The Role of Ocean Mesoscale Eddies in the Response of the Climate System to Increasing Greenhouse Gases

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Objective

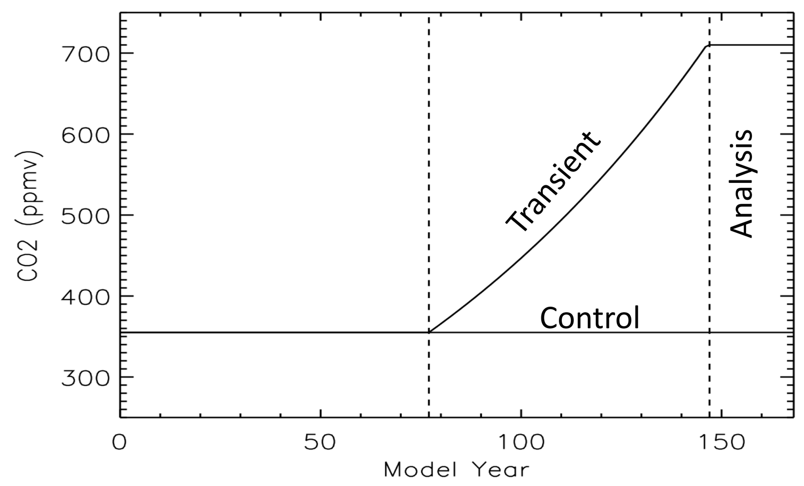
The objective of this study is to determine if explicitly resolving ocean mesoscale eddies quantitatively alters projections of climate change in response to increasing greenhouse gases relative to simulations in which the effects of eddies are parameterized.

Experiment Design

We use the Community Climate System Model version 3.5 in two configurations, both with a 0.5° resolution version of the atmosphere and land component models. The ocean and sea ice models differ:

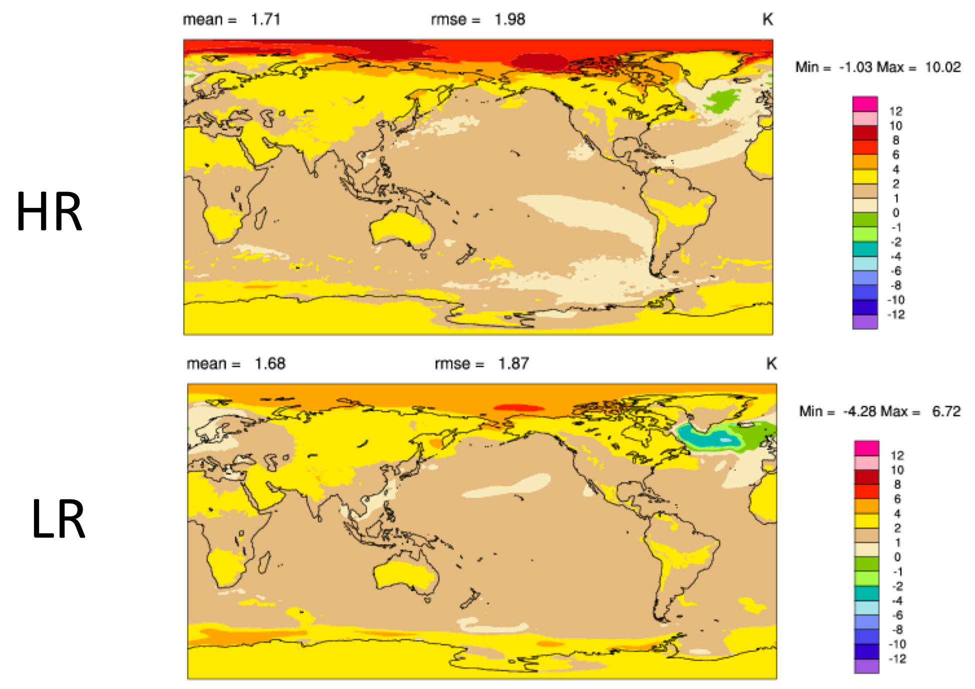
- **LR** : 1.0° ocean with the Gent-McWilliams eddy mixing parameterization including flow-dependent diffusivity (Danabasoglu and Marshall, 2007) and near surface eddies (Danabasoglu et al, 2008).
- **HR :** 0.1° ocean using a biharmonic sub-grid scale closure.

For each configuration we run a control experiment with CO_2 concentration of 350 ppm and a transient climate change experiment with a 1% per annum increase in CO_2 until the concentration is doubled. The analyses below are carried out on averages over the final 21 years of the simulations (the period with with doubled $CO)_2$.



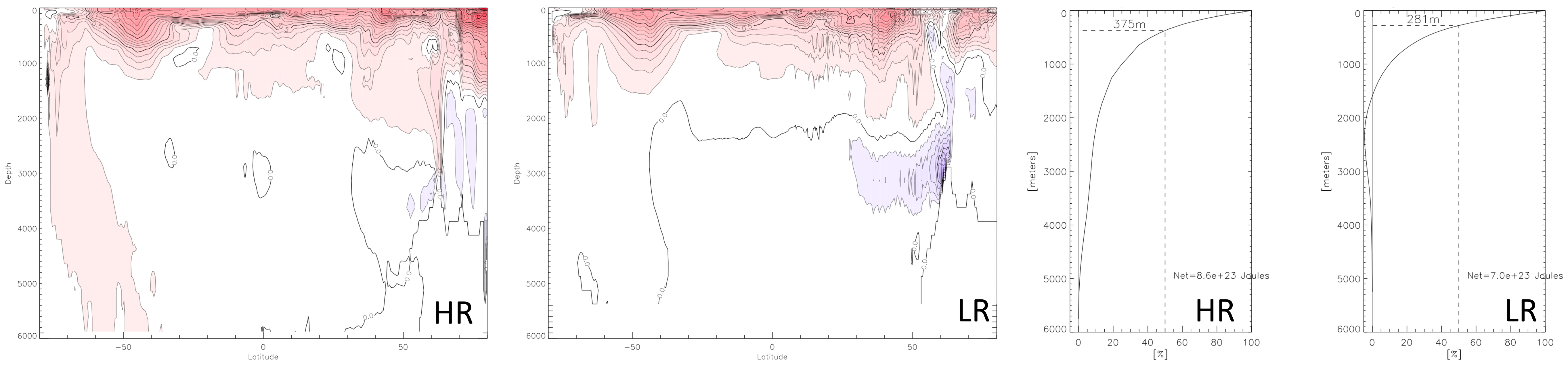
Surface Climate Change

The change in global mean surface temperature is nearly identical in the two experiments (1.7°C). The HR model has a larger change in the Arctic due to lower initial sea ice concentration. There a more extensive and intense region of cooling in the subpolar North Atlantic in the LR case. Details of the evolution of this localized cooling require further investigation, but we speculate that it is due to a larger decrease in the AMOC in the LR case (7 to 8 Sv) compared to the HR case (3 to 4 Sv).



Heat Uptake

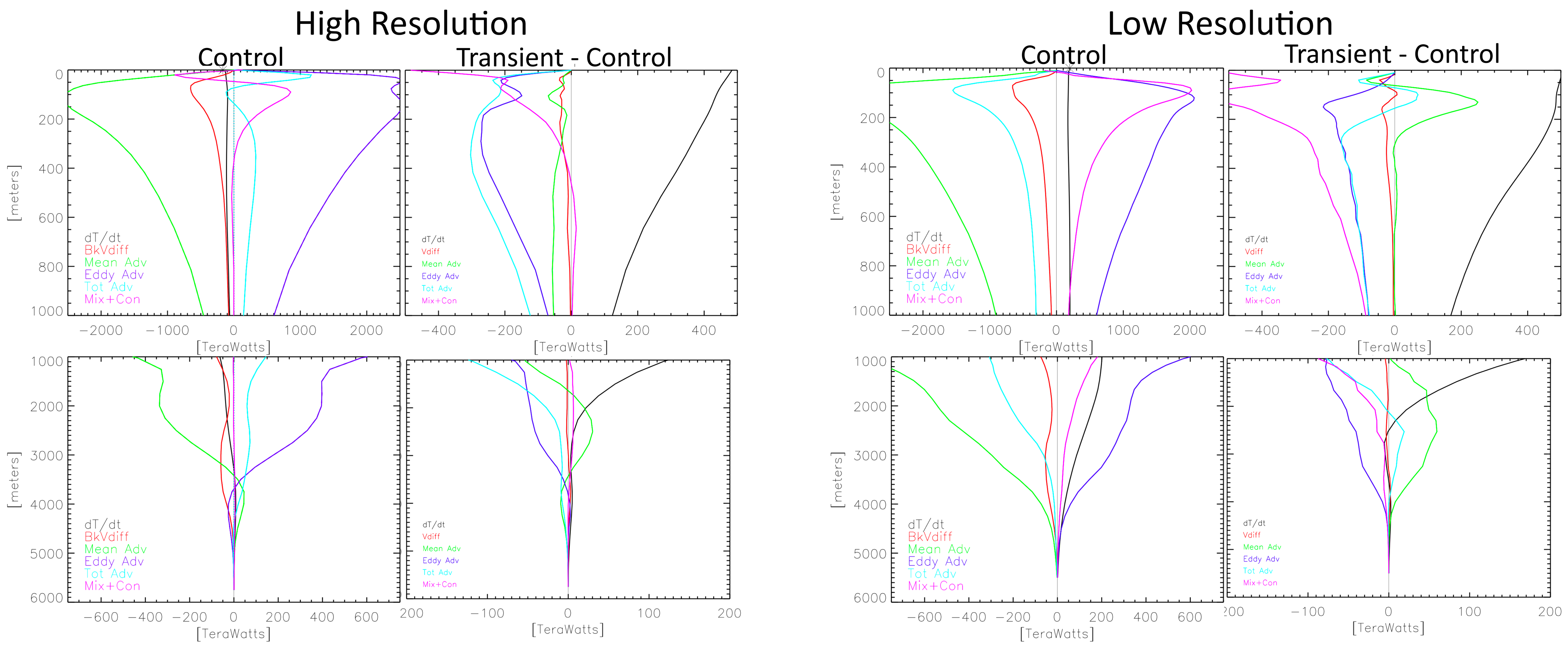
The zonal average temperature change is shown in the panels on the left below. Notable differences are enhanced warming of the deep southern ocean and smaller cooling of the mid-depths of the subpolar North Atlantic in the high resolution model. As a result, the net global heat uptake shown in the panels on the right is larger and penetrates deeper in the high resolution case.



Horizontally Integrated Heat Budget

To investigate the mechanisms of ocean heat uptake, we consider the heat budget for a control volume below depth z. Note that positive fluxes (out of the volume) are cooling terms, negative fluxes (into the volume) are warming terms. For the HR case the eddy advective flux is computed directly from the transient motions, for the LR case the eddy advective flux is computed from the bolus velocity of the GM parameterization. The diffusive flux in the figures below is due to the prescribed background mixing. Additional diapycnal mixing from the convection and the surface mixed layer parameterizations, as well as isopycnal diffusion in the LR case is computed as a residual.

$$\int_{-D}^{z}\iint_{A}\frac{\Delta H}{\Delta t}\,dA\,dt+\iint_{A}\overline{w}\,\overline{H}\,dA+\iint_{A}\overline{w'H'}\,dA-\iint_{A}\kappa\frac{\partial H}{\partial z}\,dA-\int_{-D}^{z}\iint_{A}SMS\,dA=0$$



Conclusions

For the control climate in the both the HR and LR cases the dominant heat balance at all depths is between mean advection (warming) and eddy advection (cooling). For the LR case additional cooling by isopycnal diffusion is important in the upper few hundred meters. The heat uptake in the upper ocean in both transient cases is due primarily to a decrease in the cooling terms (eddy advection, isopycnal mixing and convection), rather than an increase in the heating terms. The deep cooling in the LR case is primarily associated with changes in mean advection.

In terms of global average surface climate and upper ocean heat content, current parameterizations of mesoscale eddies provide a quantitatively similar control climate and response to increasing greenhouse gases as directly simulating the eddies. Differences between the simulations that do arise are attributable to changes in both mean and eddy processes.