REAL-TIME MM5 FORECASTING FOR ANTARCTICA

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1. BACKGROUND

In May 2000 the Antarctic Weather Forecasting Workshop (AWFW) was held at the Byrd Polar Research Center of the Ohio State University to review the state of the science of weather forecasting over the Antarctic. It was formally recognized there that guidance from numerical forecast models was critical to forecasters at McMurdo Station (see Figs. 1,2). Furthermore, while a few models (*e.g.*, AVN, NOGAPS) were yielding products covering Antarctica, their guidance was felt of limited utility. The reasons included: (i) horizontal resolution inadequate to resolve mesoscale features crucially affecting short-term (6–24 hr) forecasting and flight operations, (ii) inadequate representation of physical properties unique to the Antarctic troposphere and boundary layer, and (iii) poor representation of Antarctic topography and surface features.

A key conclusion from the AWFW was thus that focussed efforts were needed to improve NWP for the Antarctic through an Antarctic mesoscale modeling initiative (Bromwich and Cassano 2000). Foremost among numerous recommendations to NSF for improving NWP capabilities for the U.S. Antarctic Program (USAP) was the implementation of a higher-resolution Antarctic forecast domain (*i.e.*, grid sizes $\leq$ 15 km) for the 2000/2001 USAP field season.

In light of these needs, an experimental **A**ntarctic **M**esoscale **P**rediction **S**ystem (AMPS) using the MM5 (Grell *et al.* 1995) has been developed. Since October 2000, AMPS has been furnishing twice-daily numerical guidance for both Antarctica and the McMurdo Station area. Personnel being served have been research planners, polar meteorologists at McMurdo and elsewhere, and flight forecasters responsible for supporting flights between Christchurch, New Zealand and McMurdo Station.

The goals of the AMPS project include the following:

- to provide real-time mesoscale and synoptic forecast products for Antarctica, tailored to the needs of field forecasters at McMurdo Station;
- to improve and incorporate physical parameterizations suitable for the Antarctic region into the MM5; and
- to stimulate close collaboration between forecasters, modelers, and researchers by making the forecast products and the model output available to the community through a web interface, public archive, and workshop/conference interactions.

The project has completed its first field season, and the system was eagerly received by the forecasting contingent in McMurdo. In addition, AMPS forecasts were used during the April 2001 South Pole rescue of U.S. scientist Dr. Ronald Shemenski, and AMPS products are being displayed for support of the GLOBEC field study (southern Antarctic Peninsula region) through 2002.

2. THE FORECASTING SYSTEM

The MM5 in AMPS is configured with three domains with horizontal grid sizes of 90 km, 30 km, and 10 km (Figs. 1,2). The coarsest grid includes New Zealand, as Christchurch is the origin of flights to McMurdo. Covering Antarctica, the 30-km domain reflects the users' desire that the entire continent be under a mesoscale grid with better resolution, topographic data, and landuse information than in other available models.

The 10-km grid was designed to cover the McMurdo Station area with the highest practicable resolution. A grid spacing of near 10 km was necessary for improved prediction in the vicinity of Ross Island (see Fig. 2), and, more specifically, to resolve the local, observed mesoscale features. There are 29 σ-levels, with the model top at 100 mb. All nesting is two-way.

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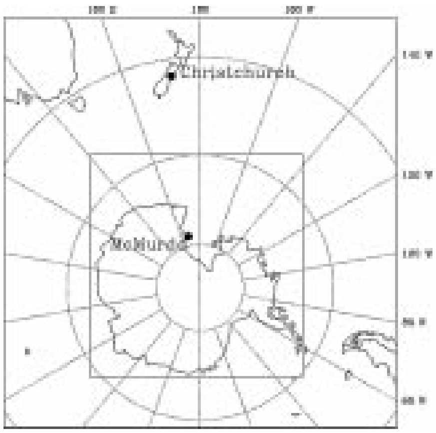

Figure 1. 90-km and 30-km AMPS domains. Inner frame bounds area of 30-km grid. Dots locate Christchurch, New Zealand and McMurdo Station.

MM5 initial and boundary conditions are derived from NCEP's global AVN model. A backup system allows the IC's and BC's to come from real-time global runs of the MM5 at NCAR. The first-guess field is reanalyzed with available observations via Little-r. The data in the Antarctic region include reports from manned surface stations, surface automatic weather stations (AWSs), and upper-air stations over the continent and beyond; some satellite-derived wind measurements are also available. In the future it is envisioned that 3DVAR will be employed. Initializations are at 0000 and 1200 UTC, with the 10-km grid being turned on at six hours. Forecast lengths are 48 hours for the 90-km and 30-km grids and 24 hours for the 10-km grid.

Modifications have been made to a number of physical schemes in the MM5 (Version 3.4) to improve their performance in the polar region. The resulting package is called the "Polar MM5" and includes:

Figure 2. 10-km AMPS domain. McMurdo Station indicated.

(i) accounting for a separate sea ice category with specified thermal properties; (ii) using the latent heat of sublimation for calculations of latent heat flux over ice surface, and assuming ice saturation when calculating surface saturation mixing ratios over ice; and (iii) modifiying the CCM2 radiation scheme to include the radiative properties of clouds as determined from the microphysical species. A number of other tunings have also been implemented, and the impact of the polar package is being examined.

Users may access a range of products via the web at http://www.mmm.ucar.edu/rt/mm5/amps. To support subsequent verification work and research of scientists, students, and forecasters, the forecasts are being archived.

3. CASE RESULTS

An example of AMPS's performance is here considered with a forecast event of 14–16 January 2001. This complex case involves two mesoscale lows in the western Ross Sea, and the analysis described here follows Bromwich *et al.* (2001). A northern low (L_N in Fig. 3) developed northeast of the Terra Nova Bay region prior to 00 UTC 14 Jan and tracked generally south-southwestward. Travelling to the north side of Ross Island, it became indistinguishable after 06 UTC 15 Jan. Meanwhile, from about 03 UTC 14 Jan another low formed west of Ross Island (L_S in Fig. 3). This center strengthened on its eastward track south of Ross Island, and then veered southeastward over the Ross Ice Shelf after about 00 UTC 15 Jan. These systems are of interest because they produced snow, low clouds, and low visibility at McMurdo Station, and caused conditions to deteriorate to close to flight operation limits. Figure 3 presents the best estimates of the actual low tracks (boldface).

In contrast to the analyses, AMPS developed only one low during this period. This organized in Terra Nova Bay and moved southward. Figure 3 presents the three 10-km grid forecast tracks (solid) for the period, with the corresponding grid start times printed (14/06 UTC, 14/18 UTC, 15/06 UTC) and the 6-hourly forecast positions marked with dots. In agreement with the analyses, the model low did align with L_S, move and intensify over the Ross Ice Shelf, and track east-southeastward.

Figure 4a compares the observed and model (10-km) time series for AWS station 112 (located in Fig. 3). The 24-hr period shown runs from 1800 UTC 14 Jan. While the model reproduces the magnitude and timing of the diurnal trend, there is a warm bias.

Aggregate error statistics for AWSs 112 and 111 (located in Fig. 3) have been calculated for the three

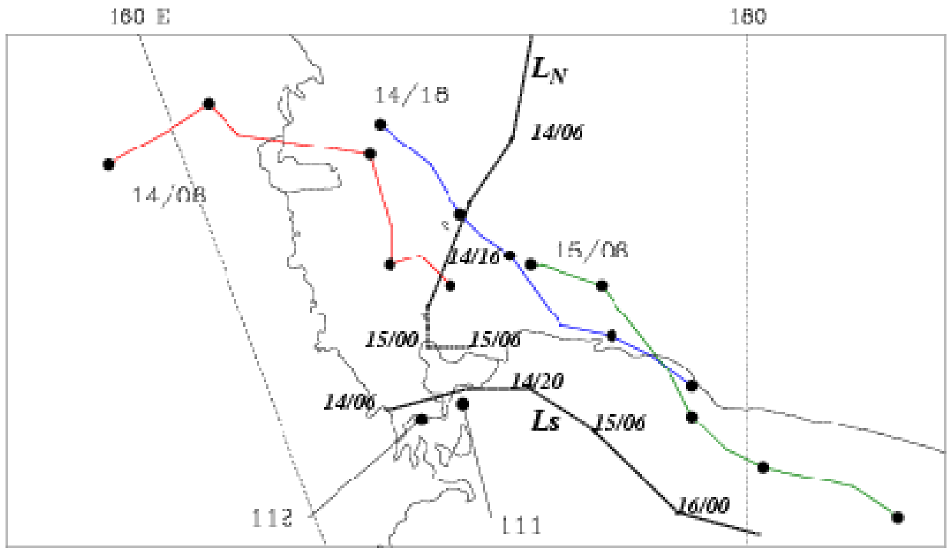

Figure 3. Tracks of analyzed and 10-km AMPS low centers. Track of actual lows (L_N, L_S) dashed, with times at various positions indicated in bold italic (*14/06*= 14 Jan 0600 UTC). The three forecast tracks (solid) begin at 0600 and 1800 UTC 14 Jan and 0600 UTC 15 Jan 2001. Dots on forecast tracks mark positions every six hours.

forecasts reflected in Fig. 3. The statistics reflect hourly model/observation comparisons, and Tab. 1 presents the averaged AMPS results. For temperature (T), the biases and RMSEs are: AWS 112— bias= +2.1 C, RMSE= 2.4 C; AWS 111— bias= +2.9 C, RMSE= 3.2 C. The warm bias indicated in Fig. 4a is thus confirmed for the event as a whole.

Both sites also evince a moist bias, with dewpoint temperatures averaging 1.2–2.6 C higher than observation (Tab. 1). Wind speeds (WS) are somewhat overestimated by the model: the biases +2.0 and +1.4 ms^{-1} at AWSs 112 and 111, respectively. This is due in part to the relatively smooth model terrain and limited resolution. Also, the model winds considered are at the lowest half-sigma level, about 27 m AGL. Wind speed RMSE's average 2.4 ms^{-1} at 112 and 111, compared to mean observed wind values during the forecast period of about 1.9 ms^{-1} at the sites.

To assess value added by AMPS over other numerical guidance historically available for Antarctica,

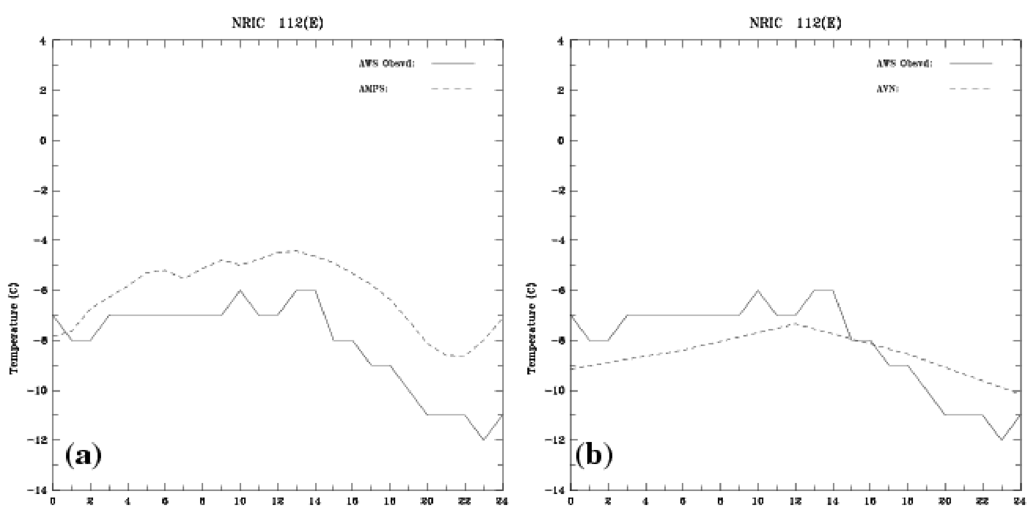

Figure 4. Time series of observed and model surface temperature at location of AWS 112. Temperatures in °C. Time period shown is the 24-hr 10-km grid forecast period beginning 1800 UTC 14 Jan 2001. Observed solid; model (AMPS, AVN) dashed. (a) Observed v. AMPS. (b) Observed v. AVN.

AMPS (10-km)

	AWS 112			AWS 111		
	MAE	Bias	RMSE	MAE	Bias	RMSE
T	2.2	2.1	2.4	2.9	2.9	3.2
Td	2.3	1.8	2.6	4.0	3.8	4.4
Sfp	2.0	1.3	2.4	4.7	4.7	5.2
WS	2.1	2.0	2.5	1.9	1.4	2.3

AVN

	AWS 112			AWS 111		
	MAE	Bias	RMSE	MAE	Bias	RMSE
T	1.4	-0.79	1.7	0.98	0.55	1.2
Td	3.5	-3.5	3.8	1.2	.007	1.5
Sfp	19.0	-19.0	19.0	13.6	-13.6	13.6
WS	7.5	7.5	8.0	6.7	6.7	7.1

Table 1: Error statistics for AMPS 10-km grid and AVN forecasts during the event period at AWSs 112 and 111. AMPS values are derived from 24-hr forecasts commencing at 0600 and 1800 UTC 14 Jan, and 0600 UTC 15 Jan 2001. AVN values are derived from corresponding 24-hr periods of forecasts initialized at 0000 and 1200 UTC 14 Jan and 0000 UTC 15 Jan 2001. T= temperature; T_d= dewpoint temperature; Sfp= surface pressure; WS= wind speed. MAE= mean absolute error; RMSE= root mean square error.

time series comparisons and error statistics for NCEP AVN runs have been produced. These have used values from 6-hourly output from the 1° AVN data available, interpolated to the MM5 90-km grid. Figure 4b presents the AVN and observed temperature time series for AWS 112 for the period 1800–1800 UTC 14–15 Jan. In contrast to the AMPS result (Fig. 4a), the 6-hourly data do not reveal more than a crude diurnal trend. While the actual measures of error are less (Tab. 1), this is at the expense of details on the timing and magnitude of temperature changes.

Table 1 presents the averaged statistics for the three 10-km AMPS and corresponding AVN runs. Both temperature RMSEs and biases are smaller in the AVN than AMPS forecasts. As for dewpoints, the 10-km AMPS errors show improvements over the AVN for station 112, but not for station 111. As for wind speeds, these are significantly overpredicted in the AVN, with the biases positive and a few times the magnitudes of those in AMPS. This is likely due to the much smoother topography in the AVN and to the effects of it on circulations around Ross Island and the other land masses in the area. Lastly, the AVN shows strong negative biases in surface pressure (13–19 mb). This simply reflects the fact that whereas the actual elevations of stations 112 and 111 are 2 m and 20 m, respectively, the heights of the sites for the AVN data (regridded using a 30 min topographic database) are 166 m and 146 m. In contrast, the 10-km AMPS has station heights of 10 m and 11 m, respectively.

4. SUMMARY

In a collaborative effort, NCAR and the Byrd Polar Research Center have designed and implemented a real-time MM5 system (AMPS) for Antarctica. Review of a forecast event from the first season shows mixed success. In this western Ross Sea cyclogenesis, AMPS had difficulty in reproducing multiple mesolows. This in significant part is due to the absence of signals of the systems in the initial conditions, which in turn reflects a lack of upper-level data with which to correct the background field. Additional issues to be investigated are a possible warm bias in surface temperatures in the McMurdo area and the quantification of forecast benefits from the suite of polar physics modifications used.

The plan for AMPS is systematic forecast verification and solicitation of user recommendations. These suggestions, and the Polar MM5 modifications derived from the verification work, will be implemented for the second field season in 2001–2002.

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