5B.5 VERIFICATION OF POLAR MM5 SIMULATIONS OF ANTARCTIC ATMOSPHERIC CIRCULATION

Zhichang Guo*, David H. Bromwich, and John J. Cassano

Polar Meteorology Group, Byrd Polar Research Center, The Ohio State University, Columbus, Ohio

1. INTRODUCTION

Verification of a complete annual cycle of 72h nonhydrostatic mesoscale model simulations of the Antarctic atmospheric circulation is presented. The simulations are generated with the Pennsylvania State University-National Center for Atmospheric Research Fifth-generation Mesoscale Model (MM5), which is modified for polar applications, and is referred to as the Polar MM5. With a horizontal resolution of 60km, the Polar MM5 has been run for the period of January 1993 through December 1993 in a year-long series of short-term forecasts from initial and boundary conditions provided by the operational analyses of the European Centre for Medium-Range Weather Forecasts (ECMWF). For every short-term forecast the model is integrated for 72 hours with the first 24 hours being discarded for spin-up purposes. The simulations to be analyzed are compiled from the series of remaining 48 hours forecasts.

A brief description of Polar MM5 is presented in section 2. The model performance primarily in relation to observations from automatic weather station (AWS) sites, manned stations and climatological maps, is evaluated in section 3 on annual, seasonal, synoptic and diurnal time scales. Concluding remarks on the model performance are given in Section 4.

2. POLAR MM5

The Polar MM5 model is based on version 2 of the PSU / NCAR MM5, which includes three-dimensional prognostic equations for the horizontal and vertical components of the wind, temperature, and pressure perturbations in its nonhydrostatic version. Additional three-dimensional prognostic equations for the water vapor, cloud water (ice) and rain water (snow) mixing ratios are also part of the model equations. Parameterizations for moist physics, radiative transfer, and turbulence are included in the model, with multiple options available for the representation of many of these processes. A detailed discussion of the modifications made to the standard version of MM5 for use over polar regions is described in Bromwich et al. (2001) and Cassano et al. (2001). A brief description of Polar MM5 and its configuration for simulations over Antarctica is presented in this section.

In moist physics of the Polar MM5 the Reisner explicit microphysics parameterization is used to represent the resolvable scale cloud and precipitation processes, and the Grell parameterization is used to represent the sub-grid scale cloud processes. Results from MM5 sensitivity simulations show that excessive cloud cover was a problem over the Antarctic and the use of the Fletcher (1962) equation in the parameterization scheme is the major reason for this bias. In order to eliminate this cloudy bias in simulations the equation for ice nuclei concentration from Meyers et al. (1992) was used in Polar MM5 to replace the Fletcher (1962) equation in the explicit microphysics parameterization.

The radiative transfer of shortwave and longwave radiation through the atmosphere is predicted with a modified version of the NCAR community climate model, version 2, (CCM2) radiation parameterization, in which the predicted cloud water and ice mixing ratios are used to determine the radiative properties of the modeled cloud cover. The modified radiation scheme allows for a consistent treatment of the radiative and microphysical properties of the clouds and for the separate treatment of the radiative properties of liquid and ice phase cloud particles,

Turbulent fluxes in the atmosphere are parameterized using the 1.5 order turbulence closure parameterization used in the National Centers for Environmental Prediction Eta model. Heat transfer through the model substrate is predicted using a multi-layer “soil” model. The thermal properties used in the “soil” model for snow and ice surface types are modified following Yen (1981), and two additional substrate levels have been included in Polar MM5 to increase the substrate depth. Also, a sea ice surface type is added to the 13 surface types available in the standard version of MM5 (Hines et al., 1997). The sea ice surface type allows for fractional sea ice cover in any oceanic grid point, with surface fluxes within the sea ice grid points calculated separately for the open water and sea ice portions of the grid point. These fluxes are then averaged before interacting with the overlying atmosphere.

The model domain used in this study consists of 120$\times$120 grid points, centered at the South Pole, with a horizontal resolution of 60 km. The pressure at the model top is set at a constant pressure of 100 hPa, and a total of 28 vertical sigma levels are used, of which seven are located within the lowest 400 m of the atmosphere. The lowest sigma level is located at a nominal height of 11 m above ground level (AGL). This relatively high resolution near the surface is required to accurately represent the evolution of the shallow katabatic layer over the Antarctic ice sheet.

The model topography data over the Antarctic continent are interpolated from a 5 km resolution digital elevation model of Antarctica. The areas for Filchner-Ronne Ice Shelf and Ross Ice Shelf are manually identified from the climatic maps. The 2.5° horizontal resolution ECMWF surface and upper air operational

* Corresponding author address: Zhichang Guo, Polar Meteorology Group, Byrd Polar Research Center, The Ohio State University, 1090 Carmack Road, Columbus, OH 43210-1002; e-mail: guo@polarmet1.mps.ohio-state.edu

analyses are used to provide the initial and boundary conditions for the model atmosphere. In addition the 1.125° ECMWF global surface analyses are used to specify the initial surface temperature and deep soil temperature. The daily polar gridded sea ice concentration data with 25-km horizontal resolution derived from the National Snow and Ice Data Center are used to identify the sea ice surface type and its coverage fraction over each model grid.

The Polar MM5 is used to produce short duration (72 h length) simulations of the atmospheric state over Antarctica from Jan. 1993 through Dec. 1993. The model is initialized with the 00 UTC ECMWF analyses for each preceding even day or 31st of the preceding month of each forecast mode, with the 24 – 72 h forecasts used for model verification.

3. VERIFICATION RESULTS

Model output from the Polar MM5 simulations over the Antarctica is compared to available observational data on annual, seasonal, synoptic, and diurnal time scales in this section. The primary data sources used for verification of the Polar MM5 simulations presented in this paper are climatological maps, and observations from the University of Wisconsin automatic weather stations and the manned stations over Antarctica. The validation is intended to demonstrate the high level of skill present in the Polar MM5 simulations. This analysis also serves to highlight areas requiring additional model improvements.

Annual mean fields from the Polar MM5 simulations are calculated for the surface temperature, near-surface temperature inversion, near-surface winds, total cloud cover, and accumulated precipitation minus sublimation. The model verification using climatological maps indicates that the Polar MM5 reproduced these fields with a high degree of realism.

Figure 1 shows the mean annual near-surface temperature in 1993 simulated by Polar MM5. In comparison with climatological map synthesized by Giovinetto et al. (1990) tremendous fidelity between the simulated and observed temperature fields can be found for both distribution and magnitude. Both maps have the coldest mean annual temperatures -60°C which are located near the highest elevation of the ice sheet, in a region of least cloud cover. In addition the temperature gradients along the East Antarctic escarpment are reproduced quite well in the simulated field. There is also a clear representation of the Antarctic Peninsula and West Antarctic Plateau in the temperature field. As will be shown below, the model reproduces the annual cycle of temperature quite accurately at a large number of AWS and manned sites located on the Antarctic ice sheet, lending further credence to the distribution of the mean annual temperature simulated by the Polar MM5.

The Polar MM5 annual resultant wind vectors from the lowest model level (approximately 11 m AGL) with the model surface elevation are shown in Figure 2.

In comparison with the detailed streamline pattern obtained by Parish and Bromwich (1987), Polar MM5 clearly produces the continent-scale drainage flow over East Antarctica as cold low-level air flows from the high plateau to the sea. The drainage flow over the ice sheet is directed downslope and to the left of the ice fall line, as expected for katabatic flow in the Southern Hemisphere. The weakest resultant wind speeds are located along the ice divide, with stronger flow located over the steep coastal slopes, where the most persistent katabatic flow is likely to be located.

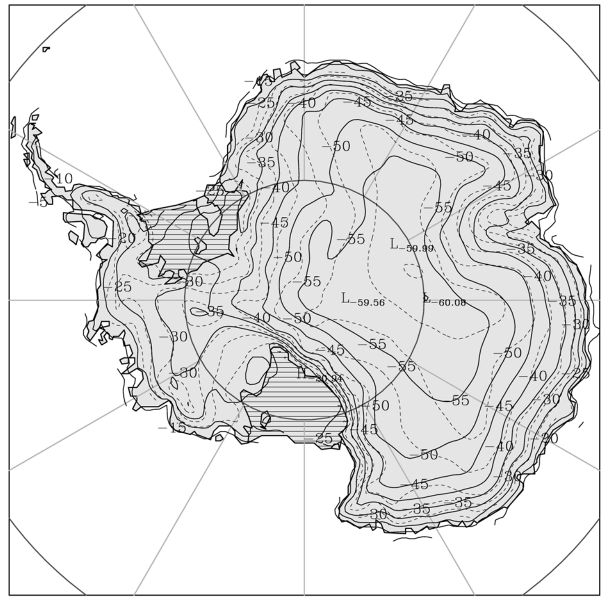

Figure 1. Annual mean surface air temperature (°C) in 1993 simulated by the Polar MM5.

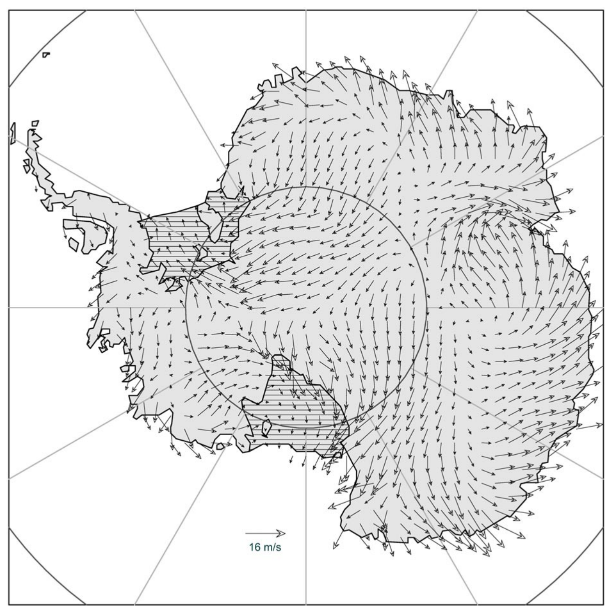

Figure 2. Annual resultant near-surface wind fields in 1993 simulated by the Polar MM5.

The variables air temperature, wind speed, wind direction, and relative humidity, which will be used for model verification, are measured at both the AWS and the Antarctic manned stations. The AWS basic units measure these variables at a nominal height of 3 meters above the surface. The temperature and wind speed predicted by the Polar MM5 is interpolated from the model lowest level (nominal 11 m AGL) to a constant height of 3 m AGL for comparison with the AWS and manned station measurements. This interpolation is done by applying Monin-Obukhov similarity theory to the temperature and wind speed at the lowest model level, the model surface temperature, and the model specified surface roughness length. The model surface pressure has also been adjusted from the model grid point elevation to the elevation of the AWS observation, using the hypsometric equation.

The model verification using observations from the AWS array and manned stations indicates that the Polar MM5 simulates the near-surface atmospheric state with a high degree of accuracy.

The monthly mean values of surface pressure, temperature, wind speed, wind direction and water vapor mixing ratio are averaged for four AWS sites (Dome C, Ferrell, Nico, Lynn) and four manned stations (Neumayer, Hally, Davis, Vostok) that had nearly complete records of all variables from Jan. 1993 through Dec. 1993 and for the corresponding model grid points in the Polar MM5. These monthly means are plotted in Figure 3. The monthly bias, root mean square error (RMSE), and correlation coefficient from the comparison of the Polar MM5 simulations to the AWS observations are also calculated from the observations and model output (not shown). The bias is defined as the difference between the Polar MM5 monthly mean and the AWS observed monthly mean value of a given variable.

Figure 3 shows that the seasonal cycle in near-surface temperature, pressure, wind speed and wind direction is reproduced by the model quite well although persistent biases exist in surface pressure. Comparison of the observed and modeled surface pressure and the model verification statistics reveals a positive bias in the modeled surface pressure that persists throughout the twelve month period. This bias ranges from 2 hPa to 8 hPa when averaged over eight sites. The persistent biases in the pressure are attributed in part to an uncertainty in the station elevation and associated error in the initialization fields. The correlations between the observations and the model forecasts, for the surface pressure, are high (around 0.8) when averaged over the eight sites, and are indicative of the high level of skill present in the Polar MM5 forecasts.

Similar to the surface pressure, the near-surface air temperature is well simulated by the Polar MM5. The monthly mean bias averaged over the eight sites ranges from -3.2°C to -1.7°C. The negative bias in the near-surface air temperature corresponds to the positive pressure bias over the entire 12 months. This anticorrelated variation in the temperature and pressure biases is consistent with the hydrostatically expected variations in the model pressure (i.e., colder temperatures lead to increased surface pressures). The correlation between the observed and modeled near-surface temperature is not as large as that for the surface pressure, but is still moderately large (around 0.65) when they are averaged over the eight sites. The RMSE averaged over the eight sites varies from 3°C to 8°C. It is at a minimum during the summer months, when synoptic forcing is weakest and the diurnal variability is dominant, and is at a maximum during the more synoptically active winter months.

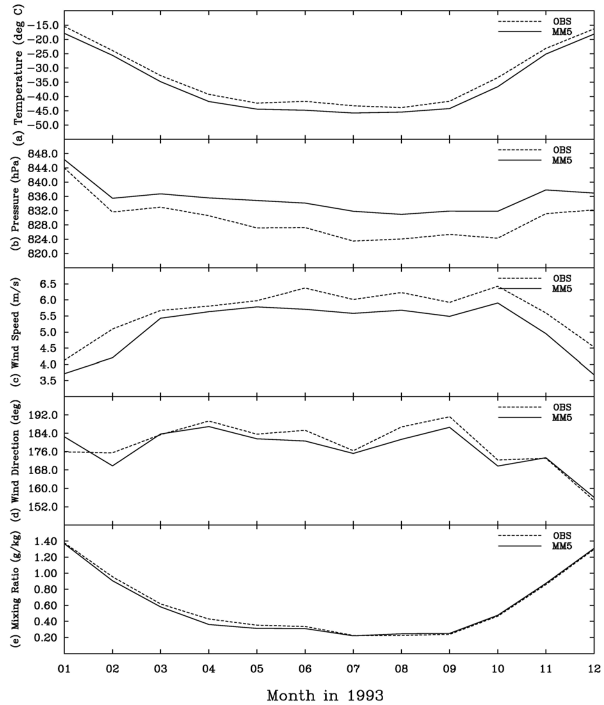

Figure 3. Monthly mean values of air temperature at 3 m (a), pressure (b), wind speed at 3 m (c), wind direction (d), and mixing ratio (e) calculated from the Polar MM5 simulation (dotted lines) and from the AWS and manned station observations (solid lines) for January through December 1993. The monthly mean values have been averaged over eight sites (and model grid points) as described in the text.

The seasonal cycle of modeled wind speed and wind direction is similar to the observations when averaged over the eight sites. The model verification statistics reveals a relatively high correlation (around 0.68) and a small bias between the observed and modeled wind direction. Among five variables shown in Figure 3 the correlation between the observed and modeled wind speed is the lowest, with little seasonal variation. It is believed that the errors in the ECMWF initialization, coarse spatial resolution (smoothing of topography), and cold biases in near-surface temperature, which have important effects on the predicted katabatic flow, are main causes in biases of wind speeds. Although the correlation of wind speed is poor there is a good agreement between the monthly mean values of observed and modeled wind speed, and the model captures trends in the monthly mean wind speed with a reasonable degree of skill.

The model also reproduces seasonal variations of the mixing ratio accurately. The correlation between the modeled and observed water vapor mixing ratio is qualitatively similar to that for the temperature, but is slightly lower for the mixing ratio than the temperature.

The synoptic variability in the model simulations is evaluated by considering time series of the daily running mean and 3-hourly observations and the Polar MM5 output.

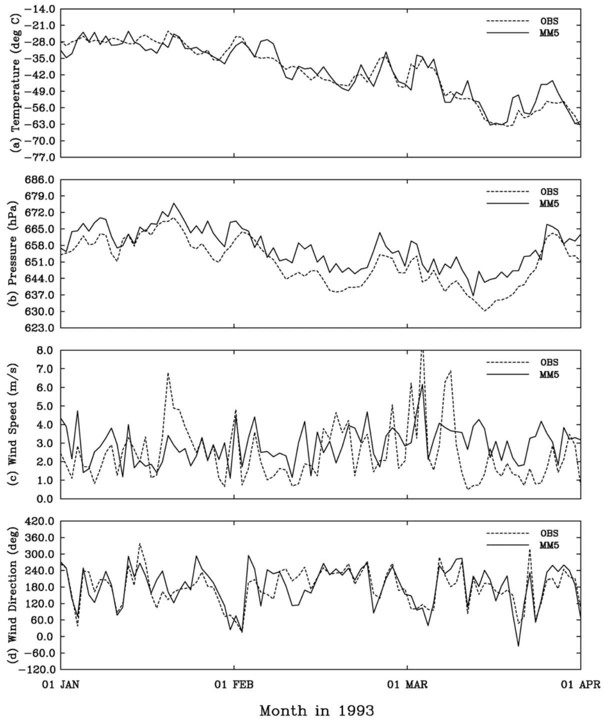

Figure 4. Time series of daily running mean AWS (dotted lines) and Polar MM5 (solid lines) data at Dome C AWS for Jan. Feb. and Mar. 1993.

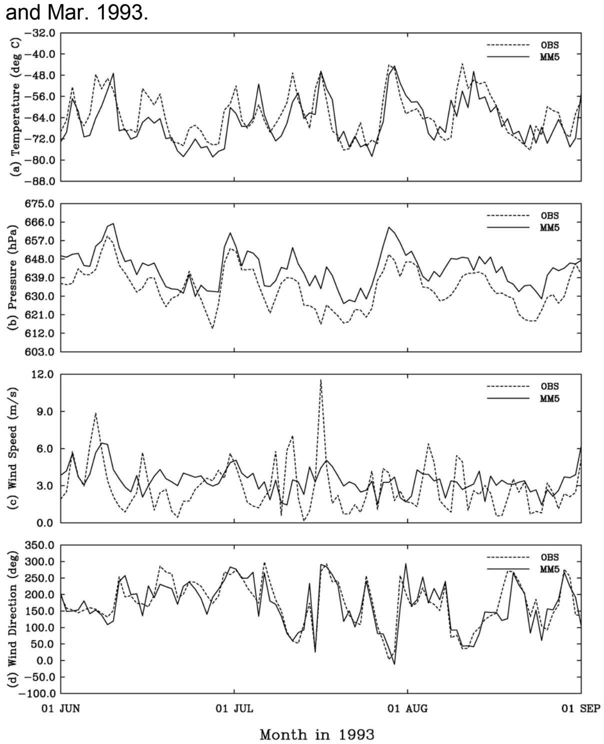

Figure 5. Time series of daily running mean AWS (dotted lines) and Polar MM5 (solid lines) data at Dome C AWS for Jun. Jul. and Aug. 1993.

Figures 4 and 5 show time series of daily running mean AWS (dotted lines) and Polar MM5 (solid lines) data at Dome C AWS for the summer (Jan. Feb. Mar.) and winter (Jun., Jul., Aug.) 1993 respectively. A positive bias is evident in the surface pressure at Dome C as found and discussed for monthly mean pressure biases averaged over eight sites. The monthly mean wind speeds are generally well represented, however, the model tends to underestimate the wind speed variance such that periods of higher wind speeds are not well forecast. Despite these biases, most of the variability of surface pressure, temperature, wind speed, and wind direction at Dome C site is well represented by Polar MM5 for both winter and summer time. The good agreement between the modeled and observed time series is consistent with the high monthly correlation of the modeled and observed values.

4. SUMMARY

The performance of the Polar MM5 has been evaluated over Antarctica for time scales from annual to diurnal. A comparison of a year-long series of short-term forecast of atmospheric state with observations from AWS and manned stations and climatological maps shows that simulations from Polar MM5 accurately capture both the large and regional scale circulation features with minimal bias in the modeled variables. Over all time scales the Polar MM5 is most skillful in the prediction of the surface pressure, temperature, wind direction, and water vapor mixing ratio, with slight less skillful predictions of wind speeds.

5. ACKNOWLEDGEMENTS

This research was funded by National Science Foundation grants OPP-9725730 and OPP-9905381 to D.H. Bromwich.

6. REFERENCES

Bromwich, D.H., J.J. Cassano, T. Klein, G. Heinemann, K.M. Hines, K. Steffen, and J.E. Box, 2001: Mesoscale modeling of katabatic winds over Greenland with the Polar MM5. *Mon. Wea. Rev.*, in press.

Cassano, J.J., J.E. Box, D.H. Bromwich, L. Li, and K. Steffen, 2001: Verification of Polar MM5 simulations of Greenland's atmospheric circulation. *J. Geophys. Res.*, Special Issue on the PARCA (Program for Arctic Regional Climate Assessment), in press.

Fletcher, N.H., 1962: *Physics of Rain Clouds.* Cambridge University Press.

Giovinetto, M.B., N.M. Waters, and C.R. Bentley, 1990: Dependence of Antarctic surface mass balance on temperature, elevation and distance to open ocean. *J. Geophys. Res.*, **95**, 3517-3531.

Hines, K.M., D.H. Bromwich, and Z. Liu, 1997: Combined global climate model and mesoscale model simulations of Antarctic climate. *J. Geophys. Res.*, **102**, 13747-13760.

Meyers, M.P., P.J. DeMott, and W.R. Cotton, 1992: New primary ice-nucleation parameterizations in an explicit cloud model, *J. Appl. Meteor.,* **31***,* 708-721.

Parish, T.R., and D.H. Bromwich, 1987: The surface wind field over the Antarctic ice sheets. *Nature*, **328**, 51-54.

Yen, Y.C., *Review of thermal properties of snow, ice and sea ice.* CRREL Rep. 81-10, 1981.