Ocean vortices: pacemakers of Southern Ocean climate change?

Effects of eddies on the response of the Southern Ocean to global warming

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In Short

• We developed a new global model configuration with refined horizontal resolution in the Southern Ocean.

• The response of the Southern Ocean circulation and mesoscale eddy activity to climate change was investigated.

• The next goal will be to assess the Southern Ocean sink of anthropogenic CO2 in an eddying ocean.

Motivation and state-of-the-art

Driven by strong westerly winds, the Antarctic Circumpolar Current (ACC) is the dominant feature of the Southern Hemisphere ocean circulation. The ACC is an area extremely rich in mesoscale eddies, i.e. small-scale rings and loops shed by the ACC (Figure [1]). Owing to its vigorous meridional overturning circulation, the ACC is of unique importance for air-sea exchanges of heat, fresh water and atmospheric trace gases, and thus for the evolution of climate under increasing greenhouse gas emissions. The ACC regime accounts for a large fraction of global ocean warming, and for about 40 percent of the global oceanic uptake of anthropogenic CO2 [1]. Observational estimates [2] have recently suggested that the Southern Ocean carbon sink may have significantly weakened in the past decades. It was hypothesized that a concomitant strengthening of the meridional overturning circulation - possibly connected to a sustained increase in Southern Hemisphere westerly winds in past decades - would have brought more carbon-rich waters to the surface, thereby weakening the efficiency of the ACC to absorb CO2. This view is corroborated by coarse-resolution climate models, in which the adjustment of the ACC to a wind increase is dominated by a progressive increase in the tilt of density surfaces across the ACC in response to enhanced northward Ekman fluxes.

On the other hand, high-resolution models with explicit eddies [3] have challenged this view by suggesting that the increase in northward Ekman transport may be compensated by a wind-induced increase in southward mesoscale eddy fluxes. Indeed, observations show that the ACC transport has remained relatively stable in the past decades [4] despite the concomitant wind increase. According to the “eddy saturation” hypothesis, the recent trends in wind forcing should have become primarily manifested in the energy of the ocean mesoscale eddy field - through the release of potential energy via baroclinic instability - with little change in the mean flow strength of the large-scale circulation. Changes in the mesoscale activity therefore appear critical in shaping the Southern Ocean response to climate change. However, ocean eddies themselves exhibit a complicated relationship to atmospheric forcing, and it is still not clear whether mesoscale activity is predominantly wind-forced or stochastic (i.e. unrelated with the overlying wind forcing). Another aspect that adds uncertainty to future climate projections is the role of water mass properties trends for the Southern Ocean circulation. In the past decades the frigid Antarctic Bottom Water forming in the seas around Antarctica has steadily warmed, but the dynamical impacts of this warming on the overturning circulation are still unclear.

This project aims at assessing the role of mesoscale eddies and of water mass property trends in the Southern Ocean response to climate change by using a hierarchy of ocean numerical experiments. The experiments are based on a global configuration of the ocean sea-ice model NEMO-LIM2 used at increasing horizontal resolutions, from 1/2° resolution (ORCA05, non-eddying), to 1/4° (ORCA025, partially-resolved eddies) to 1/12° resolution in the ACC regime (ORION12, eddy-resolving). The ORION12 configuration, developed within the current project, achieves the horizontal resolution of 1/12° in the ACC regime by means of a novel two-way nesting technique, and is capable of providing a highly realistic representation of the Southern Ocean circulation and of its mesoscale eddy activity (Figure [1]).

First results

a. Variability and trends in Southern Ocean mesoscale eddy activity: using ORION12, [5] elucidated the role of Southern Ocean mesoscale eddies in a changing climate. Over the satellite period, the model was capable of capturing the temporal variability of the observed mesoscale activity. In response to the sustained increase in westerly winds since the 1950s, [5] found that the wind-driven trends in mesoscale eddy activity were not uniformly distributed along the ACC. Moreover, the simulations exposed regional differences in the relative importance of stochastic and wind-related contributions to interannual eddy kinetic energy changes. These results add to the complexity of understanding changes in
ocean CO2 uptake, as they open the possibility that the non-uniform distribution of wind-related changes in the eddy activity could affect the regional patterns of ocean circulation and biogeochemical responses to future climate change.

b. Dynamical impacts of abyssal warming around Antarctica: a prominent signal of multi-decadal change in the World Ocean is the warming since at least the 1980s of Antarctic Bottom Water (AABW) forming in the seas around Antarctica. AABW sinks into the abyss and remains relatively isolated from further heat exchanges as it spreads northward to fill the deepest ocean with frigid dense waters. The consequences of this abyssal warming on the global climate are as yet uncertain. [6] found that the ongoing warming of Antarctic Bottom Water, already affecting much of the Southern Hemisphere with a rate of up to 0.05°C decade⁻¹, has important implications for the large-scale meridional overturning circulation in the Atlantic Ocean. In conjunction with a slowdown of the lower limb of the MOC, the upper cell of Atlantic MOC was found to strengthen by 5-10 percent, thereby providing a stabilizing mechanism to the projected weakening of the upper limb of the AMOC as a result of dwindling deep water formation in the subpolar North Atlantic.

Objective for the next year: our goal for the next year will be to develop a new model configuration at an eddy-permitting resolution, capable of realistically simulating the ocean uptake and spreading of atmospheric transient gases (CO2 and CFCs). The simulated distribution of CFCs in the ocean interior provides a valuable means of assessing the model performance with respect to observed values. The analysis of the spatio-temporal variability of CFCs in the ocean interior will provide an estimate of changes in the water mass formation, which is a key process for the uptake of anthropogenic CO2. In addition, through the coupling of the ocean model with a simple biogeochemical model, we envisage a set of simulations designed to assess the magnitude and temporal changes in the oceanic anthropogenic carbon inventory as well as the role of ocean circulation changes for the uptake of anthropogenic CO2.

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More Information


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