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SEA ICE RESPONSE TO WIND FORCING FROM AMIP MODELS

Cecilia M. Bitz*
Polar Science Center, University of Washington, Seattle, WA

John C. Fyfe and Gregory M. Flato
Canadian Centre for Climate Modelling and Analysis, Victoria, BC

Richard E. Moritz
Polar Science Center, University of Washington, Seattle, WA

1. INTRODUCTION

Sea ice components of coupled climate models are increasing in complexity in an attempt to improve high latitude climate simulations. Many models now include improved solutions of the ice momentum equation and some even represent the subgrid scale distribution of sea ice thicknesses (e.g., Flato et al., 2000; Bitz et al., 2001). These sea ice model improvements will be effective only if the atmosphere and ocean component models provide accurate forcing. Wind forcing is particularly important for transporting and deforming sea ice and creating open water. However, analysis of arctic atmospheric surface circulation patterns suggests serious biases exist in many atmospheric general circulation models (Walsh and Crane, 1992; Bromwich et al., 1994). As an example, Weatherly et al. (1998) show a highly unrealistic sea ice thickness pattern, with ice build-up in excess of 10 m in the East Siberian and Chukchi Seas.

In this study we examine the response of a particular sea ice model to winds from eight models participating in the Atmospheric Model Intercomparison Project (AMIP). The results are compared to simulations with the sea ice model forced by winds from two atmospheric reanalyses. In this way we assess the arctic atmospheric surface circulation in the context of driving sea ice motion.

2. FORCING DATA AND SEA ICE MODEL

The names and countries of origin for the two reanalyes and eight AMIP models used in this study are given in Table 1. The AMIP models use prescribed monthly mean sea surface temperature (SST) and sea ice extent for the period 1979-1988. Boundary conditions in the presence of sea ice vary among AMIP model.

The sea ice model used for this study is a two-category, dynamic-thermodynamic model, on an 80-km Cartesian coordinate grid of the Arctic Ocean and northernmost portions of the Pacific and Atlantic Oceans. Sea ice velocity is computed from the equation of motion for a material with a viscous-plastic rheology (Hibler, 1979). The vertical temperature profile is resolved in the ice and snow with an explicit brine-pocket parameterization from the study of Bitz and Lipscomb (1999). The sea ice overlies a slab mixed layer model with prescribed ocean currents and heat flux from the deep ocean.

In an effort to isolate the response to the atmospheric surface circulation alone, only the geostrophic winds from the AMIP models and reanalyses are used to force the sea ice model. In all simulations, the 2-m air temperature is prescribed for the AMIP period from the Polar Exchange at the Sea Surface (POLES) dataset. The model is integrated with wind and air temperature forcing from the period 1979-1988 over two cycles: The first serves as a spinup and the second is used for analysis.

3. ATMOSPHERIC SURFACE CIRCULATION IN THE REANALYSIS AND AMIP MODELS

In winter (December-February) the reanalysis 1979-1988 mean sea level pressure (MSLP) is characterized by a ridge extending from Siberia to North America through the Beaufort Sea (not shown) and the extension ofthe Icelandic low into the Norwegian and Barents Sea. The resulting geostrophic winds drive sea ice motion that on average exhibits an anticyclonic Beaufort gyre, a general drift from the Siberian Arctic towards Greenland, through Fram Strait, and out to the northern North Atlantic. Summertime (June-August) MSLP gradients are weak compared to winter and there is a very weak low pressure center near the North Pole.

The AMIP models, averaged over the same period, capture the major features of the wintertime circulation. However, the Icelandic low does not penetrate far enough into the Arctic (not shown). The MSLP difference between models and reanalyses (Fig. 1a) shows a high pressure bias over most of the Arc-

*Corresponding author address: C. M. Bitz, 1013 NE 40th St, Polar Science Center, Applied Physics Lab, Seattle, WA 98105-6698; email: bitz@apl.washington.edu

Table 1: Full names and country of origin for the two reanalyses and eight AMIP models used in this study.

Model	Full Name	Country
ERA	European Centre for Medium-Range Weather Forecasts Reanalysis	England
NCEP	National Centers for Environmental Prediction Reanalysis	United States
BMRC	Bureau of Meteorology Research Centre	Australia
CCC	Canadian Centre for Climate Modelling and Analysis	Canada
CSIRO	Commonwealth Scientific & Industrial Research Organization	Australia
CSU	Colorado State University	United States
ECMWF	European Centre for Medium-Range Weather Forecasts	England
MRI	Meteorological Research Institute	Japan
RPN	Recherche en Prévision Numérique	Canada
UGAMP	The UK Universities' Global Atmospheric Modelling Programme	England

tic Basin, especially over the Kara Sea, and a low pressure bias over northwestern North America. This pattern creates an unrealistically strong northeasterly geostrophic wind in the Chukchi Sea. Summertime MSLP among AMIP models is on average too high over the entire Arctic (see Fig. 1b). None of the AMIP models reproduces the closed low centered near the North Pole that is observed.

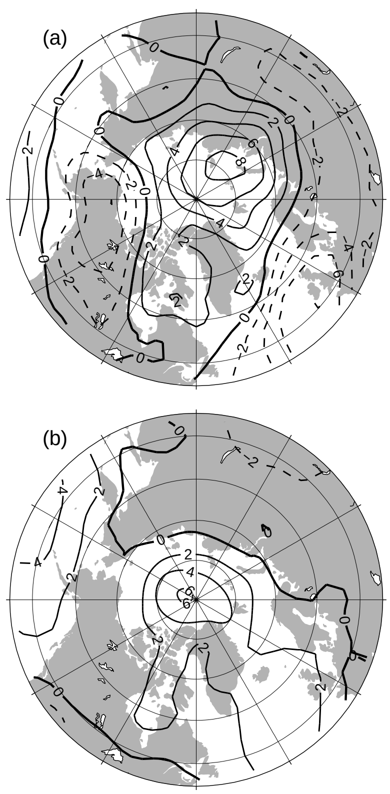

Figure 1: Difference between (a) winter (December-February) and (b) summer (June-August) mean sea level pressure fields in millibars averaged across the AMIP models and ERA and NCEP reanalyses.

4. COMPARISON OF SEA ICE RESPONSE TO AMIP MODEL FORCING

To illustrate the effects of the circulation errors discussed above, we force a sea ice model with geostrophic winds from the eight AMIP models and two reanalyses. Figure 2 shows the April mean ice thickness for each simulation. The two reanalysis data sets differ somewhat in their estimates of MSLP and this leads to a modest difference in sea ice patterns (upper 2 panels). In both cases, the spatial patterns are in broad agreement with observational estimates (e.g., Bourke and Garrett, 1987). Although the climatological ice thickness is poorly known, the ice thickness appears to be biased low in parts of the central Arctic, which is common in two-category simulations. The thickness patterns that are forced by AMIP model output share some common errors that range in severity. AMIP model winds tend to drive too much ice into the East Siberian Sea and not enough north of Greenland and the Canadian Archipalego. Among the worst cases in Figs. 2, the pattern of ice thickness in the Arctic is rotated by roughly 180° relative to what is expected, with the thickest ice north of Siberia and thinner ice on the North American side. One consequence of this excessive build-up is the lack of a proper summertime melt back in the Chukchi Sea.

Seasonally averaged geostrophic winds from the AMIP models and reanalyses in the Chukchi Sea indicate that most of the models have an anomalous northerly and/or easterly component. Wind forcing from the ECMWF and CCC model yield a sea ice response in the Chukchi Sea in best agreement with the reanalysis results. The differences between the winds from these models and the reanalyses are small and vary in direction throughout the annual cycle.

Sea ice export west of Svalbard, through Fram Strait, is a key component of the freshwater trans-

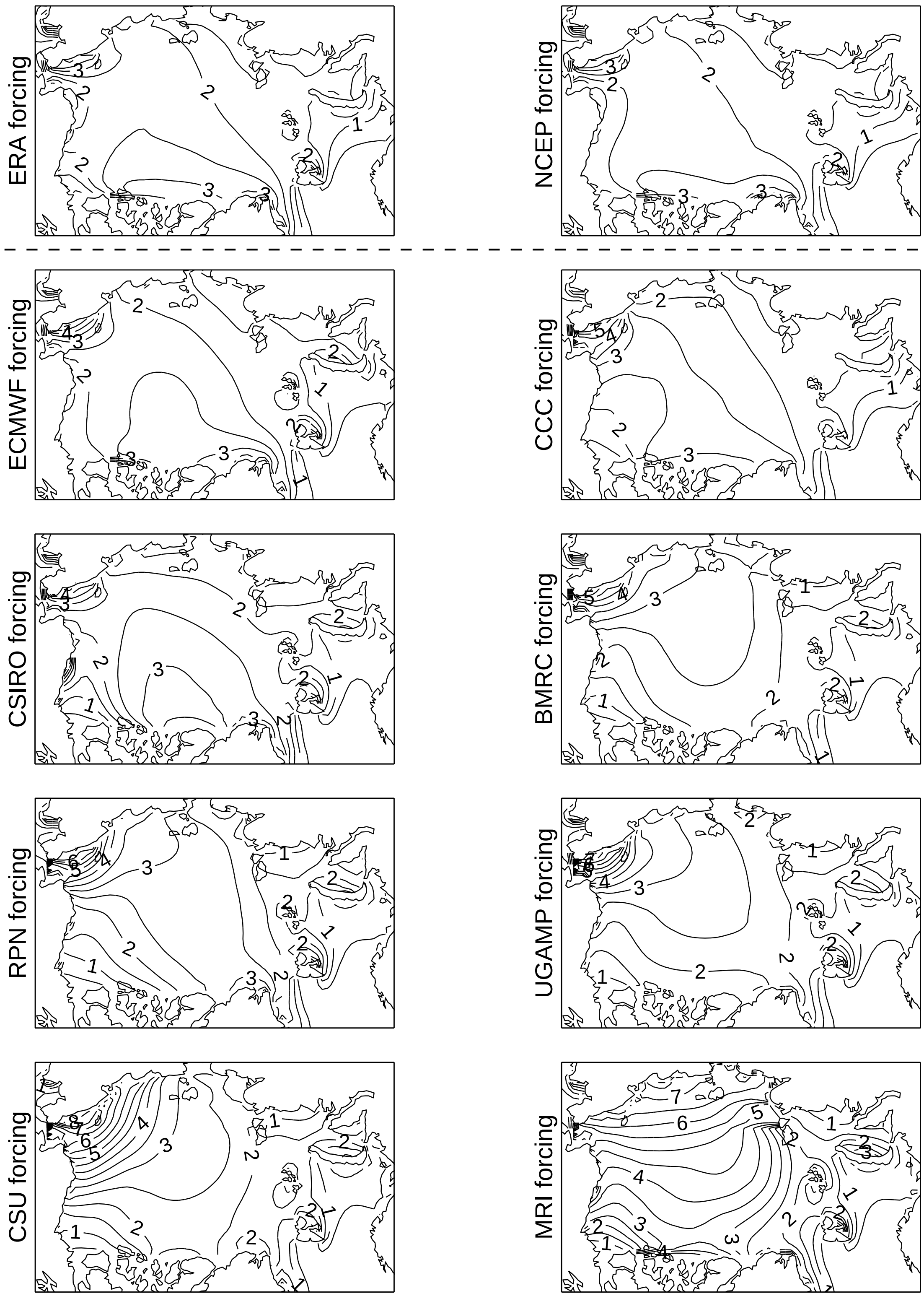

Figure 2: April mean simulated ice thickness for a sea ice model forced with two reanalyses and eight AMIP models. The later eight integrations are ordered roughly according to how successfully they compare to the simulations forced with reanalysis winds.

port and influences the heat balance in the subpolar seas. Figures 3a and b show the modeled sea ice export west and east of Svalbard for all ten simulations. Figure 3c shows the net export from both sides of Svalbard averaged over the two reanalyses and the eight AMIP model cases, along with an estimate of the 1990-1995 mean export through Fram Strait based on observations (Kwok and Rothrock, 1999). Observational estimates of ice export vary from 0.038 to 0.12 Sv, in part due to large interannual variability but also due to uncertainty in the measurements and assumptions used. It is typical for low-resolution, two-category sea ice models to predict values that are at the low end of this range because the ice being exported is too thin and the ice velocity through the strait is not well resolved. Some models also tend to erroneously transport ice on the east side of Svalbard, where observations show no substantial transport. If we include export on both sides of Svalbard (i.e., net ice export), the reanalysis cases predict about 23% less sea ice export than was estimated by Kwok and Rothrock (1999).

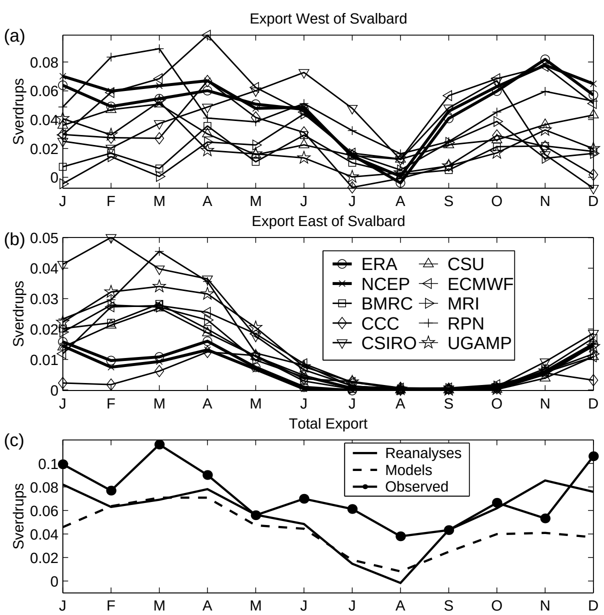

Figure 3: Sea ice export (a) east and (b) west of Svalbard and (c) total export. (1 Sverdrup = 10^6 $m^3 s^{-1}$)

Generally the response to AMIP winds qualitatively reproduces the mean annual cycle of export, but an even greater fraction of the net export occurs east of Svalbard than in the cases forced with reanalysis winds. The net export averaged over the AMIP wind-driven cases is 24% less than the average over the reanalysis wind-driven cases.

5. DISCUSSION AND CONCLUSIONS

Comparing various features of the various AMIP models, did not reveal any particular attribute was key to the model's ability to produce a realistic surface circulation. We examined the mean sea level pressure in six CMIP models as well and found the biases are roughly the same as those in the AMIP models. The CMIP models include coupled sea ice and ocean components and are generally more recent models. We also looked at both coupled (with and without prognostic sea ice) and uncoupled integrations from one model and found that the sea ice state does not have a large influence on the surface circulation.

Sea ice plays an important role in the postive feedbacks leading to enhanced high-latitude warming in coupled climate model projections. Improvements are therefore being made to the sea ice components of many climate models, particularly by introducing more realistic treatments of sea ice dynamics. The results here indicate that biases in the arctic surface circulation produced by the atmospheric component of such climate models are a major source of error in the modeled ice thickness and transport patterns.

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