Verification of MPAS Forecasts Over Antarctica

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1. INTRODUCTION

The Antarctic Mesoscale Prediction System (AMPS) is a real-time numerical weather prediction capability that provides model guidance for the forecasters of the U.S. Antarctic Program (USAP) (Powers et al. 2012). While AMPS uses WRF as its primary NWP model, the Model for Prediction Across Scales (MPAS) has been implemented. This study provides an initial assessment of seasonal comparative performance between WRF and MPAS in AMPS, as well as the first-ever upper-air evaluation of MPAS over Antarctica. The objective is to increase the understanding of MPAS forecasts over the high latitudes.

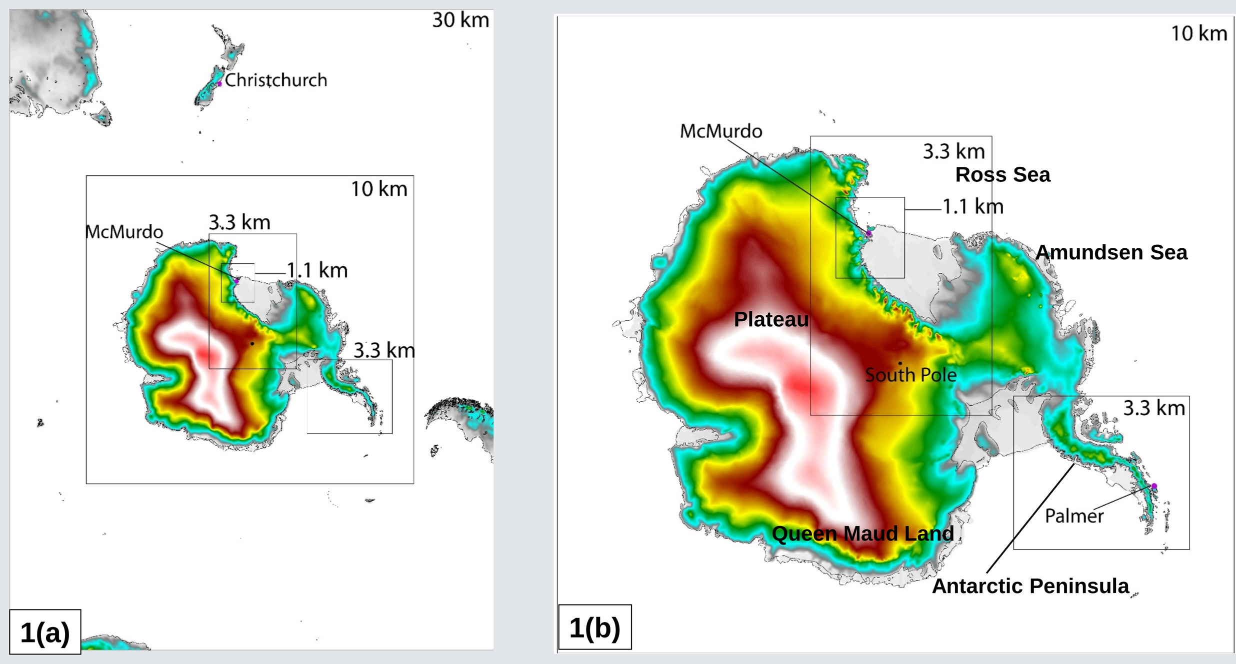


Fig. 1: WRF domain setup, topography shaded. (a) Coarse (30-km) and continental (10-km) grids. (b) Finer grids over Antarctica. Outer frame : 10-km grid. Inner frames: 3.3-km and 1.1-km grids.

2. TEST SETUPS

MPAS and WRF runs are configured similarly, but different model capabilities and computer limitations prevent them from being identical. Table 1 lists the run specs.

Both surface and upper-air verifications are performed. The former are for austral winter and summer periods: Jul–Aug 2016 and Dec–Jan 2016–2017. Automatic Weather Station (AWS) data and station reports from over 70 sites are used to verify surface temperature, wind speed, and pressure. The upper-air verifications are performed for the austral autumn period of April–May 2017 using the available radiosonde sites (approx. 12).

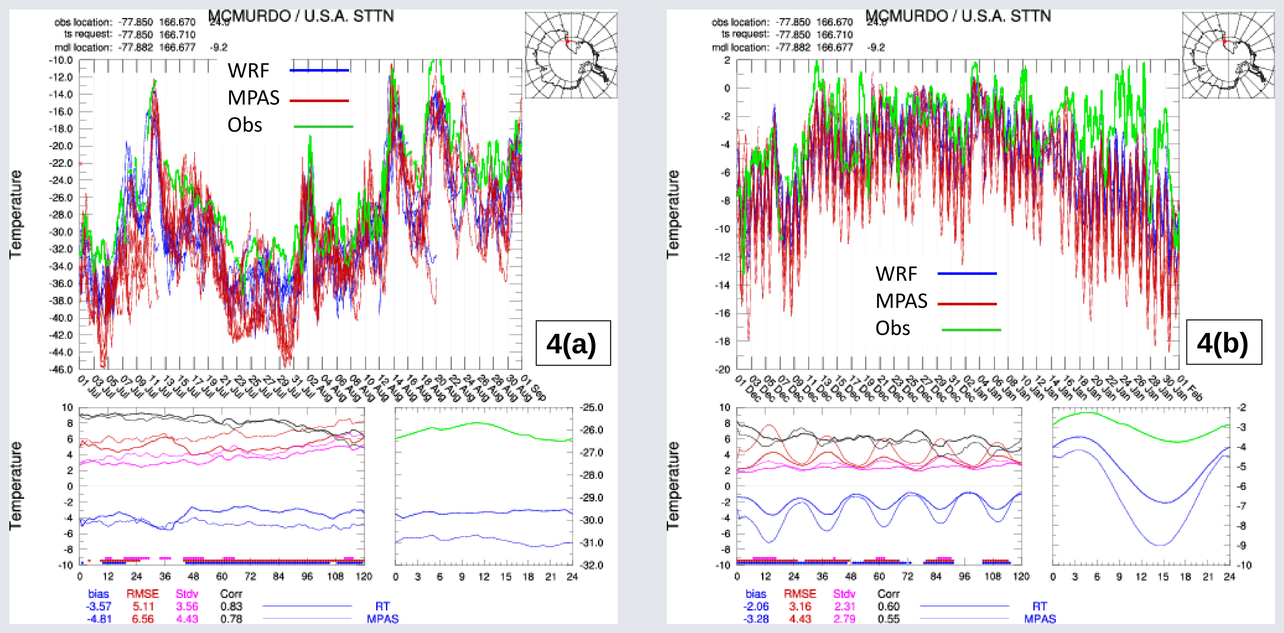


Fig. 4: Surface temperature forecasts and error statistics for MPAS and WRF at McMurdo. Top panel: Observations (green), MPAS forecast (red) temperatures, and WRF forecast (blue) temperatures. Bottom left: Average errors (°C) per forecast hour (hrs 0–120)— WRF thick solid, MPAS thin solid. Blue= bias; red= RMSE; pink= bias-corrected RMSE; black= correlation. Dots along bottom indicate that the corresponding error differences for given hr are statistically significant. Bottom right: Average observed and forecast temperatures (°C) for a 24-hr diurnal period in the verification periods. (a) Jul.–Aug. 2016. (b) Dec.–Jan. 2016–2017.

Table 1: WRF & MPAS Configurations

Grids
WRF: 30-/10-/3.3-/1.1-km multiple nesting   MPAS: 60-km global mesh
15-km Antarctic refinement

Model Top and Vertical Levels
WRF: 10 mb (~31 km)   60 half-levels
MPAS 30 km (~12 mb)   45 half-levels

Initial Conditions
Twice-daily runs: 0000, 12000 UTC initializations
WRF: GFS first-guess, WRFDA hybrid 3DVAR-ensemble data assimilation
MPAS: GFS first-guess, no data assimilation

Shared Physics
- LSM: Noah (MPAS V3.3.1, WRF V3.7.1)   Cu: Kain-Fritsch (MPAS V3.5, WRF V3.7.1)
- LW radiation: RRTMG (MPAS V3.4.1, WRF, V3.7.1)
- Surface layer: MYJ/Eta (MPAS V3.5, WRF, V3.7.1)

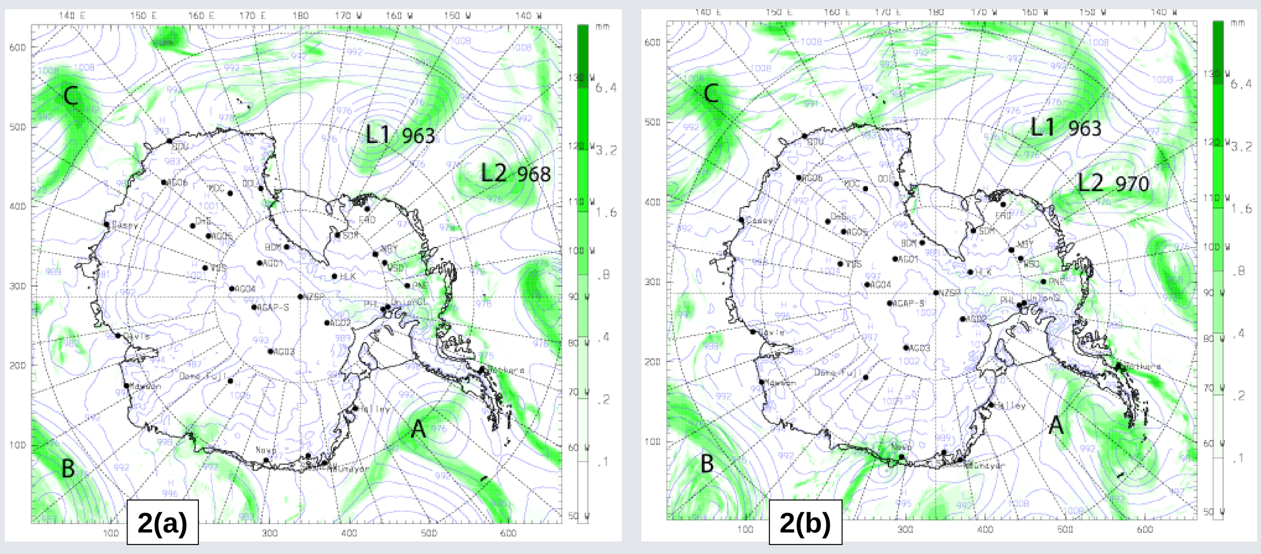
Different Physics

• PBL	WRF: MYJ	MPAS: YSU
• Microphysics	WRF: WSM-5	MPAS: WSM-6
• SW radiation	WRF: Goddard	MPAS: RRTMG

3. RESULTS

a. MPAS and WRF— Forecast Behavior Overview and Model Consistency

We have verified the basic consistency of WRF and MPAS over Antarctica. Based on a review of its operation in AMPS, we first note that MPAS (i) is well-behaved (no unphysical behavior) and provides consistent forecasts in the high southern latitudes and (ii) is computationally robust (stable across seasons and initializations). We find that MPAS and WRF evolve similarly through the first two days, with increasing divergence in the latter part of the forecast (day 3+).



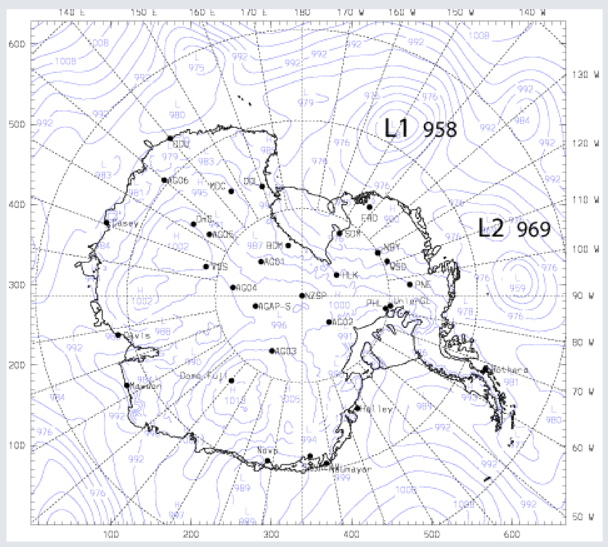


Fig. 2: WRF and MPAS 96-hr forecasts for 1200 UTC 5 June 2017 (1200 UTC 1 June initialization) and analysis. Sea level pressure (contoured, interval= 4 mb) and 3-hourly precipitation (mm, scales to right) shown. Low L1 and L2 and precipitation areas A, B, and C referred to in text. (a) WRF. (b) MPAS. (c) AMPS analysis for 1200 UTC 5 June 2017.

Figure 2 illustrates a forecast comparison. At hour 96, the WRF (Fig. 2(a)) and MPAS (Fig. 2(b)) SLP and 3-hourly precipitation fields parallel each other. First, all lows in WRF have counterparts in MPAS— the models are tracking each other. Second, there is consistency in the depth and placement of all pressure centers. For example, in the Ross and Amundsen Seas (Fig. 1(b)), a pair of lows appears (L1, L2). The depth of L1 is 963 mb in both, while L2 is 968 mb in WRF and 970 in MPAS. Compared with the analysis for this time (Fig. 3(c)), both runs are accurate, with the analyzed depth of L1 at 958 mb.

In this example, and as seen across forecasts, WRF and MPAS produce comparable amounts of precipitation for systems captured. Fig. 2 shows this in the areas labeled A, B, and C, and the precip shading is consistent (scale to right).

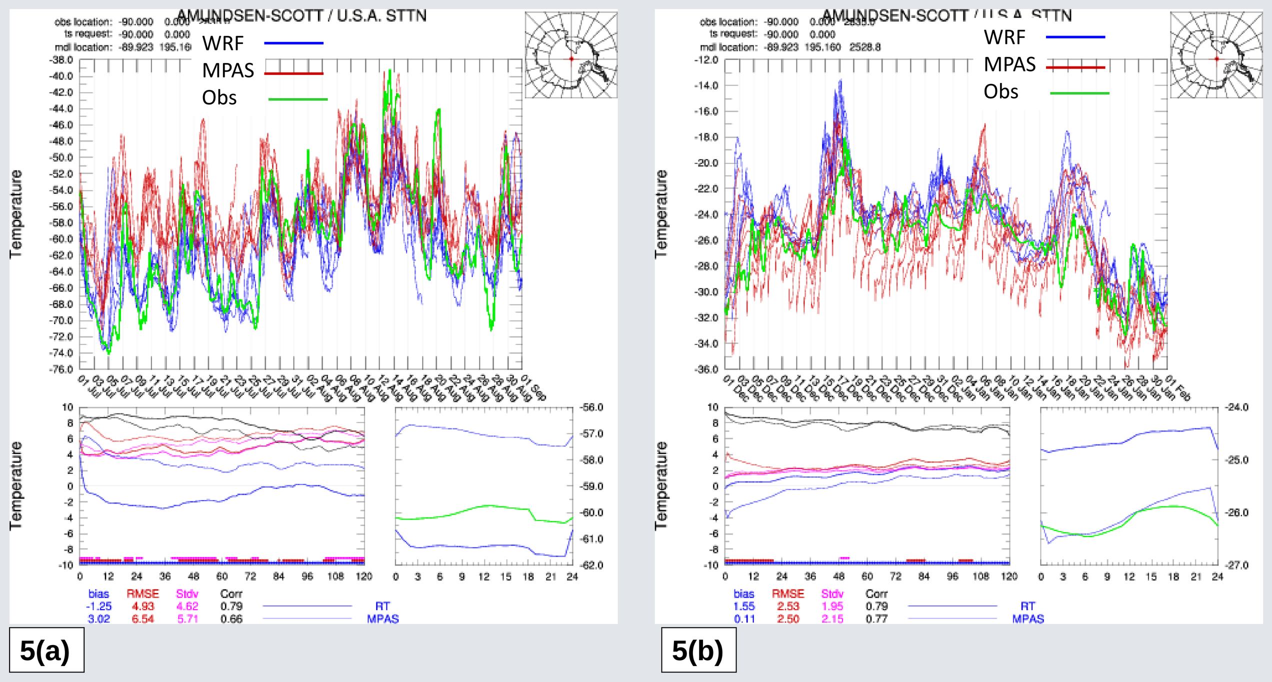


Fig. 5: Surface temperature forecasts and error statistics for MPAS and WRF at South Pole (Amundsen-Scott Station). Panels as in Fig. 4. (a) Jul.–Aug. 2016. (b) Dec.–Jan. 2016–2017.

b. Verification Statistics

Statistical verifications with significance testing have been performed for surface temperature (T), pressure, wind speed, and humidity. As an example, Fig. 4 shows the seasonal T forecast results for the key USAP site of McMurdo Station (Fig. 1(b)). In winter (Fig. 4(a)) both the WRF and MPAS forecasts are colder than observations. However, MPAS has a greater cold bias, most apparent in the 24-hr plots in the lower right. WRF is statistically better than MPAS for hours 12–18 and after hour 39 (Fig. 4(a), lower left). In summer (Fig. 4(b)) both models again display a cold bias, but MPAS's is larger. The model bias differences are significant for most of the forecast period. We find a diurnal variation of T bias/RMSE in both models for summer, with this of higher amplitude in MPAS. The average biases (i.e., for both seasons combined) here at McMurdo are -2.8C for WRF and -4.0C for MPAS.

Figure 5 shows the temperature results for South Pole. For winter (Fig. 5(a)) MPAS's warm bias is apparent from the observations (top panel: MPAS— red, Obs— green). WRF, in contrast, has a cold bias that is of lesser magnitude (Fig. 5(a), lower right). For summer (Fig. 5(b)), MPAS has a minimal average temperature bias (-0.1 C) , while WRF displays a warm bias (+1.6 C). The MPAS winter gain is statistically significant for all forecast hours. Thus, model performance varies with season.

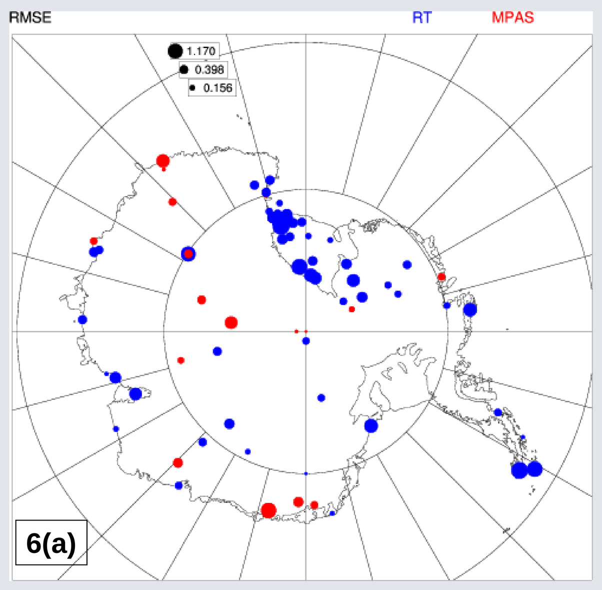
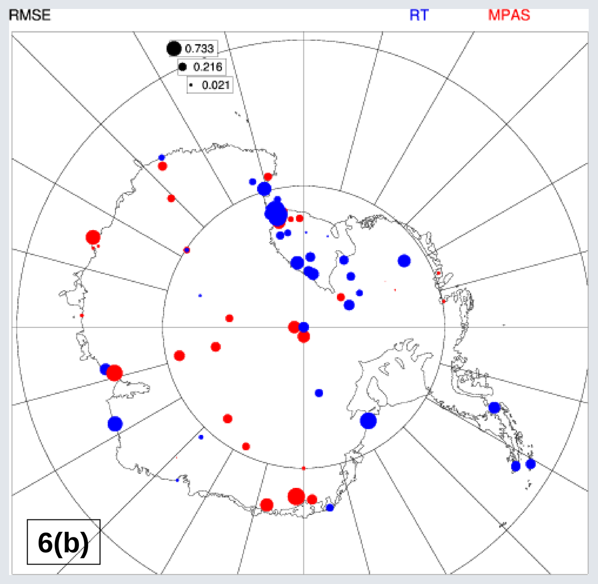


Fig. 6: Comparisons of surface temperature and wind speed biases for MPAS and WRF for Dec.–Jan. 2016–2017. Red= MPAS better; blue= WRF better. Circle size proportional to magnitude of improvement and scaling values in upper part of panel in °C (a) and ms^{-1} (b). (a) Temperature. (b) Wind speed.



Comparisons of temperature (T) and wind speed (WS) RMSEs for summer across the continent are shown in Fig. 6. For T (Fig. 6(a)), WRF widely outperforms MPAS, although the Plateau and Queen Maud Land show a mix of results. For WS (Fig. 6(b)), WRF outperforms MPAS for the Ross Is. region, the Ross Ice Shelf, West Antarctica, and the Peninsula, while MPAS is better over the Plateau and across East Antarctica.

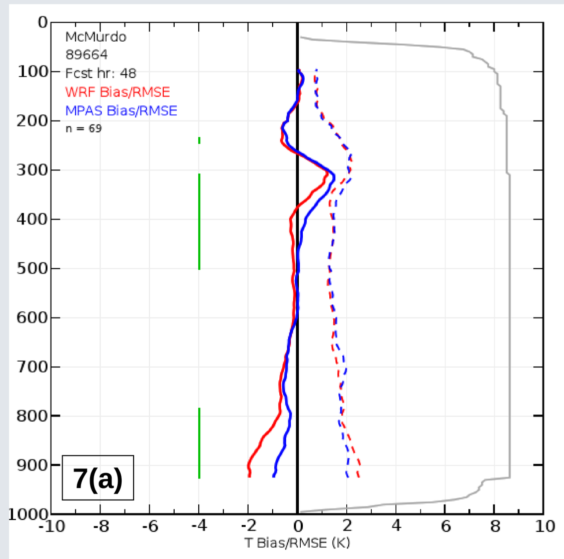
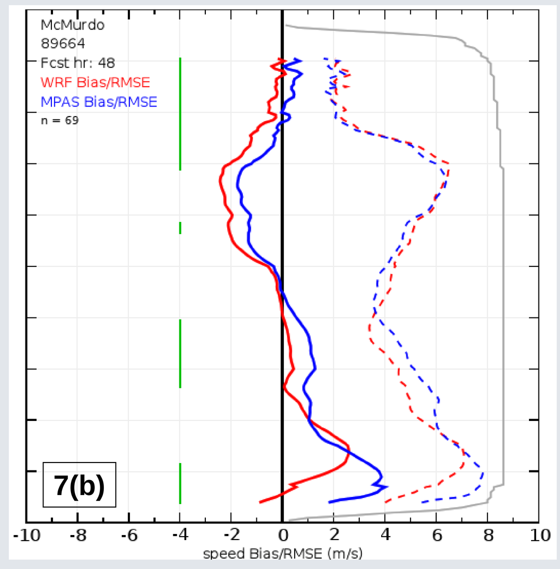


Fig. 7: Error profiles for forecast hr 48 for McMurdo for Apr.–May 2017. Pressure (mb) in (a) shown along vertical axis. Green bars mark levels at which model bias differences are statistically significant. (a) Temperature bias (solid, °C) and RMSE (dashed). WRF red, MPAS blue. (b) Wind speed bias (solid, ms^{-1}) and RMSE (dashed) WRF red, MPAS blue.



Upper-air verification has been done for the period April–May 2017. For McMurdo T (Fig. 7(a)) the biases are small through the column: mostly less than 1C, except the near-surface layer for WRF and around the tropopause. There are statistically significant differences (green bars) in the biases through 800 mb, with MPAS being better with about half of WRF's cold bias. Mid-tropospheric bias differences are negligible. For the column, model RMSE differences are minimal (<2C). For WS (Fig 9(b)), both models have positive biases through 500 mb, with WRF being significantly better in the near-surface and 700–600 mb layers. MPAS is better in the upper troposphere/lower stratosphere, but the actual error magnitudes are small (<2 ms^{-1}).

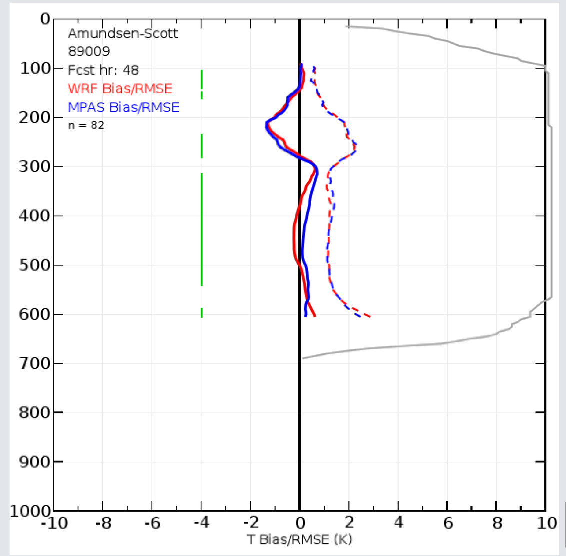
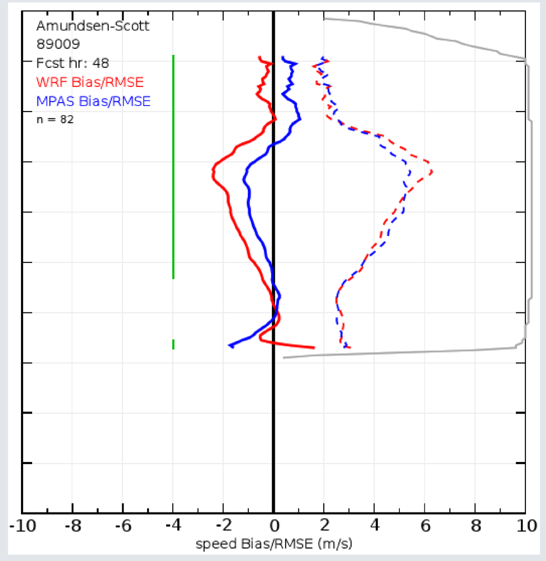


Fig. 8: Error profiles for forecast hr 48 for South Pole for Apr.–May 2017. Curves, labelling, and significance bars as in Fig. 7. (a) T bias (solid, °C) and RMSE (dashed). WRF red, MPAS blue. (b) WS bias (solid, ms^{-1}) and RMSE (dashed) WRF red, MPAS blue.



For South Pole there are minimal T error differences for either bias or RMSE through the column at hour 48 (Fig. 8(a)). However, the small bias differences are in WRF's favor and are statistically significant. For WS (Fig. 8(b)) WRF shows (significantly) smaller biases in the near-surface layer. Both models display negative speed biases through the middle-troposphere to about 275 mb; these are quite small (< 2 ms^{-1}), however, with MPAS being better with significance. While for other sites there is more lower-tropospheric difference in the errors in T and, in particular, WS, the differences are generally small, and the models are performing similarly.

4. SUMMARY

For NWP guidance for the USAP forecasters and to explore MPAS in polar applications, MPAS has been implemented into AMPS operations. Synoptically, it is found that the MPAS forecasts are largely consistent with WRF's, and there is correspondence out to 3-4 days of mesoscale features (e.g., pressure centers, precipitation). Divergence at longer lead times is tied to the differences in the models, their physics options, and their initializations in AMPS.

From the surface verifications it is found that overall WRF performs better statistically than MPAS. Surface temperature (T) forecast errors are better on the whole across the continent for WRF, while wind speed (WS) forecast results are mixed. From upper-air verifications (T, WS), the largest differences between the models are in the lower troposphere and around the tropopause. Overall we find that differences aloft between the models are small, and vary with location, rather than either WRF or MPAS being uniformly superior.

It is found that across Antarctica both models exhibit better forecast scores in summer than winter: this seasonal performance loss is an area for improvement for both WRF and MPAS. Regarding MPAS, even with its coarser configuration, it holds its own with WRF and even statistically outperforms in selected sites and regions. Higher resolution and updated polar-modified physics are planned for MPAS in AMPS.

REFERENCE

Powers, J. G., K. W. Manning, D. H. Bromwich, J. J. Cassano, and A.M. Cayette, 2012: A decade of Antarctic science support through AMPS. *Bull. Amer. Meteor. Soc.*, **93**, 1699–1712.

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