Can we observe the Atlantic overturning?

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New possibilities offered by the Argo float program and the Andro displacement data base

http://wwz.ifremer.fr/lpo

To obtain the 3D large scale general oceanic circulation

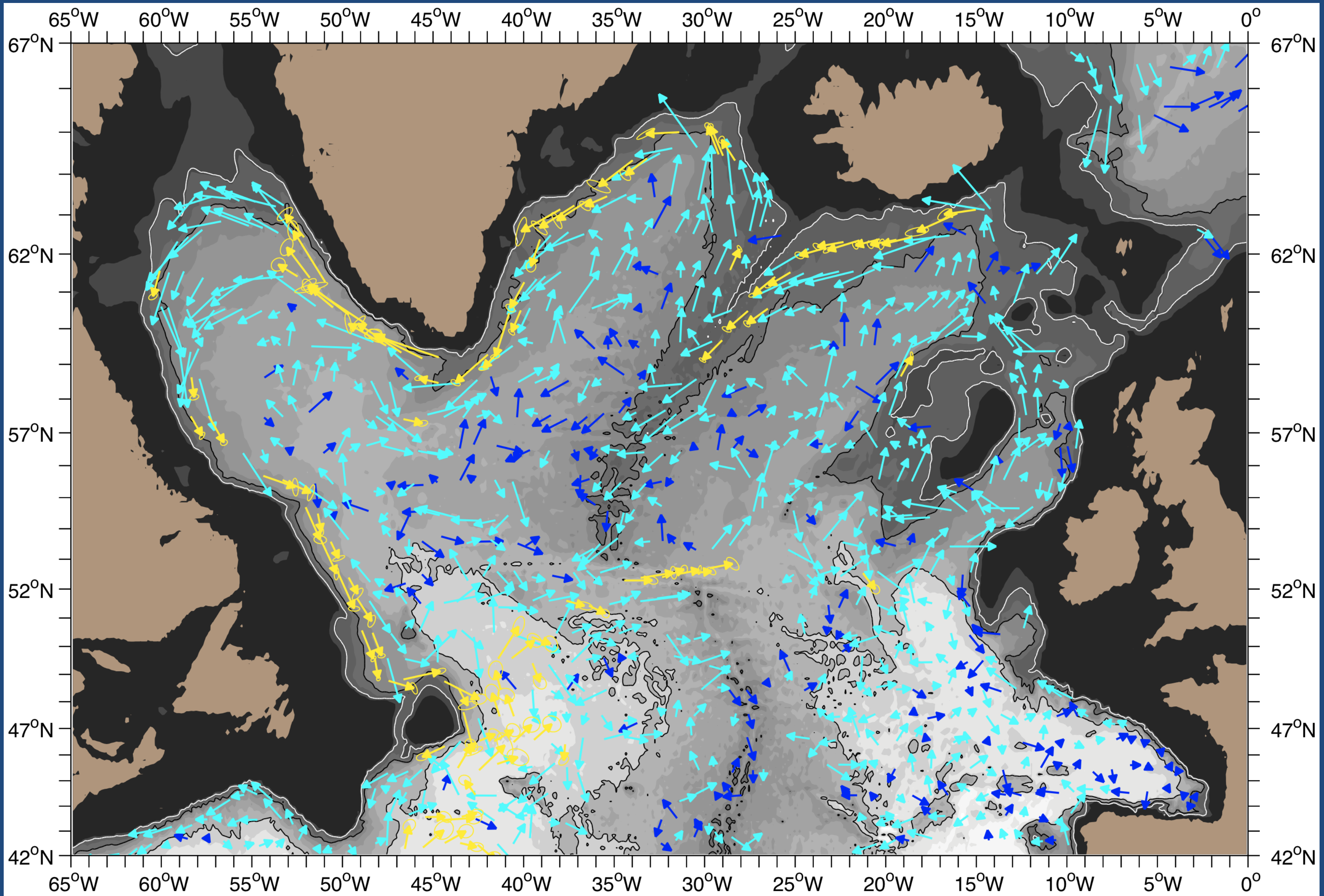
- Thermal wind equations give vertical shear:

$$\mathbf{U}(z)=\mathbf{U}(z_R) + \int \partial_Z \mathbf{U}\, dz$$

- Currents are surface trapped : if z_R is taken near the surface, then **U** becomes ill-determined under the thermocline.

- The Argo float program provides a deep reference field

Mapping the lagrangian data over eulerian arrays: divergence is as large as relative vorticity



Knowing the geopotential Φ, **U** is obtained easily from the local operation:

$$-f\, v = -1/a \cos(\theta) \partial_\lambda \Phi|_p$$

$$f\, u = -1/a\, \partial_\theta \Phi|_p$$

To restore quasi-non divergence, get Φ from u and v. How?

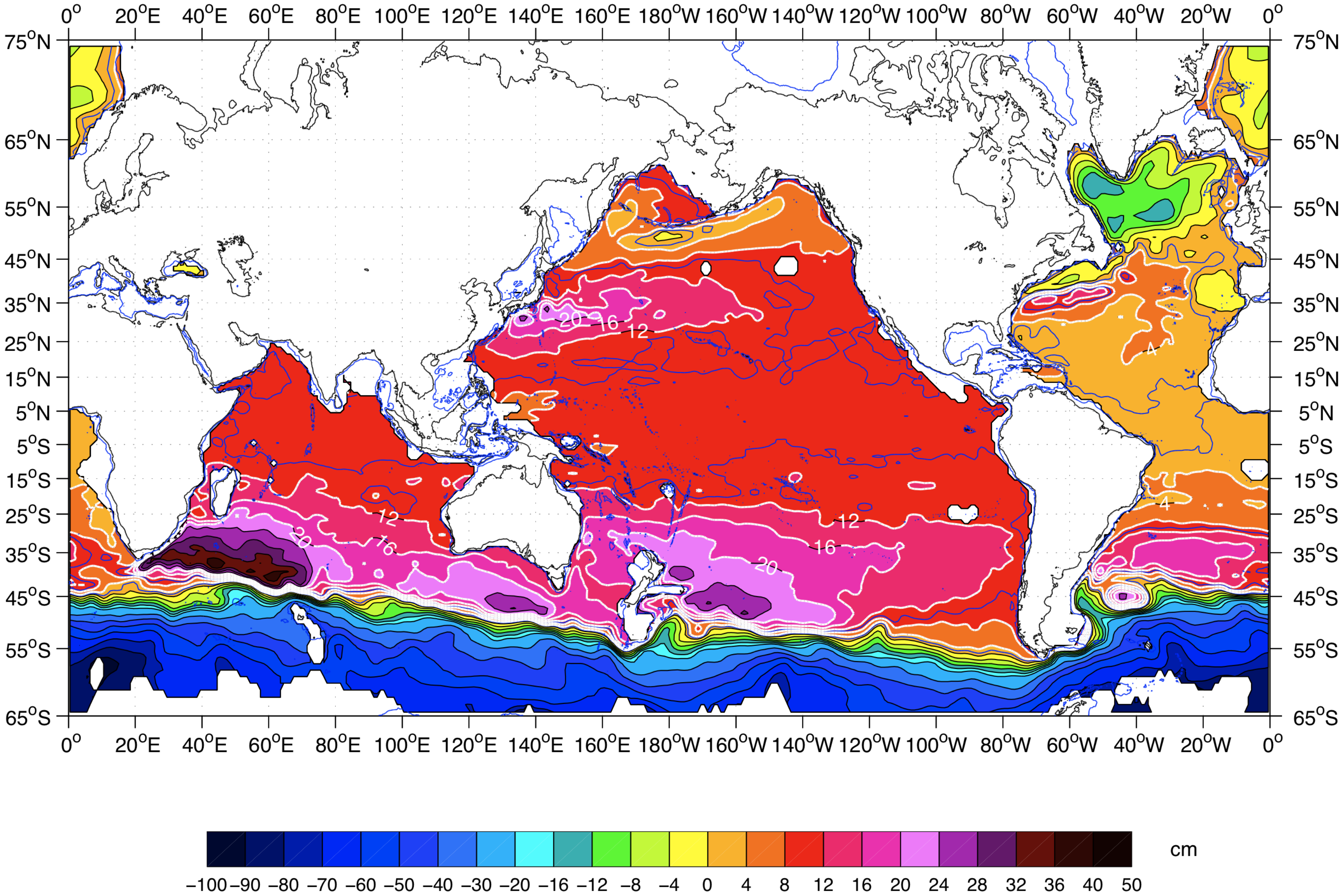
Inversion of the first Laplacian

$$\partial_{\lambda\lambda}\Phi + \partial_{\theta\theta}\Phi = a\,[\partial_{\lambda} fv \cos\theta - \partial_{\theta} fu]$$

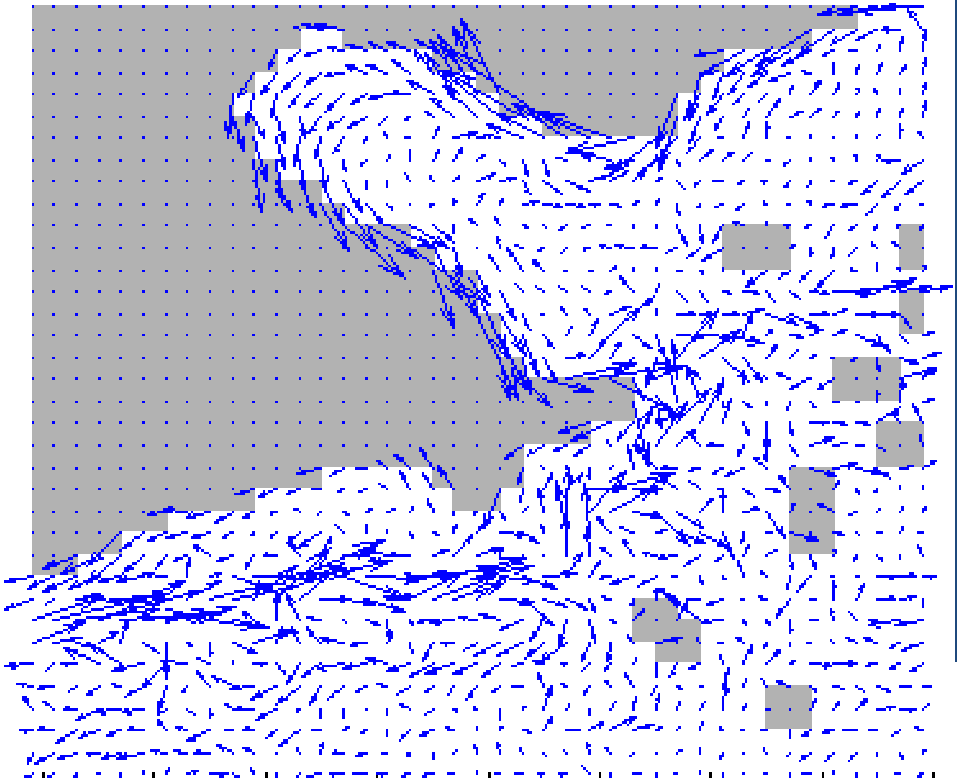
with Neuman BC: $\partial_n \Phi = f\, u_{//}$ at solid boundaries

Geopotential [cm] near 1000 db

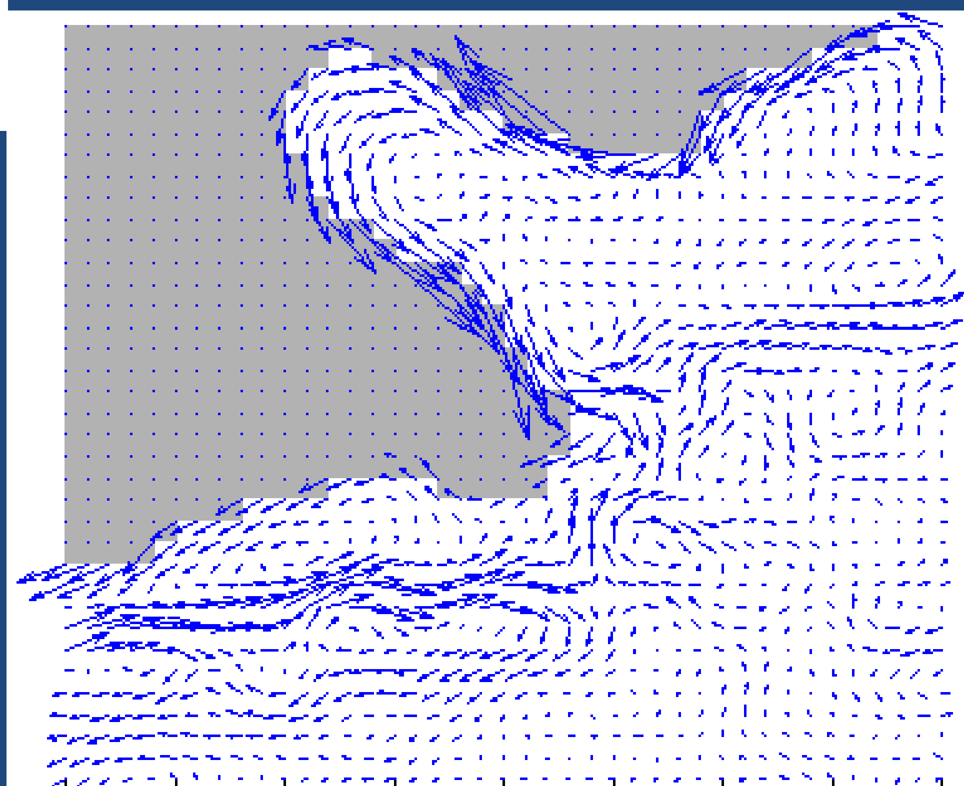
Ollitrault, Colin de Verdiere, 2014



Gulf Stream extension



Before

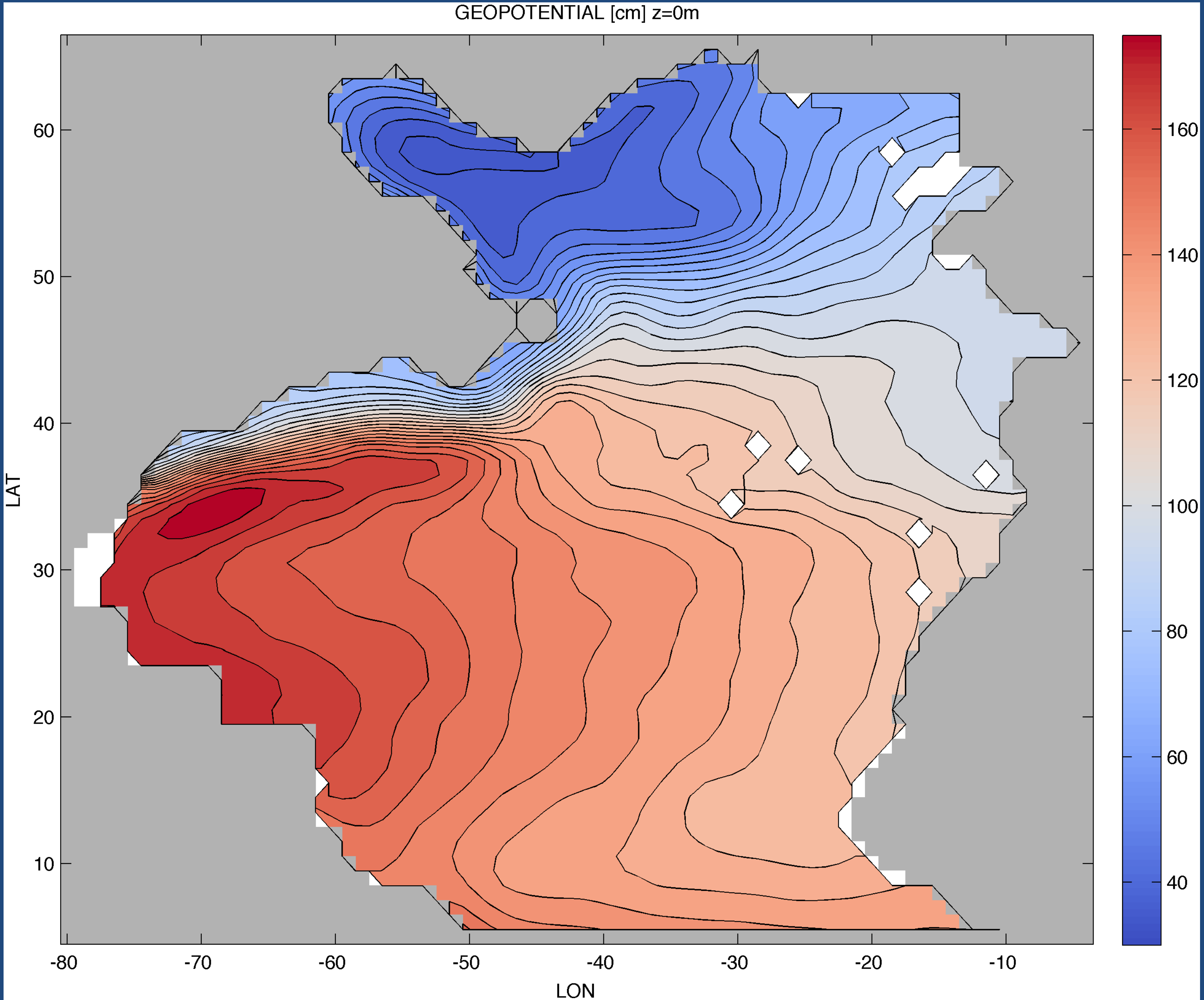


After

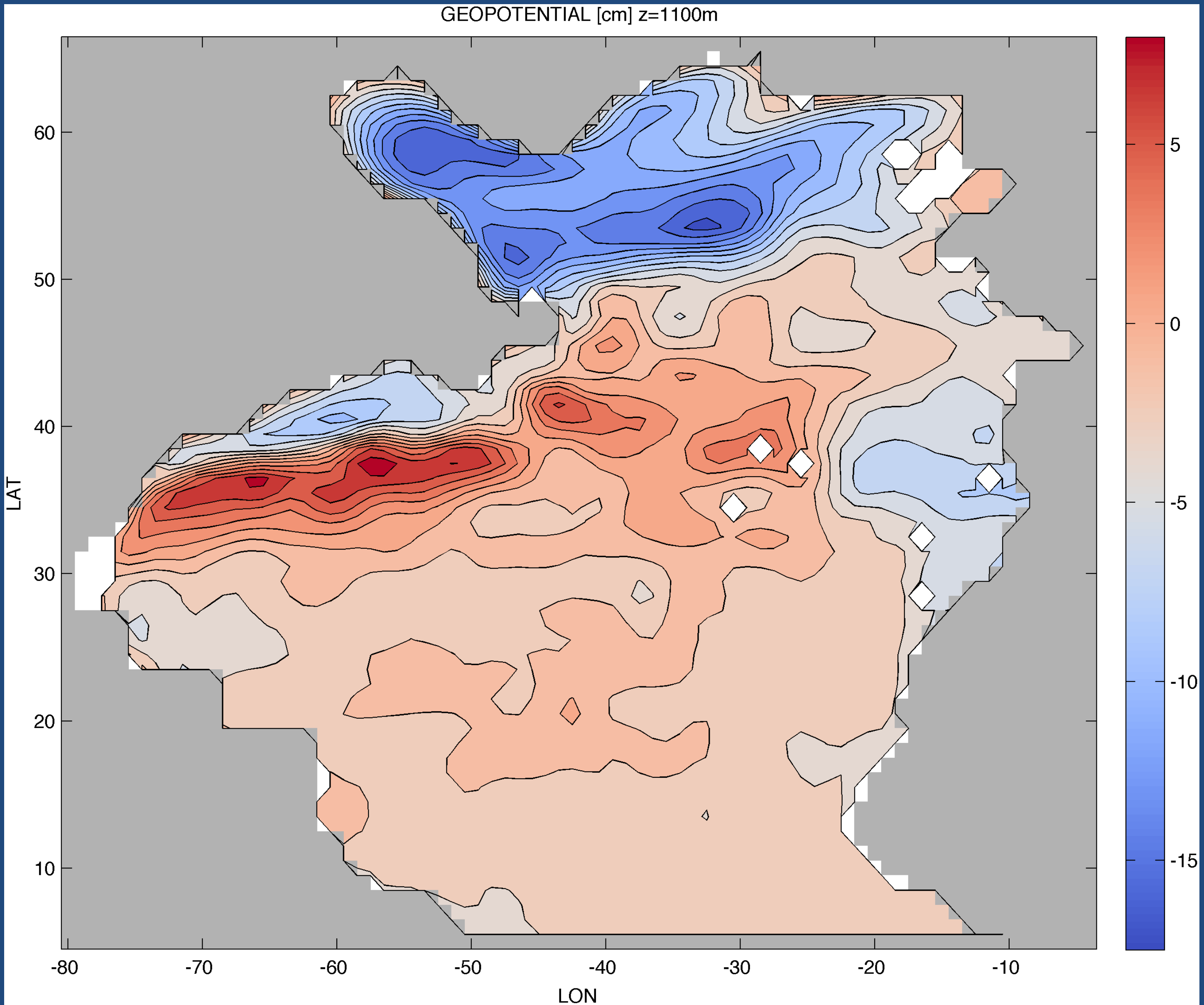
Once Φ is known at a pressure $p_{R,}$
Φ is known everywhere from hydrostatics with T, S from WOA 2009:

$$\partial\Phi / \partial p = - 1/\rho$$

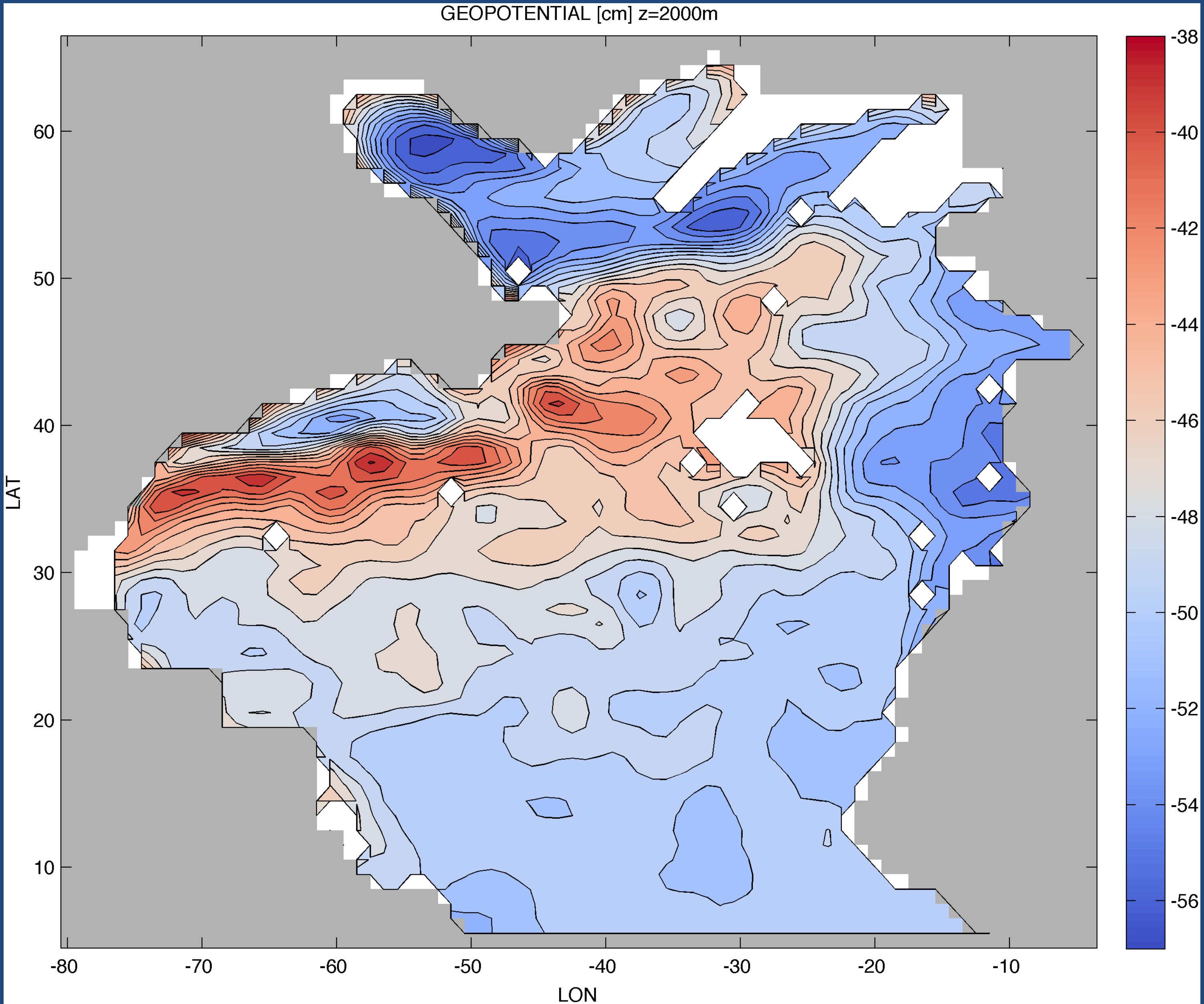
Geopotential surface



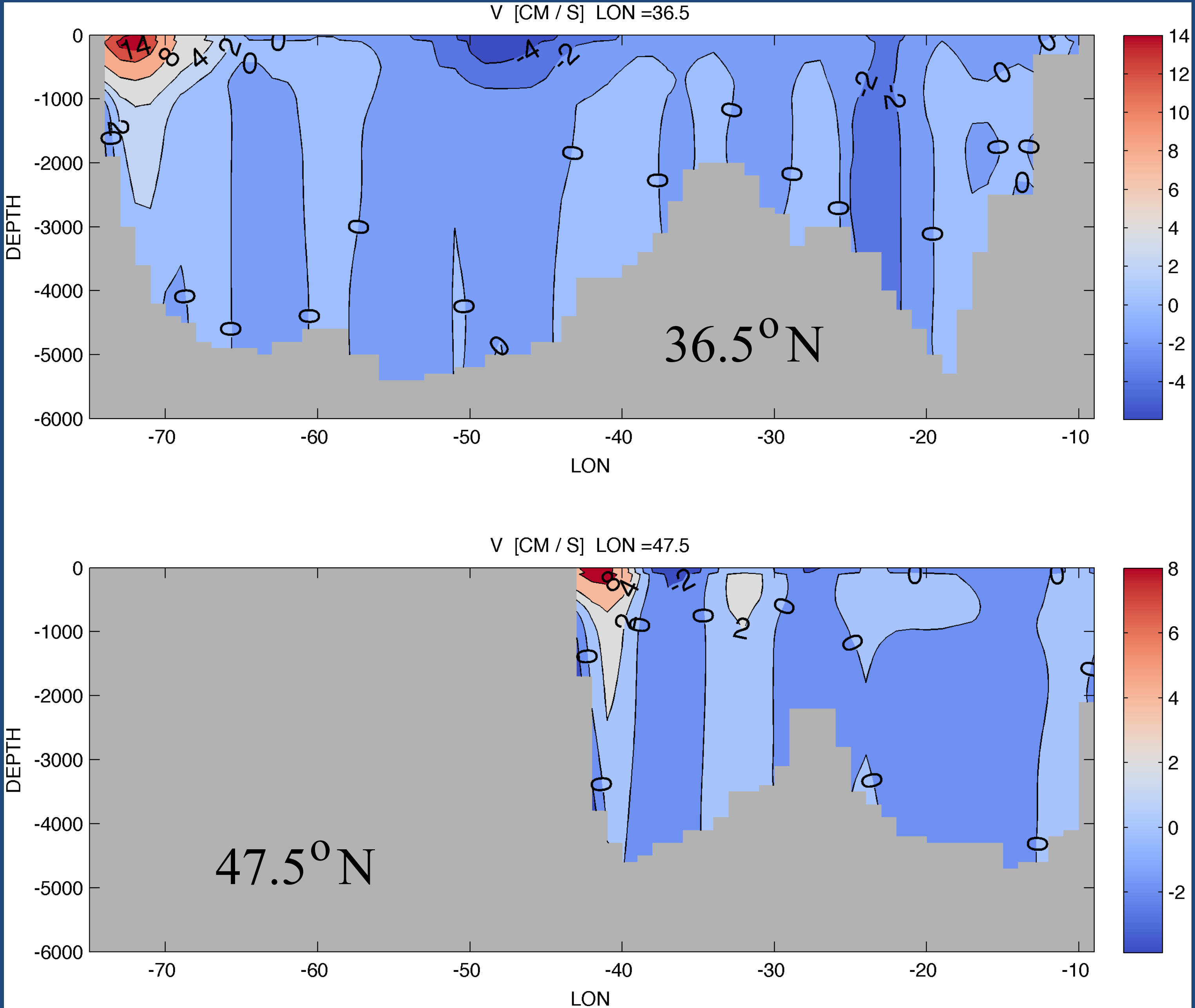
Geopotential 1100m



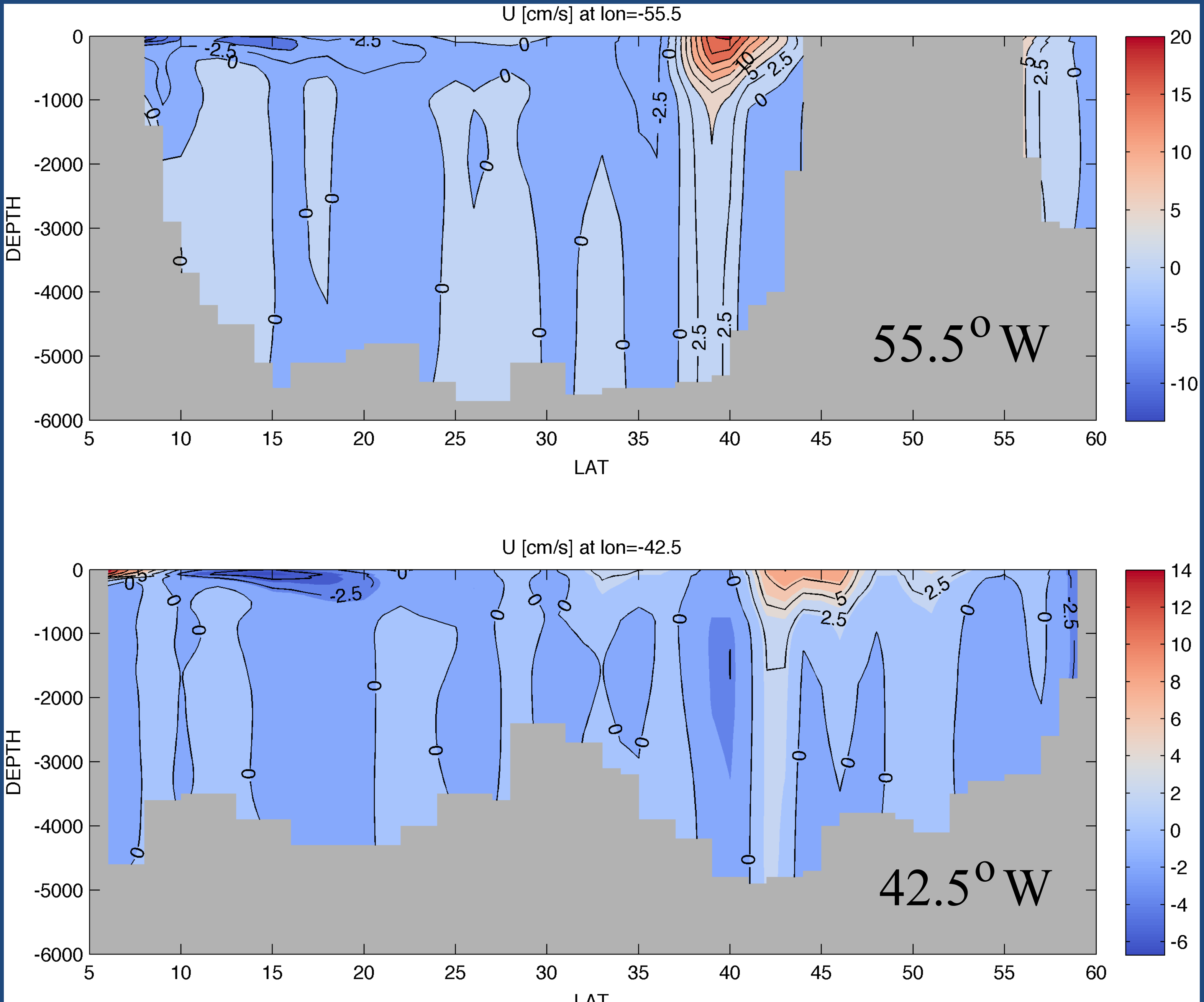
Geopotential 2000m

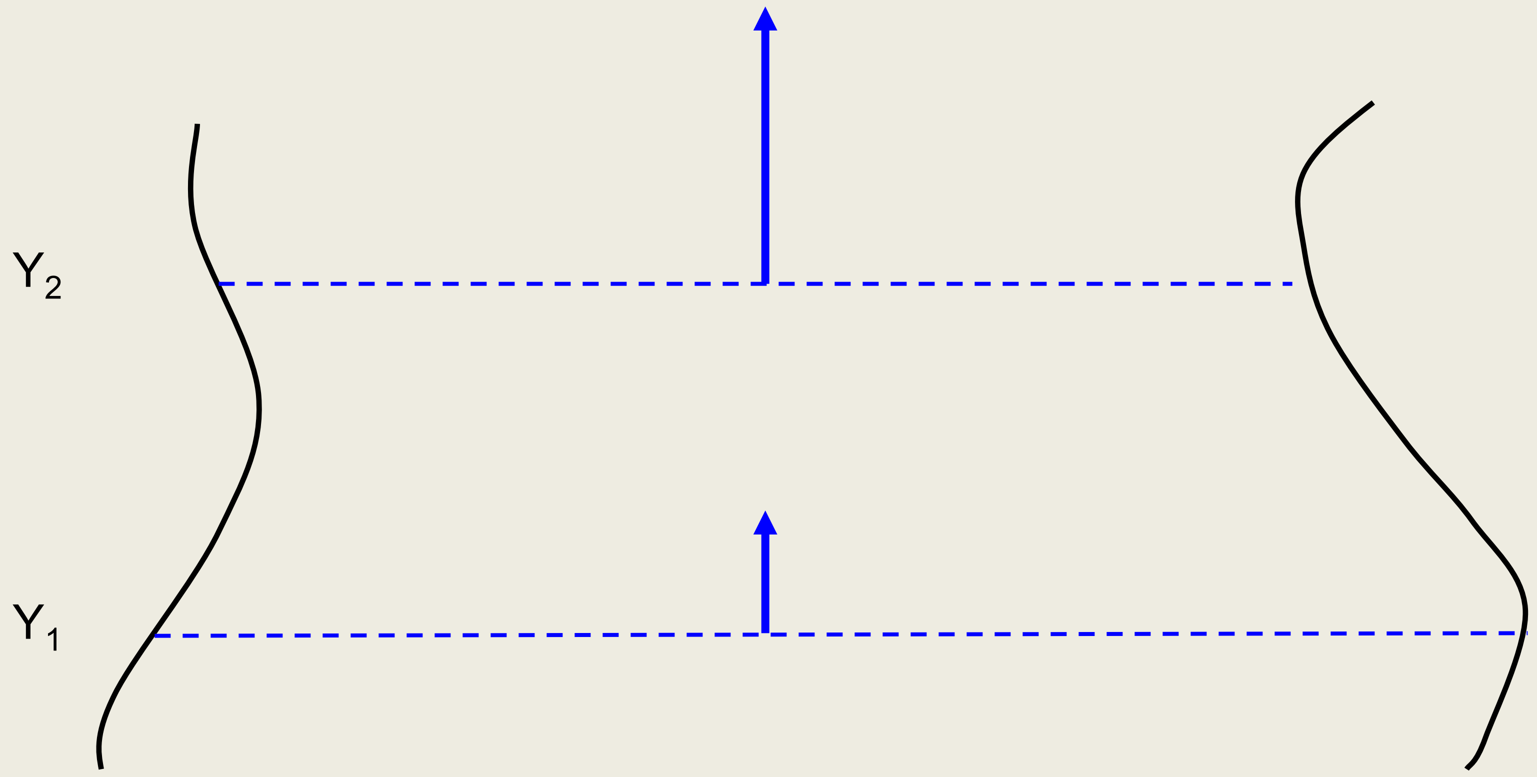


The V velocity



The U velocity





Requirements:

$$\iint V \, dxdz \equiv 0 \quad \text{at} \quad Y_1 \quad \text{and} \quad Y_2$$

How to get the overturning?

Across a zonal section, require that:

$$\iint V \, dxdz = 0$$

$$V = V_G + V_{Ek}$$

$$V = \frac{V^+}{H} + V^- \qquad \text{where:}$$

$$V^+ = \int_{-H}^{0} V \, dz \text{ is the barotropic transport}$$

$$V^- = V - \frac{1}{H}\int_{-H}^{0} V \, dz \text{ is the baroclinic velocity}$$

The barotropic circulation

- required for heat transport
- test of the Sverdrup relation
- end state of turbulence cascade

$$\mathbf{U}^{+} = \int (\mathbf{U}_{G} + \mathbf{U}_{ekman})\, dz$$

to conserve mass, $\nabla . \mathbf{U}^{+}$ must be 0

but it is not 0…

A second inversion

Write:

$u^+ = -1/a \partial_\theta \Psi \qquad v^+ = 1/a \cos\theta \, \partial_\lambda \Psi$

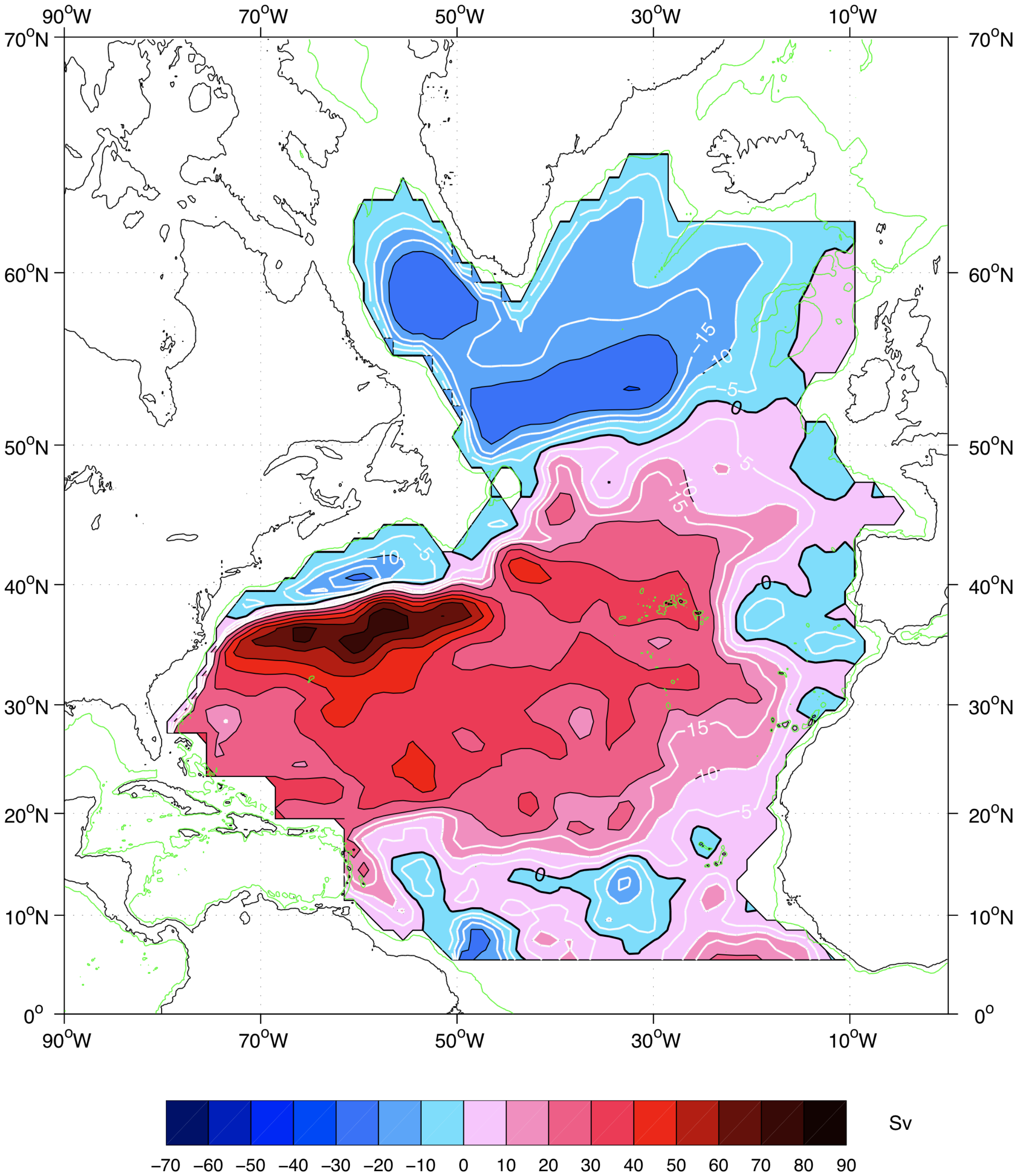
then:

$$\nabla^2 \Psi = a \left[\partial_\lambda v^+ \cos\theta - \partial_\theta u^+\right]$$

relative vorticity

On solid boundaries:

Dirichlet BC: $\mathbf{u^+.n} = 0$ or Ψ = constant



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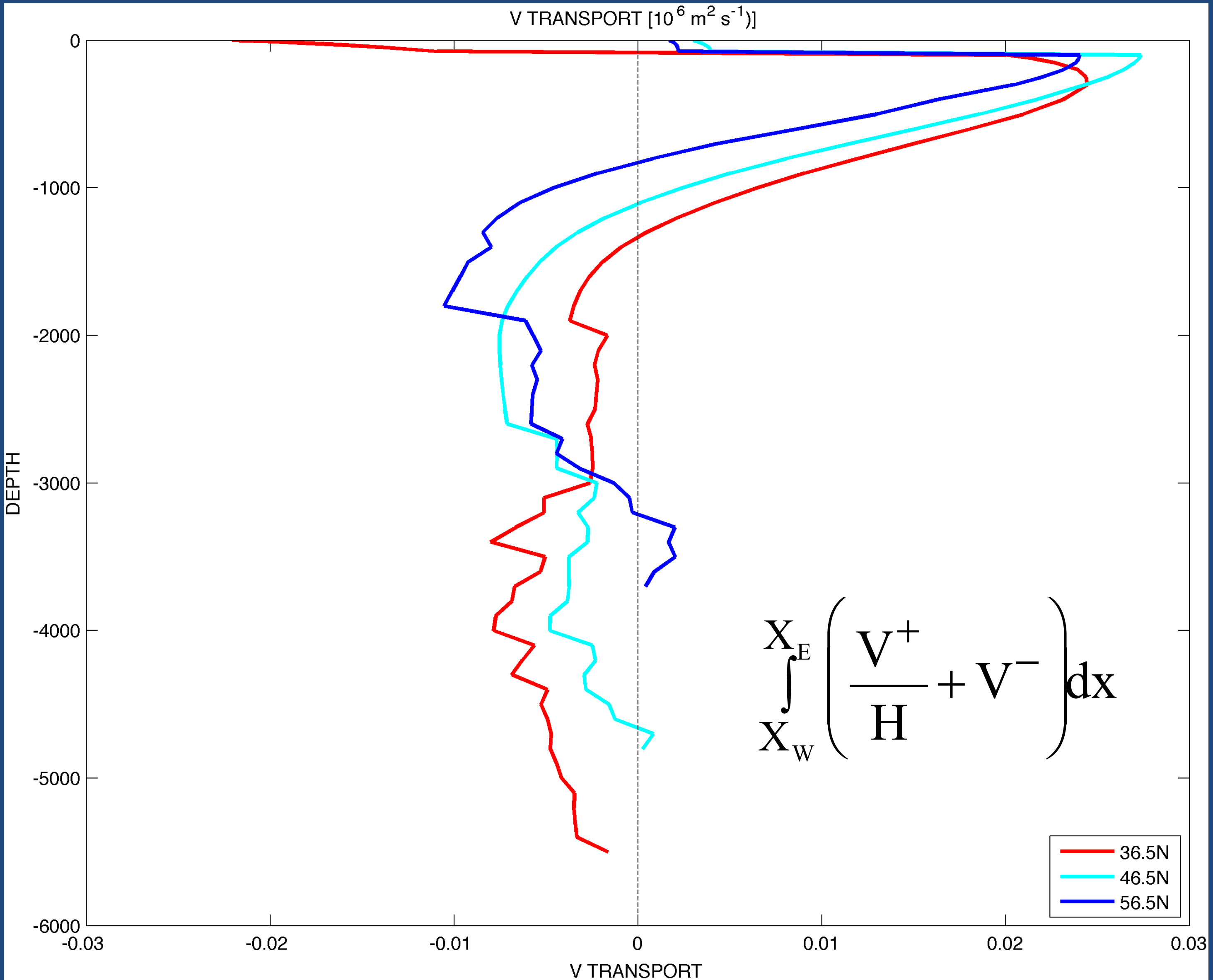
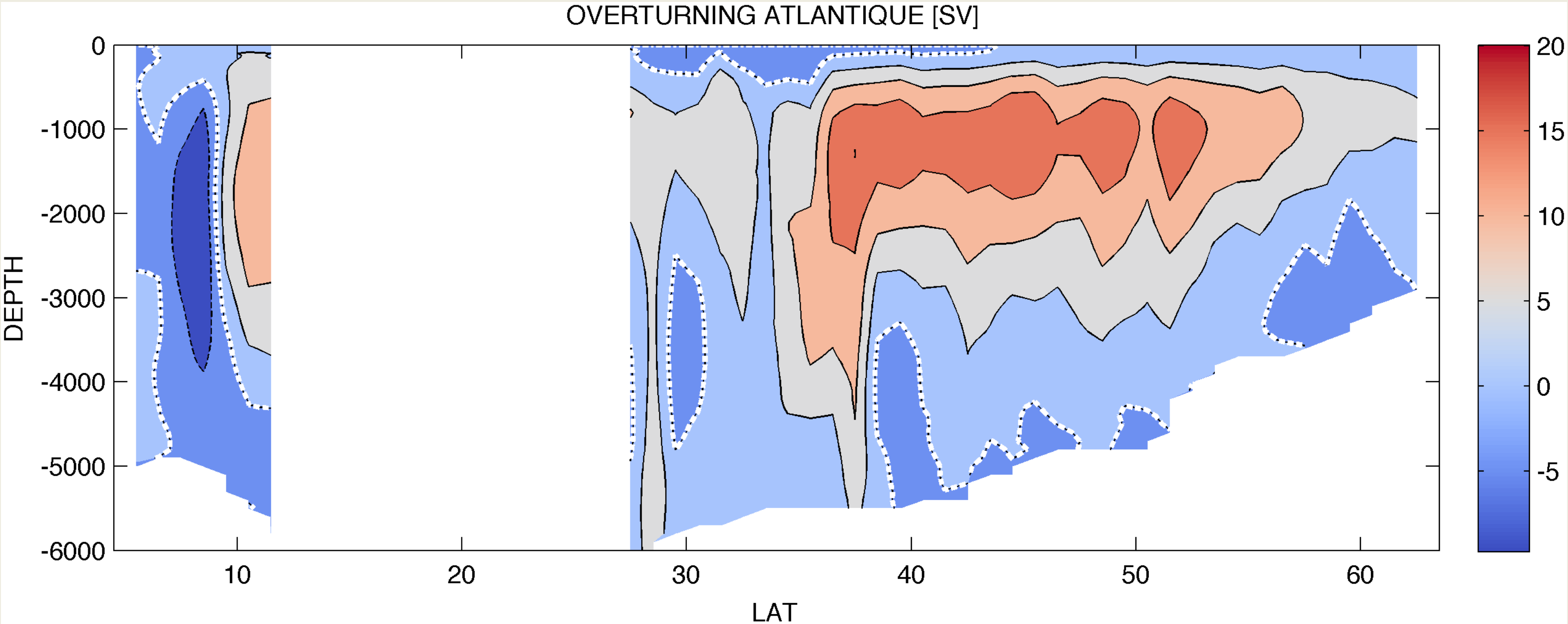
Meridional transport

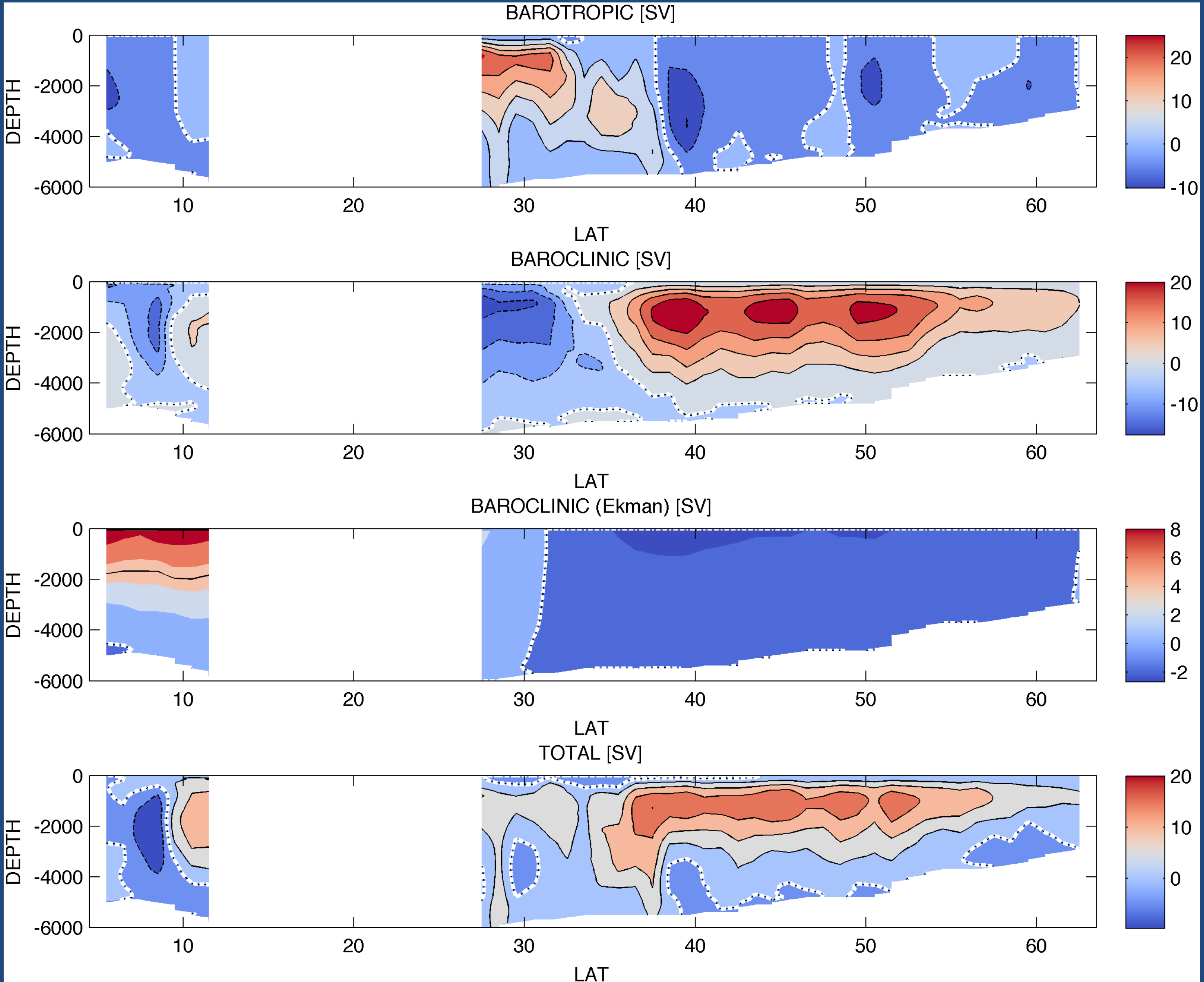


The Overturning

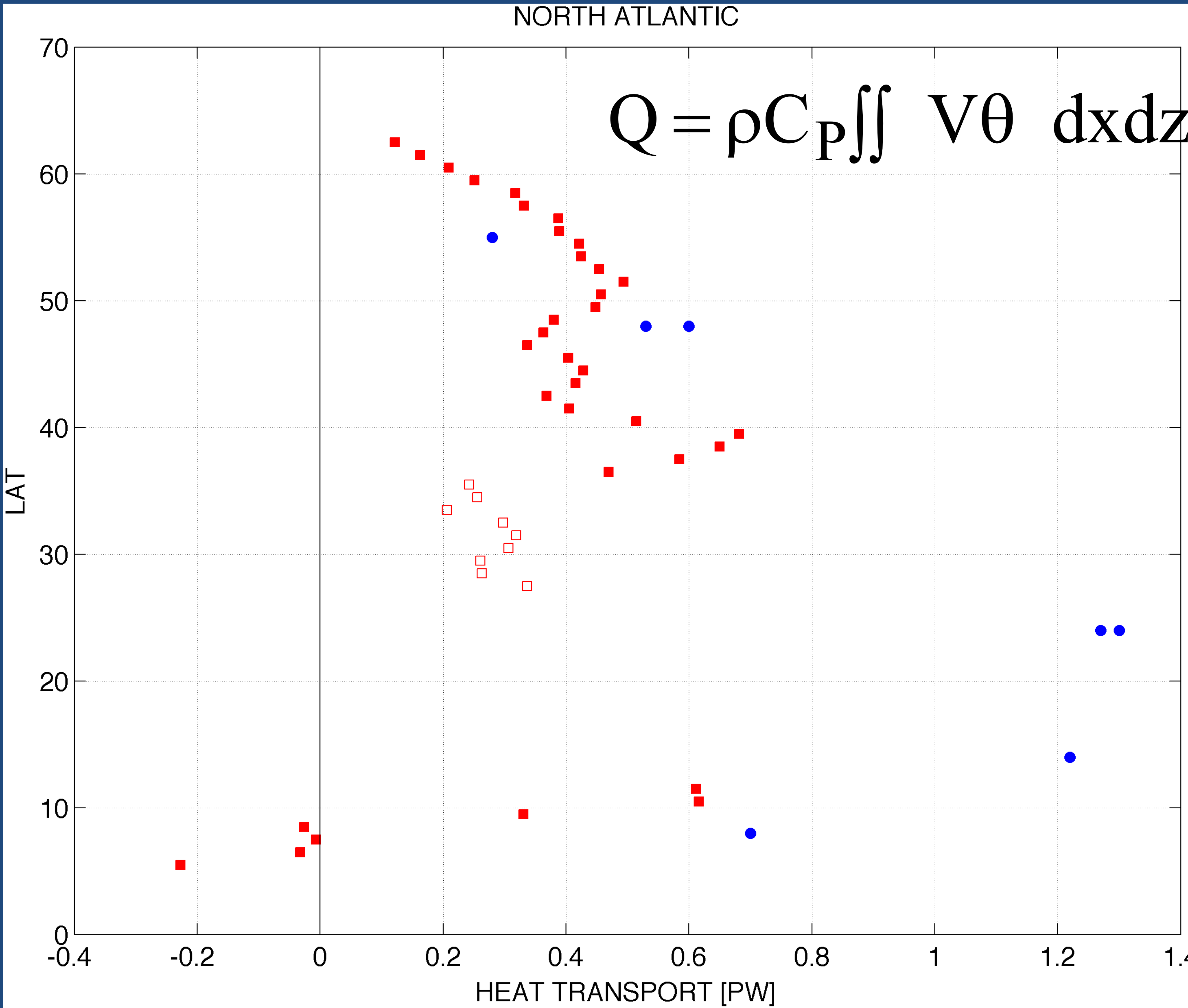
$$\psi_{\text{overturning}} = -\int_{-H}^{z} \left[\int_{x_W}^{x_E} V\,dx \right] dz$$



Various contributions



Meridional heat fluxes



$$Q = \rho C_P \iint V\theta \, dxdz$$

Meridional Heat Fluxes: baroclinic, barotropic, Ekman contributions