ARCTIC LAND SIMULATIONS WITH POLAR WRF*

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1. Introduction

Previously, the “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, Skamarock et al. 2006, http://www.wrf-model.org/index.php) has been developed by the Polar Meteorology Group of Ohio State University's Byrd Polar Research Center. The Polar WRF (http://polarmet.mps.ohio-state.edu/PolarMet/pwrf.html) is envisioned to fulfill a variety of Arctic and Antarctic applications. A current example is daily operational numerical weather prediction to assist NSF-supported Antarctic field operations (Bromwich et al. 2005; Powers et al. 2003; Powers 2007).

Components of Polar WRF that require regional testing include the boundary layer parameterization, cloud physics, radiation, 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).

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The Polar WRF has 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). The model is also used for the production of the Arctic System Reanalysis (Bromwich et al. 2009b).

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 synoptic conditions and the seasonal cycle over the Arctic Ocean. A new treatment for grid points containing both open water and sea ice was added to the polar-optimized model starting with WRF version 2.2. The fractional sea ice treatment developed by the Polar Meteorology Group is available to the community as a standard option in the very recently released version 3.1 of WRF. The surface layer component of the boundary layer routine is called separately for the ice and liquid portions of a grid box in pack ice. The land surface model is then called for the ice portion to obtain the surface fields. For the open-water fraction, surface fluxes are computed by the atmospheric surface boundary layer routine, and the LSM is not invoked there. The new sea ice treatment has been tested with the Noah LSM.

The SHEBA simulations also included the polar-optimizations for snow and ice surfaces within the modified Noah LSM from Hines and Bromwich (2008). The simulations also used the fully two-moment ice and liquid water microphysics of Morrison et al. (2005) that is now a standard physics option starting with WRF Version 3.0. The horizontal domain was a western Arctic grid with 25-km resolution (Bromwich et al. 2009a). The 141×11 domain is displayed in Fig. 1. Arctic conditions were simulated for the selected months: January 1998, June 1998, and August 1998 representing mid-winter, early summer and late summer conditions, respectively, from SHEBA. Initial and boundary conditions were supplied by the European Centre for Medium-Range Weather Forecasts 40-yr Reanalysis (ERA-40). Sea ice albedo was specified as a constant 0.8 during January, as function of latitude and time during June, and as a function of time during August. Very good results were obtained for all three months and the findings are presented in Bromwich et al. (2009a).

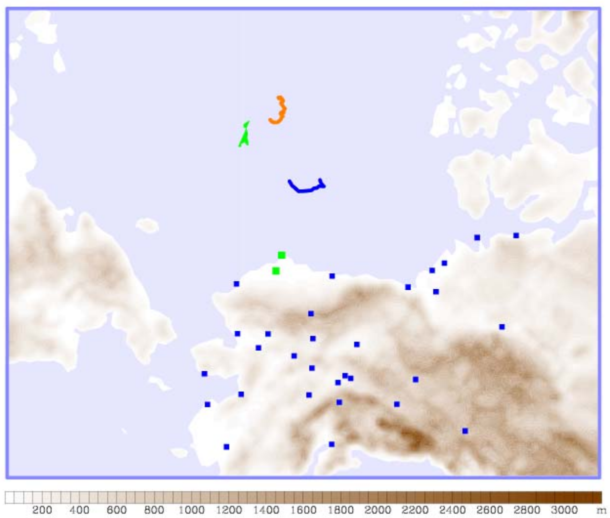

Figure 1. Domain for the Polar WRF simulations of the western Arctic. Squares show selected Arctic land observing stations. Green squares show the locations of Barrow, AK and Atqasuk, AK. Marks in the Arctic Ocean show the location of Ice Station SHEBA during January (blue), June (green) and August (red) 1998.

3. Arctic Land Simulations

The current study, representing the third of the three stages of evaluation of Polar WRF for Arctic surface types, prioritizes results over land for Arctic simulations. For this study, the polar optimizations are added to WRF version 3.0.1.1. Simulations are run with a similar procedure as in Bromwich et al. (2009a) with a series of 48-hr integrations starting each day at 0000 UTC for the study period from 15 November 2006 until 30 July 2007, including part of the International Polar Year (IPY). Atmospheric initial and boundary conditions every 6 hours are adapted from the Global Forecasting System (GFS, Global Climate and Weather Modeling Branch, 2003) model of the National Centers for Environmental Prediction. Sea ice fraction is obtained from AMSR-E retrievals available from the National Snow and Ice Data Center (NSIDC).

Due to the slow spin-up of soil variables in WRF, a continuous simulation of soil temperature and moisture within the unified Noah LSM is performed through cycling the 48-hr soil output into the WRF initial conditions at the appropriate valid times. Initial soil conditions for 15 November 2006 are taken from a 10-yr High-Resolution Land Data Assimilation (HRLDAS, Chen et al. 2007) run performed by the third author at NCAR. The deep soil temperature is taken from a database of the mean annual temperature at the bottom of the phase change boundary compiled by the fourth author at the Cooperative Institute for Research in Environmental Sciences (CIRES) and NSIDC.

The same western Arctic grid as in Bromwich et al. (2009a) is used for these simulations (Fig. 1). 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. The initial spin-up time for the atmospheric simulation set at 24 hours, and the model output from hours 24-45 is combined into multi-month fields.

Over the Arctic pack ice, the ice surface conditions show significant season changes. Therefore, following Bromwich et al. (2009a), sea ice albedo is specified at 0.82 until the onset of spring/summer melt. Sea ice albedo then decreases linearly in time over 35 days until reaching a value of 0.5. During July, the sea ice albedo changes linearly in time from 0.5 (representing a mix of bare ice and developing melt ponds) to 0.65 at the end of the month (when the melt ponds are deeper and taken to be represented as part of the open-water fraction). The onset of snow melt over sea ice is taken as a function of latitude and julian day for 2007 from a dataset provided by Mark Anderson of the University of Nebraska-Lincoln.

The albedo of snow over land is taken as 0.8 until the onset of the snowmelt transition. The onset is estimated as a function of latitude varying from 21 April in the southern part of the domain until early June for the northernmost land grid points within the domain. The snow albedo is taken to rapidly change from 0.8 to 0.65 during the transition specified to be 5 days long.

Simulation results are compared to climatological observing sites of the Atmospheric Research Measurement North Slope of Alaska (NSA) sites at Barrow, AK and Atqasuk, AK, and the Long Term Ecological Research (LTER) sites at Bonanza Creek, AK and near the Kuparuk River Basin.

4. Results

Figure 2 shows time series of 2-m temperature. The observations are from the Atmospheric Research Measurement North Slope of Alaska (NSA) site Barrow, AK. The nearest Polar WRF grid point over land to Barrow has a land use type of mixed tundra. The first panel covers the time period from 26 December 2006 to 25 April 2007. The second panel is for 5 April to 3 August. Good agreement is shown between the simulated and observed temperature for synoptic variability and seasonal change until early June 2007. The biases from January to May are less than 2°C in magnitude for each month. The snow cover melts by early June, then maximum daytime temperature frequently exceed observed values by about 10°C. The bias for June is 5.0°C and that for July is 3.1°C. The coastal impact at Barrow, however, probably has a strong impact on the positive bias for Polar WRF. At the NSA site Atqasuk, located several grid points south of the coastline, the bias is smaller, 2.8°C for June and only 0.1°C for July (not shown).

Figure 3 shows time series of 10-m wind speed for the observations at Barrow and the model results. During winter and spring, the model qualitatively captures the variability of the wind speed at Barrow, with a few exceptions. Barrow tends to have higher maximum wind speeds than are represented by the model as seen in Fig. 3. The biases vary from -0.3 to -1.2 m s^{-1} during the winter and spring months. The biases are smaller magnitude or possibly reversed in sign during the summer months. The tendency to simulate smaller than observed wind speed is also seen at Atqasuk (not shown).

5. 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). The second phase of testing was a comparison of Polar WRF simulations to observations over the Arctic pack ice at SHEBA. The current study shows the test results for the third phase. Polar WRF simulations based upon WRF version 3.0.1.1 are compared to observations over Arctic land. Planned future enhancements to Polar WRF include adding variable sea ice thickness, and improving the thermodynamic treatment of snow over sea ice.

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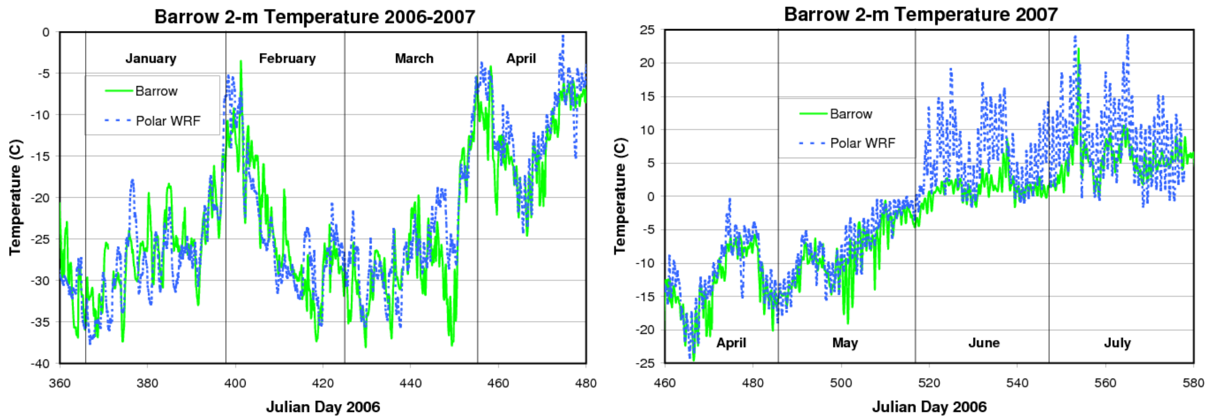

Figure 2. Time series 2-m temperature (°C) from observations at Barrow, AK and the nearest Polar WRF land grid point.

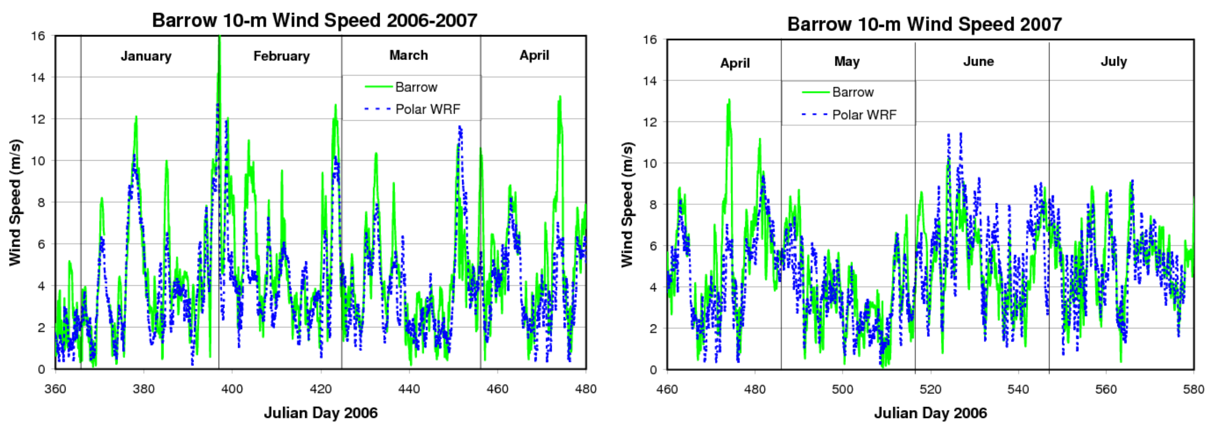

Figure 3. Time series 10-m wind speed (m s^{-1}) from observations at Barrow, AK and the nearest Polar WRF land grid point.