3A.7 PARALLEL CLIMATE MODEL SIMULATIONS WITH A DYNAMIC-THERMODYNAMIC ICE THICKNESS DISTRIBUTION MODEL

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1. INTRODUCTION

Global climate model simulations are influenced by the explicit or parameterized physical processes that they include. Most climate models have some representation of sea ice in the polar regions, which contributes to ice-albedo feedback and a dramatic increase in climate change in the polar regions. Some sea ice components of coupled climate models have been improved in recent years to include ice dynamics and more complex ice thermodynamics, which can, in some cases, highlight deficiencies in other components of the model. Achieving the most realistic representation of ice processes in a climate model requires a balance between the most important processes and their computational costs.

The newest generation of the coupled climate model described here includes a significant improvement in the sea ice model component. It has realistic ice dynamics, thermodynamics, thickness distribution, and is run on a high-resolution horizontal grid. It should provide a more accurate representation of ice processes and ice-albedo feedback than previously included in climate models. Results of simulated ice cover from a long-term coupled climate simulation are presented.

2. MODEL DESCRIPTION

A global atmosphere-ocean-sea ice general circulation model called the PCM/CCSM Transition Model (or PCTM) has been developed from the Parallel Climate Model (PCM, Washington et al., 2000) and the NCAR Community Climate System Model (CCSM), which use similar model components. The PCTM has also been called PCM version 2. The PCTM is composed of the NCAR CCM3 atmospheric GCM, the Parallel Ocean Program (POP) ocean model, and a dynamic-thermodynamic sea ice model. The CCM3 atmosphere is run at T42 resolution (2.8° by 2.8°) with 19 vertical layers. The ocean and sea ice grid is a curvilinear, orthogonal grid with the north pole displaced to a position over Hudson's Bay, and the south pole remaining at 90°S. It has a global-average resolution of about 0.6°, with 1° resolution at the equator, and about 0.25° in the Arctic Ocean. This allows the model to resolve the Bering Strait and some of the Canadian Archipelago. The POP ocean model now also includes the Gent-McWilliams parameterization for isopycnal mixing of subgrid-scale eddies.

The most significant development in the PCTM over the PCM version 1 is the implementation of a new sea ice model component to be used in both PCTM and the NCAR CCSM. It uses the mass- and energy-conserving thermodynamics of Bitz and Lipscomb (1999), the ice thickness distribution model of Bitz et al. (2001), and the elastic-viscous-plastic (EVP) dynamics of Hunke and Dukowicz (1997) with an improved computation of the ice stress tensor (Hunke, 2001). The model uses an implicit solution of the heat equation in sea ice and accounts for the effect of internal brine-pocket melting on surface ablation. It uses a temperature- and salinity-dependent heat capacity and thermal conductivity for sea ice. Surface temperature, albedo, energy fluxes and growth rates are computed separately for each thickness category. Four internal ice-layer temperatures and five categories of ice thickness are used in the GCM run shown here.

3. RESULTS

The PCTM is used to simulate climate and climate change resulting from natural and anthropogenic influences (such as greenhouse gases, sulfate aerosols, and solar radiation changes) over timescales from years to centuries. The results shown here are taken from years 250 to 260 of a simulation of pre-industrial climate using constant greenhouse-gas concentrations from the year 1870. This type of run is used as a spin-up to simulating

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the years 1870 to 2000.

The PCTM sea ice concentrations are shown in Fig. 1, along with the observed 10% concentration from SMMR and SSM/I satellite data (NSIDC, 1997). In the Northern Hemisphere, the modeled ice edge shows considerable agreement with the observed, though excess ice appears in the Pacific Ocean and too much open water appears in the Beaufort Sea in summer. In the Southern Hemisphere, ice cover is too large in winter, and it is too little in summer in the Pacific Ocean sector and Weddell Sea. Overall, these results are substantially better than the excess ice cover in PCM version 1 (Weatherly and Zhang, 2001).

Ice thickness is shown in Fig. 2 for winter in each hemisphere. The central Arctic ice is 2 to 3 m thick; which is about 1 m thinner than observations before 1989, though more consistent with recent observations (Rothrock et al., 1999). Since this is a simulation of 1870 conditions, this is too thin. Ice and snow albedos can

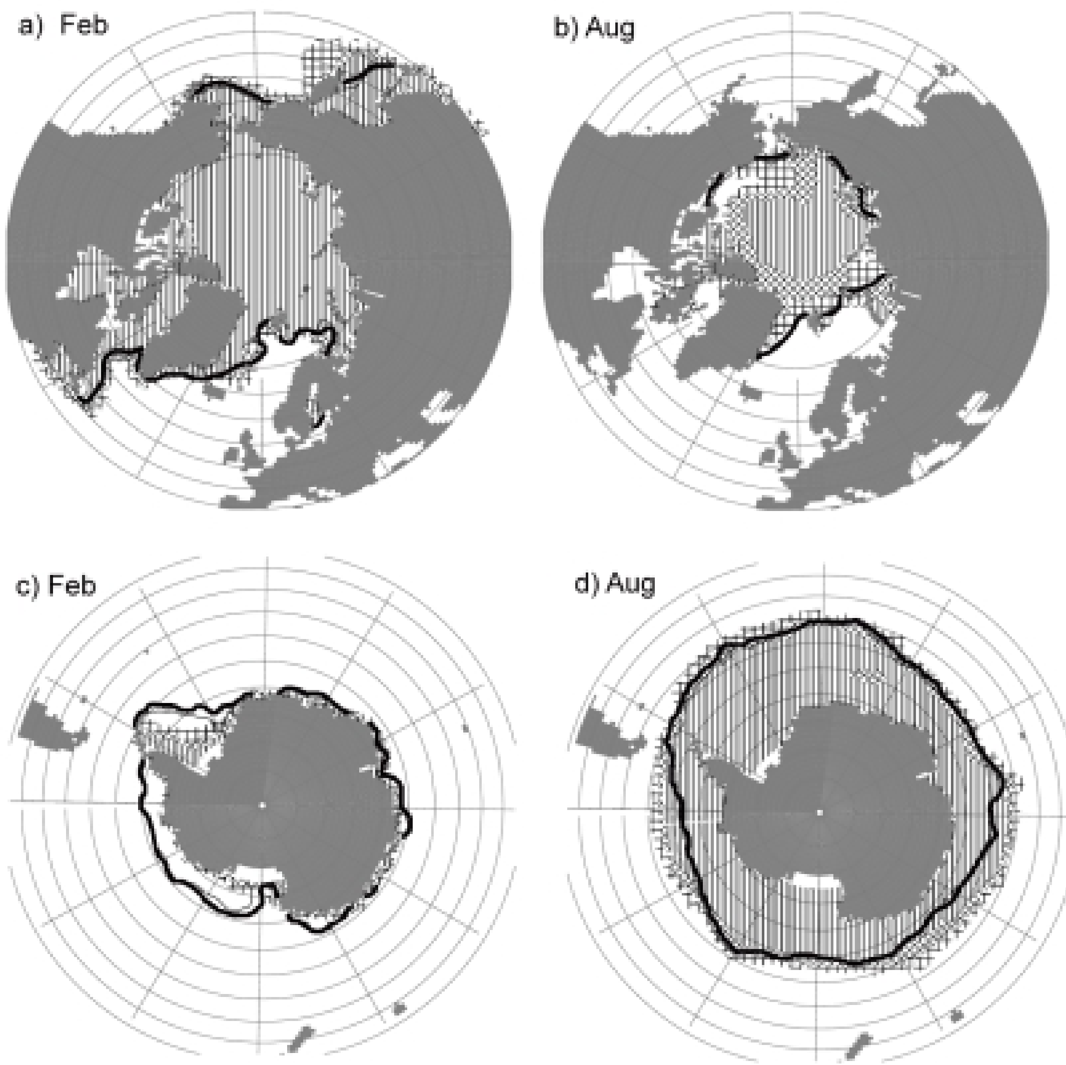

Fig. 1. Sea ice concentration from the PCTM in (a) February, (b) August, (c) February, and (d) August. Hatching denotes concentrations of: 10%-40% (square hatching), 40%-70% (cross hatching), and 70%-100% (vertical stripe). Thick solid line denotes 10% concentration limit from satellite data over 1979-1991.

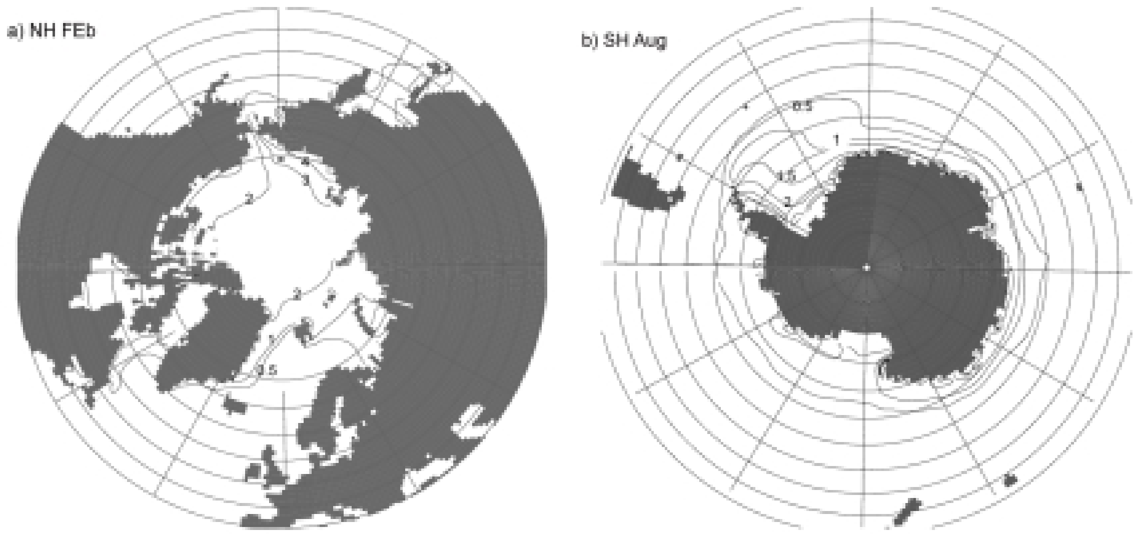

Fig. 2. Ice thickness (m) in PCTM in (a) February in NH, and (b) August in SH.

be adjusted to improve this thickness, though this must be done carefully to avoid an excessive snow cover in summer. The Arctic thickness does not show a buildup of ridged ice north of Greenland and Canada, because of the more central anticyclonic circulation, shown in the PCM by Weatherly and Zhang (2001) and in the CSM by Weatherly et al. (1998).

The annual accumulation of ice growth, bottom melt, and surface melt in the Arctic Basin are shown in Fig. 3. Ice growth from September to May totals about 160 cm. Ice surface melt from May to August totals about 65 cm, and bottom melt about 75 cm. The difference between total growth and melt of about 20 cm is accounted for by dynamic export out of the Arctic. In Contrast, observations at the SHEBA ice camp in the Beaufort Sea from October 1997 to October 1998 show winter growth averaging about 50 cm, surface melt averaging 58 cm, and bottom melt of 50 cm (Perovich et al, 1999). The SHEBA ice camp lost net thickness, as the year had anomalously high total melt. The PCTM exhibits larger growth, surface and bottom melt through the annual cycle. The reason why this is the case is still being explored.

Antarctic ice growth, surface and bottom melt is shown in Fig. 4. There is about 83 cm of growth, 75 cm of bottom melt, and only 8 cm of surface melt. The large oceanic contribution to the bottom melt in the Southern Hemisphere is captured, so the model captures the major difference between the two hemispheres. The net growth is zero when averaged over the entire Southern Hemisphere ice pack because the sea ice thickness is in equilibrium.

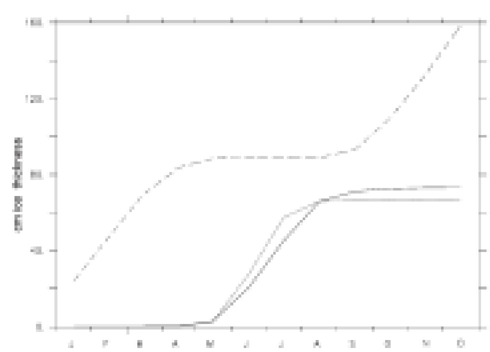

Fig. 3. Arctic-average ice growth (long dash), surface melt (short dash), and bottom melt (solid line), accumulated over one year (in cm).

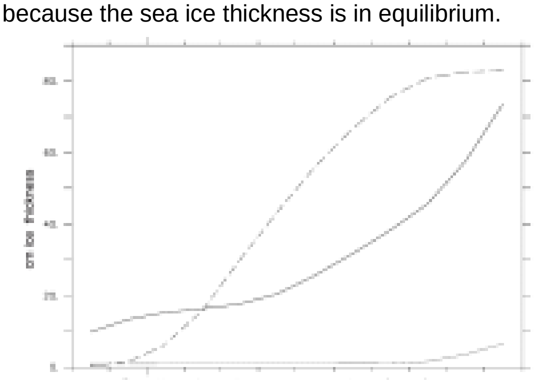

Fig. 4. Antarctic-average ice growth (long dash), surface melt (short dash), and bottom melt (solid line), accumulated over one year (in cm).

4. SUMMARY

The PCTM's main improvement over the previous version of PCM is that it includes more complete thermodynamics and an ice thickness distribution model. The EVP dynamics have been improved as well over PCM version 1. The modeled extent of ice cover in both hemispheres is improved over that simulated in the PCM. Some of these improvements are not necessarily the result of the new ice model. The Antarctic ice cover improved significantly with the use of the Gent-McWilliams isopycnal ocean mixing parameterization. This was similar to the Antarctic ice cover seen in the NCAR CSM, which also used isopycnal mixing. The Northern Hemisphere ice extent was affected less by the isopycnal mixing and more by a reduction in the radiative cloud-water path, which increased ocean surface heating and reduced ice extent. The ice thickness pattern is still similar to the PCM and CSM, as the wind patterns are much the same. The Arctic ice thickness is slightly thin, with too large an annual cycle of growth and melt.

The ice model alone, when forced with observed atmospheric data for the Arctic, simulates the ice pack more realistically than in the coupled model. The simulated arctic climate, wind patterns, ocean heat fluxes and currents greatly control most aspects of the ice simulation. Improvements in the ice physics can also lead to improvements in surface fluxes and the simulated polar climate. Continued improvements in atmosphere and ocean models will be crucial in improving the simulations of the polar regions in global climate models.

5. ACKNOWLEDGEMENTS

The authors would like to thank Bill Lipscomb, Bruce Briegleb, Warren Washington, Jerry Meehl, Tom Bettge, Tony Craig, Gary Strand, and Julie Arblaster. This research is supported by the Dept. of Energy Climate Change Prediction Program, the National Science Foundation, and the National Center for Atmospheric Research.

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