DEVELOPMENT AND TESTING OF POLAR WRF*

Keith M. Hines[1] and David H. Bromwich[1,2]
[1]Polar Meteorology Group, Byrd Polar Research Center,
The Ohio State University, Columbus, Ohio

[2]Atmospheric Sciences Program, Department of Geography
The Ohio State University, Columbus, Ohio

1. Introduction

A polar optimized version the 5th generation Penn State/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) was developed to fill climate and synoptic needs of the polar science community. Applications include polar hydrology (Box et al. 2006), ENSO teleconnections (Bromwich et al. 2004), paleoclimate studies (Bromwich et al. 2005), studies of Antarctic and Greenland katabatic winds (Cassano et al. 2001). The model is also used for daily operational numerical weather prediction to help NSF-supported Antarctic field operations (Bromwich et al. 2003; Powers et al. 2003). The Polar MM5 has been developed by the Polar Meteorology Group at The Ohio State University with the support of NCAR, and it is implemented into the public MM5 system at NCAR. Testing shows that inclusion of enhanced physics specifically adapted to the polar regions enables Polar MM5 to achieve a much improved performance (Bromwich et al. 2001; Cassano et al 2001).

Now that MM5 is no longer the vehicle for future mesoscale model development at NCAR, we must turn our attention to applying the developed polar skills toward the state-of-the-art Weather Research and Forecasting model (WRF). Testing and tune-ups are especially needed for the boundary layer parameterization, cloud physics, snow surface physics and sea ice treatment. Developmental simulations are needed for at least three types of polar climate regimes: (i) ice sheet areas (Antarctica and Greenland), (ii) polar oceans (especially sea ice surfaces) and (iii) Arctic land. Recent field projects such as the Surface Heat Budget of the Arctic (SHEBA) and the Atmospheric Radiation Measurement (ARM), combined with various in-situ and remote-sensing operations provide the observational data to validate the Polar WRF simulations.

*Corresponding Author Address: Keith M. Hines, Byrd Polar Research Center, The Ohio State University, 1090 Carmack Road, Columbus, OH 43210-1002, email: hines.91@osu.edu.

2. Greenland Simulations

Following the path used to develop Polar MM5, we consider simulations over a Greenland domain similar to that used by (Bromwich et al. 2001). The domain is a Lambert projection consisting of 110 points in the east-west direction and 100 points in the north-south direction. Grid spacing is 40 km. Vertical discretization consists of 28 sigma levels from the surface to 10 hPa with highest resolution in the boundary layer. The lowest two layers are centered at approximately 15 and 45 m, respectively AGL. Initial and boundary data, available every 6 hours, are supplied by the aviation model (AVN). Automatic weather station (AWS) data are readily available for validation from 16 sites of the Greenland Climate Network (Steffen and Box 2001; Box et al. 2004). Furthermore, radiation measurements at Summit (72.5794°N, 38.5042°W, 3254 m ASL) are available from June 2000 to June 2002.

A winter month, December 2002, and a summer month, June 2001, are simulated by WRF version 2.1.1 in a series of 48-hour integrations, each initialized at 0000 UTC. Following Bromwich et al. (2001), the first 24 hours are taken as an adjustment period that allows the model physics to spin-up the boundary layer and the hydrologic cycle. These first 24 hours are then discarded, and the 24-48 hour forecasts (one each day) are combined into a month-long output field.

Encouraging results from Polar WRF over Greenland during December 2002 appear in Table 1 that shows the average for 8 to 12 AWS ice sheet sites of the bias and correlation of model results to valid observations. The version of WRF2.1.1 for the results in Table 1 has the Hall-Thompson 2-moment cloud microphysics scheme, YonSei University (YSU) planetary boundary layer scheme, RRTM longwave radiation, and Noah land surface model. The Noah scheme was modified to simulate an improved surface energy balance over snow surfaces. From Table 1, Polar WRF and Polar MM5 have similar skill for the near-surface variables. We also tested WRF with physics options including the RUC boundary layer scheme, the WSM single-moment cloud physics scheme and the Eta planetary boundary layer scheme. The results with these other physics parameterizations are very similar to those shown in Table 1. Figure 1 shows the temperature every 6 hours interpolated to 2 m AGL for the AWS observations at Swiss Camp (69.5683°N, 49.3158°W, 1149 m ASL) and Summit along with the interpolated temperatures from WRF and Polar MM5. Temperature is almost always colder at Summit than along the sloping surface at Swiss Camp. Both models show good skill simulating the variability at both stations. The correlations are 0.94 for Polar MM5 and 0.91 for Polar WRF at Swiss Camp. Both models have a correlation of 0.85 for Summit. The Polar MM5 shows a cold bias of 2-3°C at both sites, apparently due to a deficit in downward longwave radiation.

Table 1: Comparative performance of Polar WRF and MM5 over Greenland, December 2002, for short-term forecasts compared against 6-h observations from 8-12 GC-Net AWS sites. Polar MM5 results are given in parentheses. From Hines and Bromwich [in preparation]

Variable	Bias	Correlation
Surface Pressure (hPa)	-1.8 (-0.8)	0.97 (0.98)
2-m Temperature (°C)	2.6 (-2.3)	0.91 (0.91)
2-m Specific Humidity (g/kg)	-0.07 (-0.32)	0.88 (0.85)
10-m Wind Speed (m/s)	1.6 (3.3)	0.82 (0.82)

Table 2: As in Table 1 except for June 2001.

Variable	Bias	Correlation
Surface Pressure (hPa)	-3.4 (-2.0)	0.91 (0.91)
2-m Temperature (°C)	-0.8 (-0.1)	0.81 (0.88)
2-m Specific Humidity (g/kg)	-0.11 (-0.01)	0.77 (0.81)
10-m Wind Speed (m/s)	-0.5 (0.1)	0.75 (0.78)

Figure 2 shows the 10-m wind speed for the same locations. The wind speed for Swiss Camp (Summit) corresponds to the scale on the left (right). Wind speed is typically higher at Swiss Camp due to the katabatic drainage. The December 2002 wind speed at Swiss Camp is clearly simulated better by Polar WRF than by Polar MM5. The former has a correlation of 0.87 and a bias of 0.47 m s^{-1}, while the latter has 0.76 and 4.32 m s^{-1}, respectively. In contrast, Polar MM5 has a slightly higher correlation at Summit (0.90) than that for Polar WRF (0.86). A positive wind speed bias is again seen for Polar MM5 with an excess of 2.43 m s^{-1}. The bias is smaller, 1.83 m s^{-1}, for Polar WRF. Interestingly, the correlations between the WRF and MM5 model results (not shown) are similar to those between the model results and the AWS observations. This was found for the temperature, wind speed, specific humidity and surface pressure at many sites. Thus, the errors in the MM5 and WRF simulations are more or less independent. In summary, this comparison illustrates skillful Polar WRF performance for the highly stable winter boundary layer.

Table 2 shows that somewhat less skill is found for the June 2001 WRF simulation. The diurnal cycles of temperature and wind speed are pronounced but synoptic variability is much weaker during this early summer month. Polar MM5 shows smaller biases and higher or equal correlations for all the variables in Table 2. Additional analysis (not shown) finds that the Polar WRF simulation has deficiencies including insufficient downward shortwave radiation at the surface and a slow spinup of the subsurface temperatures (which tend to be too cold especially during the latter half of June).

Figure 3 shows, however, that WRF well simulates the downward longwave radiation for June. The figure shows the diurnal cycle of average, minimum and maximum downward longwave radiation at Summit for Polar WRF and the observations. The average for Polar MM5 is also shown. Data were available every hour for the observations, every 3 hours for WRF and every 6 hours for MM5. The observed minimum and maximum define a realistic range for the month including cloudy and clear conditions. The diurnal cycle is not large in Figure 3. Polar WRF captures the range and the average very well. On the other hand, Polar MM5 shows a significant deficit. The different results for longwave and shortwave radiation is somewhat surprising as both should be heavily influenced by cloud cover.

3. SUMMARY AND COMMENTS

The development of Polar WRF will provide an improved mesoscale model applicable for Arctic and Antarctic climates following up on the previous work with Polar MM5. Earlier tests demonstrated that the model well captures the synoptic variability. Testing of the physical parameterizations is needed for the various Arctic and Antarctic environmental conditions including those found over ice sheets, the polar oceans and Arctic land. Regional optimization of the physics is needed analogous to the development of Polar MM5. The results presented here suggest that presently available parameterizations for WRF with modest adaptations should work well for the polar regions during the winter months, with a skill level equaling or exceeding that of Polar MM5. More improvements, however, will be required to successfuly simulate the summer months. We find that summertime downward longwave radiation is very well simulated, however, the downward shortwave radiation is undersimulated.

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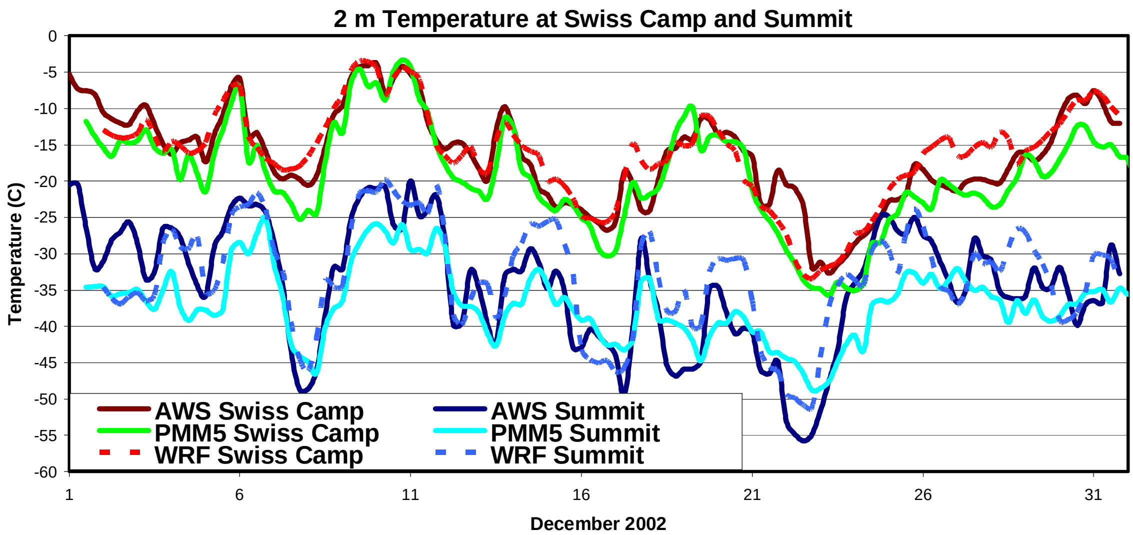

Figure 1. 2-m temperature (°C) at during December 2002 at Swiss Camp and Summit for automatic weather station (AWS) observations and simulations by Polar WRF and Polar MM5.

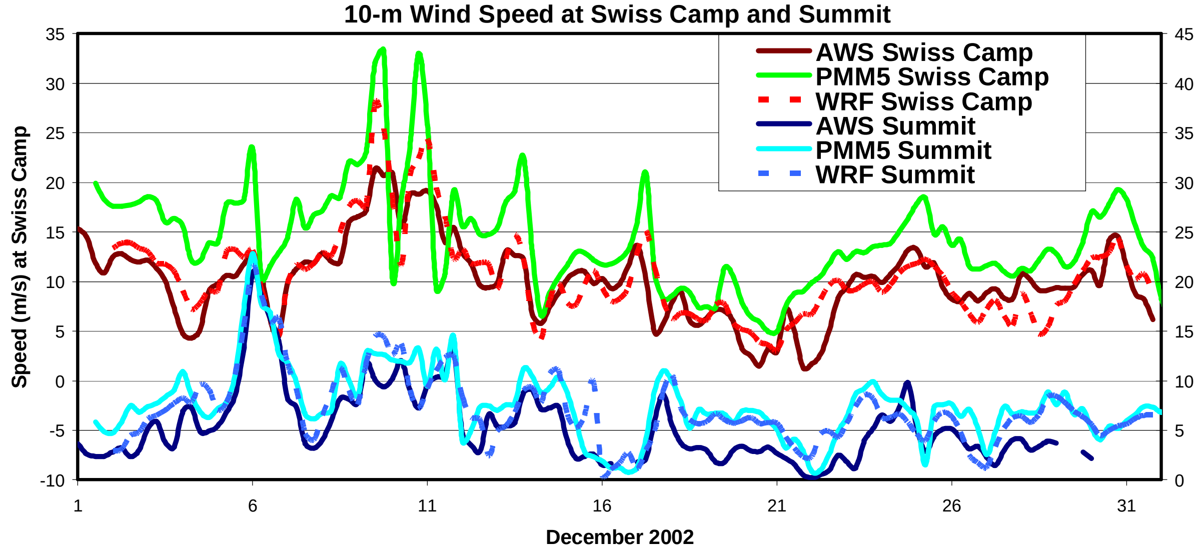

Figure 2. Same as Fig.1 except for 10-m wind speed (m s^{-1}).

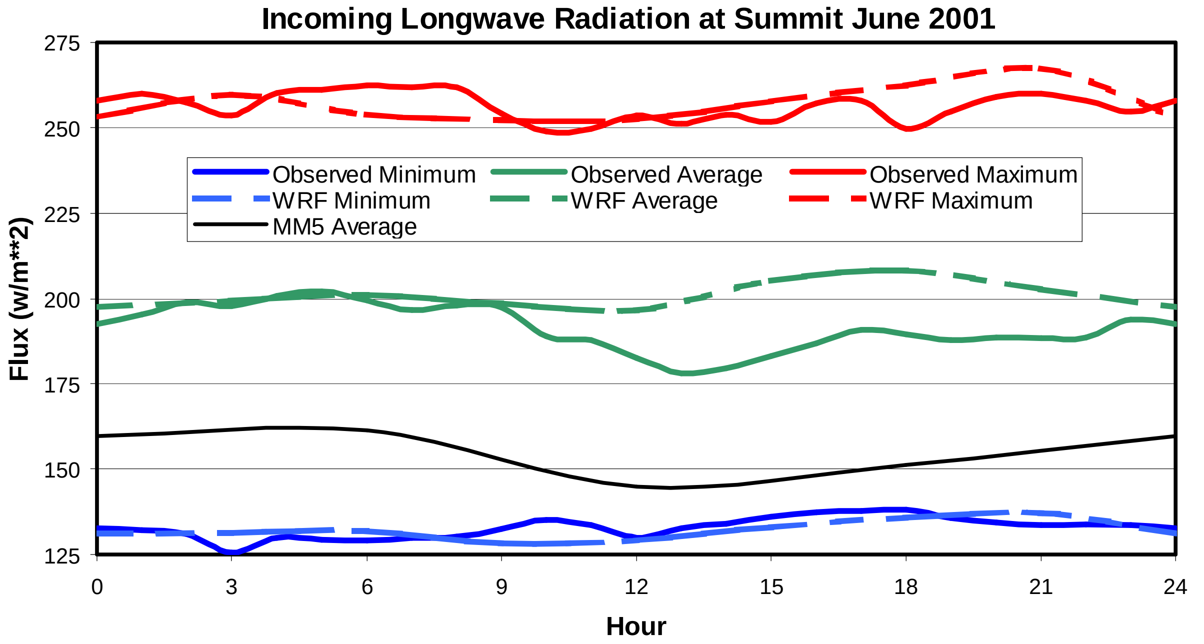

Figure 3. Diurnal cycle of downward longwave radiation (w m^{-2}) at Summit during June 2001 for Polar WRF and observations. The minimum, maximum and average are shown. The average for Polar MM5 is also shown.