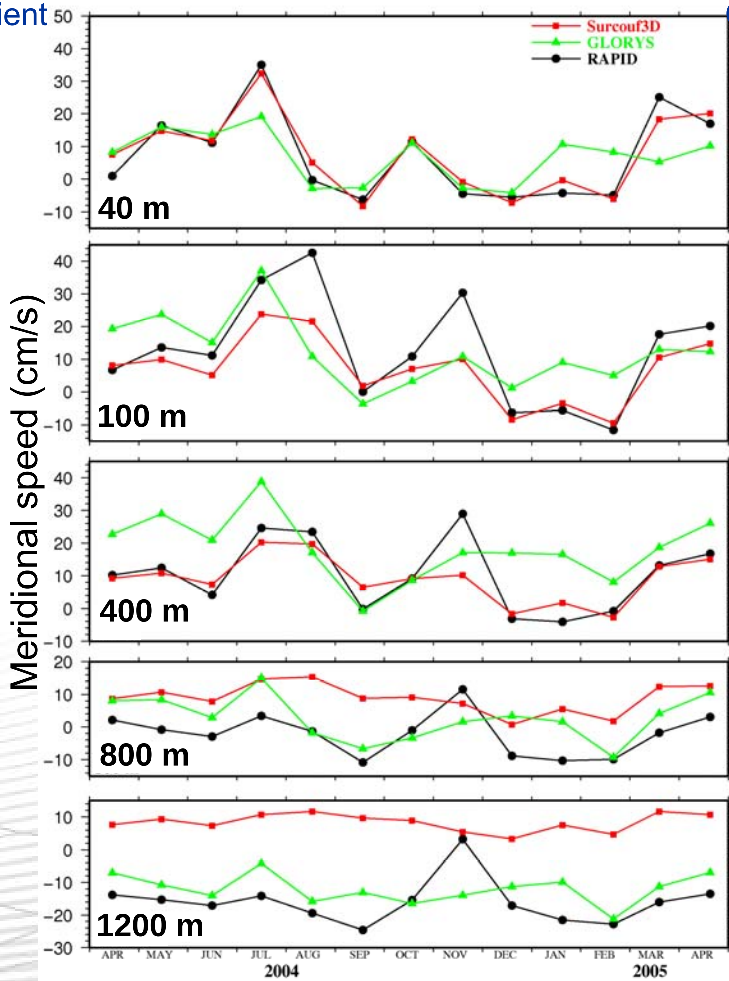
76.5°West






April 2004 April 2005

| Correlation Coefficient | Surcouf3D | Glorys |
|---|---|---|
| 40 m | 0.85 | 0.67 |
| 100 m | 0.85 | 0.80 |
| 400 m | 0.78 | 0.51 |
| 800 m | 0.71 | 0.07 |
| 1200 m | 0.68 | -0.01 |




April 2004 April 2005

| Correlation Coefficient | Surcouf3D | Glorys |
|---|---|---|
| 40 m | 0.85 | 0.69 |
| 100 m | 0.90 | 0.62 |
| 400 m | 0.85 | 0.64 |
| 800 m | 0.60 | 0.63 |
| 1200 m | 0.05 | 0.27 |

# To sum up

- Variability and intensity of Surcouf3D speed consistent with *in-situ* observations (comparisons with Argo floats, RAPID-MOCHA) and with numerical model (GLORYS)

- Limitation: the method failed to represent the speed inversion at 1200m

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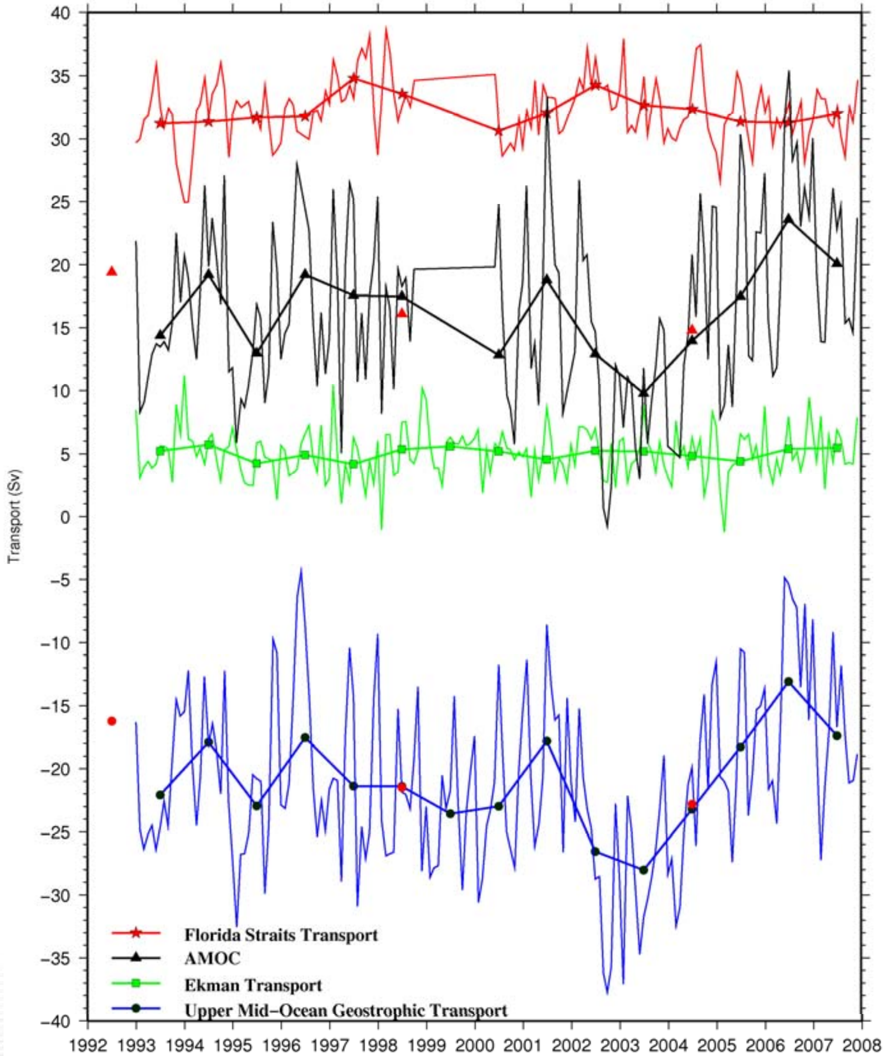
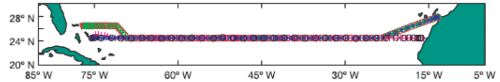
- **AMOC variability at 25°N**
  - Comparison with *Bryden et al, 2005*
  - Comparison with GLORYS and RAPID-MOCHA
- Conclusions and perspectives

# 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 Bahamas)




*(Bryden et al,2005)*

Floride Strait Transport from electrical cable

AMOC
(black : Surcouf3D, red : Bryden et al., 2005)

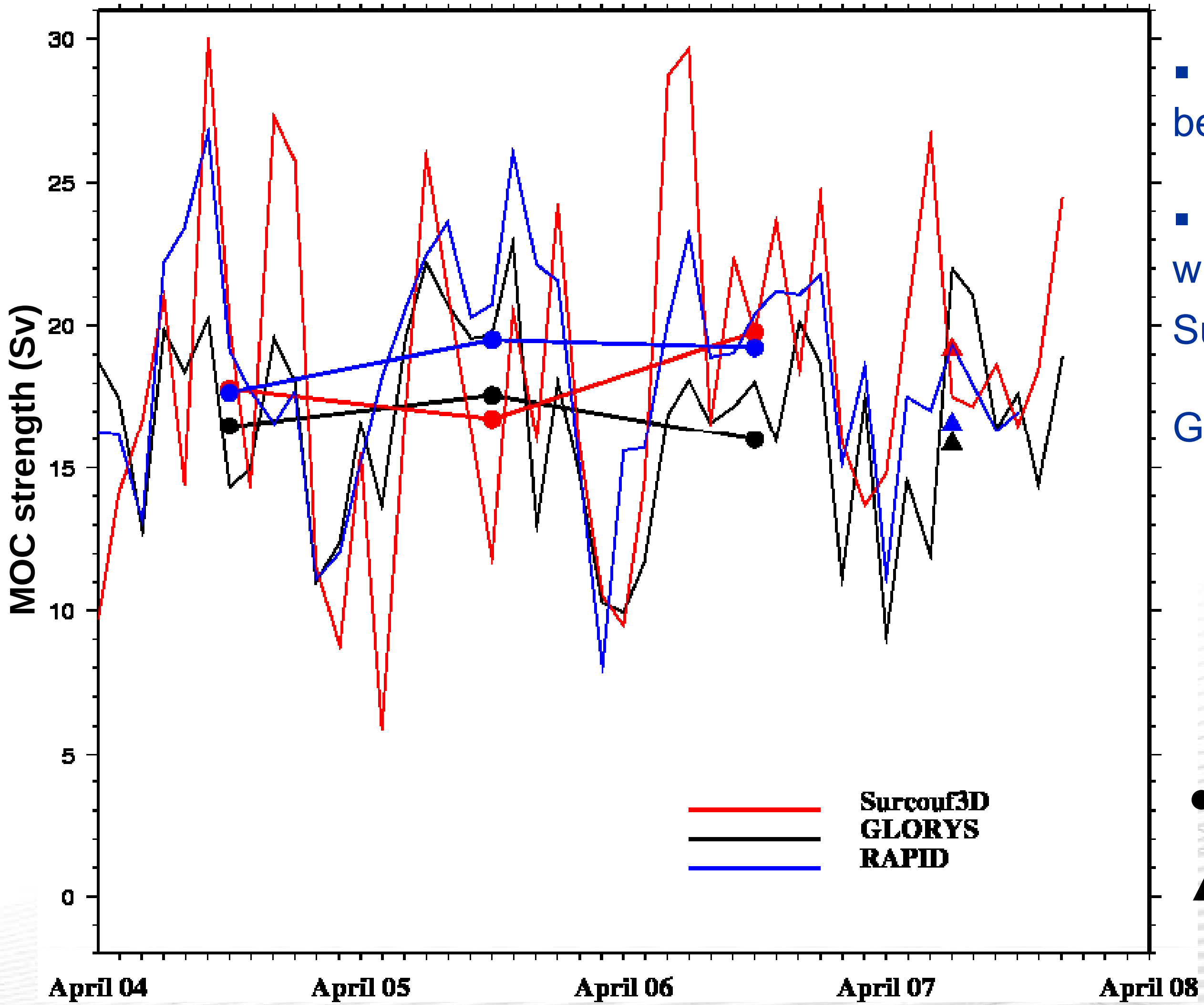
Ekman Transport from wind stress ERAInterim

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

- Very consistent with *Bryden et al, 2005*
- High inter-annual variability :
  - 21 Sv ± 4 Sv
- Hard to distinguish a long-term trend

# AMOC variability at 25°N

- Comparison with RAPID-MOCHA and GLORYS (section at 26.5°N from Africa to Bahamas)




- annual average: good agreement between the 3 methods

- monthly average: good correlation with RAPID-MOCHA time serie

Surcouf3D **0.55** (**0.64** without May/Oct 2005 and June 2007)

GLORYS **0.74**

● ● ● yearly average (April 200X - April 200X)

▲ ▲ ▲ incomplete yearly average (April 2007 - Oct 2007)

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- ➢ Validation of Surcouf3D (1993/2007)
- ➢ AMOC variability at 25°N
  - ➢ Comparison with *Bryden et al, 2005*
  - ➢ Comparison with GLORYS and RAPID-MOCHA
- ➢ **Conclusions and perspectives**

# Conclusions / Perspectives

- **Simple** method to compute 3D currents from **observations**
  - Vertical resolution given by *in-situ* data (24 Levitus levels)
  - Good horizontal resolution given by satellite data (1/3°)

- **Very good consistency** with numerical model (GLORYS) and *in-situ* data (Argo floats, current meters from RAPID-MOCHA)

- **Limitation:**

  Area where the method fails (inversion in the western current off the Bahamas)

  → Identification of other areas

  → Understand why it does not work

  → Improve the method

# Conclusions / Perspectives

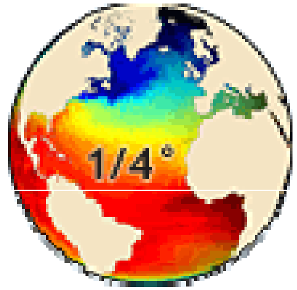
- **Application**: monitoring the MOC

  1993-2007 time serie of AMOC at 25°N consistent with other studies (GLORYS, RAPID-MOCHA, *Bryden et al*, 2005)

  → Compute MOC at other key sections (Ganachaud et al, 2003)

- Compute a new reanalysis from 1993 up to now using:
  - new MDT CNES_CLS09
  - reanalysis of SLA
  - reanalysis of Armor3D

# VALIDATION - Data used for validation

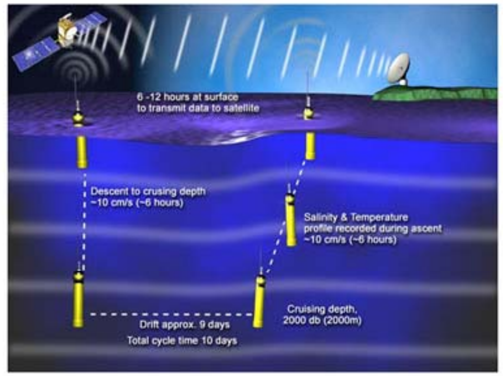



❑ **GL**obal **O**cean **R**eanal**Y**ses and **S**imulations 2002/2008 ("Argo period")

✓ Reanalysis of the operational system PSY3V2 from Mercator-Océan
Global ; 1/4° ; daily ; 50 vertical levels (38 from 0 to 1500m)

✓ Use the **A**ssimilation **S**ystem of **M**ercator version **2** (SAM2)
- Map of SST
- *In-situ* temperature and salinity profiles (mainly Argo)
- SLA along track (MDT = CMDTRIO05 combined with inshore numerical model)

❑ Armor3D velocities (relative current with level of no motion at 1500m)

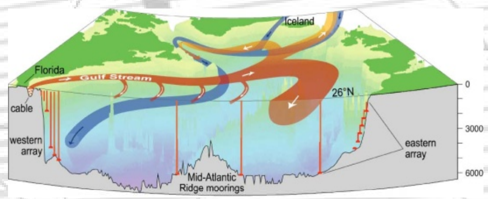



$$u_{/1500}(z = z_i) = \frac{g}{\rho f}\int_{z=1500}^{z_i} \frac{\partial}{\partial y}\rho'(z)dz \qquad v_{/1500}(z = z_i) = -\frac{g}{\rho f}\int_{z=1500}^{z_i} \frac{\partial}{\partial y}\rho'(z)dz$$

❑ **A**rgo **N**ew **D**isplacement **R**annou **O**llitrault

Currents deduced from the Argo float deplacement at the surface, **1000m** and 1500m

❑ Rapid Climate Change (RAPID) data

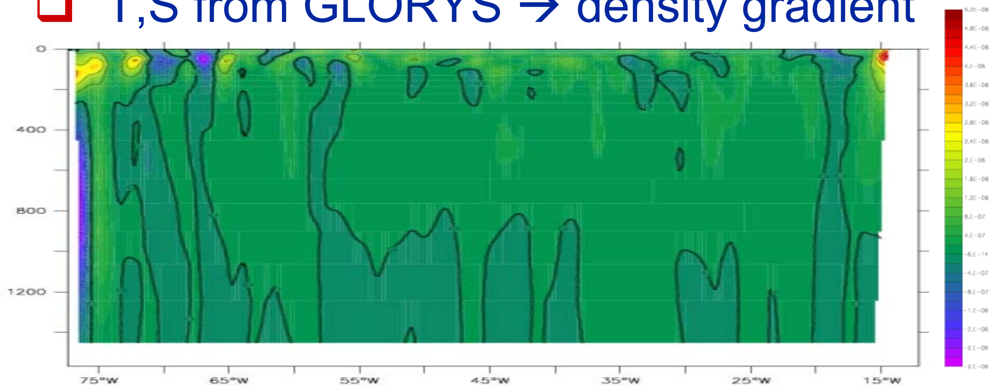



✓ Development and maintenance of a pre-operational prototype system that will continuously observe the strength and structure of the MOC

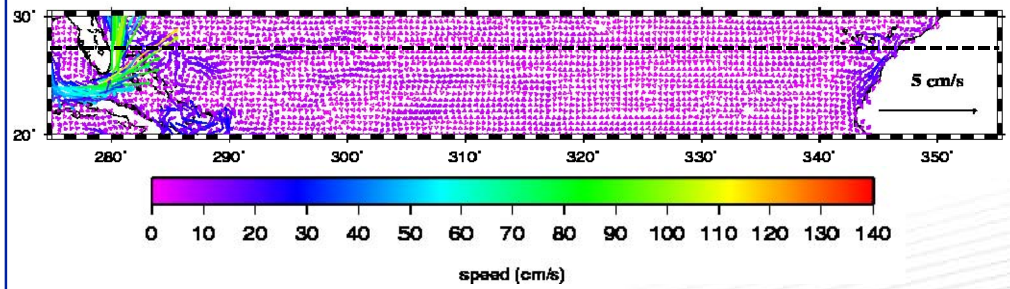
✓ 20 moorings : CTDs, bottom pressure sensors, currents meters (off the Bahamas)

# VALIDATION - Reconstruction of GLORYS

- T,S from GLORYS → density gradient

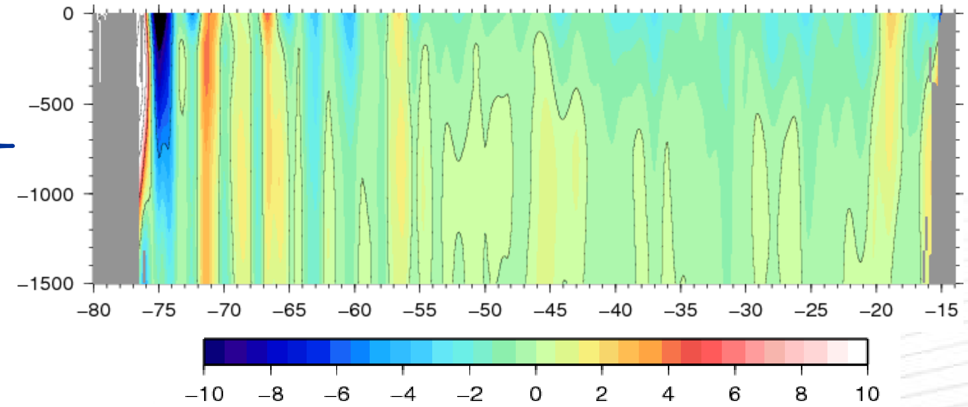



- ADT from GLORYS → surface geostrophic speed

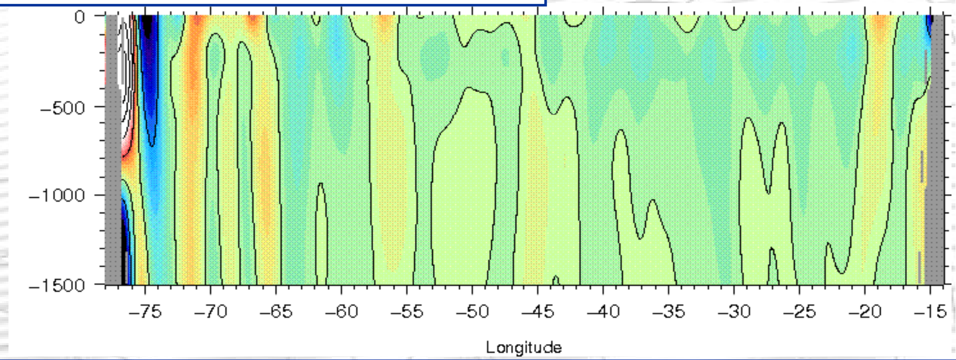



Example in 2003

- Reconstruction of geostrophic GLORYS speed (THERMAL WIND)




Original GLORYS speed



# AMOC variability at 25°N

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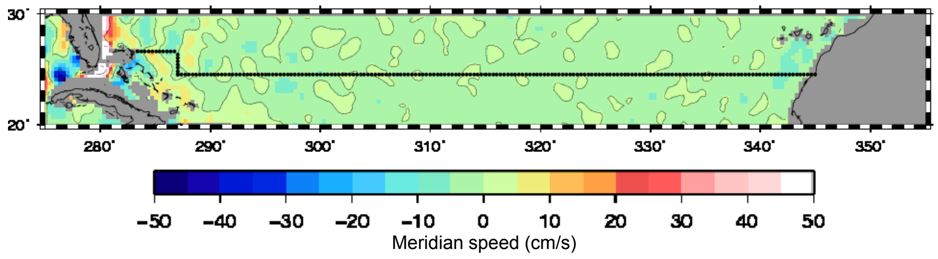
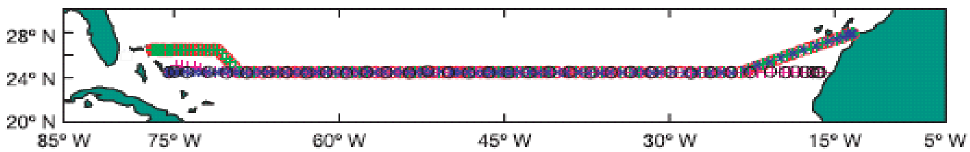
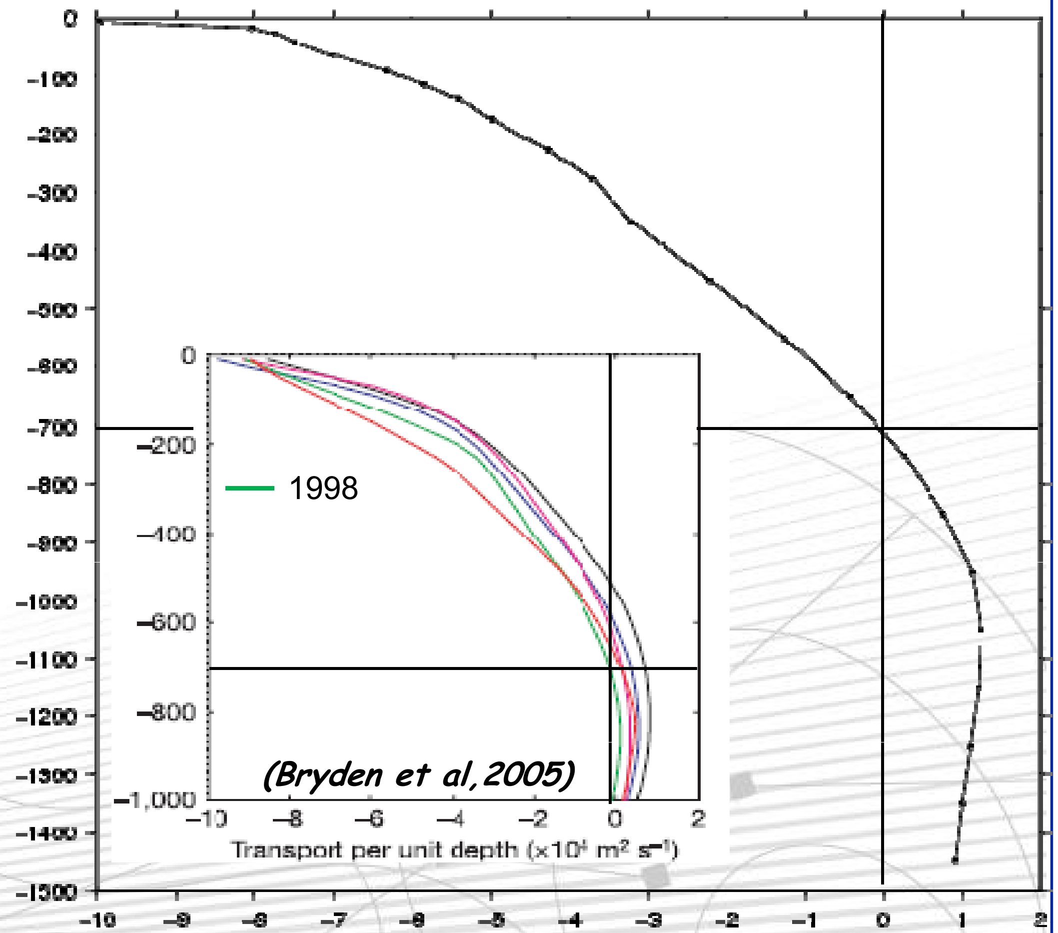



*(Bryden et al, 2005)*



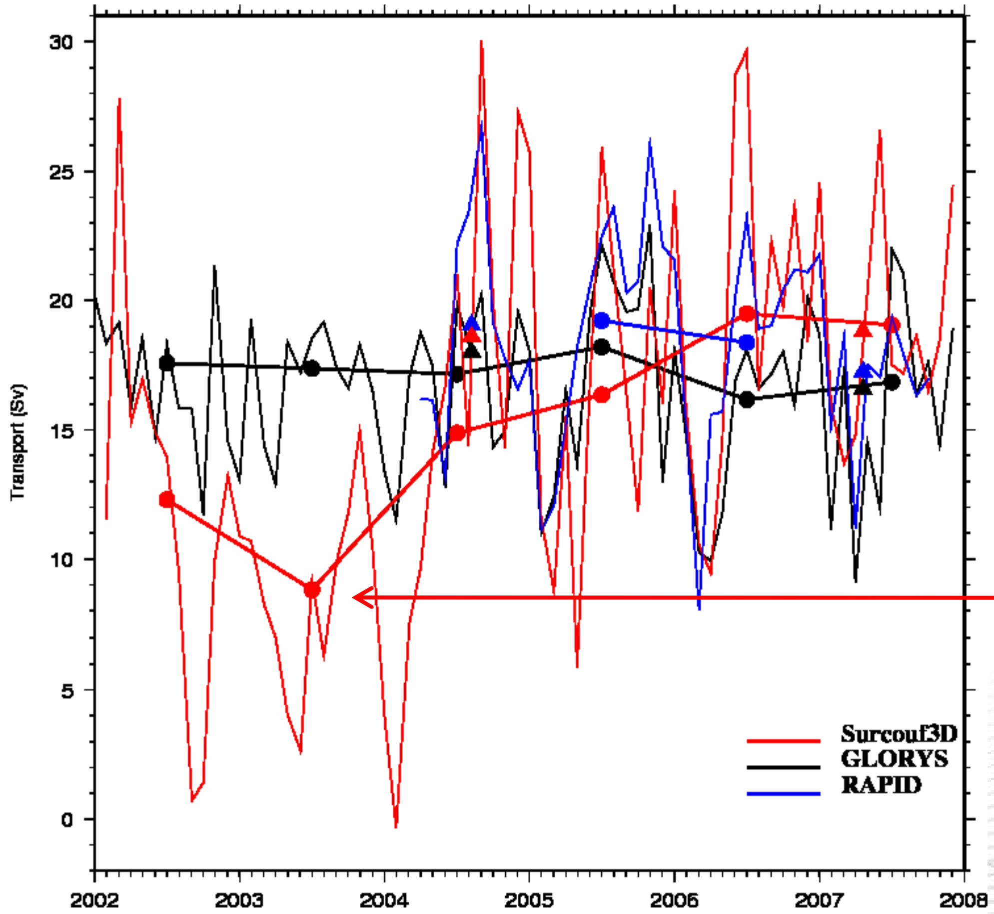
| | Ancienne réanalyse | Nouvelle réanalyse | Bryden et al. (2005) |
|---|---|---|---|
| 1998 | - 20.5 Sv | - 21.7 Sv | - 21.5 Sv |
| 2004 | | - 23.3 Sv | - 22.8 Sv |

Transport per unit depth ($10^4$ $m^2.s^{-1}$) in 1998



# AMOC variability at 25°N

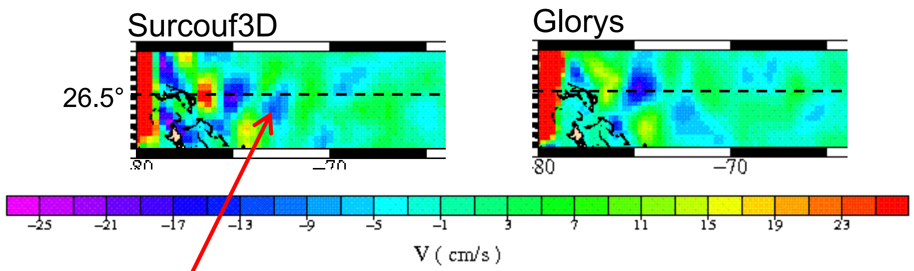
## ❑ Comparison with RAPID and GLORYS (section at 26.5°N from Africa to Bahamas)




▲▲▲ incomplete yearly average du to RAPID period (April 2004 - Sept 2007)
in 2004 : April to December
in 2007 : January to September

- In 2003 ?

Surface geostrophic current (meridional component) in 2003:




High southward current
→ High southward meridional transport