J1.5 MESOSCALE MODELING OF THE ANTARCTIC ATMOSPHERE

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1. INTRODUCTION

Based on years of effort with mesoscale modeling in polar regions by the Polar Meteorology Group of the Byrd Polar Research Center at The Ohio State University, the Pennsylvania State University (PSU)-National Center for Atmospheric Research (NCAR) Fifth-generation Mesoscale Model (MM5, Grell et al. 1994) has been modified for use in polar regions (referred to as the Polar MM5). The key modifications are:

- Revised cloud / radiation interaction
- Modified explicit ice phase microphysics
- Optimized turbulence (boundary layer) parameterization
- Implementation of a sea ice surface type
- Improved treatment of heat transfer through snow / ice surfaces.

The nonhydrostatic Polar MM5 is now available as options in the public release version of MM5 (v3.5 and later) from NCAR. Here the applications of Polar MM5 in Antarctica are reviewed.

Case studies, extended validations, and climatological investigations have demonstrated that Polar MM5 performs with skill on time scales from three hourly to interannual, both in the continental interior and coastal environment (Bromwich et al. 2001, Cassano et al. 2001, Bromwich et al. 2003, Guo et al. 2003, Monaghan et al. 2003, Bromwich et al. in press). Skill decreases for areas with complex (primarily coastal) terrain with spatial scales well below the model resolution.

Recent Polar MM5 developments include the formulation of a new upper boundary condition that effectively damps the high wave activity of the Antarctic coastal environment and notably improves AMPS forecasts (Wei et al., submitted). Efforts are underway to enhance the calculation of the horizontal pressure gradient force for improved simulations of surface winds in areas of complex terrain and to alter the cloud-radiation interactions to eliminate residual biases in the surface temperature prediction.

Fig. 1. Twin Otter aircraft on the snow at Amundsen-Scott Station, South Pole, during the rescue in April 2001 (from Powers et al. 2003).

2. APPLICATIONS OF POLAR MM5

2.1 *Real-time forecasting*

In response to the need for improved weather prediction capabilities in support of the U.S. Antarctic Program's field operations, the Antarctic Mesoscale Prediction System (AMPS) was implemented in October 2000 (Powers et al. 2003). AMPS employs the Polar MM5 and is a collaborative effort between the National Center for Atmospheric Research (NCAR) Mesoscale and Microscale Meteorology group and the Polar Meteorology Group.

Forecasters use the model output to meet the operational and logistic needs of the United States Antarctic Program (USAP) air operations. AMPS simulations are performed at the NCAR twice per day, and cover progressively finer domains ranging from 90 km (covering most of the Southern Hemisphere) to 3.3 km (covering the region immediately surrounding McMurdo Station, the base of USAP operations).

Powers et al. (2003) discuss two noteworthy international rescue efforts in which AMPS provided invaluable forecast guidance. In April 2001 AMPS forecasts were used to predict a window of calm winds so that a Twin Otter aircraft could land at the South Pole to evacuate an employee with pancreatitis (Fig. 1). This was the furthest into autumn an aircraft has ever landed at the South Pole due to the near 24-hour darkness and extreme cold temperatures that prevail for six months out of the year. Since the Powers et al (2003) publication, the system has provided guidance for medical evacuations in September 2003 from South Pole and in April 2004 from McMurdo.

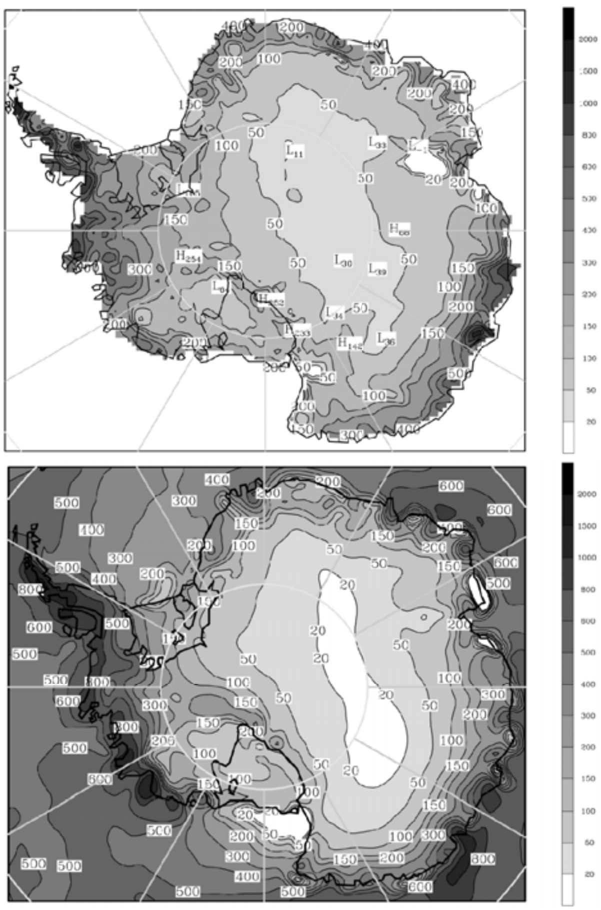

Fig. 2. Top: Vaughan et al. (1999) long-term annual accumulation distribution. Bottom: Polar MM5 annual P-E from July 1996-June 1999 (from Bromwich et al. (2004a). Units are mm yr^{-1} water equivalent.

2.2 *Simulating Antarctic Surface Mass Balance*

Estimates of Antarctic surface mass balance are still not well constrained; approximations from various observational, remote sensing, and modeling techniques range from 133 mm yr^{-1} to 186 mm yr^{-1}. The current best estimate of Antarctic accumulation from observations is 166 mm yr^{-1} (Vaughan et al. 1999).

The Polar MM5 can provide a detailed depiction of accumulation and its components over Antarctica. The two main components are precipitation (P) and sublimation (E). Other processes are also important, and In the next year drift snow processes such as redistribution and sublimation of airborne particles will also be included in the Polar MM5 formulation.

Bromwich et al. (2004a) study the spatial and temporal variability of Antarctic precipitation and accumulation. Fig. 2 compares the Polar MM5 P-E to the accumulation map of Vaughan et al. (1999). All major features are reproduced by the Polar MM5. Both maps show large values along the coast of East and West Antarctica, and over the Antarctic Peninsula, and small amounts over the plateau of East Antarctica and around the Ross and Filchner/Ronne ice shelves, and Lambert Glacier. The spatial distribution of the modeled P-E distribution is in good qualitative agreement with the accumulation analysis of Vaughan et al. (1999). Several differences also exist. The primary difference is that the areas enclosed by the 20 and 50 mm yr^{-1} contour lines in the simulated field are larger than those shown by Vaughan et al. (1999) and the simulated P-E values in the enclosed areas are smaller than the climatologically depicted annual accumulation from Vaughan et al. (1999). The reasons for this are discussed in Bromwich et al. (2004a).

2.3 *Studies of Climate Variability*

Bromwich et al. (2004b) employ the Polar MM5 to examine the El Niño-Southern Oscillation (ENSO) modulation of Antarctic climate for July 1996-June 1999, which is shown to be stronger than for the mean modulation from 1979-1999 and appears to be largely due to an eastward shift and enhancement of convection in the tropical Pacific Ocean. Their study using Polar MM5 provides a more comprehensive assessment than can be achieved with observational datasets.

The most pronounced ENSO response is observed over the Ross Ice Shelf-Marie Byrd Land and over the Weddell Sea-Ronne/Filchner Ice Shelf. In addition to having the largest climate variability associated with ENSO, these two regions exhibit anomalies of opposite sign throughout the study period, which supports and extends similar findings by other investigators (e.g., Yuan and Martinson 2001). The dipole structure is observed in surface temperature (Fig. 3), meridional winds, cloud fraction and precipitation. The ENSO-related variability is primarily controlled by the large-scale circulation anomalies surrounding the continent, which are consistent throughout the troposphere. When comparing the El Niño / La Niña phases of this late 1990s ENSO cycle, the circulation anomalies are nearly mirror images over the entire Antarctic, indicating their significant modulation by ENSO. Large temperature anomalies, especially in autumn (MAM), are prominent over the major ice shelves (Fig. 3). This is most likely due to their relatively low elevation with respect to the continental interior making them more sensitive to shifts in synoptic forcing offshore of Antarctica, especially during months with considerable open water. The Polar MM5 simulations are in broad agreement with observational data, and the simulated precipitation closely follows the European Centre for Medium-Range Weather Forecasts Tropical Ocean - Global Atmosphere precipitation trends over the study period. The collective findings of this work suggest the Polar MM5 is capturing ENSO-related atmospheric variability with good skill.

3. SUMMARY

Polar MM5 is a useful tool for modeling weather and climate in Antarctica. Current work involves a reanalysis of the past several decades of Antarctic surface mass balance and climate with Polar MM5, which is anticipated to shed insight on recent trends with higher confidence than has been previously possible. In addition, a continually evolving database of archived forecasts from AMPS yields high-resolution climatological data that are useful to a broader Antarctic research community. The database has already been applied to construct a climatology of the Ross Island area based on 1-y of AMPS 3.3-km resolution output (Monaghan et al. in press). The results have shown for the first time the dominant impact of precipitation shadowing on the climate of the Dry Valleys region. Soon the AMPS archive will be available to researchers via an Internet database. Finally, MM5 is transitioning to the reseach community's newest weather prediction tool, the Weather Research and Forecasting (WRF) model. Plans are underway to migrate the polar physics to the WRF framework in the near future to produce a Polar WRF.

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5. ACKNOWLEDGMENTS

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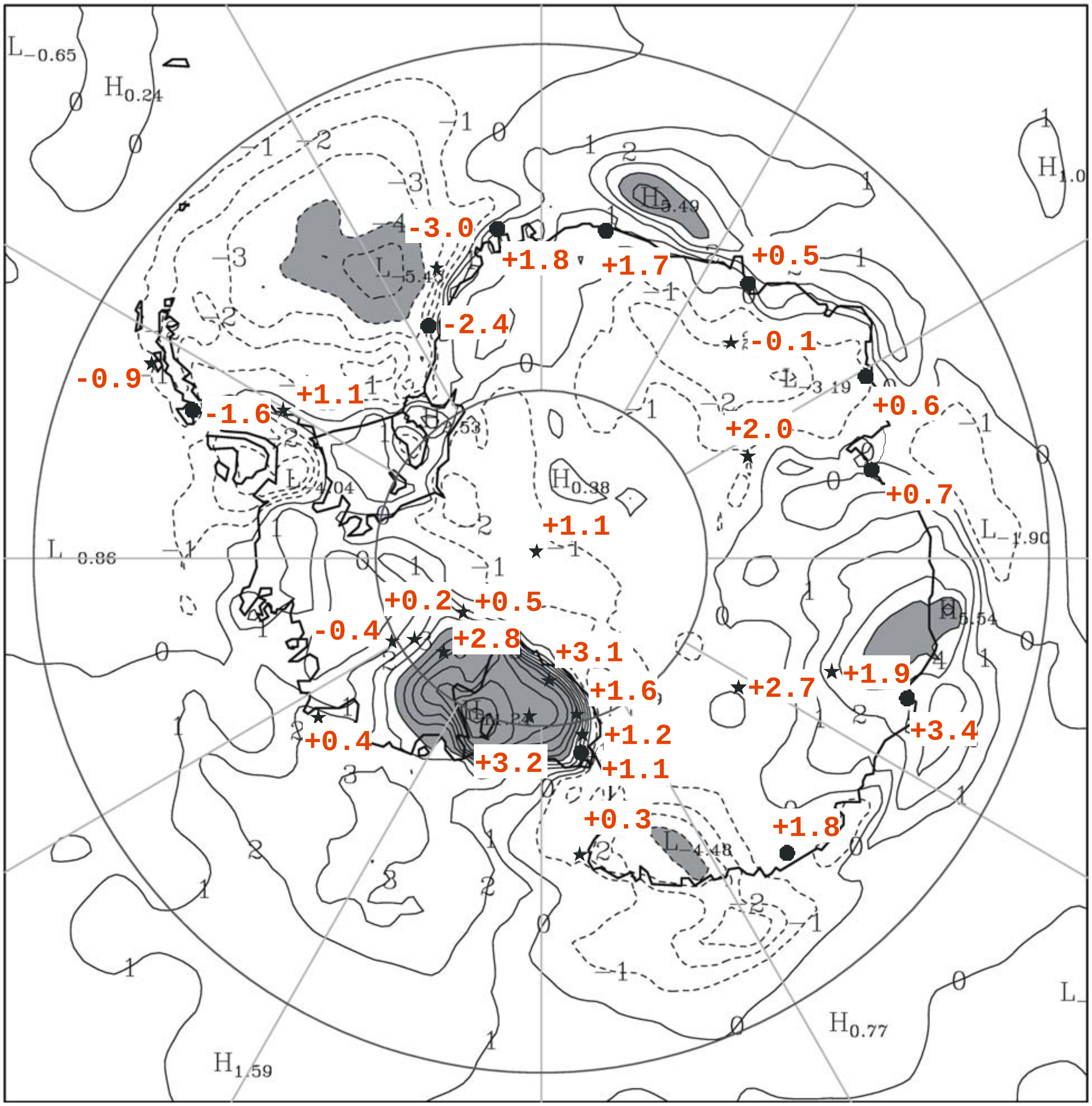

Fig. 3. MAM 1997 (El Nino) minus MAM 1999 (La Nina) Polar MM5 surface temperature anomalies (from Bromwich et al. 2004b). Observed anomalies are given in red next to the stations indicated. (contour interval = 1 K; areas with change > |4 K| are shaded; negative contours are dashed.