VERIFICATION OF MPAS FORECASTS OVER ANTARCTICA

Jordan G. Powers and Kevin W. Manning
Mesoscale and Microscale Meteorology Laboratory
National Center for Atmospheric Research
Boulder, Colorado, USA

1. INTRODUCTION

The Antarctic Mesoscale Prediction System (AMPS) is a real-time numerical weather prediction capability that provides guidance for the forecasters of the U.S. Antarctic Program (Powers et al. 2012). AMPS also supports scientific field campaigns, researchers and students, and international Antarctic efforts. While AMPS has used the Weather Research and Forecasting (WRF) Model (Skamarock et al. 2008) for its forecasts and products since 2006, AMPS has begun running the Model for Prediction Across Scales (MPAS) (Skamarock et al. 2012). MPAS is an emerging global model that was designed to capture atmospheric evolution down to the cloud (i.e., nonhydrostatic) scales. It offers global coverage with either uniform or variable-resolution grids, with the latter achieved via mesh refinement over user-selected regions.

Unlike WRF with its rectangular grid, MPAS has an unstructured mesh composed of varied polygons (predominately hexagons). Figure 1 presents an example of an MPAS variable-resolution mesh with a finer grid over East Asia. NCAR supports the MPAS atmospheric model to the community, and the current version is 5.1. MPAS has been applied for research (Park et al. 2014) as well as real-time forecasting (e.g., Clark et al. (2012)).

Here MPAS is implemented for real-time forecasting in the polar context of AMPS. This not only provides the USAP forecasters with another source of NWP guidance, but also serves for testing and evaluation of this new capability over the high latitudes. This study pursues that, and here MPAS and WRF forecasts for winter, summer, and autumn periods are analyzed and compared.

Preliminary work (Powers and Manning 2016) considered a limited span of MPAS runs that were available in 2016, when the model had not yet been running long in AMPS. Furthermore, the forecasts examined were not cleanly separated into summer and winter. With a year of MPAS operation completed in AMPS, however, the current work examines the seasonal differences and, for the first time, evaluates the upper-air performance of MPAS over Antarctica.

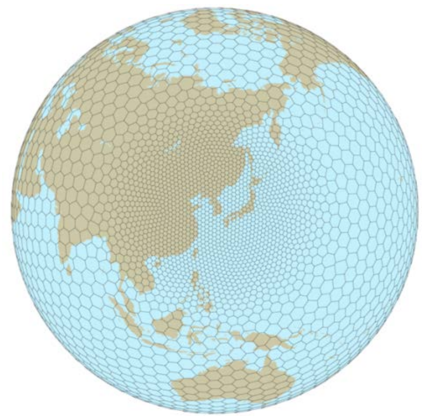
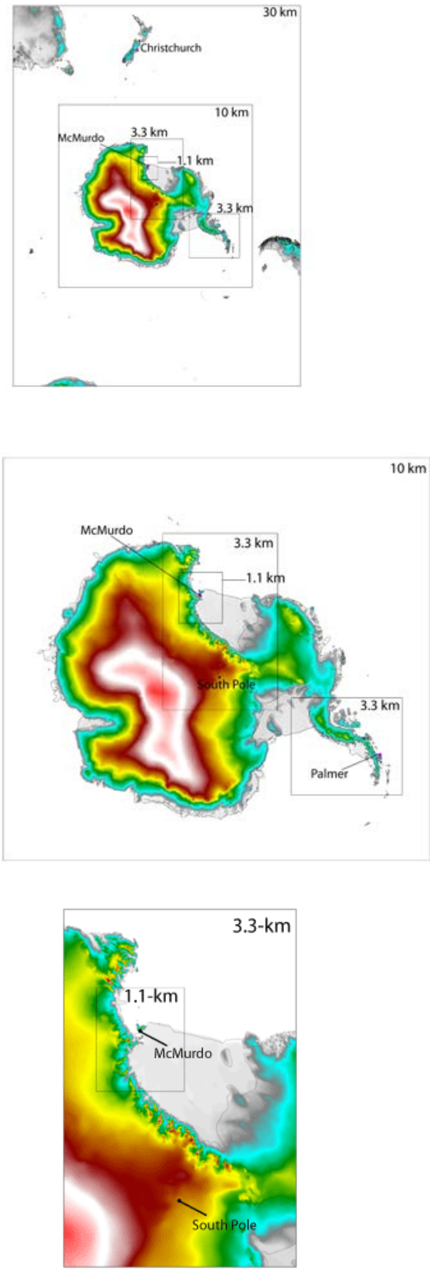


Fig. 1: Example of MPAS variable-resolution mesh. Mesh composed of polygons with higher resolution (finer mesh spacing) seen over center of plotted global domain.

Because of constraints on computing and inherent model differences, WRF and MPAS have not been run identically in AMPS. First, the AMPS WRF forecasts limit the computer resources for the more computationally-costly MPAS. Thus, MPAS cannot be run at the same continental resolution as WRF in AMPS. Second, MPAS does not offer all of the physics packages and versions that WRF does, and so the model physics configurations are not identical. Third, MPAS does not have its own data assimilation system. Thus, in contrast to the WRF forecasts, the MPAS runs do not involve data assimilation, and the model initialization processes differ.

2. MODEL SETUPS AND FORECAST VERIFICATIONS

The AMPS WRF forecasts compared with MPAS here are from the system's five-domain nested setup generating guidance out to five days. Figure 1 shows these domains. Since the nests are two-way, the WRF results reflect the finer-grid values for locations covered by a nest. In contrast, MPAS cannot be run with standalone, limited-area domains: it requires a global grid. MPAS does allow for regional refinement, however, so that a target area can have finer resolution (Fig. 1). Thus, here MPAS is run with a global 60-km mesh that decreases to 15 km over Antarctica. The MPAS forecast information verified over the continent therefore reflects a 15-km horizontal mesh.



(a) (b) (c)

Fig. 2: AMPS WRF domain setup. Topography shaded. (a) All AMPS grids. Outer domain is 30 km, and continental domain is 10 km. (b) AMPS WRF domains over Antarctica. Outer frame is the 10-km domain, while inner frames are 3.3-km Ross Ice Shelf and Antarctic Peninsula grids. (c) 3.3-km Ross Ice Shelf/Ross Sea domain and 1.1-km Ross Is. domain.

The WRF configuration is the 30-/10-/3.3/1.1-km domain setup used operationally, shown in Fig. 2. The 30-km and 10-km domains (Fig. 2(a)) run out to 120 hr, while the 3.3-km and 1.1-km grids (Figs. 2(b),(c)) run out to 39 hr. To approximate the 10-km WRF domain (Fig. 2(b)), the MPAS refined mesh region covers Antarctica and surrounding ocean. However, this is run with 15-km spacing as the available compute resources did not allow MPAS refinement down to 10 km.

Another model setup difference is in the number of vertical levels. While WRF in AMPS has 60 half-levels, computing constraints here mean that MPAS has 45. The model tops are about the same, however. For the height-coordinate MPAS, this is 30 km (~12 mb), while for WRF it is 10 mb (~31 km). Both models are run out to five days from 0000 UTC and 1200 UTC initializations.

Both models use the NCEP Global Forecast System (GFS) forecasts for their first-guess fields and for boundary conditions. However, as noted above the WRF run reflects a data assimilation (DA) step using a hybrid 3DVAR-ensemble approach, while no DA/ reanalysis is done in MPAS.

The model codes used are WRF Version 3.7.1 and MPAS Version 4.0. WRF contains polar modifications (see, e.g., Hines and Bromwich 2008) to better capture the characteristics and conditions of the high latitudes, and these are available to both WRF and MPAS to the extent of the code version used. The physics schemes available in MPAS are a subset of those in WRF, as not all of the WRF physics are available in MPAS. For some processes the schemes are the same, although the scheme versions differ. For example, the WRF physics here are from WRF Version 3.7.1, while the available packages in MPAS are from WRF Versions 3.3–3.5. Table 1 lists the physics options used. The shared packages are the Noah land surface model, Kain-Fritsch cumulus parameterization, the RRTMG longwave radiation scheme, and the Eta/MYJ surface layer scheme.

To illuminate seasonal model performance and differences, austral winter and summer periods have been reviewed: July–August 2016 and December 2016–January 2017. For these, AWS and surface reports are used to verify surface temperature, pressure, and wind speed from the forecasts. For a third period, reflecting autumn (April–May 2017), upper-air verifications and error comparisons are performed in addition to the surface verifications. The upper-air verification was not done for the prior winter and summer periods because the capability for saving the upper-air profiles for the real-time WRF and MPAS runs was not in place when the operational runs were made.

3. RESULTS

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

Before digging into error statistics, it is important to begin with a taking wider view and examining the forecasts synoptically. To this end, and for verifying the basic consistency of WRF and MPAS over Antarctica, forecasts have been subjectively compared on a regular basis from the real-time runs. As found in the preliminary examination of Powers and Manning (2016), MPAS and WRF evolve quite similarly through the first two days, with increasing divergence in the latter part of the forecast (day 3+). With some track record of operational implementation in AMPS, we do begin by noting that MPAS is no longer an unknown. It has been providing consistent forecasts and is well-behaved/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)

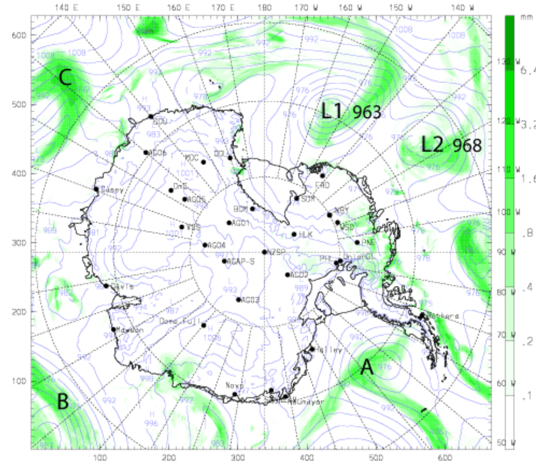
Different

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

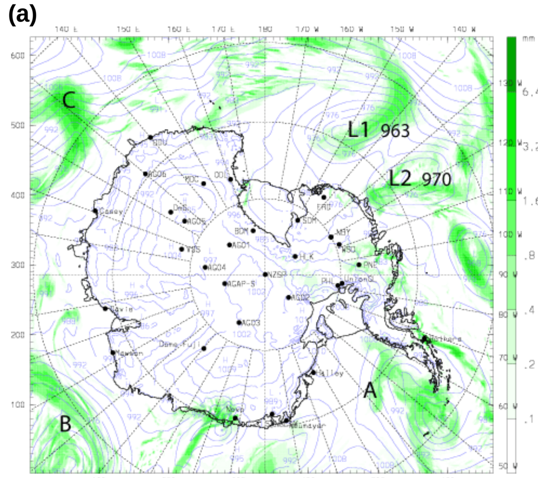
Tab. 1: Physics options used in MPAS and WRF runs. While a number of schemes are the same, the versions of the schemes are not.

We present one case here as an example of how MPAS and WRF forecasts can compare. Figures 3(a) and 3(b) show WRF and MPAS forecasts from the 1200 UTC 1 June 2017 initialization. At hour 96, the WRF (Fig. 3(a)) and MPAS (Fig. 3(b)) SLP and 3-hourly precipitation fields parallel each other. First, all pressure centers in MPAS have counterparts in WRF— neither model is generating or evolving features absent in another. Second, in this example the depth and placement of all centers in and around the continent is consistent. There is a pair of lows in the northeastern Ross Sea and Amundsen Sea, marked L1 and L2 in the figure. The depth of L1 is 963 mb in both, while L2 is 968 mb in WRF and 970 in MPAS. Compared with the AMPS analysis for this time (1200 UTC 5 June 2017) (Fig. 3(c)), both runs are accurate, with the analyzed depth of L1 is 958 mb. Similar correspondences can been seen in the other centers around the continent.

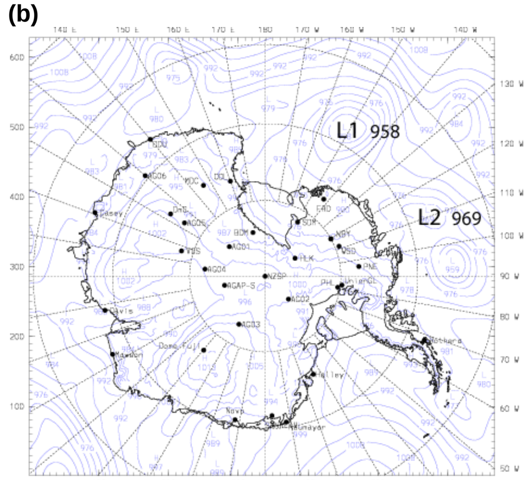
The third point to note is the similarity in accumulated precipitation associated with each system in the forecasts. The areas labeled A, B, and C are examples. The shading is consistent (scale to right), and thus the models are producing comparable amounts of precipitation.



(a)



(b)



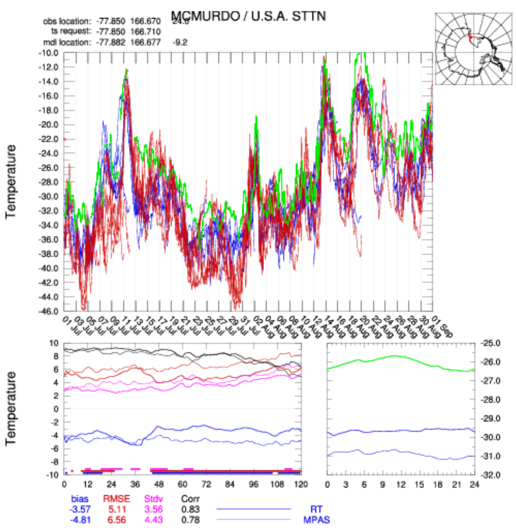
(c)

Fig. 3: WRF and MPAS 96-hr forecasts for 1200 UTC 5 June 2017 (1200 UTC 1 June 2017 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

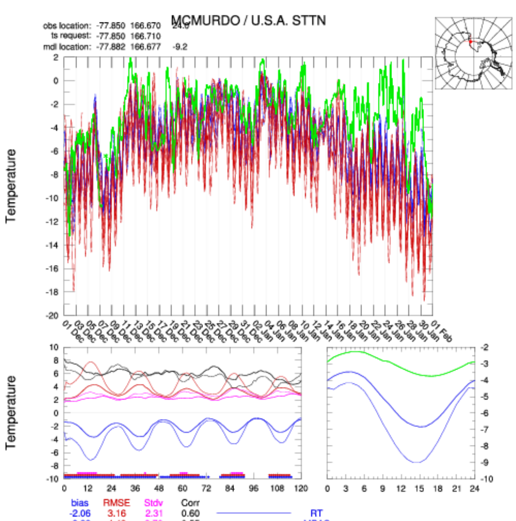
areas A, B, and C referred to in text. (a) WRF. (b) MPAS. (c) AMPS analysis for 1200 UTC 5 June 2017.

b. Verification Statistics

As noted in Sec. 1, for all three periods (Winter 2016, Summer 2016–2017, and Autumn 2017) verifications of surface parameters (temperature, pressure, and wind speed) are performed. These are based on AWS and station data from approximately 70 sites. For the first time for MPAS over Antarctica, we have also performed upper-air verification. We do this for the autumn 2017 test period mentioned in Sec. 2, using the approximately 12 active radiosonde sites in Antarctica. For all parameters examined, statistical significance testing has been done on the differences in model bias errors.



(a)

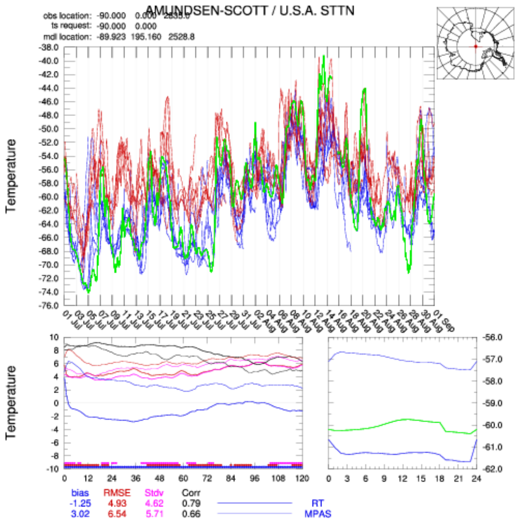


(b)

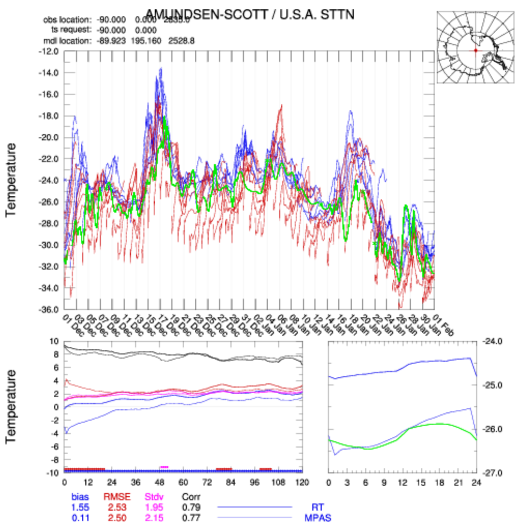
Fig. 4: Surface temperature forecasts and error statistics for MPAS and WRF at McMurdo. Top panel: Observations (green), MPAS forecast (red) temperatures, and WRF forecast (blue) temperatures. Bottom left: Average errors per forecast hour (hrs 0–120)— WRF thick solid, MPAS thin solid. Blue= bias; red= 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 forecast temperatures (°C) for a 24-hr daily period. (a) Jul.–Aug. 2016. (b) Dec. 2016–Jan. 2017.

Figure 4 shows the surface temperature results for McMurdo for the winter (Jul.–Aug. 2016 (Fig. 4(a)) and summer (Dec.–Jan. 2016 (Fig. 4(b)) periods. The top panel presents the MPAS (red) and WRF (blue) forecasts, along with the observations (green). The lower left panel shows the model bias (blue), RMSE (red), bias-corrected RMSE ("Stdv"; pink), and correlation coefficient (black) averaged over the 120-hr forecast periods. WRF results are in the thick lines and MPAS results in the thin lines. The statistical significance of the differences in the metric between the two runs at the 95% level is indicated by colored dots for the given hour along the bottom axis. Lastly, the lower right panel presents the average forecast and observed temperatures over the diurnal cycle during the period, with MPAS and WRF the thin and thick traces, as in the lower right. 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 main USAP Antarctic station, the top panel in Fig. 4(a) reveals that in winter both the WRF and MPAS forecasts are colder than observations. However, from the lower panels MPAS has a greater cold bias, and this is particularly apparent in the 24-hr plots in the lower right. WRF is statistically better than MPAS for hours 12–18 and after hour 39 (when the fine grid shuts off). Figure 4(b) presents the summer results, with both again having a cold bias, but with MPAS's of greater magnitude. The bias differences are significant for most of the forecast period. There is also a diurnal variation of T error/bias that emerges in both models, but is of higher amplitude in MPAS than WRF. The average bias (i.e., for both periods, as shown in lower left panel) here at McMurdo or WRF is -2.8C, while for MPAS it is -4.0C.



(a)



(b)

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

Figure 5 shows the temperature results for South Pole, the USAP's other key base. For summer (Fig. 5(a)) MPAS's warm bias is apparent when viewing its forecasts with the observations (top panel: MPAS—red, obs— green). WRF, in contrast, has a cold bias that is of lesser magnitude. This is brought out in the lower right panel of Fig. 5. In contrast, for the summer period (Fig. 5(b)), MPAS has, on average, a minimal temperature bias (-0.1 C) , while WRF displays a warm bias (+1.6C). The difference is statistically significant for all forecast hours. Thus, model performance varies significantly with season.

The relative forecast performance of the models also varies by region. To see this Tab. 2 presents the average surface temperature (T) forecast errors by region for the winter 2016 and summer 2016–2017 periods. The regions defined are: Ross Island, East Antarctica, Plateau/Pole, Queen Maud Land, West Antarctica, and the Antarctic Peninsula. Differing numbers of stations are grouped for each region, as the distribution of AWSs is diverse. Ross Is., for example, has many AWSs (about 11 in this analysis), while East Antarctica and Plateau/Pole have relatively few (3 each in this analysis). The values shown are averages of the given statistic over all forecast hours out to 120 hr. Areas of particular interest to the USAP are Ross Is., Pole, and the Antarctic Peninsula. For Ross Is., both WRF and MPAS have a cold bias. WRF's is lower in the summer, while MPAS's is lower in the winter. WRF, however, has lower yearly RMSEs. For Pole, the models are comparable for the summer, with WRF superior in winter. Around the Peninsula, WRF shows lower biases and RMSEs for both seasons. Lastly, one notable trend is that for both models, the T RMSEs are all greater for the winter season, and the biases are mostly of larger magnitude.

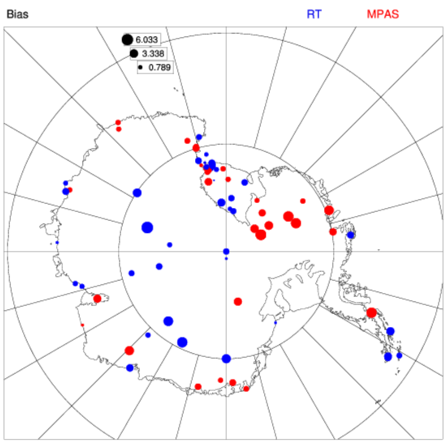
Table 3 presents the regional results for surface wind speed (WS). The Ross Is. biases for both models are very small (.5 ms^{-1} or less) for both seasons, and this average reflects uniformly small values for individual sites (not shown) that for most stations are of magnitude 1.5 ms^{-1} or less. The WS RMSEs for this region are comparable as well. For Pole, MPAS is slightly better than WRF for both bias and RMSE. Continent-averaged WS biases and RMSEs are slightly lower for MPAS than WRF.

As with temperature, there are higher WS biases and RMSEs for the winter for all regions. Thus, in both AMPS models, performance declines in winter. This may reflect weaknesses in the physics that are accentuated in the winter or the reduction in observations going into initialization (which will affect either the GFS first-guess or WRFDA reanalysis). It is an area for forecast improvement.

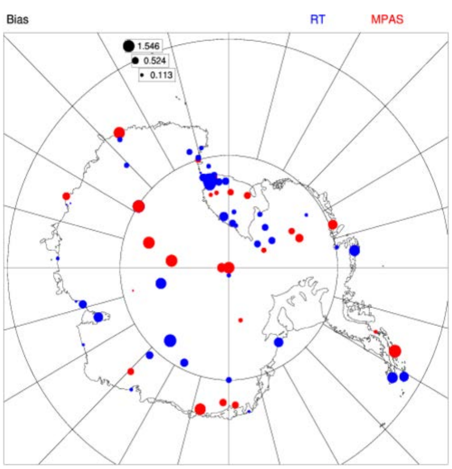
Comparisons of surface variable biases and RMSEs across the continent are shown in Figs. 6-8. Here the circle color indicates which run is better at the given site, and the circle size is proportional to the magnitude of the improvement. As exemplified by the stations highlighted above, the results are mixed. For temperature bias, Fig. 6(a) presents the winter results. WRF is better over the Antarctic Plateau and the immediate Ross Is. region; MPAS is better over West Antarctica, Queen Maud Land, and the Ross Ice Shelf (RIS). For summer (Fig. 6(b)), WRF's performance in the Ross Island region is enhanced and generally better than MPAS's. This is important for USAP operations, as summer is the critical field season. MPAS, however, shows gains over the central Plateau (out to Dome C) and is better at Pole.

For T RMSEs, Fig. 7(a) shows that for winter the patterns follow the biases. WRF is better over the Plateau and Ross Island region, with MPAS emerging over West Antarctica and the central part of the RIS. For summer (Fig. 7(b)), WRF widely outperforms MPAS. Although, the Plateau and Queen Maud Land show a mix of results.

For surface wind speed, MPAS has smaller biases than WRF over most areas for winter (Fig. 8(a)). These include the Plateau, East Antarctica, Queen Maud Land, and West Antarctica. The Ross Island region results vary, but MPAS has an edge. For summer (Fig. 8(b)) WRF outperforms MPAS for West Antarctica and the Antarctic Peninsula. The WS RMSE comparisons for both seasons (not shown) have patterns similar to the summer biases, with WRF presenting gains in West Antarctica and the RIS and the results being more mixed overall.

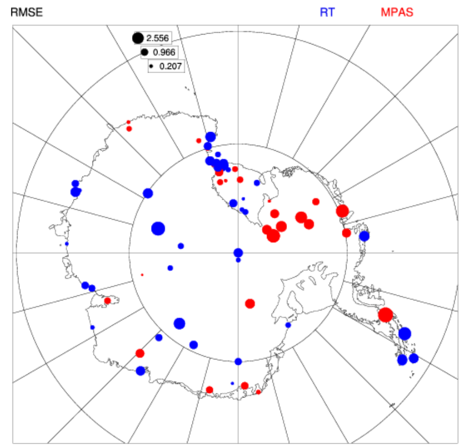


(a)

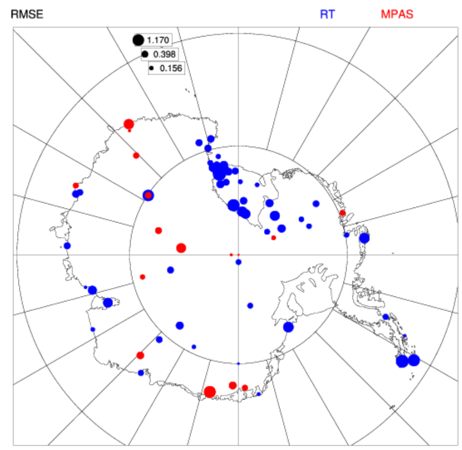


(b)

Fig. 6: Comparison of surface temperature biases (°C) for MPAS and WRF. Red= MPAS better; blue= WRF better. Circle size proportional to magnitude of improvement. (a) Jul.–Aug. 2016. (b) Dec.–Jan. 2016–2017.

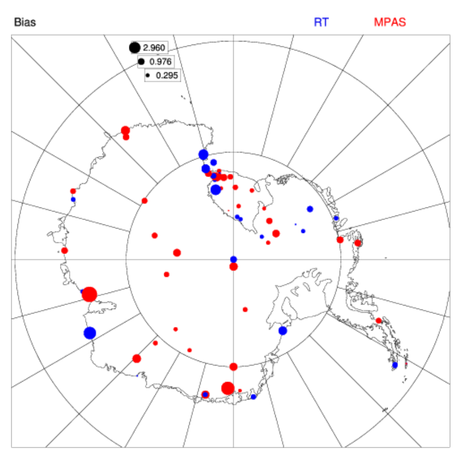


(a)

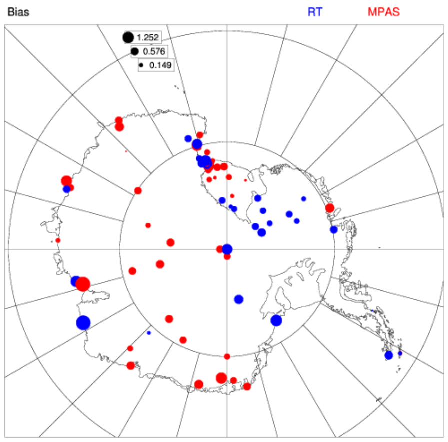


(b)

Fig. 7: Comparison of surface temperature RMSEs (°C) for MPAS and WRF. Red= MPAS better; blue= WRF better. Circle size proportional to magnitude of improvement. Circles appearing in both red and blue are actually two locations near each other. (a) Jul.–Aug. 2016. (b) Dec.–Jan. 2016–2017.



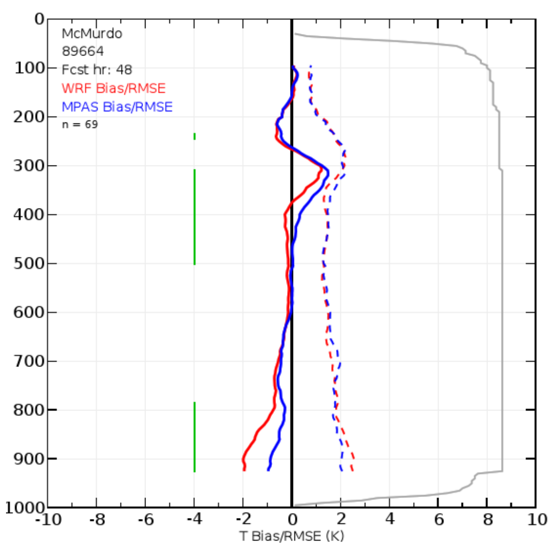
(a)



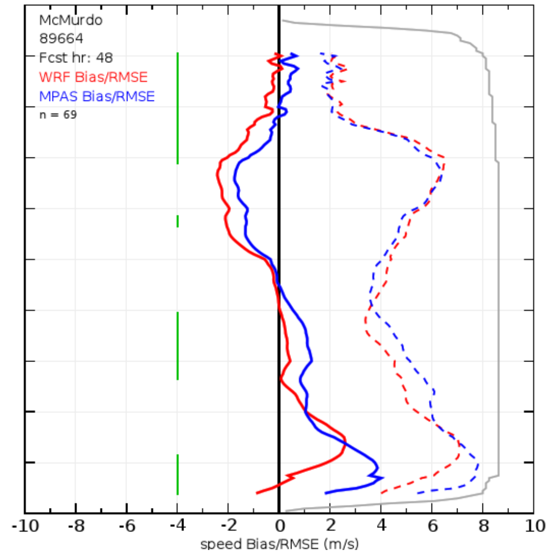
(b)

Fig. 8: Comparison of surface wind speed biases (ms^{-1}) for MPAS and WRF. Red= MPAS better; blue= WRF better. Circle size proportional to magnitude of improvement. (a) Jul.–Aug. 2016. (b) Dec.–Jan. 2016–2017.

Upper-air verification has been done for the period April–May 2017 for the continental radiosonde sites operating. These are: McMurdo, South Pole (Amundsen-Scott), Neumayer, Marambio, Rothera, Novolazarevskaya, Syowa, Casey, Mawson, Davis, Mirnyj, and Dumont D'Urville. Fields verified have been temperature, zonal and meridional wind components, and wind speed.



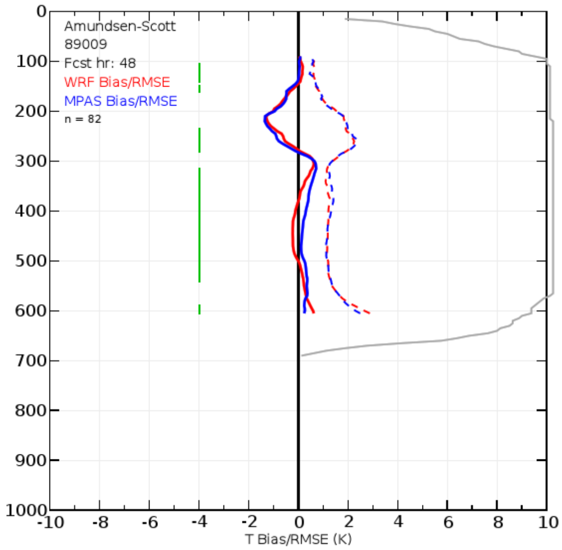
(a)



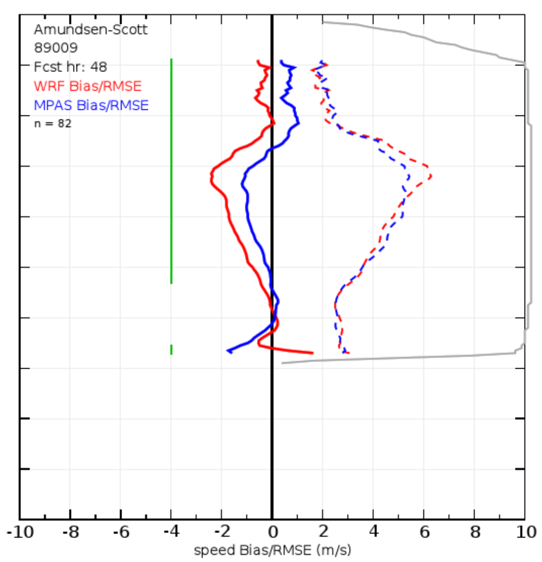
(b)

Fig. 9: Error profiles for forecast hr 48 for McMurdo for period 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, °C). WRF red, MPAS blue. (b) Wind speed bias (solid, ms^{-1}) and RMSE (dashed, ms^{-1}) WRF red, MPAS blue.

Figures 9 and 10 show the results for forecast hour 48 for temperature and wind speed at McMurdo and Pole. For McMurdo temperature (Fig. 9(a)) note first the low magnitude of the biases through the column: the errors are mostly less than 1°C, except the near-surface layer for WRF (and in the tropopause layer). Statistically significant differences (marked by green bars) appear in the biases through 800 mb, with MPAS being better than WRF and having about half of WRF's cold bias. Mid-tropospheric bias differences are negligible. Likewise, for the whole column, RMSE differences are minimal, and the values themselves are less than 2°C. For wind speed (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 and lower stratosphere, but the actual error magnitudes are small (<2 ms^{-1}). MPAS shows an overforecasting of WS in the lower troposphere in this autumn period, which is different from the summer and winter errors calculated for McMurdo (not shown, but incorporated in the Ross. Is. results in Tab. 3).



(a)



(b)

Fig. 10: Error profiles for forecast hr 48 for South Pole for period 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, °C). WRF red, MPAS blue. (b) Wind speed bias (solid, ms^{-1}) and RMSE (dashed, ms^{-1}) WRF red, MPAS blue.

For South Pole there are minimal T error differences for bias and RMSE through the column at hour 48 (Fig. 10(a)). However, the small bias differences are in WRF's favor and are statistically significant. For wind speed (Fig. 10(b)), WRF shows smaller biases in the near-surface layer, with statistical significance seen. Both models display negative speed biases through the middle-troposphere to about 275 mb; these are quite small (< 2 ms^{-1}), with MPAS 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 thus the models are performing similarly. Lastly, as forecast hour increases (not shown), errors do increase at almost all vertical levels, as would be expected.

4. SUMMARY

The Model for Prediction Across Scales (MPAS) is an emerging global model designed to capture scales down to the nonhydrostatic and cloud-resolving. To provide another source of NWP guidance for the USAP forecasters and to explore the value of MPAS in polar applications, MPAS has been implemented into AMPS operations. MPAS forecasts are run twice daily with a global 60-km mesh that has a refinement to approximately 15 km over Antarctica. This study follows up from a preliminary look at MPAS over Antarctica from 2016 (Powers and Manning 2016). The aim is to provide the WRF and MPAS communities with a glimpse into the relative performance of MPAS in the high latitudes, and specifically Antarctica.

The MPAS and WRF forecasts reflect model configurations that are as similar as practicable, but with a number of differences. First, MPAS does not have the nesting structure of WRF and thus can only be set up with the single regional refinement. Second, MPAS does not have all of WRF's physics options, and its schemes here reflect those from earlier versions of WRF. Third, the computational cost of MPAS limited the continental spacing to 15 km instead of 10 km, as in WRF.

Seasonal model performance has been assessed through verifications of (austral) winter and summer forest periods: July–August 2016 and December–January 2016–2017. Furthermore, for the first time, MPAS upper-air performance over Antarctica is assessed, using more recent forecasts from autumn 2017.

Subjective comparisons of MPAS and WRF forecasts show consistency of the models, even with their different setups. As illustrated, there is correspondence out to 3-4 days of synoptic and mesoscale features (pressure centers, fronts, precipitation). No systematic differences in precipitation totals or structures associated with synoptic systems is seen. For the most part, divergence in the progs becomes apparent after 3–4 days, however. This is tied to the differences in the models (e.g., grids, topographic data) and the physics options used, and also to the different initializations (i.e., data assimilation) in the AMPS setting.

While only a limited sample of results can be shown here, from the surface verifications for all sites it is found that overall WRF still performs better statistically than MPAS. Surface temperature forecasts are overall better (RMSE, bias) across the continent for WRF, while wind speed forecasts are mixed (MPAS better bias, WRF comparable in RMSE). With wind speed, biases are very low (<1.5 ms^{-1}) in summer, while these errors increase in winter. The primary USAP operation areas of Ross Island and South Pole have low errors in both models; while this was known for WRF, this is a good sign for MPAS. For both temperature and wind speed, both models have better forecast performance (lower errors) in summer than winter, a finding seen across the various continental regions examined. Thus, this seasonal performance loss is an area for improvement for both models.

For the first time for MPAS over Antarctica, we have done upper-air verification and comparisons with WRF. The period reviewed is April–May 2017. In temperature and wind speed, the largest differences between the models are in the lower troposphere (e.g., up to 750 mb, depending on the site). Temperature generally displays small errors (i.e., biases <2C) through the troposphere, to about 350 mb. Overall, error differences between the models are small, with the better model varying with location. The tropopause level sees the greatest errors and differences between the models. As would be expected, as forecast hour increases, errors do increase at almost all vertical levels.

The key sites for the USAP are McMurdo and Pole. For McMurdo, both models show a low magnitude of forecast T biases through the column, but with MPAS having a statistical edge in the lower troposphere. As is the case continent-wide, mid-tropospheric bias differences are negligible. Wind speed error magnitudes are small (<2 ms^{-1}) for both models. At Pole we find minimal differences in either T bias or RMSE through the column, although the small bias differences are statistically in WRF's favor. For wind speed, WRF has smaller biases in the near-surface layer, while MPAS is better above this, with error differences significant in both cases. For other sites, WS errors between the models are generally small, and thus the models are performing similarly across the continent.

In conclusion, even with its coarser configuration, MPAS holds its own and shows statistically significant better performance at many sites and in different regions, depending on the variable. This is encouraging, as the grid and physics configuration of MPAS has not yet been refined for the AMPS Antarctic application as with WRF. MPAS will continue to be run in AMPS, and higher resolution and updated polar-modified physics are planned.

ACKNOWLEDGEMENTS

The authors thank the NSF Division of Polar Programs for its support of AMPS.

REFERENCES

Clark, A. J., and Coauthors, 2012: An Overview of the 2010 Hazardous Weather Testbed Experimental Forecast Program Spring Experiment. *Bull. Amer. Meteor. Soc.*, **93**, 55–74. doi:10.1175/BAMS-D-11-00040.1

Hines, K. M., and D. H. Bromwich, 2008: Development and testing of Polar WRF. Part I. Greenland ice sheet meteorology. *Mon. Wea. Rev.*, **136**, 1971–1989.

Park, S.-Y., J. B. Klemp, and W. C. Skamarock, 2014: A comparison of mesh refinement in the global MPAS-A and WRF models using an idealized normal-mode baroclinic wave simulation. *Mon. Wea. Rev.*, **142**, 3614–3634. doi:10.1175/MWR-D-14-00004.1.

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.

Powers, J. G., and K. W. Manning, 2016: MPAS testing in AMPS. 11th Antarctic Meteorological Observation, Modeling, and Forecasting Workshop. Columbus, OH, The Ohio State Univ.

Skamarock, W.C., J.B. Klemp, J. Dudhia, D.O. Gill, D.M. Barker, M.G. Duda, X.-Y. Huang, W. Wang, and J.G. Powers, 2008: A description of the Advanced Research WRF Version 3. NCAR Tech. Note, NCAR/TN-475+STR, 113 pp. doi: 10.5065/D68S4MVH.

Skamarock, W. C., J. B. Klemp, L. D. Fowler, M. G. Duda, S.-H. Park, and T. D. Ringler, 2012: A multiscale nonhydrostatic atmospheric model using centroidal Voronoi tesselations and C-grid staggering. *Mon. Wea. Rev.*, **140**, 3090–3105. doi: 10.1175/MWR-D-11-00215.1

Table 2: Averaged surface T errors (°C) for WRF and MPAS by region.

Jul.–Aug. 2016	Bias	RMSE

	WRF	MPAS	WRF	MPAS
Ross Is.	-.66	-1.10	2.49	3.05
East Antarctica	2.17	.24	2.73	2.14
Plateau/ Pole	.78	-.74	2.55	2.77
Queen Maud Land	-1.81	-1.64	2.95	2.77
West Antarctica	.11	.14	2.46	2.72
Antarctic Peninsula	-1.76	2.28	2.29	3.08

Dec.–Jan. 2016–2017

	Bias		RMSE	
	WRF	MPAS	WRF	MPAS
Ross Is.	-1.36	-.02	5.16	6.14
East Antarctica	-.17	5.40	5.08	7.24
Plateau/Pole	-.97	3.02	4.87	5.72
Queen Maud Land	-2.13	1.11	5.39	5.30
West Antarctica	-4.77	.62	6.85	4.68
Antarctic Peninsula	1.35	-1.84	5.71	5.39

Table 3: Averaged surface wind speed errors (ms^{-1}) for WRF and MPAS by region.

Jul.–Aug. 2016

	Bias		RMSE	
	WRF	MPAS	WRF	MPAS
Ross Is.	.20	-.21	4.96	5.26
East Antarctica	2.03	1.12	2.49	1.93
Plateau/Pole	2.94	1.23	3.50	3.17
Queen Maud Land	3.73	1.07	5.77	4.83
West Antarctica	1.76	1.58	3.75	4.03
Antarctic Peninsula	2.23	1.67	5.20	4.95

Dec.–Jan. 2016–2017

	Bias		RMSE	
	WRF	MPAS	WRF	MPAS
Ross Is.	-.54	-.43	3.42	3.63
East Antarctica	.52	-.04	1.45	1.41
Plateau/ Pole	1.48	.61	2.40	2.55
Queen Maud Land	1.28	.34	2.83	2.53
West Antarctica	.20	.24	2.54	2.68
Antarctic Peninsula	1.18	1.31	3.41	3.79