3.5 APPLICATION OF THE WEATHER RESEARCH AND FORECASTING (WRF) MODEL IN ANTARCTICA

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1. INTRODUCTION

The Antarctic Mesoscale Prediction System (AMPS) (Powers et al. 2003) provides numerical forecasts over Antarctica in support of the flight operations and scientific activities of the United States Antarctic Program (USAP). AMPS is an experimental real-time mesoscale modeling system which since 2000 has used the MM5 (Fifth-Generation Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model [Grell et al. 1995]). While originally developed to improve the guidance available to the USAP forecasters at McMurdo Station (Fig. 2(c)), over the years it has expanded to serve a broad range of international activities (including emergency rescues) across Antarctica. The principals of the AMPS program have been the Mesoscale and Microscale Meteorology Division of the National Center for Atmospheric Research (NCAR) and the Polar Meteorology Group of the Byrd Polar Research Center (BPRC), The Ohio State University. The National Science Foundation has supported the effort. Users may access the range of AMPS products at http://www.mmm.ucar.edu/rt/mm5/amps.

The Weather Research And Forecasting Model (WRF) has been developed as a next-generation mesoscale modeling system designed for both NWP and idealized research simulations. Version 2 of the system (WRFV2) (Wang et al. 2004) was released in June 2004 and represents the first research-quality version of the model. WRFV2 offers a grid nesting capability, which is a must for the multi-domain AMPS configuration. Given that WRF ultimately is to be used in AMPS, and given the maturation of its capabilities, WRF's application over Antarctica has been initiated. WRF has been configured to run over the continent, and this study present some early results. The initial questions to be addressed are how well WRF, in its current state, can capture a given event, how its performance compares to the MM5, and what issues are involved in applying WRF over Antarctica.

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2. CASE BACKGROUND AND MODEL CONFIGURATIONS

2.1 May 2004 Case

The event simulated is that of a severe storm that hit the McMurdo Station area (see Fig. 2(c)) on May 16, 2004. It shut down activities with intense winds that were sustained at over 100 mph (160 kph/44 ms^{-1}) and that gusted to 160 mph (256 kph/71 ms^{-1}). Official anemometers blew away when the wind exceeded 96 mph and 116 mph (43 and 52 ms^{-1}). The winds damaged roofs and peeled siding off of dormitories, and blown-in doors allowed snow to cover the interiors of garage and storage areas. Figure 1 presents time series of average and peak winds in McMurdo over the critical hours. This event offers a test for WRF's ability to simulate extreme polar conditions in the critical McMurdo region, as well as a vehicle for a comparison with the existing MM5 in AMPS.

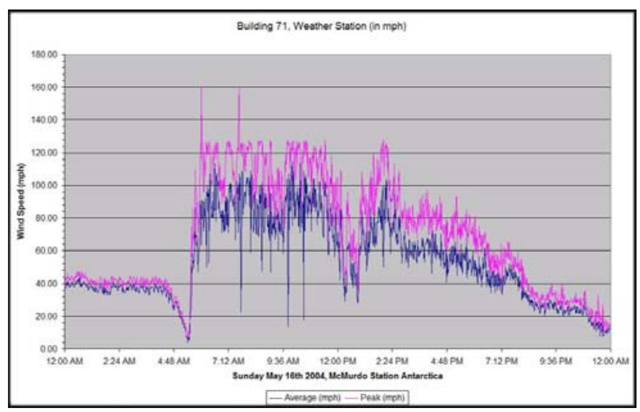


Fig. 1: Wind speeds in McMurdo 12 UTC 15 May–12 UTC 16 May 2004. Blue curve is avg. speed (mph), pink curve is peak speed (mph). Abscissa shows local time, UTC+12 hr.

2.2 AMPS and WRF Configurations

The model currently used in AMPS is the MM5 (Grell et al. 1995). The MM5 configuration (and that used for WRF, see below) features five forecast grids, with horizontal spacings of 90 km, 30 km, 10 km (3 domains), and 3.3 km. The 90-km domain (Fig. 2(a)) includes New Zealand, as Christchurch is the origin of flights to McMurdo. Covering Antarctica, the 30-km domain (Fig. 2(b)) reflects the users' desire that the entire continent be contained in a mesoscale grid with better resolution and topographic data than available in other models when the system was created. The original 10-km grid (Fig. 2(b),(c)) in AMPS was designed to cover the western Ross Sea/McMurdo Station region with the highest resolution practicable in light of the original computer resources.

For focussing on conditions over the South Pole (for the several hundred flights flown there annually), another 10-km grid was applied to that area (Fig. 2(b)). And, because of the complex topography of the Antarctic Peninsula, and the relatively coarse resolution of it afforded by the 30-km grid, a 10-km nest was laid over the Peninsula in September 2003 (Fig. 2(b)). Lastly, to bring the flows and atmospheric structures around Ross Island into better focus, a 3.3-km grid was nested within the 10-km McMurdo/Ross Is. domain (Figs. 2(c),(d)). This is the highest resolution available for the McMurdo vicinity from any real-time NWP system.

All nesting is two-way interactive. The vertical resolution reflects 32 σ-levels between the ground and the model top at 50 hPa. Model initializations are at 0000 and 1200 UTC. Forecast lengths are currently 120 hours for the 90-km and 30-km grids[1] and 36 hours for the 10-km and 3.3-km grids.

The MM5's initial and boundary conditions are derived from NCEP's (National Centers for Environmental Prediction) Global Forecast System (GFS) model. The GFS first-guess field is reanalyzed with the available observations using a 3-dimensional variational (3DVAR) data assimilation system (Barker et al. 2003). The data within the domains used in 3DVAR includes reports from manned surface stations, surface automatic weather stations (AWSs), upper-air stations, and satellite cloud-track winds. AMPS also ingests sea ice data daily from the National Snow and Ice Data Center (NSIDC) for initializing its fractional sea ice depiction.

AMPS employs the "Polar MM5" (Bromwich et al 2001; Cassano et al. 2001). This is a version of the model which has been developed by BPRC and contains modifications to a number of physical schemes to improve their performance in the polar regions and to capture features unique to extensive ice sheets, such as steep coastal margins and lack of conventional soil and vegetation types. The Polar MM5 modifications include: (i) accounting for a separate sea ice category with specified thermal properties; (ii) representing fractional sea ice coverage in grid cells, and (iii) using the latent heat of sublimation for calculations of latent heat fluxes over ice surfaces, and assuming ice saturation when calculating surface saturation mixing ratios over ice. While a future effort will be to implement the polar modifications into WRF, there is no polar suite in WRF at this time, and the simulation here has used the standard WRF available to the community.

The domain configuration for WRF reflects that of the AMPS MM5. As in Fig. 2, there are a total of six domains, with grid sizes of 90 km, 30 km, 10 km (3 domains), and 3.3 km. There are 32 vertical levels, with a smaller vertical spacing in the PBL, similar to AMPS's distribution. The model top is 50 hPa. One difference from the AMPS runs is that all WRF domains are started upon initialization time (hour 0), while in the AMPS MM5 the 10-km and 3.3-km grids are started at hour 6 (due to real-time constraints). In addition, in this test of WRF there is no 3DVAR reanalysis.

Although WRF is compared to the MM5, this initial implementation of WRF is not meant to duplicate the physics of the AMPS model. As mentioned above, it cannot, as the polar physics are not in WRF at this time. In this simulation, WRF employs a 5-species microphysics scheme (WRF single moment scheme), the Eta PBL scheme, the Noah Land Surface Model, and the Kain-Fritsch cumulus parameterization. As in the MM5, the 3.3-km grid is run fully explicit. Sea ice is assumed at water points where the skin temperature (obtained from the GFS first-guess) is less than 271.4K; the capability to ingest the NSIDC data is not yet in WRF.

[1] The 90- and 30-km grid forecast lengths were 72 hrs in May 2004.

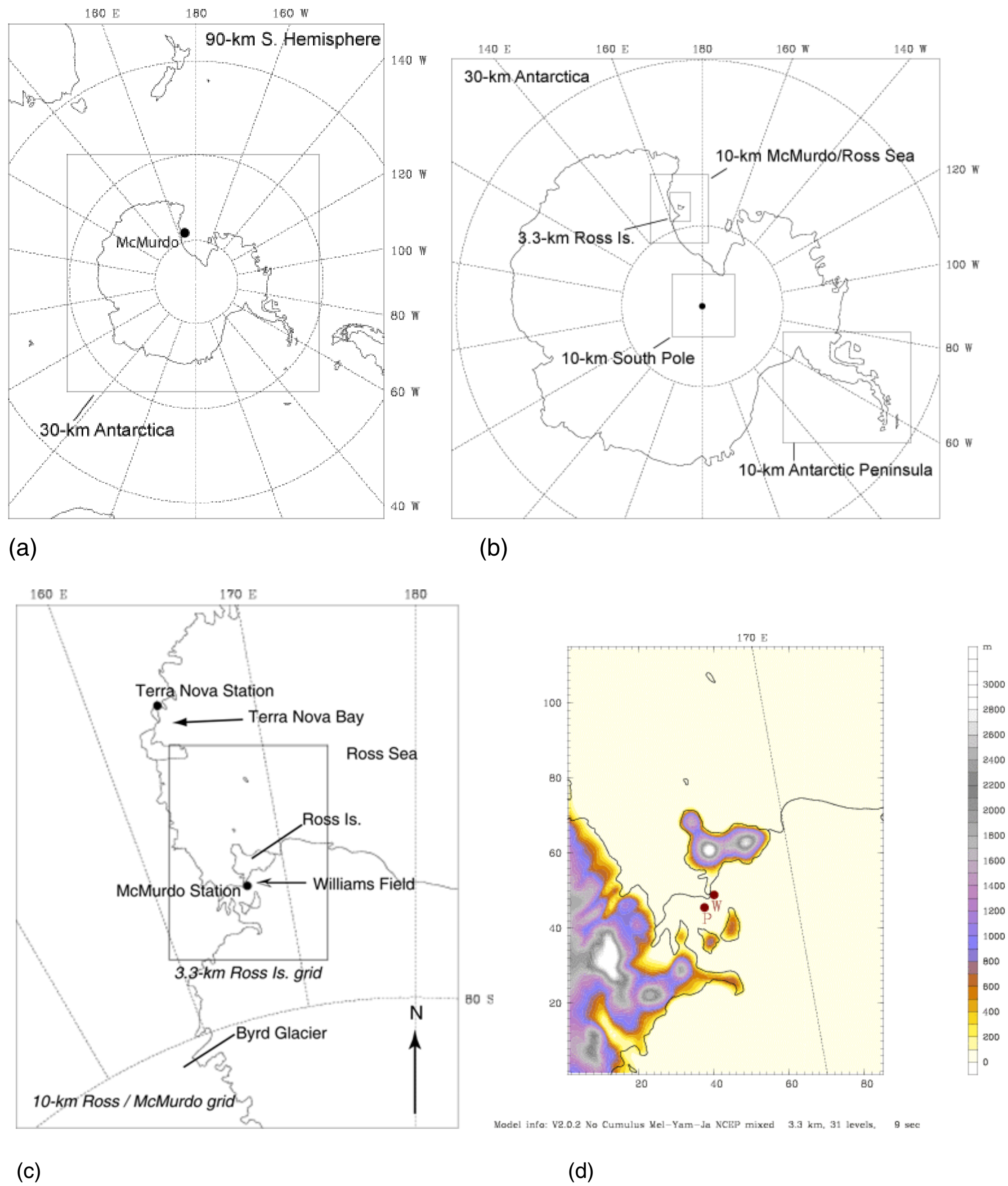


Fig. 2: AMPS domains and Antarctic locations. (a) 90-km grid. (b) 30-km grid (outer frame) with 10-km McMurdo/Ross Sea grid, 10-km South Pole grid, and 10-km Antarctic Peninsula grid. 3.3-km Ross Is. grid marked within 10-km Ross Sea domain. (c) 10-km McMurdo/Ross and 3.3-km Ross Island grids. (d) Terrain (*m*) (shaded, scale at right) on 3.3-km Ross Is. domain. "P" marks location of Pegasus North; "W" marks location of Williams Field.

3. RESULTS

Surface observations from the McMurdo area (Fig. 2(c)) for the 15 May episode indicate the passage of a deep (<960 hPa) low through the region, with minimum pressures occurring from 12–16 UTC 15 May. Satellite imagery does not reveal a consistently coherent cloud signature for the system, which appears to have traveled westward from the Siple Coast across the Ross Ice Shelf and then through the Ross Island region .

Figures 3(a)–(c) suggest the track of the system in the GFS-based analyses for 0000 UTC 15 May–1200 UTC 16 May[2]. At 00 UTC 15 May, a 942 hPa low sits in western Marie Byrd Land just northeast of the Siple Coast (Fig. 3(a)). By 1200 UTC the center has tracked across the Ross Ice Shelf to a position about 375 km SSE of McMurdo. The system then moves northeastward, propagates inland south of Ross Island over the Transantarctic Mountains, and appears to merge with another area of low pressure over the northern Victoria Land coast (Fig. 3(c)).

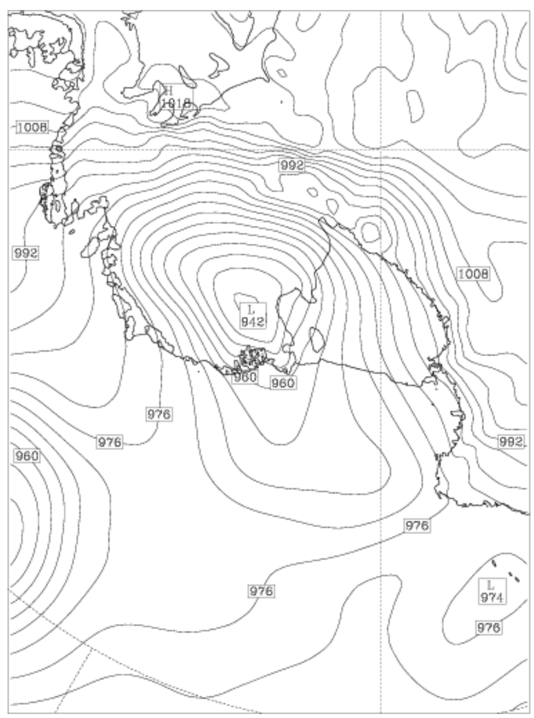
WRF captures movement of the system across the Ross Ice Shelf. Figures 4(a)–(c) show the hr 0, hr 12, and hr 24 SLP forecasts from the 30-km grid (shown because of its coverage of the entire path of the cyclone). The low's intensity on the shelf at 1200 UTC is reasonably simulated in the 942 hPa center seen in Fig. 4(b). For example, the WRF minimum SLP at Gill AWS on the shelf (position shown in Fig. 4) was 948.8 hPa at 0900 UTC. The observed SLP at that time was 943.6 hPa, with Gill experiencing minimum pressures of 943–945 hPa from 07–12 UTC as the low passed.

Figure 5 presents the observed and WRF-simulated SLP traces for Pegasus North AWS (approx. 11 km SSW of McMurdo; located in Fig. 1(d)). Other McMurdo-area traces are similar, with a broad trough indicated. Comparing the timing of the Gill minimum SLPs with the later times of the minima at the McMurdo/Ross Island-area AWSs (e.g., Fig. 5) reveals consistency with the westward traverse of the system. At Pegasus, both the WRF and observed minima are approximately 959 hPa. While the simulation's exact minimum occurs slightly earlier (3 hrs) than observed, the trough is broad and of the same duration in both. The AMPS and observed SLP traces for Pegasus in Fig. 6 show that AMPS also is early on the passage of the low, although there is good agreement after the period of minimum pressures.

The strongest winds buffeted McMurdo from 18 UTC 15 May–00 UTC 16 May. This is seen in Fig. 1. In the 1-hourly output from the models, neither WRF nor the MM5 (AMPS) approach the extreme observed winds (peak: 71 ms^{-1}; avg: 40 ms^{-1})for grid points around McMurdo. Figure 7 compares the observed and WRF winds at the helicopter pad in town. The observations cease at 1830 UTC after readings of 42 ms^{-1} and 32 ms^{-1}, while the last plotted hourly value in Fig. 6 is 18.5 ms^{-1}. WRF underpredicts the winds during this period, and later peaks with hourly values of about 20 ms^{-1}.

Figure 8 offers a wind comparison at Pegasus North, as this is a location less sensitive to the lack of resolution of the topography around McMurdo proper. The maximum winds at Pegasus occurred from 20–23 UTC 15 May (Fig. 8). The WRF simulation shifts this to 00–04 UTC 16 May and underpredicts the maxima. Note that the values in Fig. 8 are at corresponding times on the hour: for these the highest observed speed was 35 ms^{-1}, while the simulation yields 23 ms^{-1}.

Figure 9 shows the observed 15-min data plotted with the AMPS output. There is no WRF comparison for the 15-min maximum observed value of 39.6 ms^{-1}, plotted in Fig. 9, as the model data were saved only hourly. The AMPS MM5 forecast (Fig. 9) generally mirrors the timing of the observed peaks, but it underpredicts the speeds at Pegasus. The MM5's maximum was approximately 27 ms^{-1}.



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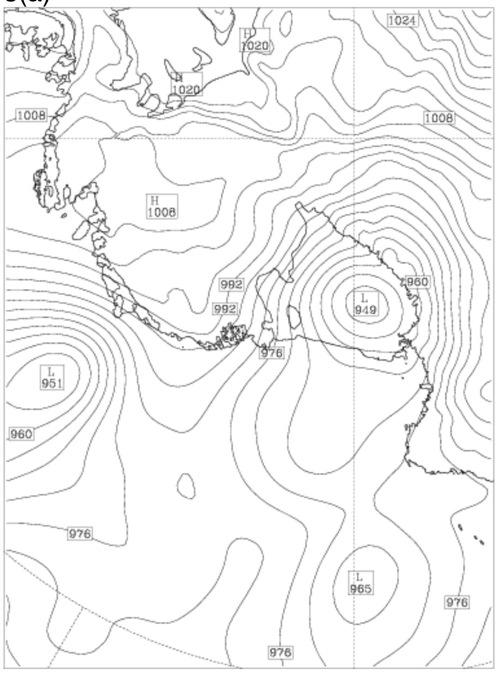
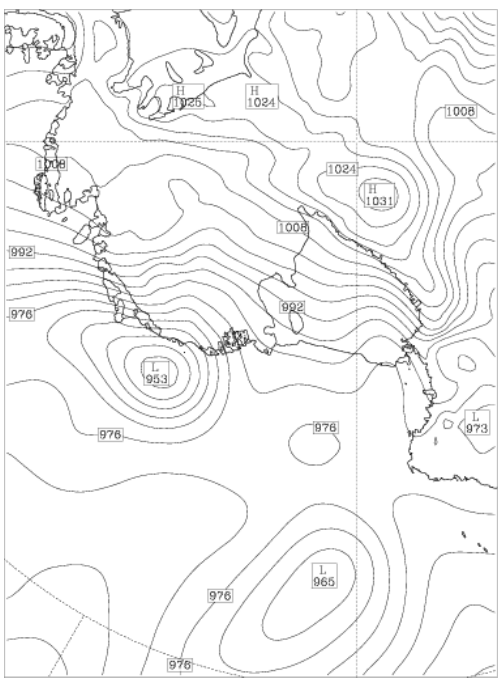
[2] These are the initial analyses from AMPS based on the hour 0 analyses of GFS during the period.

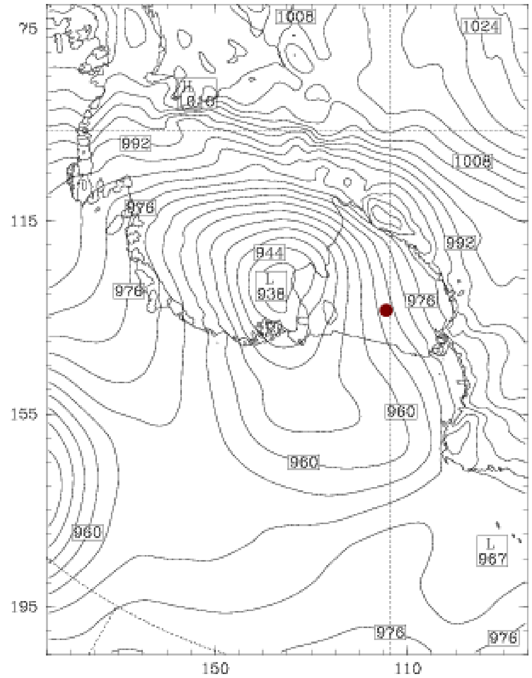
3(a)



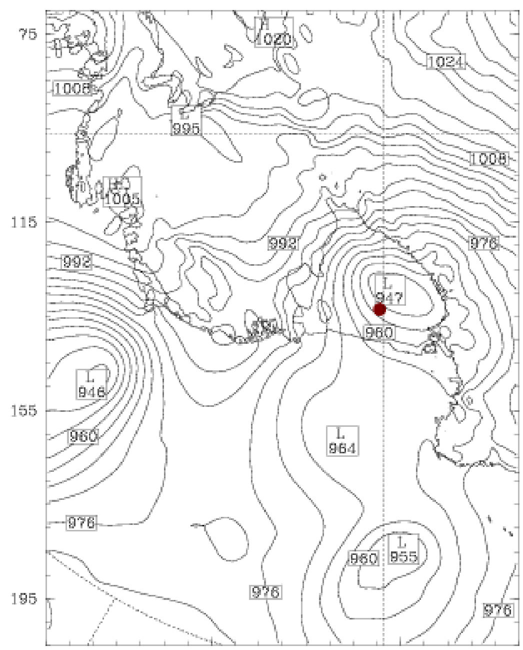
3(b)



3(c)

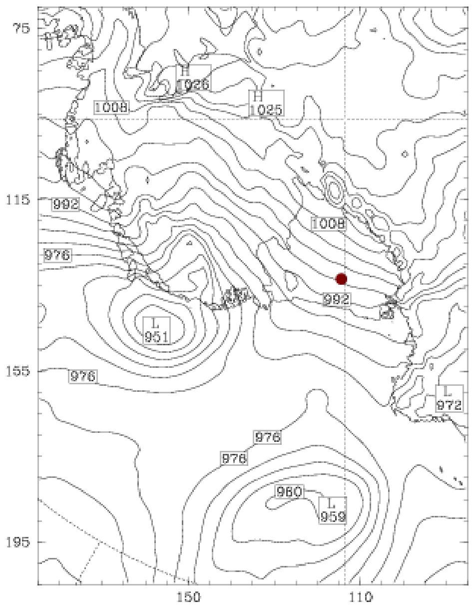


4(a)



4(b)

Fig. 3 SLP analyses from AMPS initializations, based on GFS. Interval= 4 hPa. Window of full 30-km domain shown. (a) 0000 UTC 15 May 2004. (b) 1200 UTC 15 May 2004. (c) 0000 UTC 16 May 2004.



4(c)

Fig. 4: SLP forecasts from WRF hrs 0, 12, and 24. Interval= 4 hPa. Window of full 30-km grid shown. Red dot marks location of Gill AWS. (a) 0000 UTC 15 May 2004. (b) 1200 UTC 15 May 2004. (c) 0000 UTC 16 May 2004.

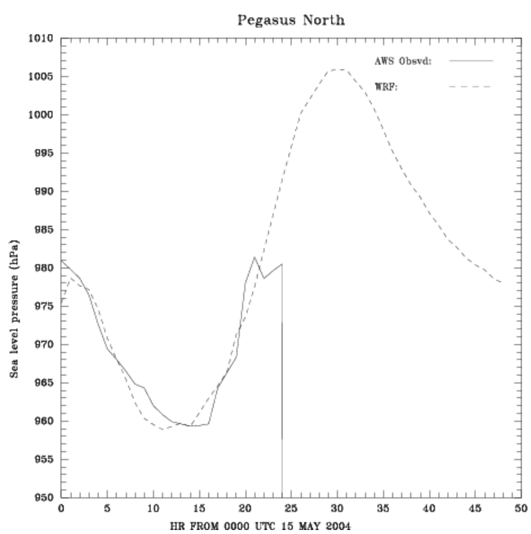


Fig. 5: Observed (solid) v. WRF (dashed) sea level pressure (hPa) at Pegasus North AWS site (see Fig. 1(d) for location). Abscissa shows time in hours from 00 UTC 15 May. WRF simulation initialized at 00 UTC 15 May 2004 and 3.3-km output plotted. The observed trace drops off after 23 UTC 15 May as the AWS record ends after this time.

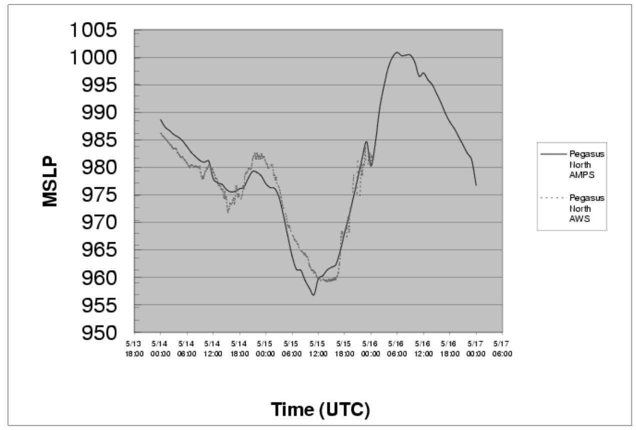


Fig. 6: Observed (dashed) v. AMPS MM5 (solid) sea level pressure (hPa) at Pegasus North AWS site (see Fig. 1(d)). AMPS simulation initialized at 00 UTC 14 May 2004. The observed trace stops at 00 UTC 16 May as the AWS record ends after this time.

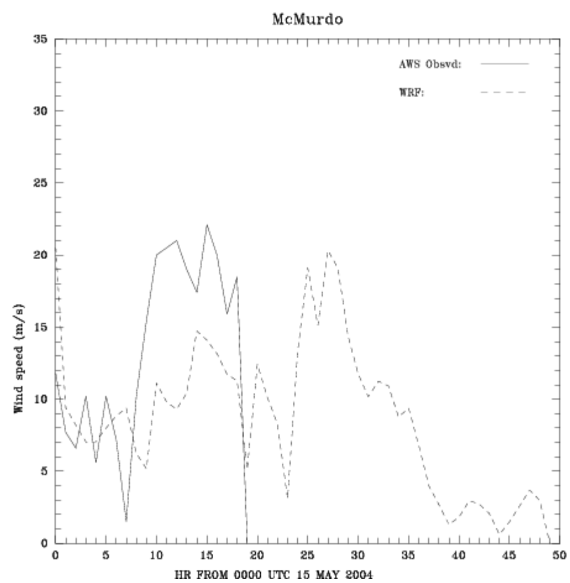


Fig. 7: Observed (solid) v. WRF (dashed) wind speed (ms^{-1}) at McMurdo (see Fig. 2(c)) Helicopter Pad. Abscissa shows time in hours from 00 UTC 15 May. WRF simulation initialized at 00 UTC 15 May 2004 and 3.3-km output plotted. The observed trace drops off after 18 UTC 15 May as the AWS record ends after this time.

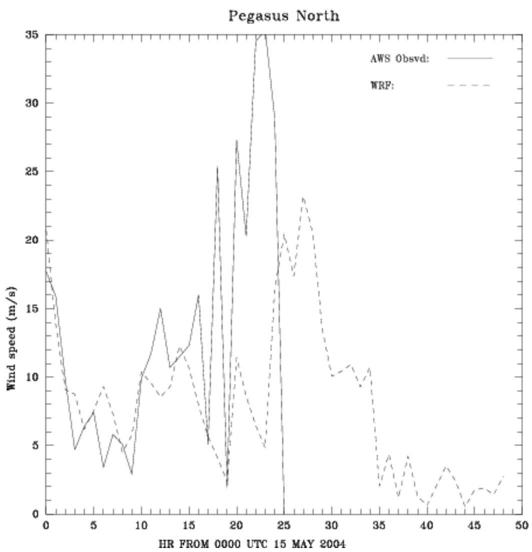


Fig. 8: Observed (solid) v. WRF (dashed) wind speed (ms^{-1}) at Pegasus North AWS site (see Fig. 1(d)). Abscissa shows time in hours from 00 UTC 15 May. WRF simulation initialized at 00 UTC 15 May 2004 and 3.3-km output plotted. The observed trace drops off after 00 UTC 16 May as the AWS record ends after this time.

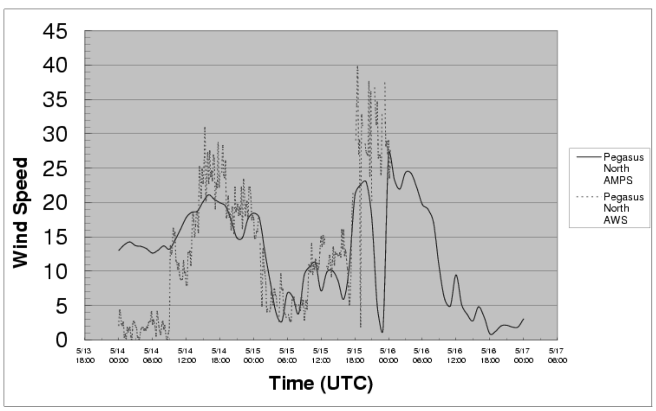


Fig. 9: Observed (dashed) v. AMPS MM5 (solid) wind speed (ms^{-1}) at Pegasus North AWS site (see Fig. 1(d)). AMPS simulation initialized at 00 UTC 14 May 2004. The observed trace stops at 2345 UTC 15 May as the AWS record ends after this time

4. SUMMARY AND CONCLUSIONS

In the setting of the Antarctic Mesoscale Prediction System (AMPS), the Weather Research and Forecasting (WRF) model has been applied for the first time to Antarctica. AMPS, which has been providing real-time NWP guidance using the MM5, will transition to WRF over the next year. An initial simulation of the severe storm that struck McMurdo on 16 May 2004 using WRF V2.0 has begun to explore the ability of this new mesoscale model to capture Antarctic weather.

WRF simulates the synoptic evolution of the surface low in the event, and it compares fairly well with surface analyses and satellite imagery. WRF's depiction of the pressure trends around McMurdo associated with the passage of the low are realistic, as are the MM5's. Both models however, fail to capture the extreme intensity of the winds at McMurdo. Across the area, the maximum wind speeds are underforecast in both WRF and the MM5. This may reflect subsynoptic differences in the tracks of the model and actual lows, viz. the location of the pressure gradient relative to McMurdo. In addition, the complexity of the topography of the McMurdo vicinity is still not completely resolved by even the 3.3-km grid. The impact in this case of the lack of polar modifications in WRF is unknown at this time. No overwhelming differences are seen between WRF and the MM5 in this event.

Overall analysis on this case will continue in order to identify more completely WRF's strengths and weaknesses in recreating the event. The implementation of the polar modifications into WRF is a future effort, and this case will likely be a test vehicle to assess their impact.

ACKNOWLEDGMENTS

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