AMPS UPDATE – AUGUST 2022

Kevin W. Manning and Jordan G. Powers

Mesoscale and Microscale Meteorology Laboratory
National Center for Atmospheric Research
Boulder, Colorado

1. Introduction

The Antarctic Mesoscale Prediction System (AMPS) has provided numerical weather prediction (NWP) guidance to Antarctic weather forecasters for over two decades (Powers et al, 2012). Funded by the National Science Foundation (NSF) Office of Polar Programs (OPP), AMPS operates specifically in support of the weather forecasters of the United States Antarctic Program. AMPS forecast products are openly available on the AMPS web page: https://www2.mmm.ucar.edu/rt/amps.

The main NWP model used in AMPS is the Weather Research and Forecasting (WRF) model (Skamarock, et al., 2021). For use in AMPS, WRF has been adapted and configured for the polar environment, and includes modifications developed under the Polar-WRF effort (Xue et al., 2022) of the Ohio State University Byrd Polar and Climate Research Center. In addition to the WRF Model, AMPS also runs the Model for Prediction Across Scales (MPAS; Skamarock et al, 2012).

2. Recent developments in AMPS

The AMPS team keeps in close coordination with the USAP forecasters, as well as forecasters supporting Antarctic research efforts of other nations. The product suite provided by AMPS is therefore frequently updated in response to requests from forecasters. These requests range from mostly the minor (tuning color scales on plots, additional sites for meteograms, etc.) to occasionally the major (e.g., entirely new capabilities in AMPS). Recently-added products include plots of forecast Integrated Vapor Transport (IVT), now available on all AMPS grids, and a visibility estimate derived from microphysical species in the model grids.

AMPS has also continued developing its cloud-computing capabilities. Cloud computing offers off-site, on-demand computational resources, useful to AMPS as a fallback option in case AMPS's primary computer is undergoing maintenance or experiences other, unplanned, outages. Use of cloud resources in AMPS has been supported by NCAR's Computational and Information Systems Laboratory (CISL).

More effort this past year has been put toward testing and development of the models (WRF and MPAS) used in AMPS, in preparation for a new and more powerful computational platform soon to be available to AMPS.

3. Update on AMPS computing

AMPS runs primarily on NCAR's community supercomputer, named "Cheyenne" and residing at the NCAR-Wyoming Supercomputing Center (NWSC). NSF-OPP contributions to the purchase of the Cheyenne computer have provided AMPS the CPU time on Cheyenne, as well as a high-priority queue for quick start-up of the twice-daily AMPS forecast cycles. With Cheyenne near its end of life, however, NWSC and the NCAR supercomputing community are awaiting delivery of a new supercomputer, named "Derecho". Delivery is now expected near the beginning of 2023, with Derecho available to users later that spring.

Once Derecho is available, AMPS should have roughly two to three times the computing capacity it currently has on Cheyenne. This boost in capacity will allow for some computationally-intensive upgrades to be implemented in AMPS.

A top priority for model upgrades is the microphysical scheme used in WRF. Another enhancement anticipated, this time to MPAS, is a high-resolution mesh. Other enhancements may include (depending on the computational resources still available) additional members for the AMPS ensemble and implementation of an MPAS ensemble. Overall, the new computing power will also likely accelerate a transition from WRF to MPAS.

While updates to the modeling system in AMPS have been delayed by the delayed hardware, initial testing of several of these key upgrades is currently underway.

4. WRF updates in testing

One key model upgrade is with the land surface model (LSM) used within WRF, updating from the Noah LSM to the Noah-MP LSM. The Noah LSM has reached end-of-life, with no new development planned for it and limited ongoing support. The Noah developers are now focusing their efforts on the Noah-MP ("Multi-Physics") replacement for Noah. Noah-MP extends Noah with a greater variety of options for configuring the LSM. Perhaps most appealing for AMPS is the inclusion of a more advanced snowpack model, representing snowpack properties and processes in multiple layers.

The microphysics parameterization in AMPS has also been identified as a component to improve. The current microphysics scheme used in AMPS, the WRF Single-Moment (WSM5) option, was selected largely for its computational efficiency, an important consideration for the timely production of real-time NWP guidance. However, this scheme has also been identified as a factor contributing to a noted deficit of cloud in AMPS. Higher-order (e.g., "double-moment") microphysical parameterizations better represent properties of, and interactions among and within, various microphysical species, yet this more complex representation comes with a substantial computational cost. With new computing resources coming soon, the time is right to evaluate use of a higher-order scheme in AMPS.

To take advantage of recent development in these schemes (Noah-MP LSM and microphysics), these options are tested in an updated version of WRF. AMPS currently runs WRFv3.9.1.1, and is due to be upgraded to a release in the WRFv4 generation. So these three changes (LSM, microphysics, and WRF version) are tested together.

Forecast statistics are available for the current Austral winter season; alternate WRF configurations are run in real-time with a 2-domain configuration. Austral summer statistics will be examined during the upcoming summer season. A small selection of forecast statistics results are presented here.

In the Ross Ice Shelf/Ross Island region and in West Antarctica, surface forecast statistics generally show improvements with the new configurations. Across the continent, a high surface wind speed bias is markedly reduced with the new configurations (Fig. 1). An occasional recurring result is suggested during warmer events, where the configuration with the Morrison microphysics notably outperforms the other two configurations in capturing the higher temperatures (e.g., Fig. 2). For stations on the East Antarctic plateau, the new configurations have generally made a warm bias worse (e.g., Fig. 3). For coastal sites of East Antarctica, results are less clear.

Above the surface, forecast statistics as compared to radiosonde reports (e.g. Fig. 4) primarily show differences in the relative humidity profiles, with the Morrison configuration significantly moister. Frequently noted as well is an improvement in the temperature bias below about 700 hPa, attributable to the use of Noah-MP.

5. WRF/MPAS comparison

AMPS has been testing MPAS as an additional forecast model for several years. At some future point, AMPS is likely to make a full transition to MPAS.

MPAS is similar to WRF in physics, dynamics, and history. The most obvious difference of MPAS from WRF is its use of an unstructured, mostly-hexagonal mesh that can smoothly transition from low-resolution to high-resolution regions. MPAS, as a newer model, offers a more modern software design, better suited to modern supercomputer hardware, including GPU architectures. MPAS development continues with links to larger projects: NCAR's System for Integrated Modeling of the Atmosphere (SIMA) and the multi-agency Joint Effort for Data assimilation Integration (JEDI). These projects offer possibilities for coupled modeling (SIMA) and advanced data assimilation (JEDI) with MPAS.

Use of MPAS in AMPS also presents several challenges. The smooth mesh refinement for high-resolution regions in MPAS (as opposed to WRF's telescoping nest strategy) make the broad range of scales that AMPS encompasses difficult or unfeasible to match in real-time applications without resorting to one-way nests. Options for physical parameterizations are more limited in MPAS, as in contrast WRF has had a fairly wide-open policy of accepting new physics schemes. The effort for AMPS is now porting Noah-MP into MPAS; this work is underway.

Current comparison of MPAS with WRF in AMPS is encouraging. Forecast statistics are available for the current Austral winter season. Sites for statistical comparison are located across the Antarctic continent, in the WRF 8-km grid (AMPS domain 2) and the MPAS 8-km mesh refinement region that spans the continent. A small selection of forecast statistics results are presented here.

Surface temperature and wind statistics are broadly comparable between WRF and MPAS forecasts (Fig. 5), with MPAS showing notable improvement in surface temperature statistics over West Antarctica. Notably, areas where WRF seems to outperform MPAS are areas where the WRF forecasts have high-resolution nests in place. At some sites, MPAS sometimes forecasts significantly colder temperatures than observed and colder than WRF (e.g., Fig. 6), perhaps related to low-wind periods.

Forecast statistics as compared to radiosonde reports (Fig. 7) largely show MPAS largely removes a dry bias in RH. This might be attributable to the use of the Thompson microphysical scheme in MPAS. Other statistics are generally similar between WRF and MPAS.

6. Conclusion

AMPS continues to offer high-quality NWP products to Antarctic forecasters. With new computing resources soon to be available, AMPS will be able to enhance its current capabilities with WRF, and it will explore new configurations with MPAS.

7. References

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. https://doi.org/10.1175/BAMS–D–11–00186.1.

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

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, Z. Liu, J. Berner, W. Wang, J. G. Powers, M. G. Duda, D. Barker, and X. Huang. (2021). A Description of the Advanced Research WRF Model Version 4.3 (No. NCAR/TN-556+STR). https://doi.org/10.5065/1dfh-6p97.

Xue, J., Z. Xiao, D. H. Bromwich, and L. Bai, 2022: Polar WRF V4.1.1 simulation and evaluation for the Antarctic and Southern Ocean. *Front. Earth Sci.* (2022). https://doi.org/10.1007/s11707-022-0971-8.

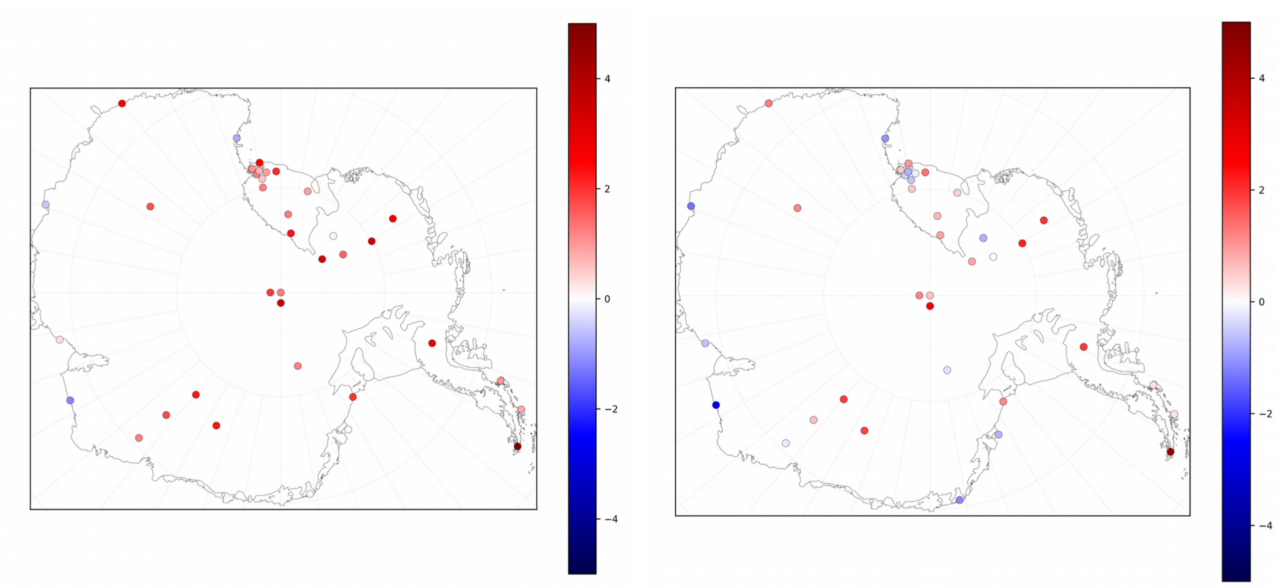

Fig.1. Surface wind speed bias (model minus observations) in m s^{-1} for a) WRF3/Noah/WSM5 and b) WRF4/Noah-MP/Morrison. Statistics computes for hours 12 to 72 of forecasts initialized between 01 Apr 2022 and 24 May 2022.

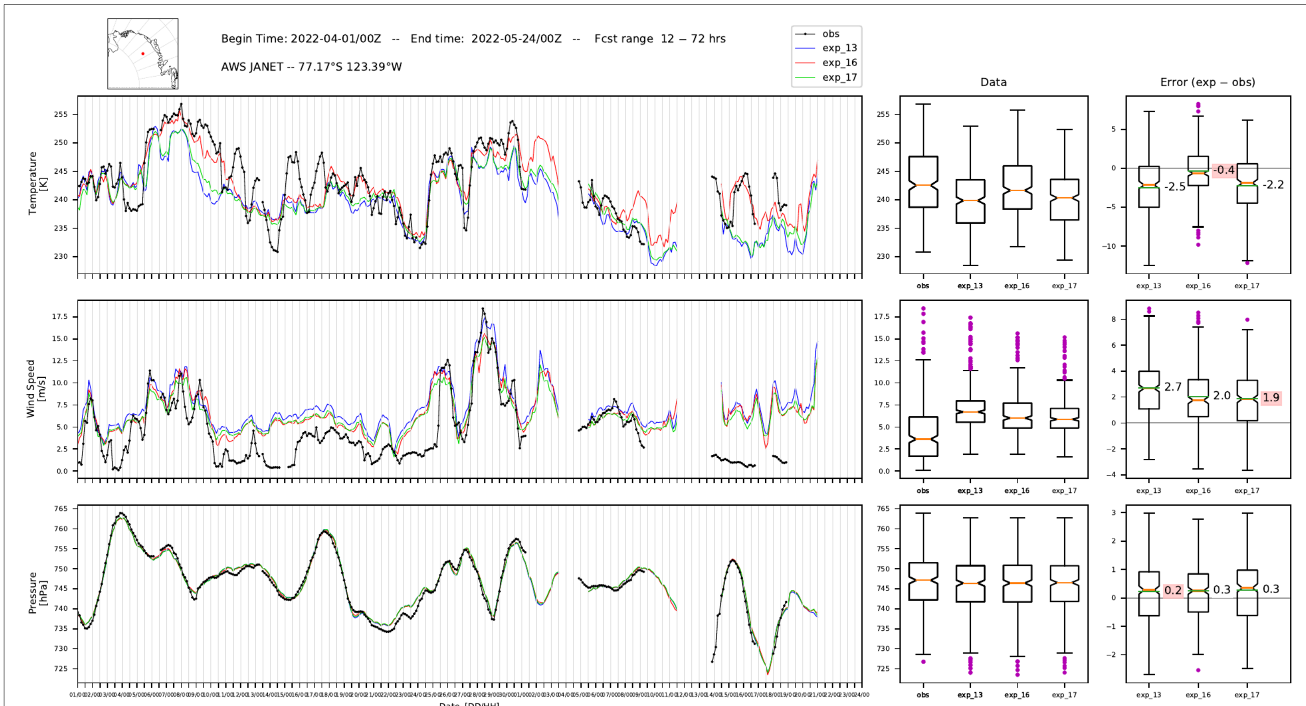

Fig. 2. Forecast statistics for surface temperature, wind, and pressure, at the site of Janet AWS. Black lines: Observations. Blue lines (exp_13): WRF3/Noah/WSM5 experiment. Red lines (exp 16): WRF4/Noah-MP/Morrison experiment. Green lines (exp_17): WRF4/Noah-MP/WSM5 experiment. Statistics computed for hours 12-72 of forecasts initialized between 01 Apr 2022 and 24 May 2022.

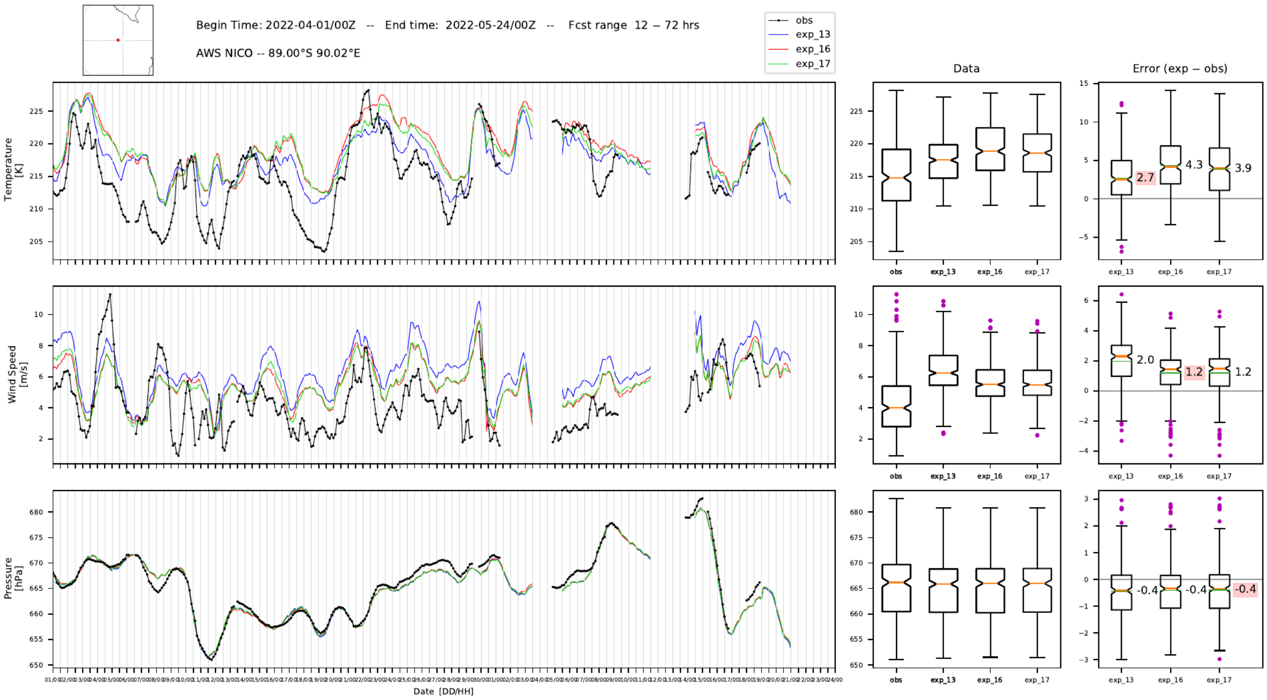

Fig. 3. As for Fig 2, but for Nico AWS.

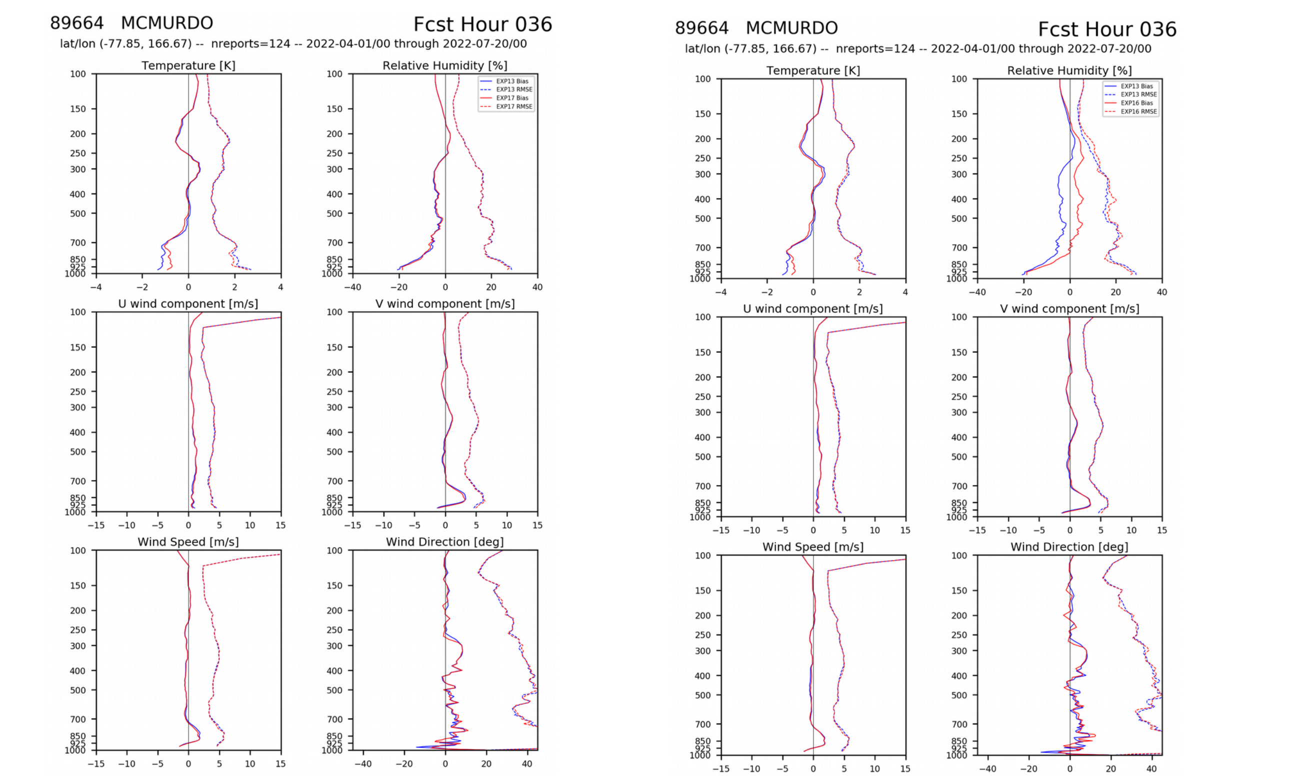

Fig. 4. Statistics (bias and RMSE) for forecast experiments as compared to McMurdo radiosonde reports for forecast hour 36 of forecasts initialized from 01 Apr 2022 to 20 Jul 2022: a) WRF3/Noah/WSM5 experiment in blue, WRF4/Noah-MP/WSM5 experiment in red. b) WRF3/Noah/WSM5 experiment in red, WRF4/Noah-MP/Morrison experiment in red.

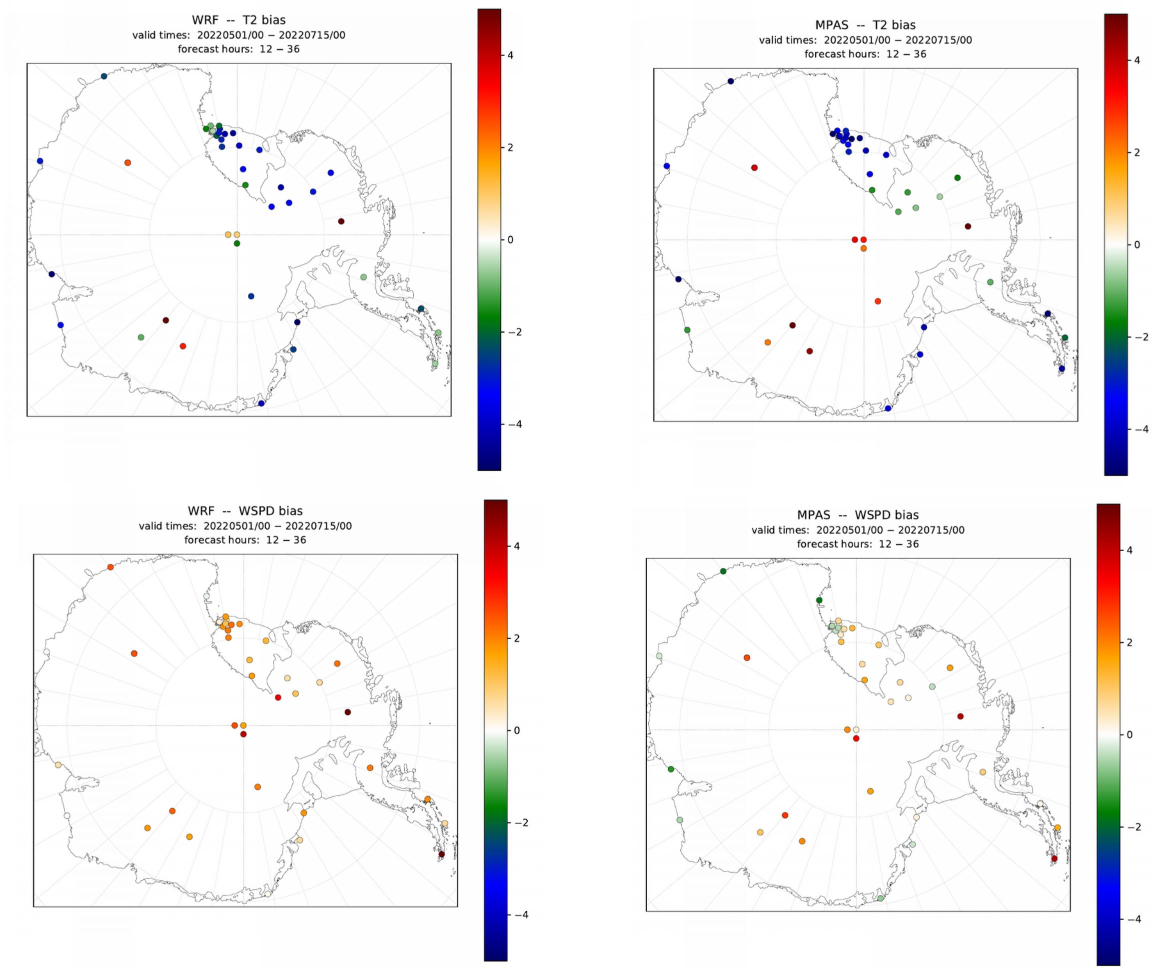

Fig. 5. WRF and MPAS surface temperature and wind bias statistics for forecast hours 12-72, forecasts initialized between 01 May 2022 and 15 Jul 2022. a) WRF Temperature bias. b) MPAS Temperature bias. c) WRF Wind Speed bias. d) MPAS Wind Speed bias.

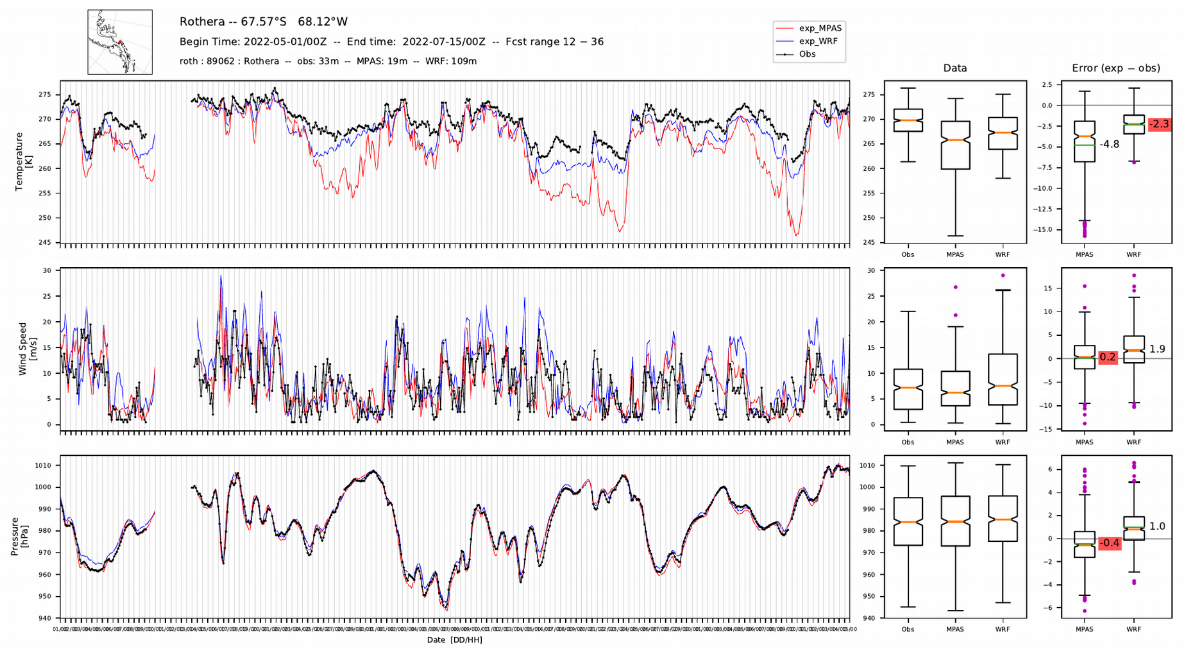

Fig. 6. Forecast statistics for MPAS (red) and WRF (blue) as compared to observations (black) at Rothera. Statistics computed for forecast hours 12-36 for forecasts initialized between 01 May 2022 and 15 Jul 2022.

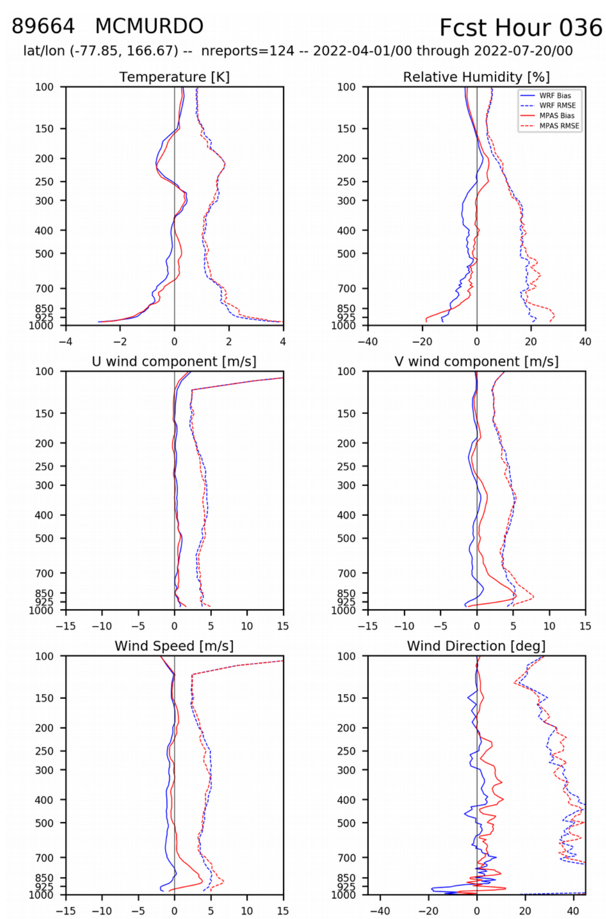

Fig. 7. Bias and RMSE statistics for WRF (blue) and MPAS (red), as compared to McMurdo radiosonde reports. Statistics computed for foreast hour 36 of forecasts initialized between 01 Apr 2022 and 20 Jul 2022.