A Modeling Investigation of an Antarctic Mass Loss Event

Jordan G. Powers

Mesoscale and Microscale
Meteorology Laboratory National
Center for Atmospheric Research
Boulder, Colorado, USA

1. INTRODUCTION

In a period of less than a week beginning in late June 1988, surface air pressures across Antarctica dropped significantly. These changes occurred in conjunction with widespread continental outflows, in particular with a vigorous Ross Ice Shelf Airstream (RAS) induced by a deep cyclone north of the Ross Sea. This mass loss event was investigated by Parish and Bromwich (1999) (hereinafter PB99), who documented the atmospheric conditions and evolution of the period. From the coarse ECMWF reanalysis dataset available at that time, they found that surface pressures over Antarctica decreased up to 20 mb for the episode, while, in contrast, there were pressure increases over the middle latitudes north of the continent.

The current work revisits this case through the application of MPAS, the Model for Prediction Across Scales (Skamarock et al 2012). As MPAS is a global atmospheric model, it can capture the hemispheric scale of this event fully, without the lateral boundary limitations of a limited-area model. For many years MPAS has been applied for forecasting in AMPS, the Antarctic Mesoscale Prediction System. AMPS is a real-time numerical weather prediction (NWP) capability covering Antarctica and the high southern latitudes (Powers et al. 2012). While its primary mission is to provide guidance for the weather forecasters of the U.S. Antarctic Program, it also assists international programs. Thus, MPAS has already been relied on for Antarctic simulations.

MPAS is applied here to investigate the Antarctic mass loss event described by PB99, and preliminary results are presented. The foci are determining the model's ability to capture the event and examining the case evolution via a dataset that is much better-resolving than that available to PB99. A number of figures from PB99 are reproduced to provide the observational background, and credit is given PB99 on their original work

2. MODEL CONFIGURATION

MPAS V8.2.3 is run here as global model with a refined mesh area over Antarctica and the Southern Ocean. The variable-resolution mesh has a coarsest spacing of 8 km over Antarctica and decreases to 48 km northward of the middle southern latitudes. Figure 1 presents an example of a regionally-refined MPAS mesh. In this example, however, the refined area is over North America, instead of Antarctica.

MPAS is configured with 51 vertical levels with a top at 30 km. The set of physics schemes in MPAS is designated as the "mesoscale reference suite" and consists of the following.

Microphysics: WSM6
Convection: nTiedke PBL: YSU
LSM: Noah-MP
Surface layer: Monin-Obukhov revised
Radiation: RRTMG LW/SW
Gravity wave drag: YSU GWDO

Model initial conditions (ICs) are produced from ERA5 analyses for 1200 UTC 27 June 1988. The simulation runs 156 hours, from 1200 UTC 27 June to 0000 UTC 4 July 1988. As no special observations were available to incorporate into the ICs, no additional data assimilation was done for the MPAS simulation.

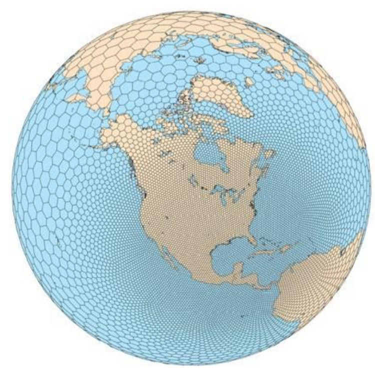


Fig. 1: Example of MPAS global mesh with regional refinement (i.e., smaller mesh spacing). This example shows refinement over North America, while the mesh used in the study has the refined area over Antarctica and the Southern Ocean.

3. CASE BACKGROUND

The event examined was centered on 28 June–2 July 1988. This period covers the greatest detected surface pressure (SFP) decreases over the continent, with the majority of these occurring over 48 hrs. PB99 used ECMWF (European Center for Medium-Range Weather Forecasting) model analyses with 2.5-deg lat/lon grid spacing for their analyses. The coarseness of this dataset was one motivation for the current study.

Work prior to PB99 found annual and semiannual variations in surface pressure to occur over Antarctica (e.g., van Loon 1967, Schwerdtfeger 1967). These oscillations reflect variations in midtropospheric temperature gradients between the middle and high latitudes, the attendant mean locations of the circumpolar trough, and the influence on the trough and its synoptic pressure forcings on the Antarctic continental area. PB99 began their case analysis with considering the predominant katabatic flows off the Antarctic land mass. They recognized that the regular surface off-continent flows implied mass removal at low levels, with such polar mass moving in the direction of the subpolar latitudes. Given continuity constraints, however, a subsequent return flow was to be expected, thus setting up an average meridional circulation.

While the noted seasonal signals in surface pressure are climatological and statistical, episodes of sharp surface pressure declines over the continent can be superimposed on the cycles, and the June 1988 event is the case in point. Here, the main period of SFP decrease was from 00 UTC 29 June to 00 UTC 2 July 1988. Figure 2 reproduces PB99's analysis of the differences in surface pressure (SFP) over the 48-hr period of 00 UTC 29 June–00 UTC 1 July, based on the ECMWF analysis dataset. For the event, the maximum SFP decreases of over 18 mb were centered over Marie Byrd Land (MBL) and the Siple Coast, while decreases of over 8 mb extended across West Antarctica and the Plateau.

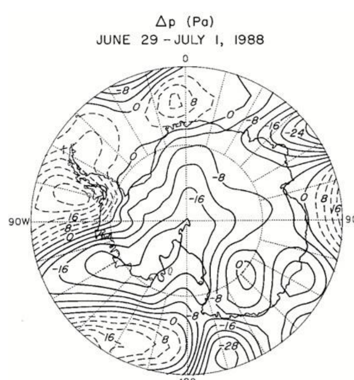


Fig. 2: Surface pressure changes (mb) over the period 00 UTC 29 June–00 UTC 21 July 1988, from PB99. Contour interval 4 mb; solid= pressure decreases; dashed= pressure increases.

A surface wind streamline analysis for the event period from PB99 (Fig. 3) shows the largely off-continent flow, with a pronounced RAS (Ross Ice Shelf Air Stream) seen along 180 E and offshore flows seen across East Antarctica. The strong Ross Ice Shelf flow is in response to a deep low pressure system north of the Ross Sea that persists through the period. An SLP analysis from the ECMWF dataset (Fig. 4, reproduced from PB99) shows this system. Figure 4 also reveals lows off Queen Maud Land (0 E) and East Antarctica (90 E) that are contributing to the offshore flows on, and low-levels mass transport out of, those sectors of the continent.

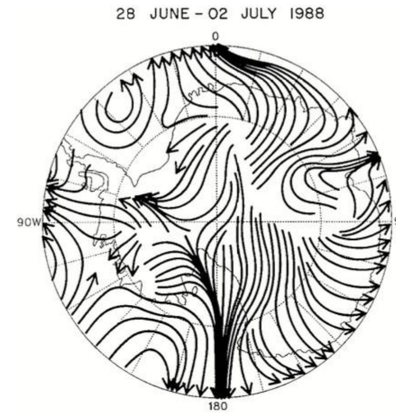


Fig. 3: Analysis of streamlines of surface winds averaged over the period 00 UTC 28 June–00 UTC 2 July 1988 from PB99.

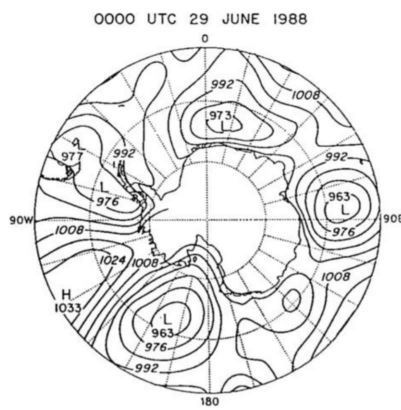


Fig. 4: SLP analysis for 00 UTC 29 June 1988 from PB99. Contour interval= 6 mb. Cyclones driving low-level, off-continent flows seen in the northern Ross Sea (150–180 W) as well as off East Antarctica (near 90E lon) and Queen Maud Land (near 0 E lon).

4. MODEL RESULTS

One of the current questions driving this investigation is whether MPAS can capture the mass loss event, which Fig. 2 summarizes with the multi-day SFP differences for the episode. Figure 5 is a simulation counterpart to this, the MPAS SFP differences over Antarctica and the Southern Ocean for 00 UTC 29 June–00 UTC 4 July 1988. As in Fig. 2, pressure decreases for the period are in solid contours, increases in dashed contours. In the simulation, almost the entire continent experiences SFP decreases. The simulation maximum of >-32 mb is significantly greater than the PB99 analyzed value of >-20 mb. Given the ECMWF's coarseness (2.5 deg), however, it may be that those results underrepresent the event's amplitude and do not resolve the different areas of SFP change maxima that MPAS can produced. Also, the MPAS maximum is centered over Dome A, while the PB99 maximum is over the Marie Byrd Land (MBL) and Siple Coast areas of West Antarctica. Given, however, that Fig. 5 shows an MPAS has secondary decrease extremum of greater than 24 mb off MBL, the MPAS maximum decrease region does encompass that observed by PB99; it is simply of greater magnitude. There is one small area on the continent where MPAS shows a pressure increase, of >-16 mb near 90 E. However, even the coarse ECMWF-derived estimate shows a decrease nearby, just offshore (see Fig. 2). In summary, MPAS does succeed in reproducing the significant surface pressure decreases that characterized the event.

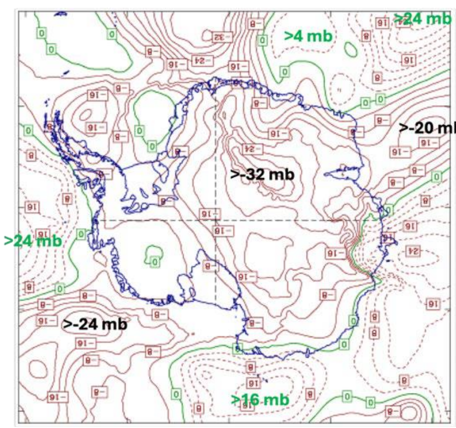
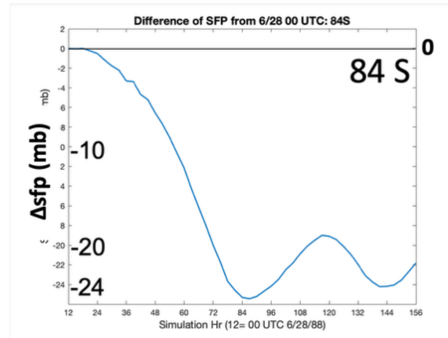
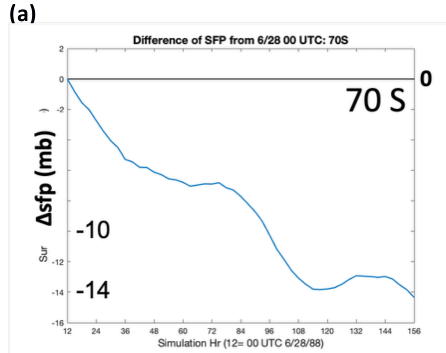


Fig. 5: SFP differences for the period 00 UTC 29 June–00 UTC 1 July 1988 from MPAS simulation. Solid contours= increases; dashed contours= decreases, interval= 4 mb. Local extrema labeled.

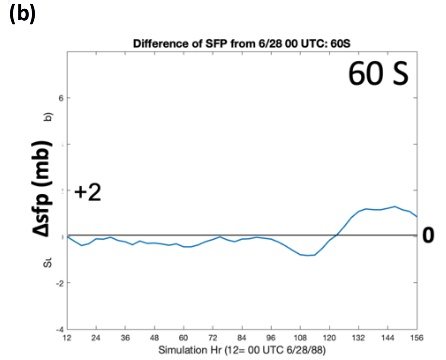
Analyses of zonal pressure changes from the subtropics to the pole reveal that the mass adjustments vary with latitude. As noted by PB99, net SFP *decreases*, reflected in zonally-averaged decreases across latitudes, are seen over the continent, while *increases* appear from the midlatitudes to the subtropics. Figures 6(a)–(d) show selected latitudinal SFP responses in MPAS for 84S, 70S, 60S, and 44S for the period 00 UTC 28 June–00 UTC 4 July. Large pressure decreases (e.g., >-20 mb) occur over the high Antarctic latitudes (Figs. 6(a),(b) for 84S and 70S). Near the continental margin, at 60S (Fig. 6(c)), the pressure trend is flat. In the lower latitudes (Fig. 6(d), 44S), pressure *increases* are seen, consistent with the net transport of mass northward. These plots imply that the event entails a hemispheric mass redistribution.



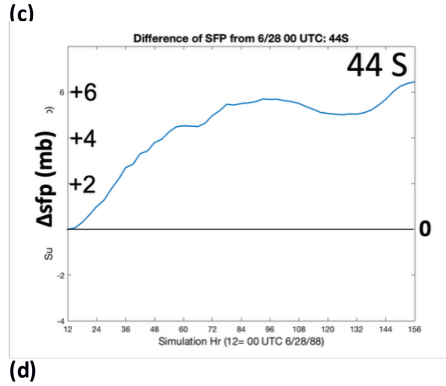
(a)



(b)



(c)



(d)

Fig. 6: Zonally-averaged surface pressure changes (mb) for different latitudes for the period 00 UTC 28 July–00 UTC 4 July 1988 from the MPAS simulation. (a) 84S. (b) 70S. (c) 60S. (d) 44S.

The Pole-to-Equator variation in mass changes for the event can be seen in compositing zonal averages for different periods. Figure 7(a) shows the PB99 analysis of the changes across latitudes for multiple periods beginning 00 UTC 28 June. For a 24-hr period ending 00 UTC 29 June to a 96-hr period ending 2 July, there is a clear SFP decrease for all latitudes south of ~54S, while there are increases for latitudes north of this, peaking for ~44S. Equatorward of ~26S, minimal changes occur.

Figure 7(b) presents the MPAS simulation results. They are verified well by the PB99 analysis: large decreases, of >-24 mb for July 2, are seen over the continent. In contrast, over the middle latitudes, there are SFP increases; these have an amplitude of up to about 5 mb, the same as seen by PB99. One difference between the ECMWF and MPAS depictions is that in MPAS the null latitude (i.e., the latitude with no SFP change for the period considered) is about 60S, while from ECMWF it is about 56S. This difference may be a consequence of the 2.5-deg resolution of ECMWF, however.

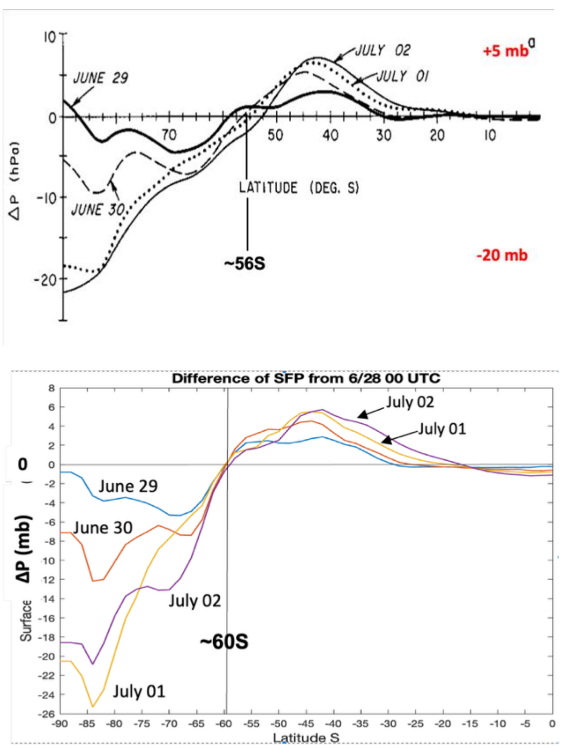


Fig. 7: Analyses of zonally-averaged SFP changes (mb) from Pole to Equator for 00 UTC 28 June to 00 UTC of date indicated. (a) PB99 analysis from ECMWF dataset. (b) MPAS simulation.

As to the synoptic elements linked to the low-level off-continent flows, the simulation shows several deep cyclones around Antarctica during the event. Figure 8 is the model counterpart SLP analysis to that of Fig. 4, for 00 UTC 29 June 1988. The Ross Sea system noted by PB99 as helping to force the RAS in the case is marked L1 in Fig. 8. In the simulation its central pressure is down to 966 mb. A second zone of low pressure systems extends from 90E farther east to Adelie Land, and the centroid is marked L2 in Fig. 7. Lastly, there is a strong system of 959 mb off of Queen Maud Land (near 0 E), labeled L3.

Figure 9 shows the near-surface wind fields induced by these systems. This presents the .5-km AGL wind field for 00 UTC 29 June (as in Fig. 8) and is a model rendition of the low-level flow during the period of the time-averaged surface wind field of Fig. 3. Not only is a concentrated RAS flow seen (labeled "RAS"), but other broad zones of off-continent flows appear in East Antarctica (labeled "EA") and Queen Maud Land (labeled "QML"). All of these flow regimes are working to evacuate mass at low levels off the continent, resulting in the model SFP decreases.

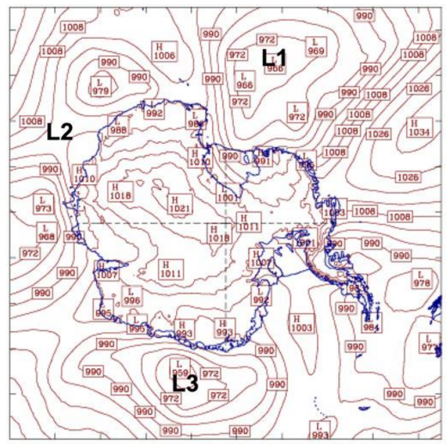


Fig. 8: MPAS SLP field for 00 UTC 29 June 1988. Contour interval= 6 mb (as in Fig. 4). Lows referred to in text labeled.

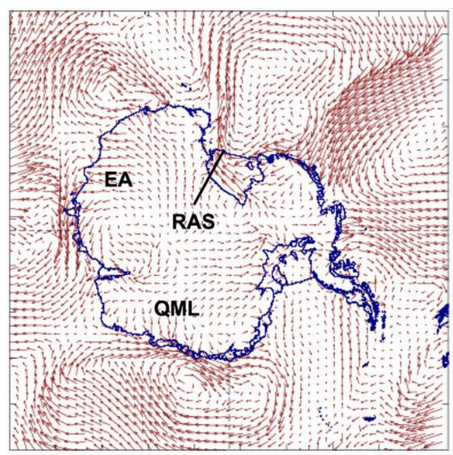


Fig. 9: MPAS .5-km AGL wind field for 00 UTC 29 June 1988. Ross Ice Shelf (RAS), East Antarctica (EA), and Queen Maud Land (QML) flows described in text labeled.

4. SUMMARY

While cyclic annual and semi-annual fluctuations in surface pressures over Antarctica have been recognized as an element of its climatology, occasionally there are episodes of rapid, prominent decreases in surface pressures superimposed on it. Parish and Bromwich (1999) ([PB99]) were the first to examine one of these phenomena, identifying a case from June 1988. The current study applies a tool not available to PB99 for a new examination of it, the Model for Prediction Across Scales (MPAS). Here this is applied for a relatively high-resolution investigation of the event's conditions and mechanisms.

The June 1988 event was marked in AWS observations by surface pressure (SFP) falls, and the coarse ECMWF datasets used by PB99 indicated synoptic-scale decreases of >-20 mb over a few days. The MPAS simulation captures continent-wide decreases over a 4–5-day period, but with notably greater amplitudes than previously identified. For zonally-averaged SFP changes across latitudes from the Pole to the Equator, the MPAS results are verified by the previous analyses, both in terms of magnitude and timing. MPAS shows the event to be characterized by SFP decreases over the continental latitudes, transitioning to increases north of 60S, indicating shifts of atmospheric mass to the lower latitudes. A strong RAS as well as broad, low-level offshore flows from East Antarctica and Queen Maud Land all contribute to the temporary evacuation of mass from the continent. The drivers for these flows appear to be deep cyclones in the Ross Sea and off East Antarctica. For the period of the event, this low- level continental outflow appears not to be balanced by return (i.e., southward) flows at higher levels. The results here are preliminary, and further analysis of the MPAS simulation is in progress.

ACKNOWLEDGEMENTS

The author thanks the NSF Office of Polar Programs for its support of AMPS. The author acknowledges the prior seminal study of Parish and Bromwich (1988).

REFERENCES

Parish, T.R., and D.H. Bromwich, 1988: A case study of Antarctic katabatic wind interaction with large-scale forcing. *Mon. Wea. Rev.*, **126**, 199–209.

Powers, J.G., K.W. Manning, D.H. Bromwich, J.J. Cassano, and A.M. Cayette, 2012: A decade of Antarctic science support through AMPS. *Bull. Amer. Meteor. Soc.*, **93**, 1699–1712.

Schwerdtfeger, W., 1967: Annual and semi-annual changes of atmospheric mass over Antarctica. *J. Geophys. Res.,* **72,** 3543–3547.

Skamarock, W. C., J. B. Klemp, M. G. Duda, L. Fowler, S.-H. Park, and T. D. Ringler, 2012: A multi- scale nonhydrostatic atmospheric model using centroidal Voronoi tessellations and c-grid staggering. *Mon. Wea. Rev.*, **240**, 3090–3105. doi:10.1175/MWR-D11-00215.1

van Loon, H., 1967: The half-yearly oscillations in the middle and high southern latitudes and the coreless winter. J. Atmos. Sci., **24**, 472–486.