Towards Improvement of Sea-ice Physics in MM5 for the Arctic Regional Modeling

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1. Introduction

Observational and modeling studies show the amplification of global warming in high latitudes of the northern hemisphere (e.g., Manabe and Stouffer, 1994; Hansen, et al., 1999). Sea ice, ocean and land surfaces have undergone unprecedented changes in recent decades over the Arctic Region. The changed sea ice and land surfaces alter interactions between the atmosphere and the underlying surface as well as the energy balance. For example, the reduced sea ice cover allows the Arctic Ocean to receive more heat from both the atmosphere and the Atlantic and Pacific oceans (Zhang and Zhang, 2001). In return the Arctic Ocean releases more heat back to the atmosphere.

To better understand the detailed scenarios of the weather and climate change over the Arctic region, further exploration of atmosphere/sea-ice/ocean/land-surface interactions is needed. Development and application of a regional atmosphere model with more sophisticated sea-ice, snow and land-surface physics will give us a better ability to perform such exploration

This work is focused on creating a regional modeling system over the Arctic region in which the interactions between atmosphere and underling surface will be carefully considered. Chen and Dudhia (2001) have included the interactions between atmosphere and land-surface by coupling a detailed land surface model into the PSU/NCAR mesoscale model MM5. Zhang and Tilley (2001) updated the land surface model with one (NOAH-LSM, Koren et al.,1999) in which winter season processes have been described more carefully. However, sea ice physics in these models is very simple and doesn't consider the effect of varying sea ice concentration on surface energy exchange. However, previous studies (e.g.,Tilley and Curry, 1994) show that large variability during transition seasons in sea ice concentration has pronounced impact on the development of weather system. So it is necessary for an Arctic region modeling system to include more comprehensive sea ice physics to account for sea ice concentration and its variation.

In this work, we couple a thermodynamic sea-ice model to the MM5. In the following section we describe the sea ice model used. Results from this new coupled system are given in section 3.

2. Description of Sea-ice Model

The sea ice thermodynamic treatment is similar to that of *Parkinson and Washington* (1979). The sea ice thickness (volume per area) and concentration at each grid cell is described by following the two governing equations:

$$\frac{\partial h}{\partial t} = F_h \qquad (1)$$

$$\frac{\partial A}{\partial t} = F_A \qquad (2)$$

where A is the sea ice concentration at each grid cell; F_h and F_A are the thermodynamic sources.

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F_A is parameterized following *Hibler* (1979):

$$F_A = \frac{F_h}{2h} A + \frac{\left(\partial h / \partial t\right)^0_{therm}}{h_0} (1 - A) \qquad (3)$$

And F_h is determined by local thermodynamic growth rate of sea-ice thickness:

$$F_h = \left(\frac{\partial h}{\partial t}\right)^1_{therm} A + \left(\frac{\partial h}{\partial t}\right)^0_{therm} (1 - A) \qquad (4)$$

where h_0 is the thickness of new sea ice and set to $0.2m$ here; superscript "0" represents new sea ice forming over open water; while superscript "1" represents existing sea ice; A is the sea ice concentration; and $\left(\frac{\partial h}{\partial t}\right)_{therm}$ is the local rate of sea ice growth and melt determined from an energy balance calculation:

$$\left(\frac{\partial h}{\partial t}\right)_{therm} = \frac{1}{q_0}(H_w - H_T) \qquad (5)$$

where q_0 is the heat of fusion; H_T is the net energy flux at the sea ice or ocean surface derived as the residual of the other terms in the surface energy balance; H_w is the underlying turbulent heat flux between the bottom of sea ice and ocean, parameterized following *Ebert and Curry* (1993):

$$H_w = \rho_o c_{po} C_t \left(T_o - T_f\right) \qquad (6)$$

where ρ_o is the density of ocean water; c_{po} the ocean specific heat; C_t the bulk transfer coefficient, taken as $1.16 \times 10^{-5} m/s$; and T_f the freezing temperature; T_o is the ocean temperature which is defined as a constant value taken from the input data (EVMWF or NCEP analysis).

Sensible and latent heat fluxes are calculated from the bulk aerodynamic formulae in which the transfer coefficients are calculated by the MM5/PBL scheme. Sea ice surface temperature is calculated based on the surface energy balance.

3. Modeling results

A spring season case of 15-18 May, 2000 is chosen as our simulation object. The simulation domain and initial sea ice concentration distribution are shown in Figure 1. We utilize a model grid resolution of 120km for this test on a computational grid of 61(X) x 61(Y) x 23(Z). A model time step of 360 s is used.

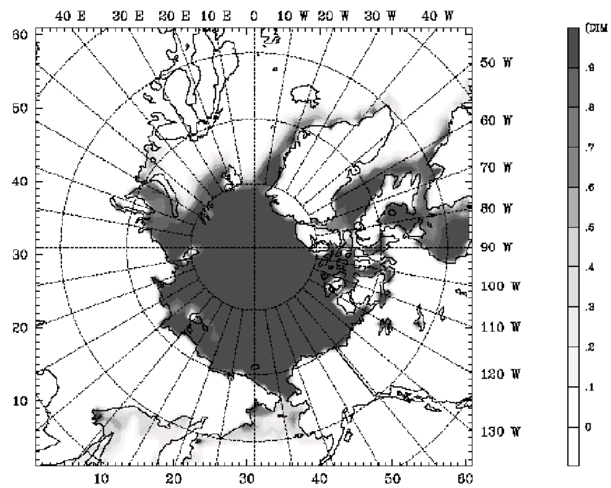

Figure 1. Simulation domain and initial sea-ice concentration distribution at 00UTC 15May, 2000.

In all simulations, we employed the following physical parameterizations: the Dudhia (1989) simple ice microphysics scheme; the Grell (1993) cumulus scheme; the MRF planetary boundary layer scheme (Hong and Pan 1996); a simple cloud radiative cooling scheme (Benjamin 1983); and the Chen and Dudhia (2001) land surface model. NCEP/NCAR reanalysis data are used to provide initial and boundary conditions to the modeling system. Initial sea ice concentration is from NCEP/NCAR climate data assimilation system (CDAS) in which sea ice concentration grids are constructed from the SSMI sensor on the DMSP F-13 (11) satellite.

We perform two different experiments for the case under consideration: (1) an experiment without the sea ice model (referred to hereafter as the flag run) where sea ice distribution is specified as invariant over time and (2) an experiment with the coupled sea ice model (referred to hereafter as the sea-ice run) in which sea ice thickness, sea ice concentration and sea ice temperature are all predicted as described in section 2.

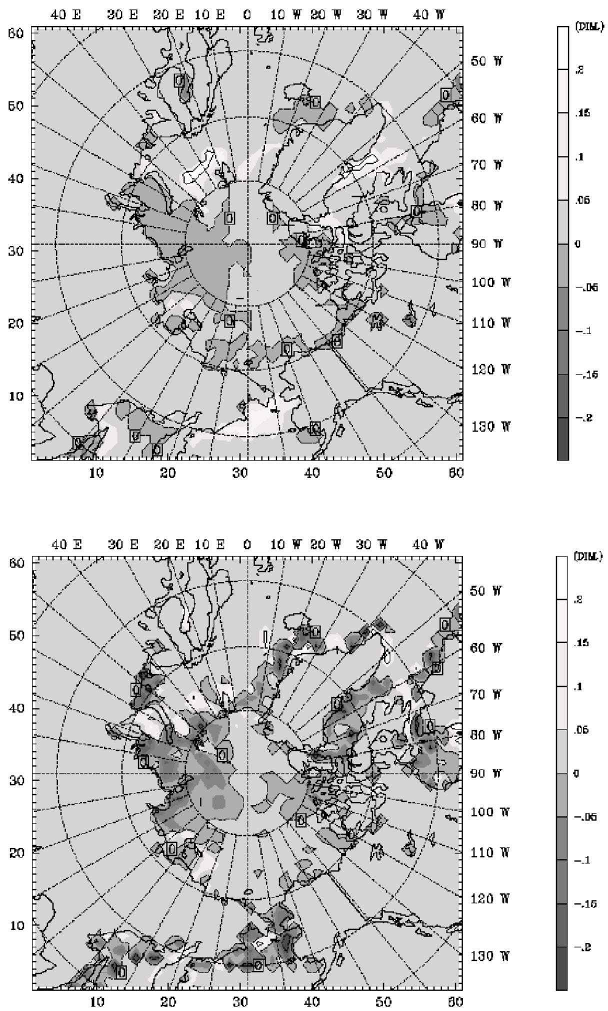

Figure 2. Change of sea-ice concentration for simulation period of 00UTC 15May–00UTC 18May, 2000. Upper panel is modeling result and lower panel is satellite data.

Figure 2 shows the sea ice concentration change for 15-18 May, 2001 from both the sea-ice run and satellite data from NCEP/NCAR-CDAS. The comparisons show that the coupled model system of MM5/Sea-ice reasonably predicted the variation of sea ice concentration except over sea ice edge areas (such as Bering Sea, Baffin Bay and GIN Sea) where the model did not properly simulate the decrease of sea ice seen in the satellite data. By contrast, the coupled model simulated an excessive increase of sea ice over Bering Sea and Baffin Bay areas. The increase of sea ice concentration might result from the constant sea surface temperature in the current model as well as the uncertainty of the sea ice thickness distribution. A simple mixed layer ocean model could predict the variation of ocean temperature and we hope to include such a model in a future version. But how to define the distribution of sea ice thickness remains an unresolved issue for sea ice modelers and requires further study.

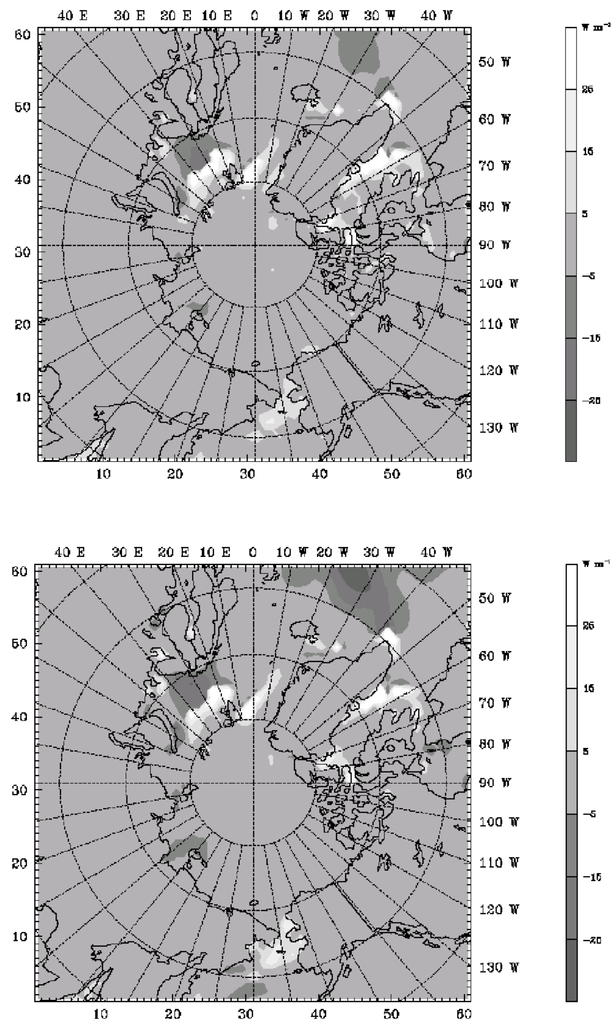

Figure 3. Difference of sensible heat flux (upper panel) and latent heat flux (lower panel) between sea-ice run and flag run (sea ice run-flag run) at 06UTC 15May,2000.

Figure 3 shows a comparison of sensible and latent heat fluxes between the flag run and the sea-ice run. This comparison illustrates the effect of sea-ice concentration especially over sea ice edge where the grid mesh is partly covered by the sea ice. At these grid points, the surface can absorb more shortwave radiation because of the low albedo of open water. Then, in turn, there is greater latent heat flux and sensible heat flux to atmosphere over these grid points.

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