1. Introduction

Previously, “Polar MM5” a version of the 5th generation Penn State/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5) demonstrated that regional optimizations specific for the polar regions can yield a much improved performance for both the Arctic and Antarctic applications (e.g., Bromwich et al. 2001, 2003; Cassano et al. 2001; Powers et al. 2003). Therefore, a polar-optimized version of the state-of-the-art Weather Research and Forecasting model (WRF) was developed by the Polar Meteorology Group of Ohio State University’s Byrd Polar Research Center. Polar WRF is envisioned to fulfill a variety of needs for Arctic and Antarctic applications. An example is the daily operational numerical weather prediction to assist NSF-supported Antarctic field operations (Bromwich et al. 2003; Powers et al. 2003; Powers 2007).

The polar-optimization has been performed for the state-of-the-art Weather Research and Forecasting model (WRF). Components that require testing include the boundary layer parameterization, cloud physics, snow surface physics and sea ice treatment. Developmental simulations consider three types of polar climate regimes: (i) ice sheet areas (Antarctica and Greenland), (ii) polar oceans (especially sea ice surfaces) and (iii) Arctic land. The testing and development work for Polar WRF began with both winter and summer simulations for ice sheet surface conditions using Greenland area domains (Hines and Bromwich 2008). The simulations facilitated improvements to ice sheet surface energy balance and snow firn energy transfer for the Noah land surface model (LSM).

The Polar WRF will have the capability to join the forecast skill of a modern mesoscale model with advanced data assimilation techniques under development for WRF-Var (Barker et al. 2004).

2. Arctic Ocean Simulations

The Surface Heat Budget of the Arctic Ocean (SHEBA, Persson et al. 2002) during 1997/98 provided an excellent opportunity to test Polar WRF for various Arctic conditions. A new treatment for grid points containing both open water and sea ice was added to WRF Version 2.2 for this work. The surface boundary layer routine is called separately for the ice and liquid portions of a grid box. The land surface model (LSM) is then called for the ice portion. The new sea ice treatment has been tested with the Noah LSM (Chen and Dudhia 2001; Skamarock et al. 2006). However, the fractional sea ice treatment is outside the LSM. The SHEBA simulations also include the polar-optimizations for snow and ice surfaces within the Noah LSM from Hines and Bromwich (2008). The new simulations also include the fully-two-moment ice and liquid water microphysics of Morrison et al. (2005) that is now a standard physics option in WRF Version 3. 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 European Centre for Medium-Range Weather Forecasts (ECMWF) 40-Year Reanalysis (ERA-40).

For this round of simulations, we use a western Arctic grid with 25-km resolution (Bromwich et al. 2008). The 141×11 domain for is displayed in Fig. 1. the initial spin-up time for the simulation set al 24 hours, and the model output from hours 24-45 is combined into the month-long fields. Arctic conditions are simulated for the selected months: January 1998, June 1998, and August 1998 representing mid-winter, early summer and late summer conditions, respectively from SHEBA. High quality observations are available for many atmospheric and oceanic fields during SHEBA (e.g., Persson et al. 2002). Relevant locations of Ice Station SHEBA are shown in Figs. 1 and 2.
Figure 1. Domain for the Polar WRF simulations of the western Arctic. Squares show station locations. Marks in the Arctic Ocean show the location of Ice Station SHEBA during January (blue), June (green) and August (red) 1998.

Figure 2. Color scale of average sea ice fraction during August 1998. The track of Ice Station SHEBA during August is shown next to the arrow. Land and ice-free grid points are unshaded.

Table 1. Model performance statistics for Polar WRF during January, June and August 1998 in comparison to Ice Station SHEBA observations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Correlation</th>
<th>January</th>
<th>June</th>
<th>August</th>
<th>January</th>
<th>June</th>
<th>August</th>
<th>January</th>
<th>June</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Pressure (hPa)</td>
<td></td>
<td>0.98</td>
<td>0.97</td>
<td>0.99</td>
<td>0.5</td>
<td>1.1</td>
<td>1.6</td>
<td>2.2</td>
<td>2.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Surface Temperature (°C)</td>
<td></td>
<td>0.83</td>
<td>0.38</td>
<td>0.46</td>
<td>-2.2</td>
<td>0.4</td>
<td>0.2</td>
<td>4.3</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>*2.0/2.5 m Temperature (°C)</td>
<td></td>
<td>0.82</td>
<td>0.45</td>
<td>-</td>
<td>-1.8</td>
<td>0.2</td>
<td>-</td>
<td>4.0</td>
<td>1.1</td>
<td>-</td>
</tr>
<tr>
<td>10 m Temperature (°C)</td>
<td></td>
<td>0.80</td>
<td>0.49</td>
<td>0.55</td>
<td>-2.1</td>
<td>0.3</td>
<td>0.1</td>
<td>4.2</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>10 m Wind Speed</td>
<td></td>
<td>0.88</td>
<td>0.71</td>
<td>0.83</td>
<td>-0.6</td>
<td>-0.6</td>
<td>-0.6</td>
<td>1.5</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>*2.0/2.5 m Specific Humidity (g kg⁻¹)</td>
<td></td>
<td>0.82</td>
<td>0.63</td>
<td>0.62⁺</td>
<td>-0.04</td>
<td>0.13</td>
<td>0.0⁺</td>
<td>0.12</td>
<td>0.29</td>
<td>0.27⁺</td>
</tr>
<tr>
<td>Incident Longwave Radiation (W m⁻²)</td>
<td></td>
<td>0.84</td>
<td>-0.19</td>
<td>0.29</td>
<td>-10.2</td>
<td>-9.4</td>
<td>2.8</td>
<td>24.3</td>
<td>173.7</td>
<td>24.6</td>
</tr>
<tr>
<td>Incident Shortwave Radiation (W m⁻²)</td>
<td></td>
<td>-</td>
<td>0.47</td>
<td>0.38</td>
<td>-</td>
<td>-6.3</td>
<td>5.9</td>
<td>-</td>
<td>171.4</td>
<td>114.1</td>
</tr>
</tbody>
</table>

* Observations were available at 2.5 m from tower observations and are used to verify 2.0 m Polar WRF results.
+ Observations at 2.5 m were not available for August so the 2.0 m Polar WRF specific humidity was compared against tower observations at 10-m.

the ice surface conditions change greatly over the course of late spring, then summer, and finally onto Autumn (Perovich et al. 2007). Figure 2 shows the fraction of sea ice for ocean grid points with model domain during August 1998, when the Arctic open water fraction is considerably larger...
than during most other months Based upon in-situ and remote-sensing observations, the albedo of sea ice is specified as a function of time and latitude for June and as a function of time for August. Details are presented in Bromwich et al. (2008). Simulation results are compared with the observations of the drifting ice station SHEBA in the Arctic ice pack.

3. Results

The Polar WRF simulations show good agreement with observations for all three months. Model performance statistics are presented in Table 1. Figure 3 shows the excellent agreements between observed surface pressure and simulated surface pressure during the winter month January. Similar simulation quality, with correlations of 0.97 or larger, for surface pressure occurs during the early summer month June and the late summer month August (Table 1). The very good agreement between the simulated and observed surface pressure demonstrates that Polar WRF is well capturing the synoptic variability. Due to the strong influence of local boundary layer processes and the surface energy balance, however, surface temperature is a more difficult field to simulate than surface pressure, hence the temperature correlations are much smaller in Table 1.

Figure 4, which shows the time series of surface temperature, reflects these complications, as the high-frequency fluctuations of temperature are not necessarily well-captured by Polar WRF. The high-frequency fluctuations in temperature seen in Fig. 4 are primarily due to variability in water and ice clouds near SHEBA (Bromwich et al. 2008). This is not surprising as Arctic clouds are frequently problematic for numerical simulations. Figure 5, which shows the liquid water path for 7-17 June 2008, demonstrates the importance of properly capturing the liquid and ice species. In this example, Polar WRF simulates too much liquid cloud between 8-11 June. Therefore, the cold events are not well represented during this time. Nevertheless, the over temperature biases are small during June and August, and the simulations show very good promise for their ability to capture the synoptic variability in the Arctic. Overall, we find Polar WRF to be a skillful tool for studies of Arctic Ocean meteorology. Furthermore, Hines and Bromwich (2008) show that Polar WRF simulates a superior surface energy balance over Greenland than the earlier generation Polar MM5.

4. Summary and Comments

The development of Polar WRF provides an improved model for Arctic and Antarctic climate and synoptic applications. Following the path used to develop Polar MM5, testing began with simulations of the Greenland Ice Sheet region (Hines and Bromwich 2008). To test Polar WRF over sea ice, a new specified fractional sea ice is implemented. The model is now evaluated with a western Arctic domain based upon the SHEBA 1997/98 observational study (Bromwich et al. 2008). Simulations are run for the mid-winter month January, the early summer month June, and the late summer month August, 1998. The simulations were verified against the detailed

![January Surface Pressure at Ice Station SHEBA](image_url)

Figure 3. Surface pressure (hPa) from observations and Polar WRF at Ice Station SHEBA for January 1998.
Figure 4. Time series of surface temperature (°C) from observations (solid lines) and the Polar WRF simulations (dashed lines) at Ice Station SHEBA for (a) January, (b) June and (c) August 1998. Correlation, bias and root mean square error (RMSE) statistics are shown for each month.
SHEBA observations and showed small biases for all three months. Testing of the physical parameterizations is still needed over the Antarctic ice sheets and Arctic land surfaces.

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6. REFERENCES


Figure 5. Liquid water path (kg m⁻²) and ice water paths at Ice Station SHEBA from vertically-integrated cloud observations of Shupe et al. [2005] and Polar WRF simulation of liquid cloud, ice cloud and snow for 7 June – 17 June 1998.