Variations of the large-scale ocean circulation since 1950

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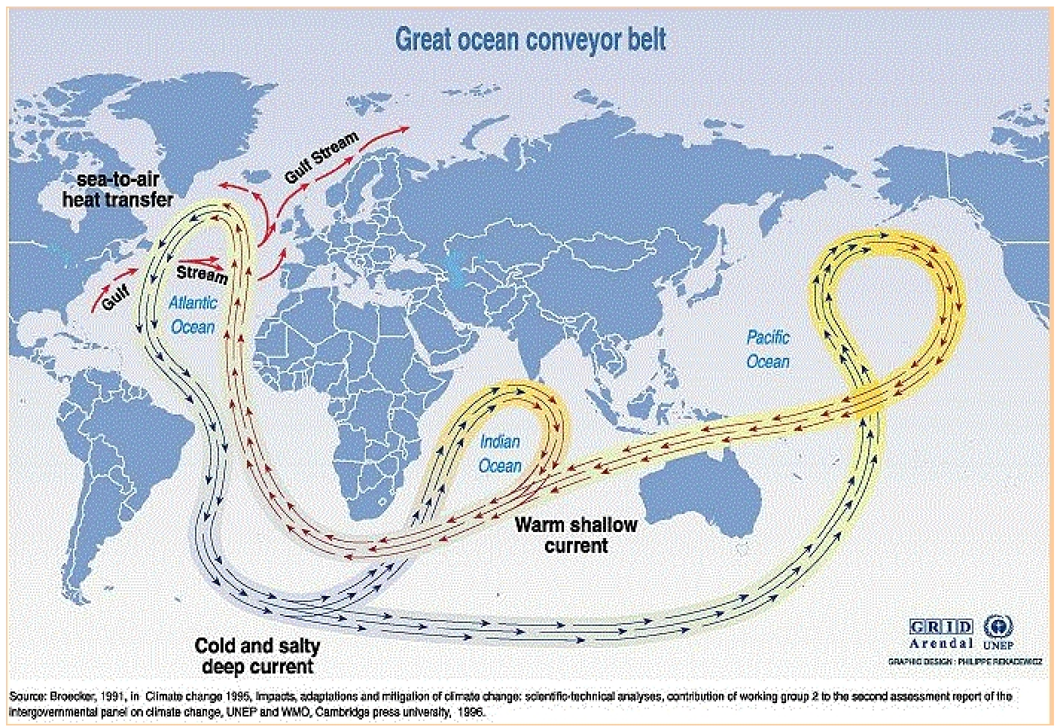


[Broecker 1991]

MOTIVATIONS

• variations of the large-scale ocean circulation may have climatic impact through poleward heat transport

• what are these variations over the last decades in relation with natural variability, global warming, North Atlantic Oscillation, ...?

• traditionnally investigated through sparse and synoptic hydrographic sections, and with realistic ocean models forced through surface fluxes
(large uncertainty, relaxation to surface observations)

⇒ why not use directly insitu TS measurements: NODC CTD and XBT database, Argo profiling floats, ...?

GOAL

Reconstruct large-scale ocean circulation (steady, geostrophic) from density field (T S) and surface wind stress

• diagnostic planetary geostrophic dynamics: Sverdrup balance + thermal wind!

DATA

• T+S: pentadal temperature and salinity anomalies down to 3000 m (28 levels) from 1955-59 to 1994-98, superposed to mean climatology down to the bottom (WOD2004, Boyer et al. 2005)
also annual temperature anomalies 0-700 m (16 levels) from 1955-1945 to 2003 (WOD2004, Levitus et al. 2005, Ishii et al. 2003)

•Wind stress: ECMWF ERA40 1958–2001, 5-year averaged
also NCEP 1948–now

METHOD: SVERDRUP + THERMAL WIND

planetary-geostrophic diagnostic inviscid dynamics in spherical coordinates

$$-fv = -\frac{1}{a\cos\theta\rho_0}\partial_\phi P + \frac{\tau^x}{\rho_0\, h_E} H(z+h_E)$$

$$fu = -\frac{1}{a\rho_0}\partial_\theta P + \frac{\tau^y}{\rho_0\, h_E} H(z+h_E)$$

$$\partial_z P = -\rho g$$

$$\nabla\cdot\mathbf{u} = \frac{1}{a\cos\theta}\partial_\phi u + \frac{1}{a\cos\theta}\partial_\theta(\cos\theta\, v) + \partial_z w = 0$$

equation of state for seawater insitu density $\rho(T,S,P)$

T potential temperature, S salinity, P pressure, (u,v,w) velocity, θ latitude, ϕ longitude, z height, a Earth radius, H Heaviside step function, h_E surface Ekman layer thickness, $f = 2\Omega\sin\theta$ Coriolis parameter and β its meridional gradient, $(\tau^x,\, \tau^y)$ surface wind stress

NB wind stress is uniformly distributed in Ekman layer to avoid resolving explicitly this frictional boundary layer

Velocities are split in barotropic and baroclinic components:

$$\mathbf{u}(\phi,\theta,z) = \bar{\mathbf{u}}(\phi,\theta) + \mathbf{u}'(\phi,\theta,z)$$
$$\bar{\mathbf{u}}(\phi,\theta) = \frac{1}{h(\phi,\theta)}\int_{-h(\phi,\theta)}^{0} \mathbf{u}(\phi,\theta,z)\,dz$$

$\Rightarrow$ Sverdrup balance for barotropic meridional velocity:

$$\beta\,\bar{v} = \frac{1}{h\,\rho_0 a\cos\theta}\left[\partial_\phi \tau^y - \partial_\theta(\tau^x\cos\theta)\right] - \frac{f w_B}{h}$$

Fundamental Hypothesis: vertical velocities are assumed to cancel at the bottom (this does not mean flat bottom!) $\Rightarrow w_B = 0$

• **western boundary currents (westernmost grid point of each basin) are set to satisfy mass conservation at every latitude in each basin** ($\Rightarrow$ some continuity problems with latitude when number of basins vary...)

• zonal barotropic transport is determined through mass conservation (through barotropic streamfunction)

Baroclinic component satisfies momentum equations, once substracted the barotropic component, hence has a zero vertical integral:

$$
\begin{aligned}
-fv' &= -\frac{1}{a\cos\theta\rho_0}\partial_\phi P' + \frac{\tau^X}{\rho_0}G(z), \\
fu' &= -\frac{1}{a\rho_0}\partial_\theta P' + \frac{\tau^Y}{\rho_0}G(z)
\end{aligned}
$$

where $G(\phi,\theta,z) = H(z+h_E)/h_E - 1/h(\phi,\theta)$, has a zero vertical integral, and baroclinic hydrostatic pressure P' verifies

$$\partial_z P' = -\rho g \ , \ \int_{-h(\phi,\theta)}^{0} P' dz = 0$$

NB this baroclinic component may not be valid in frictional western boundary currents, but we have tried to reduce deviations from geostrophy

TRADITIONAL DIAGNOSTICS

- meridional overturning streamfunction

$$\psi(\theta, z) = \int_{\phi_W}^{\phi_E} \int_z^0 v \, dz \, a \cos\theta d\phi$$

- poleward heat transport

$$\mathrm{PHT}(\theta) = \int_{\phi_W}^{\phi_E} \int_{-h(\phi,\theta)}^0 vT \, dz \, a \cos\theta d\phi$$

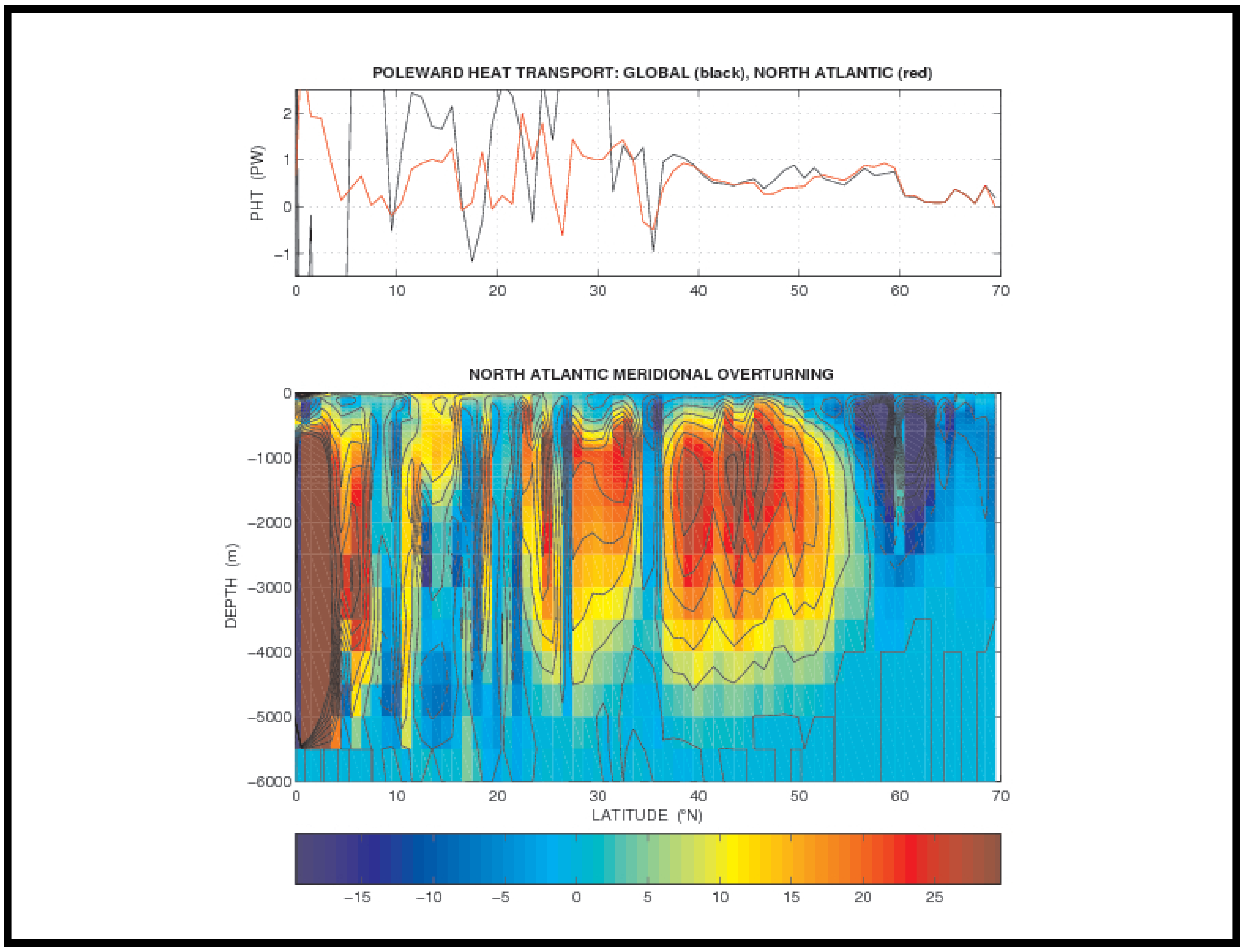
assuming poleward mass transport through the section cancels:

$$\int_{-h(\phi,\theta)}^0 v \, dz \, a \cos\theta d\phi \equiv 0$$

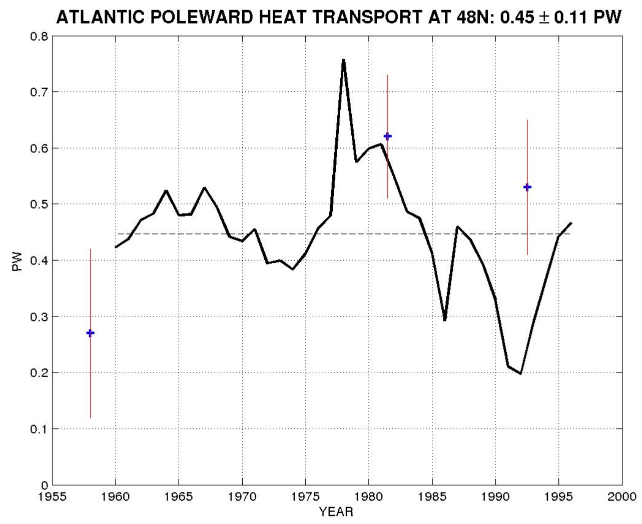
hence $\psi(\theta, 0) = 0$ at the surface $\Rightarrow \psi(\theta, -h(\phi, \theta)) = 0$ at the bottom

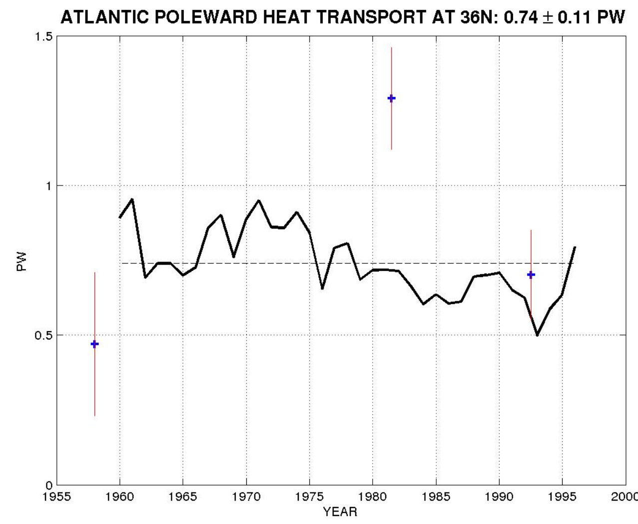
$\star$ **It is verified on seasonal data that annual mean poleward heat transport is accurately diagnosed through annual mean data**

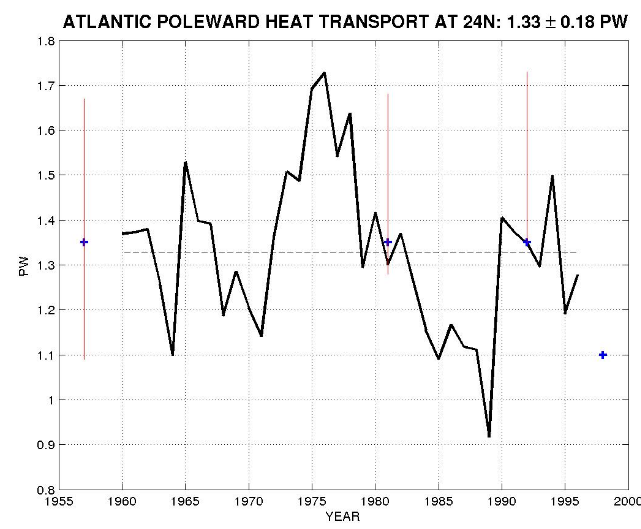
$$\overline{\mathrm{PHT}(\theta)} = \overline{\int_{\phi_W}^{\phi_E} \int_{-h(\phi,\theta)}^0 v \, T \, dz \, a \cos\theta d\phi} \simeq \int_{\phi_W}^{\phi_E} \int_{-h(\phi,\theta)}^0 \overline{v} \, \overline{T} \, dz \, a \cos\theta d\phi$$

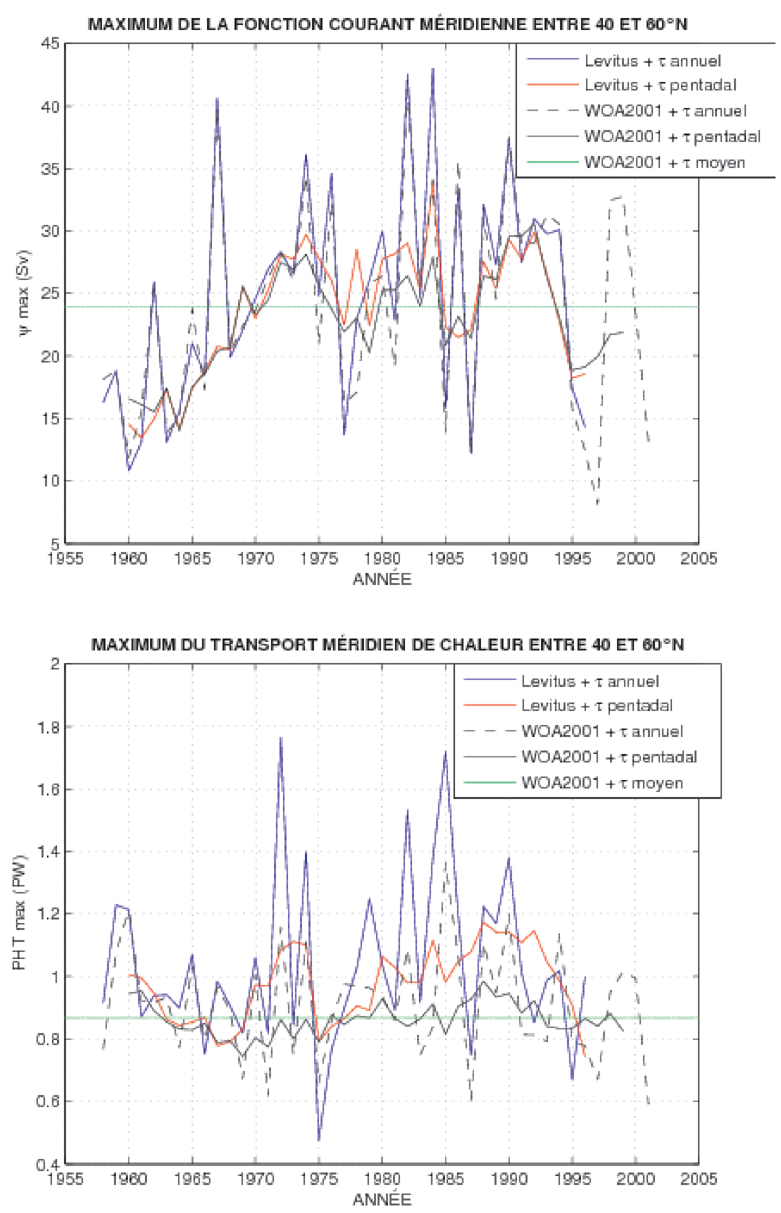

POLEWARD HEAT TRANSPORT: GLOBAL (black), NORTH ATLANTIC (red)
PHT (PW)
NORTH ATLANTIC MERIDIONAL OVERTURNING
DEPTH (m)
LATITUDE (°N)

VARIATIONS OF POLEWARD HEAT TRANSPORT AT 24N, 36N AND 48N VS. HYDROGRAPHIC SECTIONS









MAXIMUM DE LA FONCTION COURANT MÉRIDIENNE ENTRE 40 ET 60°N
Levitus + τ annuel
Levitus + τ pentadal
WOA2001 + τ annuel
WOA2001 + τ pentadal
WOA2001 + τ moyen
ψ max (Sv)
ANNÉE
MAXIMUM DU TRANSPORT MÉRIDIEN DE CHALEUR ENTRE 40 ET 60°N
Levitus + τ annuel
Levitus + τ pentadal
WOA2001 + τ annuel
WOA2001 + τ pentadal
WOA2001 + τ moyen
PHT max (PW)
ANNÉE

VARIATIONS OF NORTH ATLANTIC MERIDIONAL OVERTURNING AND POLEWARD HEAT TRANSPORT MAXIMUM 40N–60N

→ maximum meridional overturning varies roughly from 15 Sv in the 1960's to 30 Sv in the early 1990's

→ maximum poleward heat transport varies from 0.8 PW in 1965-70 to 1.2 PW in 1985-90

NB variations of overturning and heat transport maximum are not necessarily in phase!

→ 5-yr averaged winds considerably reduce the amplitude of interannual variations, especially for heat transport

→ low-frequency variations of overturning and heat transport are controlled by thermohaline variations, whereas interannual variations are of larger amplitude and controlled by the wind variations

CONCLUSIONS

• annual mean T S data is sufficient to estimate annual mean poleward heat transport

• **low-frequency variations of overturning and heat transport are controlled by thermohaline variations**, whereas interannual variations are of larger amplitude and controlled by the wind variations (imprint of wind forcing in thermohaline structure?)

• **significant increase in maximum subpolar poleward heat transport from 1970-1975 to 1990-1995 (+25%), but weakening since then?**

• Levitus *et al.* (2005b) concluded *"Our results suggest that using 5-year or even 10-year running composites of ocean data to produce temperature anomaly fields is reasonable for estimating the interdecadal variability of ocean heat content"*. Similar conclusions apply here to estimate the variations of the large-scale ocean circulation: large interannual wind variability (NAO) ⇒ large and noisy interannual variations of the genreal ocean circulation, whereas circulations diagnosed on 5-yr averaged T S and wind show more coherent variations

→ interpretation of the variations are underway...

DISCUSSION

- robustness should be estimated regarding climatologies, wind stress forcing, resolution of the analysis, and **uncertainties should be estimated**

- zero bottom vertical velocities hypothesis is important, and consequences are being verified in more sophisticated models

• **a better estimation of the barotropic flow will improve the mean values for poleward heat transport, but its variations are certainly well captured by the baroclinic flow**

- **variations of TS below 3000 m are not captured in this work** (Bryden et al. 2005) and may have significant impact on diagnosed quantities!

- products presently available on shelves (WOD2004) do not allow 'real time' analysis, for hydrographic cruise support for instance (Ovide repeated sections between Greenland and Portugal)
→ tools are being built within the Coriolis/Argo french program (F. Gaillard and E. Autret, IFREMER)

RÉFÉRENCES

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