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STUDYING THE THERMOHALINE CIRCULATION WITH A COUPLED HIGHER-RESOLUTION SEA-ICE - COARSE-RESOLUTION OCEAN GCM

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1 INTRODUCTION

High-latitude surface conditions play a crucial role in determining the long-term deep-ocean properties and circulation of the World's ocean. Such conditions are to a large extent controlled by the presence of sea ice, in particular by processes associated with its formation and melting, and its drift and dynamic compression. Of particular importance is the occurrence of leads and polynyas. These can be a product of divergent ice drift, either near the shore line or in the open ocean, or of oceanic heat flux, e.g. in conjunction with convection.

Ocean general circulation models (GCMs) typically used for climate studies and studies of the global thermohaline circulation are unable to resolve leads and polynyas. Rather, such are parameterized as open-water fraction per grid cell of a sea-ice model that is coupled to the ocean GCM. Higher resolution (sea-ice) - ocean GCMs would be a logic step toward a more detailed representation of openings in the ice pack. This, however, is not feasible because of the long deep-ocean adjustment time which constrains an ocean model to coarse resolution. Here we present a compromise in which the resolution of merely the sea-ice component is enhanced, thereby refining the representation of leads and polynyas, while retaining the ocean model efficient enough to conduct investigations on the impact of high latitude processes on global deep-ocean properties and circulation.

2 THE MODEL

A global coarse-resolution version of the Hamburg Ocean Primitive Equation (HOPE) model is the starting point for the new model setup. This version is identical to that described in Stössel *et al.*(2002), which is a majorly revised offspring of the version of Drijfhout *et al.*(1996). An overall revised and curvilinear version of this model is described in Marsland *et al* .(2003). The sea-ice component includes thermodynamics following Owens and Lemke (1990) and dynamics that are based on Hibler (1979). Crucial for the coupling of the atmospheric fields to the ocean is the detailed surface heat balance calculation, which features a subgrid distinction between the open-water and ice-covered part of a model grid cell. The overall heat flux per grid cell is thus a direct function of the modelled ice concentration. In order to capture leads created by atmospheric synoptic processes, the wind forcing over Southern Ocean sea ice is provided by daily analyses fields of the European Centre for Medium-Range Weather Forecasts. Otherwise, the momentum, heat and fresh-water flux are based on climatological fields (see Stössel et al., 2002). Furthermore, the model includes a subgrid-scale plume convection parameterization following Paluszkiewicz and Romea (1997)(Kim and Stössel, 2001).

As a first attempt of a higher-resolution sea-ice model "nested" in a coarse-resolution ocean model, we enhanced the resolution of the sea-ice model by a factor of 9, i.e. each (upper-layer) ocean grid point is coupled to 9 sea-ice grid points. For the time being, we introduced this only in the southern hemisphere south of 50S, north of which sea ice does normally not occur (Gloersen *et al.*, 1992). In order to avoid artificial gradients across coarse grid cell borders, all atmospheric forcing fields are smoothed over 9 fine grid points, respectively. All

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relevant oceanic fields are converted from the coarse to the fine grid each time step before sea ice is integrated forward. This procedure involves smoothing of the ocean currents and the sea-surface height. Each time step the prognostic sea-ice calculation is completed, its impact on the ocean requires a conversion of the affected ocean variables to the coarse grid, which involves a simple averaging procedure. Note that the sea-ice variables are not subject to this conversion procedure.

3 RESULTS

Figs.1 show the equilibrium Atlantic meridional overturning circulation resulting from the original model where the sea-ice grid is as coarse as the ocean grid (a) and from the new model version where the sea-ice grid is finer in the Southern Ocean (b). Closer examination reveals that Antarctic Bottom Water (AABW) occupies a larger volume in the new model than in the original model. As a result, the southward flow of North Atlantic Deep Water (NADW) across 30S has diminished, in this case by some 3 Sv. This result suggests an increase of the formation rate of AABW in the new model.

Figs.2 show the winter ice concentration of (a) the original and (b) the new model. Note that the new model results represent averages over the respective coarse-grid areas. Large regional differences occur in the southern Weddell Sea and eastern Ross Sea. These are associated with short-term strong local overturning, which is a common feature when plume convection is applied (Stössel and Markus, this volume). With a finer sea-ice grid, these features seem to vanish. Apparently, the more detailed sea-ice surface conditions are effective in smoothing coarse-grid gradients, thereby inhibiting extreme local coarse-grid scale fluxes.

As enhanced in Fig.3, a substantial reduction of ice concentration along several critical stretches of the Antarctic coastline (e.g., along the Weddell Sea) emerges with the finer sea-ice grid. This essentially translates into larger coastal polynyas. The corresponding difference pattern in the annual net freezing rate (not shown) indicates substantial enhancement at such coastal grid points. This is the main driver for the enhanced AABW formation, resulting in the larger volume of AABW on the global scale.

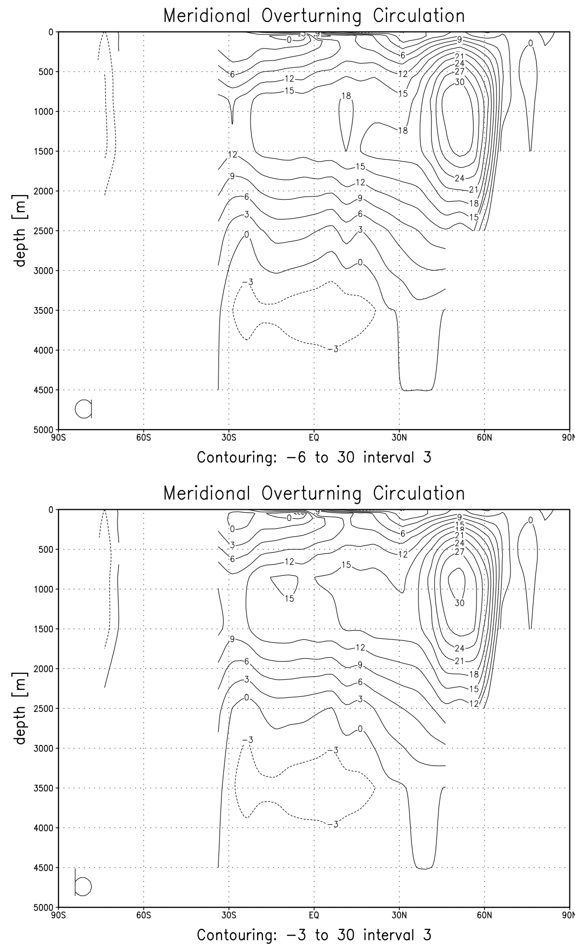

Figure 1: Atlantic Meridional Overturning Circulation of the original model (a) and the new model (b).

4 DISCUSSION

The reason for the lower coastal ice concentration, and thus larger coastal polynyas is obviously the more detailed representation of ridging and lead formation within coastal grid cells. Since the land-sea distribution follows the coarse grid, "bays" emerge in the finer grid, within which sea ice is now represented by 9 points rather than one. It seems that the wider openings in the ice pack are most prominent when the winds blow along the coast. This allows sea ice in the offshore section of a coarse grid cell area to disperse from the coast in the fine grid model. In the original coarse grid model, on the other hand, ice cannot detach from the coast unless the ice drift attains an offshore component.

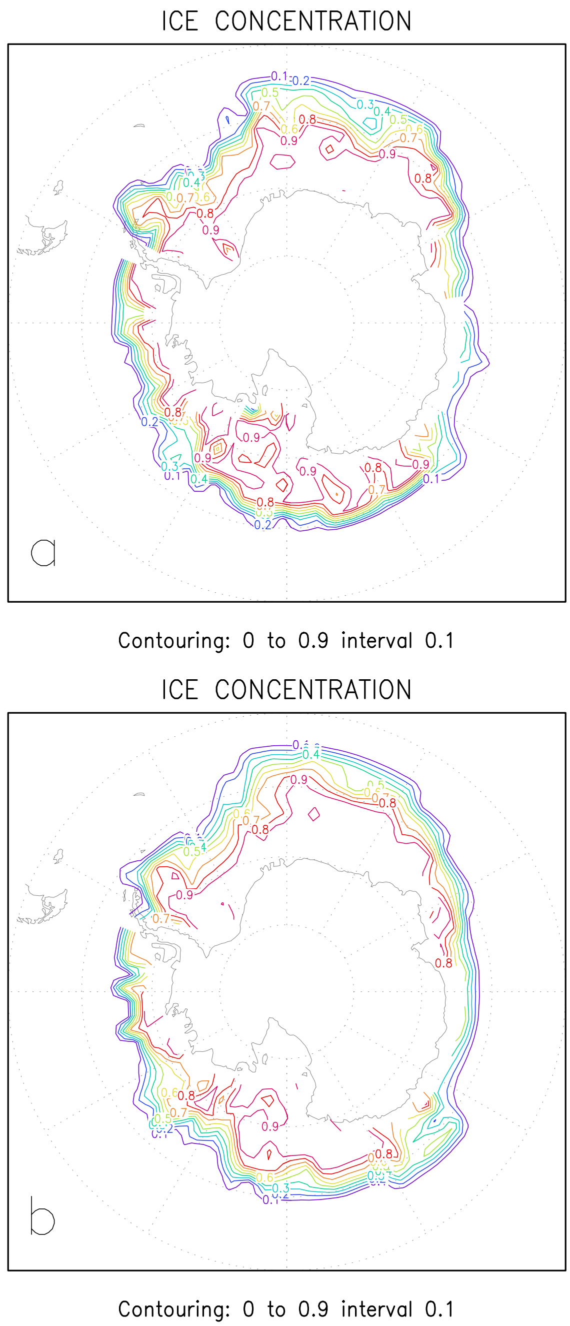

Figure 2: Ice concentration in winter of the original model (a) and the new model (b).

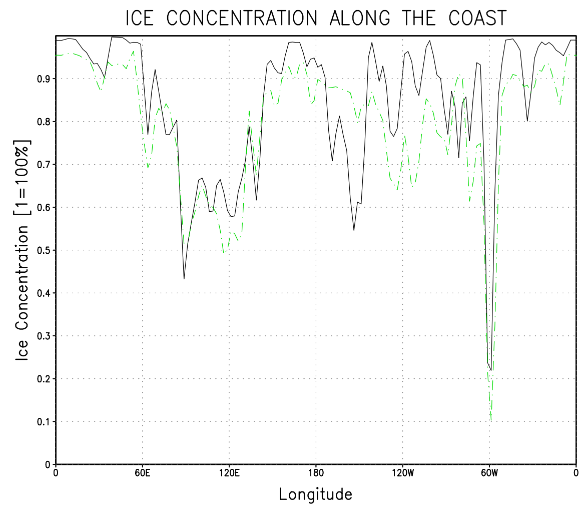

Figure 3: Winter mean ice concentration along Antarctica as simulated by the original model (solid line) and the new model (green, dashed line).

5 CONCLUSIONS

• A finer sea-ice resolution model embedded in a coarse ocean model seems to deliver wider coastal polynyas due to more details emerging in the ice pack along (coarse) coastal structures, such as "bays" and "headlands".

• Spuriously vigorous local open-ocean convection diminishes as a result of the finer sea-ice grid; apparently, the finer sea-ice representation leads to a smoothing of coarse-grid gradients of the surface buoyancy fluxes that ultimately drive plume convection.

• To our knowledge, this is the first attempt of nesting a higher-resolution sea-ice model in a coarse-resolution global ocean GCM; this configuration constitutes an efficient tool for investigations of the impact of high-latitude processes on the long-term deep-ocean circulation while enhancing the resolution of one of the most critical contributors to high-latitude processes, namely the dynamic-thermodynamic sea-ice pack.

6 OUTLOOK

Our intention is to enhance the sea-ice resolution by another factor of 9, i.e. ultimately to an 81-fold higher resolution than that of the ocean component. Such resolution would be close to that of currently available satellite passive microwave data. Such data being provided with daily resolution in time allows for a thorough verification of both the time and the space scale of the sea-ice concentration as simulated in an ocean GCM of the sort typically used for global climate studies.

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