BIPOLAR MODELING OVER ICE SHEETS WITH MM5

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1. INTRODUCTION

Simulations of the atmospheric state over the Antarctic and Greenland ice sheets are presented. The simulations are performed with a modified version of the Pennsylvania State University / National Center for Atmospheric Research (NCAR) fifth generation mesoscale model (MM5), referred to as the Polar MM5 [a description of the standard version of MM5 is available in Dudhia (1993) and Grell et al. (1994)].

The modifications made to the model and the model options used for the polar simulations are described in Section 2. The simulations include simulations for an entire annual cycle over the Greenland (April 1997 – March 1998) and Antarctic (1993) ice sheets, as well as real-time operational forecasts over the Antarctic continent (starting in January 2000). Verification results from these simulations are presented in sections 3 and 4. A discussion of future applications of the Polar MM5 is included in Section 5.

2. DESCRIPTION OF THE POLAR MM5

The community mesoscale model MM5 (and earlier versions of this model) has been used by members of the Polar Meteorology Group at the Byrd Polar Research Center to simulate the atmospheric state over the extensive ice sheets of Antarctica and Greenland (e.g. Hines et al. 1995; Hines et al. 1997a; Hines et al. 1997b). Based on analysis of these simulations it is apparent that the standard version of MM5 poorly represents the cloud cover and radiative fields over extensive ice sheets (particularly during the winter months). In addition, an accurate representation of the surface turbulent fluxes and boundary layer is required for realistic simulation of the katabatic flow regime over the ice sheets. Based on this experience, MM5 is modified in an attempt to resolve some of these problems.

Hines et al. (1997a, 1997b) documented an extensive (and unrealistic) cloud cover over the Antarctic. Similarly Manning and Davis (1997) discuss an over-prediction of cold clouds over the continental United States. To minimize this problem, the Meyers et al. (1992) ice nuclei concentration equation is implemented in the explicit microphysics parameterizations of the Polar MM5, as suggested by Manning and Davis (1997).

A second problem related to cloud cover in the polar simulations is an over-prediction of downwelling longwave radiation under cloudy sky conditions (Hines et al. 1997a, 1997b). This problem is traced to the representation of cloud – radiation interactions in the CCM2 radiation parameterization option in MM5. In this parameterization, the radiative properties of clouds are based on the grid point relative humidity values from the model (Hack et al. 1993). Sensitivity experiments with MM5 reveal that the cloud cover predicted from the grid point relative humidity is an overestimation of the cloud cover predicted by the explicit microphysics parameterization. To resolve this bias, the cloud ice and water content predicted by the explicit microphysics parameterization is now used to determine the radiative properties of clouds in the CCM2 radiation parameterization in the Polar MM5. The radiative properties for the water and ice phase cloud particles are identical to those used in the CCM3 radiation parameterization described by Kiehl et al. (1996).

The standard version of MM5 provides a number of options for the representation of turbulent fluxes in the surface layer and planetary boundary layer (PBL). MM5 simulations over Greenland, that used different PBL options, were compared to aircraft observations of wind and temperature profiles in the katabatic layer [collected during KABEG'97 and described by Heinemann (1999)]. Results from these numerical experiments indicate that the Blackadar PBL (Zhang and Anthes 1982) and the Hong and Pan (1996) PBL (referred to as the MRF PBL in MM5 documentation) simulate an overly deep katabatic layer. In contrast, the 1.5 order closure PBL parameterizations of Burk and Thompson (1989) and Janjić (1994) (referred to as the ETA PBL in MM5 documentation) produce shallower katabatic layers that are in good agreement with the observed profiles (Bromwich et al. 2000). Other simulations indicate that the surface fluxes under statically stable conditions are too small when the Burk and Thompson (1989) PBL parameterization is used (Cassano et al. 2000), and as such the ETA PBL has been used for all simulations with the Polar MM5.

The multi-layer parameterization of heat transfer through the model substrate presented by Dudhia (1996) is used in the Polar MM5. The parameterization is modified to include two additional substrate levels [which increases the substrate depth to 1.91 m (compared to 0.47 m in the unmodified version)] and to use thermal properties that are in better agreement with observations of ice surfaces.

A final modification to MM5 is the addition of a variable fraction sea ice surface type. This surface type allows a fractional sea ice cover to be specified for each oceanic grid point in the model domain. The surface fluxes for the sea ice grid points are calculated separately for the open water and sea ice portions of the grid point, and are averaged before interacting with the overlying atmosphere.

For the simulations discussed in this extended abstract, the Polar MM5 is used with the hydrostatic

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dynamics option. The model physical parameterizations used include the Reisner et al. (1998) mixed phase microphysics parameterization (modified to include the Meyers et al (1992) ice nuclei concentration equation), the Grell cumulus parameterization (Grell et al. 1994), the ETA PBL parameterization, and the modified CCM2 radiation scheme. A total of 28 vertical levels are used for all simulations, with the lowest model level located at a nominal height of 12 m AGL.

3. GREENLAND SIMULATIONS

The atmospheric state over the Greenland ice sheet is simulated with the Polar MM5 from April 1997 through March 1998. For the 12 months of simulations the model is initialized once per day and integrated forward in time for 48 h. The model is allowed to spin-up for the first 24 h of the simulation, and the final 24 h of the simulation is used to generate continuous model output for the 12 months of the study. The model results for April and May 1997 (during the KABEG'97 field campaign) are verified with automatic weather station (AWS) data (Steffen et al. 1996) and instrumented aircraft observations (Heinemann 1999) by Bromwich et al (2000).

The observed and modeled time series of near surface pressure, air temperature, wind speed, wind direction, and water vapor mixing ratio for May 1997 are shown in Fig. 1 for the Dye-2 AWS (66° 29' N, 46° 17' W) located near the crest of the Greenland ice sheet. The Polar MM5 accurately simulates the synoptic and diurnal evolution of the observed variables. In particular the diurnal temperature range is well simulated by the model. In addition, the model reproduces the period of reduced wind direction variability (from 11 to 21 May 1997). Similar results are found for other months and AWS locations.

Table 1 lists the monthly bias, root mean square error (RMSE), and correlation coefficient for the near surface temperature, pressure, and wind speed for the Polar MM5 simulations compared to the AWS observations at Dye-2 for May 1997 and January 1998. From the statistics listed in the table it is evident that the Polar MM5 simulations of the near surface air temperature and pressure are quite skillful, with slightly less skill evident for the simulated wind speeds than the other variables. In addition the model appears to have similar skill for both months (which are representative of mid-winter and early summer conditions).

4. ANTARCTIC SIMULATIONS

Simulations of the atmospheric state over Antarctica for all of 1993 are underway at the Byrd Polar Research Center. For these simulations the model is initialized once every two days and is integrated forward in time for 72 h. The model is allowed to spin-up for the first 24 h of the simulation, and the final 48 h of the simulation is used to generate continuous model output for the entire annual cycle.

Preliminary evaluation of these simulations indicates a moderate level of skill in the simulation of the near surface atmospheric state over Antarctica. Table 1 lists the monthly bias, RMSE, and correlation coefficient for the temperature, pressure, and wind speed simulated by the Polar MM5 compared to observations from the University of Wisconsin AWS at the South Pole for January and June 1993 (Stearns et al. 1993). The model results over Antarctic have slightly larger RMSE and smaller correlation coefficients compared to the Greenland simulations discussed in Section 3. The reduced skill of the Antarctic simulations is likely due in part to the much sparser observational network (and thus lower quality atmospheric analyses available for model initialization) in the Antarctic compared to Greenland.

The Polar MM5 is also being used to produce real-time operational mesoscale numerical forecasts over all of Antarctica. The real-time simulations were started in January 2000, and continue through the present time.

For the operational simulations, the Polar MM5 is initialized once per day at 12 UTC, using the 12 h forecast from the National Centers for Environmental Prediction (NCEP) medium range forecast (MRF) model. The 12 to 82 h MRF output is used to supply lateral boundary conditions to the Polar MM5 for the operational Antarctic forecasts.

A 72 h forecast is generated by the Polar MM5, and is available 24 h after the model initial time. The simulations are currently performed at a horizontal resolution of 60 km, and are run on a PC with a 466 MHz Celeron processor. Surface and constant pressure plots over the entire Antarctic continent as well as meteograms and skew-T diagrams at selected locations are plotted from the model output and are posted to the internet at *http://www-bprc.mps.ohio-state.edu* (under the *Antarctic Numerical Weather Prediction* link) once per day.

5. CONCLUSIONS

A brief summary of recent and on-going simulations with the Polar MM5 (a modified version of MM5) over the Antarctic and Greenland ice sheets is presented. Based on this verification it appears that the Polar MM5 is able to accurately simulate the near surface atmospheric state over both ice sheets throughout the entire year. The simulations over Antarctica appear to be slightly less skillful than those over Greenland, and this may be related to the sparser observational network available in high southern latitudes.

Continued verification of the Polar MM5 simulations over both ice sheets is planned. In addition the Polar MM5 is being used to simulate the atmospheric portion of the mass budget of the Antarctic ice sheet (precipitation and wind transport of snow) and as an operational forecast model in support of the U.S. Antarctic program. In addition, the Polar MM5 is being used for climate simulations over the Laurentide ice sheet during the last glacial maximum.

Table 1. Monthly model verification statistics [bias, root mean square error (RMSE), and correlation coefficient] for the near surface air temperature (T), pressure (P), and wind speed (WS) at Dye-2, Greenland and the South Pole, Antarctica.

Location / month	Bias			RMSE			Correlation Coeff.		
	T (K)	P (hPa)	WS (m s^{-1})	T (K)	P (hPa)	WS (m s^{-1})	T	P	WS
Dye-2 / (May 1997)	-0.9	-1.4	-2.7	2.7	2.1	3.7	0.88	0.97	0.52
Dye-2 / (Jan. 1998)	-1.9	-0.5	0.3	3.7	1.9	2.8	0.91	0.99	0.89
S. Pole / (Jan. 93)	1.0	-1.1	0.8	3.0	2.8	1.8	0.82	0.90	0.39
S. Pole / (Jun. 1993)	-2.0	3.0	2.2	6.6	4.7	2.8	0.67	0.94	0.20

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