POLAR-OPTIMIZED WRF*

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1. Introduction

A polar-optimized version of the 5th generation Penn State/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) was previously developed to fill climate and synoptic needs of the polar science community. As an example, the model is used for daily operational numerical weather prediction to assist NSF-supported Antarctic field operations (Bromwich et al. 2003; Powers et al. 2003). The Polar Meteorology Group at The Ohio State University optimized the model with the support of NCAR. The Polar MM5 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).

The polar-optimization is now being performed for 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.

The new Polar WRF will be an excellent tool for regional analyses in the polar regions combining the forecast skill of a modern mesoscale model with advanced data assimilation techniques under development by the working group for WRF data assimilation development.

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2. Greenland Simulations

The work begins with simulations for domains that include a North Atlantic 110x100 grid with 40-km horizontal resolution and a Greenland-area 97x139 grid with 24-km resolution. The latter grid is also used for recent studies of Greenland and Iceland climate with Polar MM5 (e.g., Bromwich et al. 2005). The present paper will only show results for the latter grid. In the vertical, 28 sigma levels extend from the surface to 10 hPa, with the lowest 10 layers over Greenland centered approximately at 14, 42, 75, 118, 171, 238, 325, 433, 561, and 748 m, respectively above ground level. 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, 3208 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 integrations, each initialized at 0000 UTC. Following Bromwich et al. (2005), the first 12 hours are taken as an adjustment period that allows the model physics to spin-up the boundary layer and the hydrologic cycle. These first 12 hours are then discarded, and the 12-36 hour forecasts (one each day) are combined into a month-long output field.

3. Results

Encouraging results from Polar WRF over Greenland during December 2002 appear in Table 1 that shows average statistics of bias and correlation of model results to valid observations for 8 to 12 AWS sites. The version of WRF2.1.1 for the results in Table 1 has the WRF Single-Moment 5-Class cloud microphysics scheme, the Eta planetary boundary layer scheme, the RRTM longwave radiation, the Goddard shortwave scheme and the Noah land surface model. The

Noah scheme was modified to simulate an improved surface energy balance over snow surfaces (Hines and Bromwich 2007). From Table 1, Polar WRF has smaller biases for 2-m temperature, 2-m specific humidity and 10-m wind speed than Polar MM5. The latter does have a smaller magnitude bias, -0.9 hPa, for surface pressure than the value, -1.4 hPa, for WRF. The average correlations of the time-varying fields are similarly large for both models. Table 2 shows that the model results for June 2001 compare best to the AWS observations for the Polar MM5 simulation. Nevertheless, Polar WRF shows similar skill to Polar MM5 for the summer case.

Table 1: Comparative performance of Polar WRF and Polar 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 (2007).

Variable	Bias	Correlation
Surface Pressure (hPa)	-1.4 (-0.9)	0.98 (0.98)
2-m Temperature (°C)	1.2 (-2.3)	0.90 (0.89)
2-m Specific Humidity (g kg^{-1})	-0.05 (-0.29)	0.87 (0.85)
10-m Wind Speed (m s^{-1})	1.6 (3.3)	0.82 (0.81)

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

Variable	Bias	Correlation
Surface Pressure (hPa)	-3.6 (-2.0)	0.91 (0.91)
2-m Temperature (°C)	-0.8 (-0.1)	0.81 (0.83)
2-m Specific Humidity (g kg^{-1})	0.03 (-0.19)	0.77 (0.77)
10-m Wind Speed (m s^{-1})	-0.9 (0.0	0.78 (0.78)

Figures 1 and 2 show the diurnal cycle of incident shortwave and longwave radiation, respectively, at Summit, Greenland for observations, Polar MM5 and Polar WRF simulations during June 2001. Data are available every hour for the observations, every 3 hours for WRF and every 6 hours for MM5. The minimum values for longwave radiation and maximum values for shortwave radiation will occur for clear skies, with the opposite being the case for cloudy skies. The figures show that WRF well simulates the both the downward longwave and shortwave radiation radiation for June. On the other hand, Polar MM5 shows a significant deficit for longwave radiation. Thus, the surface energy balance for Polar WRF is more reasonable.

4. January 1998 Western Arctic Simulation

Polar WRF is also for run for January 1998 with a grid consisting of 141 points in the east-west direction and 111 points in the north-south direction (Bromwich et al. 2008, in preparation). Horizontal resolution is 25 km, and 28 levels are again used in the vertical. For this simulation, WRF is taken from version 2.2 of the model with the polar modifications added. The initial simulation includes the Thompson et al. (2004) 2-moment microphysics, the Yonsei University boundary layer, the Noah LSM, the Goddard shortwave radiation, and the RRTM longwave radiation. Simulations with other configurations of the WRF physics are ongoing and will be discussed in future publications.

Figure 3 shows the observed surface and 2.5-m temperature at SHEBA camp during the mid-winter month January 1998. The simulated temperatures at the surface and 2 m are also shown. Except for a few events, especially 03 January to 05 January, the simulation well captures the surface-layer temperature and its synoptic variability. The bias is only -0.3°C for the surface temperature and within observational uncertainty for the 2/2.5 m comparison. The correlations are 0.87 at the surface and 0.86 for the slightly higher level. The simulated 10-m wind speed, downwelling longwave radiation, and shortwave radiation (not shown) also agree well with observations. These results are highly encouraging for Polar WRF. On the other hand, earlier results for simulations of June 1998 suggest there may be a model bias to overpredict the thickness and persistence of liquid water clouds in the boundary layer. Additional verifications are needed for these fields.

5. Summary and Comments

The development of Polar WRF is expected to provide an improved model for Arctic and Antarctic climate and synoptic applications. Following the path used to develop Polar MM5, testing begins

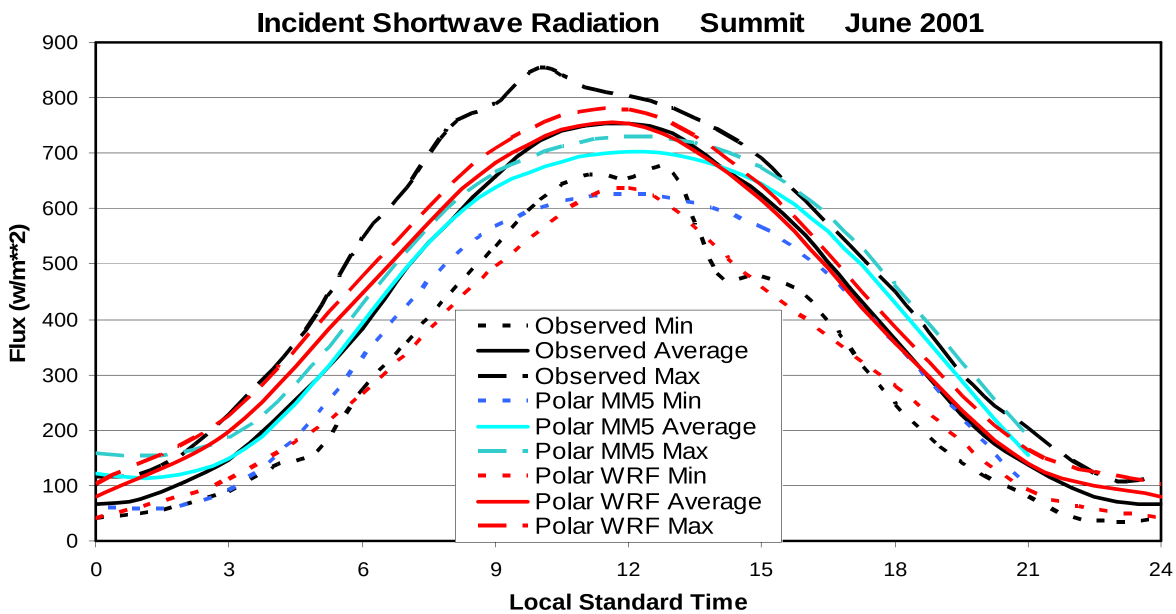

Figure 1. Diurnal cycle of incident shortwave radiation (W m^{-2}) at Summit, Greenland during June 2001 showing hourly average, minimum, and maximum values during June 2001 for observations (every hour), the Polar MM5 (every 6 hours) and the Polar WRF simulations (every 3 hours).

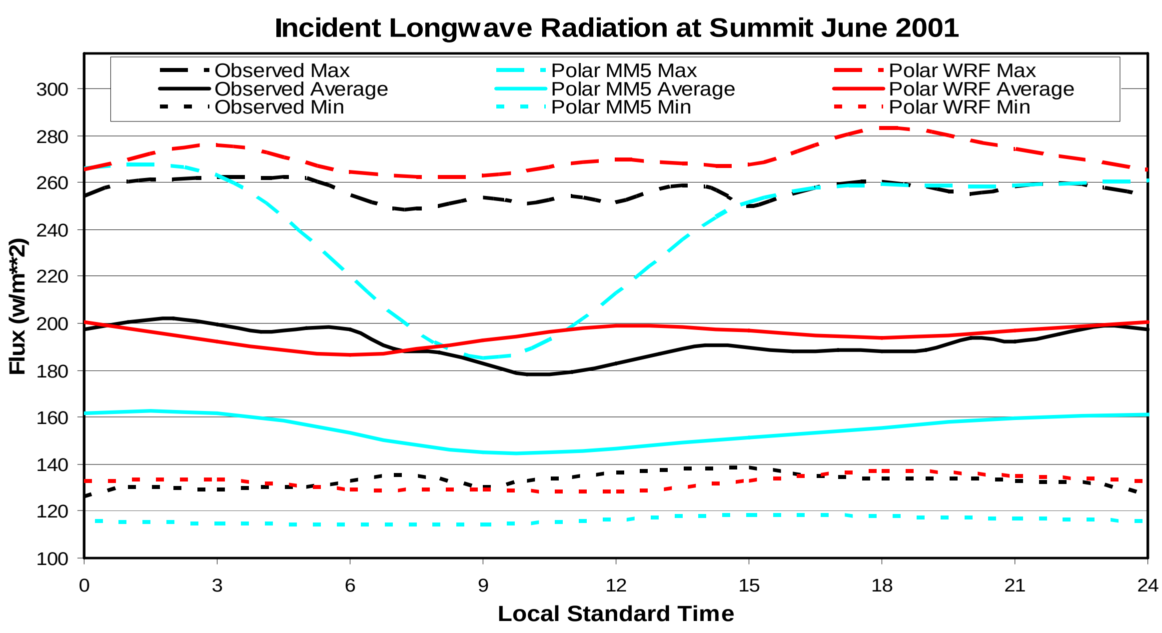

Figure 2. As in Figure 1, except for incident longwave radiation.

with simulations of the Greenland Ice Sheet region. The WRF single-moment 5 class microphysics, Noah LSM, and Eta boundary layer parameterization were selected after comparing several options. The Polar WRF simulations for December 2002 simulations show similar or better forecast skill to Polar MM5 simulations in comparison to automatic weather station observations. The June 2001 WRF simulation shows slightly less forecast skill compared to the Polar MM5 simulation for AWS-observed variables. The surface energy balance, however, is superior for the WRF simulation. Initial tests over the western Arctic region show encouraging results for January 1998. Testing of the physical parameterizations is still needed for the various Arctic and Antarctic environmental conditions including those found over ice sheets, the polar oceans and Arctic land. Reports on simulations of Polar WRF in preparation for eventual real-time weather forecasts by NCAR researchers suggest that the model will proved successful for that application.

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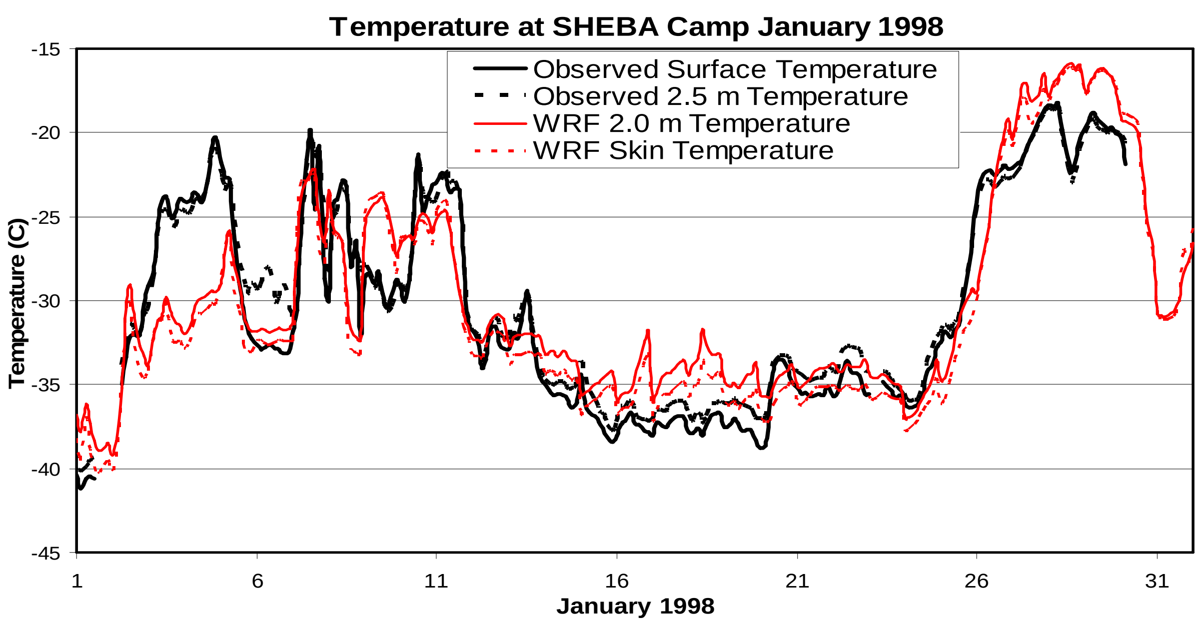

Figure 3. Surface temperature and atmospheric temperature at 2 m (simulated) or 2.5 m (observed) for SHEBA camp during January 1998 from observations and the Polar WRF simulation.