POLAR WRF TESTING IN ANTARCTICA

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1. BACKGROUND

The testing and evaluation of WRF in the polar regions are now in progress. While the model's history reflects development and application mostly in the mid-latitudes, WRF prediction over Antarctica began in November 2005, when it was implemented in AMPS (the Antarctic Mesoscale Prediction System) (Powers 2003). AMPS is a real-time forecasting system that provides NWP guidance for a range of scientific and logistical activities in Antarctica. Using the Advanced Research WRF (ARW), AMPS delivers the highest-resolution model output available on the continent and supports weather forecasting for the United States Antarctic Program (USAP), research by scientists and graduate students, and activities of the international Antarctic community.

The implementation of a polar-modified version of WRF for Antarctic NWP has been a goal of the AMPS effort. This follows from the previous deployment in AMPS of the Polar MM5 (PMM5), developed by scientists at the Byrd Polar Research Center (BPRC) of the Ohio State University (Bromwich et al 2001; Cassano et al. 2001). Described below, a polar-modified WRF has been developed, and this study investigates its performance over Antarctica. "Polar WRF" refers to a version of ARW that contains modifications to improve performance over the polar regions and better capture features unique to extensive ice sheets. The initial assessment of Polar WRF was through its application in Greenland (Bromwich and Hines 2006).

The goals of the development of Polar WRF are to improve WRF's capabilities for high-latitude research and for Antarctic forecasting. Before such applications, however, the impacts of the modifications need to be understood. To that end, this study tests Polar WRF in Antarctica. Polar-modified WRF is run for approximately two-week periods in Summer and Fall 2007 and the results verified against AWS (automatic weather station) observations and radiosondes at sites across the continent. Forecasts from polar WRF are compared with both the unmodified WRF and the Polar MM5.

2. POLAR WRF AND EXPERIMENTS

The polar modifications to the ARW involve lower boundary and land surface characteristics. First, polar WRF (PWRF) accounts for fractional sea ice coverage in grid cells. Grid cells which are not fully ice-covered or fully ice-free are characterized as fractionally covered. In contrast, in the default approach in WRF cells are either fully open or fully covered.

Most of the polar changes are to the Noah LSM. These are: the use of the latent heat of sublimation for calculations of latent heat fluxes over ice surfaces (permanent ice, sea ice, and snow cover); the assumption of ice saturation when calculating surface saturation mixing ratios over ice; an increase in the value of snow albedo; adjustment of snow density; adjustment of snow heat capacity and thermal diffusivity for the subsurface layers; an increase in the emissivity value for snow; and, a modification of the skin temperature calculation (enforcing a sensible heat/latent heat/radiation energy balance at the surface).

The periods evaluated are 26 January–6 February 2007 and 6–30 April 2007. These allow a look at PWRF's performance in the summer and in a cold season.

3. RESULTS

Surface temperature and wind speed errors for the experiments have been calculated through verification with the AWS data for sites across Antarctica. To show a sample of these locations, the sites discussed here are Henry, Byrd, Dome C, and Williams Field. Figures 1(a) and (b) show the AMPS domains and AWS locations. The sites represent a variety of sub-regions if Antarctica— South Pole, East Antarctica, West Antarctica, and the Ross Island area. The full number of AWS sites verified against is 28.

Henry AWS is near the South Pole, and is chosen because Pole's record was hampered by missing observations for the Jan.–Feb. window (hereinafter "January"). For April (Fig. 2(a)), PMM5's surface temperature biases and RMSEs are larger than either of WRF's for approximately the first 12 hrs. After that (forecast hrs 12–120), however, the MM5 displays the lowest bias and RMSE. Both WRF and PWRF have a pronounced warm bias. This WRF behavior is seen at other sites across the continent. There is some

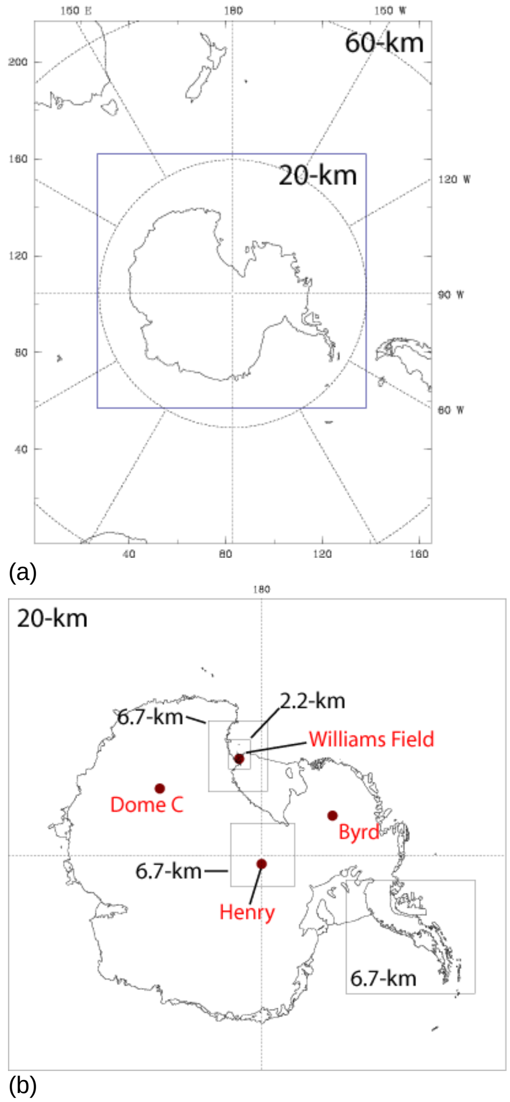


Fig. 1: Model grids and locations of AWS sites examined. (a) 60-km and 20-km grids. (b) 20-km, 6.7-km, and 2.2-km grids and verification sites.

possibility that this may reflect substrate temperatures that are too warm in WRF's initializations, and testing on this is in progress.

The positive result at this location, repeated at other sites, is that the polar modifications in WRF reduce the warm bias. Here, the improvement is about 3–4C. For January at Henry (Fig. 2(b)), PWRF and the MM5 have a cold bias, but one of lesser magnitude after 24 hrs than WRF's (warm) bias. The polar modifications have improved PWRF over WRF for forecasts longer than 48 hrs.

The April wind speed biases at Henry (Fig. 2(c)) are significantly higher for PWRF and WRF than for the MM5 in the first six hrs. After that, both polar and regular WRF biases average less. RMSE's are comparable for PWRF and WRF after the first 12 hrs.

For January (not shown), both WRF runs show higher wind speed biases and RMSE's than the MM5 for approximately the first 20 hrs. After that, they are equivalent. The wind speed biases for all the runs are lower on average in April than in January.

Byrd's (Fig. 3(a)) April temperature results are similar to those at Henry, in terms of relative bias. PWRF improves upon WRF, with the bias being less positive. The MM5, however, is running cold here.

For April winds (Fig. 3(b)), biases and RMSEs are comparable across the experiments, averaging about +3 ms^{-1} and 4.5 ms^{-1}, respectively. January's errors (not shown) are a little lower, with an RMSE of about 3 ms^{-1}.

For April at Dome C (Fig. 4(a)), PWRF has the lowest surface temperature bias and RMSE for the first 24 hrs, after which the MM5 outperforms it. WRF and PWRF's biases are more significant after that point, averaging 10–14 C. Again, the polar modifications reduce the positive bias in WRF, and this carries over to a reduced RMSE.

January at Dome C displays cyclic temperature error amplitudes (Fig. 4(b)). These are in step with the diurnal temperature cycle seen in the observations (not shown). The models' errors are cyclic because, while the forecasts are in phase with observation, they are all underpredicting the magnitude of the diurnal cycle. This leads to error maxima at the times of the for the actual temperatures' daily maxima and minima. Both the PWRF and MM5 biases, however, are within 5C of each other. For PWRF this is a significant improvement over April. All of the experiments display comparable wind speed biases for both months (not shown) and no improved signal is seen from PWRF.

Table 1 presents the surface temperature biases (°C) for the April period at Dome C for the three experiments. The results for the 12-, 24-, and 48-hr forecasts are shown. The lower errors in PWRF compared to WRF are statistically significantly different than those in WRF for the three forecast times (95% confidence level).

Dome C
Surface temperature biases

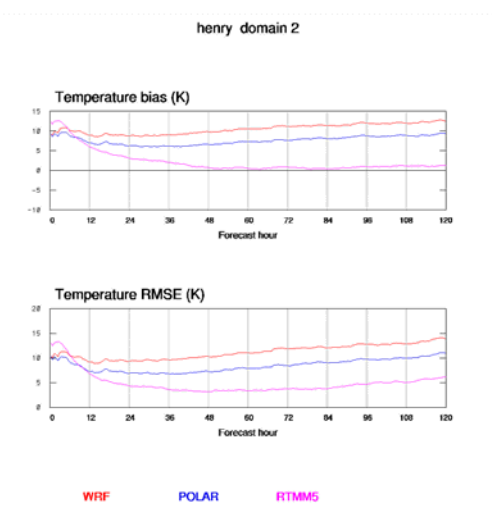
Hr	WRF	PWRF	MM5
12	10.00	8.36	11.04
24	10.19	8.07	8.54
48	13.53	10.94	7.31

	WRF/PWRF	WRF/MM5	PWRF/MM5
12	T	T	T
24	T	T	F
48	T	T	T

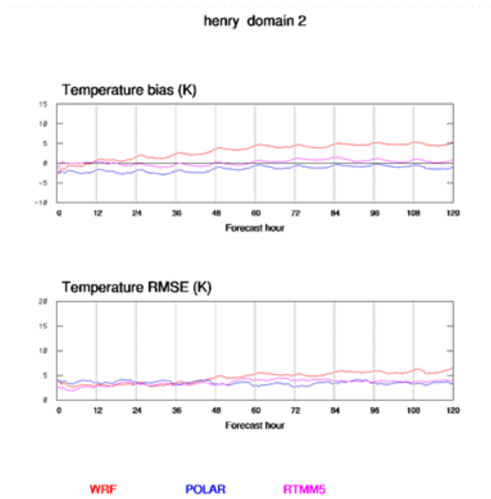
Tab. 1: **Surface temperatures biases (°C) for April period at Dome C for varying forecast hours.**

Statistical significance of error differences between WRF, PWRF, and MM5 indicated. 95% confidence level considered.

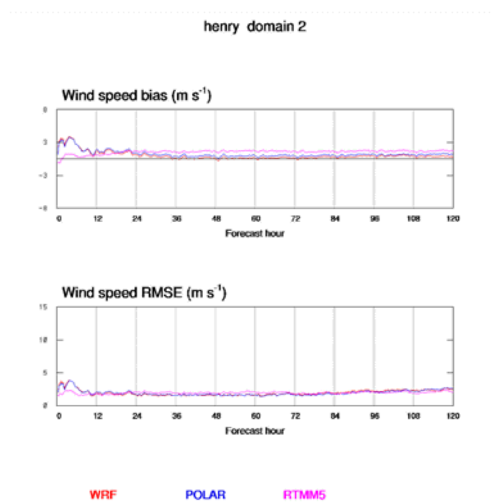
The results for Williams Field (Figs. 5(a),(b)) for April are presented for the 20-km AMPS domain. The 6.7-km grid over this area only runs to 36 hrs, while the 20-km grid goes to 120 hr. The results for temperature (Fig. 5(a)) reveal RMSE and bias improvement in PWRF over WRF on the order of 1C. The MM5 shows smaller errors than PWRF, however. For all of the runs, the wind speed bias and RMSE results are mixed (Fig. 5(b)). Note the jump in temperature bias in WRF at the 36-hr mark for April. This corresponds to the shutting off of the 6.7-km grid, when feedback from the higher-resolution mesh ends. The surface temperature bias at this point increases from about 5C to 10–11C in both WRF runs. For January (not shown), in contrast, an approximately 5C cold bias in PWRF disappears at this time, and PWRF's performance improves. As at the other sites, PWRF's bias is less positive than WRF's, for both periods. For the January wind speed errors, as with temperature, there is a signal in increased bias and RMSE at 36 hrs with the shutoff of the 6.7-km grid.



(a)



(b)



(c)

Fig. 2: Henry surface temperature and wind speed bias and RMSE for range of forecast hours from 0–120. (a) April temperature bias and RMSE. (b) January temperature bias and RMSE. (c) April wind speed bias and RMSE.

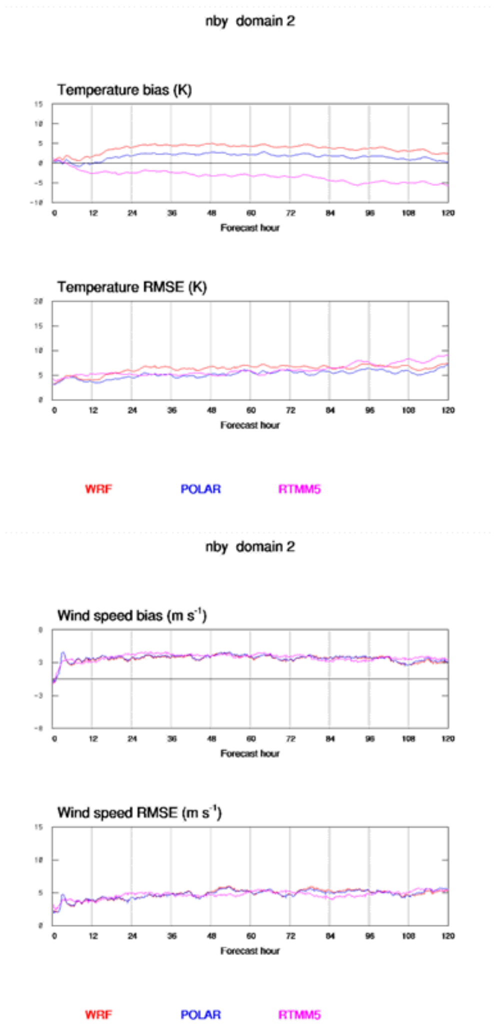
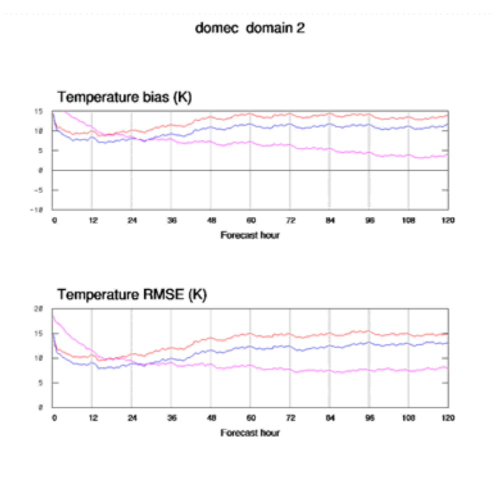
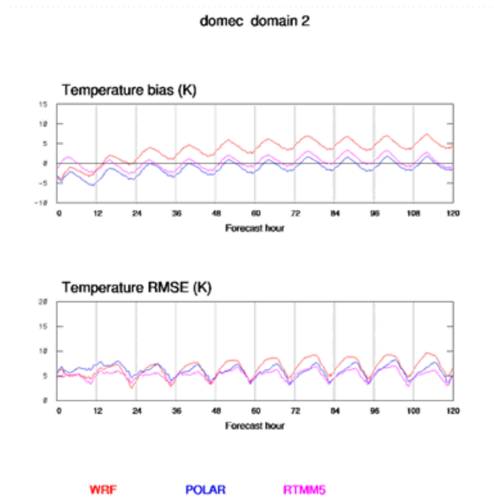


Fig. 3: Byrd surface temperature and wind speed bias and RMSE for April period. (a) T bias and RMSE. (b) Wind speed bias and RMSE.

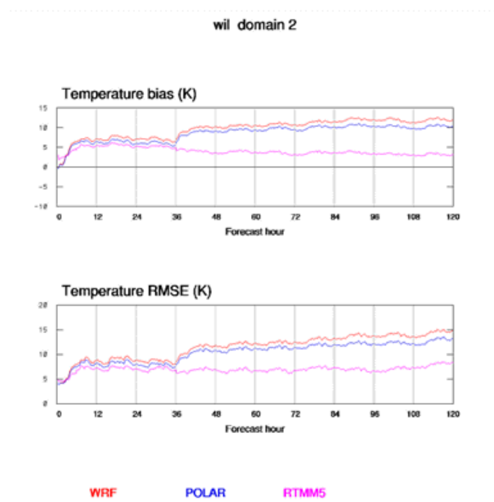


(a)

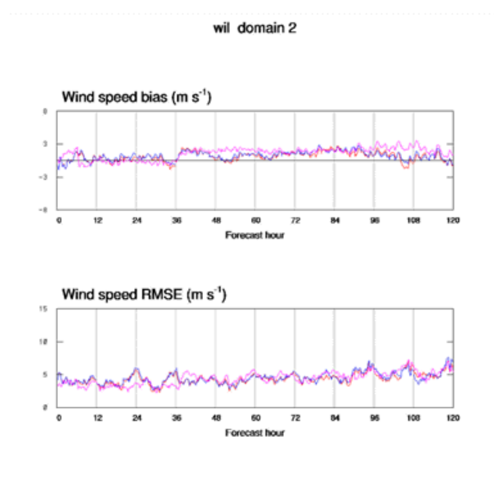


(b)

Fig. 4: Dome C surface temperature bias and RMSE. (a) April. (b) January.



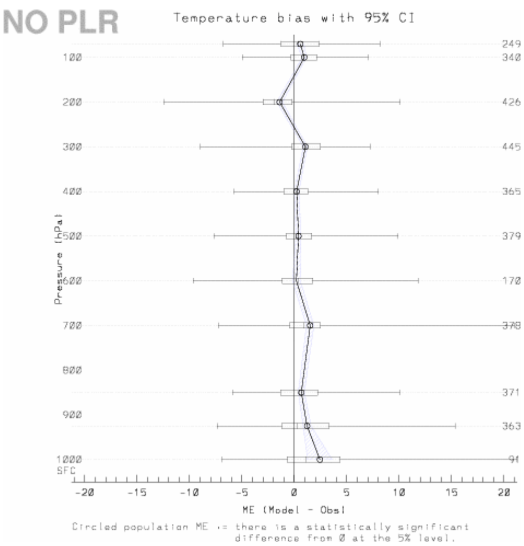
(a)



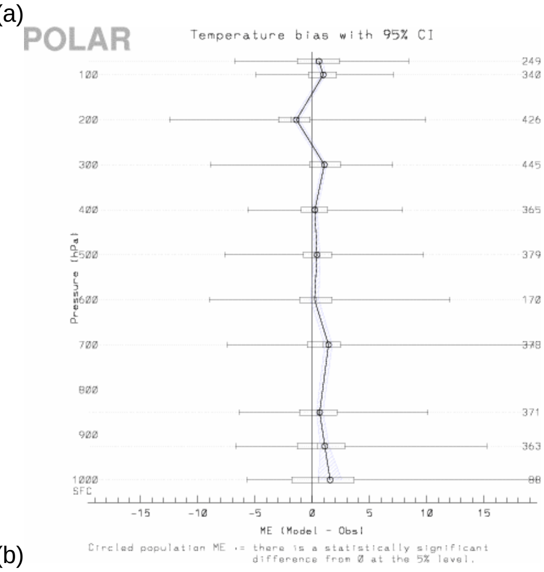
(b)

Fig. 5: Williams Field surface temperature and wind speed biases and RMSEs for April period. (a) Temperature. (b) Wind speed.

Error profiles, reflecting the combined statistics for verifications against all radiosonde sites over Antarctica, show the vertical distributions of biases and RMSEs. Figures 6(a) and (b) present these for hr 48. For temperature, PWRF displays a lesser the warm bias at the surface, but at levels above differences are not noticeable. In wind speed error profiles (not shown), however, there are no significant differences at any level.



(a)



(b)

Fig. 6: Regular WRF (a) and PWRF (b) vertical profiles of temperature biases (°C).

4. SUMMARY AND CONCLUSIONS

An initial version of Polar WRF has been tested over Antarctica. Run within AMPS, experiments using the ARW with and without polar modifications have been conducted for Summer and Fall season periods. The results are verified against surface (AWS) and upper-air observations across the continent. They are also compared with results from Polar MM5.

Overall, the polar modifications improve PWRF's surface temperature forecast performance compared to the standard WRF. The lower biases in PWRF compared to WRF translate to lower RMSEs. However, it is seen that WRF, modified or not, tends to have a warm bias in surface air temperature prediction (as also seen in the MM5 overall). This is under investigation.

Surface wind speed errors do not exhibit sensitivities to the presence of the polar modifications in WRF. This is not surprising, as the modifications address heat and radiation fluxes and not momentum directly. For example, ice surface roughness lengths are not modified.

The impacts of the polar modifications are not significant above the PBL. In the simulations reviewed the PWRF/WRF differences are seen to dominate in the lowest models levels, near the surface.

This Polar WRF evaluation is an initial analysis, and the real-time implementation of PWRF into AMPS will follow further testing. Ultimately, the polar modifications for the ARW will be provided to the WRF repository.

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