Sea-Ice Parameterization in the MIT GCM

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Introduction

Sea ice covers up to 30×10^6 km^2 of the ocean's surface (almost 10%). Because of lack of data, meteorological fields have large uncertainties in polar regions. The inclusion of a sea ice model will permit ECCO to make use of satellite observations over ice-covered oceans. For example, SSM/I ice motion may be a better estimate of surface stress than that provided by NCEP or ECMWF. Another motivation for including sea ice is that global estimates of atmospheric fluxes over the ocean are *not* possible without a sea ice model because of huge storage and transport sea ice terms, e.g., latent heat of fusion and freshwater transport. Finally, a complete global ocean state estimation, the central goal of ECCO, requires inclusion of the Arctic Ocean. Proper representation of polar regions in the ECCO products will make it possible to address a host of interesting and important science questions pertaining to oceanographic links in polar-subpolar interactions.

A sea ice model is now available for the MIT GCM and ready for inclusion in the first public release of the model. The sea ice code is robust (53-year global integration with NCEP forcing), sensible (results already compare favorably with data prior to any tuning or assimilation), clean (a single entry point and relatively trouble-free parsing by the adjoint model compiler), and parallelized (the 53-year integration used 32 processors). Herein we discuss sea-ice model characteristics, its numerical implementation, some prelinary results, and remaining challenges.

Sea-Ice Model Description

Sea-ice model thermodynamics are based on Hibler [1980], that is, a 2-category model that simulates ice thickness and concentration. Snow is simulated as per Zhang et al. [1998]. Although recent years have seen an increased use of multi-category thickness distribution sea-ice models for climate studies, the Hibler 2-category ice model is still the most widely used model and has resulted in realistic simulation of sea-ice variability on regional and global scales. Being less complicated, compared to multi-category models, a 2-category model will permit easier application of adjoint model optimization methods.

Note, however, that the Hibler 2-category model and its variants use a so-called zero-layer thermodynamic model to estimate ice growth and decay. The zero-layer thermodynamic model assumes that ice does not store heat and, therefore, tends to exaggerate the seasonal variability in ice thickness. This exaggeration can be significantly reduced by using Semtner's [1976] three-layer thermodynamic model that permits heat storage in ice. Recently, the three-layer thermodynamic model has been reformulated by Winton [2000]. The reformulation improves model physics by representing the brine content of the upper ice with a variable heat capacity. It also improves model numerics and consumes less computer time and memory. We plan to adapt and make use of Winton's thermodynamic sea-ice model in our study.

The ice dynamics models that are most widely used for large-scale climate studies are the viscous-plastic (VP) model [*Hibler,* 1979], the cavitating fluid (CF) model [*Flato and Hibler,* 1992], and the elastic-viscous-plastic (EVP) model [*Hunke and Dukowicz,* 1997]. Compared to the VP model, the CF model does not allow ice shear in calculating ice motion, stress, and deformation. EVP models approximate VP by adding an elastic term to the equations for easier adaptation to parallel computers. Because of its higher accuracy in plastic solution and relatively simpler formulation, compared to the EVP model, we decided to use the VP model as the dynamic component of our ice model. To do this we extended the alternating-direction-implicit (ADI) method of Zhang and Rothrock [2000] for use in a parallel configuration.

Numerical Implementation

The sea ice model is implemented as a package and follows standard MIT GCM package structure and guidelines. To improve portability to all existing and future versions of the MIT GCM, the sea ice package has a single entry point: it replaces the subroutine that loads external forcing fields. All sea-ice input, output, checkpointing, and pickup operations as well as the dynamic and thermodynamic components take place during this single call. Furthermore, contrary to existing practice, the sea ice model does not modify surface temperature and salinity directly. Instead the interaction with the MIT GCM is through the computation of equivalent net fluxes at the ice-ocean interface. This facilitates interfacing with other MIT GCM packages, for example, the mixed layer parameterization.

The sea ice model requires the following input fields: 10-m winds, 2-m air temperature and specific humidity, downward longwave and shortwave radiations, precipitation, evaporation, and river and glacier runoff. The sea ice model also requires surface temperature from the ocean model and third level horizontal velocity which is used as a proxy for surface geostrophic velocity. Output fields are surface wind stress, evaporation minus precipitation minus runoff, net surface heat flux, and net shortwave flux. The sea-ice model is global: in ice-free regions bulk formulae are used to estimate oceanic forcing from the atmospheric fields.

Preliminary Results

The coupled sea-ice ocean model was tested in a 53-year integration using the same configuration as that of the ECCO 2° optimization, that is, an 80°S–80°N quasi-global configuration with 23 vertical levels. KPP and GM mixing schemes were turned on. Daily forcing (12-hourly for winds) was from the NCEP 1948–2000 reanalysis. Overall, the resulting estimates of sea ice extent compare favorably with passive microwave (SMMR, SSM/I) data producing a realistic seasonal cycle and interannual variability prior to any tuning or data assimilation. There are of course residual differences, for example, the model tends to underestimate extent of summer sea-ice around Antarctica. These differences will become the signal for the planned assimilation of passive microwave data.

To understand the impact of sea ice on the large scale ocean circulation, a second 53-year integration was carried out excluding the dynamic/thermodynamic sea-ice model, but maintaining a minimum cap of $-1.8°$ C in the surface temperature. Fig. 1 compares meridional overturning strength in North Atlantic and Southern Oceans for the two 53-year integrations. The presence of sea ice in the model damps both the amplitude and variability of overturning strength. Although the causes for these large differences have not yet been fully diagnosed, it is clear that the proper representation of sea ice can have a huge impact on the large-scale model circulation.

Discussion

The sea ice model is an important step towards the goal of a truly *global* ocean circulation estimate by the ECCO consortium. But much work is still needed. This includes obtaining and testing the adjoint sea-ice model, learning to use passive microwave and other sea ice data as constraints in the optimization, and experimenting with effective sea ice control parameters, for example, ice strength, drag coefficients, and surface albedo. It is proposed that these tasks be undertaken in the older, quasi-global, 2° ECCO configuration before being ported to the current higher resolution one. Another important task is the inclusion of the Arctic Ocean, either through the elegant, but still experimental, cubed-sphere configuration that is being developed by A. Adcroft or through a more conventional approach, for example, by displacing the North Pole singularity over a land location or by using a nested-grid.

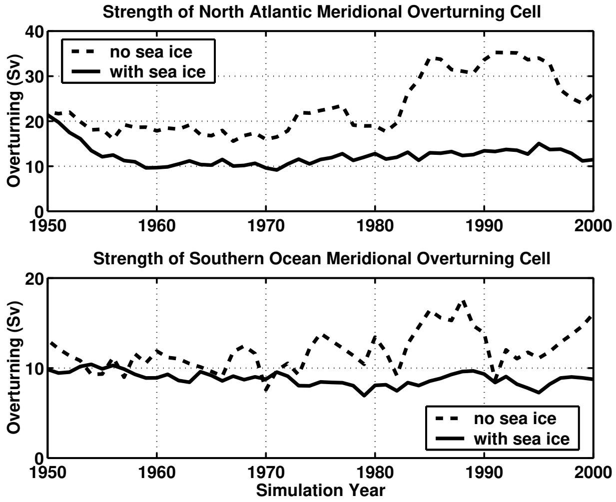

Figure 1. Impact of Sea Ice on Ocean Circulation.

References

G. M. Flato and W. D. Hibler, III. Modeling pack ice as a cavitating fluid. *J. Phys. Oceanogr.*, 22:626–651, 1992.

W. D. Hibler, III. A dynamic thermodynamic sea ice model. *J. Phys. Oceanogr.*, 9:815–846, 1979.

W. D. Hibler, III. Modeling a variable thickness sea ice cover. *Mon. Weather Rev.*, 1:1943–1973, 1980.

E. C. Hunke and J. K. Dukowicz. An elastic-viscous-plastic model for sea ice dynamics. *J. Phys. Oceanogr.*, 27:1849–1867, 1997.

A. J. Semtner, Jr. A model for the thermodynamic growth of sea ice in numerical investigations of climate. *J. Phys. Oceanogr.*, 6:379–389, 1976.

M. Winton. A reformulated three-layer sea ice model. *J. Atmos. Oceanic Technol.*, 17:525–531, 2000.

J. Zhang, W. D. Hibler, III, M. Steele, and D. A. Rothrock. Arctic ice-ocean modeling with and without climate restoring. *J. Phys. Oceanogr.*, 191:191–217, 1998.

J. Zhang and D. Rothrock. Modeling arctic sea ice with an efficient plastic solution. *J. Geophys. Res.*, 105:3325–3338, 2000.