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ON ADAPTING A NEXT-GENERATION MESOSCALE MODEL FOR THE POLAR REGIONS*

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1. INTRODUCTION

The need for a broad, interdisciplinary, multi-scale study of the Arctic inspired the Study of Environmental Arctic Change (SEARCH) project (Overland et al. 2003). A prime component of SEARCH will be a comprehensive reanalysis of the atmosphere, ice, ocean and land from all available data. The Arctic System Reanalysis (ASR) will be conducted with a polar-optimized version of the next generation Weather Research and Forecasting (WRF, http://wrf-model.org/) model. The ASR will take advantage of the extensive knowledge gained during previous mesoscale modeling work for the polar regions. Furthermore, the production of the ASR will approximately correspond to the upcoming International Polar Year (IPY) 2007/2008) that will facilitate a renewed interest in the observing, modeling and understanding of polar phenomena. A parallel effort in the Antarctic region during this time is the Regional Interactions Meteorology Experiment (RIME), that will also require advanced mesoscale modeling. Thus, a Polar WRF is doubly important.

2. POLAR MM5

The immediate precursor to Polar WRF is the polar version (Polar MM5) of the fifth generation Penn State/National Center for Atmospheric Research (NCAR) Mesoscale Model (MM5). The Polar MM5 has been developed by the Polar Meteorology Group at The Ohio State University and implemented into the MM5 system at NCAR. The model has enhanced physics specifically adapted to the polar regions, and has achieved a much better performance than previous versions of the MM5 (Bromwich et al. 2001; Cassano et al 2001). In addition to modern Arctic and paleoclimate applications of the polar-optimized model, operational numerical weather prediction for NSF-supported Antarctic field operations is performed daily at NCAR (Bromwich et al. 2003; Powers et al. 2003).

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3. POLAR WRF

The WRF was very recently developed by a broad cross-section of the U.S. atmospheric science community including the National Centers for Environmental Prediction (NCEP) and NCAR. To facilitate the best simulations of the polar regions, the high-latitude physics in Polar MM5 needs to be ported over to WRF and further enhanced. Improvements are needed in the boundary layer, cloud physics, snow surface physics, and the sea ice treatment. Recent field projects such as the Surface Heat Budget of the Arctic and the DOE Atmospheric Radiation Measurement, combined with various in-situ and remote-sensing observations, need to be tapped into to best facilitate the polar-optimization of WRF. We begin by evaluating the parameterizations available in standard versions of WRF. Currently, version 1.3 of WRF is being tested over Arctic domains including ocean, land and ice sheet surfaces. This version runs on a local Linux cluster, and the Aviation (AVN) model is used to provide initial conditions and boundary conditions updated every 6 hours.

The model is first tested for July and December, 2002 on an Arctic grid similar to that used for current hydrological and meteorological studies with Polar MM5 of Arctic river basins, including the northern Alaska drainage. The domain has 150×150 horizontal grid points on a polar stereographic grid, and is centered at 65°N, 95°W. The horizontal resolution is 60 km, with 29 levels in the vertical. The stability of the simulations shows some sensitivity to the selection of turbulence and boundary layer parameterization and the specification of the upper boundary treatment. The most stable simulations are obtained with the use of the 2nd order horizontal diffusion, the Monin-Obukhov similarity surface layer physics similar that of the Eta model, the OSU/MM5 Land Surface Model, and the 1.5-order turbulent kinetic energy Mellor-Yamada-Janjic planetary boundary layer. Furthermore, the version we used has the RRTM longwave radiation scheme, the NCEP 5-class microphysics scheme with ice, and 4 soil layers. Better results are achieved when the depth of the upper damping layer is set at 2000 m, and the damping coefficient is set at 0.2. The results indicate that the unmodified version of WRF simulates the synoptic meteorology with similar skill to that of the polar-optimized version of MM5.

4. GREENLAND DOMAIN

The early version of WRF is also tested over a North Atlantic and Greenland domain previous used to evaluate Polar MM5 (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. Fortunately, automatic weather station (AWS) data are readily available for validation from the observations of the Greenland Climate Network (Steffen and Box 2001; Box et al. 2004). Sixteen sites produced data for July or December 2002.

The months July and December 2002 are simulated by a series of 48-hour integrations, each initialized at 0000 UTC. 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.

Figure 1 shows the surface pressure from AWS at Summit (72.58°N, 38.50°W, 3208 m elevation) for July and December 2002. Interpolated surface pressure from the WRF simulations is also shown. The surface pressure is about 20 hPa larger during the summer month than that during the winter month. The synoptic pressure change is very well captured for both months. Summer surface pressure shows little bias at Summit. During December, the interpolated pressures from WRF appear to be an average of 2-3 hPa higher the observed values after the 11th of the month. The correlation between the observed pressure and simulated pressure is 0.89 during July and 0.96 during December. The correlation may be reduced due to spurious high frequency oscillations in the AWS presssure observation. Figure 1 is reflective of a good synoptic forecast by the mesoscale model for both months. Other AWS sites (not shown) also show that WRF is well-capturing the synoptic pressure variations.

It is also necessary to know if the model is properly treating the boundary layer and surface physics over the Greenland ice sheet. Therefore, we look at the lower atmospheric temperature over the interior of Greenland. Figure 2 shows the 2 m temperatures observed by AWS at Swiss Camp (69.57°N, 49.32°W, 1149 m elevation) and simulated values by WRF interpolated from model levels. The July and December AWS values are shown by the red and blue curves, respectively. Simulated 2 m temperature is denoted by the green curves. Synoptic variability is much larger in winter than during July, when the values stay within a few degrees of 0°C. The correlations are 0.75 during July and 0.96 during December. The correlation is lower in summer at least partly due to error in representing the diurnal cycle. The WRF simulations essentially capture the synoptic change during December 2002. There is a noticeable bias, however, during winter. The WRF temperature is often 5 or more degrees warmer than the observed 2 m temperature for this month. Similar warm biases are found for other sites over the Greenland Plateau. This suggests that WRF 1.3 is not properly capturing the stable winter boundary layer over Greenland.

During July 2002, the 2 m temperature bias is much smaller than that during winter (Fig. 2). At times during early and late July the WRF forecast is too cold. Furthermore, the summer diurnal cycle at Swiss Camp, as measured by the AWS, is poorly captured by WRF. July synoptic variability is weak. Nevertheless, the WRF temperature does appear to be respond similarly with the synoptic temperature change measured by the AWS. It is more difficult to make general conclusions about the summer case, yet it is still probable that an improved simulation is possible by improving the boundary layer representation.

Figures 3 and 4 show the 10 m wind speed at Swiss Camp for July and December 2002, respectively. Wind speed is considerably stronger during winter than during summer. The July representation of 10 m wind speed by WRF appears to be very reasonable, except for some high frequency fluctuations that are not captured by the model. Overall the correlation for this month is 0.69, while it is 0.79 for December. The timing and magnitude of synoptic variations are similar for the AWS observation and the model (Fig. 3). During December 2002, however, the wind speed is under represented, especially after 22 December. Some of the largest negative errors by WRF occur during times when the synoptic change is small such as near 2 December, near 15 December and 26-29 December. In contrast, WRF approximately captures the speed of the peak wind event on December 10. This peak event is a time of large synoptic forcing, while times of small synoptic forcing appear to correspond to significant under-representation of the 10 m wind speed at Swiss Camp. This is symptomatic of a difficulty capturing the stable winter boundary layer. We expect the winter boundary layer over the Greenland Plateau to be strongly stable when there are clear skies and the synoptic forcing is weak. In fact, a correspondence can be seen in Figs. 2 and 4. Large positive errors in the temperature forecast correspond to negative errors in the wind speed. Boundary layer theory suggests that the temperature profile and the velocity profile are so linked. Therefore, significant improvements are needed to the WRF treatment of the winter inversion layer over the Greenland Ice Sheet.

5. SUMMARY

The development of Polar WRF will provide an improved model applicable for the Arctic and Antarctic regions, following up on the work done with Polar MM5. Tests with an early version (WRF 1.3) in two Arctic domains show that the model well captures the synoptic variability. The boundary layer, especially during winter, is poorly captured. Additional testing is needed for the various Arctic environmental conditions, as well as for the Antarctic region. Adjustments to Polar WRF will be needed, analogous to the updates that were implemented during the development of Polar MM5. The Polar WRF will represent an important contribution from the mesoscale modeling community to the goals of the upcoming International Polar Year.

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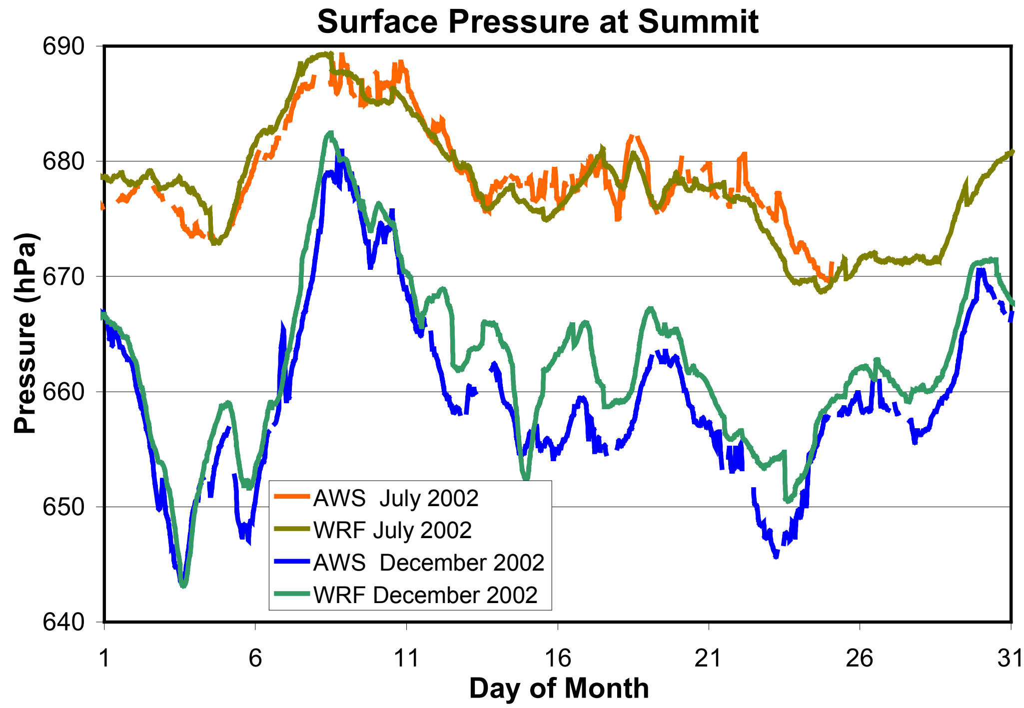

Figure 1. Surface pressure (hPa) at Summit automatic weather station (AWS) from observations and interpolated from WRF forecasts for July and December 2002.

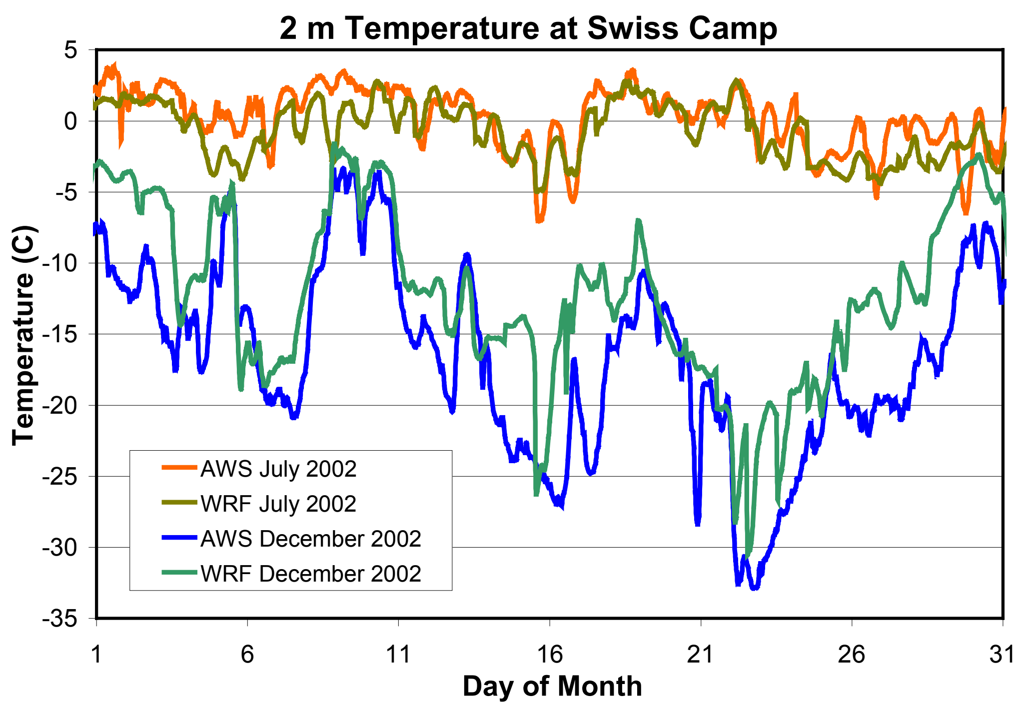

Figure 2. Temperature (°C) at Swiss Camp from AWS observations and interpolated from WRF forecasts for July and December 2002.

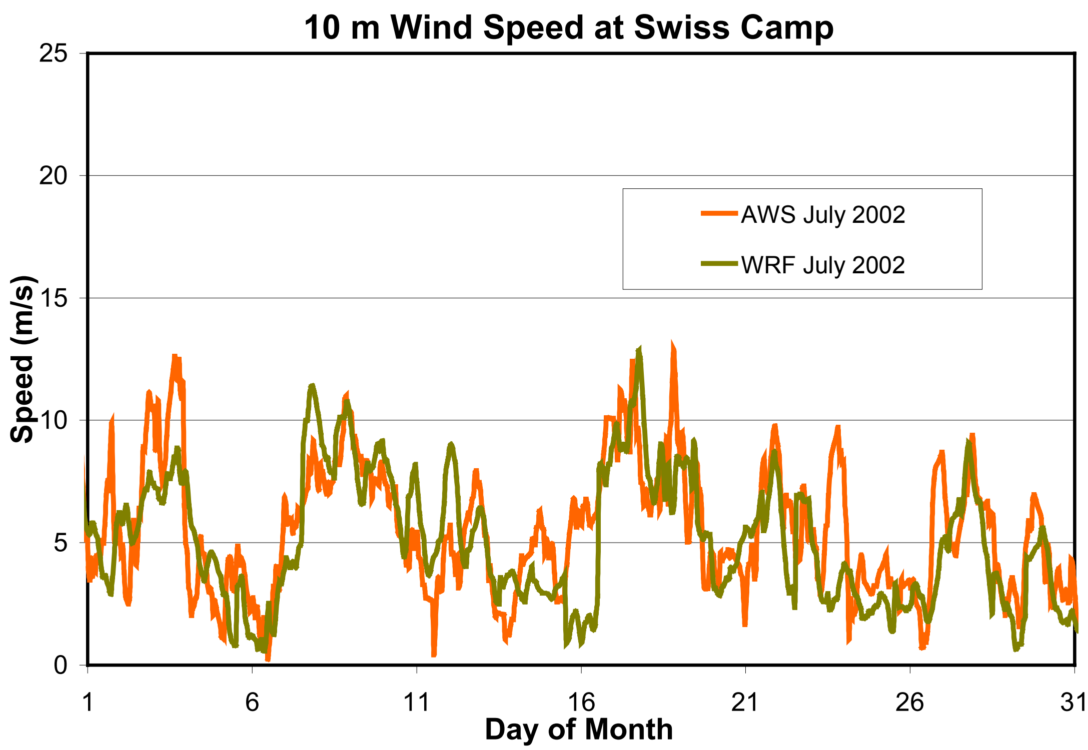

Figure 3. Wind speed (m s^{-1}) at Swiss Camp AWS from observations and interpolated from WRF forecasts for July 2002.

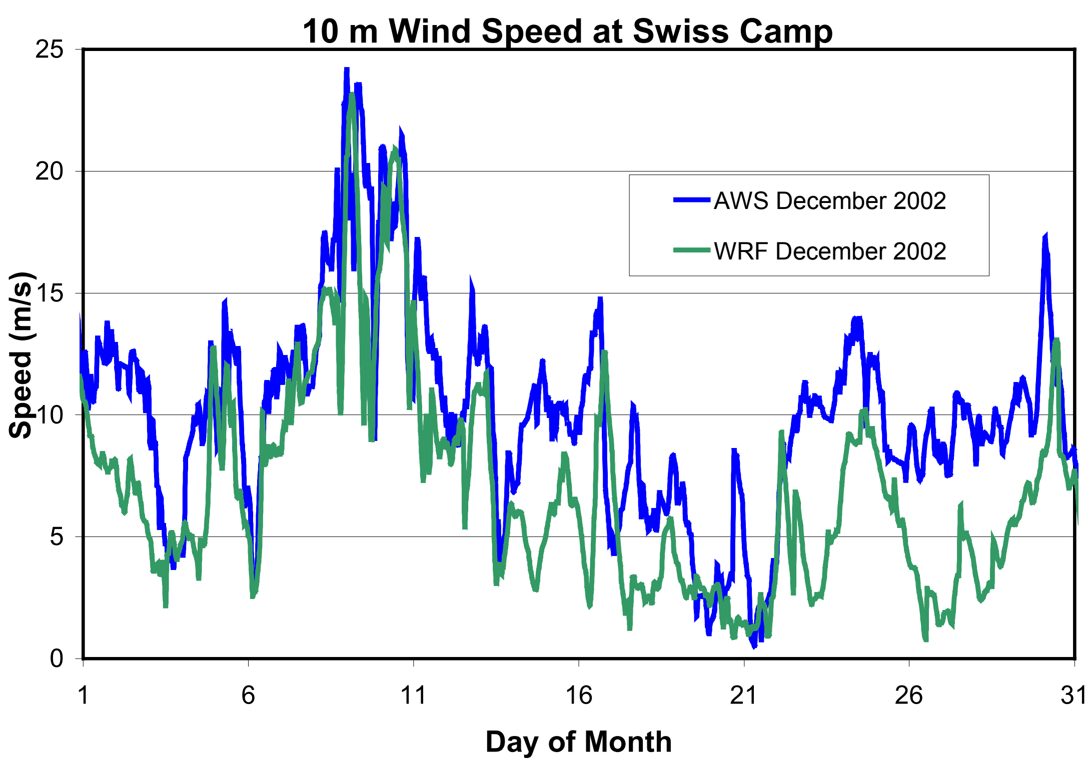

Figure 4.. Wind speed (m s^{-1}) at Swiss Camp AWS from observations and interpolated from WRF forecasts for December 2002.

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