Mesoscale ocean eddies and climate change over the Southern Ocean

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Introduction

The Southern Ocean is one of the most critical parts of the climate system, but lack of observational constraints and complexity of ocean currents in this region result in it being poorly understood and not well represented in climate models. We use intermediate-complexity models to interpret recent climate change over the Southern Ocean detected in observations and output of Coupled Model Intercomparison Project phase 3 (CMIP3; Moclo et al. 2007) simulations.

Effects of increasing winds in an eddy-resolving Southern Ocean model

In recent years, the research into the role of small-scale (~10-km) processes associated with oceanic mesoscale eddies in setting up the Southern Ocean’s dynamical regime has intensified (Hallberg and Gnanadesikan 2000; Radko and Marshall 2006; Hogg et al. 2008). In particular, modeling evidence suggests that eddies substantially affect the response of the surface and mid-depth ocean currents to changes in the wind forcing associated with human-induced global change (Fyfe et al. 2007).

We studied these effects using the eddy-resolving quasigeostrophic general circulation model (Q-GCM, version 1.3.1) in ocean-interior–mixed-layer configuration used by Hogg et al. (2008); in particular, this configuration included the Southern Ocean’s topography. While this model is dynamically idealized in the sense that it does not resolve explicitly the thermodynamics of the Southern Ocean, it is ideally suited for simulation of ocean circulation’s perturbations about the mean state, including those due to nonlinear processes and eddies (see Fig. 2).

We performed Q-GCM ensemble runs forced by linearly increasing wind-stress forcing and examined the SST trends simulated in these runs. Bottom panel of Fig. 3 shows the dependence of the south–north temperature difference trend on the rate of change of wind-stress forcing. The temperature difference was computed for SST anomalies averaged between 55ºS and 50ºS (blue line), as well as for the 60º–50ºS–50ºS SST rate of change is of about 0.1ºC per decade, which is about sufficient to rationalize the observed 0.7ºC difference between the Southern Ocean’s temperature distribution is linked to the Southern Ocean’s being in the so-called eddy-dominated regime (e.g., Hogg et al., 2008), so that increased, momentum-driven advection (i.e., eddy currents) reduces the SST rate of change, while increasing long-term time-mean currents. Increased mesoscale turbulence mixes warmer water in the northern part of the Southern Ocean with colder water in the south, thus resulting in the southern warming and northern cooling trends.

The nature of the increasing wind-stress effect onto the Southern Ocean SST trends is illustrated in Fig. 4, which shows the model’s response to a 1% per decade increase in wind-stress forcing. The model responses to the different wind stress forcing rates are plotted by light lines. Yellow dashed lines show observed 1975–99 SST trend. Model ensemble means follow the SST trend changes fairly well.

Discussion

The results presented here allow us to argue that the similarity of the CMIP3-simulated SST response to different forcing rate (Fig. 4, despite very different wind forcing (Fig. 2), is due to the models’ making two large opposite errors which balance each other. One of the errors associated with model-underestimated wind intensification is caused by the absence of the related surface cooling in the models (Fig. 4). The other, compensating, error, has to do with nonlinear dynamics of ocean-eddy response to the changing wind input (Fig. 3), since these ocean eddies are grossly under-resolved in the current generation of climate general circulation models (GCMs).

We took initial steps in parameterizing the latter effect in a GCM by tying the model’s eddy diffusivity parameters to wind forcing (Fig. 4). Such parameterizations may lead to better estimates of climate sensitivity to changes in the external forcing. We intend to pursue this line of study in future work.

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For further information

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