Ocean General Circulation observed with Argo and WOA09

A descriptive view

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The ANDRO dataset

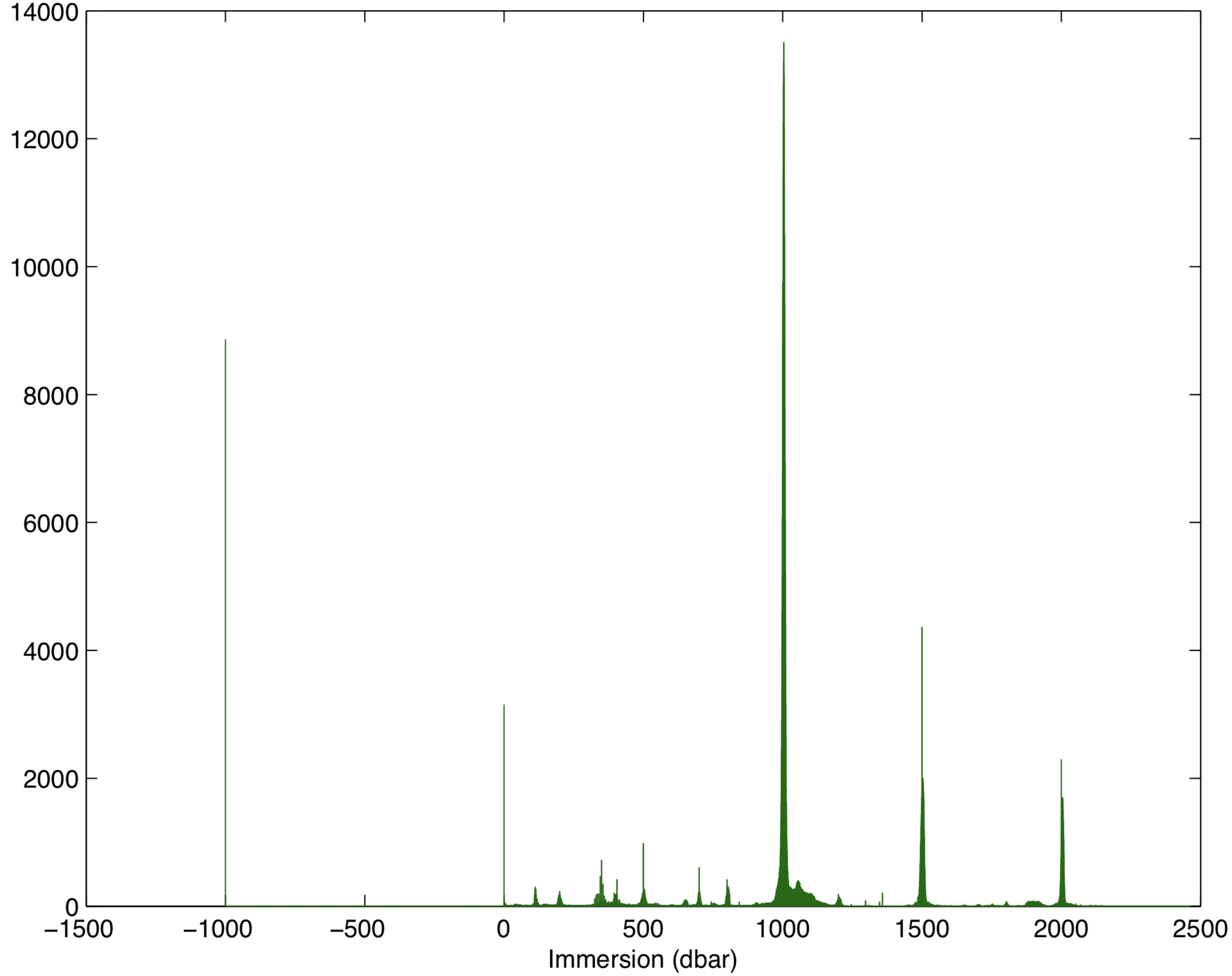
- Reprocessing of the Argo float data collected before January 1 2010
- Pressure measured during the parking phase is preserved
- Grounded cycles are excluded
- 5936 floats and 535472 displacements
- 65% of the displacements are in the [950,1150] dbar layer
- ANDRO is available (freely) at

http://wwz.ifremer.fr/lpo/Produits/ANDRO/

Ollitrault, M. & Rannou, J.-P. (2013) ANDRO: An Argo-based deep displacement dataset. Journal of Atmos. Ocean. Technology

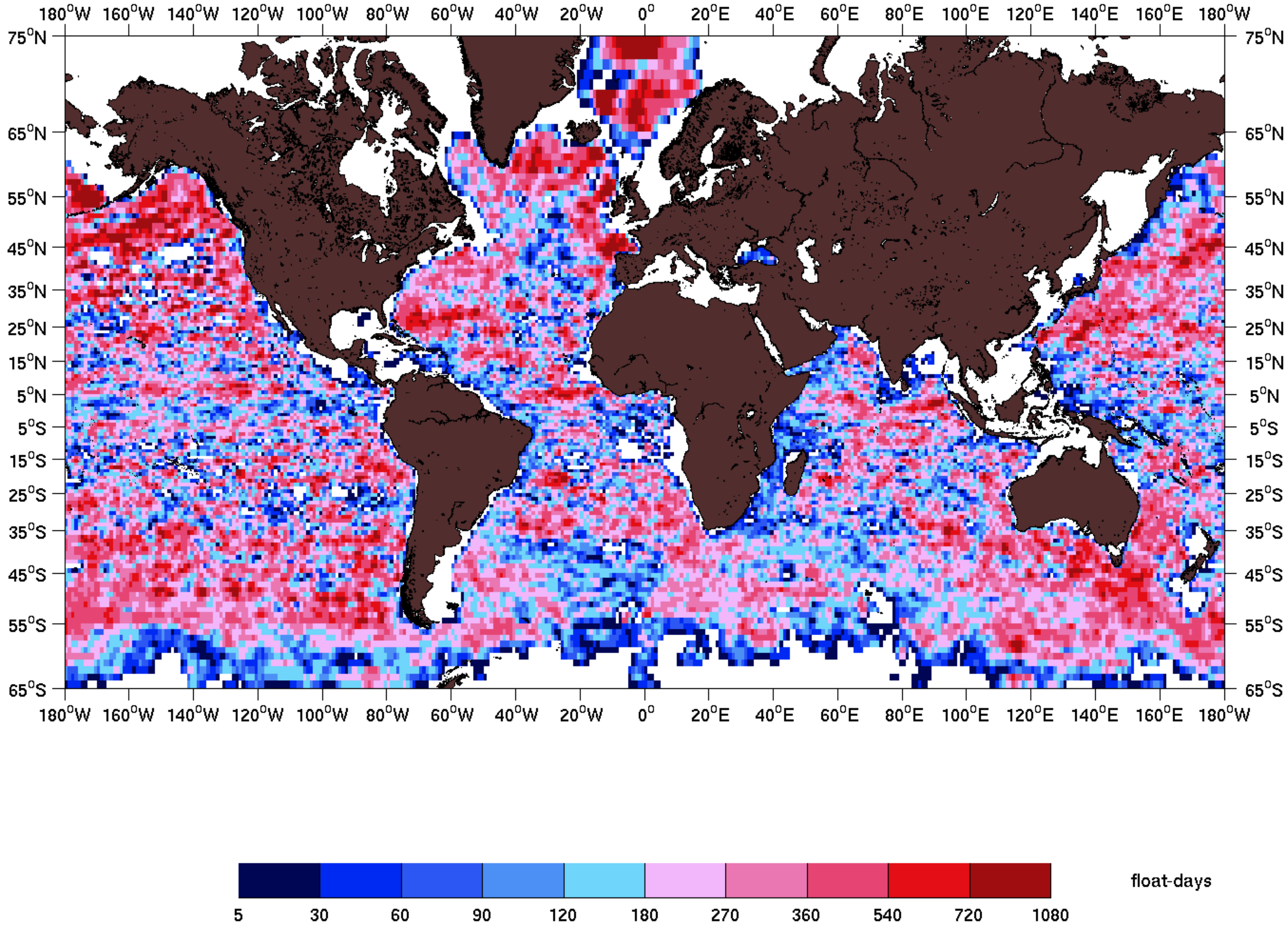
(can be downloaded from the LPO site)

ANDRO displacement depth repartition

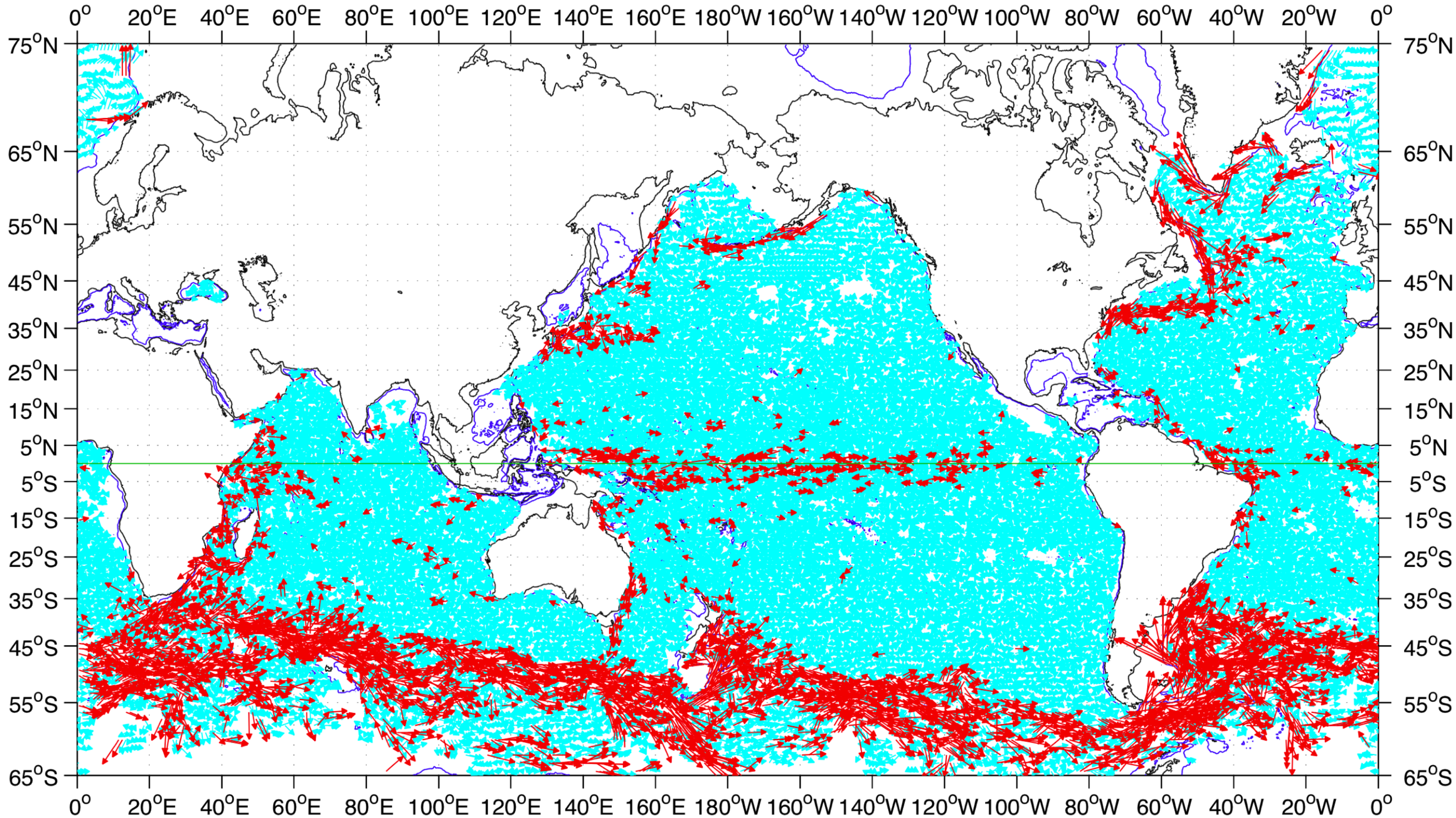


Ollitrault, M. & Rannou, J.-P. (2013) ANDRO: An Argo-based deep displacement dataset. Journal of Atmos. Ocean. Technology

Argo float-days in [950,1150] dbar layer

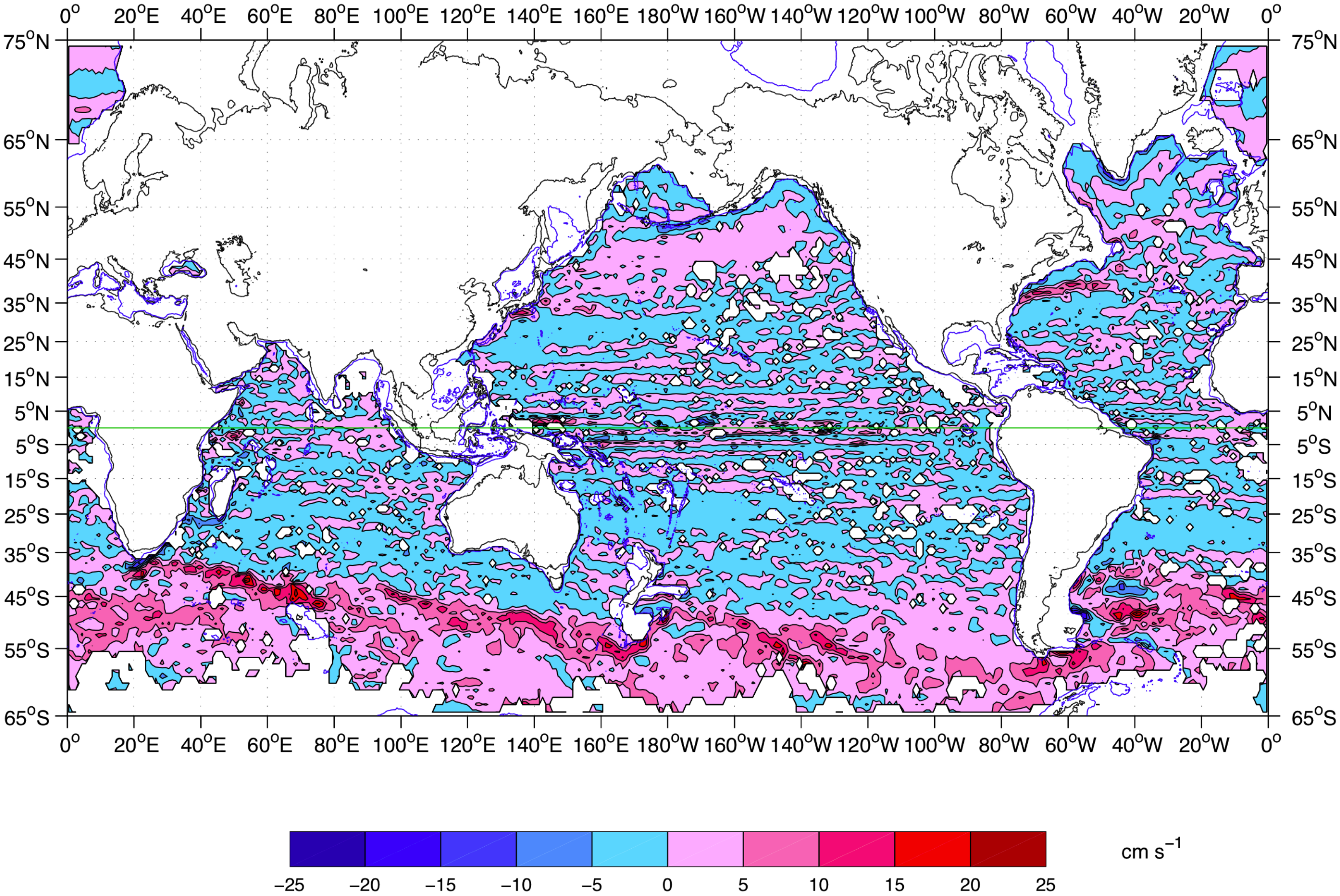


Mean currents near 1000 m depth, 60-day displacements (red if speed > 5 cm s^{-1})



Ollitrault & Colin de Verdière (2013) The Ocean general circulation near 1000 m depth. Journal Phys. Oceanography (under review)

Mean zonal component near 1000 m depth



Ollitrault & Colin de Verdière (2013) The Ocean general circulation near 1000 m depth. Journal Phys. Oceanography (under review)

Mean currents near 1000 m

- Averages over 150 km diameter discs
- ACC is the strongest mean current near 1000 m depth
- Many (mainly) western boundary currents are still strong: Agulhas, East Madagascar, East Australian, Falkland (southern hemisphere),

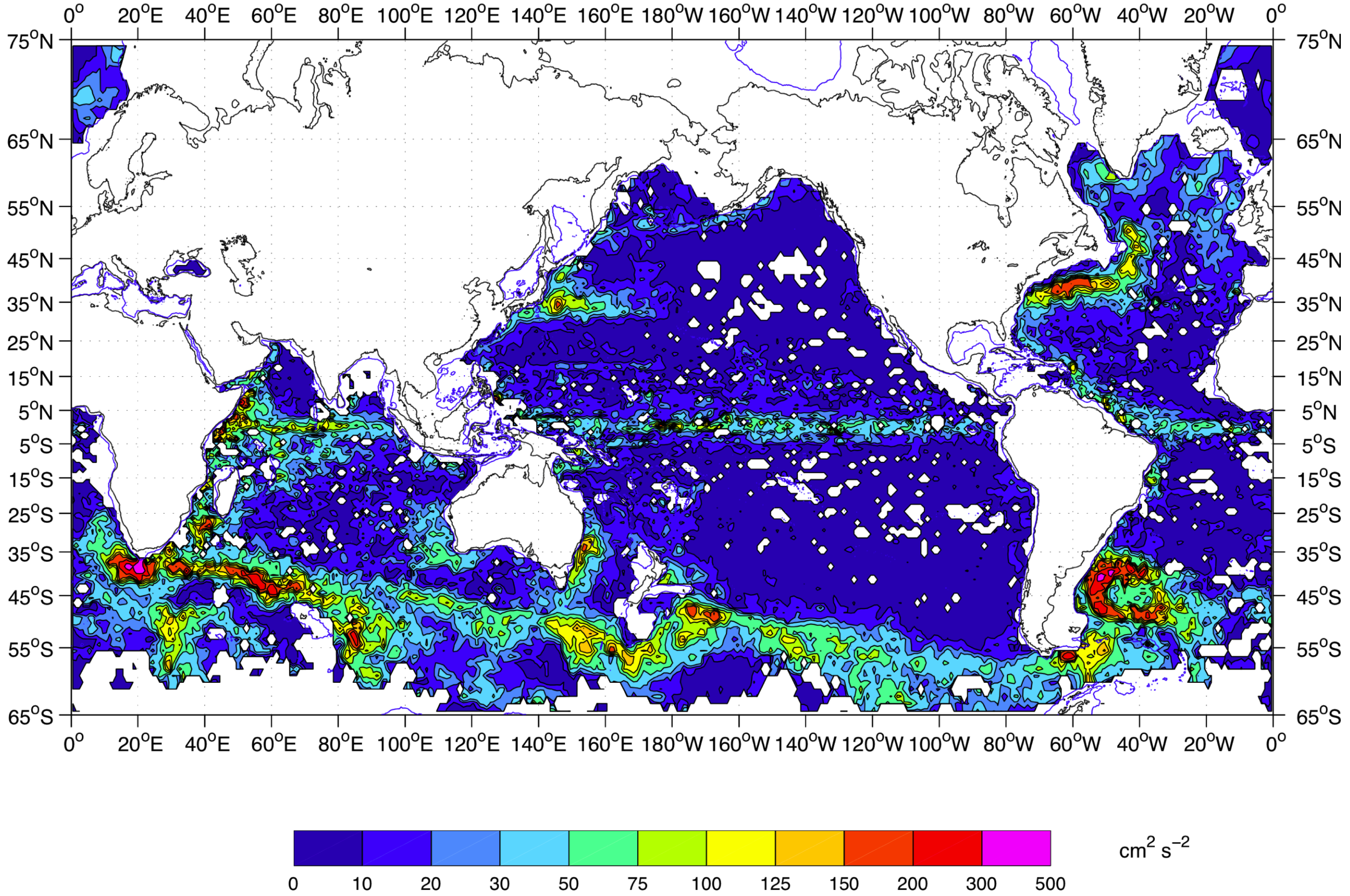
  Kuroshio, Oyashio, East Kamchatka, Alaska Stream, Gulf Stream, Labrador, East and West Greenland (northern hemisphere).
- Alternate zonal bands of the mean zonal component, between 20°S and 20°N (best marked in the Pacific)

Cravatte, S., Kessler,W. & Marin, F. (2012) Zonal jets in the tropical Pacific ocean observed by Argo floats. Journal of Phys. Ocean.

Ollitrault, M. et al. (2006) Zonal intermediate currents in the equatorial Atlantic ocean. Geophys. Res. Letters

Ollitrault & Colin de Verdière (2013) The Ocean general circulation near 1000 m depth. Journal Phys. Oceanography (under review)

EKE near 1000 m depth



Ollitrault & Colin de Verdière (2013) The Ocean general circulation near 1000 m depth. Journal Phys. Oceanography (under review)

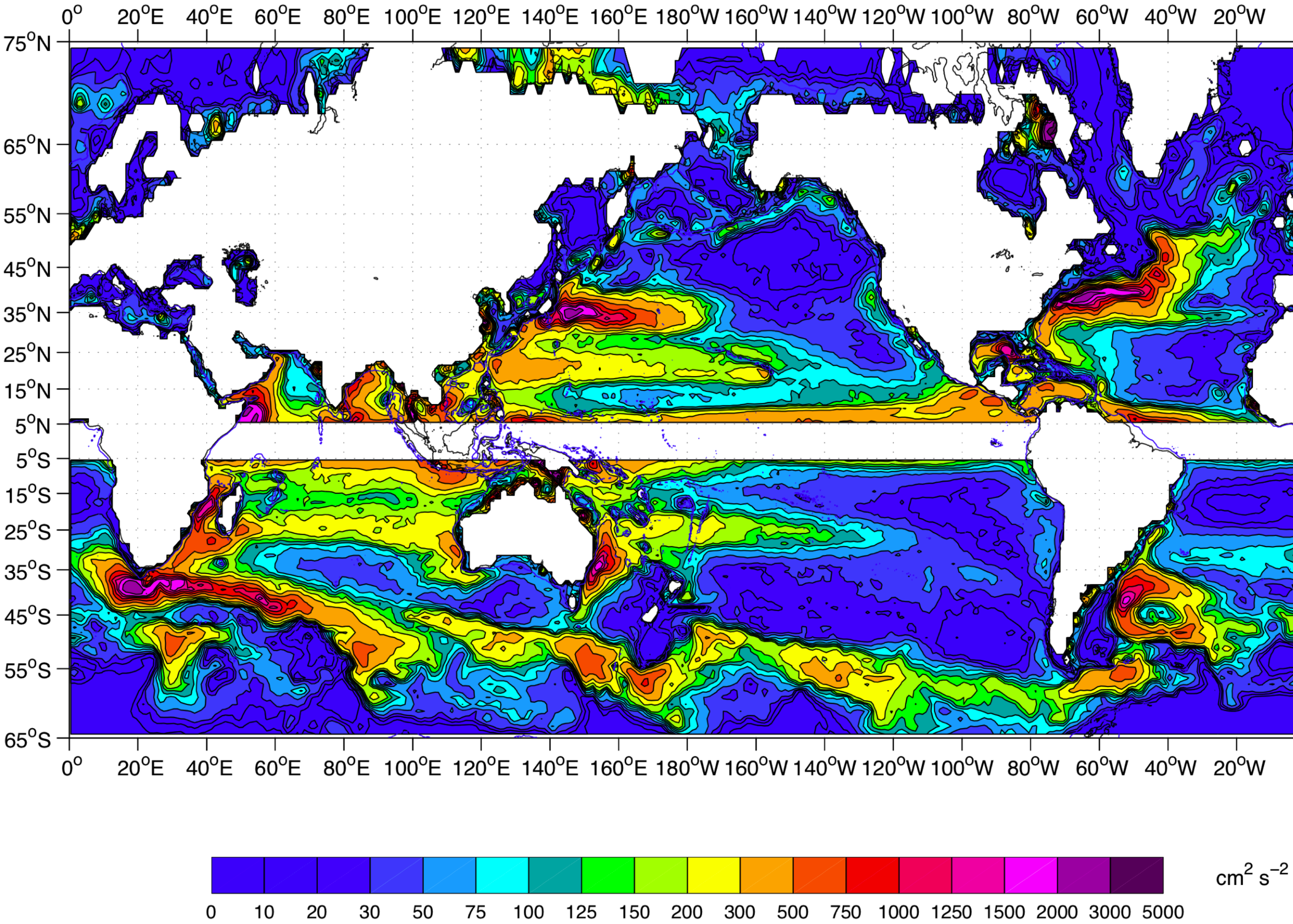
Eddy kinetic energy near 1000 m depth

- Highest values in the retroflexion, south of Cape Town and the Confluence region east of Mar del Plata (300 $cm^2\ s^{-2}$).
- Boundary currents associated with high EKE.

  Exceptions: Labrador, East Greenland and the current loop in the Bounty trough.
- Within a few degrees of equator, EKE is O(50 $cm^2\ s^{-2}$)
- Over most of the ocean interior , EKE is O(10 $cm^2\ s^{-2}$)

  Taking 10 days as Lagrangian time scale, we would need 1000 float-days to reach a 3 mm s^{-1} error on the mean current. Presently, only 2/3 of the discs have more than 6 months of data.
- Altimetric surface EKE (provided by CLS) shows very similar patterns (although with a factor of order of 10). Exceptions: strong surface variability in the Indian ocean, south and north equatorial currents in the western Pacific. Baroclinicity confirmed by $EKE_{surf}/EKE_{1000} > 30$

Altimetric surface EKE (courtesy of CLS)



A World reference geostrophic surface

- If geostrophy prevails for the interior mean circulation, except close to the equator and solid boundaries:

$$\rho_0 f v \cos\varphi = \frac{1}{a}\frac{\partial p}{\partial \lambda}, \rho_0 f u = -\frac{1}{a}\frac{\partial p}{\partial \varphi}$$

a is Earth radius, λ and φ the longitude and latitude, ρ_0 is constant.

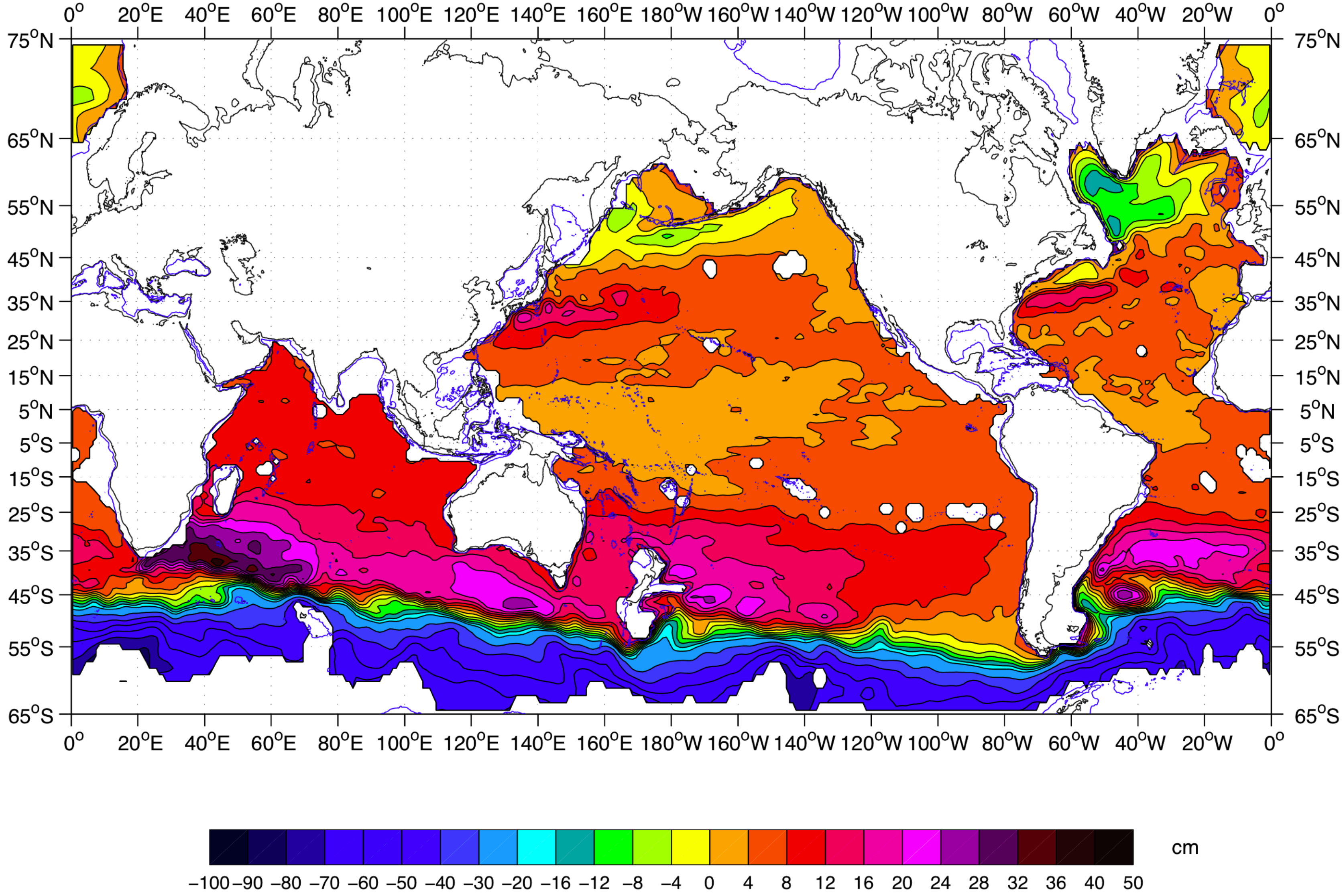
Taking the horizontal divergence, in the rectangular (λ,φ) plane, one obtains:

$$\frac{\partial}{\partial \lambda}(f v \cos\varphi) - \frac{\partial}{\partial \varphi}(f u) = \frac{1}{a}\nabla^2(p/\rho_0)$$

This is a Poisson equation whose solution is obtained as the asymptotic limit of its associated unsteady diffusion equation: (simply add $\frac{1}{a}\frac{\partial}{\partial t}(p/\rho_0)$ on the LHS). Alongshore currents

approximating the normal pressure gradient give the required Neumann boundary conditions.

Geostrophic pressure near 1000 m depth, converted to height in cm

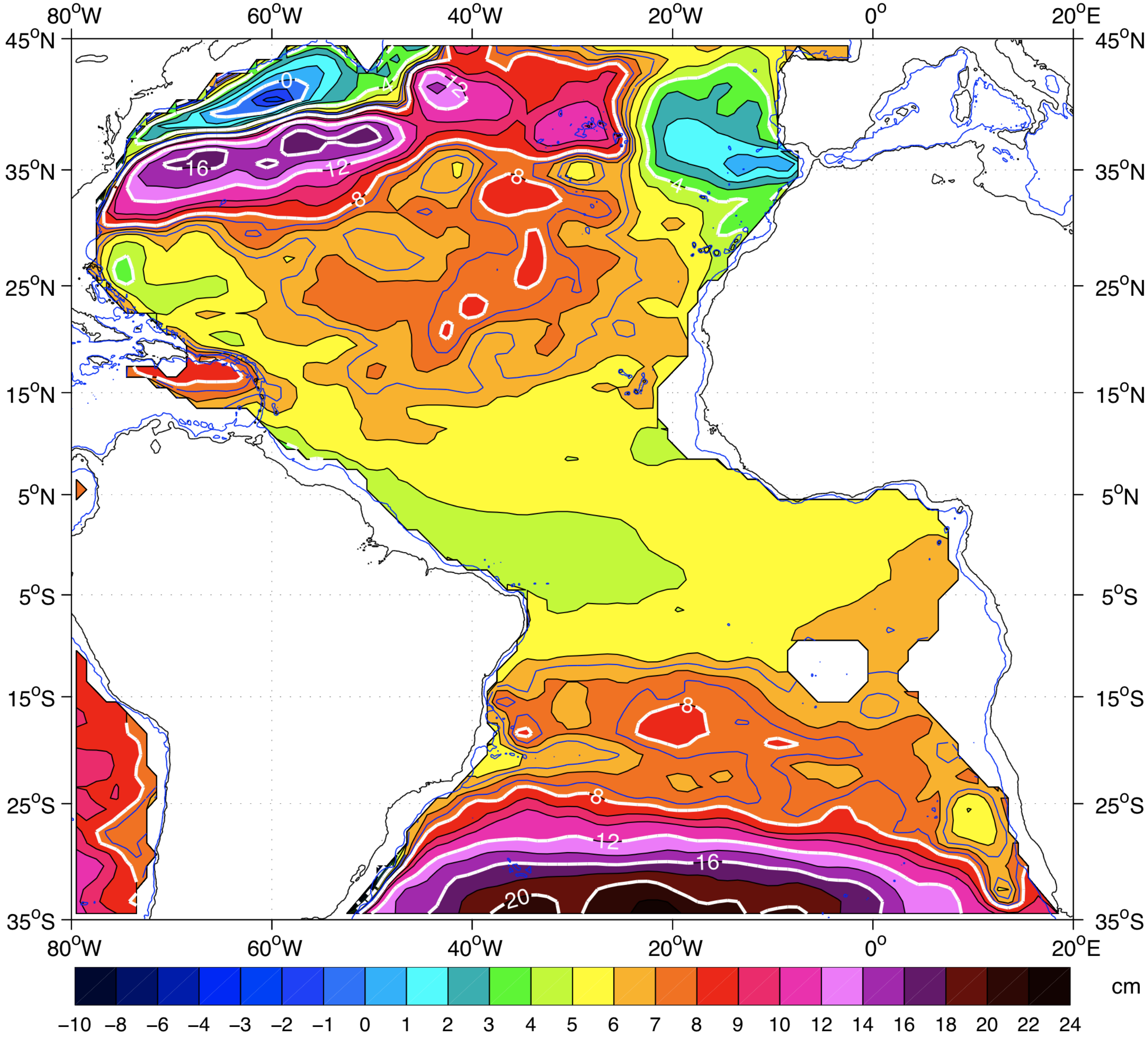


Ollitrault & Colin de Verdière (2013) The Ocean general circulation near 1000 m depth. Journal Phys. Oceanography (under review)

A few results

- ACC stands out with a 50 cm trough poleward
- The Zapiola stationary anticyclonic eddy is a 20 cm bump
- The Atlantic subpolar gyre has also a 20 cm variation in dynamic height
- The Gulf Stream recirculation is only 10 cm higher than the subtropical gyre
- In the southern hemisphere, the subtropical gyres have stronger recirculation gyres in the west (in particular the Agulhas current and retroflexion with some 30 cm variation)
- The equatorial zone is quite flat, which is not surprising since f and thus $f\mathbf{u}$ tend to zero there
- However alternating jets are retrieved in the tropical bands (between 5° and 15°)
- …

Geopotential height (cm) on 1000 dbar



First part conclusions

- The very large Argo data base has allowed the restitution of a realistic mean circulation near 1000 m depth, and the estimation of a geostrophic reference level worldwide.

Details in: Ollitrault & Colin de Verdière (2013) The Ocean general circulation near 1000 m depth. Journal Phys. Ocean. (under review), that can be downloaded from:

ftp://ftp.ifremer.fr/ifremer/lpo/lpotopo/mollitra/

- Absolute mean geostrophic currents over the whole water column can now be obtained, from a climatological hydrography and the reference surface at 1000 dbar.

Geopotentials at other depths

- Under hydrostatic approximation, we have:

$\int_0^p \delta dp = \Phi(0) - \Phi(p)$ where δ is the specific volume anomaly

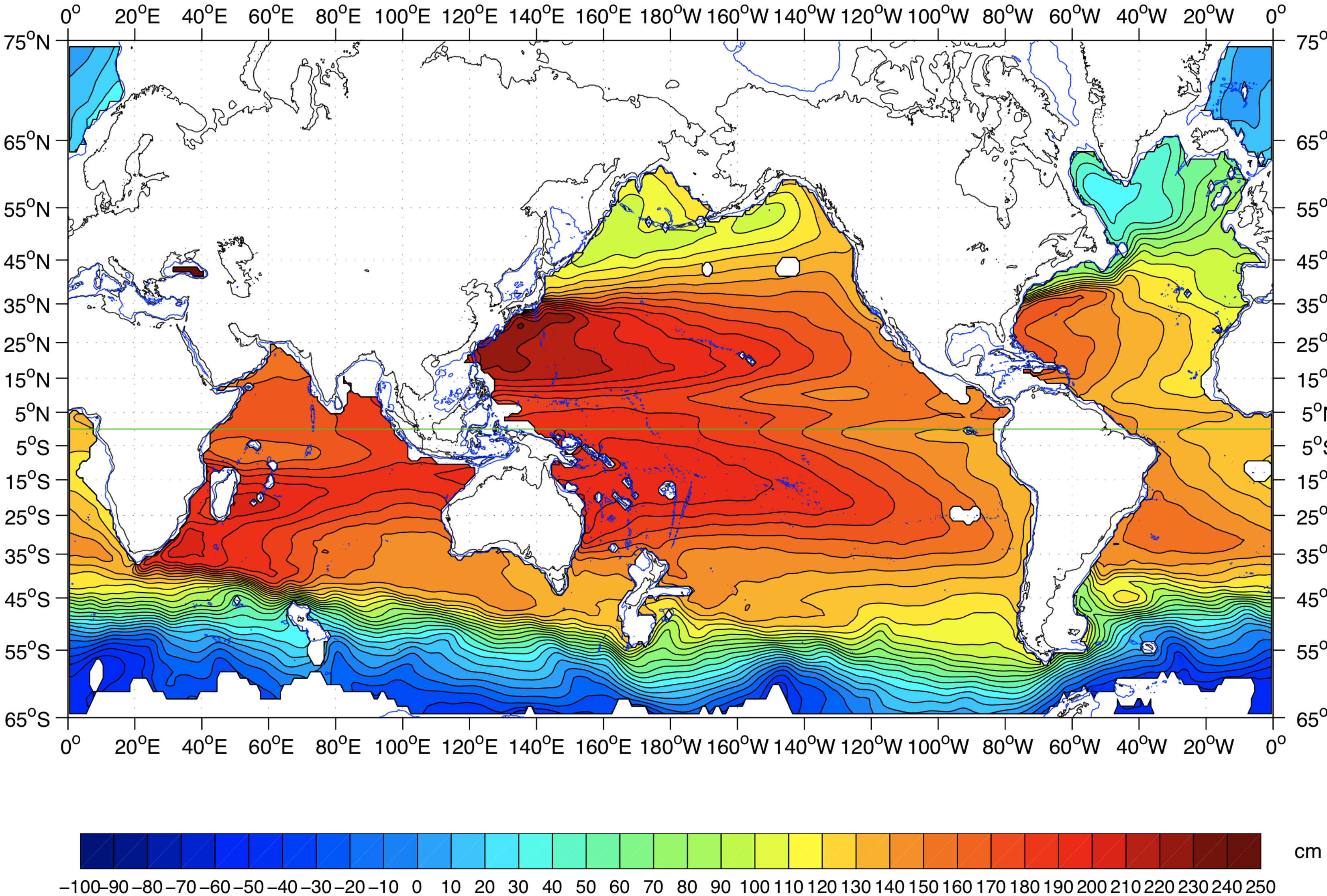
$\Phi(p)$ is the geopotential at *p* dbar.

Knowing $\Phi(1000dbar)$ it is then straightforward to obtain $\Phi(p)$ whatever *p*.

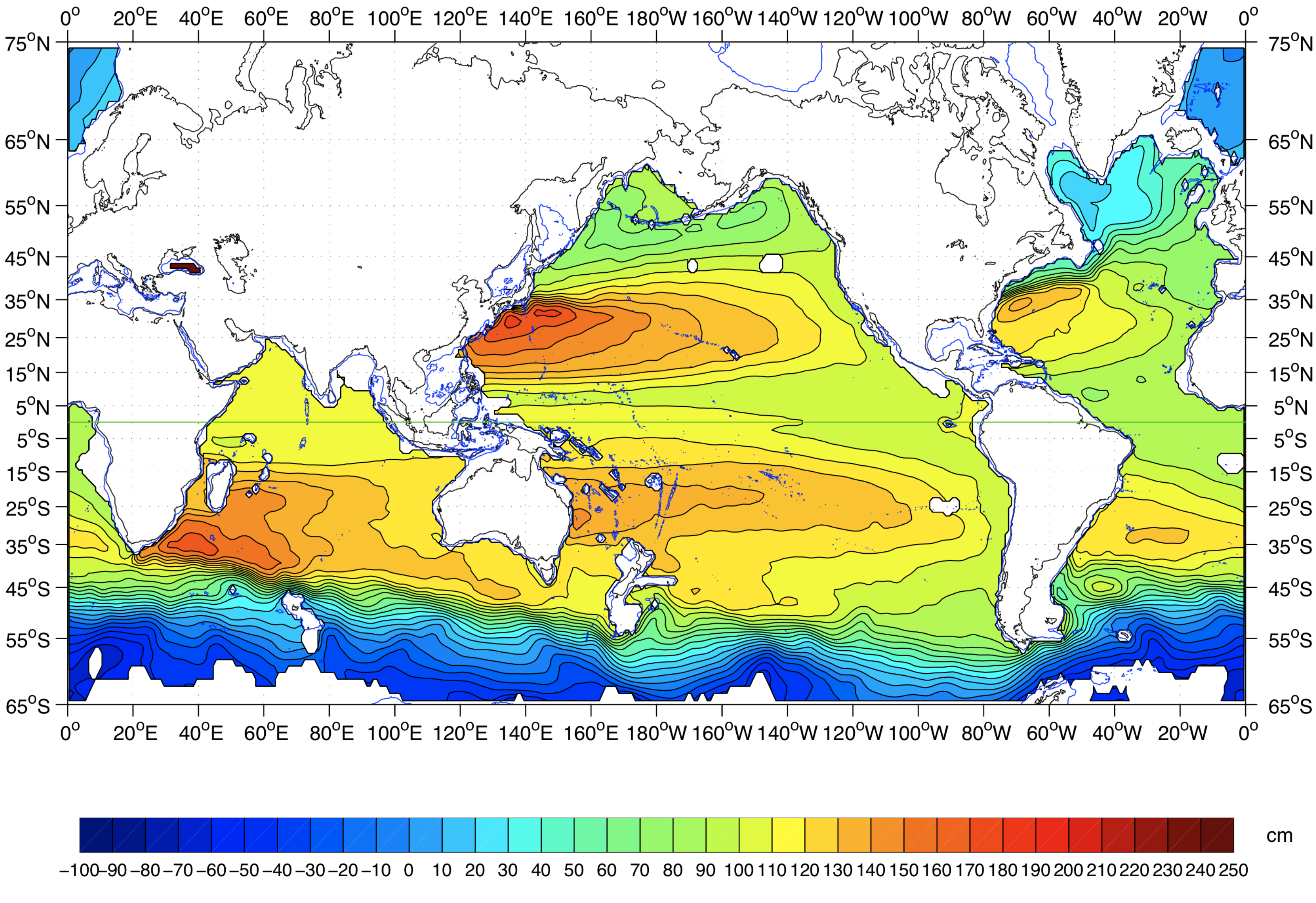
- As a first trial, we have used the WOA09 climatology (with 33 levels on the vertical).
- Geostrophic currents are then estimated readily on each presssure level:

$$-fv = -\frac{1}{a\cos\varphi}\frac{\partial\Phi}{\partial\lambda} \qquad fu = -\frac{1}{a}\frac{\partial\Phi}{\partial\varphi}$$

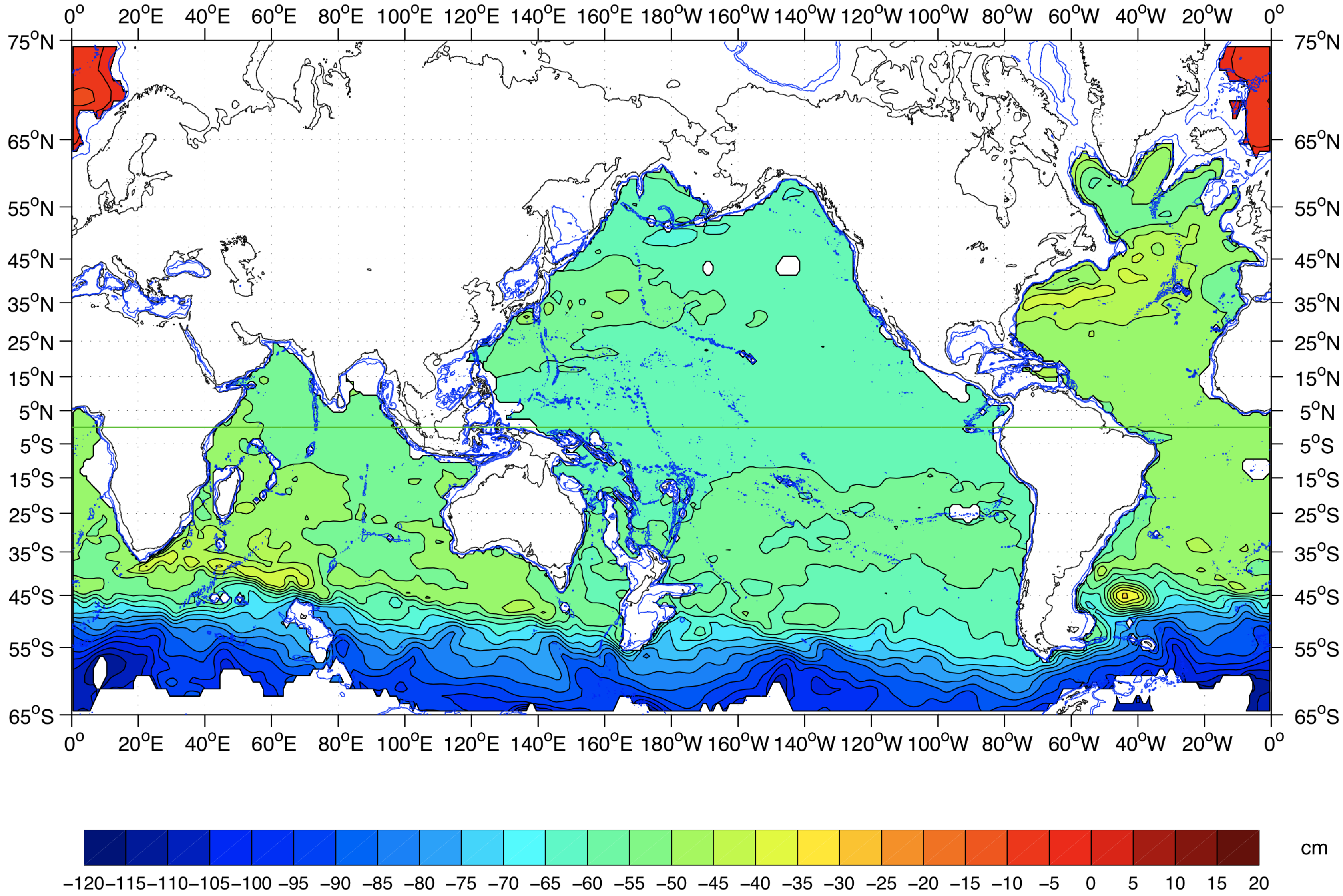
Mean geopotential height (cm) at 0 m



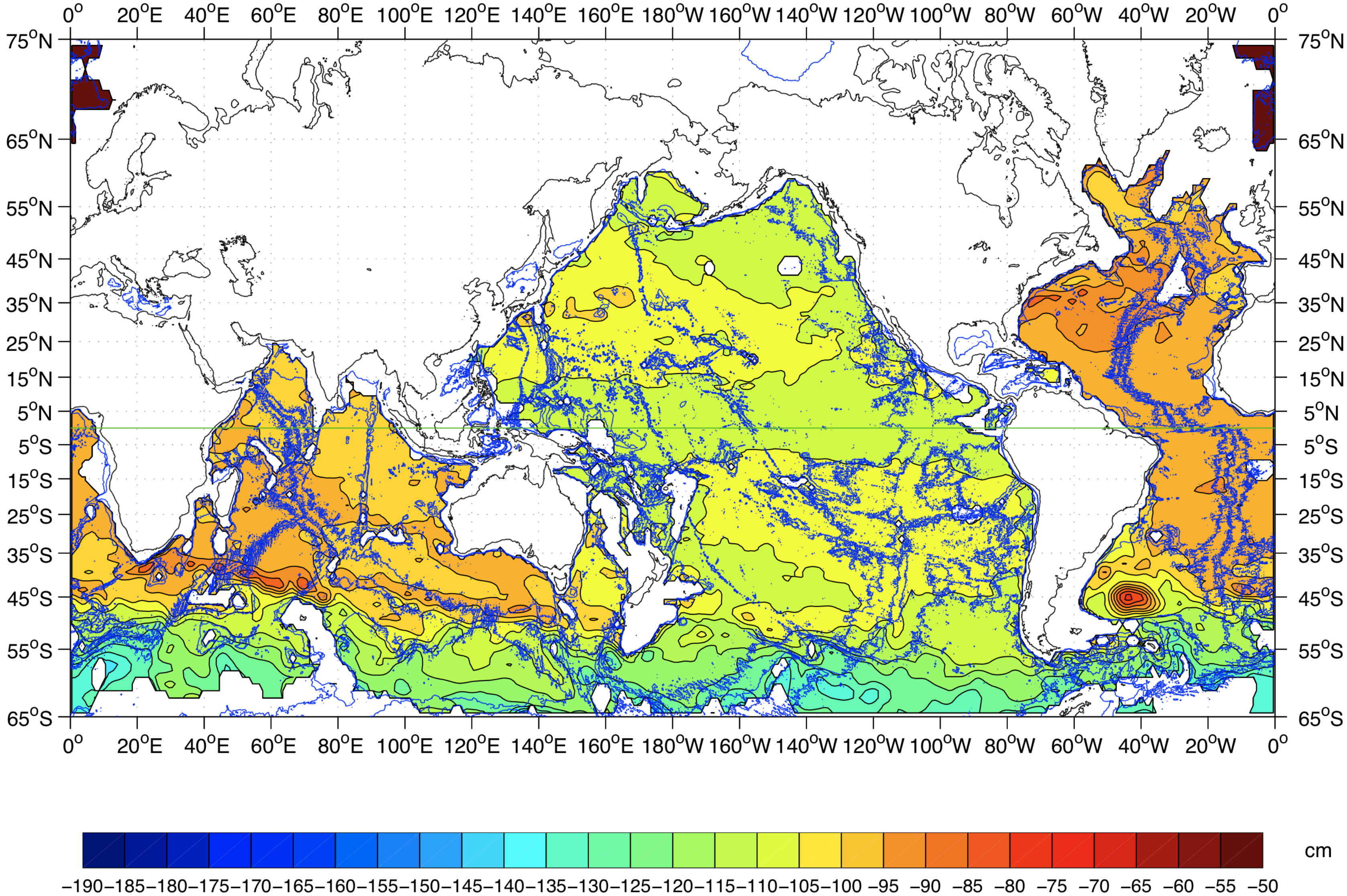
Mean geopotential height (cm) at 150 m



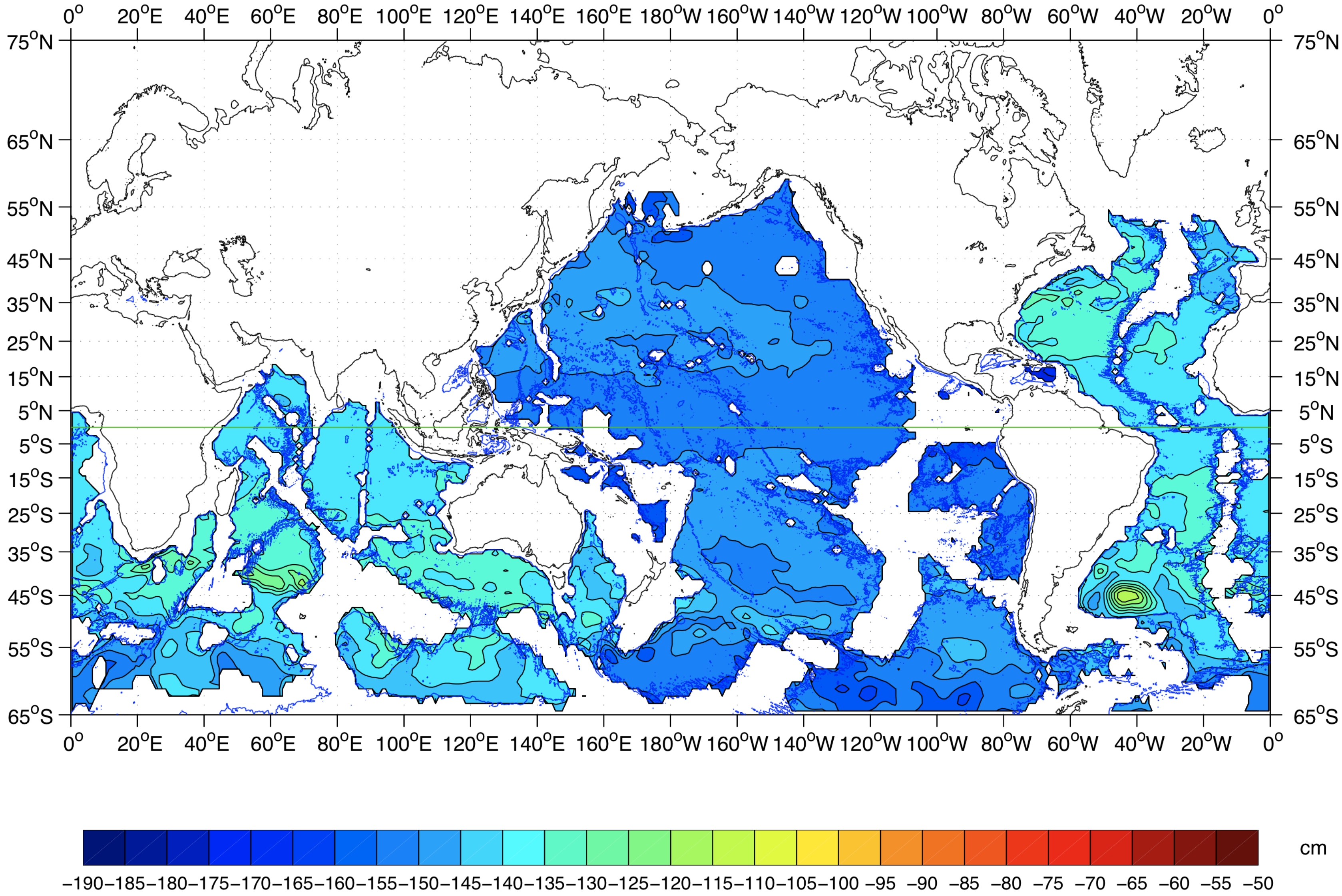
Mean geopotential height (cm) at 2000 m

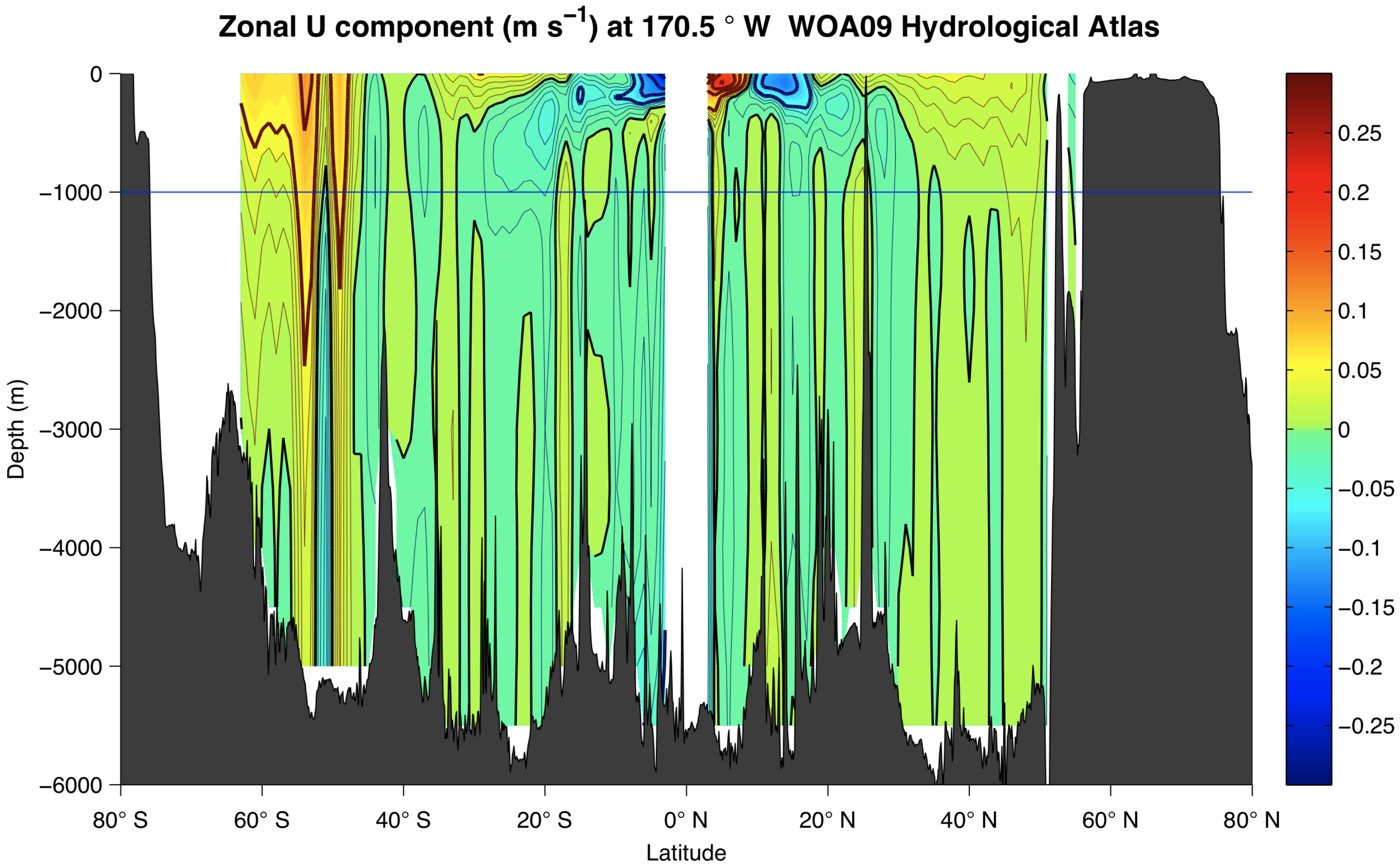


Mean geopotential height (cm) at 3000 m

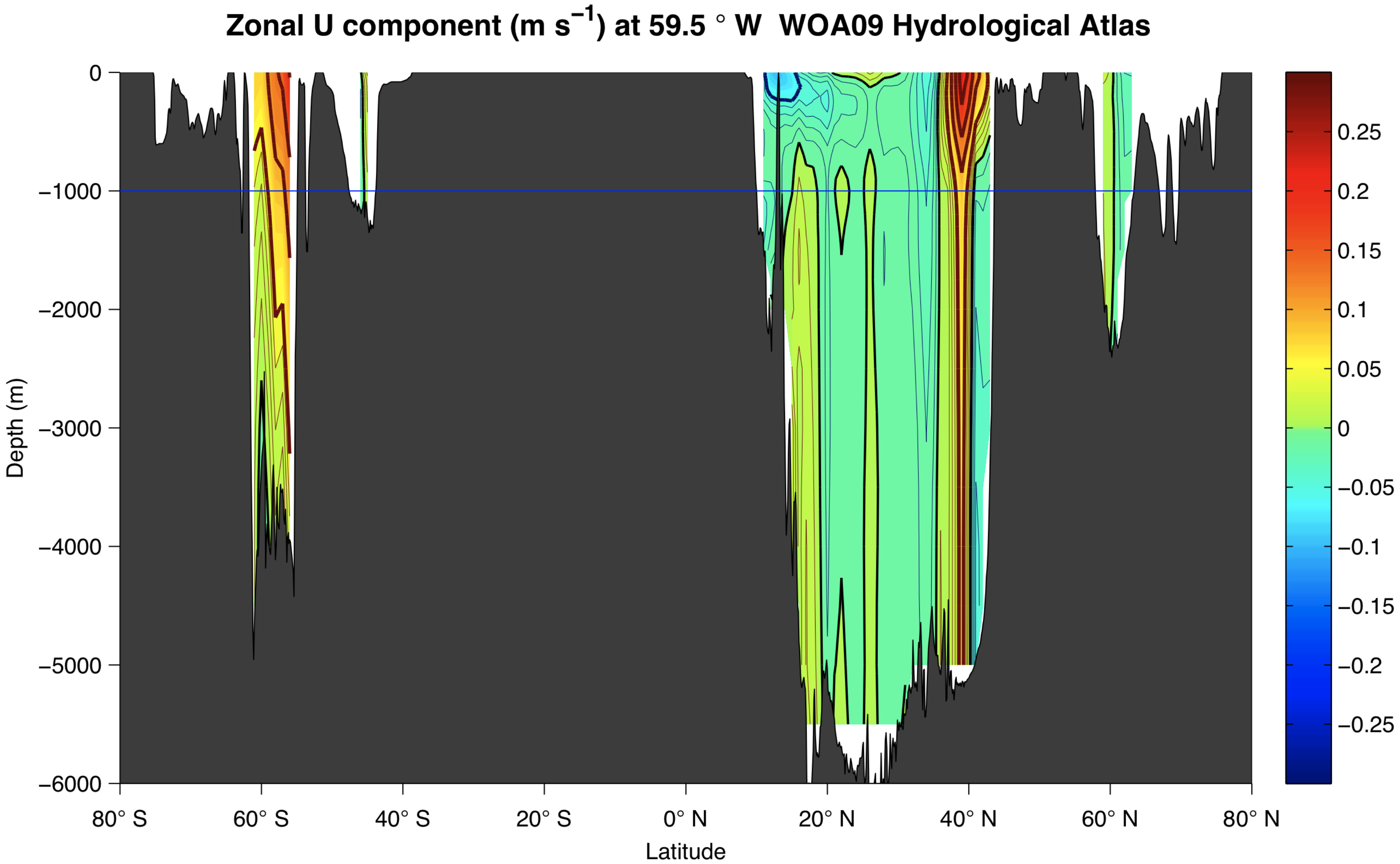


Mean geopotential height (cm) at 4000 m

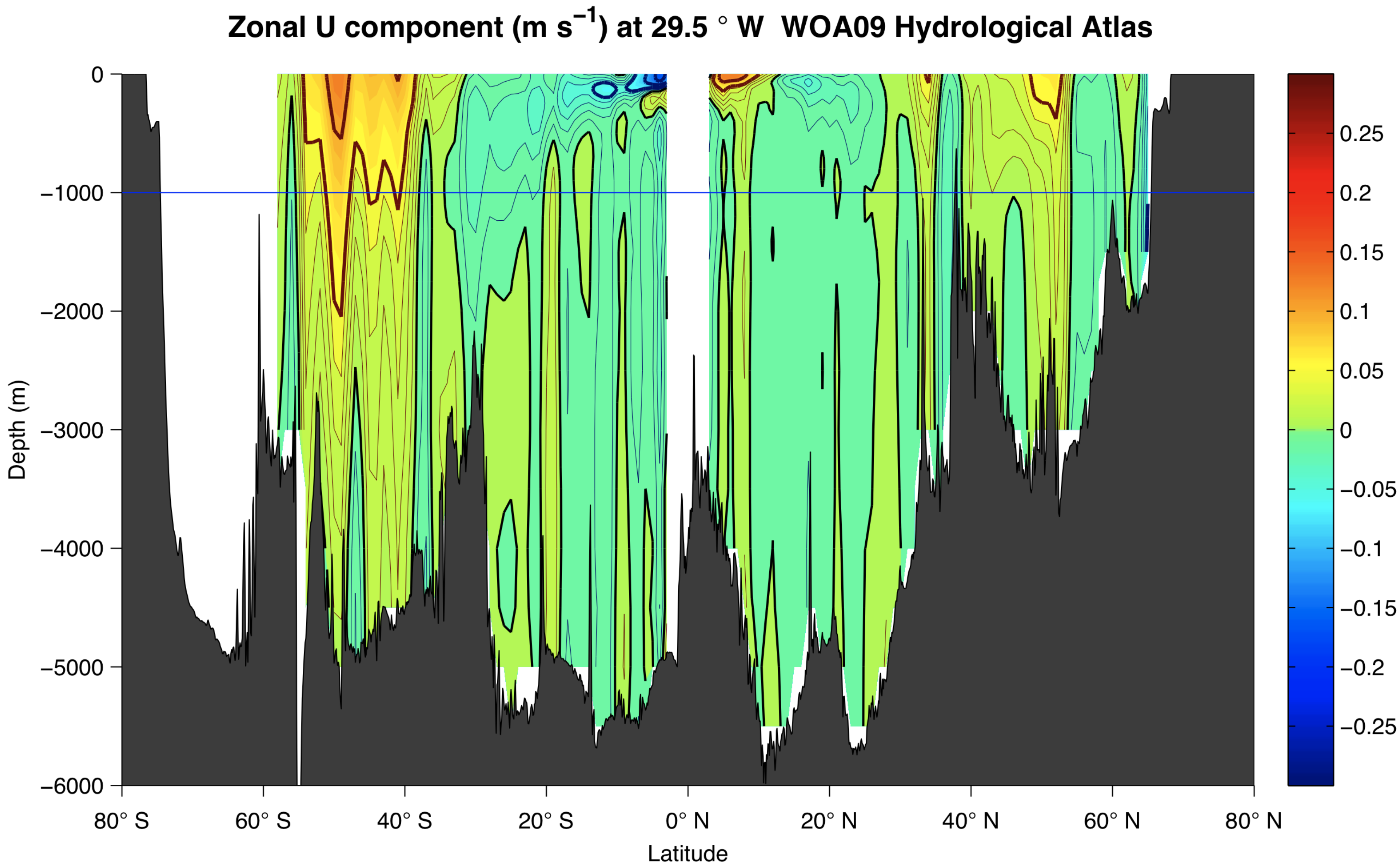




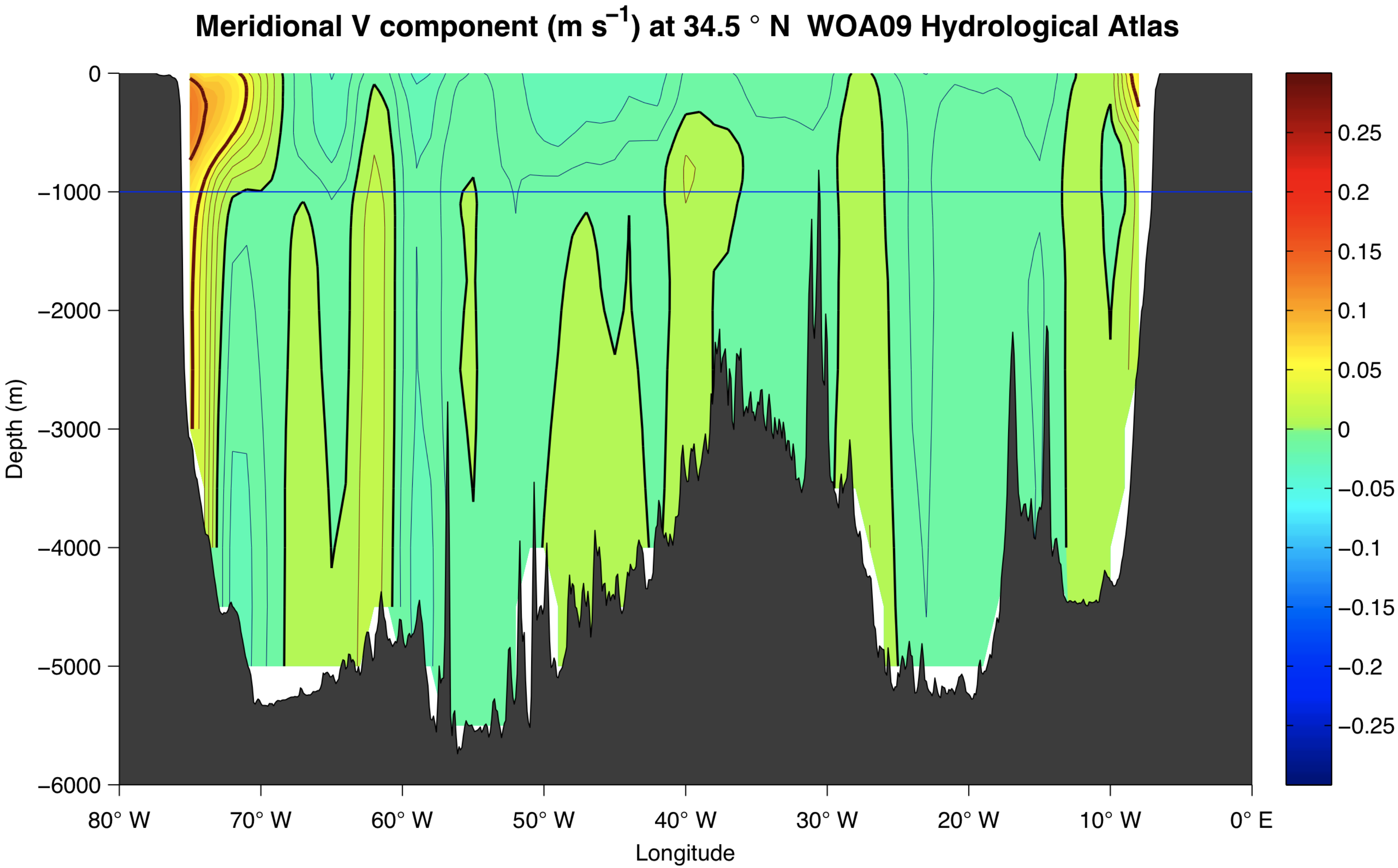
Zonal U component (m s^{-1}) at 170.5 ° W WOA09 Hydrological Atlas
Depth (m)
0
−1000
−2000
−3000
−4000
−5000
−6000
80° S
60° S
40° S
20° S
0° N
20° N
40° N
60° N
80° N
Latitude
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25



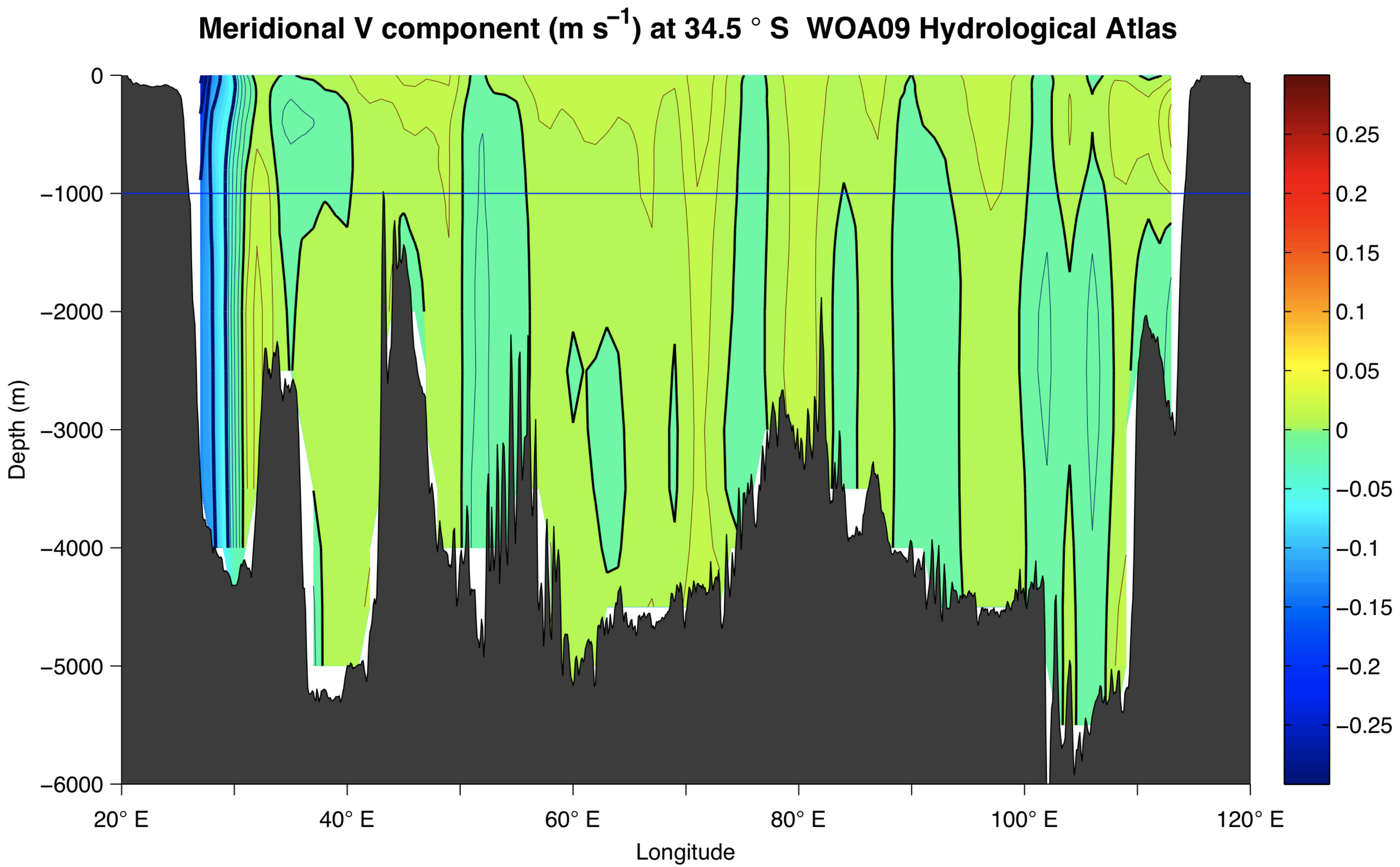
Zonal U component (m s^{-1}) at 59.5 ° W WOA09 Hydrological Atlas
0
−1000
−2000
−3000
−4000
−5000
−6000
Depth (m)
80° S
60° S
40° S
20° S
0° N
20° N
40° N
60° N
80° N
Latitude
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25



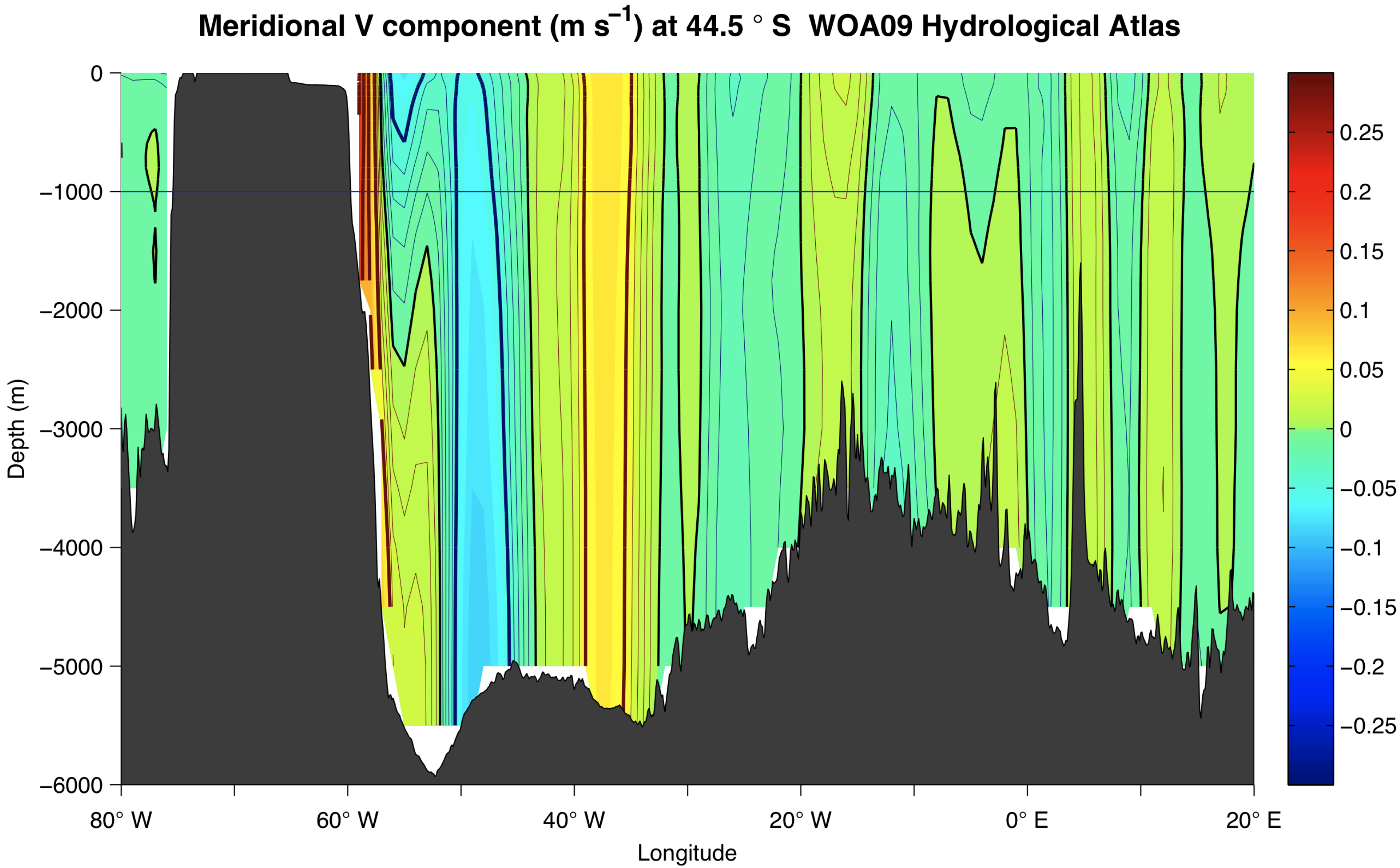
Zonal U component (m s^{-1}) at 29.5 ° W WOA09 Hydrological Atlas
Depth (m)
0
−1000
−2000
−3000
−4000
−5000
−6000
80° S
60° S
40° S
20° S
0° N
20° N
40° N
60° N
80° N
Latitude
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25



Meridional V component (m s^{-1}) at 34.5 ° N WOA09 Hydrological Atlas
Depth (m)
0
−1000
−2000
−3000
−4000
−5000
−6000
80° W
70° W
60° W
50° W
40° W
30° W
20° W
10° W
0° E
Longitude
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25



Meridional V component (m s^{-1}) at 34.5 ° S WOA09 Hydrological Atlas
0
−1000
−2000
−3000
−4000
−5000
−6000
Depth (m)
20° E
40° E
60° E
80° E
100° E
120° E
Longitude
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25


Meridional V component (m s^{-1}) at 44.5 ° S WOA09 Hydrological Atlas
Depth (m)
0
−1000
−2000
−3000
−4000
−5000
−6000
80° W
60° W
40° W
20° W
0° E
20° E
Longitude
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25

Conclusions and future

- Deep ocean (under 1000 m) is mostly barotropic, upper ocean baroclinic. Is that true? Needs refine calculations and/or more floats at 1000 m
- WOA09 is probably too large scale to reveal well frontal structures. Needs a sharper climatology (perhaps Hydrobase when available).
- An Argo climatology (with a 0.5° resolution) should be better for the upper 2000 m. To be done shortly in collaboration with B. King (NOC) and F. Gaillard (IFREMER)
- To resolve the western boundary currents, direct current measurements at shallow depths could be used.
- Geopotential height can be estimated with the full dynamical equations (easy), but how to get the full currents (difficult)?

This work was begun in 2006, while I was on sabbatical year here in NOC, thanks to Brian King's hospitality.

We acknowledge the strong financial support from IFREMER over the 6 years during which the ANDRO data set was produced, and the great work done by Jean-Philippe Rannou (from ALTRAN company) who wrote all the Matlab programs necessary to reprocess Argo data.

It is fortunate that Argo is continuing, so as to provide a sharper view of the general (and mesoscale) circulation. We hope ANDRO could be updated soon for the years 2010, 2011 and 2012 (we got funds for the Coriolis DAC only), so that deep currents can be better determined.