AN INITIAL COMPARISON OF WRF AND MPAS 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 (Powers et al. 2012). AMPS also supports researchers and students, international Antarctic efforts, and scientific field campaigns. Since 2006 AMPS has used the Weather Research and Forecasting (WRF) Model (Skamarock et al. 2008) for its forecasts and products. WRF in AMPS runs with a five-domain nested setup to produce forecasts out to five days and contains polar modifications (see, e.g., Hines and Bromwich 2008) to better capture the characteristics and conditions of the high latitudes and their ice sheets.

The Model for Prediction Across Scales (MPAS) is a new numerical weather prediction model designed to simulate from the global to the cloud (i.e., nonhydrostatic) scale (Skamarock et al. 2012). It can provide either a uniform or variable-resolution grid. As MPAS does not currently provide a stand-alone limited area capability, the latter approach can offer higher-resolution mesh refinement over target regions. Figure 1 presents an example of an MPAS global, variable-resolution mesh with a finer grid over East Asia.

MPAS is the product of a collaboration of NCAR and Los Alamos National Laboratory, and NCAR now supports the MPAS atmospheric model to the community. It has been in public release since 2013, and the current version is 4.0. MPAS has been applied for research (Park et al. 2014) and for real-time forecasting, such as in support of the NOAA Storm Prediction Center's Hazardous Weather Testbed experiment (Clark et al. 2012).

Given MPAS's emergence, the AMPS effort has begun testing of the model in real-time runs over Antarctica. The aims are: (i) to gain experience with MPAS and an understanding of its behavior and performance in a polar application, and (ii) to see how it currently compares with the long-standing WRF model. As detailed in Sec. 2, in this exploration MPAS and WRF runs are configured similarly and forecasts are compared. Subjective verifications, in which daily forecasts are reviewed, have been done on an ongoing basis, and an example is presented here. Thus far, the objective verifications for the paired MPAS and WRF runs have been limited to austral spring and autumn periods and for surface parameters only (temperature, pressure, wind speed). For this assessment, surface reports, primarily from Automatic Weather Stations (AWS), have been used. Upper-air verification is planned, but is not included in this initial evaluation.

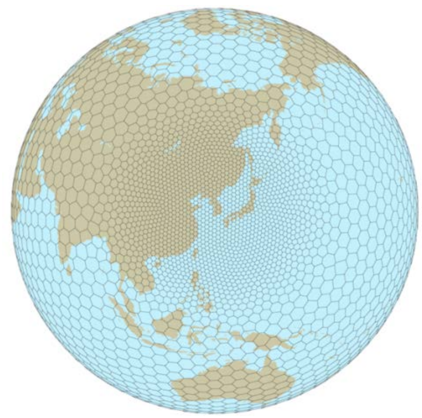


Fig. 1: Example of MPAS variable-resolution mesh. Mesh composed of polygons with higher resolution (finer mesh spacing) seen over center of global area depicted.

This MPAS testing has just begun, and there are important limitations on the use of MPAS in AMPS. First, MPAS's configuration is not identical to WRF's. Given both the state of MPAS development and the limits on computer resources, it has not been possible to match WRF's physics or grids. Second, WRF has more capabilities for regional modeling than MPAS, and this will be the case for some time. Thus, WRF will remain as the main model relied on by AMPS for a while.

2. TEST SETUPS

MPAS is set up to approximate one of the current AMPS ensemble WRF runs, subject to a number of constraints. First, MPAS does not provide for standalone, limited-area domains like WRF. Thus, one has to carry, computationally, a global mesh even though the target forecast region is a relatively small area. MPAS does allow for regional refinement, however, so that the area of concern can have finer resolution. Here that capability is used to provide a 15-km mesh over Antarctica, while the rest of the global grid runs to 60 km.

The MPAS refined region covers the area of the WRF 10-km domain of the 30-km/10-km WRF setup shown in Fig. 2. One of the existing members of the WRF ensemble running in AMPS was used for the comparison to avoid adding even more compute demand. Furthermore, given the resources available, the MPAS refined mesh could not be reduced to 10 km: 15 km was the finest grid practical.

The number of vertical levels in each model is another configuration difference due to compute limitations. The WRF run has 60 half-levels, while MPAS is run with 45. Still, the model tops are about the same. For the height-coordinate MPAS, the top is 30 km (~12 mb), while for WRF it is 10 mb (~31 km). Both models were run out to five days from 0000 UTC and 1200 UTC initializations.

To illuminate any seasonal forecast differences, there are two periods of statistical evaluation, austral spring 2015 and late summer/fall 2016: 20 Oct–31 Dec 2015 and 8 Feb–31 Mar 2016. AWS data and station reports are used for verifications of surface temperature, pressure, and wind speed.

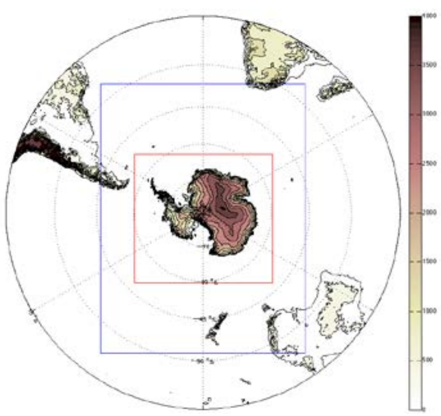


Fig. 2: WRF run domain setup. Outer frame (blue) is the 30-km domain, while inner frame (red) is the 10-km domain. Topography shaded; scale (m) to right.

Both models use the NCEP Global Forecast System (GFS) forecasts as a first-guess. However, the WRF ensemble member used involves data assimilation using WRFDA 3DVAR, while no reanalysis is done for the MPAS run.

The suite of physics schemes currently available in MPAS is a subset of those in WRF. While for some processes the schemes overlap, even with these the versions of the schemes differ. For example, for WRF in AMPS the packages are from Version 3.7.1, while those in MPAS are from WRF Versions 3.3–3.5. Table 1 lists the physics options used in both models. The shared packages are the Noah land surface model, Kain-Fritsch cumulus parameterization, the RRTMG longwave radiation scheme, and the Eta surface layer scheme.

3. RESULTS

a. Forecast Comparisons

The daily MPAS runs were first subjectively compared to WRF, and the two have been found to be similar overall. Not unexpectedly, however, individual forecasts can evolve differently. From regular review of the MPAS forecasts, it is first found that MPAS displays no overtly unphysical results or unusual behavior over Antarctica. In addition, MPAS has been computationally robust (i.e., stable).

WRF & MPAS Physics

Shared

• LSM	Noah	(MPAS V3.3.1, WRF V3.7.1)
• Cumulus	Kain-Fritsch	(MPAS V3.5, WRF V3.7.1)
• LW radiation	RRTMG	(MPAS V3.4.1, WRF, V3.7.1)
• Surface layer (Eta)		(MPAS V3.5, WRF, V3.7.1)

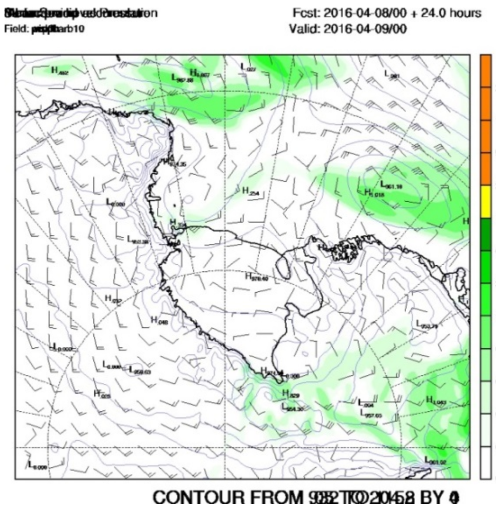
Different

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

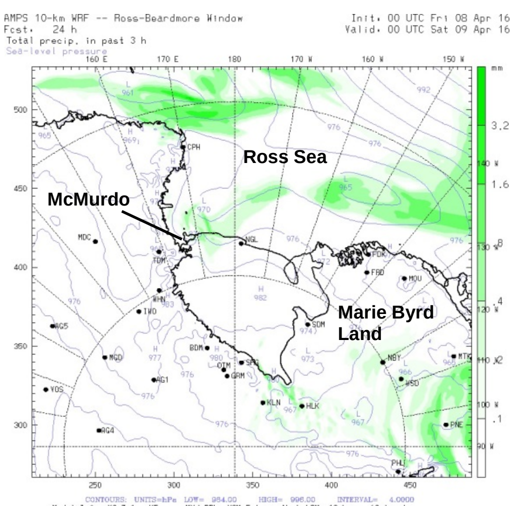
Tab. 1: Physics options used in MPAS and WRF runs. While a number of schemes are the same, the versions of the schemes are not.

As an example of how MPAS and WRF forecasts can compare, a case is highlighted here. While AMPS WRF forecasts have been scrutinized for years, MPAS is an unknown over Antarctica. Thus, one aim is to see whether MPAS does anything unusual compared to a quasi-benchmark WRF forecast.

Figures 3 and 4 show the MPAS and WRF forecasts from 0000 UTC 8 April 2016. At hour 24, the MPAS (Fig. 3(a)) and WRF (Fig. 3(b)) SLP and 3-hourly precipitation fields in the Ross Sea sector shown are similar. The noteworthy feature at this time is the deep low in the Ross Sea off Marie Byrd Land (places labeled in Fig. 3(b)), and both the placement and central pressure are aligned in both models: the MPAS low is at 961 mb, and the WRF low is at 965 mb. Compared to the AMPS analysis for this time (0000 UTC 9 April 2016) (not shown), both runs are accurate, with the analyzed low depth at 963 mb. It is found, however, that the WRF low center's position, which is slightly west of the MPAS center, is a truer to the analysis.



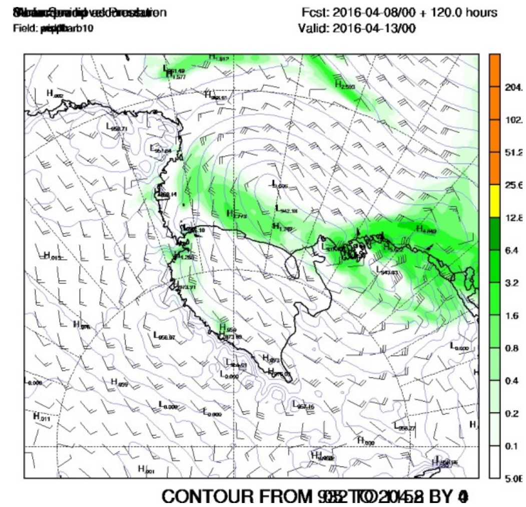
(a)



(b)

Fig. 3: MPAS and WRF 24-hr forecasts for 0000 UTC 9 April 2016 (0000 UTC 8 April initialization). Sea level pressure (solid, interval= 4 mb) and 3-hourly precipitation (mm, scales to right) shown. (a) MPAS. Wind barbs: full barb= 10 kts. (b) WRF.

By hour 120, however, the simulations have diverged (Fig. 4). WRF (Fig. 4(b)) has developed two distinct low centers, one off Marie Byrd Land (952 mb) and one in the western Ross sea (959 mb). In contrast, MPAS (Fig. 4(a)) has a single, elongated trough through the southern Ross Sea with a deeper minimum pressure of 942 mb. The AMPS analysis for this time (Fig. 4(c)) indicates that MPAS low depiction verifies better than WRF, with its two centers.



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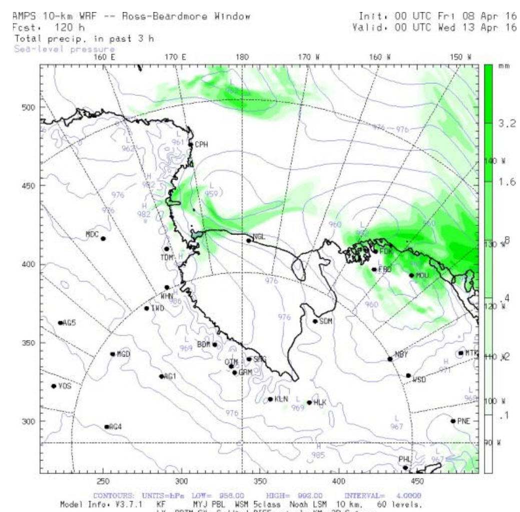

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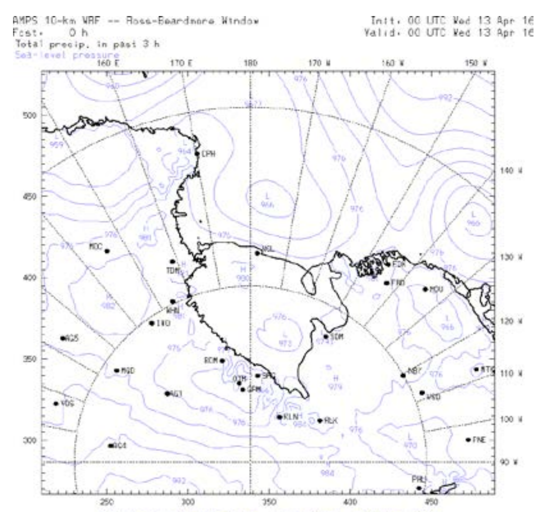
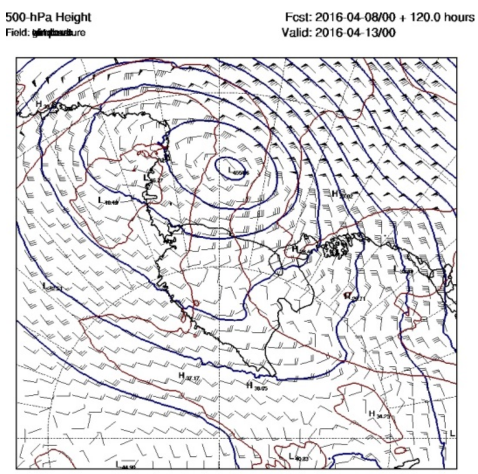


(c)

Fig. 4: MPAS and WRF 120-hr forecasts for 0000 UTC 13 April 2016 (0000 UTC 8 April initialization) and analysis. Sea level pressure (solid, interval= 4 mb) and 3-hourly precipitation (mm, scales to right) shown. (a) MPAS. Wind barbs: full barb= 10 kts. (b) WRF. (c) AMPS analysis for 0000 UTC 13 April 2016.

These surface development differences reflect differences aloft. Figures 5(a) and 5(b) show the MPAS and WRF 500 mb forecasts for this time (hr 120). While MPAS has a single 500 mb cutoff circulation, WRF has produced two centers at this level. Based on the analysis (Fig. 5(c)), the single center in MPAS is a better representation, but the positioning of the overall WRF trough, more to the west than in MPAS, shows less position error; the MPAS 500 mb cutoff low sits more eastward of the analyzed position over Victoria Land.



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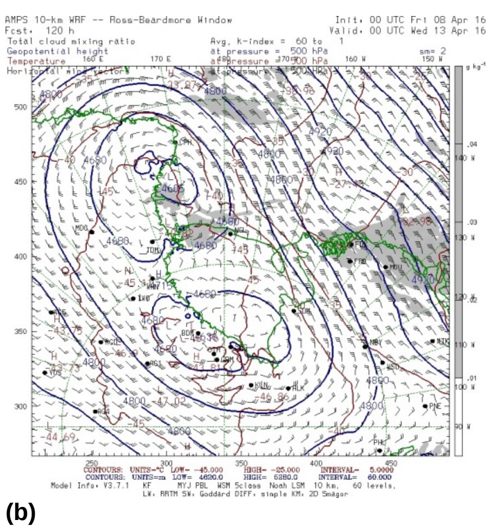

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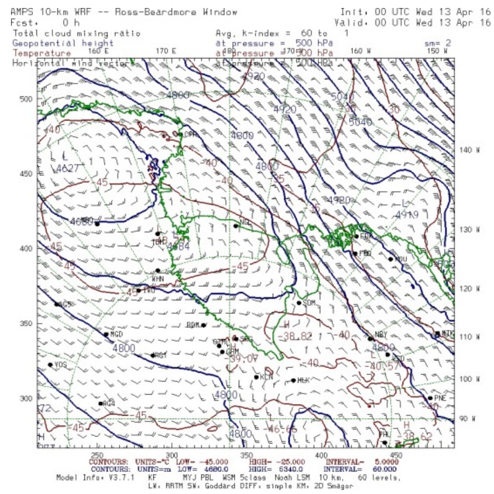
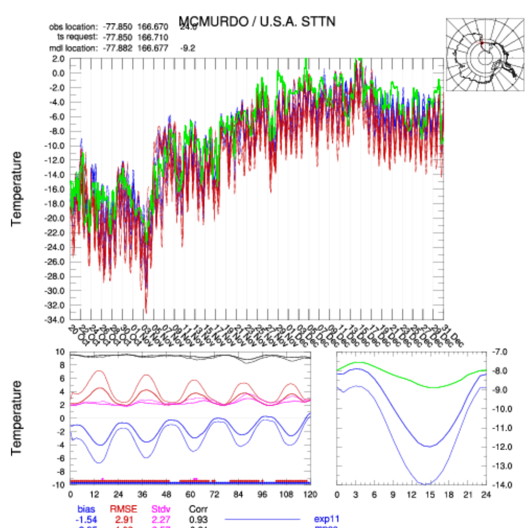


(c)

Fig. 5: MPAS and WRF 120-hr 500 mb forecasts for 0000 UTC 13 April 2016 (0000 UTC 8 April initialization) and analysis. Heights solid (m, blue, interval= 60 m), winds (full barb= 10 kt) and temperature (red) (°C, interval= 5 C). (a) MPAS. (b) WRF. (c) AMPS analysis for 000 UTC 13 April 2016.

b. Verification Statistics

Statistical verifications have been performed for the test periods for surface temperature, pressure, and wind speed. The verifications use AWS and surface station data from over 70 sites. Significance testing has been done on the differences between the error statistics for the models.



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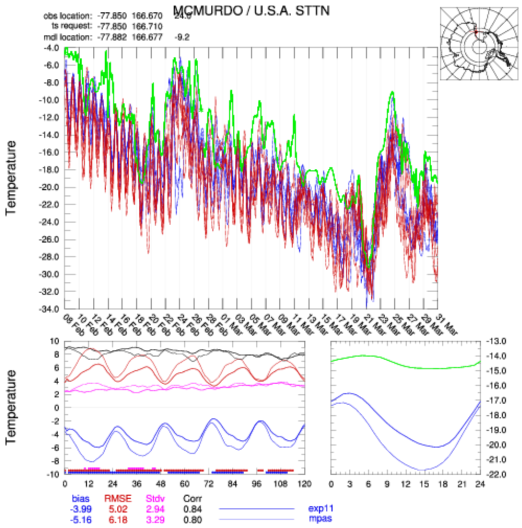
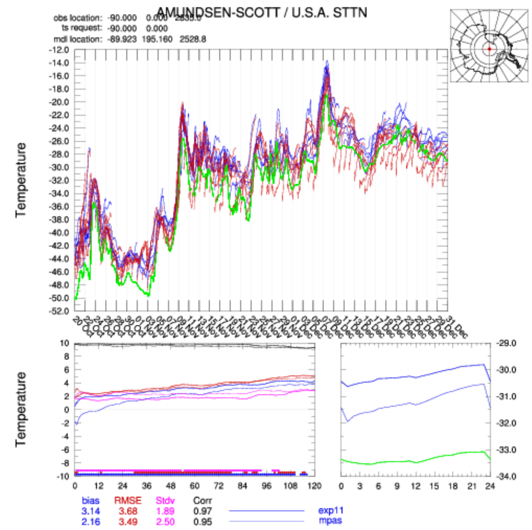


(b)

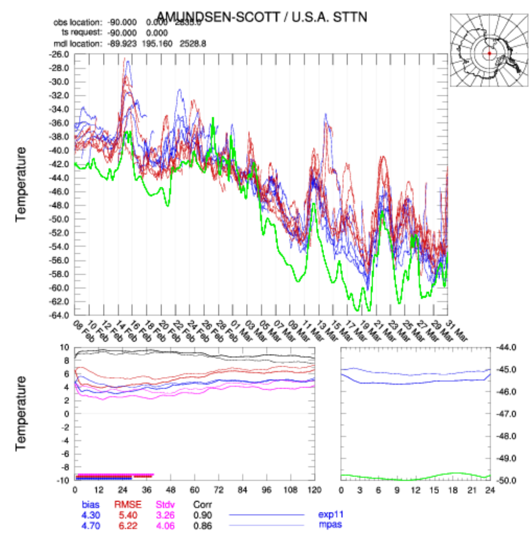
Fig. 6: Surface temperature forecasts and error statistics for MPAS and WRF at McMurdo. Top panel: Observations (green), MPAS forecast (red) temperatures, and WRF forecast (blue) temperatures. Bottom left: Average errors per forecast hour (hrs 0–120)— WRF thick solid, MPAS thin solid. Blue= bias; red= RMSE; pink= bias-corrected RMSE; black= correlation. Dots in a given color indicate that the error differences for the corresponding statistic for the given forecast hour are statistically significant. Bottom right: Average biases (°C) for a 24-hr diurnal period. (a) Oct.–Dec. 2015. (b) Feb.–Mar. 2016.

Figure 6 shows the temperature statistics for the key USAP site of McMurdo Station (location in Fig. 3(b)) for the Oct.–Dec. 2015 (Fig. 6(a)) and Feb.–Mar 2016 (Fig. 6(b)) periods. The top panel contains the MPAS (red) and WRF (blue) forecasts, along with the observations (green). The curves in the lower left panel show the model bias (blue), RMSE (red), bias-corrected RMSE ("Stdv"; pink), and correlation coefficient (black) over the 120-hr forecast periods, with the numbers below the frame being the value averages over all hours for the given season. WRF results are in the thick curves and MPAS results in the thin curves. The colored dots along the bottom axis indicate statistical significance of the differences in the metric between the two runs at the 95% level for the given hour. Lastly, the lower right panel presents the average forecast and observed temperatures over the diurnal cycle, with MPAS and WRF the thin and thick traces, respectively. For these diurnal view panels, only the model 0000 UTC runs have been used. The value for a given model hour reflects the averaged model forecast temperatures verifying for that local hour. Thus, for hour 12 it represents that day's 0000 UTC forecast for hour 12, plus the previous day's forecast for hour 36, etc.

For McMurdo the top panels reveal that the MPAS forecasts are, on the whole, colder than the WRF forecasts, which translates to an increase in the cold bias here. Throughout the forecasts there is a larger cold bias for MPAS at McMurdo for both seasons. The average bias (i.e., for both periods, as shown in the lower left panel numbers) for WRF is -2.8C, while for MPAS it is -4.0C. This larger temperature bias for MPAS is significant for almost all forecast hours.



(a)



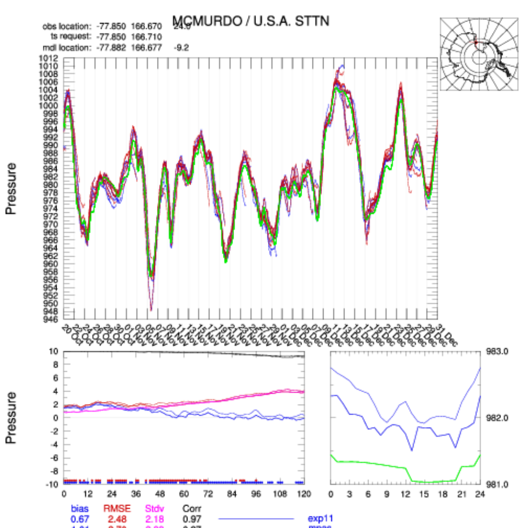
(b)

Fig. 7: Surface temperature forecasts and error statistics for MPAS and WRF at South Pole. Panels as in Fig. 5. (a) Oct.–Dec. 2015. (b) Feb.–Mar. 2016.

Figure 7 shows the temperature results for South Pole. MPAS (Fig. 7(a)) for Oct.–Dec. has less of a warm bias than WRF (Fig. 7(b)), which has always displayed a warm bias at this location. The MPAS bias is 2.2C compared to WRF's 3.1C, and the bias differences are statistically significant for virtually the entire 120-hr period. For Feb.–Mar. WRF has a lesser warm bias than MPAS, but the differences are smaller and not significant after hour 36.

Errors in surface pressure and winds have also been calculated and compared. Figure 8 shows the surface pressure results for McMurdo. First, note that the forecast traces for both models for both periods (Figs. 8(a),(b), top panels) track the observations well. Thus, the correlations for both models average a high .96. For Oct–Dec., WRF shows an improvement over WRF in bias, with a statistically significant reduction through hour 72 of .3 mb, from 1.0 mb to 0.7 mb (Fig. 8(a), lower left). For Feb.–Mar., the differences are small, with MPAS being slightly better (0.2 mb reduction) (Fig. 8(b), lower left and right).

Illustrating wind speed results, Fig. 9 presents the statistics for South Pole. Here WRF shows clear and statistically significant improvements in both bias and RMSE. The overall (i.e., averaging both seasons) bias is +0.5 ms^{-1} for WRF and -1.6 ms^{-1} for MPAS, with corresponding RMSEs being 1.7 ms^{-1} and 2.3 ms^{-1}.



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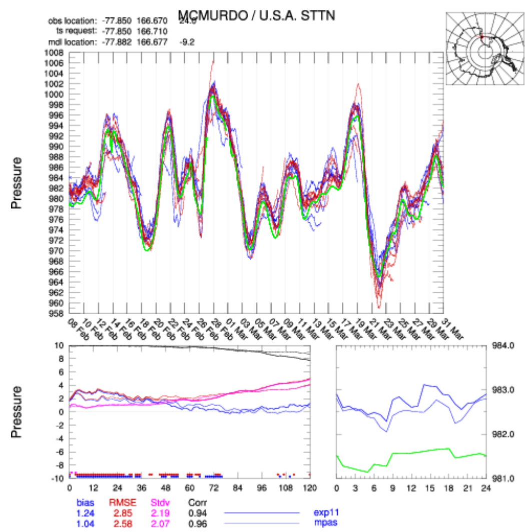

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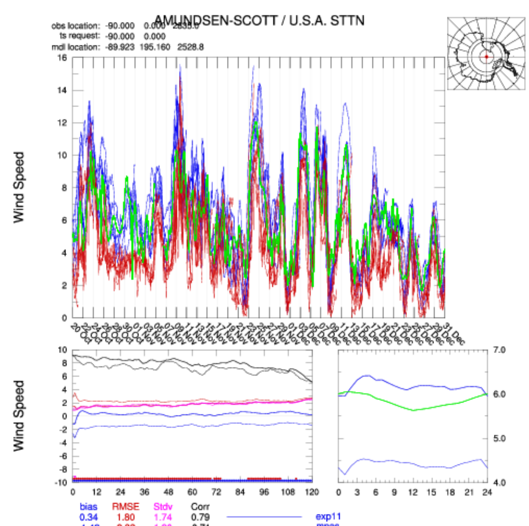
Fig. 8: Surface pressure forecasts and error statistics for MPAS and WRF at McMurdo. Panels as in Fig. 5. (a) Oct.–Dec. 2015. (b) Feb.–Mar. 2016.



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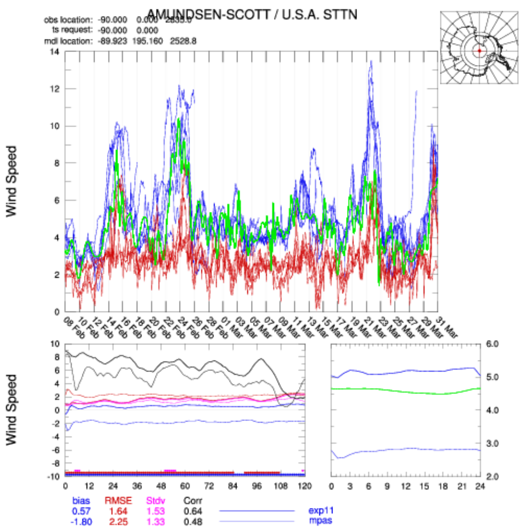
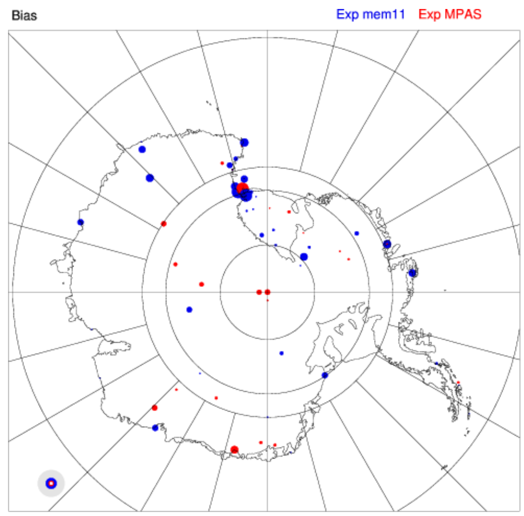


(b)

Fig. 9: Surface wind speed forecasts and error statistics for MPAS and WRF at South Pole. Panels as in Fig. 5. (a) Oct.–Dec. 2015. (b) Feb.–Mar. 2016.

As has been seen in the comparisons of pressure at McMurdo and wind at South Pole, the results vary with parameter and station. WRF overall has lower errors in the selected surface parameters across sites, but it does not always outperform MPAS. The results in Figs. 10–12 illustrate this variability. Here the circle color indicates which run is better at the given site, and the circle size is proportional to the magnitude of the improvement. For surface temperature, the results are mixed for Oct.–Dec. (Fig. 10(a)), while WRF is better for Feb.–Mar (Fig. 10(b)). Conversely, for surface wind speed, the results are mixed for late summer/fall (Fig. 11(b)), while MPAS has an edge in the spring (Fig. 11(a)). Lastly, for surface pressure, WRF is better overall for both the spring and fall periods (Figs. 12(a),(b)). As for the forecast temperature correlation with observations (not shown), there is little difference between the runs.



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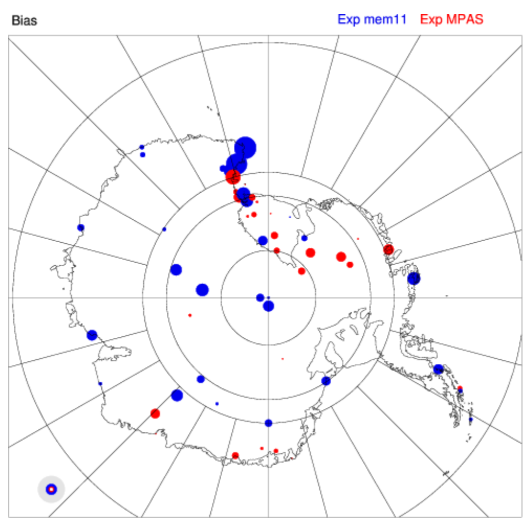
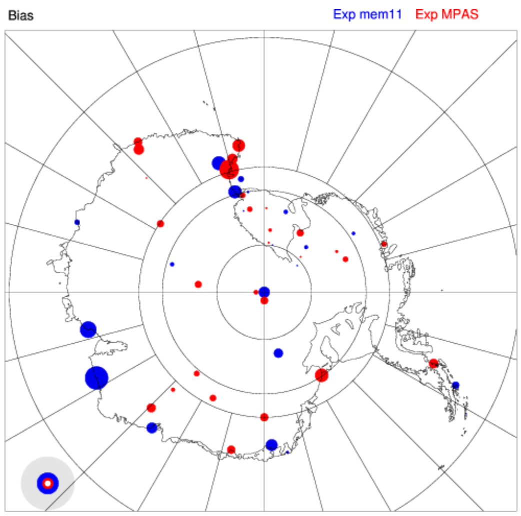


(b)

Fig. 10: Comparison of surface temperature biases for MPAS and WRF. Red= MPAS better; blue= WRF better. Circle size proportional to magnitude of improvement. (a) Oct.–Dec. 2015. (b) Feb.–Mar. 2016.



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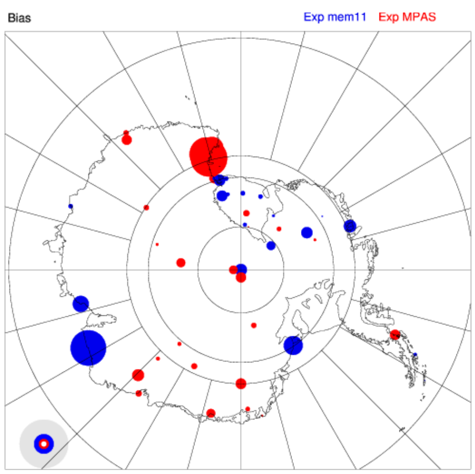


(b)

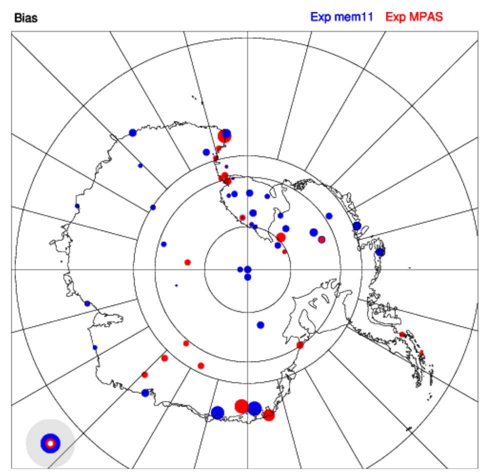
Fig. 11: Comparison of surface wind biases for MPAS and WRF. Red= MPAS better; blue= WRF better. Circle size proportional to magnitude of improvement. (a) Oct.–Dec. 2015. (b) Feb.–Mar. 2016.

4. SUMMARY AND CONCLUSIONS

The Model for Prediction Across Scales (MPAS) is an emerging global model that is designed to operate accurately down to nonhydrostatic scales. Supported by NCAR, it has been in public release since 2013 and is being applied for both research and real-time forecasting. While it only runs as a global model now, MPAS can provide mesh refinements over regions of interest. In light of MPAS's development, the AMPS effort has begun testing it over Antarctica, and this investigation is the first detailed look at MPAS over a polar region.

This study examines MPAS and WRF forecasts from similar, but not identical, configurations. Forecasts are subjectively and objectively verified, with the latter review consisting of evaluations of surface parameters. Limitations both on compute resources and on the physics options in MPAS have made for test runs that are not identical. This is the most basic caveat for this first comparison of the models over Antarctica.

From a subjective look at the forecasts, it is found that MPAS behaves consistently with WRF and does not display any gross discrepancies. In addition, MPAS has not presented any operational problems (i.e., crashes) or displayed noticeably unphysical results in this polar application.



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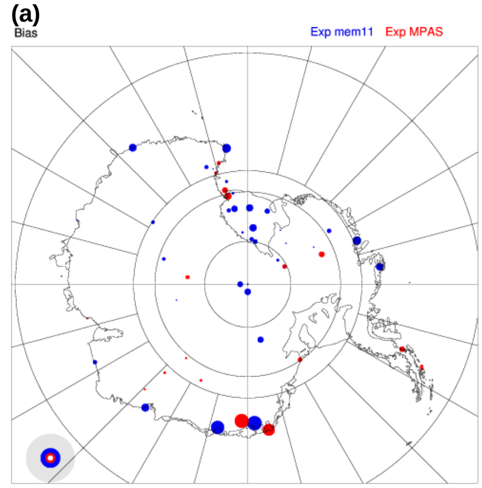

(b)

Fig. 12: Comparison of surface pressure biases for MPAS and WRF. Red= MPAS better; blue= WRF better. Circle size proportional to magnitude of improvement. (a) Oct.–Dec. 2015. (b) Feb.–Mar. 2016.

While only a limited number of examples can be presented here, from the surface verifications for all sites it is found that overall WRF performs better statistically than MPAS. Surface temperature and pressure forecasts are overall better (RMSE, bias) across the continent for WRF. However, even with its coarser configuration, MPAS holds its own and shows statistically better performance at many sites for given variables. And, it is found that the results for the models for a given site and variable can vary with the season considered: better performance in one season does not necessarily carry to the other.

Although there is no big dropoff in forecast performance with MPAS compared to WRF, even with MPAS being run on a coarser grid and without polar-modified physics, it is emphasized that full MPAS use in AMPS will not occur soon. First, MPAS is much more expensive computationally. To run a 10-km Antarctic refinement in MPAS would be about 6X the cost of the 30-km/10-km WRF run. Second, MPAS's physics options are limited, and MPAS does not have all of the current polar modifications. Third, data assimilation specifically for MPAS has not been developed. Fourth, and most importantly, more basic testing and verification of MPAS over Antarctica (e.g., longer periods, upper-air analysis) are necessary to better understand the model's performance and potential issues in this unique environment. Nonetheless, the active development of MPAS means that its use and capabilities will only grow, and it will continue to be run within the AMPS framework from now on.

ACKNOWLEDGEMENTS

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