

Ocean model utility and horizontal resolution: A systematic assessment of changes

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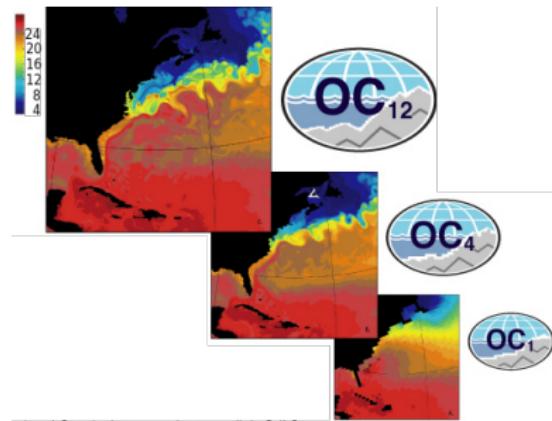
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29th June 2016

Outline

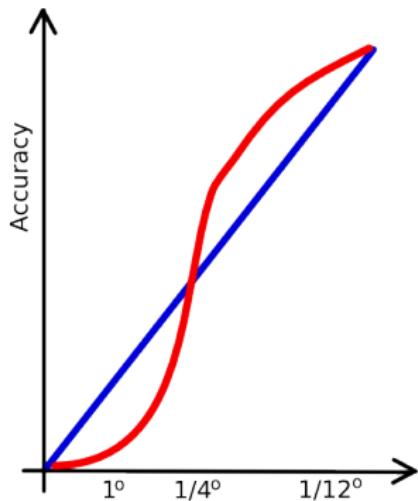
- 1 The model: NEMO
- 2 Surface: Mixed Layer Depth
- 3 Interior: Steric variability
- 4 Bottom: Bottom Pressure Torque
- 5 Utility



Systematic assessment of changes with ocean model resolution

Take home: Different resolutions suitable for different applications

Motivation



- Really big, hard, question!
- What resolution is “good enough”?
- IPCC -> Drive towards higher resolution. Is it worth it?
- Low resolution is faster, easier, cheaper...

Nucleus of European Modelling of the Ocean: **NEMO** (Madec, 2008)



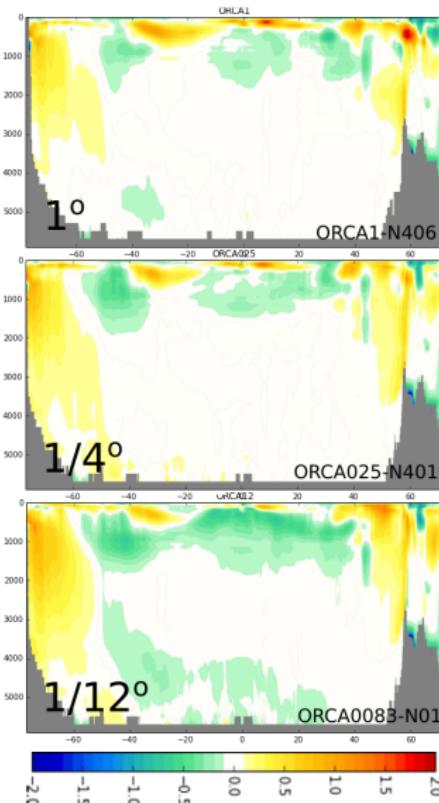
Suite of realistic GCM runs from 1978-2007
forced with DFS4.1 (Brodeau *et al.*, 2010)

What parameters change with resolution?

Name Resolution	ORCA1-N406 1°	ORCA025-N401 1/4°	ORCA0083-N01 1/12°
z, x, y	75,292,362	75,1021,1442	75,3059,4322
GM active	Yes	No	No
Horiz. laplacian eddy viscosity ($m^2 s^{-1}$)	10^4	500	500
Horiz. bilaplacian eddy viscosity ($m^4 s^{-1}$)	-1.25×10^{10}	-2.2×10^{11}	-2.2×10^{11}
Isopycnal eddy tracer diffusivity ($m^2 s^{-1}$)	10^3	300	125
Timestep (s)	3600	1440	200

Runs were designed by Andrew Coward and Beverly de Cuevas to be as comparable as feasible

Tools for comparing the model runs



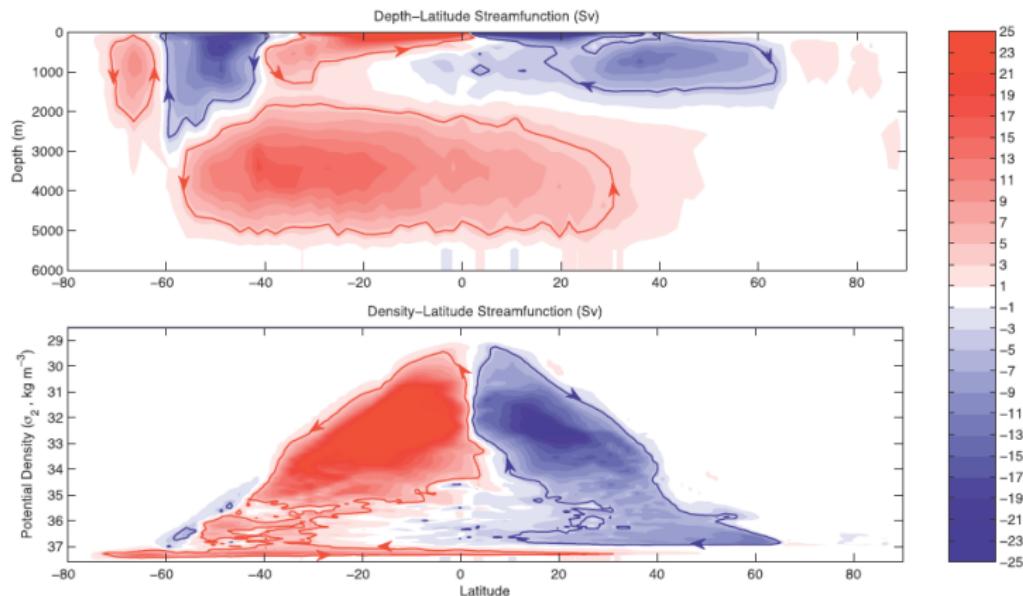
- Changes compared to observations
- $\psi(z, y)$: Depth-latitude streamfunction
EN3 bias ($^{\circ}\text{C}$) (Hyder *et al.*, In Prep.)
 - Do these changes “matter”?
 - When/where? Is cost **merited**?
- We use area averaged PDF
- We also explore “utility”, more on this later...

Density-latitude streamfunction ($\psi(\sigma, y)$): Definition

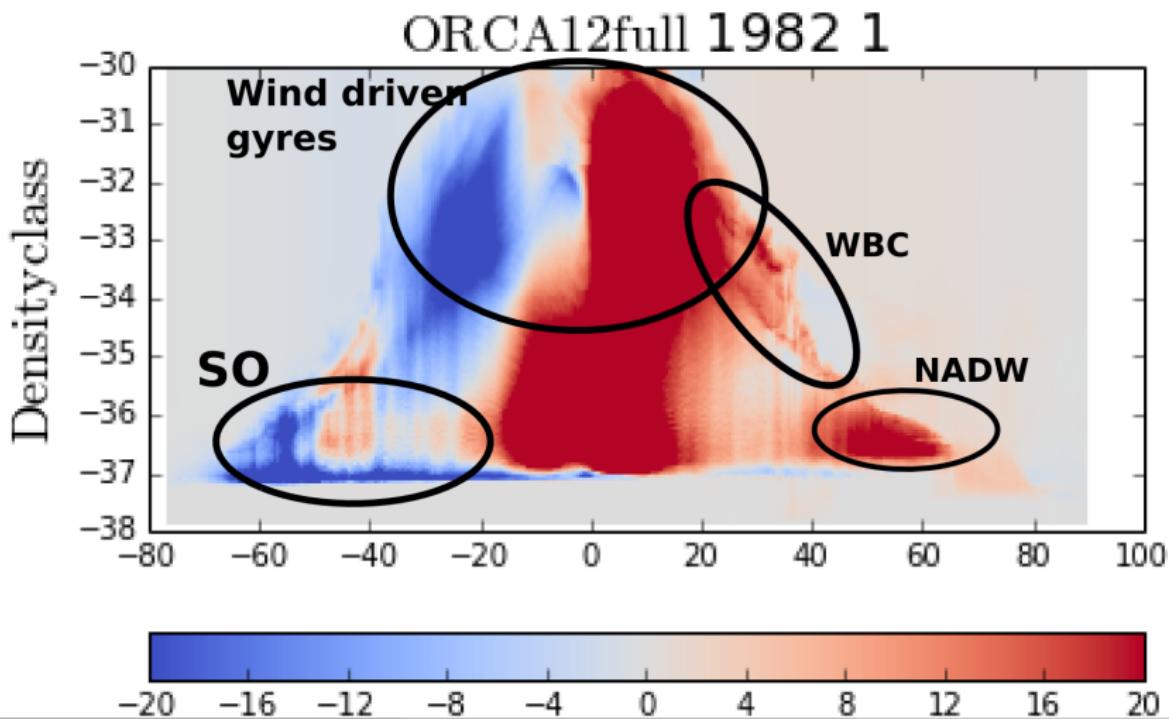
Illustrating the heat transport in the system:

Zika et al. (2012), Nurser and Lee (2004)

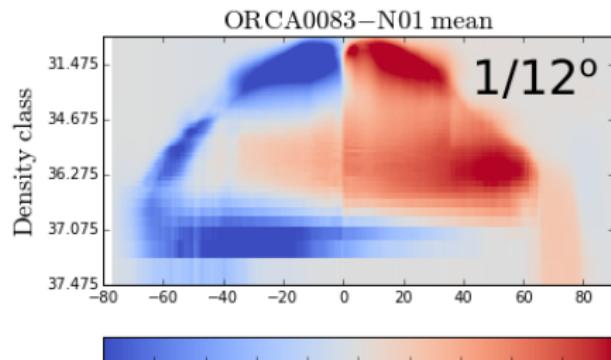
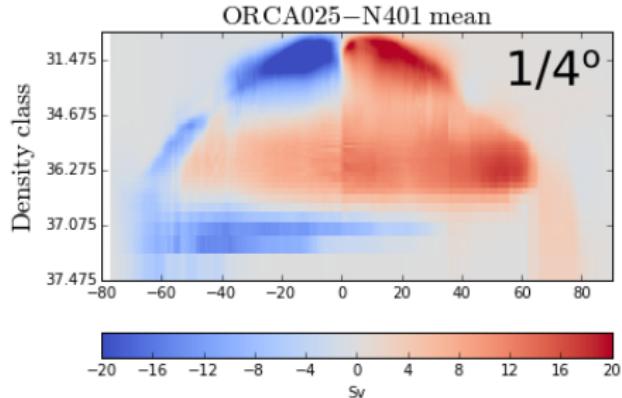
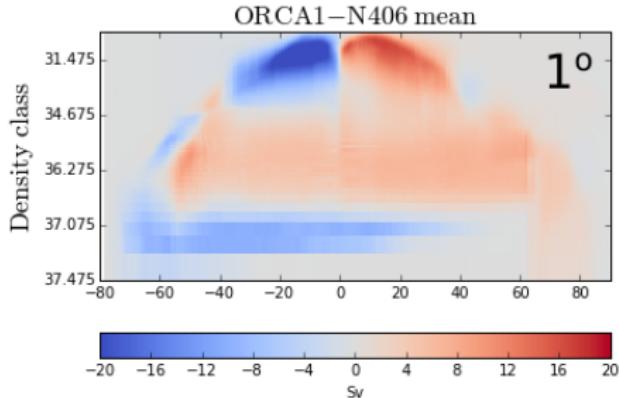
$$\psi(\sigma, y) = \int \int_{\sigma^* < \sigma} v(x, y, z) dz dx$$



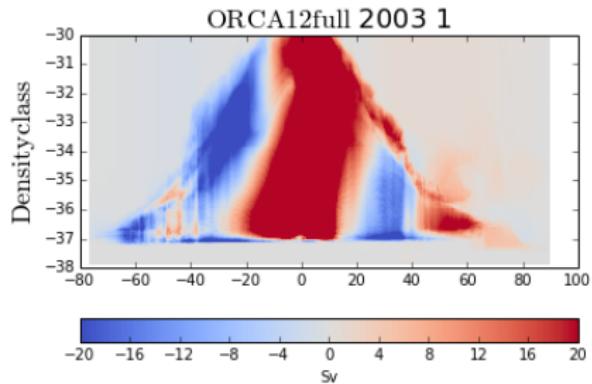
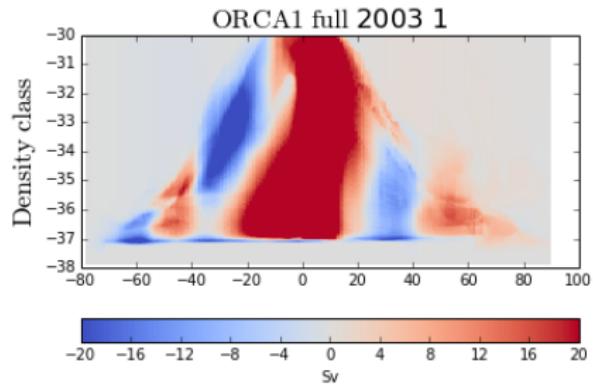
Density-latitude streamfunction ($\psi(\sigma, y)$): Interpretation



Density-latitude streamfunction ($\psi(\sigma, y)$): Mean 1978-2007

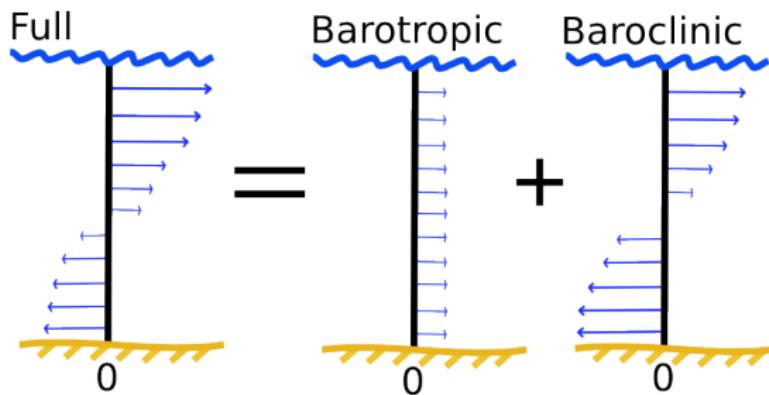


Density-latitude streamfunction ($\psi(\sigma, y)$): Transient

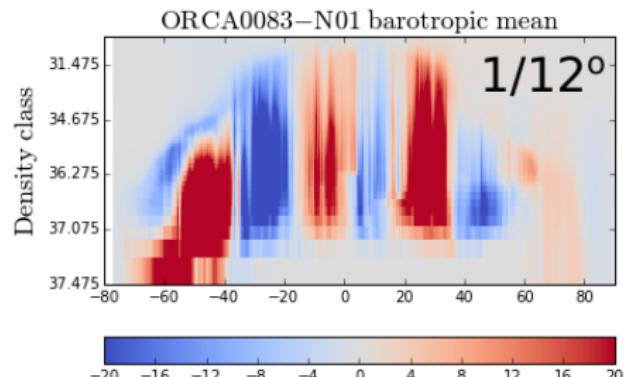
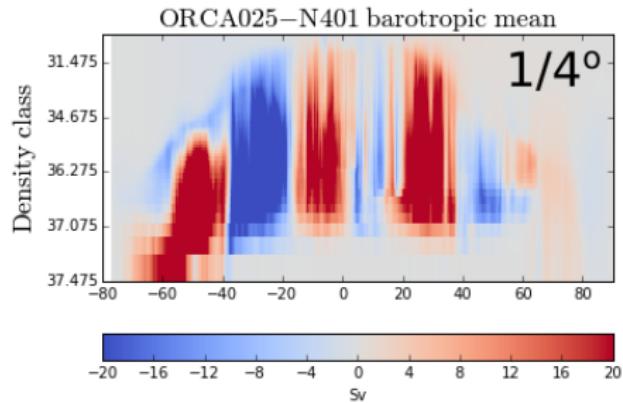
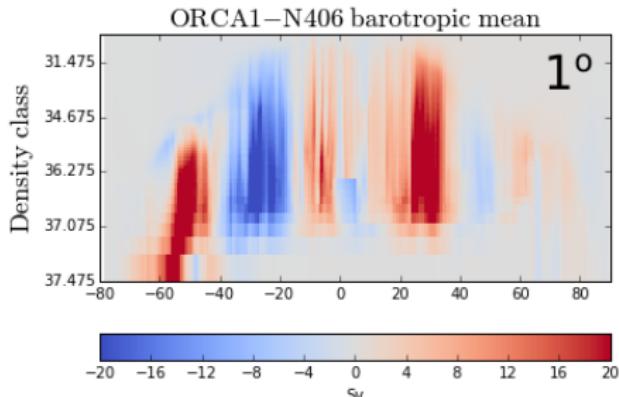


The barotropic ($\bar{\psi}$) and baroclinic (ψ') decomposition

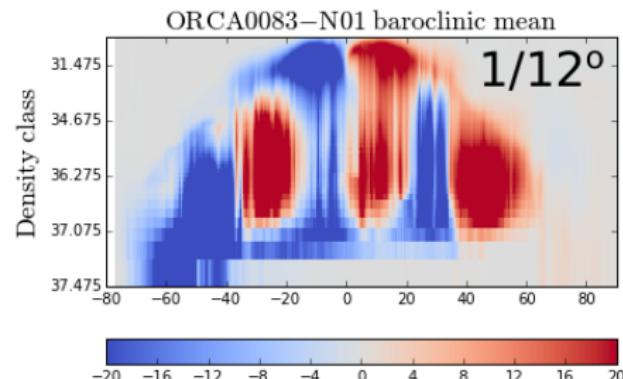
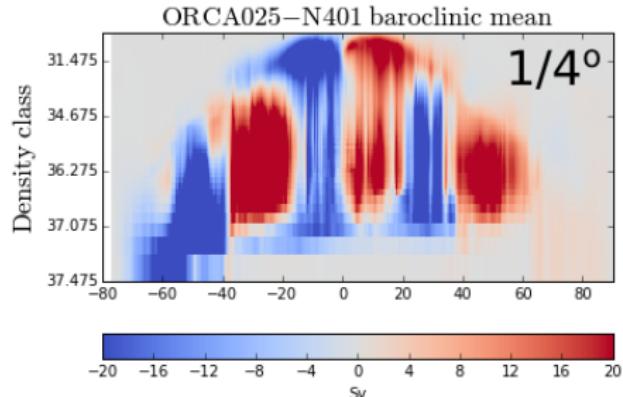
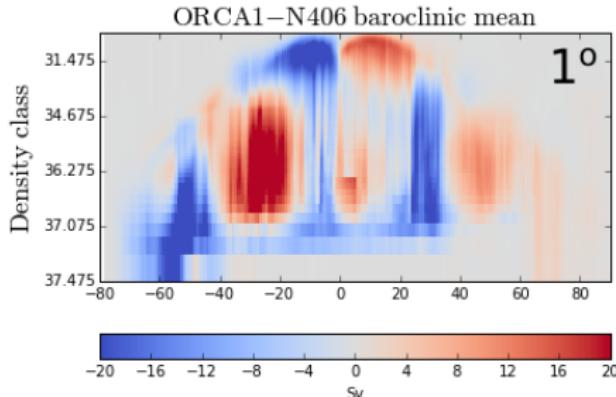
$$\psi_{\sigma y} = \bar{\psi}_{\sigma y} + \psi'_{\sigma y}$$



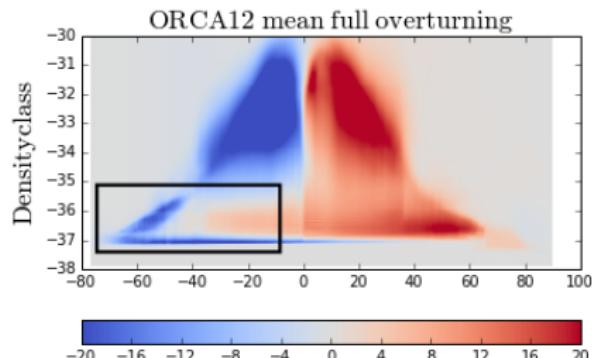
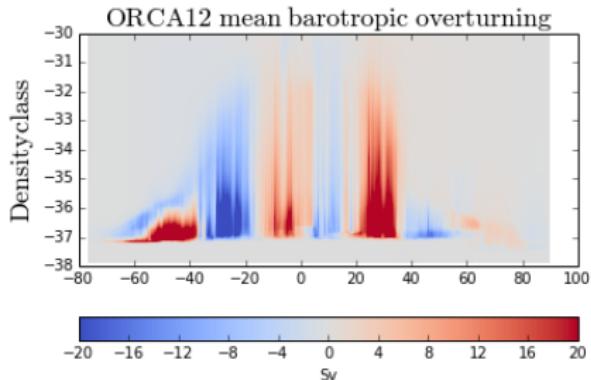
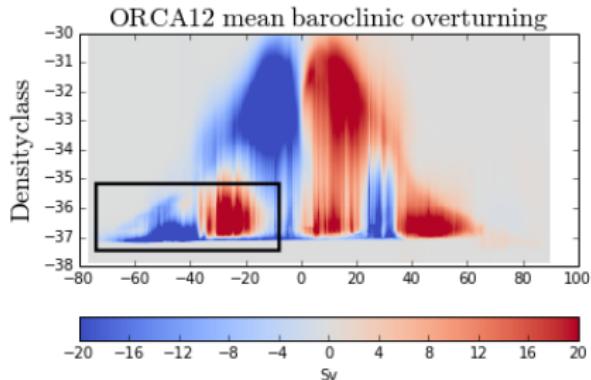
$\bar{\psi}(\sigma, y)$: Barotropic streamfunction



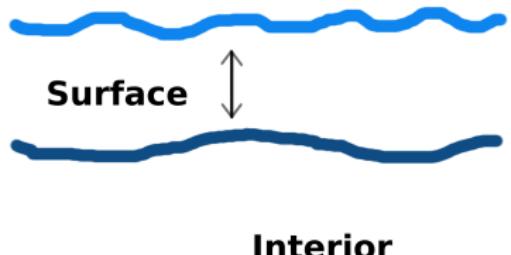
$\psi'(\sigma, y)$:Baroclinic streamfunction



1/12°: Eddy compensation? Farneti et al. (2010), Hallberg and Gnanadesikan (2006)



Where should we look for changes?



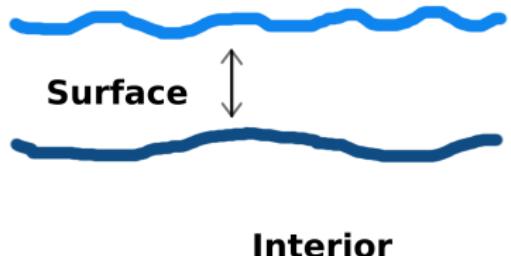
- ① Mixed Layer Depth
- ② Steric height
- ③ Bottom interactions



Depth-integrated momentum equation:

$$f\mathbf{k} \times \mathbf{U} + \nabla P = p_b \nabla H + \tau_w - \tau_b - \mathbf{R},$$

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Depth-integrated momentum equation:

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The mixed layer: Schematic

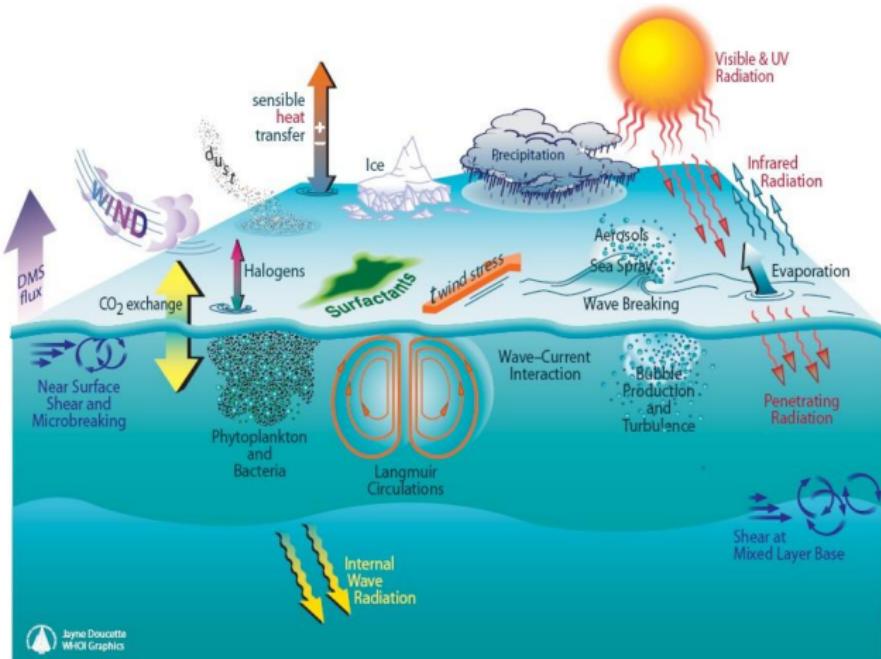
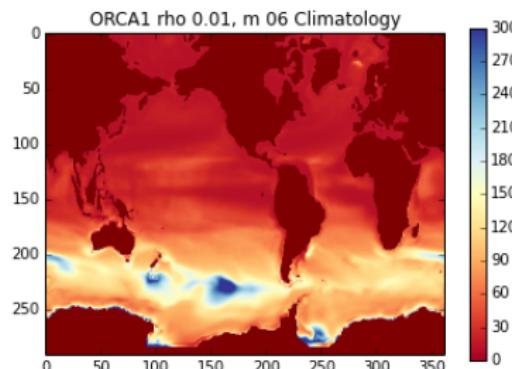
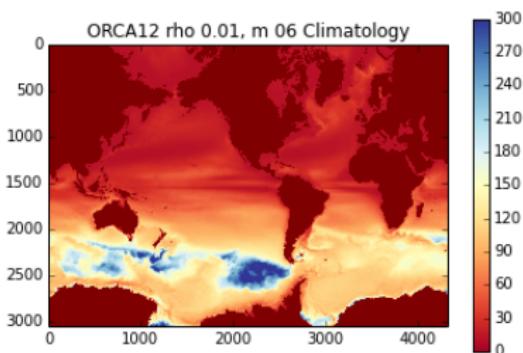


Image from: <http://www.ifremer.fr/cerweb/deboyer/mld/SurfaceMixedLayerDepth.php>

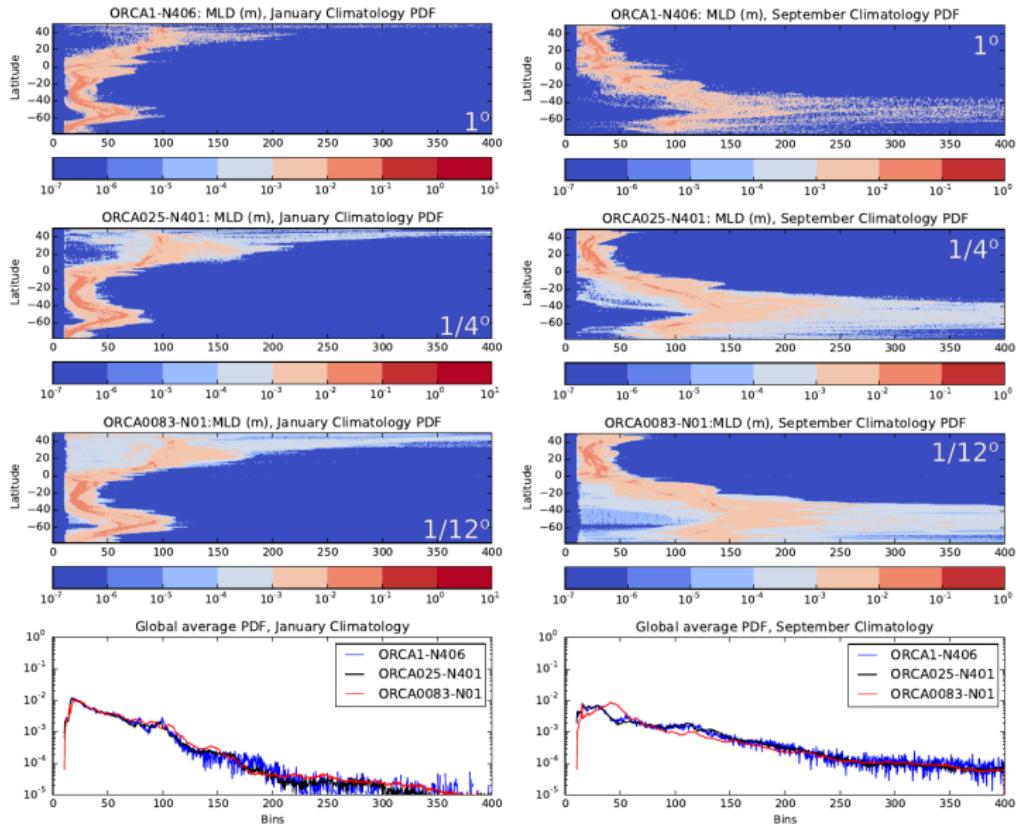
MLD (m) climatology movie, 1978-2007



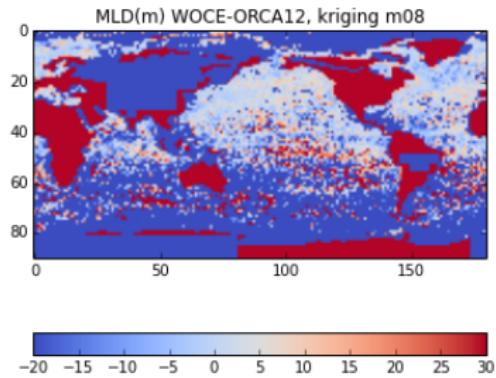
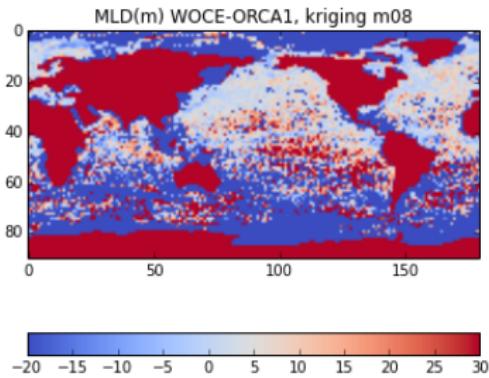
MLD criterion

$$\Delta\rho = 0.03\text{kgm}^{-3}, \Delta\rho = |\rho_s - \rho_d|$$

January and September MLD PDFs



Bias: de Boyer Montégut *et al.*, 2004 - NEMO



Surface: Summary

- No significant change in MLD observed
- Compares well with observed MLD

Likely not a place the runs differ greatly in terms of energy pathways

- This and case study of Southern Ocean zonal asymmetry:
Sonnewald, M., Ferrari, R. and Nurser, A.G., In prep.
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Steric changes

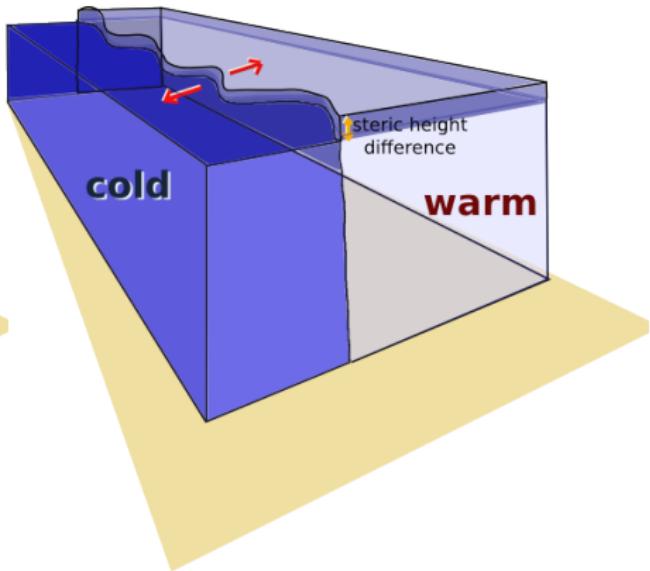
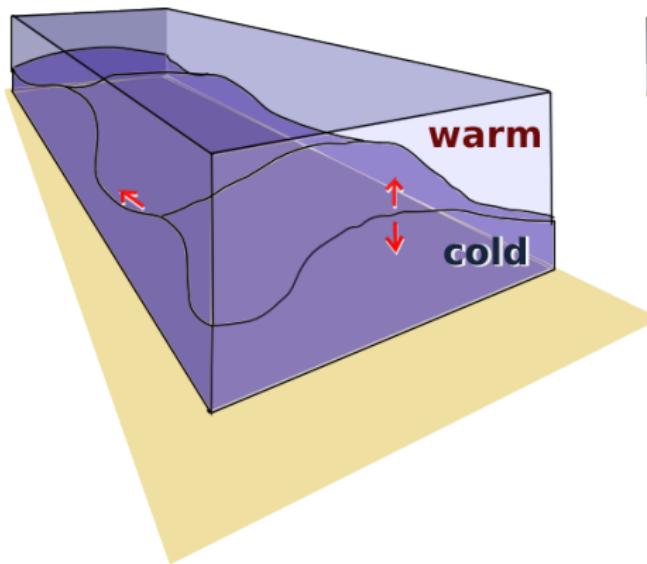
$$\eta = \frac{1}{\rho_0 g} (p_b - p_a) + SH$$

$$p_B = \int_{-H}^0 \rho g dz$$

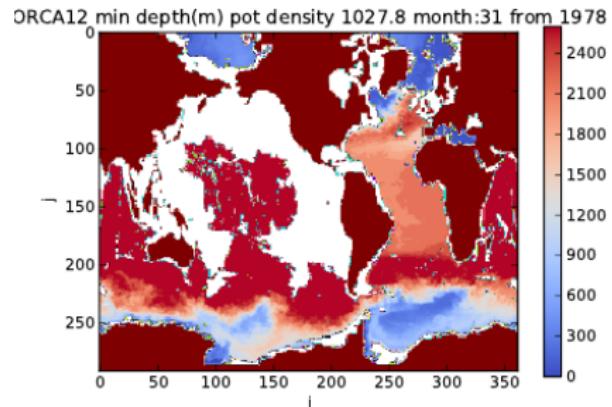
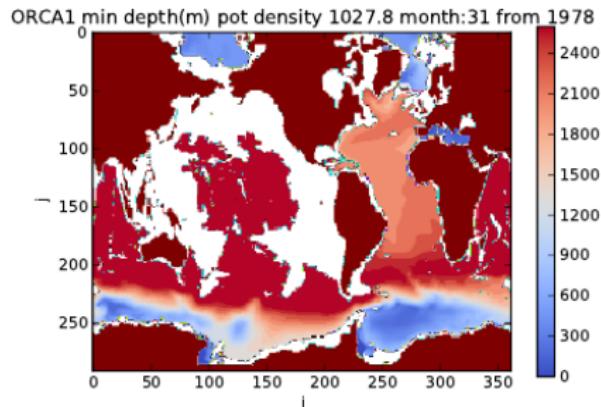
$$SH = -\frac{1}{\rho_0} \int_{-H}^0 \rho z$$

Steric variability

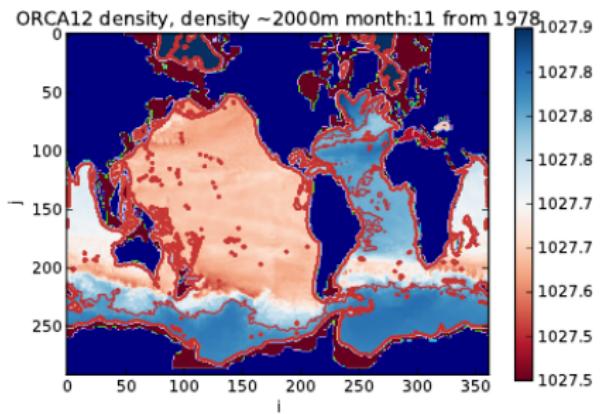
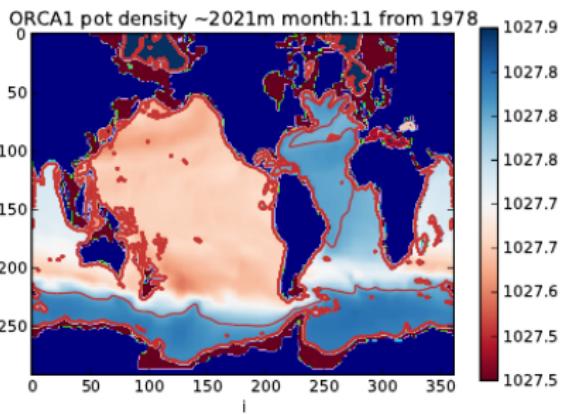
$$SH = \int_{-H}^0 \frac{\rho_0 - \rho}{\rho_0} dz$$



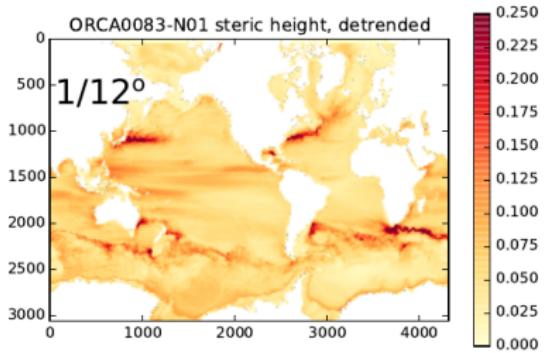
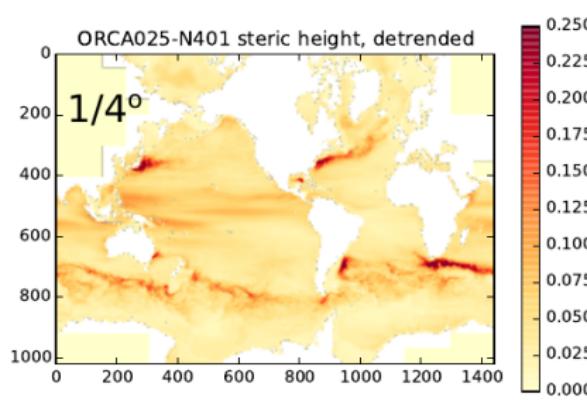
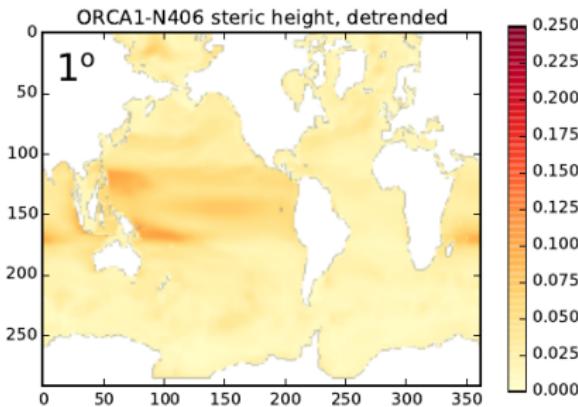
Heaving: What is the deep water water doing?



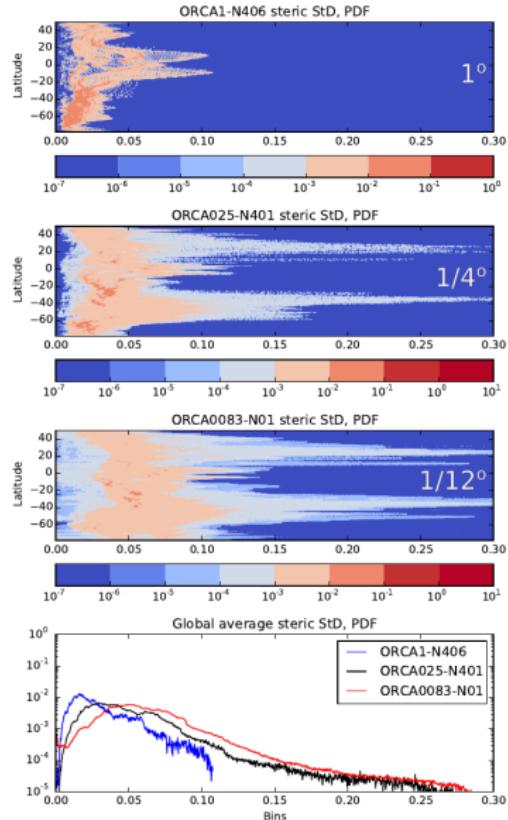
Meandering: What's happening in ρ at 2000m?



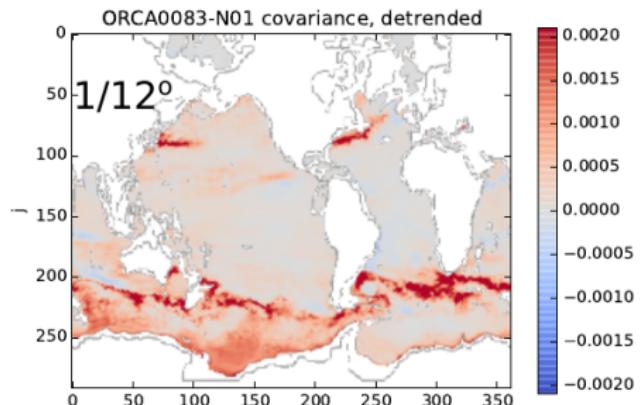
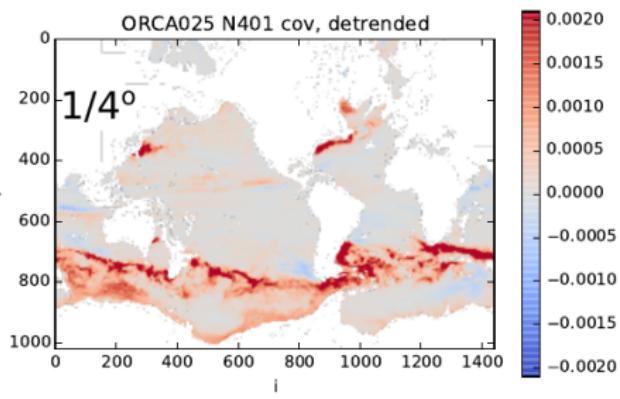
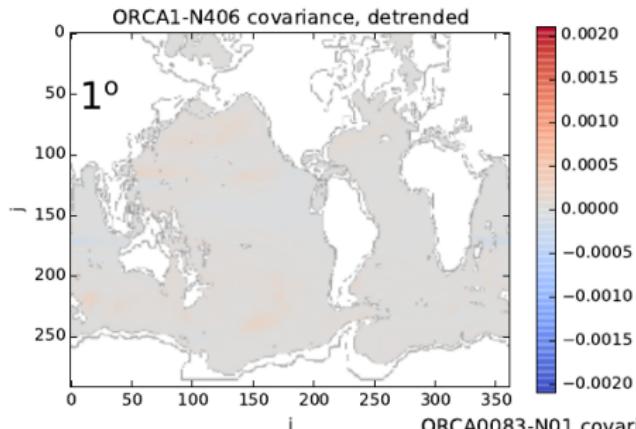
Steric variability



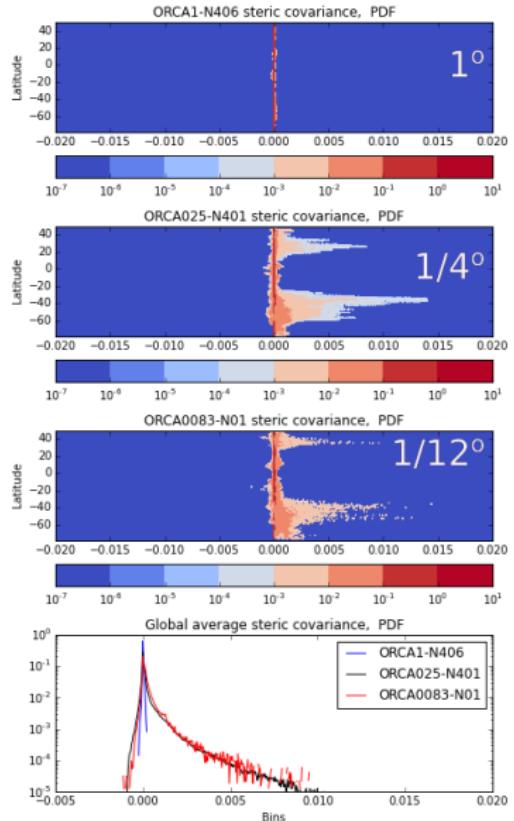
Steric variability PDF



Steric covariance



Steric covariance PDF



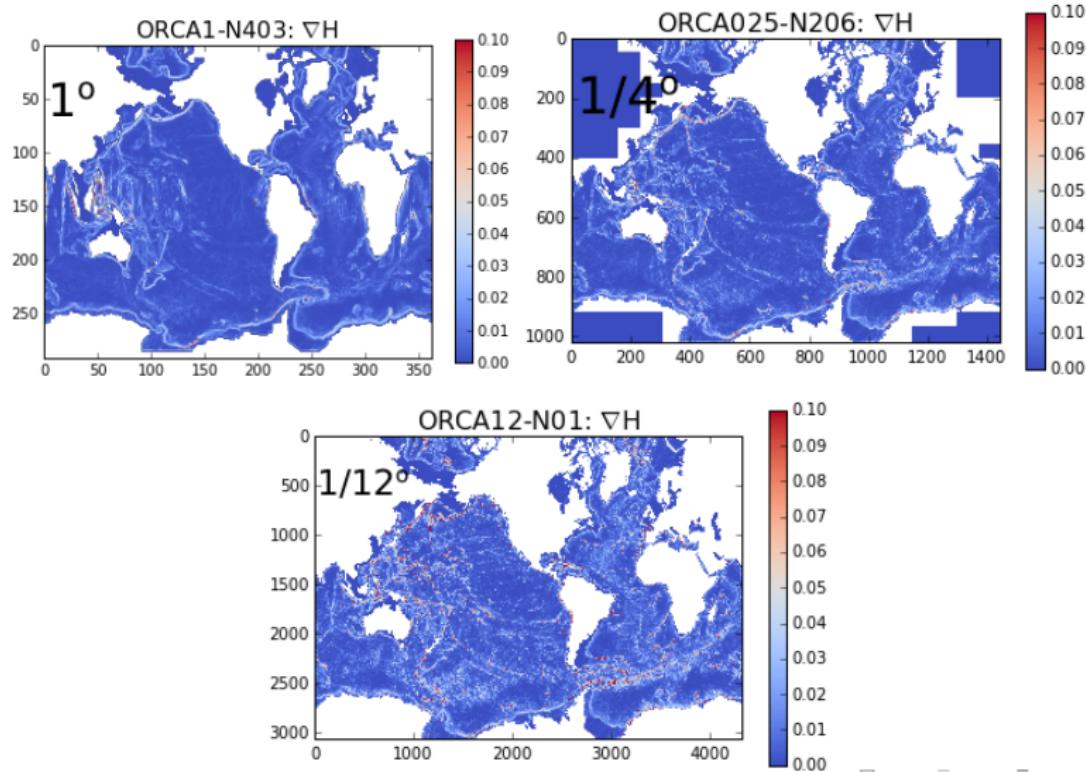
Interior: Summary

- Increase in surface<->deep covariance indicates allowing eddy-features changes information exchanges
- At 1° any covariance is confined to low temporal frequencies
- Inviscid assumption:
 - Our work does not assess the role of the interior explicitly, but suggests that the adjustment to surface fields could be affected...
- On to the interactions with topography...

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∇H : Bathymetry roughness



Bathymetry interactions:

Change in the balance of forces?

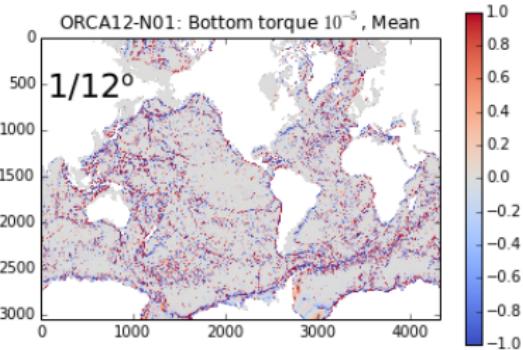
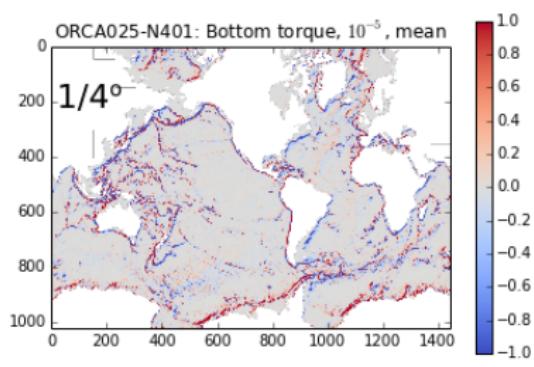
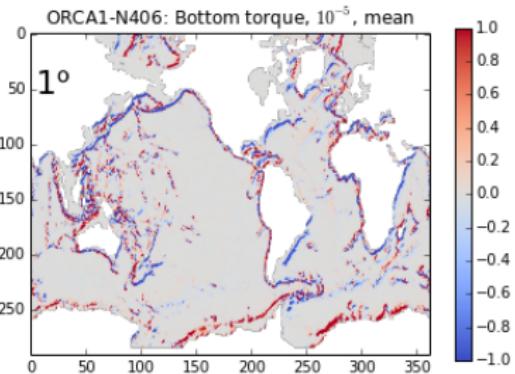
Conserving PV, wind driven gyre sees vorticity innput balanced by flow over f/H contours:

$$\beta\psi_x = \underbrace{-fw_B}_{\text{bottom velocity}} + \underbrace{\nabla \times \tau}_{\text{wind stress}} + \underbrace{R'}_{\text{Non-lin terms}}$$

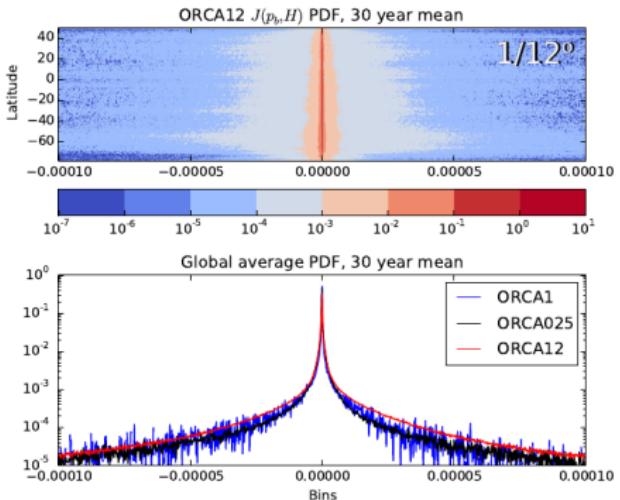
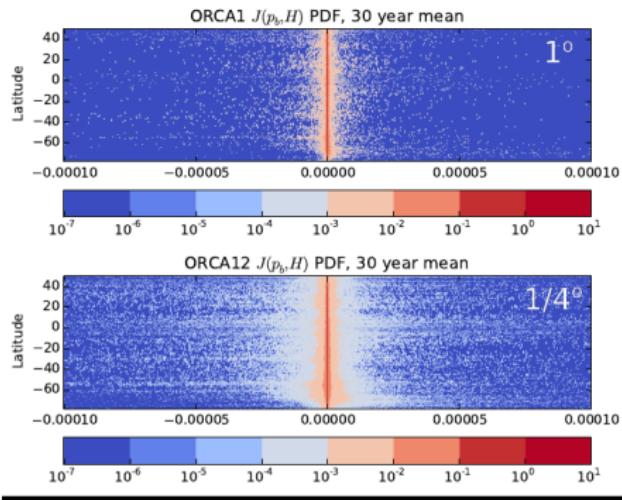
The link between H and vortex stretching:

$$w_B = u_B \cdot \nabla(H) \approx \frac{1}{\rho_0 f} J(p_B, H)$$

Bottom pressure torque ($J(p_B, H)$)



$J(p_B, H)$ PDF



Baroclinic contribution to bathymetry interaction: JEBAR

$J(p_B, H)$ does not seem to account for the change in ψ ?

$$\frac{1}{\rho_0} J(p_B, H) = f \mathbf{v}_{gb} \cdot \nabla H = \overbrace{H(JEBAR)}^{\text{Baroclinic}} + \overbrace{f \bar{\mathbf{v}}_g \cdot \nabla H}^{\text{Barotropic}}$$

Mertz and Wright (1992)

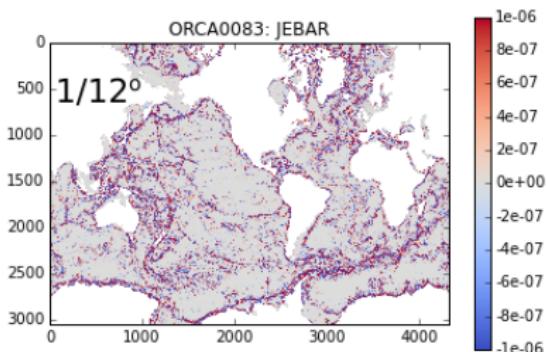
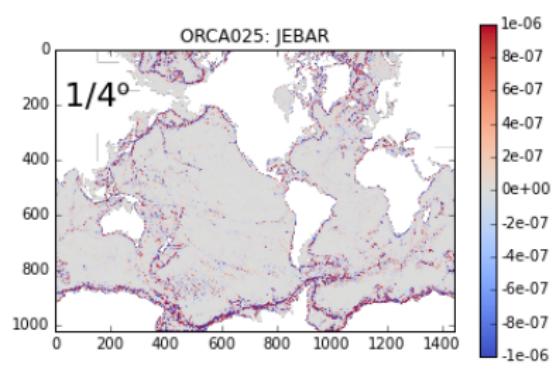
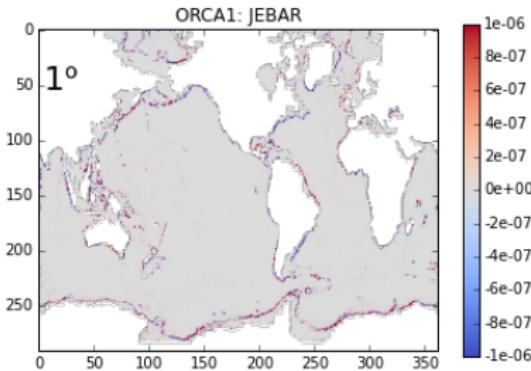
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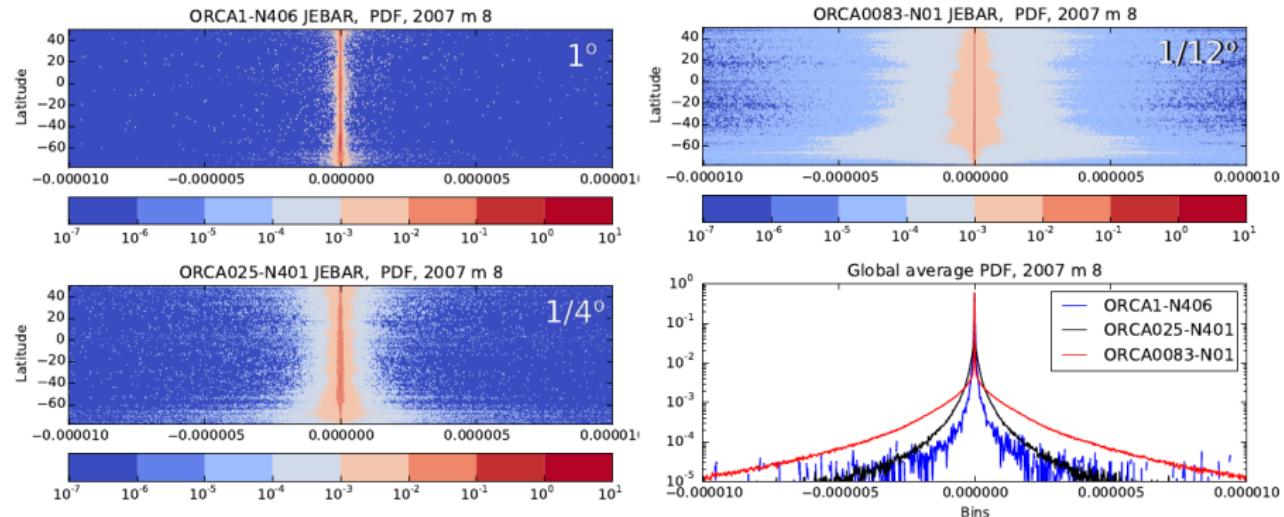
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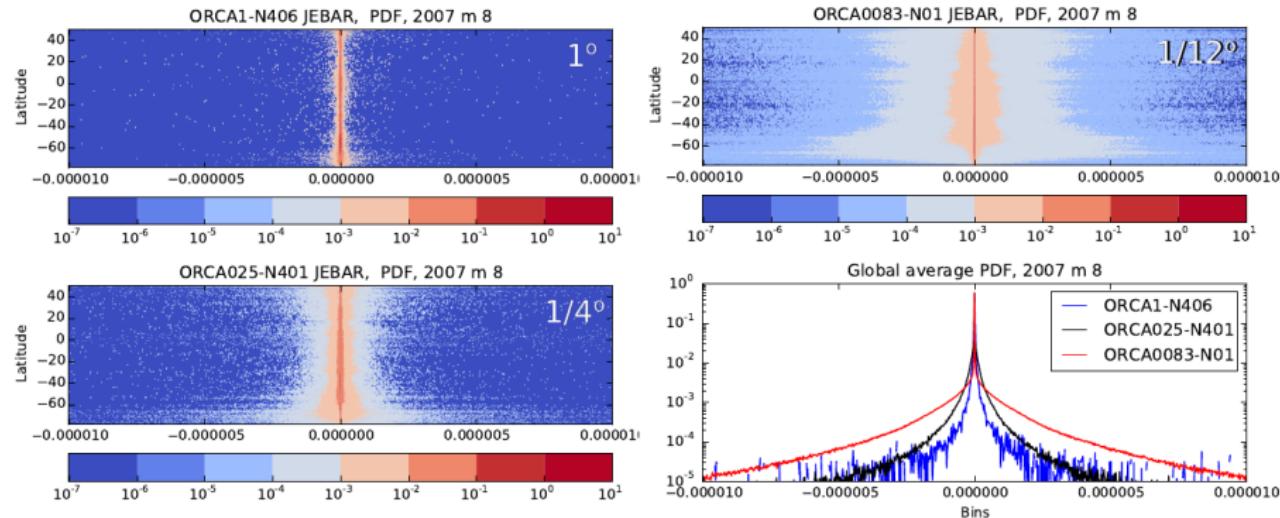


Baroclinic bathymetry interaction: JEBAR PDF



We see a large change in the distribution with resolution

Baroclinic bathymetry interaction: JEBAR PDF



We see a large change in the distribution with resolution

Summary: topography

- Stronger baroclinic contribution to overturning with resolution
- This happens mainly through changes in bathymetry interactions: JEBar
- Scotia ridge and Kuroshio case studies and further details: Sonnewald, M., Nurser, A.G. and Hirschi, J.J.-M. In Prep.

Change in energy dissipation happens baroclinically at depth

- Summarise our results for NEMO in terms of their “utility”

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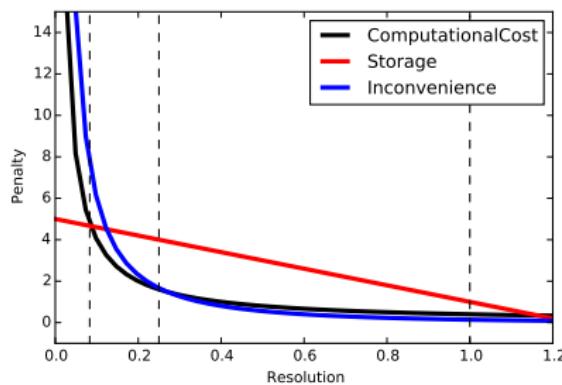
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Tools for comparing the model runs: Utility

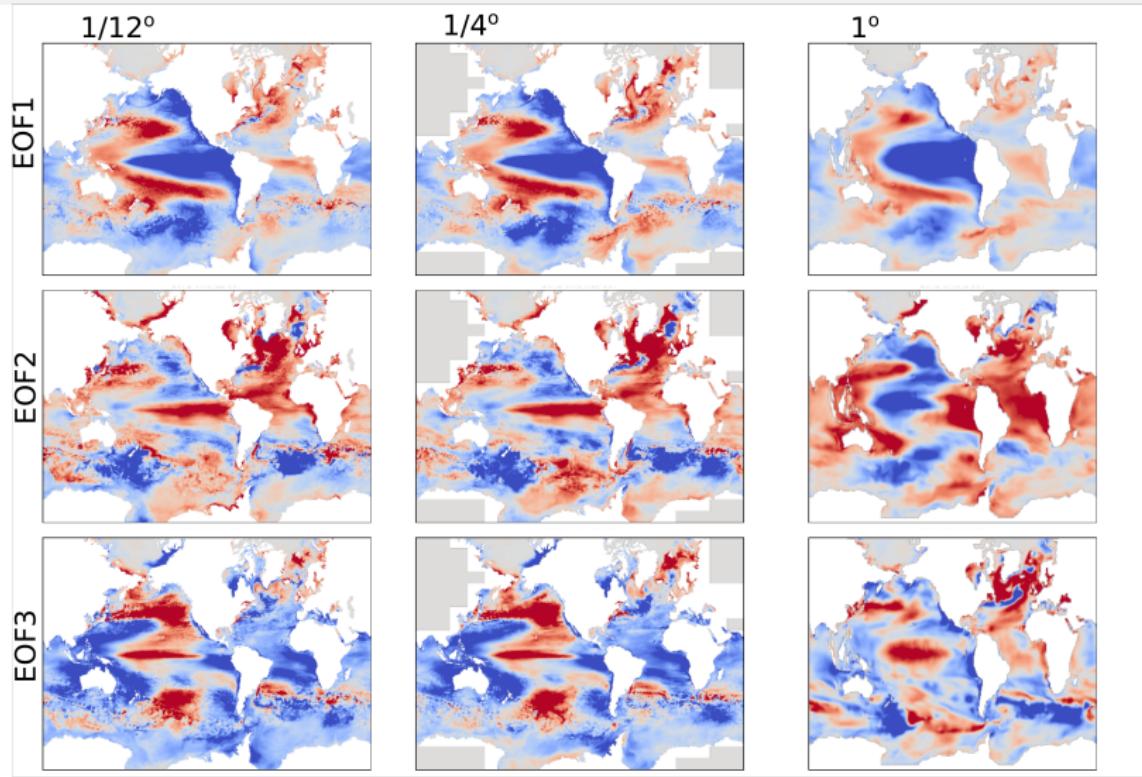
We explore “utility” using notional functions:

- Accuracy (A): $A = 100 - |\sigma_{EOFbaseline} - \sigma_{EOFmodel}|^c$
- Analysis inconvenience (I): $In = -0.2x^{-1} \ln\left(\frac{2}{x}\right)$
- Storage space (S): $S = -4x + 5$
- Computational cost (C): $C = -0.4x^{-1}$

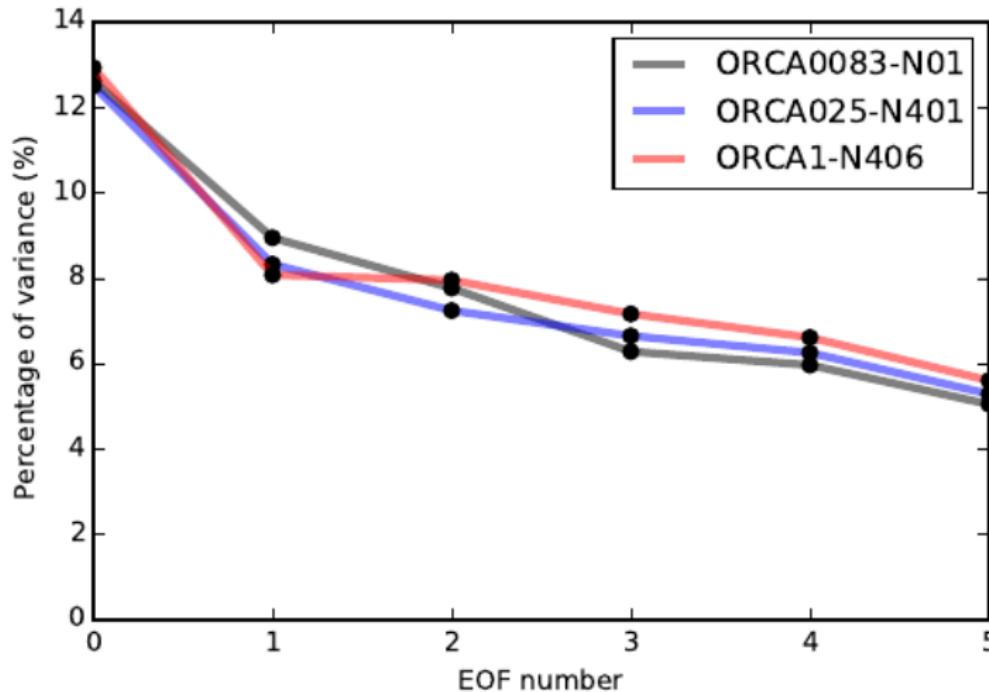
$$\text{Utility} = A + (In + C + S) I$$



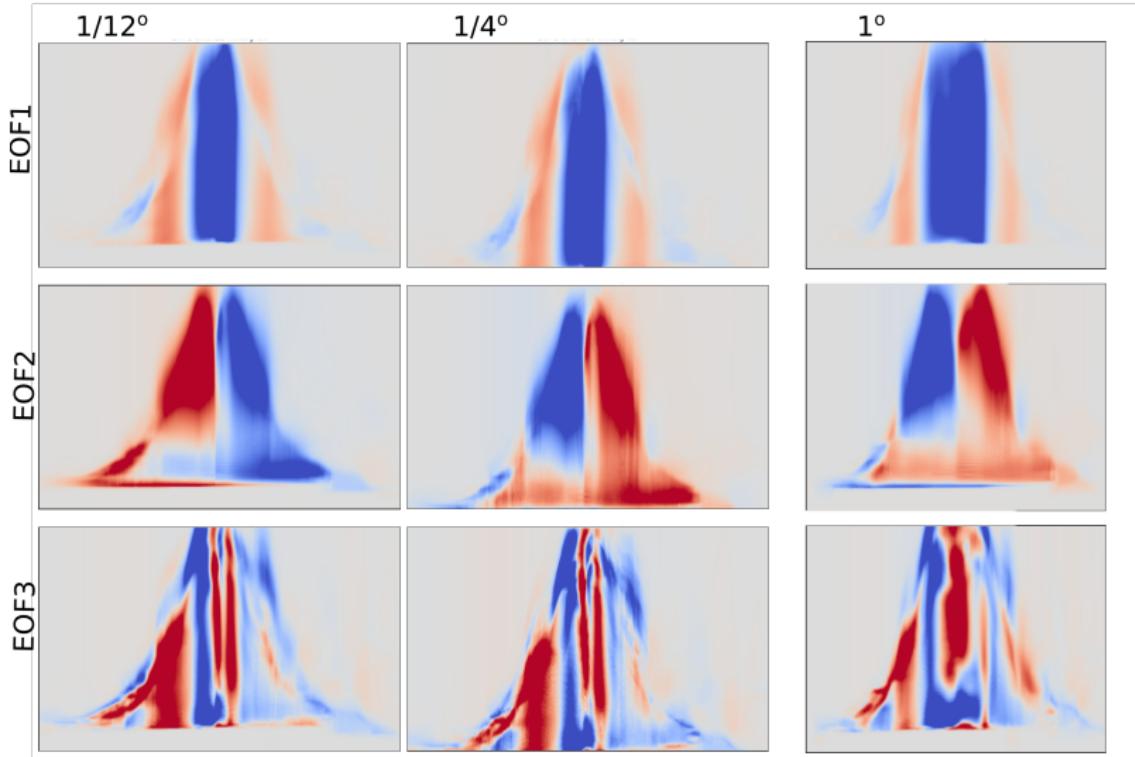
Utility: SST



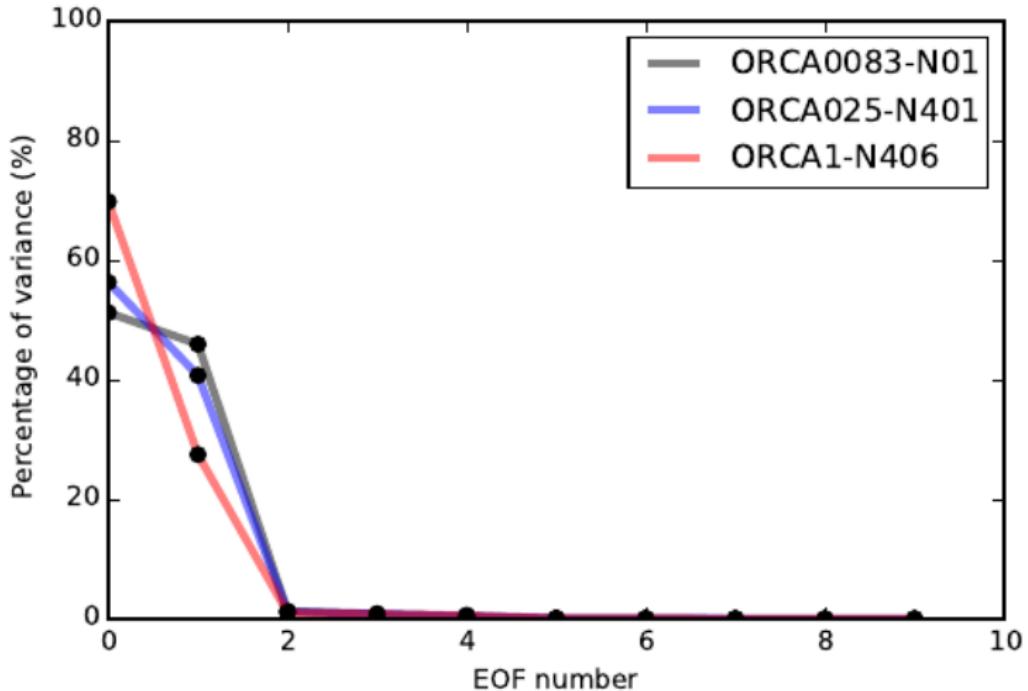
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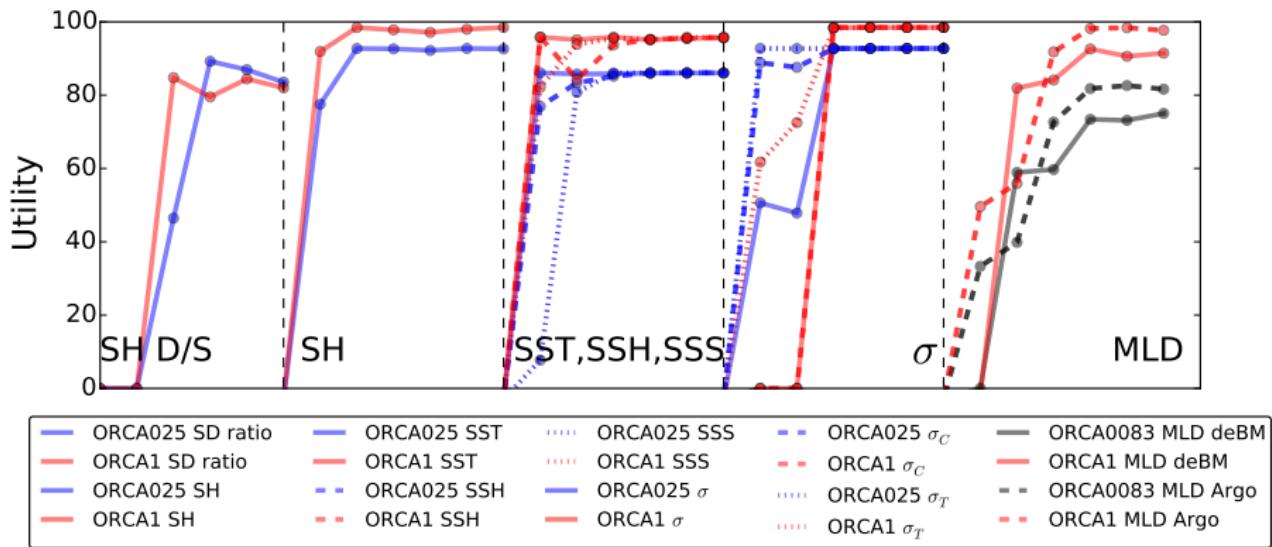


Utility: $\psi(\sigma, y)$



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Conclusion and further work

- The changes in utility in NEMO highlight that certain fields are well captured even at low resolution (MLD) while others require higher resolution.
- We see main changes through interactions with topography and eddy activity
- Finite-time Lyapunov exponents (FTLE) also explored, look at contributions to the overturning..?

Take home message

Choices of modeling tools bias results, considering changes in “utility” can aid comparison and focus efforts

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Selected references:

- Brodeau, L., Barnier, B., Treguier, A.M., Penduff, T. and Gulev, S.: An ERA40-based atmospheric forcing for global ocean circulation models, *Ocean Modelling*, 31 (3-4), 88-104, 2010.
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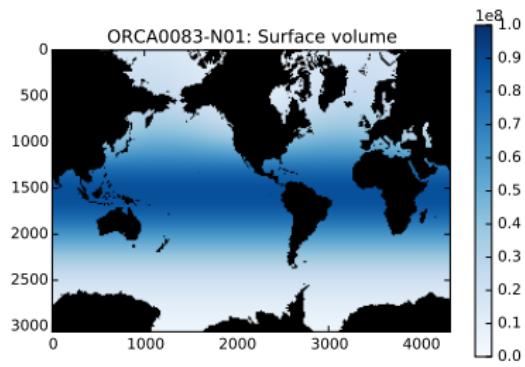
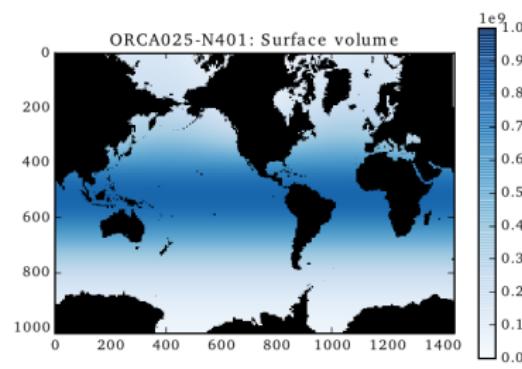
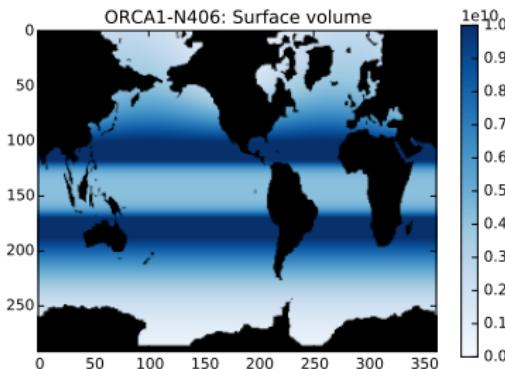
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Selected references:

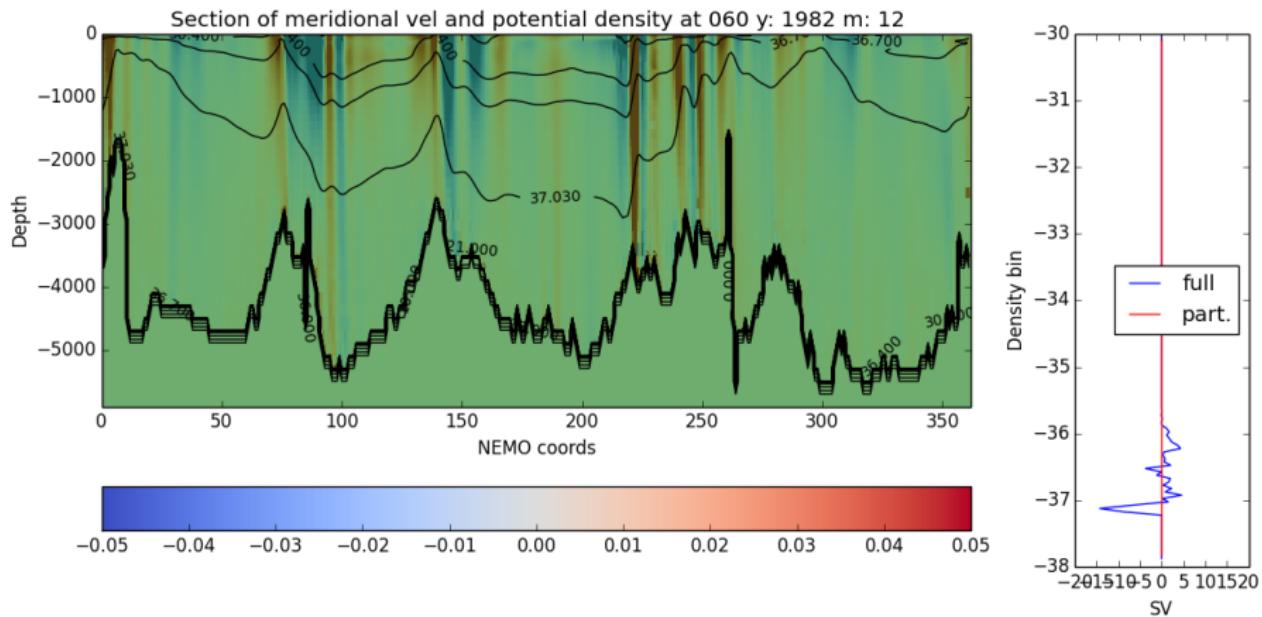
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Thank you!

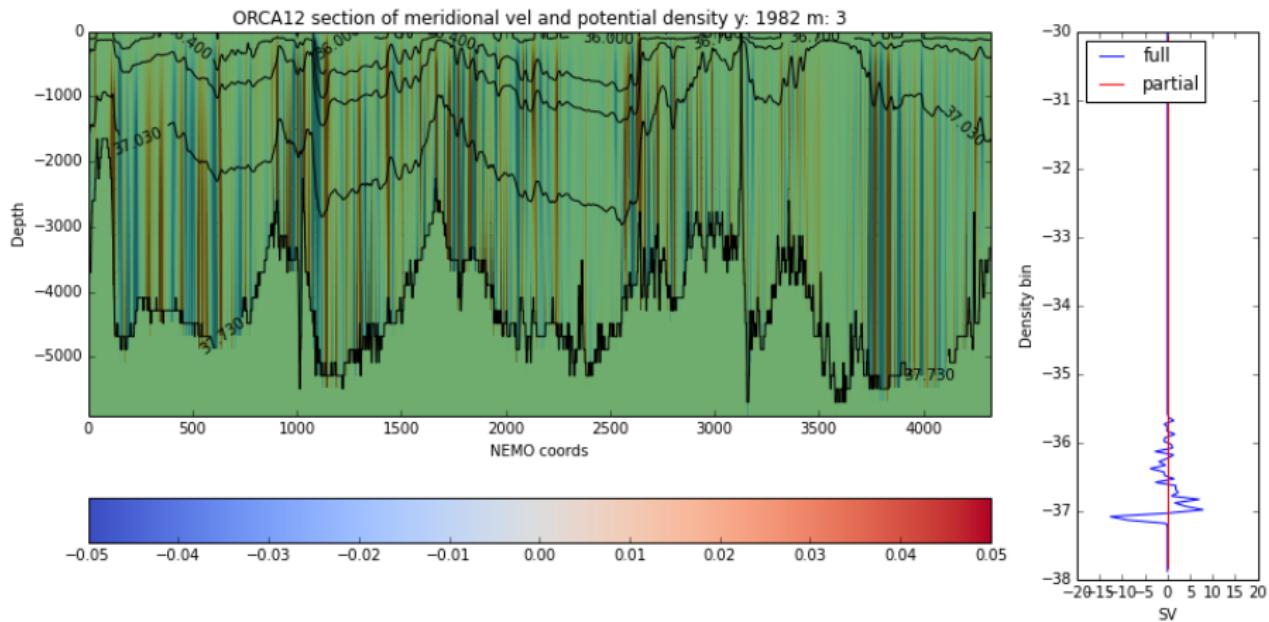
Model grid: Surface volume (m^3)



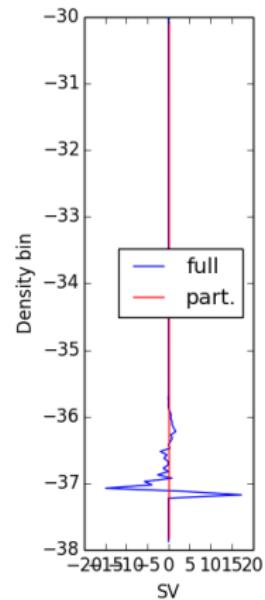
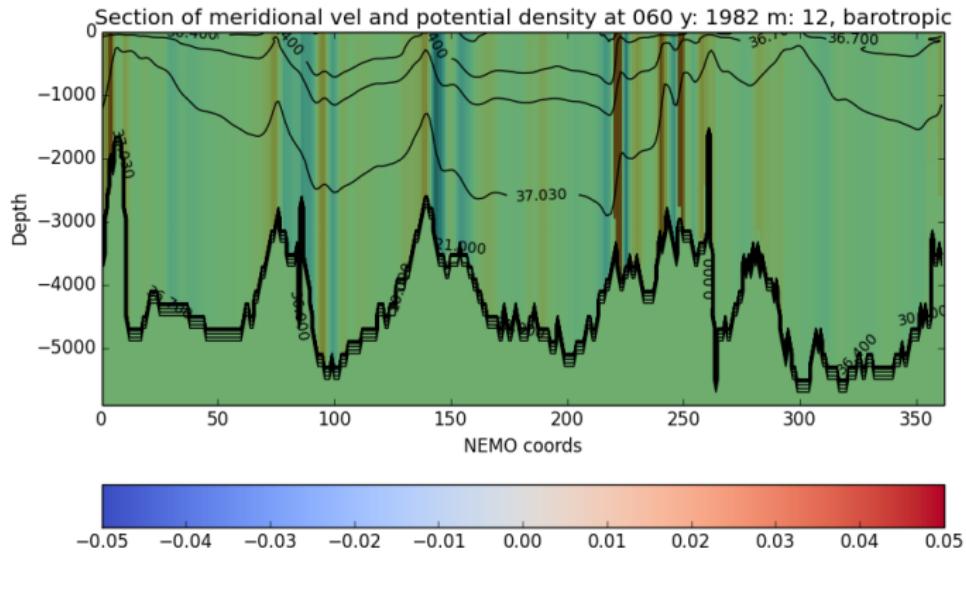
Cumulative density transport 57S: ORCA1



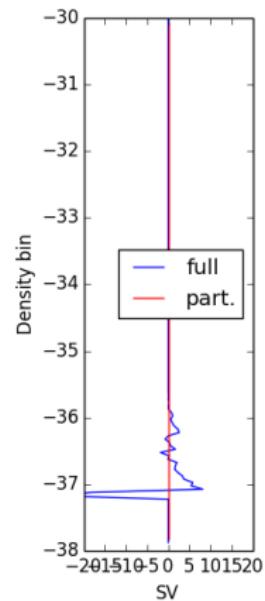
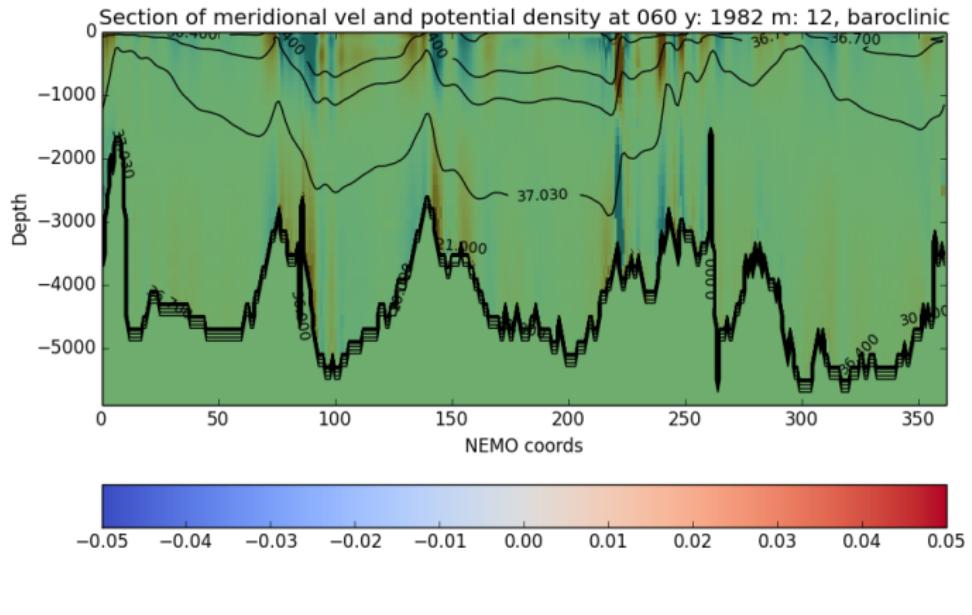
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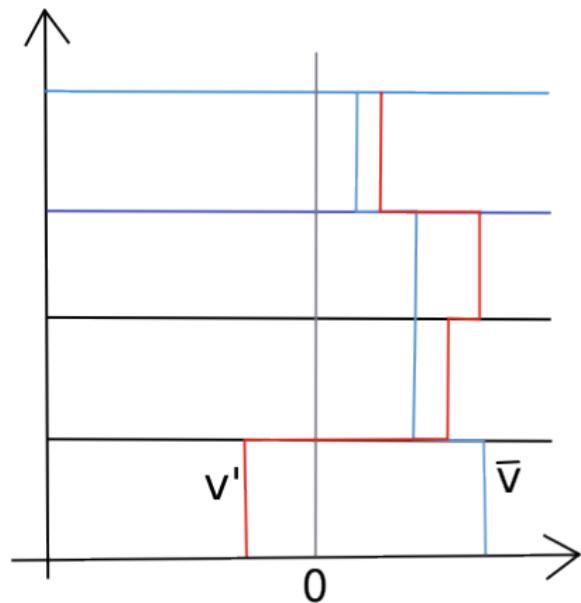
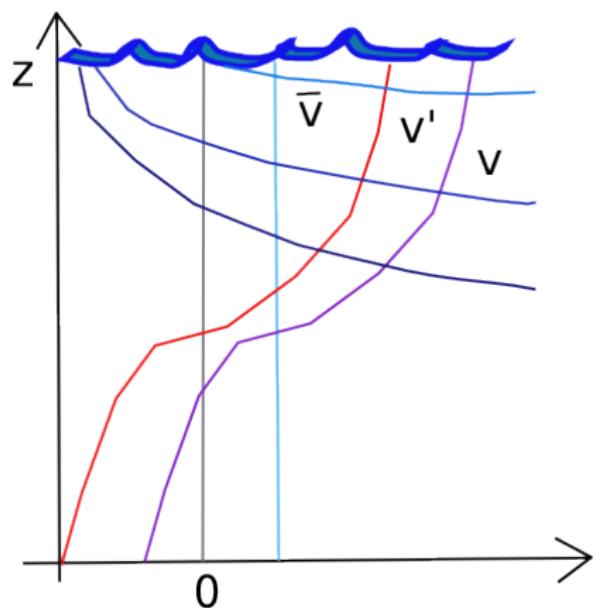
Cumulative density transport 57S: ORCA1 barotropic



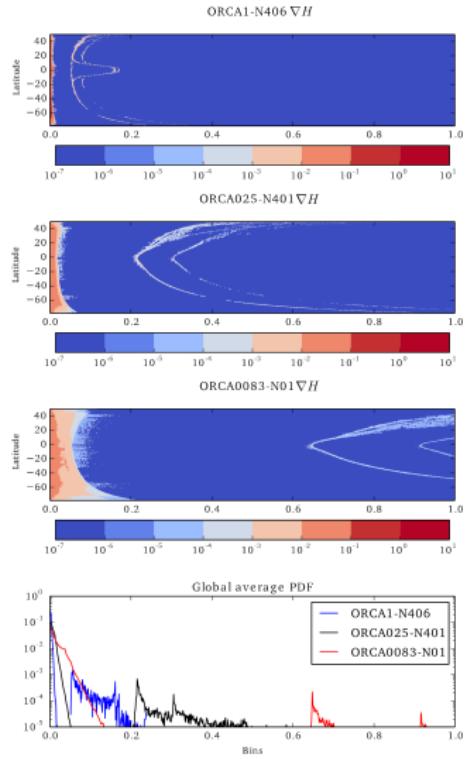
Cumulative density transport 57S: ORCA1 baroclinic

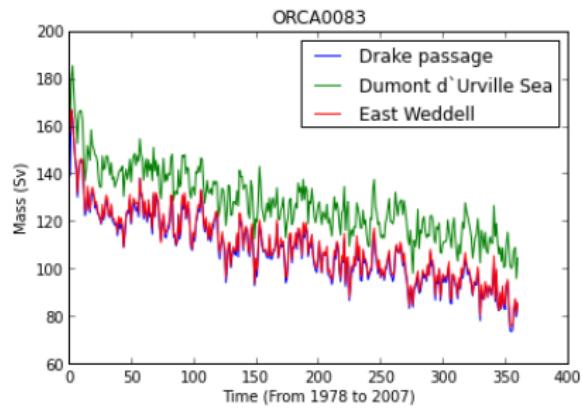
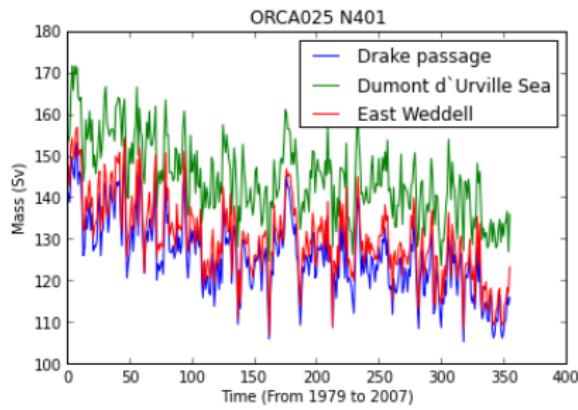
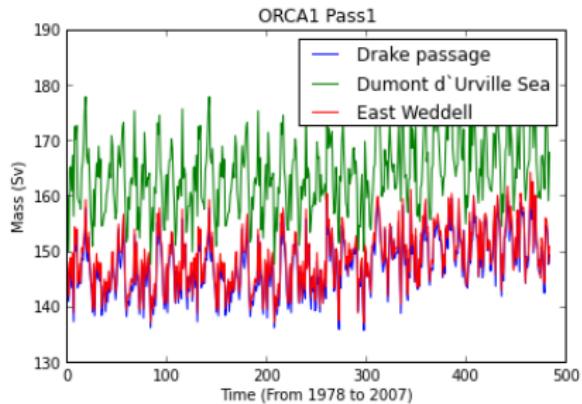


How do we interpret this...?

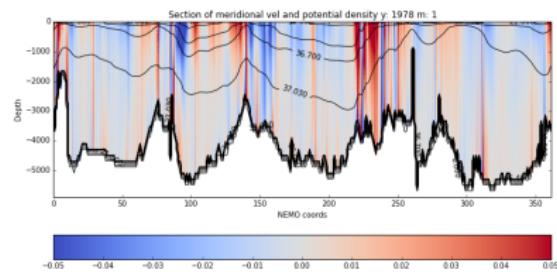
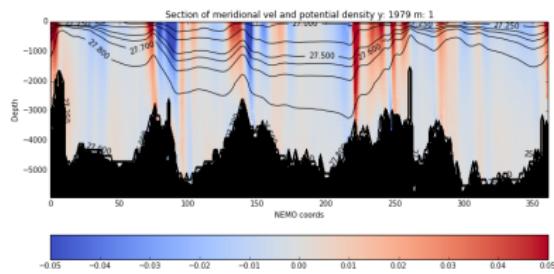


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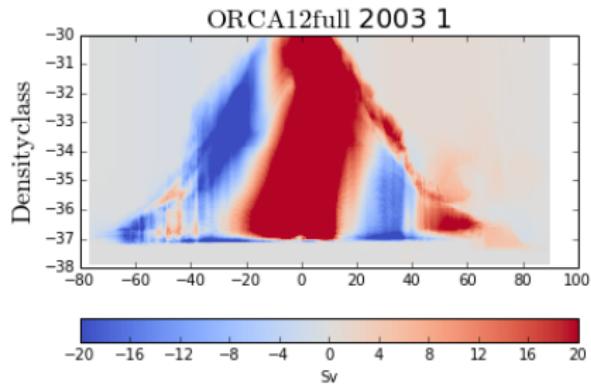
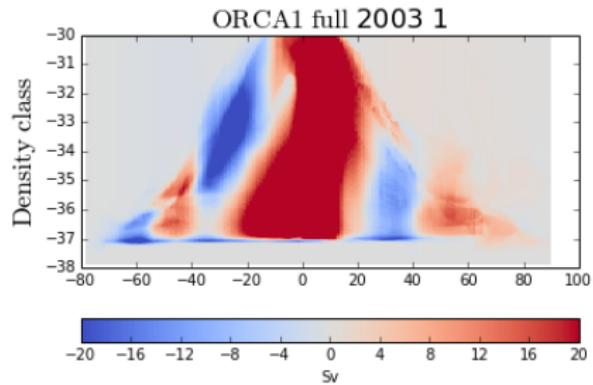




Transport section



OVERTURNING: Density space



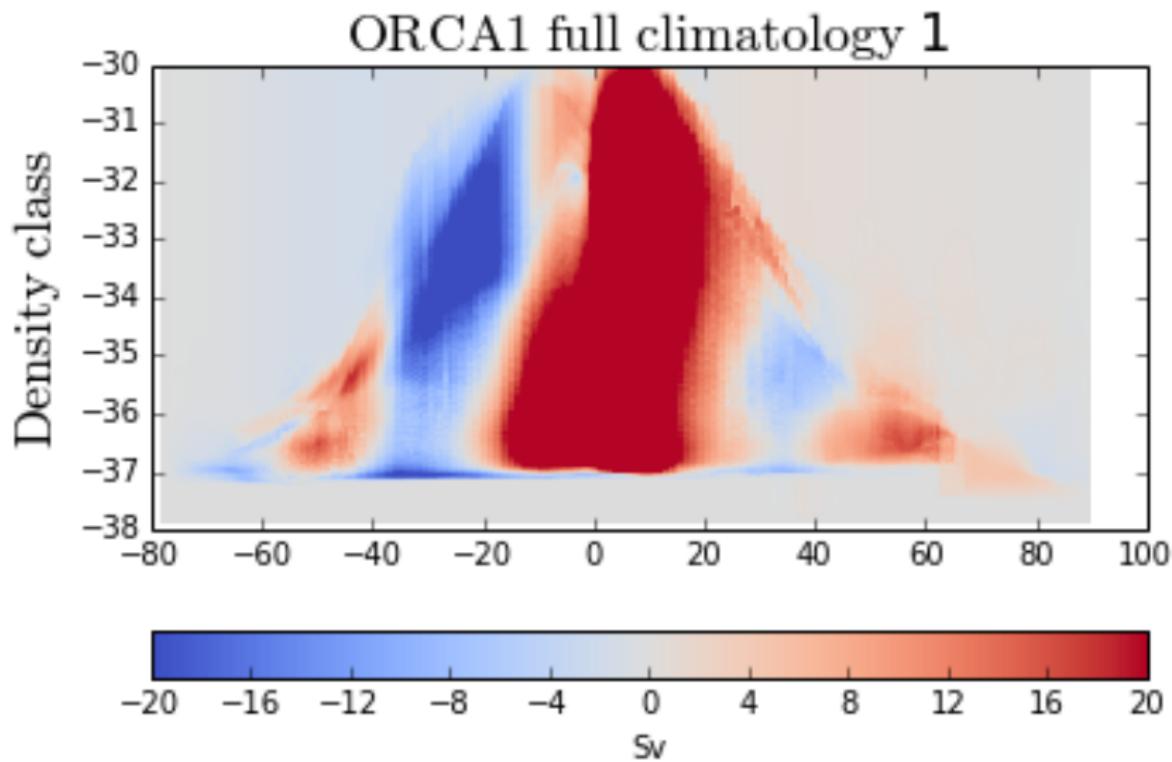
Density space overturning: Baroclinic

mergedmocsigORCA12_baroc_300.png

Density space overturning: Barotropic

mergedmocsigORCA12_barot_300.png

ORCA1-N406: Climatology 1978-2007



ORCA025-N401: Climatology 1978-2007

