P1.28 A CLIMATOLOGY OF THE MCMURDO, ANTARCTICA REGION BASED ON THE AMPS ARCHIVE

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1. INTRODUCTION

In response to the need for improved weather prediction capabilities in support of the U.S. Antarctic Program's Antarctic field operations, the Antarctic Mesoscale Prediction System (AMPS) was implemented in October 2000. AMPS employs a limited-area model optimized for use over ice sheets, the Polar MM5. Twice-daily forecasts from the 3.3-km resolution domain of AMPS are joined together to study the climate of the McMurdo region from June 2002-May 2003. Annual and seasonal distributions of wind direction and speed, 2-m temperature, mean sea level pressure, precipitation, and cloud fraction are presented. This is the first time a model adapted for polar use and with relatively high resolution is used to study the climate of the rugged McMurdo region, allowing several important climatological features to be investigated with unprecedented detail. Annual fields are presented in this text for brevity. A more detailed version of the text which includes seasonal fields is given in Monaghan et al. (in press).

2. POLAR MM5 AND AMPS

AMPS is an experimental forecasting system run at the Mesoscale and Microscale Meteorology division of the National Center for Atmospheric Research (NCAR) and dedicated to real-time numerical weather prediction in Antarctica since October 2000 (Powers et al. 2003; http://www.mmm.ucar.edu/rt/mm5/amps/). AMPS employs the Polar MM5, a version of the Pennsylvania State University/NCAR fifth generation mesoscale model (MM5; Grell et al. 1994) optimized for the environment of polar ice sheets by the Polar Meteorology Group of the Byrd Polar Research Center at Ohio State University (Bromwich et al. 2001, Cassano et al. 2001; http://polarmet.mps.ohio-state.edu). AMPS is a collaborative effort between NCAR and Ohio State.

AMPS consists of six domains: 1) a 90-km resolution domain covering most of the Southern Hemisphere; 2) a 30-km domain over the Antarctic continent; 3) a 10-km domain covering the western Ross Sea; 4) a 3.3-km domain covering the immediate Ross Island region (implemented in December 2001); 5) a 10-km domain encompassing Amundsen-Scott South Pole station (implemented in November 2001); and 6) a 10-km domain enclosing the Antarctic Peninsula (implemented in September 2003). A general overview of AMPS is provided by Powers et al. (2003), along with a description of two noteworthy international rescue efforts in which AMPS provided invaluable forecast guidance. Since that publication, the system has provided guidance for medical evacuations in September 2003 from South Pole and in April 2004 from McMurdo.

Several published studies have shown that Polar MM5 performs with good skill on hourly to seasonal timescales over Antarctica (Bromwich et al. 2003, Guo et al. 2003, Monaghan et al. 2003, Bromwich et al. in press). On seasonal timescales the intraseasonal and interseasonal variability in pressure, temperature, wind, and moisture are particularly well-resolved (Guo et al. 2003). Bromwich et al. (in press) compare the AMPS 10-km and 3.3-km resolution McMurdo forecast domains and find that the 3.3-km domain provides an enhanced depiction of the near-surface winds due to its ability to capture more of the high-frequency energy that is characteristic of the small space and short time scales of the region. A detailed validation of the work presented here is given in Monaghan et al. (in press). The model captures the monthly and seasonal variability with good skill.

Here, annual mean fields are constructed by joining hundreds of twice-daily AMPS 3.3-km domain 24, 27, 30, and 33 hour forecasts. Therefore, each pair of 00 UTC and 12 UTC model initializations provide data at 00, 03, 06, 09, 12, 15, 18, and 21 UTC on the next day. The later forecast hours are chosen to allow the model fields to spin up.

3. CLIMATOLOGY OF THE MCMURDO REGION

Figure 1 shows the annual AMPS 3.3-km domain 24-33 hour fields. The topography (Fig. 1a) resolves the important small-scale features in the region such as Black and White Islands (south of Ross Island), and Hut Point Peninsula, where McMurdo is situated.

Figure 1b shows the annual 3-m vector mean wind directions and scalar mean wind speeds. The dominance of southerly flow and the blocking effect of Ross Island are evident. Flow splitting around Ross Island, as discussed by Seefeldt et al. (2003) is also captured. Easterly winds, similar to those observed (Sinclair 1982, Stearns 1997), are simulated in the vicinity of McMurdo and Williams Field Runway. Winds are slower in the lee (north) of the island, and there are discernable quasi-permanent vorticies due to vortex shedding of the flow around the topography (Powers et al. 2003). These may be partly responsible for the high incidence of mesoscale cyclogenesis observed to the north of the island (Carrasco et al. 2003). The majority of the flow is diverted around the east side of the island and generates the Ross Sea polynya, an important source of Antarctic Bottom Water (e.g., Zwally et al. 1985). The highest wind speeds are in the mountain valleys to the west of Ross Island; inspection of the seasonal means (not shown) indicates these are greatest in winter, an indication of their katabatic origin. The winds speed up on the lee slopes of the smaller topographic features such as Minna Bluff and Black and White Islands.

Figure 1c shows the annual mean 2-m temperature. In addition to variability due to elevation, marked horizontal temperature gradients are also evident. A sharp temperature gradient is apparent within a few tens of kilometers of the ice shelf edge to the east of Ross Island and is steepest in winter (not shown), when the air-sea temperature contrast is greatest. Warm signatures are present in the McMurdo Dry Valleys, evidence of vertical mixing due to katabatic winds. A tongue of relatively warm air from McMurdo Sound extends around the west side of Ross Island and penetrates onto the ice shelf. Its effect decreases rapidly inland of Black and White Islands and Minna Bluff, where the colder southerly winds are more influential. It is likely that the blocking of the wind around these terrain features causes the northwest-to-southeast orientation of the temperature gradient on the ice shelf (noted earlier by Savage and Stearns 1985). Similar to that suggested by Bromwich et al. (1992), it appears that the relatively warm winters at McMurdo are due to the regional topography steering the bulk of the cold southerly winds from the Ross Ice Shelf to the east of Ross Island.

Figure 1d shows the annual mean sea level pressure (MSLP). Areas above 500 m are masked due to the difficulties associated with calculating MSLP over high, cold terrain. The effects of topography are well-marked. A localized area of high (low) pressure is present on the windward (leeward) side of Ross Island due to the flow separation around this obstacle. The high pressure to the south of the island is likely an important contributor to the frequent occurrence of fog at Williams Field (personal communication, Arthur Cayette, Aviation Technical Services). Similarly, localized high pressure occurs on the windward side of Minna Bluff, supporting the flow diversion to the east of the obstacle that is evident in Fig. 1b. The area of lowest MSLP is in the northeast corner of the domain, where the effects of large synoptic systems entering the Ross Sea are prominent (Simmonds et al. 2003). A smaller minimum is present in the southeast corner of the domain for the same reason; the large synoptic systems that enter the Ross Sea from the north often move onto the ice shelf. Ridging is evident on the Ross Ice Shelf along the Transantarctic Mountains due to damming of the flow from these systems by the terrain, similar to the cold-air damming observed along the eastern side of the Appalachian Mountains in the United States (Bell and Bosart 1988). The resulting pressure gradient normal to the mountains drives the persistent southerly barrier wind regime (O'Connor et al. 1994).

Figure 1e shows the annual precipitation amount (water equivalent). Strong forcing by the terrain is apparent. Orographic maxima occur on the southerly slopes of the mountains, consistent with the dominantly southerly flow regime. A strong precipitation shadow effect is apparent to the north of the mountains in the southwest corner of the domain; this appears to exert an important influence on the low precipitation accumulation observed in the McMurdo Dry Valleys (e.g., Bull 1966). An axis of higher precipitation amounts “wraps” around Ross Island from the northeast, indicating that the large synoptic systems that pass to the northeast and east of Ross Island (Simmonds et al. 2003) are the primary sources of precipitation along its slopes. This is due to the orography of Ross Island uplifting the northward flow generated on the western side of these cyclones. It appears that the precipitation maximum located in the southwest corner of the domain is also largely due to these synoptic systems; in this case the precipitation may be related to the cyclonically forced barrier winds that are set up parallel to the Transantarctic Mountains and flow northward (O'Connor et al. 1994).

Figure 1f shows the annual mean cloud fraction. Cloudiness is dominated by the amount of open water in the Ross Sea to the north. The cloudiest region is to the northeast of Ross Island in the vicinity of the Ross Sea polynya where open water occurs nearly year round, largely due to persistent southerly winds (Fig. 1b, e.g., Bromwich et al. 1998). The spatial and temporal distribution of the clouds closely follows the precipitation patterns. Areas of high cloudiness are present over Ross Island and on the south slopes of the mountains in the southwest corner of the domain, while lower cloudiness occurs over the McMurdo Dry Valleys and along the Victoria Land coast. Sinclair (1982) also noted lower cloud amounts along the Victoria Land coast based on observations; temporary field camps on the sea ice and permanent ice to the west and southwest of Ross Island were generally less cloudy than McMurdo. He speculated that this was due to the katabatic influence from the mountain valleys to the west.

4. SUMMARY

This study employs a relatively new resource to explore the climatology of the McMurdo region with high spatial resolution. Twice-daily forecasts from the 3.3-km resolution domain of the Antarctic Mesoscale Prediction System are joined together to construct this climatology for one annual cycle from June 2002-May 2003. The results demonstrate the first-order importance of terrain in shaping the regional climate, and emphasize the complex meteorological interactions that arise at the confluence of the plateau, ice shelf, and the ocean environments.

To the authors' knowledge, this is the first time a high-resolution climatology of the McMurdo region from a physically-based numerical weather prediction model adapted for polar regions has been constructed. By comparing the wind, temperature, pressure, precipitation, and cloud fraction fields side-by-side, important aspects of the regional climate have been studied in greater detail than previously possible. For example, the McMurdo Dry Valleys are the largest ice free area in Antarctica (Doran et al. 2002). It has been surmised that this is due to 1) topographic obstructions at the west ends of the valleys where they meet the East Antarctic ice sheet, 2) low annual snowfall, 3) the frequent removal of snowfall by strong winds, and 4) a persistent dry foehn wind regime due to the valleys' lower elevation with respect to the East Antarctic ice sheet (Riordan 1975). However, the cause of the low annual snowfall in the Dry Valleys has never been identified. Our results indicate that this is due to a precipitation shadow effect caused by the mountains to the south. In addition, climatological eddies in the simulated wind field to the north of Ross Island suggest that the shedding of vortices as a result of airflow separation around the island plays an important role in the frequent mesoscale cyclogenesis observed in that area.

Another motivation for this study is to fill the inevitable data voids remaining from previous observationally-based climatologies. For some fields, these are extensive; for example, year-round precipitation observations are only available from McMurdo. Thus, the first-ever detailed maps of the regional precipitation distribution are presented. Some potential applications of the climatological maps include operational and field planning; for example, the maps may aid in selecting sites for the impending Antarctic Regional Interactions Meteorology Experiment (RIME), a field program planned under the auspices of the United States National Science Foundation that has the goal of understanding in more detail the role of Antarctica in the global climate system (Bromwich and Parish 2002).

As the AMPS forecasts and the associated archive continue to mature, it will become possible construct a more accurate climatology of the region and to assess interannual variability. A climate database, more easily accessible to the broader scientific community than the archived raw forecasts, will soon be available. This database may prove practical for more detailed and interdisciplinary studies than that presented here. One example is an in-depth examination of the McMurdo Dry Valleys, which is planned for the future. This study could potentially benefit biologists, geologists, and paleoclimatologists as they endeavor to understand the unique ecosystem of the Dry Valleys. Finally, additional model domains included in the database may facilitate studies of other parts of Antarctica, such as the recently implemented 10-km domain over the Antarctic Peninsula.

5. ACKNOWLEDGMENTS

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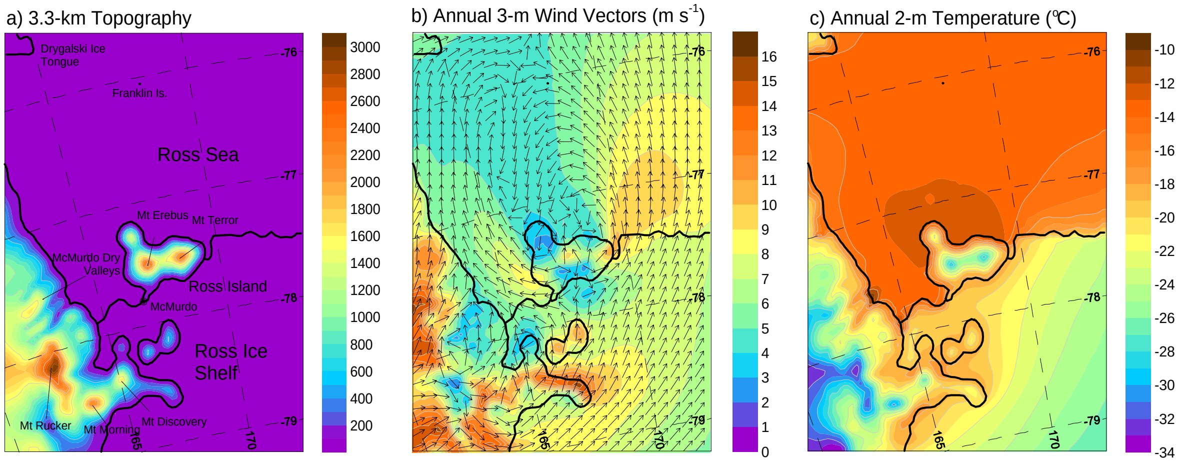
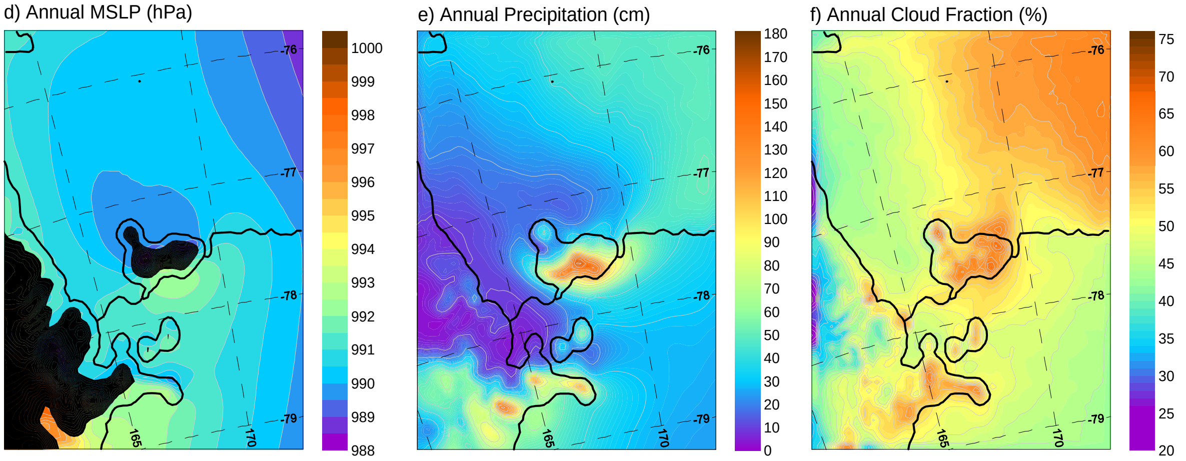

a) 3.3-km Topography

b) Annual 3-m Wind Vectors (m s^{-1})

c) Annual 2-m Temperature (℃)


d) Annual MSLP (hPa)

e) Annual Precipitation (cm)

f) Annual Cloud Fraction (%)

Figure 1. AMPS 3.3-km domain a) topography and 24-36 hour annual mean fields for June 2002-May 2003. (b) 3-m winds - Arrows show vector-mean direction and colors show scalar wind speed (m s^{-1}); (c) 2-m temperature (^{o}C); (d) MSLP (hPa); (e) precipitation (mm water equivalent); (f) cloud fraction (%).