ON THE IMPACT OF MODIS WINDS ON THE ARW 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 currently uses 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 (see Fig. 2(c)), over the years AMPS has expanded to serve a broad range of international activities (including emergency rescues) across Antarctica. The principals of the AMPS program have been 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 Advanced Research WRF (ARW) reflects a configuration of the Weather Research and Forecasting (WRF) modeling system designed for both NWP and idealized research simulations. The ARW Version 2 is based on WRF Version 2 (Wang et al. 2004) and employs the ARW dynamics solver (originally referred to as the “Eulerian mass” core or solver). Given that the ARW will replace the MM5 in AMPS, its application over Antarctica has been initiated. The ARW has been configured to run over the continent, and this study examines its performance in the May 2004 McMurdo windstorm. The initial questions to be addressed are the ARW’s performance in capturing the event (compared to the MM5) and the impact of the assimilation of MODIS (Moderate-Resolution Imaging Spectroradiometer; Key et al. 2003) polar winds on the ARW simulations.

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 meant that snow covered 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 ARW’s ability to simulate extreme polar conditions in the critical McMurdo region and provides a vehicle for assessing the potential for the use of MODIS winds in model initialization.

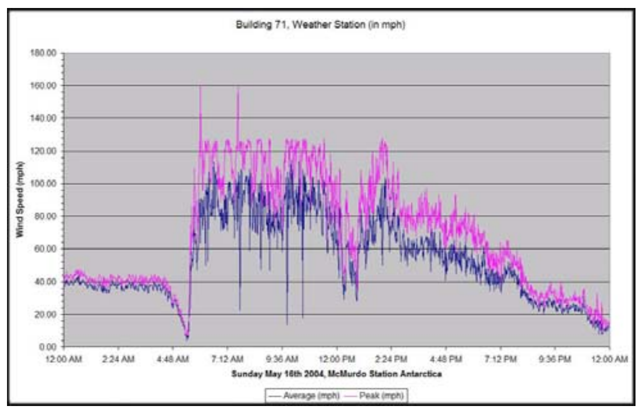


Fig. 1: Wind speeds in McMurdo 12 UTC 15 May–12 UTC 16 May 2004. Blue curve is avg. speed (mph); pink curve is peak speed (mph). Abscissa shows local time, UTC+12 hr.

2.2 AMPS and ARW Configurations

The model currently used in AMPS is the MM5 (Grell et al. 1995). The MM5 configuration (and that used for the ARW, 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. The 30-km domain (Fig. 2(b)) covers the continent, and the original 10-km grid (Figs. 2(b),(c)) covers the western Ross Sea/McMurdo Station region.

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. While a future effort will be to implement the polar modifications into the ARW, there is no polar suite in it at this time.

The domain configuration for the ARW consists of the 90-km and 30-km grids, along with the10- and 3.3-km western Ross Sea and Ross Island grids (Figs. 2(a),(c),(d)). The 10-km South Pole and Antarctic Peninsula grids are not employed in this study, as the focus is on the Ross Sea sector. There are 32 vertical levels, with a narrower 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 ARW 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). The starting time for all simulations considered here is 0000 UTC 15 May 2004.

A number of sensitivity test are performed with ARW to investigate the impact of data assimilation. The WRF variational data assimilation system (WRF-Var) is used. WRF-Var currently employs a 3DVAR approach and will be referred to as simply "3DVAR" in the following discussions. The specific question is that of the impact of assimilating MODIS polar wind retrievals (Key et al. 2003). These winds are derived from the polar-orbiting Terra and Aqua satellites and have shown promise in improving polar forecasts (see Key et al. (2003); Bormann and Thépaut (2004)). They are computed from tracking cloud features detected by the infrared (IR) and water vapor (WV) channels of the MODIS instrument. The data assimilated by 3DVAR in the simulations include the standard AMPS observational input (described above) and MODIS data. The following tests are performed.

CTRL— no 3DVAR/no data assimilation
ALL— 3DVAR using standard AMPS data plus all MODIS data
MODQC— 3DVAR using standard AMPS data plus filtered MODIS data
EXMOD— 3DVAR using standard AMPS data only

The difference between ALL and MODQC is that for MODQC only a subset of MODIS observations is used. The filtering follows the suggestion of Key et al. (2003). Over the ocean the following measurements were retained: IR above 700 hPa and WV above 550 hPa. Over land the following were retained: IR and WV above 400 hPa. This is motivated by Key et al.'s (2003) noting of the possibility of poorer-quality retrievals for the given channels below the given levels. Thus, the experiments probe the impact of 3DVAR on the forecasts with standard observations only (EXMOD), with all MODIS (ALL), and with filtered or quality-controlled (QC'd) MODIS (MODQC).

In these simulations the ARW employs a 5-species microphysics scheme (the WRF single moment 5-class (WSM-5) scheme), the Eta PBL scheme, the Noah Land Surface Model, and the Kain-Fritsch cumulus parameterization (90-, 30-, 10-km domains). As in AMPS, 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 the ARW.

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

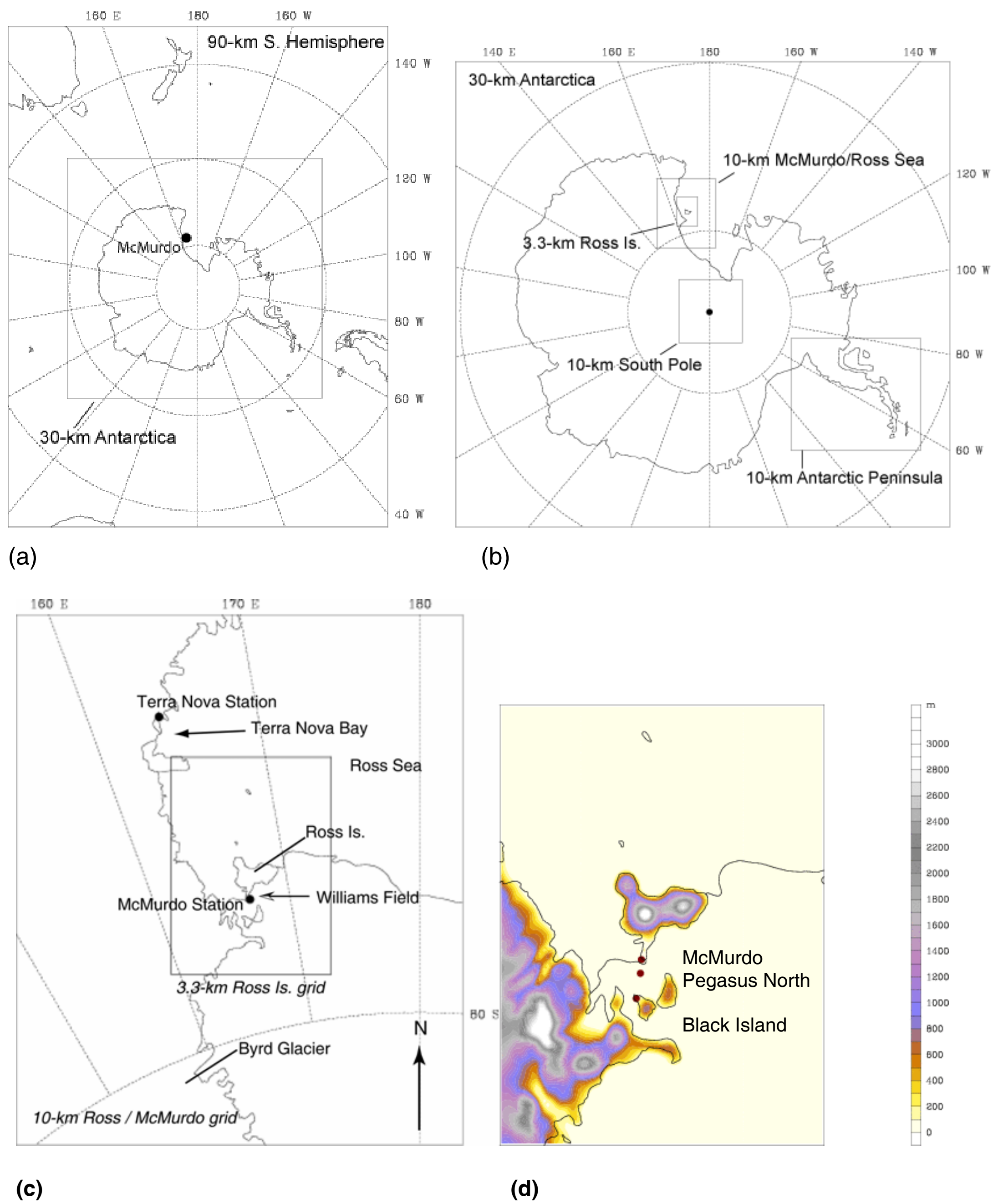


Fig. 2: AMPS domains and Antarctic locations. (a) 90-km grid. (b) 30-km grid (outer frame) with 10-km McMurdo/Ross Sea grid, 10-km South Pole grid, and 10-km Antarctic Peninsula grid. 3.3-km Ross Is. grid marked within 10-km Ross Sea domain. (c) 10-km McMurdo/Ross and 3.3-km Ross Island grids. (d) Terrain (*m*) (shaded, scale at right) on 3.3-km Ross Is. domain. Dots marks observation/AWS sites. North to south: McMurdo Station, Pegasus North, and Black Island..

3. RESULTS

Surface observations from the McMurdo area for the 15 May episode reflect the passage of a deep (<960 hPa) low through the region, with minimum pressures occurring from 12–16 UTC 15 May. Satellite imagery indicates that the system traveled westward from the Siple Coast across the Ross Ice Shelf and through the Ross Island region.

Figure 3 presents the track of the low, with the positions determined through analysis of satellite imagery. Late on 14 May the low is in western Marie Byrd Land. From 0700–1000 UTC 15 May it crosses the Siple Coast and moves westward across the Ross Ice Shelf. At 1500 it has approached the Date Line and begins a northward turn. McMurdo experienced the strongest winds from 1800 15 May –0000 UTC 16 May, and the low's positions during this period are marked in red in Fig. 3. The system passes east of Ross Island, presenting a situation in which the strong pressure gradient associated with the low will be yield intense southerly flow through the McMurdo region. After 0000 UTC 16 May, the system weakens and moves northward to the Terra Nova Bay region, where it persists but spins down.

Both the ARW and the AMPS MM5 simulate the transit of a deep low across the ice shelf. Figure 4 presents the track of the system from the AMPS MM5 forecast (0000 UTC 15 May initialization). The MM5 evolution involves a stalling of the system at 1800 UTC and a rapid filling from that point onward. Although the low persists north of Ross Island and seems to reflect the observed track northward (Fig. 3), the system is not significant during those hours.

Figures 5(a)–(d) present the ARW experiment results. Overall, MODQC yields the low track and evolution closest to observation. The system turns northward more consistently with observation compared to the other runs, and positions the system off of Ross Island's east end at 2300–0000 UTC. All of the ARW runs (as well as the MM5 forecast) tend to drive the system westward too rapidly, and do not accurately capture the northward turn. The worst in this respect is CTRL (Fig. 5(a)), which lacks any data assimilation. ALL suffers compared to both MODQC and EXMOD, indicating that MODIS observations should be filtered prior to assimilation, and that if not, it is preferable to exclude the observations. Analyses of winds through the McMurdo region (described below) confirm this result (see, e.g., Fig. 8).

Figure 6 presents the observed, AMPS MM5, and ARW EXMOD sea level pressure (SLP) traces for Pegasus North AWS (approx. 11 km SSW of McMurdo; located in Fig. 1(d)). EXMOD is compared to the MM5 here as it has the same data assimilated as in AMPS— the standard AMPS observations. Other McMurdo-area traces are similar, with a broad trough indicated. Both the ARW and observed minima are approximately 959 hPa. The RMSE for the ARW is a bit higher following the low passage, but the ARW better times the minimum. AMPS is early on the passage of the low.

The strongest winds buffeted McMurdo from 1800 UTC 15 May–0000 UTC 16 May. While both the ARW and the MM5 in general do not capture the full intensity at points around McMurdo, the ARW outperforms the MM5. Figure 7 presents the results from AMPS, EXMOD, and MODQC. The maximum winds at Pegasus occurred from 2000–2300 UTC 15 May (Fig. 7), with a peak of 35.3 ms^{-1}. The MM5 (Fig. 7(a)) predicts a maximum of 21.6 ms^{-1}. The ARW, in contrast, produces maxima of 31.5 ms^{-1} in EXMOD (Fig. 7(b)) and 36.6 ms^{-1} in MODQC (Fig. 7(c)). Thus, with the same data assimilated, the ARW better reproduces the event, while the assimilation of additional, filtered MODIS winds further improves the forecast. MODQC's timing of the peak is also excellent. The ALL and CTRL experiments (not shown) underpredict (at 24.6 ms^{-1} (CTRL) and 29.3 ms^{-1} (ALL)) and delay the onset of the strongest winds.

The wind event was marked by intense southerlies through the McMurdo area and around Ross Island as the low influenced the region. Figure 8 shows ARW's simulation of such conditions, and reveals the impact of applying the filter to the MODIS observations prior to ingest. Figure 8(a) presents the surface wind fields (shaded) around Ross Island at hour 23 of ALL. Figure 8(b) shows the same for MODQC. Shading of medium blue and darker corresponds to winds of 25 ms^{-1} (approx. 50 kts). The significantly greater strength of the flow and of the southerlies in the McMurdo vicinity is obvious in MODQC. MODQC shows >35 ms^{-1} southerlies through McMurdo, while the flow in ALL is approximately 13 ms^{-1}. The greater strength of the event in MODQC is reflected in the faster flow enveloping Ross Island as a whole (cf. Figs. 8(b),(a)). The low tracking to the east of Ross Island and the system not having filled as rapidly are the reasons for the improved results. Similar plots (not presented) show that EXMOD more accurately captures the event than ALL, but not quite as good as MODQC.

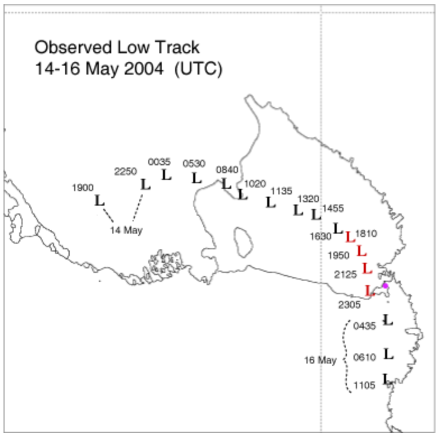


Fig. 3: Track of low forcing the May windstorm. Times (UTC) of central position of low (marked "**L**") indicated. Red "L" reflects period of the wind event at McMurdo.

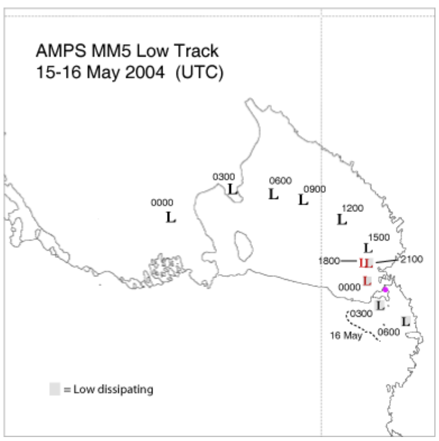
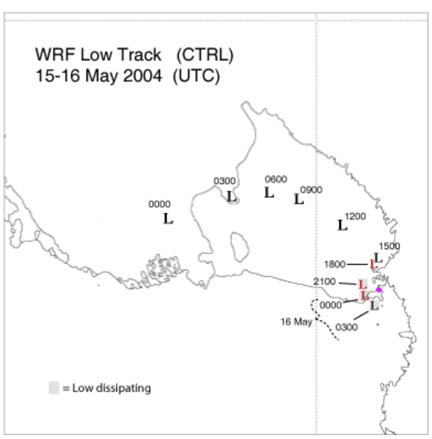
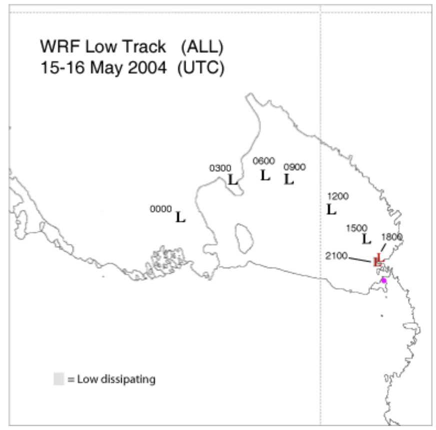


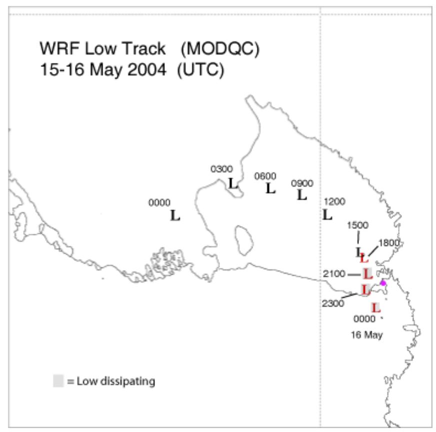
Fig. 4: MM5 low track. Times and dates as in Fig. 3.



5(a)



5(b)



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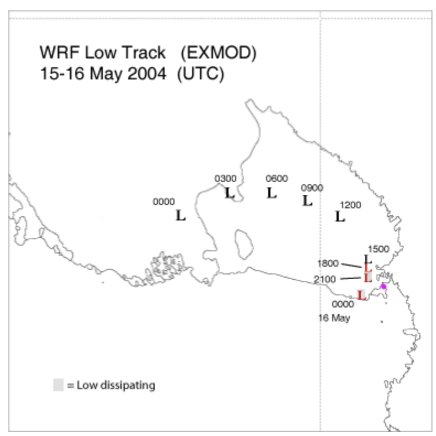
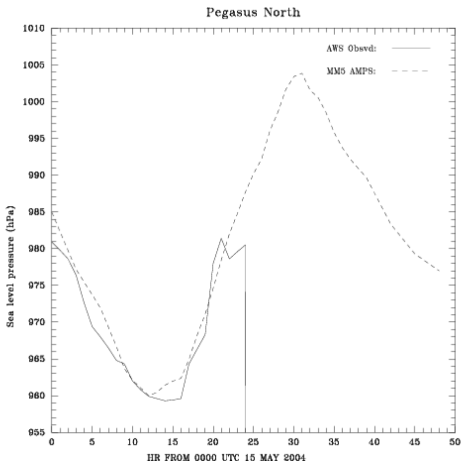
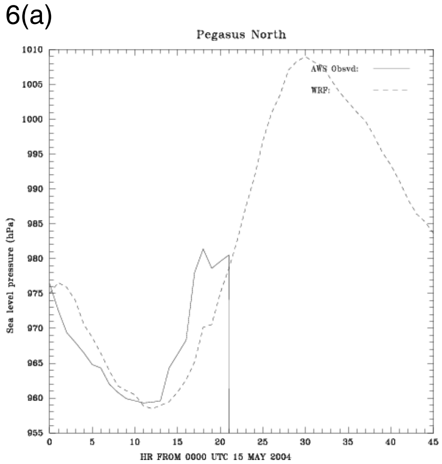


5(d)

Fig. 5: Tracks from ARW experiments. Times and dates as in Fig. 3. (a) CTRL. (b) ALL. (c) MODQC. (d) EXMOD.

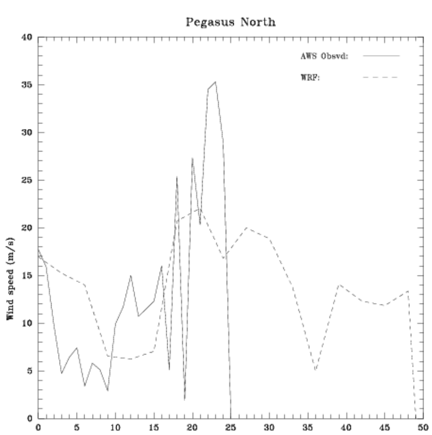


6(a)

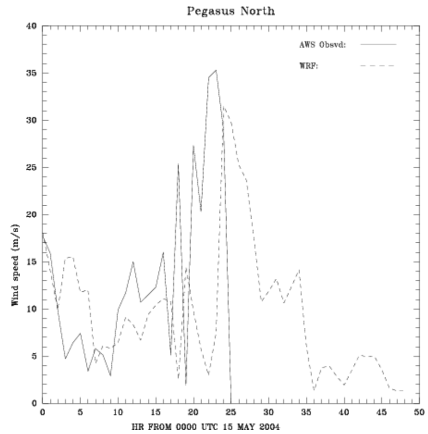


6(b)

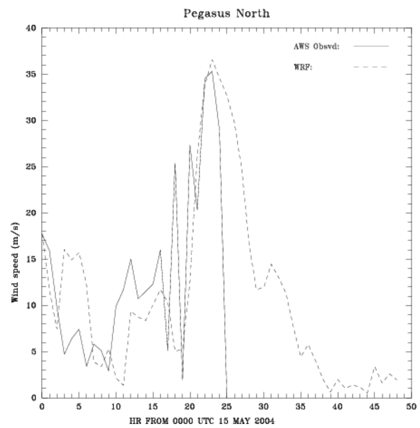
Fig. 6: Observed and model sea level pressure (hPa) at Pegasus North AWS site (see Fig. 1(d)). The observed trace stops at 00 UTC 16 May as the AWS record ends after this time. (a) Obsv'd (solid) v. AMPS MM5 (dashed). (b) Obsv'd (solid) v. ARW EXMOD (dashed).



7(a)

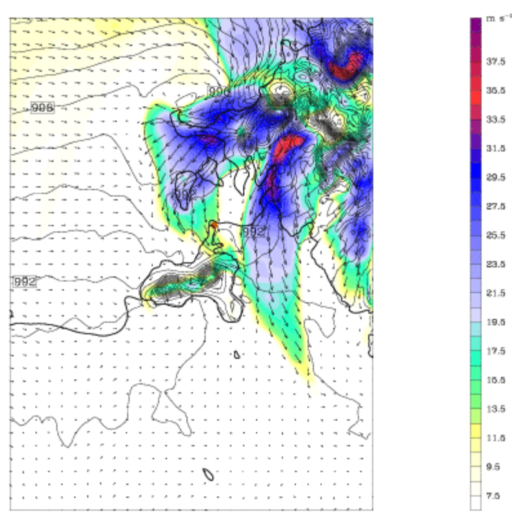


7(b)

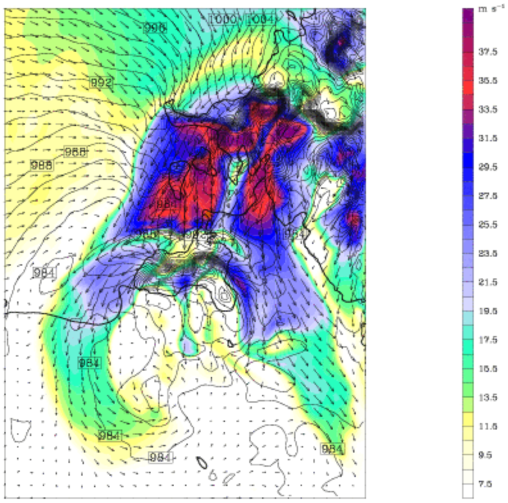


7(c)

Fig. 7: Observed (solid) v. MM5 and ARW (dashed) wind speed (ms^{-1}) at Pegasus North. Abscissa shows time in hours from 00 UTC 15 May.The observed trace drops off after 18 UTC 15 May as the AWS record ends after this time. (a) Obsv'd v. MM5. (B) Obsv'd v. EXMOD. (c) Obsv'd v. MODQC.



8(a)



8(b)

Fig. 8: Surface winds from the ARW ALL and MODQC experiments for hour 23 (2300 UTC 15 May) from 3.3-km domain. Vectors indicate wind direction. Wind speed shaded; medium blue shading approximately 25 ms^{-1}. Sea level pressure contoured; interval= 1 hPa. (a) All. Orange dot marks McMurdo. (b) MODQC.

4. SUMMARY AND CONCLUSIONS

In the setting of the Antarctic Mesoscale Prediction System (AMPS), the Advanced Research WRF (ARW) system has been applied for the first time to Antarctica. AMPS, which has been providing real-time NWP guidance using the MM5, will transition to ARW over the next year. An initial simulation of the severe storm that struck McMurdo on 16 May 2004 using ARW Version 2.0 explores its ability to capture Antarctic weather.

The ARW simulates the synoptic evolution of the surface low, and it compares fairly well with surface observations and satellite imagery. The ARW's depiction of the pressure trends around McMurdo associated with the passage of the low are realistic, as are the MM5's. The ARW, however, significantly improves over the MM5 in capturing the intensity of the winds in the McMurdo region. Both models tend to move the system too rapidly westward across the Ross Ice Shelf and then proceed to fill the system in the Ross Island region.

It is found that the use of MODIS polar winds can improve the simulation of this event. The application of a filter, however, is necessary. This approach should be taken when the ARW is ultimately implemented in AMPS. Lastly, from the results presented here, as well as from other testing of the effects of moist physics (not shown), it is apparent that for this case the impact of the polar modifications is negligible. However, this does not contraindicate their future implementation in the ARW.

ACKNOWLEDGMENTS

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