Variability of the Antarctic Intermediate Water across the Equatorial Atlantic in 2004 Detected from ARGO Float Trajectory Data

Rapid Change of Mid-Depth North Atlantic Circulations in Tropics

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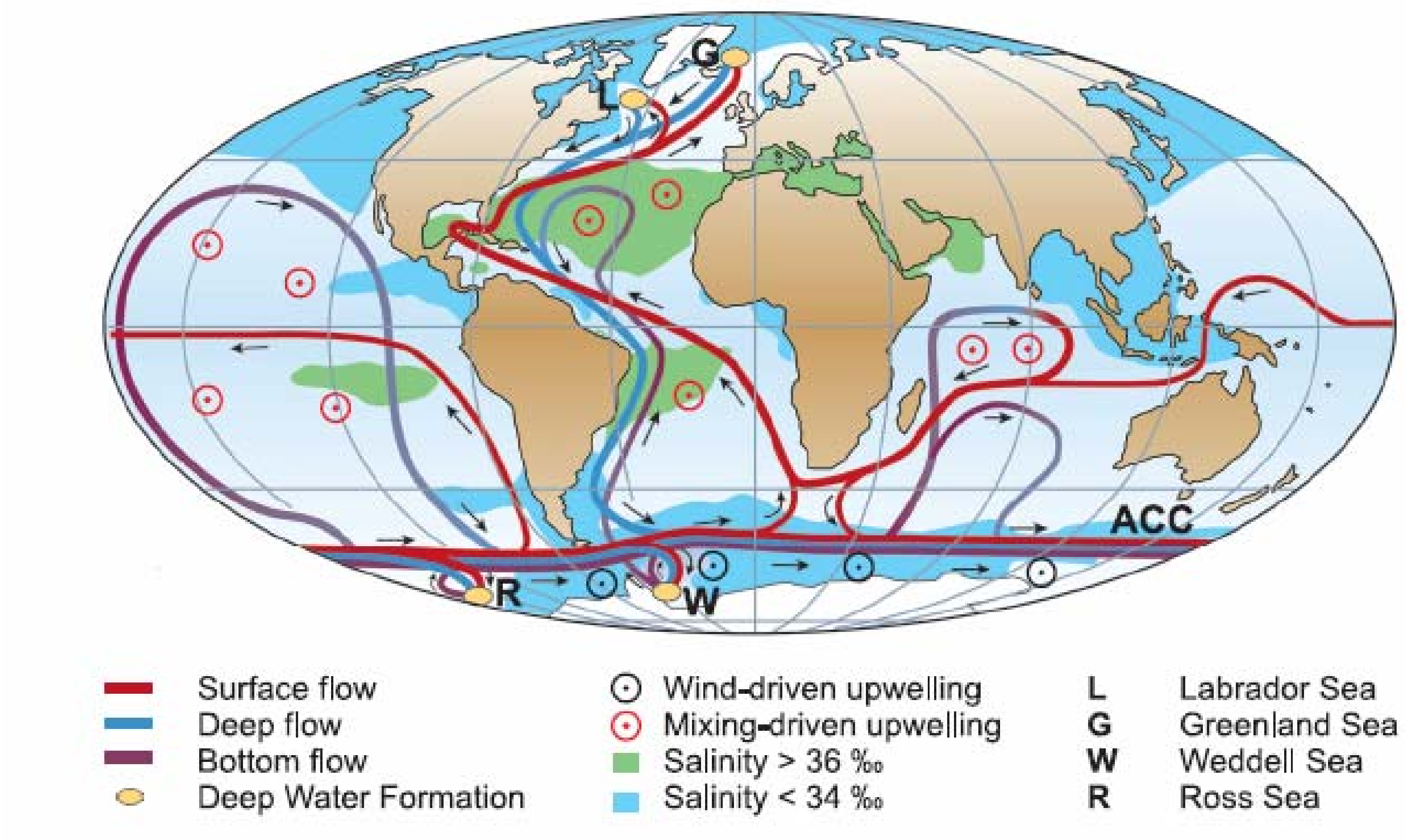
Important Element in Climate System
Meridional Overturning Circulation (MOC)

(Rahmstorf 2006)



MOC Variation →

Heat Transport Variation →

Climate Change

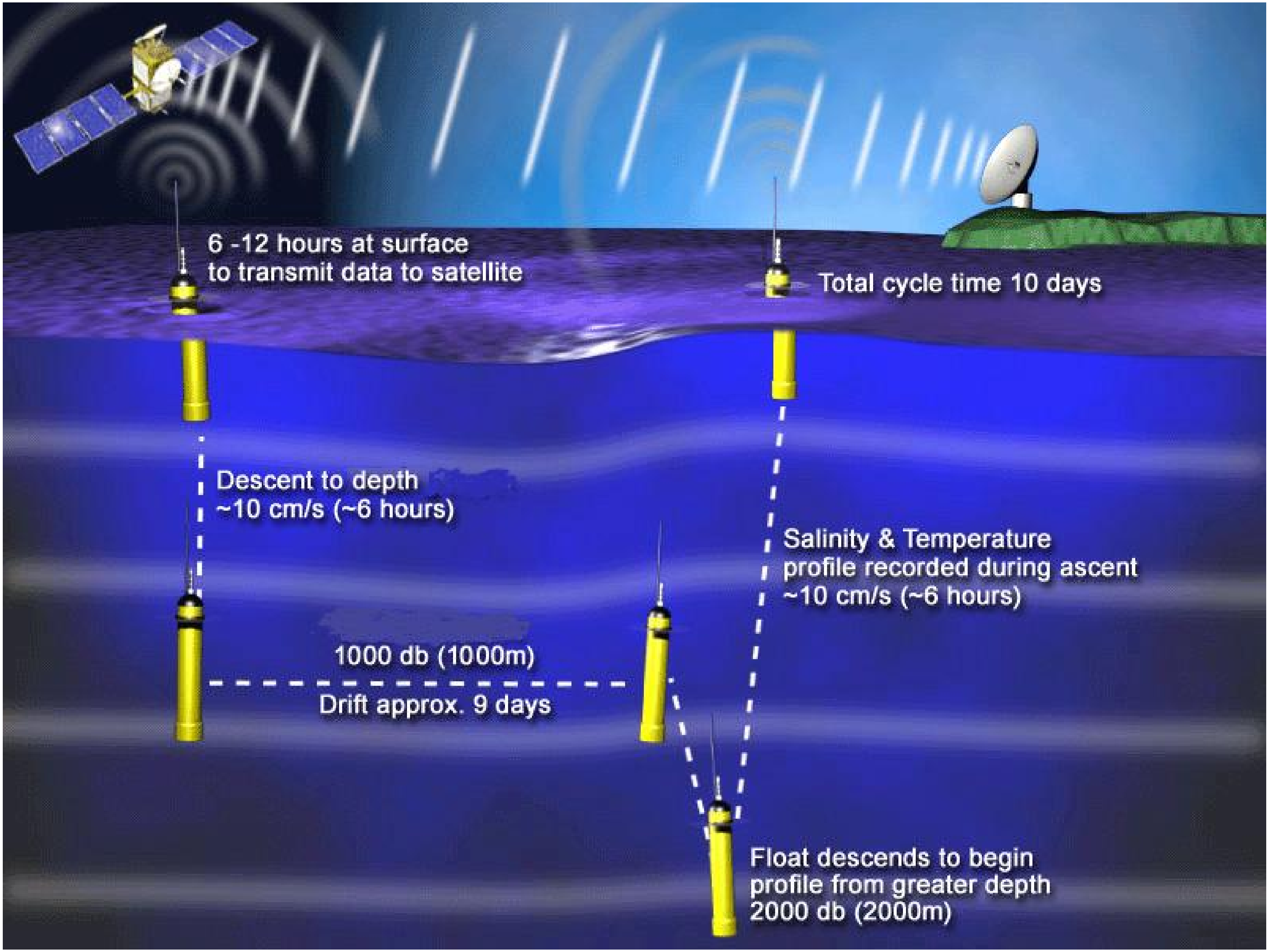
- Are mid-depth (~1000 m) ocean circulations steady?

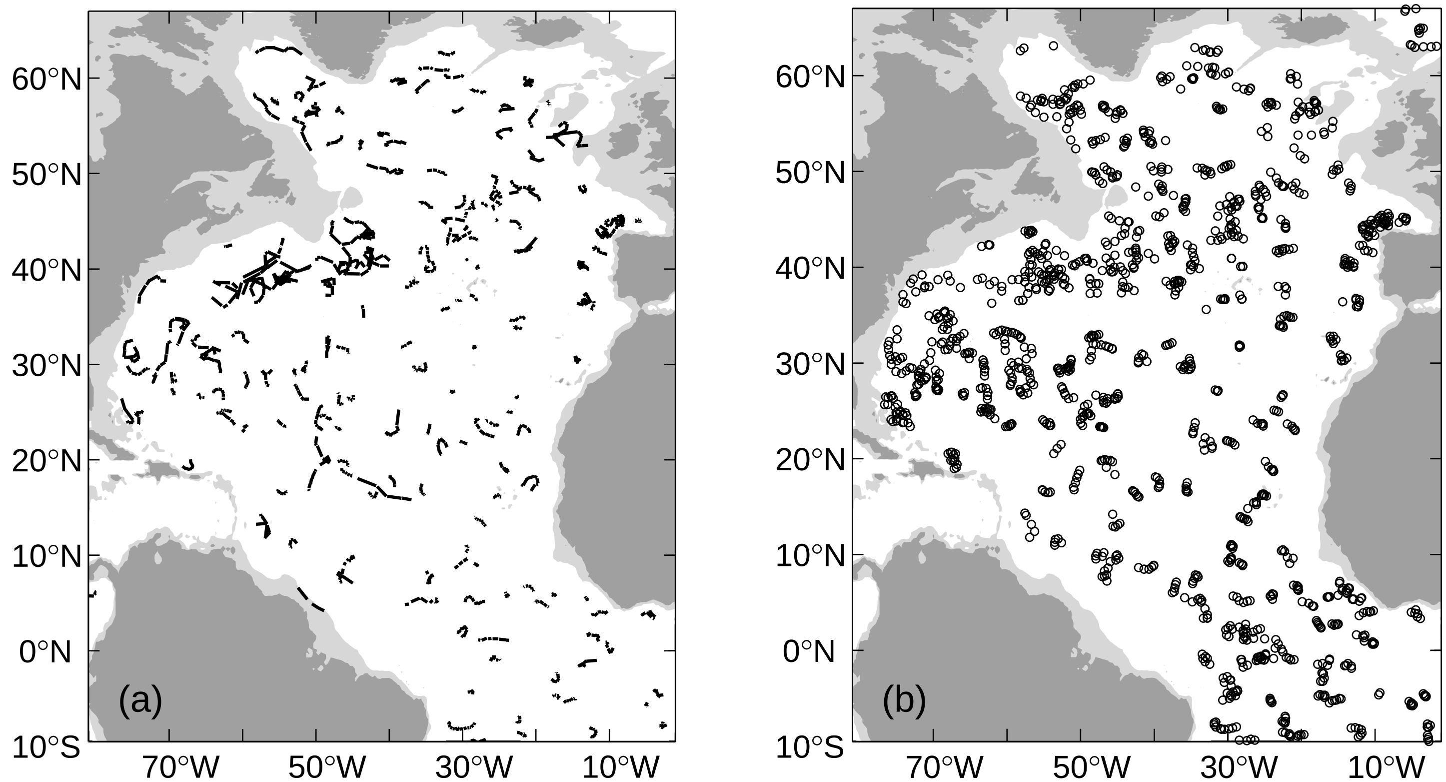
- If not,

  what mechanisms cause the change? (Rossby wave propagation)

(I will answer this question at

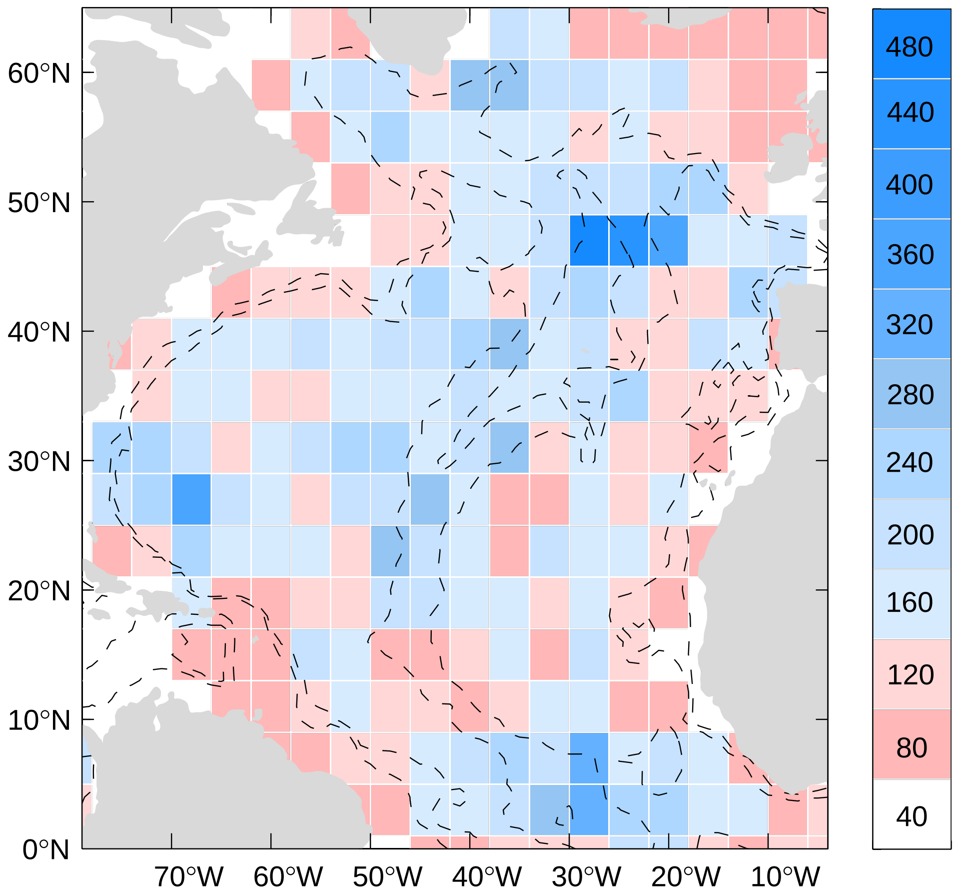
1:45 pm on Thursday at 11 IOAS-AOLS)

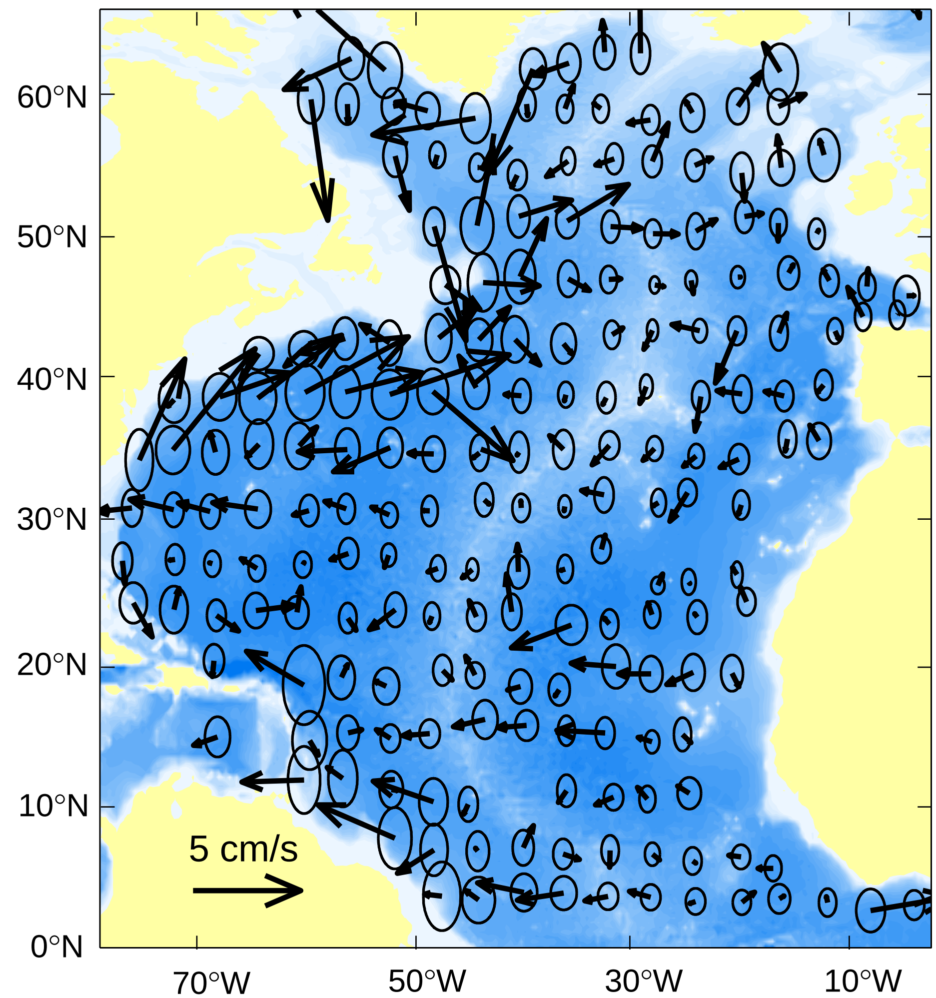

6 -12 hours at surface
to transmit data to satellite
Total cycle time 10 days
Descent to depth
~10 cm/s (~6 hours)
Salinity & Temperature
profile recorded during ascent
~10 cm/s (~6 hours)
1000 db (1000m)
Drift approx. 9 days
Float descends to begin
profile from greater depth
2000 db (2000m)



60°N
50°N
40°N
30°N
20°N
10°N
0°N
10°S
70°W
50°W
30°W
10°W
(a)
(b)

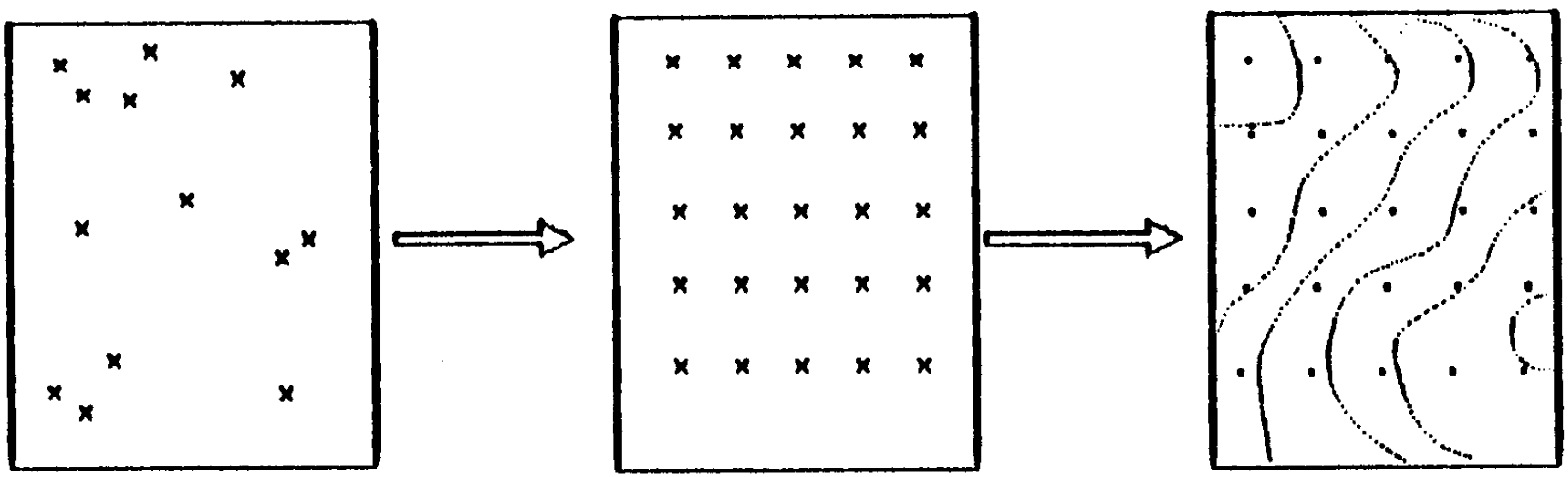
Circulations at 1000 m estimated from the original ARGO float tracks (bin method)
April 2004 – April 2005





Most Popular Method for Ocean Data Analysis

Optimum Interpolation (OI)



OI Method Requires:

- (1) First guess field
- (2) Known statistics

  such as the autocorrelation function

Ocean velocity data

- (1) First guess field (?)
- (2) Unknown autocorrelation function

Two Ways Out

- (1) Using numerical model to calculate the first guess field and autocorrelation function (Davis, 2002, 2004)

- (2) Using the OSD method

OSD
Spectral Representation

$$c(\mathbf{x}, z_k, t) = A_0(z_k, t) + \sum_{m=1}^{M} A_m(z_k, t)\ \Psi_m(\mathbf{x}, z_k),$$

Spatial Variability is represented by the basis functions

References

- Chu, P.C., L.M. Ivanov, T.P. Korzhova, T.M. Margolina, and O.M. Melnichenko, 2003a: Analysis of sparse and noisy ocean current data using flow decomposition. Part 1: Theory. Journal of Atmospheric and Oceanic Technology, 20 (4), 478-491.
- Chu, P.C., L.M. Ivanov, T.P. Korzhova, T.M. Margolina, and O.M. Melnichenko, 2003b: Analysis of sparse and noisy ocean current data using flow decomposition. Part 2: Application to Eulerian and Lagrangian data. Journal of Atmospheric and Oceanic Technology, 20 (4), 492-512.
- Chu, P.C., L.M. Ivanov, and T.M. Margolina, 2004: Rotation method for reconstructing process and field from imperfect data. International Journal of Bifurcation and Chaos, 14(8), 2991-2997.
- Chu, P.C., L.M. Ivanov, and O.M. Melnichenko, 2005: Fall-winter current reversals on the Texas-Lousiana continental shelf. Journal of Physical Oceanography, 35, 902-910
- Chu, P.C., L.M. Ivanov, O.M. Melnichenko, and N.C. Wells, 2007: On long baroclinic Rossby Waves in the tropical North Atlantic observed from profiling floats. Journal of Geophysical Research – Oceans, in press.

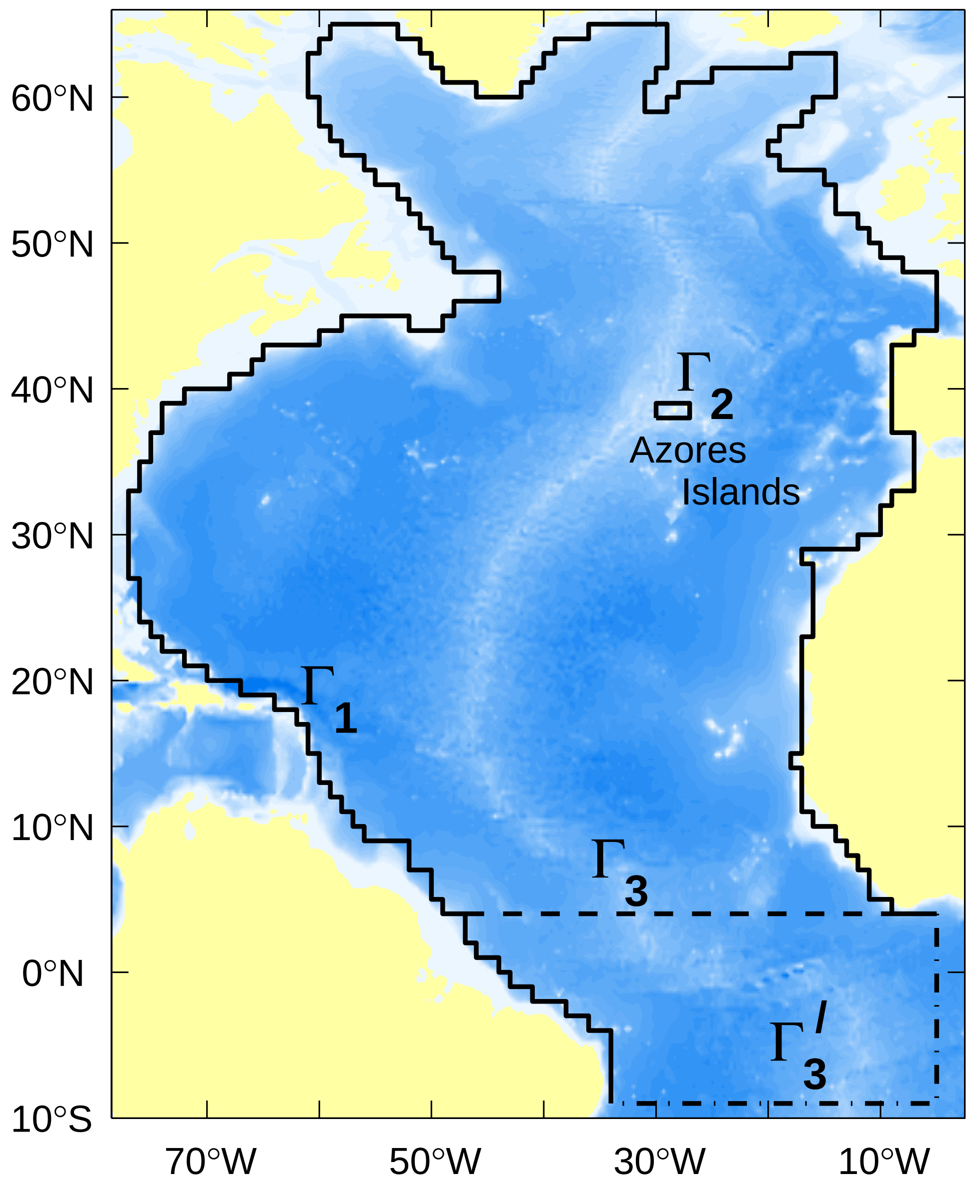
- These papers can be downloaded from:
- http://www.oc.nps.navy.mil/~chu

Two approaches to obtain basis functions

- EOFs

- Eigenfunctions of Laplace Operator
- (closed lateral boundary)

$$\nabla_h^2 \Psi_m = -\lambda_m \Psi_m, \quad \Psi_m |_\Gamma = 0, \quad m = 1, 2, \ldots, M$$



60°N
50°N
40°N
30°N
20°N
10°N
0°N
10°S
70°W
50°W
30°W
10°W
Γ1
Γ2
Azores
Islands
Γ3
Γ3/

Basis Functions of Laplace Operator (Open Boundaries)

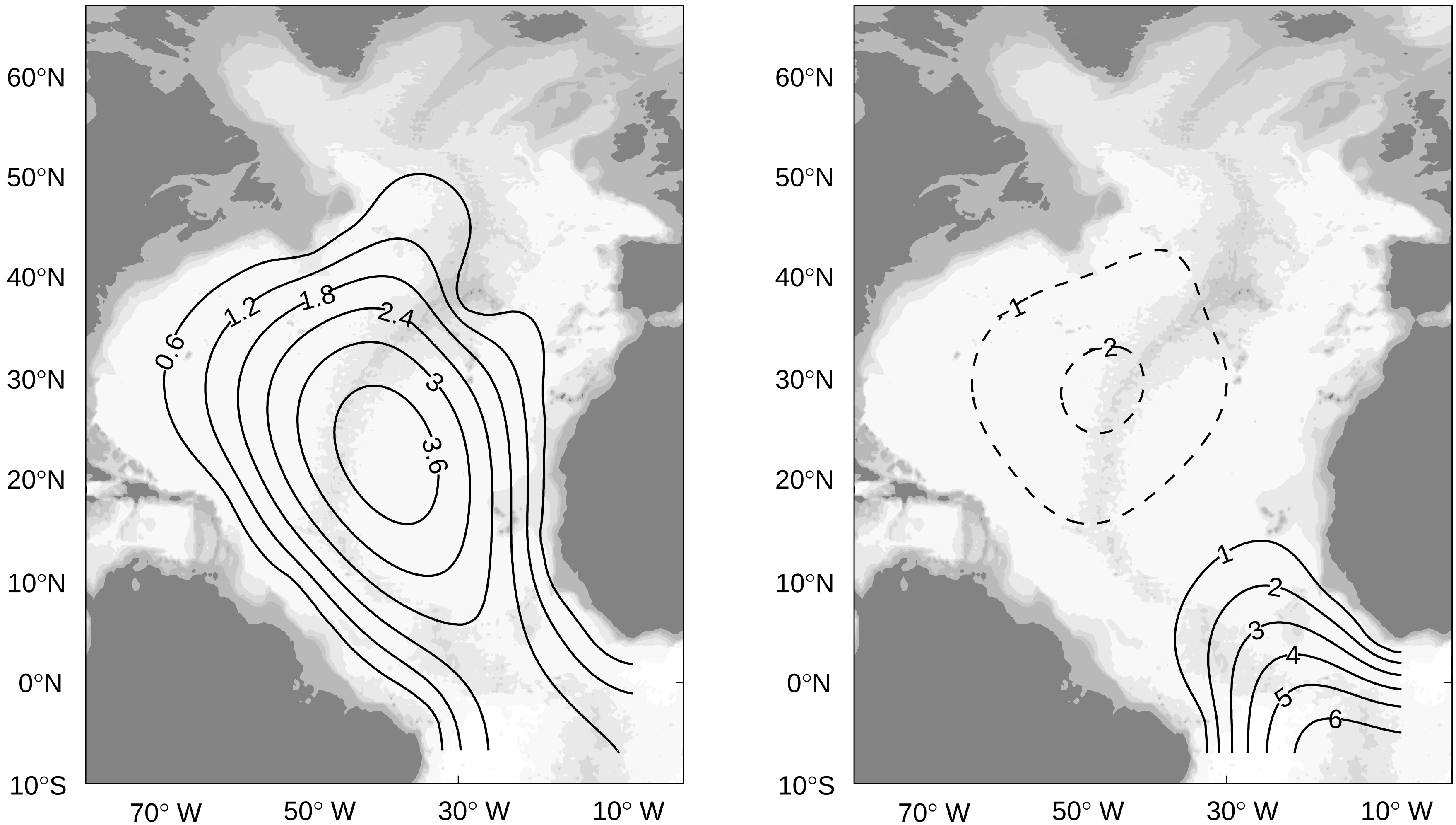
$$\triangle \Psi_k = -\lambda_k \Psi_k,$$

$$\triangle \Phi_m = -\mu_m \Phi_m,$$

$$\Psi_k|_\Gamma = 0, \quad \frac{\partial \Phi_m}{\partial n}|_\Gamma = 0,$$

$$\left[\frac{\partial \Psi_k}{\partial n} + \kappa(\tau)\Psi_k\right]|_{\Gamma_1'} = 0, \quad \Phi_m|_{\Gamma_1'} = 0,$$

Basis Functions for Streamfunction
Mode-1 and Mode-2



Spectral Decomposition

$$
\begin{aligned}
u_{KM} &= \sum_{k=1}^{K} a_k(z, t^\circ) \frac{\partial \Psi_k(x, y, z, \kappa^\circ)}{\partial y} + \sum_{m=1}^{M} b_m(z, t^\circ) \frac{\partial \Phi_m(x, y, z)}{\partial x}, \\
v_{KM} &= -\sum_{k=1}^{K} a_k(z, t^\circ) \frac{\partial \Psi_k(x, y, z, \kappa^\circ)}{\partial x} + \sum_{m=1}^{M} b_m(z, t^\circ) \frac{\partial \Phi_m(x, y, z)}{\partial y}
\end{aligned}
$$

Optimal Mode Truncation

$$J(a_{1,\ldots,}a_K, b_{1,\ldots,}b_M, \kappa, P) = \frac{1}{2}\left(\left\|u_p^{obs} - u_{KM}\right\|_P^2 + \left\|v_p^{obs} - v_{KM}\right\|_P^2\right) \rightarrow \min,$$

Vapnik (1983) Cost Function

$$J_{emp} = J(a_{1,\ldots,}a_{K,}b_{1,\ldots,}b_M, \kappa, P).$$

$$\text{Prob}\left\{\sup_{K,M,S} |\langle J(K,M,S)\rangle - J_{emp}(K,M,S)| \geq \mu\right\} \leq g(P,\mu)$$

$$\lim_{P\to\infty} g(P,\mu) = 0$$

Optimal Truncation

- ARGO Data (Mid-Depth North Atlantic)

  Kopt = 38, Mopt = 24

Determination of Spectral Coefficients (Ill-Posed Algebraic Equation)

$$\mathbf{A}\hat{\mathbf{a}} = \mathbf{Q}\mathbf{Y},$$

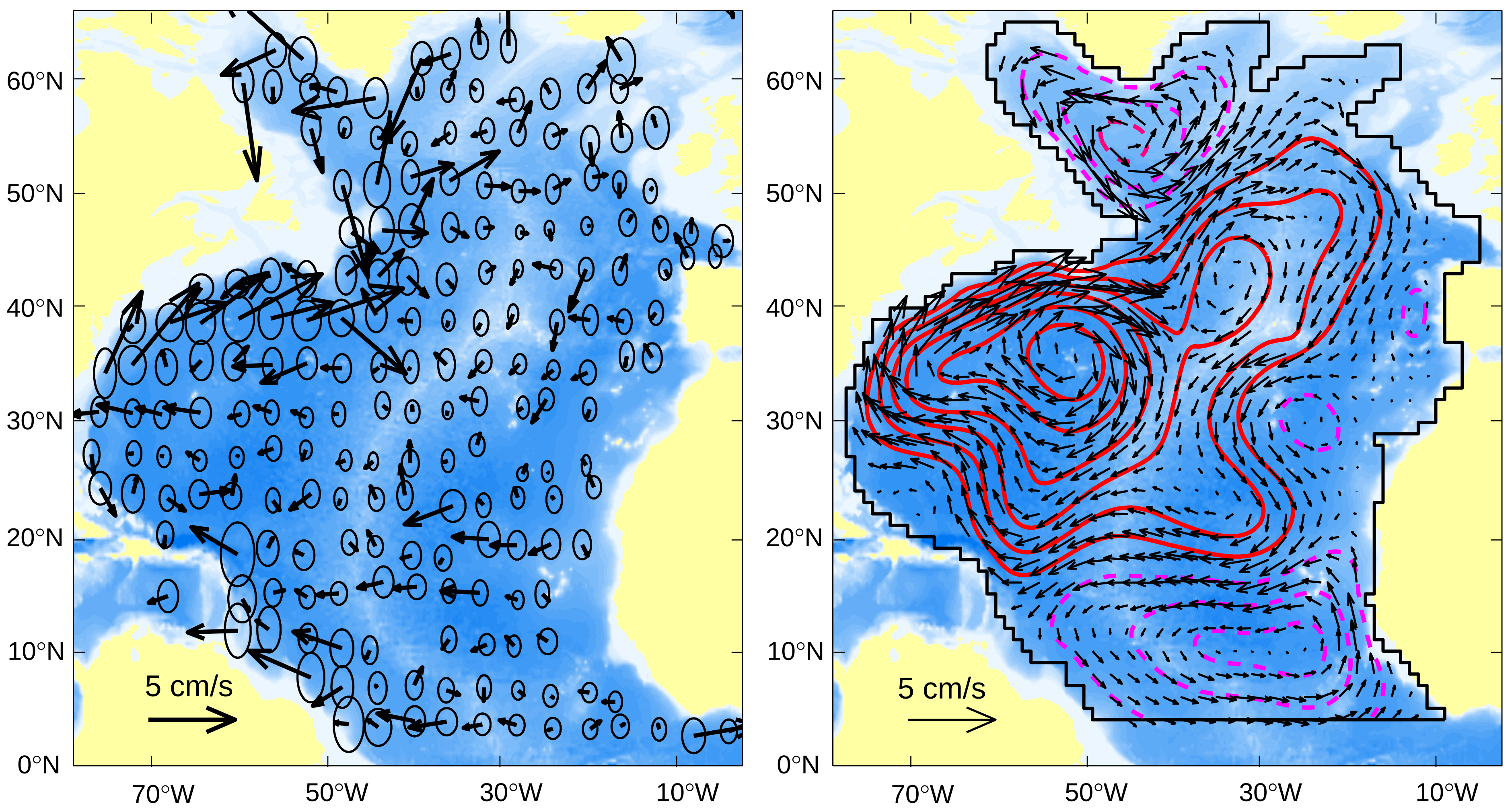
Rotation Method for Solving Ill-Posed Algebraic Equation (Chu et al., 2004)

$$\mathbf{S A \hat{a}} = \mathbf{SQY},$$

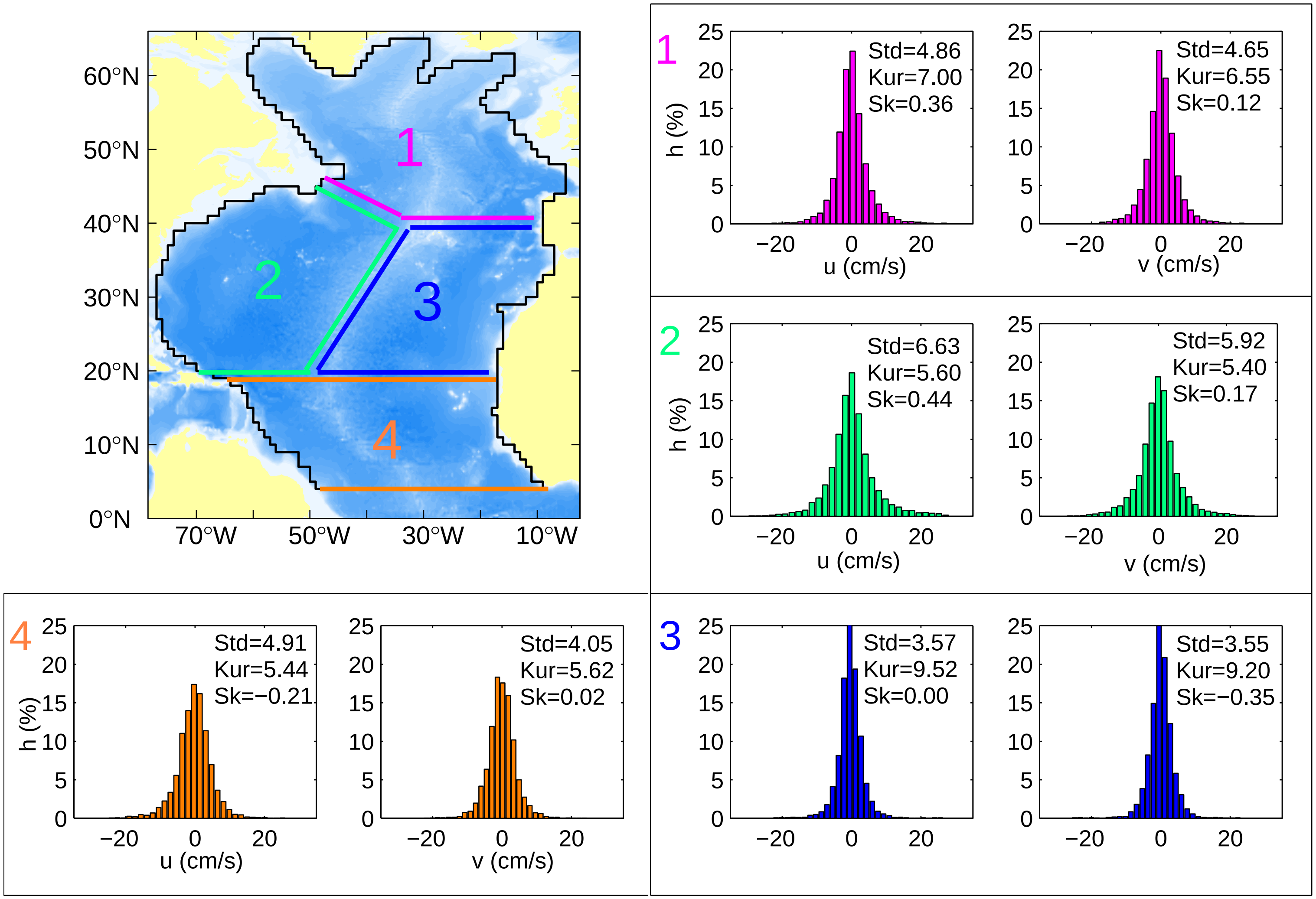
$$J_1 = \|\mathbf{A}\|^2 - \frac{\|\mathbf{SQY}\|^2}{\|\mathbf{a}\|^2} \rightarrow \max,$$

Circulations at 1000 m (March 04 to May 05)

Bin Method OSD

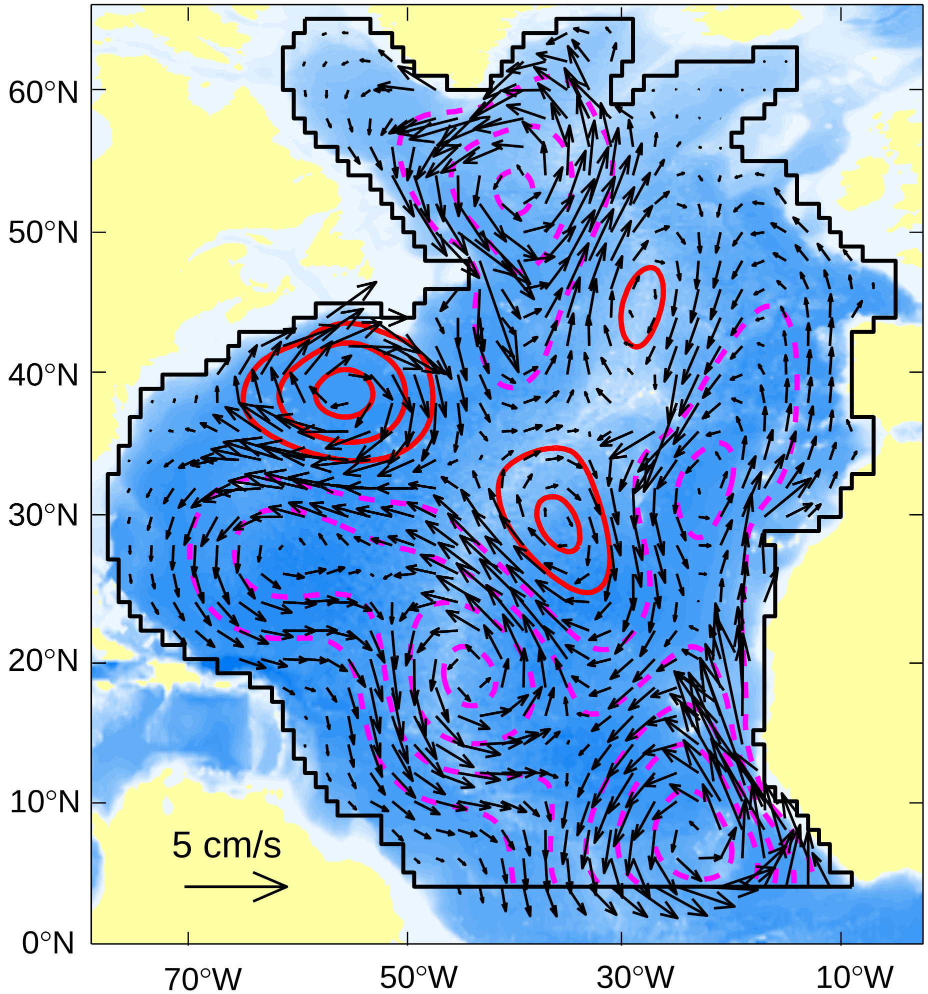


Velocity Variability (V_{obs} - $<V>_{rec}$)

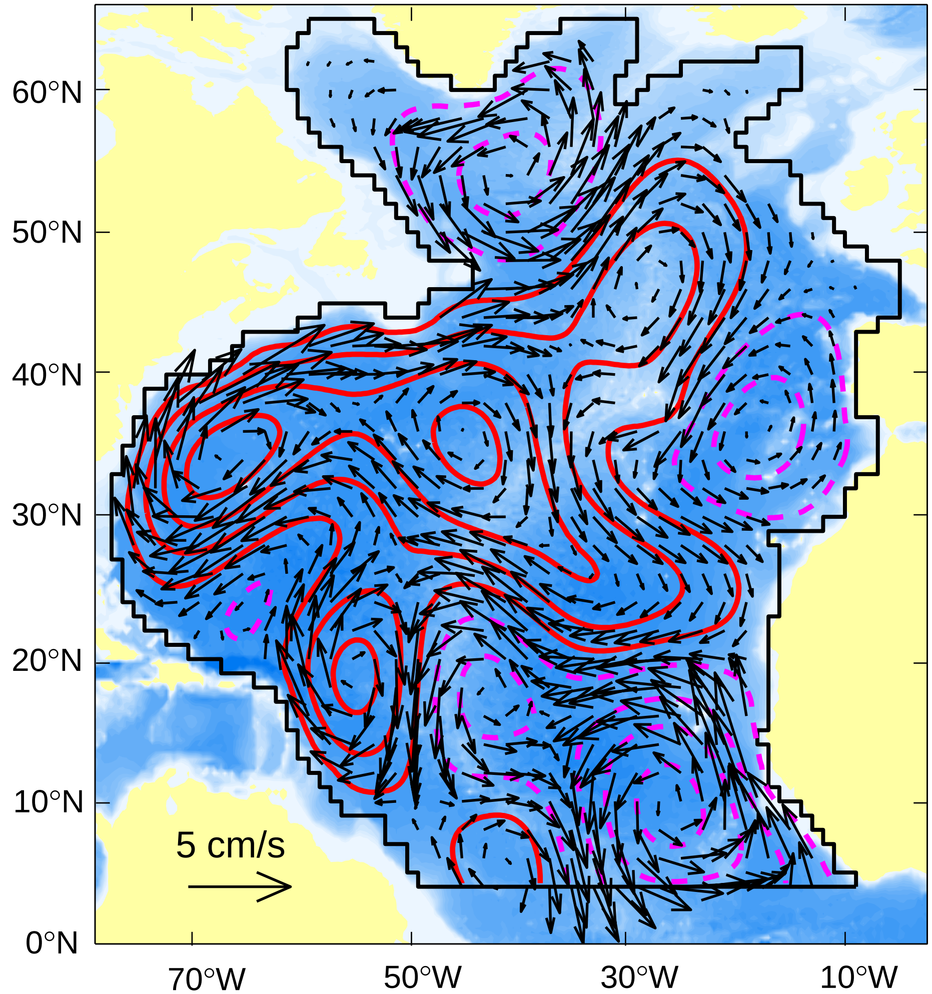


Mid-Depth Circulations (1000 m)

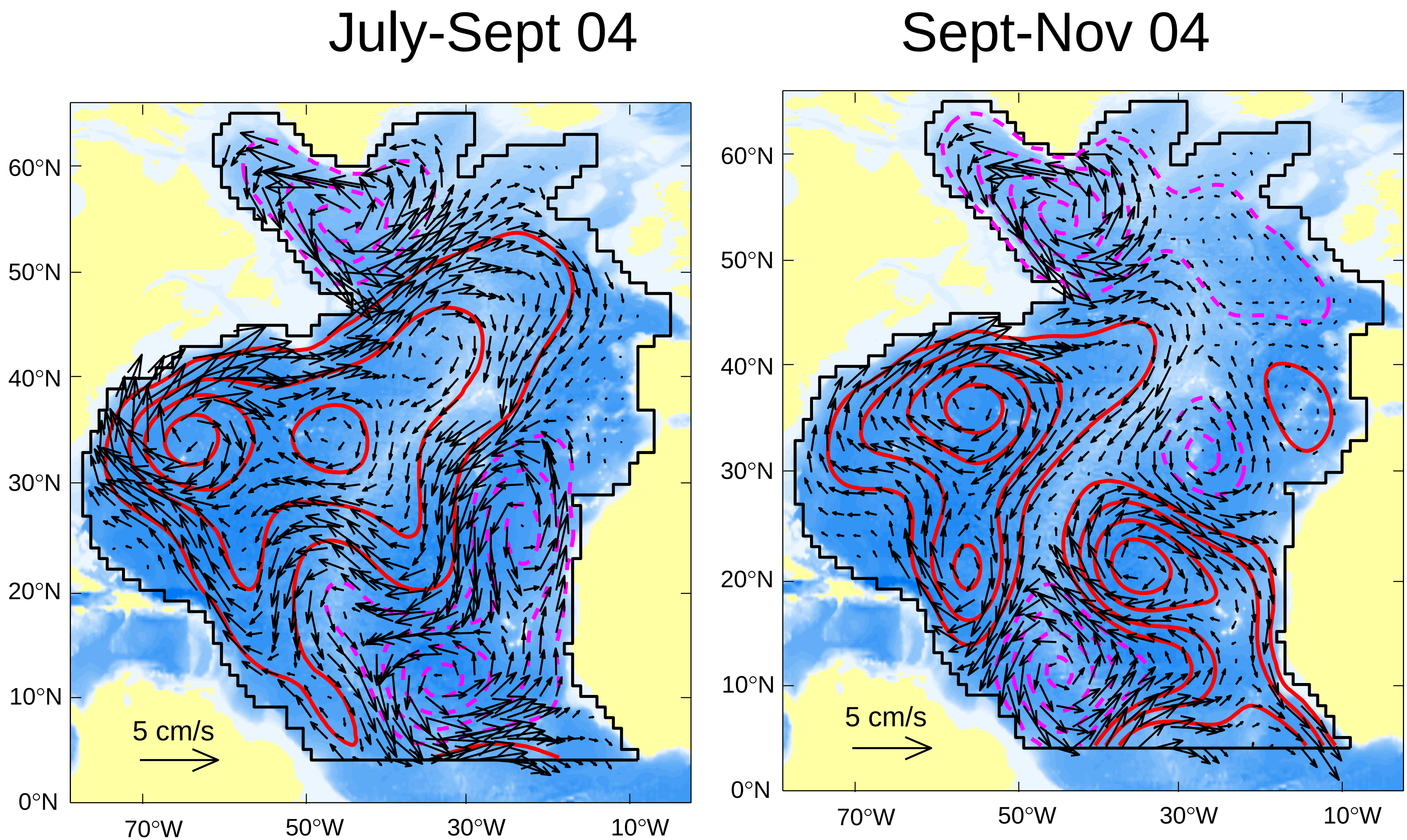
March-May 04



May-July 04

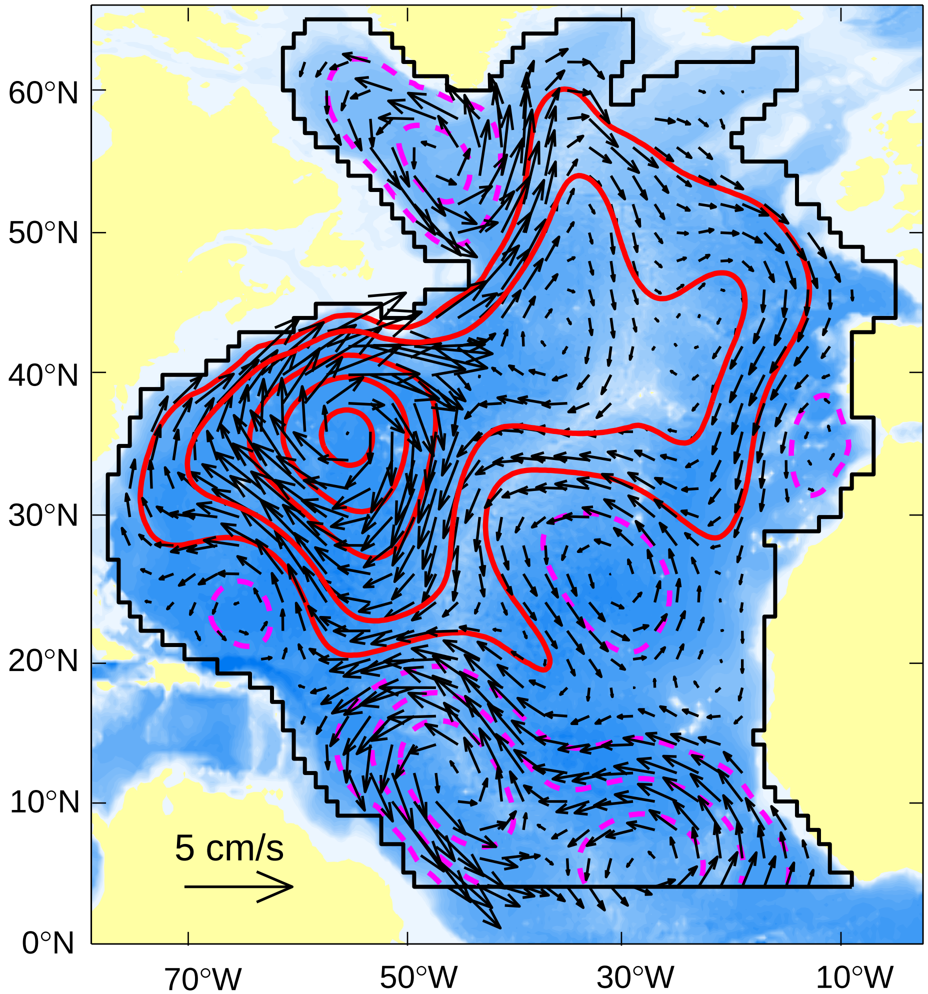


Mid-Depth Circulations (1000 m)

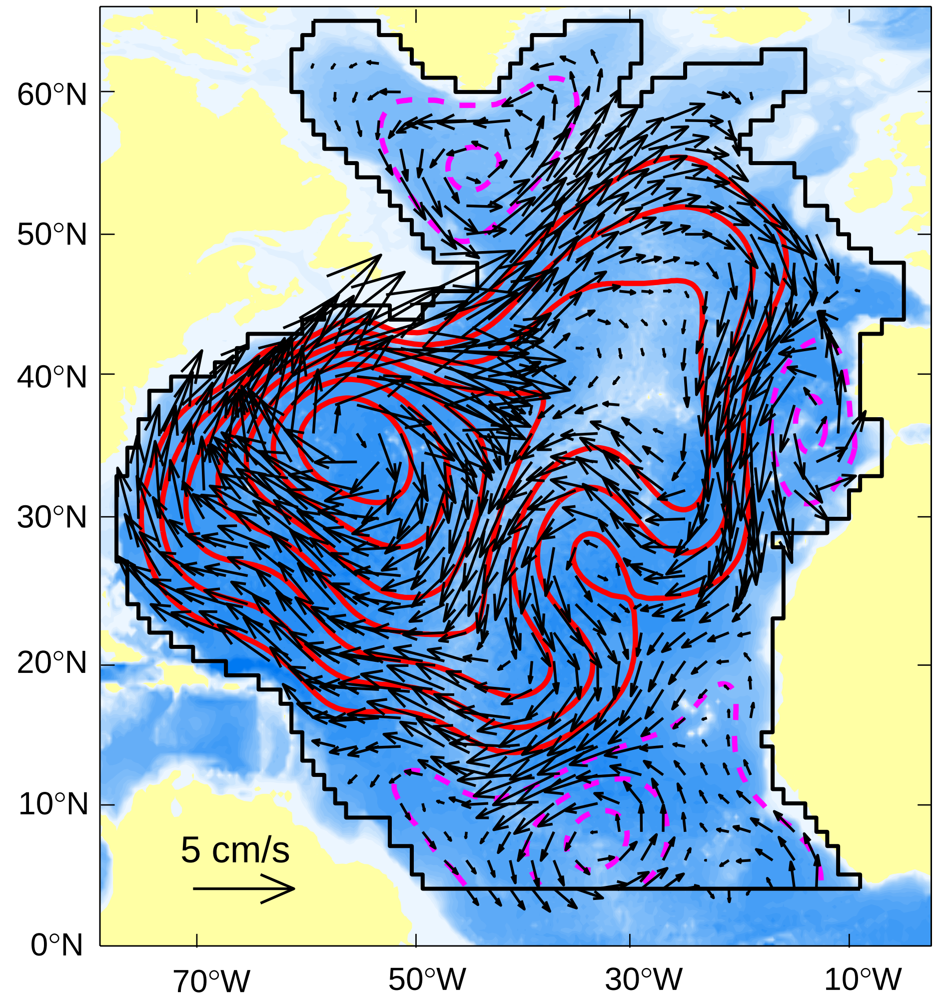


Mid-Depth Circulations (1000 m)

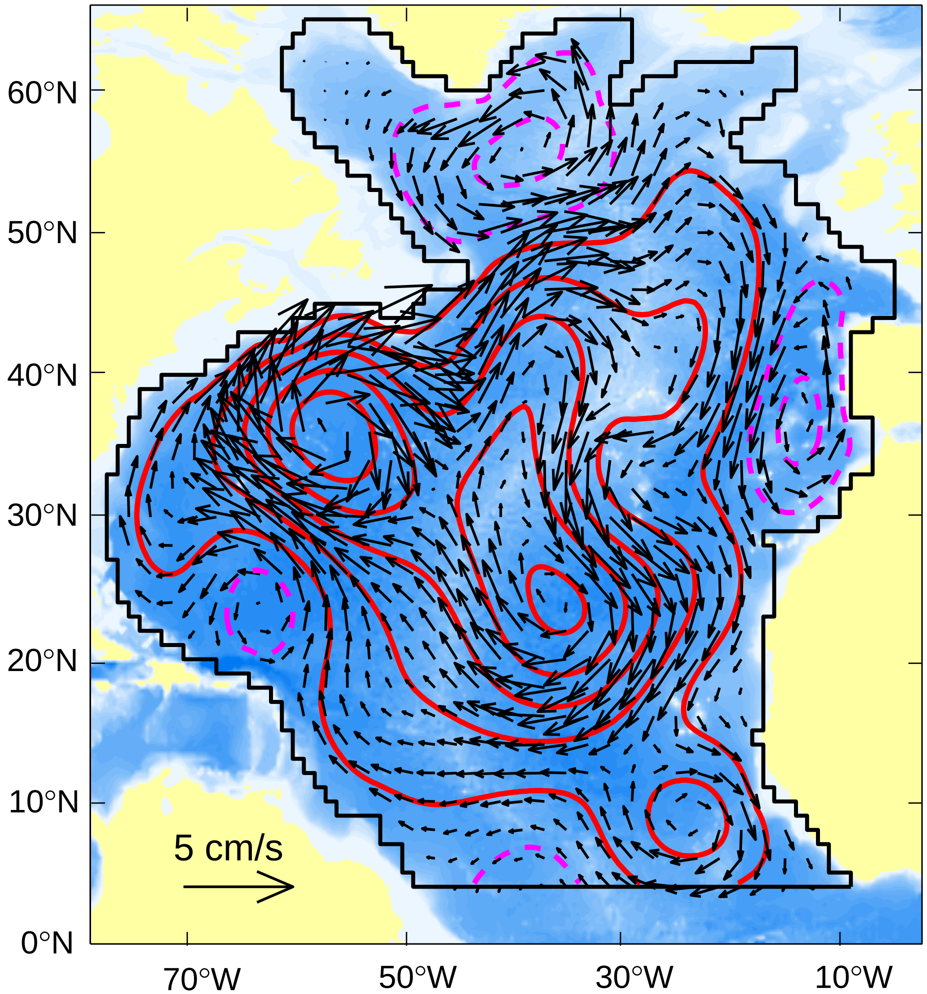
Nov 04-Jan 05



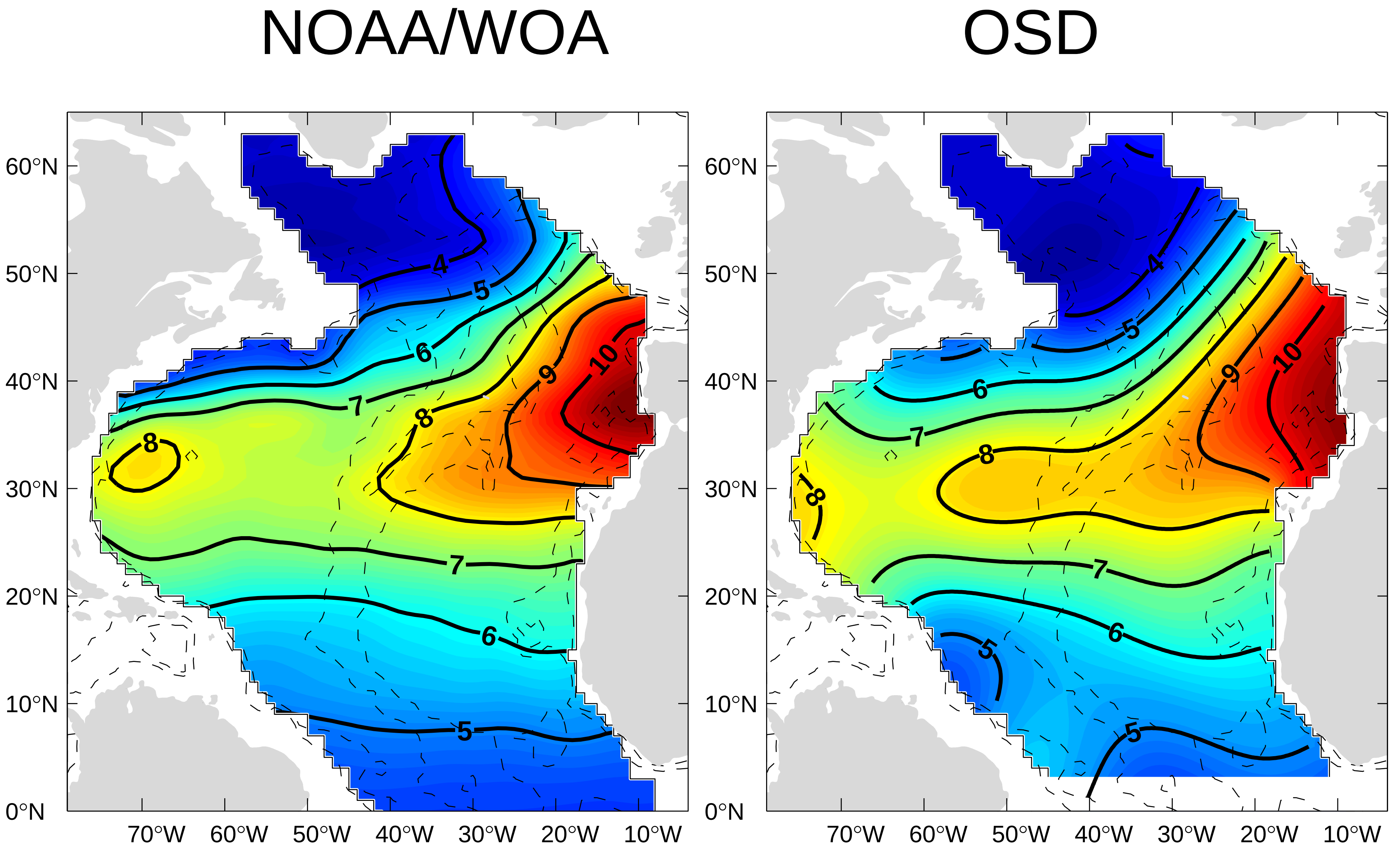
Jan-Mar 05



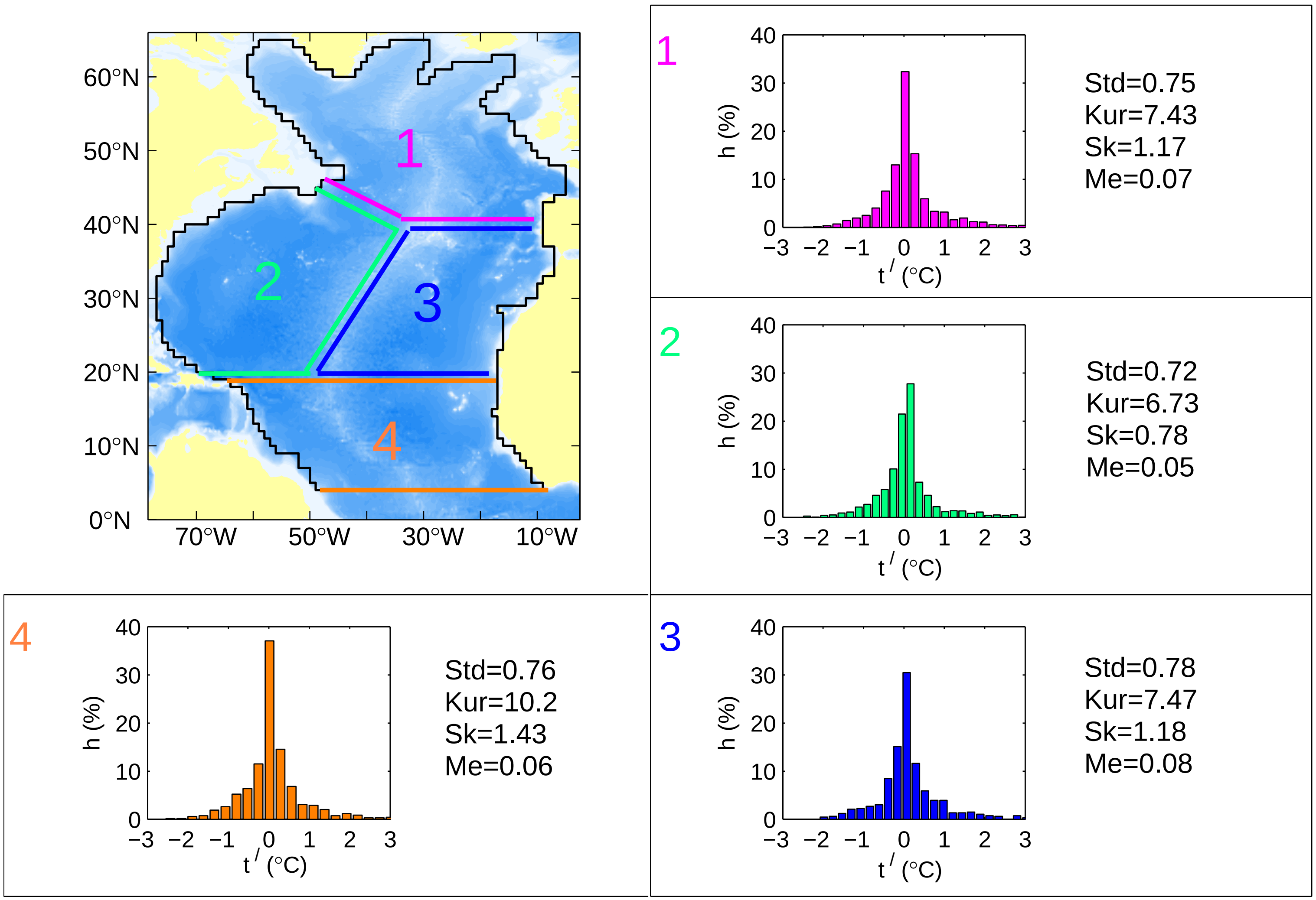
Mid-Depth Circulations (1000 m)
Mar-May 05



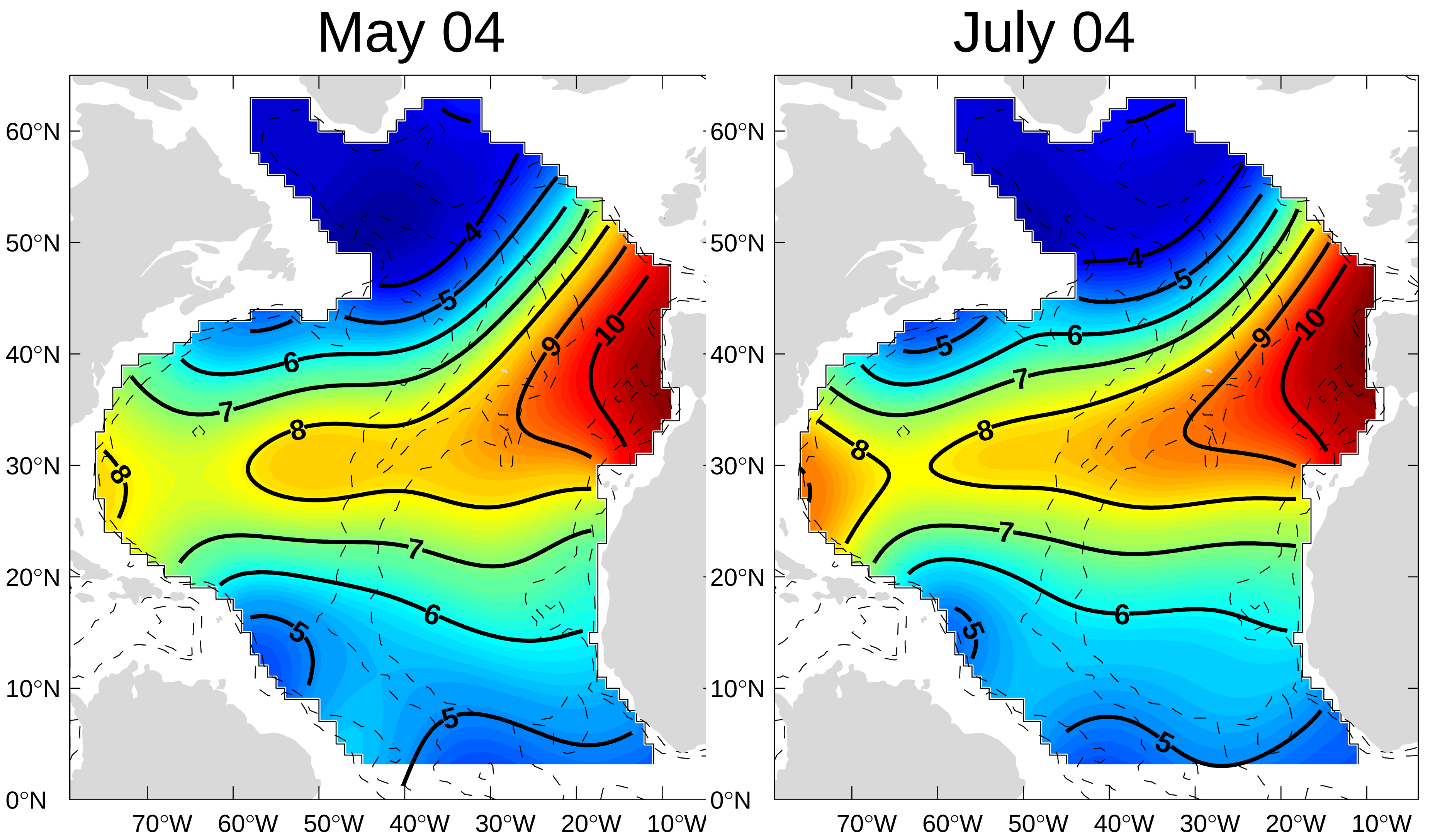
Temperature at 950 m (March 04 to May 05)



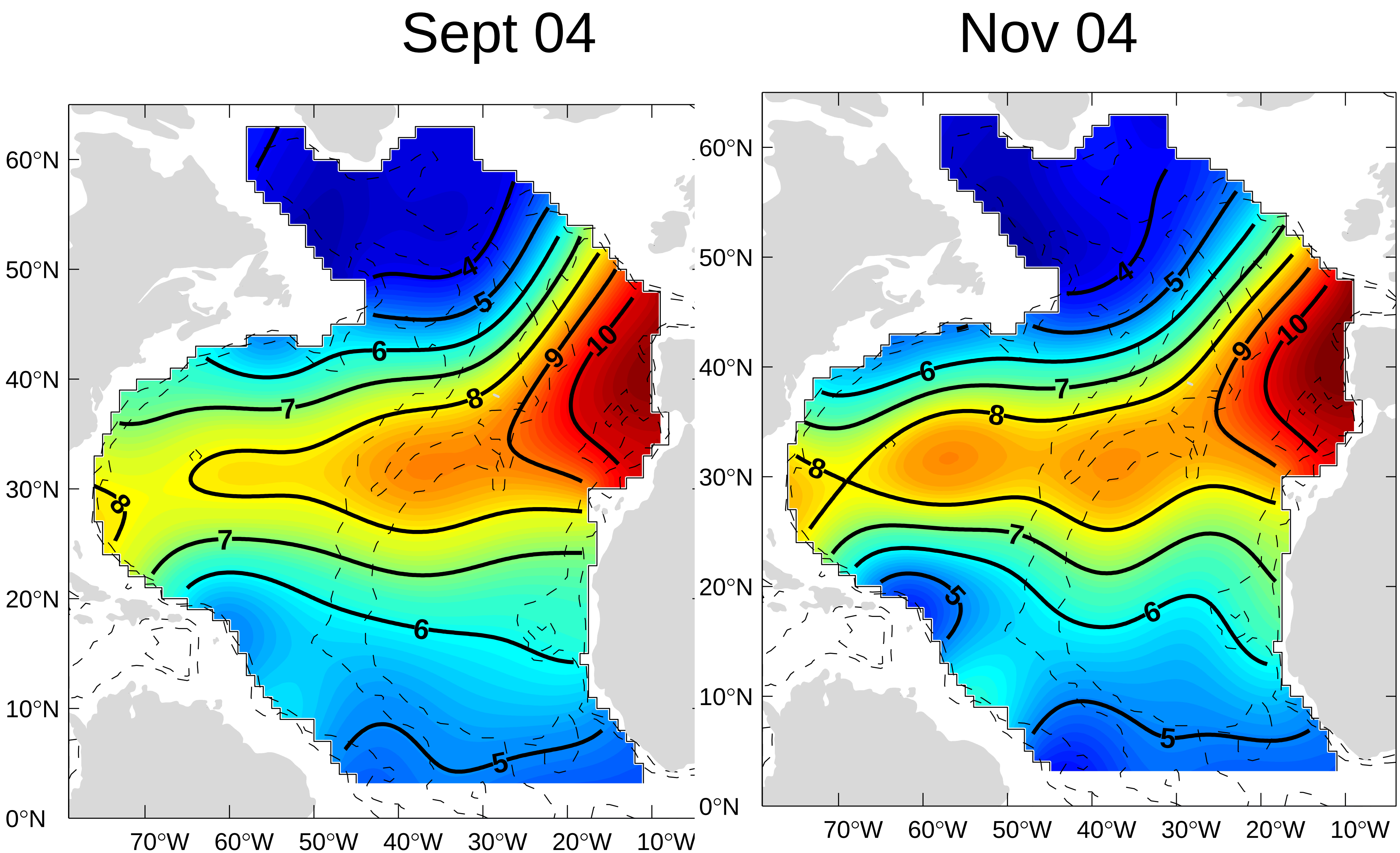
Temperature $(T_{obs} - \langle T \rangle_{rec})$



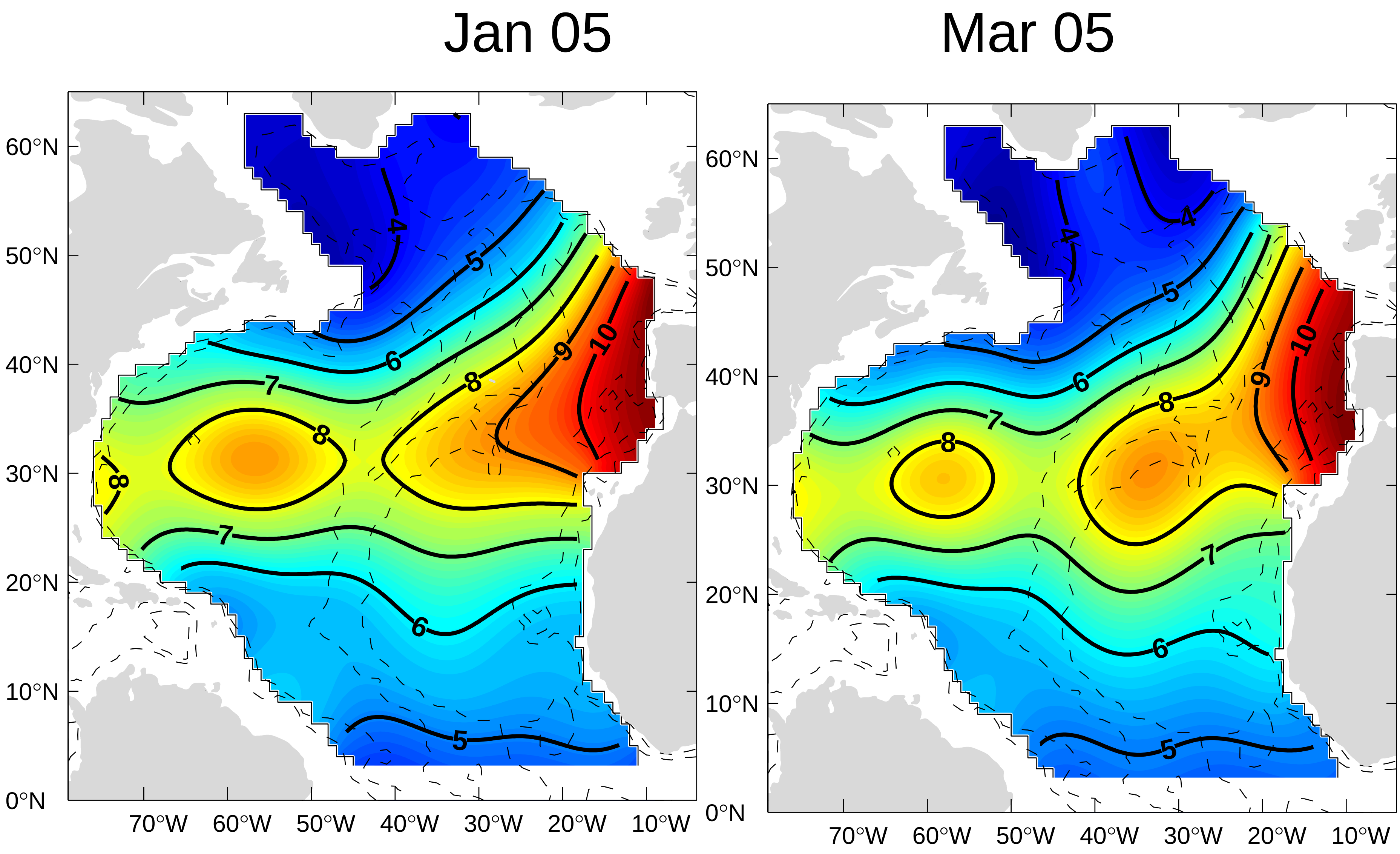
Mid-Depth Temperature (950 m)



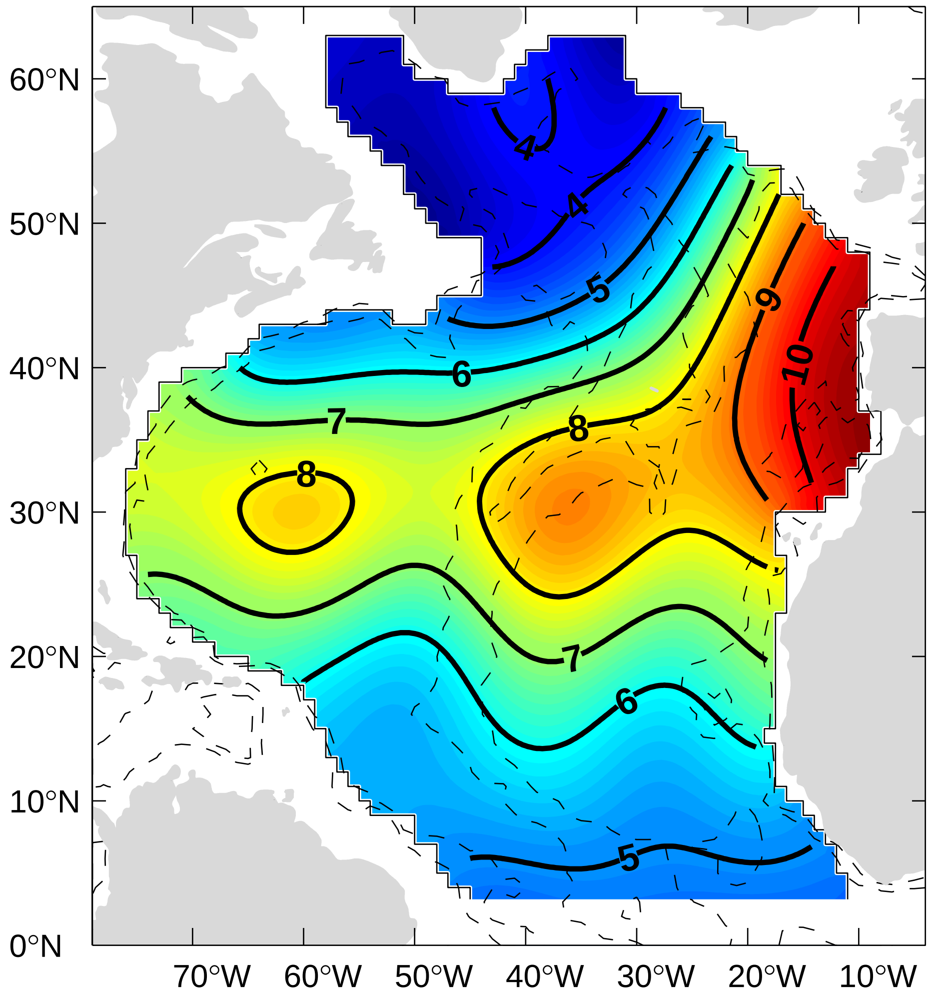
Mid-Depth Temperature (950 m)



Mid-Depth Temperature (950 m)



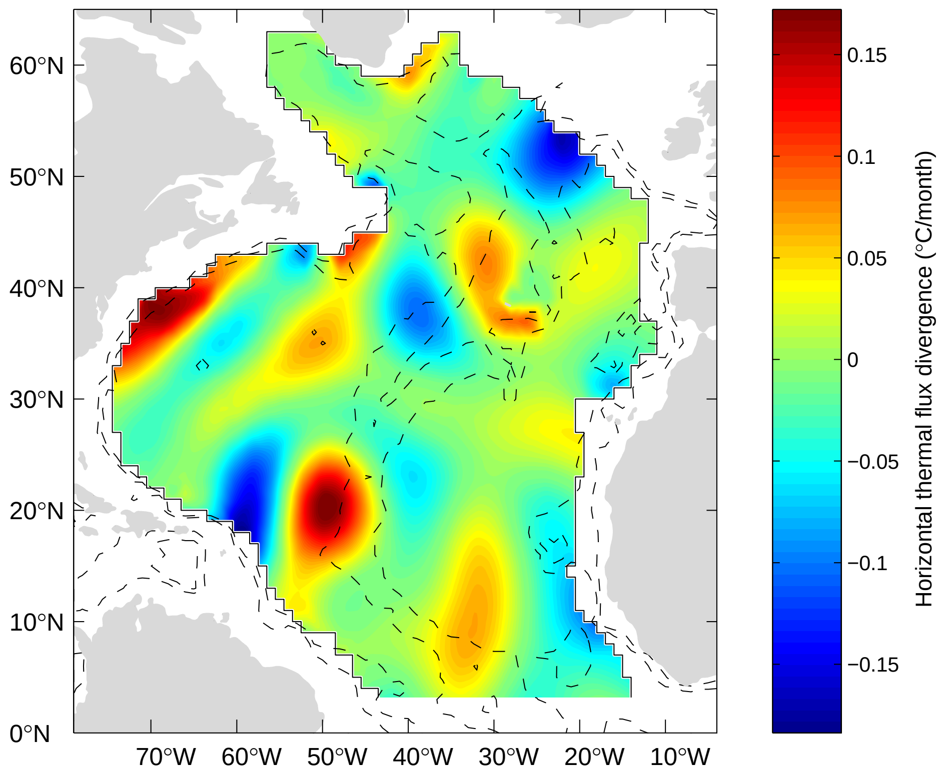
Mid-Depth Temperature (950 m)
May 05



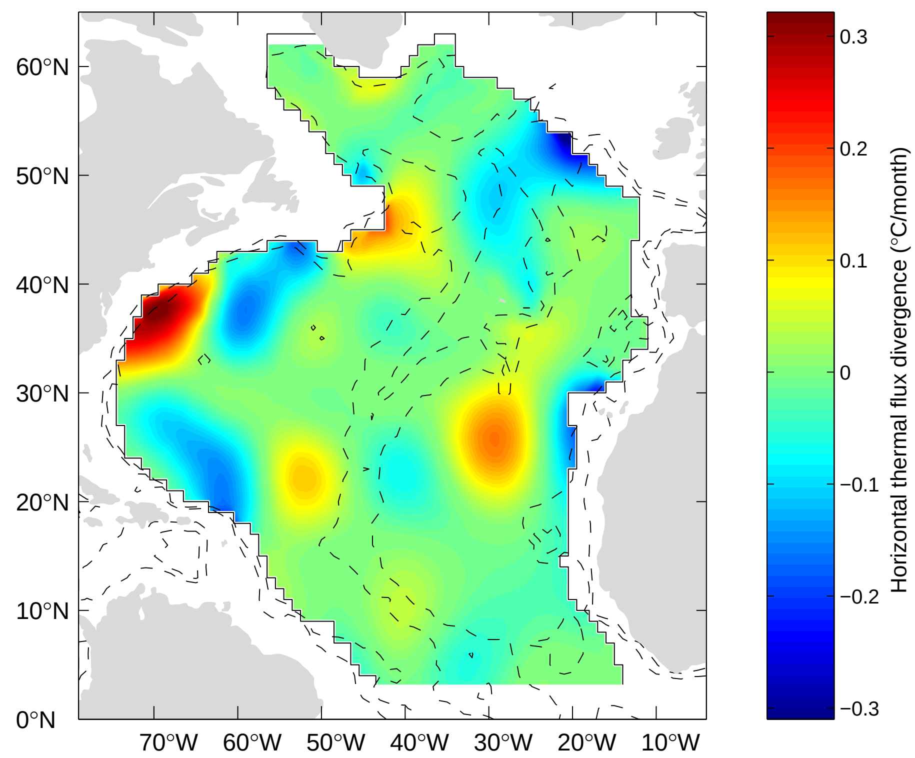
Horizontal Heat Advection at 950 m

$$-u\, \partial T/\partial x - v\, \partial T/\partial y$$

June 04



Aug 04

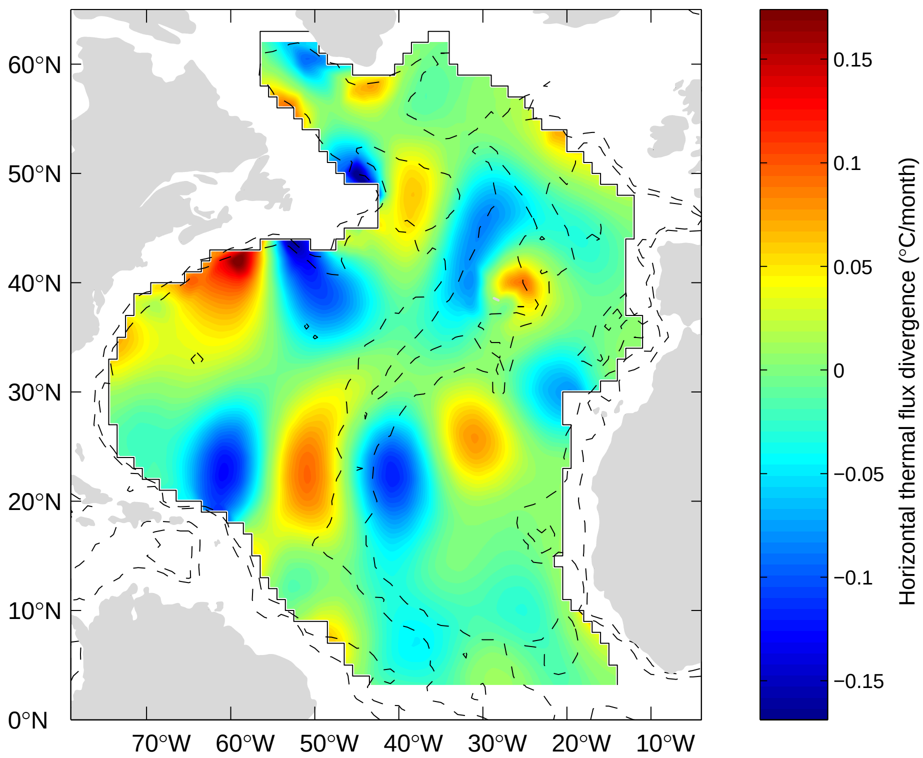


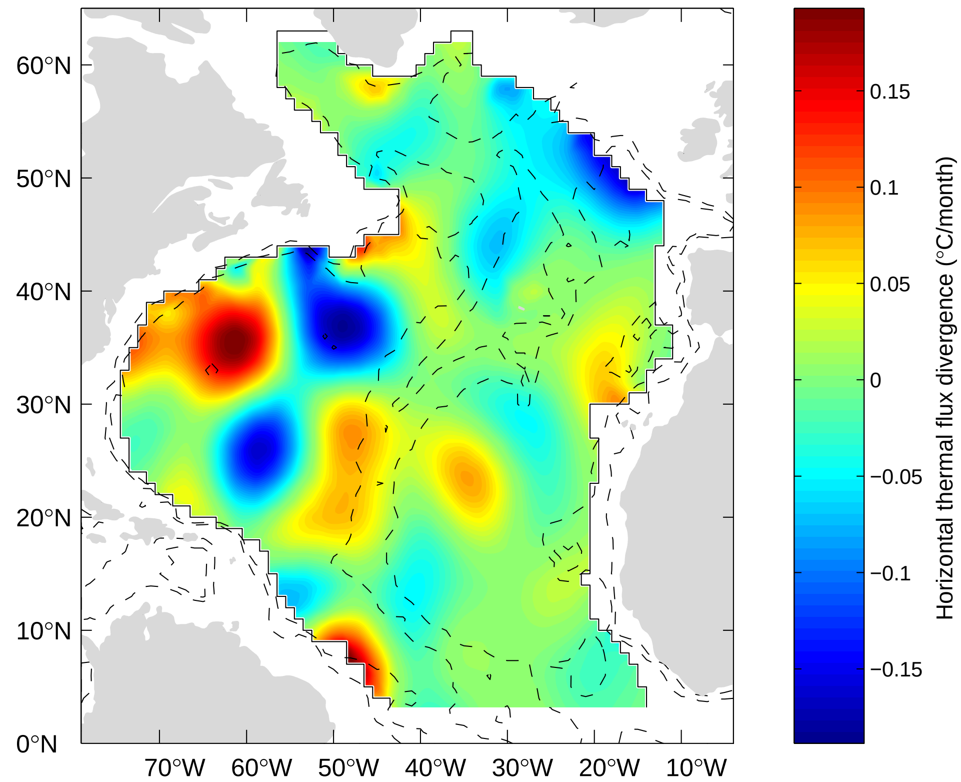
Horizontal Heat Advection at 950 m

$$-u\, \partial T/\partial x - v\, \partial T/\partial y$$

Oct 04

Dec 04



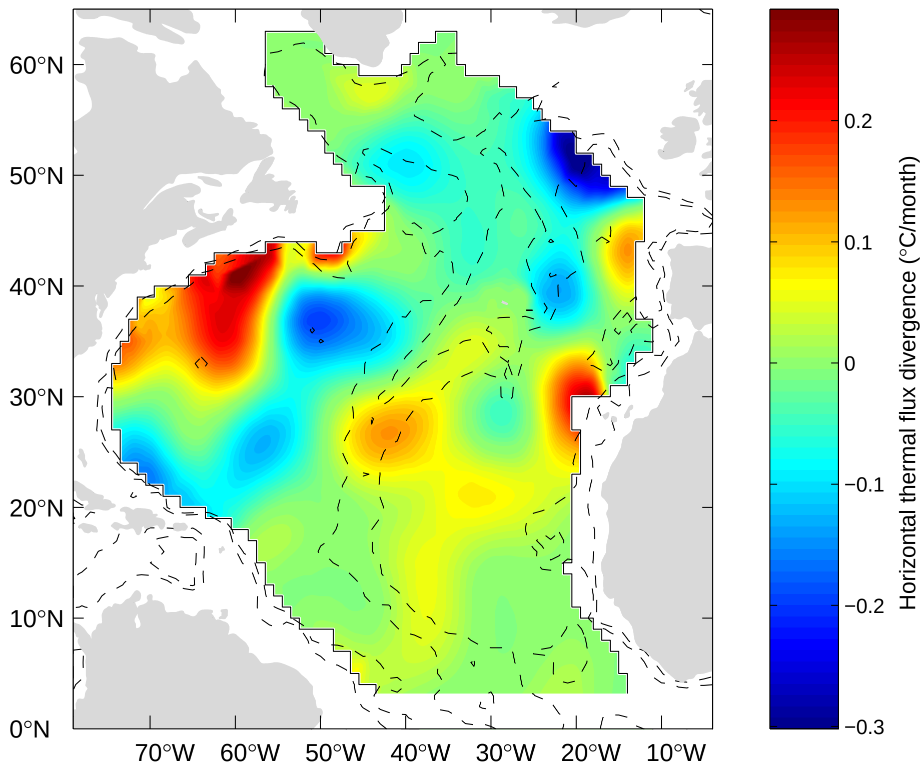


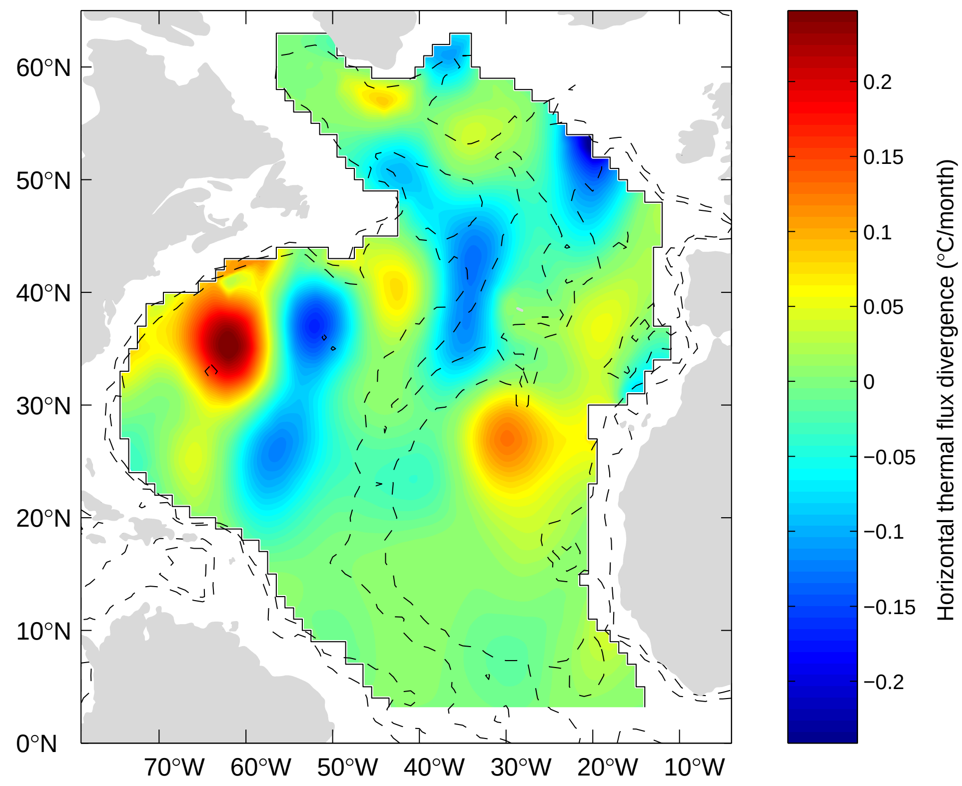
Horizontal Heat Advection at 950 m

$$-u\ \partial T/\partial x - v\ \partial T/\partial y$$

Feb 05

Apr 05





Conclusions

- Mid-depth North Atlantic Ocean circulation has rapid change (not steady !).
- The circulation variability is around 5 cm/s.
- The maximum horizontal temperature advection is around 0.25^{o}/mon.
- The velocity and temperature perturbations are not normally distributed.
- OSD is a useful tool for processing real-time velocity data with short duration and limited-area sampling especially the ARGO data.