The role of mesoscale eddies in the rectification of the Southern Ocean response to climate change

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Abstract

Mesoscale oceanic eddies are believed to have a crucial role in the dynamical and thermodynamical adjustment of the Southern Ocean but, so far, eddy fluxes have only been parameterised within coarse-resolution climate models. We present simulations from a high-resolution global coupled model, the GFDL CM2.4, and compare the results with a coarse version of the same model (CM2.1) under climate change scenarios and idealised Southern Hemisphere wind changes. Compared to the case in which eddies are parameterised, the (marginally) eddy-resolving integrations show that eddies act as a buffer to atmospheric changes and the magnitude of the oceanic circulation response is greatly reduced, consistent with recent theoretical expectations, idealised modelling studies and observations. Changes in the eddy-induced circulation and associated poleward eddy fluxes partially compensate for the enhanced equatorward Ekman transport, leading to weak modifications in isopycnal slopes and ACC transport. The different response in the oceanic circulation when eddy dynamics is active is also reflected in the atmosphere.

[1a] The Models: GFDL CM2.1 and CM2.4

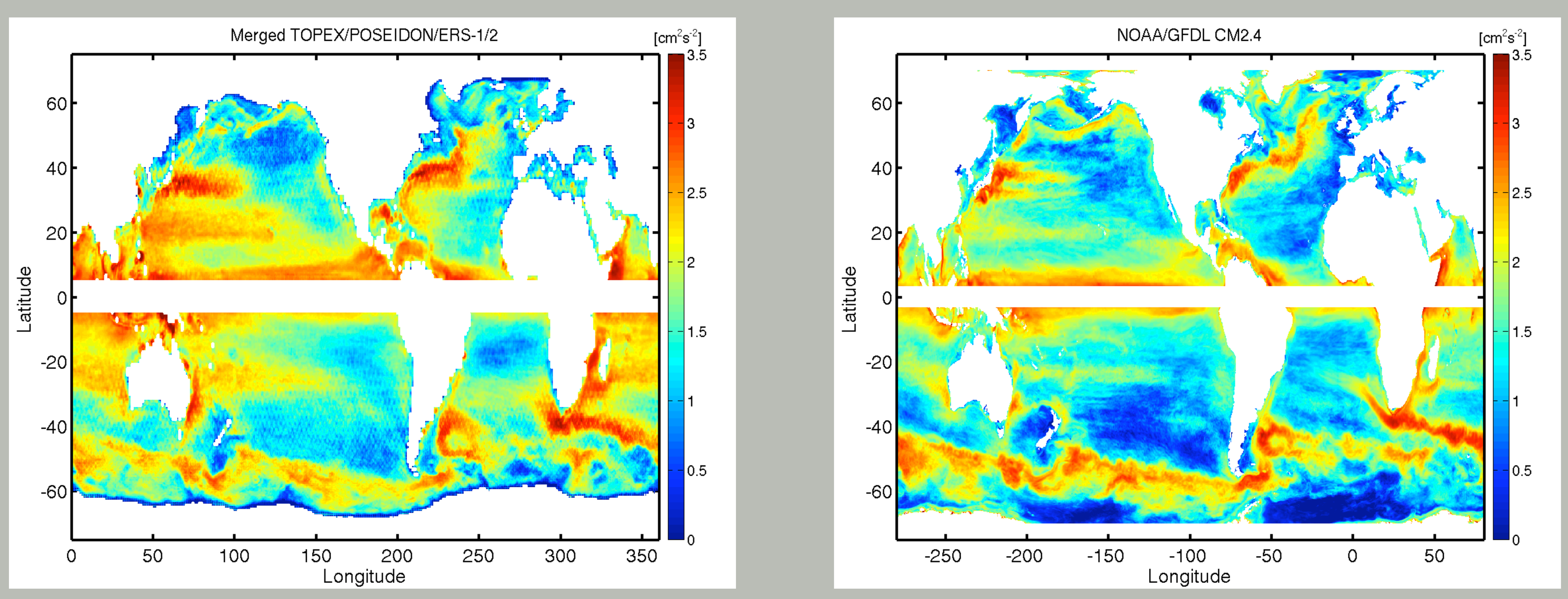


FIGURE 1: Log_{10} of the EKE on the surface geostrophic flow from altimetry (left panel) and the CM2.4 model (right panel)

CM2.1 characteristics:

- The Ocean: MOM4, with 50 vertical layers and a horizontal resolution of 1°. Bryan-Lewis profile for vertical diffusivity + KPP scheme for diapycnal mixing; Gent and McWilliams (1990) parameterisation of isoneutral diffusivity (A_I = 600 m^2s^{-1}); anisotropic lateral viscosity $\nu_h = 10^5$ m^2s^{-1}, background vertical viscosity $\nu_v = 10^{-4}$ m^2s^{-1}
- The Atmosphere: Finite Volume dynamic core, with 24 levels and a horizontal resolution of 2.5° x 2°.

Changes in CM2.4 include:

- The Ocean: a 1/4° horizontal squared grid, horizontal resolution goes down to ~10 Km in polar regions. More accurate numerics, smaller viscosity, NO numerical diffusion and NO parameterisation of mesoscale eddy mixing.
- The Atmosphere: horizontal resolution of 1° x 1°.

The result of these changes is an ocean flow that is much more energetic and realistic (see Fig.1). CM2.4 has been run for multiple century experiments using the computing facilities available at GFDL.

[1b] The Experiments

- Two set of experiments were carried out with the coarse and high resolution model:
  A) a standard climate change scenario integration (**1Pct2XCO2**) where CO_2 concentrations are linearly increased untill doubling (at year 70) and
  B) an idealised perturbation study with altered Southern Hemisphere winds (**SHW1X**), in which a constant anomalous wind stress pattern, taken from the SRES A1B scenario, is applied to the model ocean south of 20°S.
- We present results from the analysis of 5-day mean outputs averaged on a 5 year interval (176-180 yr).

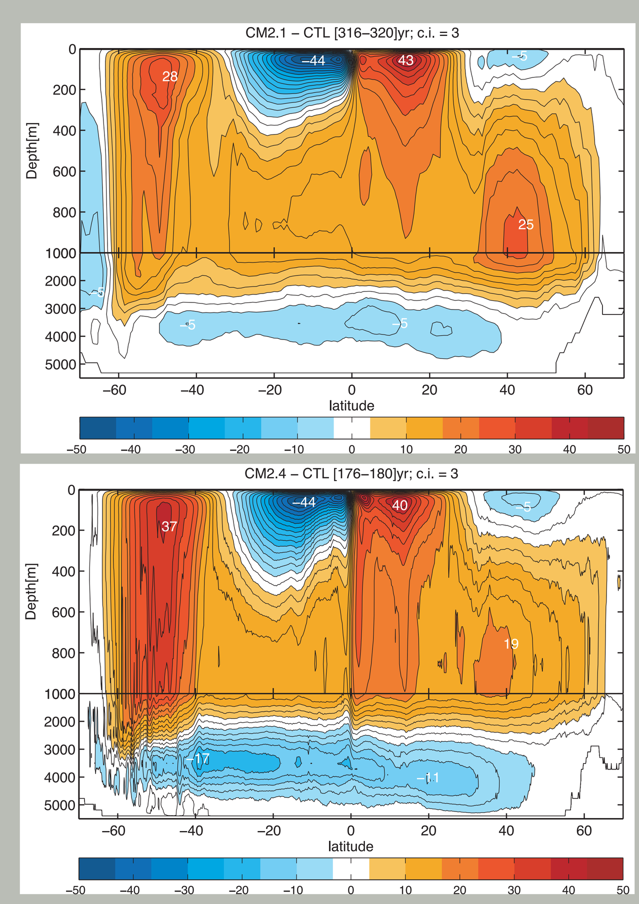


FIGURE 2: MOC in depth-space for CM2.1 (top) and CM2.4 (bottom).

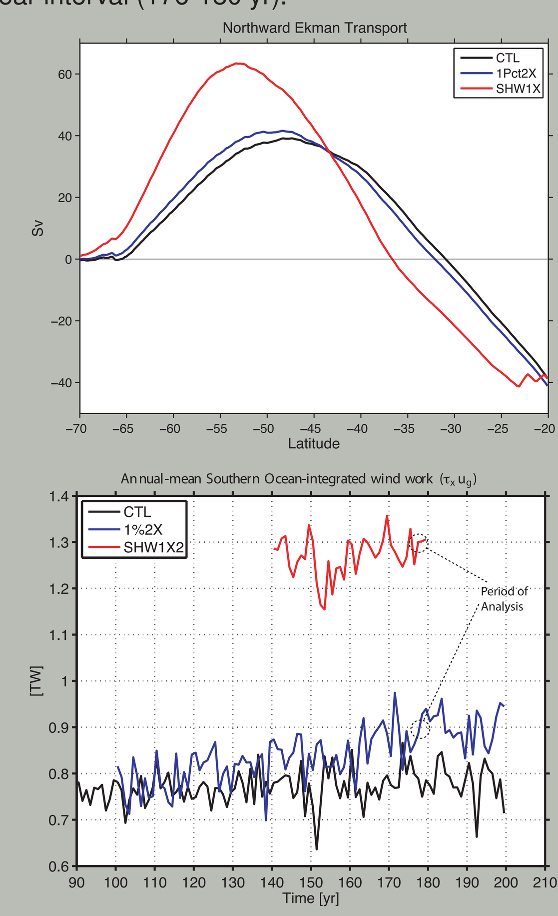
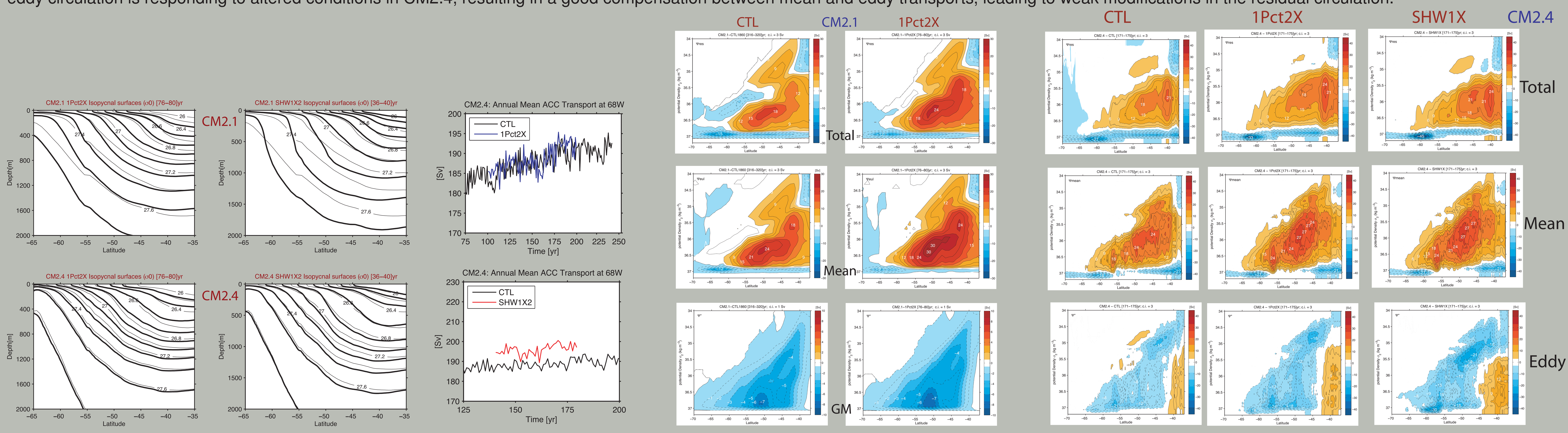


FIGURE 3: Ekman Transport (top) and integrated wind work (bottom).

[2] The Southern Ocean response to Climate Change in the models

CM2.4 shows little change in the tilt of density surfaces compared to the coarse-resolution model, consistent with a weak response in ACC transport and overturning. In CM2.1, GM does not seem to be able to compensate for the increase in mean circulation, possibly due to a parameter (the maximum isopycnal slope, S_{max}) chosen to better represent a 'GM effect' in the coupled model for the present climate. Instead, the eddy circulation is responding to altered conditions in CM2.4, resulting in a good compensation between mean and eddy transports, leading to weak modifications in the residual circulation.



The residual streamfunction Ψ_{res} is obtained by binning the meridional transport into σ_2 density classes, the mean component $\overline{\Psi}$ is computed from the mean Eulerian transport binned into the same time-mean σ_2 classes. The eddy contribution Ψ^* is just Ψ_{res}-$\overline{\Psi}$.

[3] Role of the eddies in compensating for the increased Ekman flux

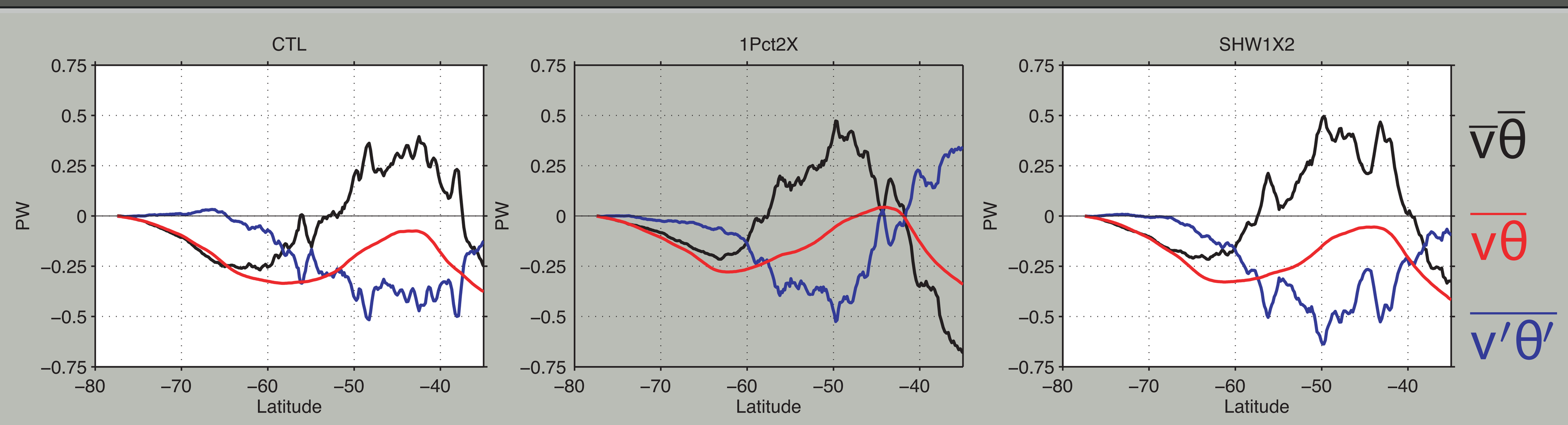


FIGURE 8: Total (red), mean (black) and eddy (red) contributions to the heat transport in the Southern Ocean in the CM2.4 model for different scenarios.

[4] Atmospheric response

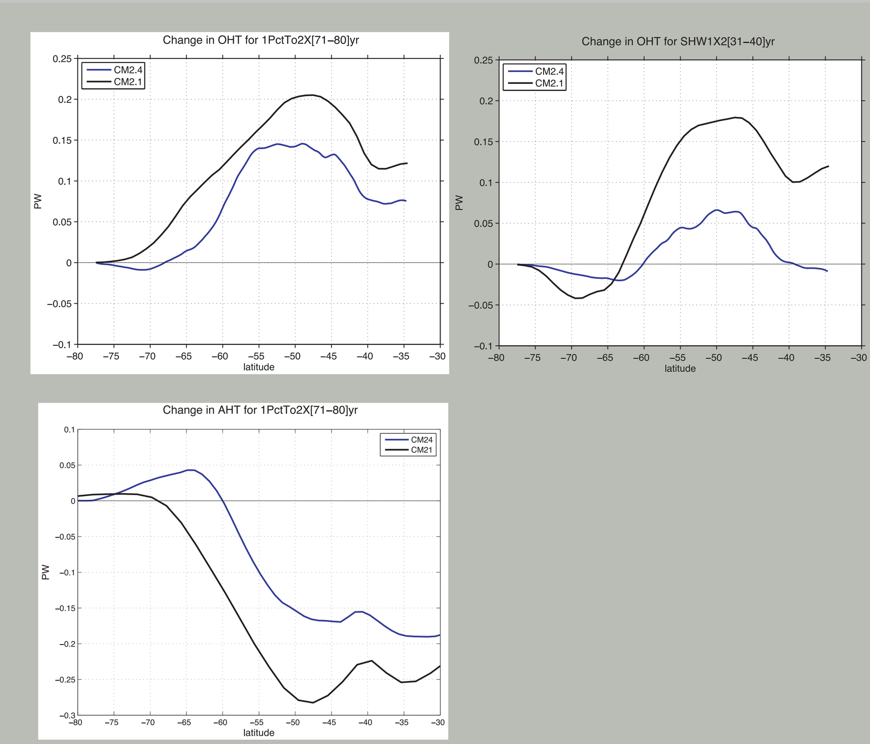


FIGURE 9: Changes in Oceanic and Atmospheric heat transports in the two models.

- In the higher resolution case, changes in the oceanic heat transport to increasing winds are reduced because of the enhanced poleward eddy flux. As the atmosphere tries to compensate for the ocean anomaly, the result is a weaker atmospheric energy transport response, with general consequences for the regional and possibly global climate.

[5] Conclusions

* The high-resolution version of the GFDL model shows a good degree of compensation by the eddies to the increased Ekman fluxes. Hence, the ACC transport and overturning in the Southern Ocean is weakly modified by the extra mechanical energy input.
* CM2.1 does not show 'eddy saturation'. S_{max} – the maximum isopycnal slope – is set to 1/500, which is probably too small for the GM effect to kick in for these simulations. A sensitivity of the GFDL models to this parameter under increasing winds will be performed.

http://www.gfdl.noaa.gov/climate-change-variability-and-prediction

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