

A HIGH RESOLUTION SOUTHERN OCEAN CYCLONE CLIMATOLOGY

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1. INTRODUCTION

We still have a relatively little knowledge of the nature, distribution and variability of intermediate scale depressions over the Southern Ocean close to Antarctica. This knowledge is important for a range of human pursuits including impacts on safety and efficiency of polar research, tourism and associated logistics. Additionally these systems form a very important component of the climate system being responsible for the poleward transport of heat, moisture and momentum towards high southern latitudes (Bromwich et al., 1995; Noone and Simmonds, 2002; Lynch et al., 2006; Uotila et al., 2007). The cyclonic activity is especially high close to the Antarctic continent (Simmonds and Lim, 2009), where the cold continental air meets the warm maritime air mass.

Earlier studies have analyzed synoptic scale depressions around Antarctica (see for example Simmonds and Keay, 2000), but fewer number of papers have been published focusing on smaller systems of the intermediate scale of atmospheric processes ranging from 20 km to 1000 km or from hours to weeks (Orlanski, 1975). A reason to this is the small number of observations from this remote region. Recently new data sets collected from satellites, weather stations and field campaigns have been created by using high resolution weather models, which implement data assimilation have been made available (Powers et al., 2003). Statistics of cyclonicity derived from the output of a high resolution model, which has been specifically implemented for Antarctica, differs significantly from statistics of cyclonicity derived from coarser resolution output based on the re-analyses (Uotila et al., 2009).

2. DATA AND METHODS

Satellite climatological investigations are a common and successful way of investigating mesoscale cyclones. Two main reasons for the success of satellite based studies are: 1) that mesoscale cyclones have characteristic cloud signatures that are easily identified in satellite imagery, and 2) that long-term archives of high resolution satellite imagery are available (Carleton and Carpenter, 1990). The satellite imagery used in this study to conduct an investigation into the climatology of mesoscale cyclones in the Antarctic region are the AVHRR (Advanced Very High Resolution Radiometer) Polar Pathfinder visible/thermal band imagery. The AVHRR twice daily imagery is taken at 0200 UTC and 1400 UTC and

covers the Antarctic continent and the surrounding Southern Ocean for the period 2000-2005.

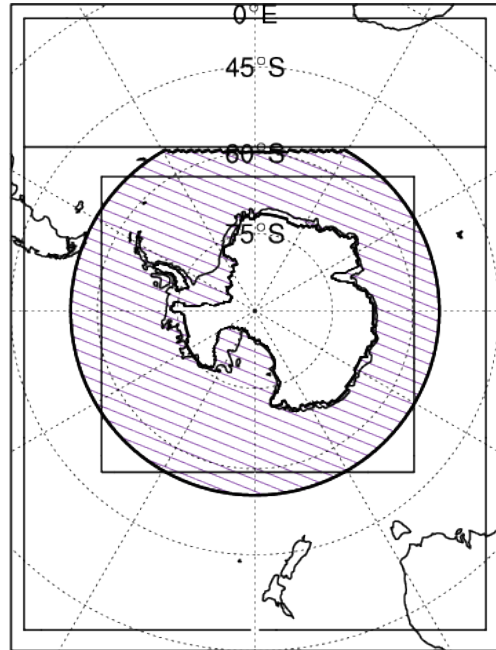


Figure 1. A map covering the largest AMPS domain marked with a rectangle extending from Australia to South Africa. A shaded circular region indicates the area where the cyclone statistics of AMPS and the re-analyses were compared.

Archived output from the Antarctic Mesoscale Prediction System (AMPS; Powers et al. 2003; Bromwich et al., 2005) contains data from January 2001 to the present on model grids ranging from the Southern Ocean wide domain at 90 km (60 km since 2006), to Antarctic-wide at 30 km (20 km since 2006), to 3.3 km and less over smaller regions (Figure 1). For this study data from the AMPS 12-23 hour forecasts were extracted from forecasts initialized every day at 0000 and 1200 UTC. AMPS model output is available every three hours. AMPS model applies a specific physics parameterization for the Antarctic (PolarMM5/WRF model). Evaluations of AMPS simulations over Antarctica have demonstrated that this model has a high level of skill in representing the Southern Polar Region (Bromwich et al. 2003; Bromwich et al. 2005; Seefeldt and Cassano 2008; Uotila et al. 2009).

Results derived using the AMPS dataset were compared to three global re-analysis products to determine differences due to the increased spatial resolution. The three re-analysis products were: NCEP (Kalnay, 1996), NCEP2 (Kanamitsu 2002) and JRA25 (Onogi, 2007). These data have a spatial coverage of 2.5 degrees in latitude by 2.5 degrees in longitude. Variables are archived at six hourly intervals.

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Cyclone detection of AMPS and re-analysis data was carried out by using the automatic cyclone tracking scheme of Murray and Simmonds (Murray and Simmonds, 1991a; Murray and Simmonds, 1991b; Simmonds et al., 1999a; Simmonds and Murray, 1999b; Simmonds, 2003a; Simmonds et al., 2003b; Lim and Simmonds 2007; Simmonds et al., 2008). The tracking scheme produces fields of cyclone frequency and properties. The cyclone properties calculated by the scheme include the system density, rates of cyclogenesis and cyclolysis, the mean central pressure of cyclones, the mean system intensity, the mean cyclone radius and the mean depth over a unit area.

We applied the Self-Organizing Maps (SOMs) technique (Kohonen, 2001) to derive large scale circulation patterns from the AMPS data. The procedure how SOMs were created for this study followed the one applied by (Cassano et al., 2006). A SOM forms a taxonomy of the input data, which is consisted of nodes representing patterns of atmospheric circulation.

3. RESULTS

On both a monthly and seasonal basis the satellite data showed greater variability than AMPS, and the seasonality was also different. In the AMPS data, Winter was the most active period for cyclones and Summer the least, while in the AVHRR data, Autumn was the most active and Spring the least. This can be explained by the capability for cyclone detections in the dry Winter air in the AMPS data, as well as the more northerly storm tracks detected in the higher resolution AMPS data over the Southern Ocean. In contrast to the AVHRR detected storm tracks, the AMPS data forms a more compact and continuous band of cyclones to suggest a more southerly Antarctic Circumpolar Trough (ACT). Strong marine lows are observed in the AVHRR imagery at more northerly latitudes that are not detected in the AMPS output or reanalysis products. These systems are largely quite small in scale and thus the resolution of the model-based products may be too coarse over the southern ocean to detect these systems. Further research in this area is needed to determine the mechanisms and scales associated with these systems.

The cyclone statistics derived from the re-analyses were relatively close to each other, while the AMPS statistics were notably different from the re-analysis statistics. Accordingly cyclone properties depend significantly on the resolution of input data, values of instruction parameters used in the tracking scheme, and model physics.

Geographically the largest differences between AMPS and the re-analyses occur in the ACT and in the coastal seas off the Antarctic continent, but not close to the boundaries of the AMPS model domain. For instance in AMPS the ACT is narrower, it is located south of the re-analysis ACTs and it does not extend as close to the embayments around Antarctica. This appears as higher AMPS system density in the ACT than the re-analysis system densities, but lower AMPS system density close to coast than the re-analysis system densities. A reasonable explanation to this is that AMPS simulates

low pressure systems better over the Antarctic coastal waters and over the marginal ice zone. This is partly because the tracking scheme is able to resolve smaller scales due to the finer spatial and temporal resolution of the AMPS data. Accordingly, the cyclone tracking algorithm detects sizes and locations of systems from the high resolution AMPS data more accurately than from the coarser resolution re-analysis data. The better performance is also due to its use of polar optimized physical parametrization, which is evident as larger differences between the AMPS and re-analysis cyclone statistics in winter than in summer. These differences extend further from the Antarctic coast in winter along with the growing sea-ice. One factor which could contribute to these differences is the AMPS (Polar-MM5) parametrization of surface fluxes over sea-ice covered areas.

The AMPS data display significantly smaller and more intense systems than the re-analyses, especially close to Antarctica, which signifies the importance of model resolution close to steep topographical features (Figure 2). In winter large systems in AMPS are detected further from coast than in summer, but this behavior was not seen to the same extent in the re-analyses. As a result the properties of the re-analysis and AMPS systems differ more over a larger area in winter than in summer. On the basis of this study one cannot state with confidence whether AMPS can simulate polar lows, but one can affirm that AMPS is able to simulate smaller systems than the re-analyses. Additionally a study by Bromwich et al, (2003) suggests that AMPS can simulate some of the polar lows. From this perspective it can be concluded that AMPS is a step further towards an ideal scenario for the simulation of mesoscale processes.

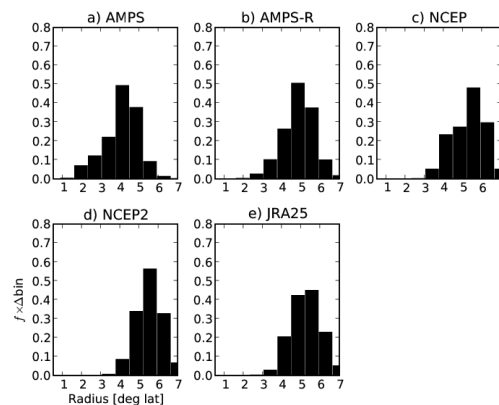


Figure 2: Distribution of system radius of (a) AMPS, (b) AMPS-R (reduced resolution), (c) NCEP, (d) NCEP2, and (e) JRA25 for 2001-2007. Distribution values are averages per grid boxes of the common grid over the comparison area illustrated in Figure 1.

4. CONCLUSIONS

New, high resolution data provide more detailed information about cyclones around Antarctica. Main findings, so far, are:

- AMPS misses some small lows that appear in the satellite data in the Antarctic Circumpolar Trough (ACT).

- AMPS shows more small systems than the re-analyses in the ACT, but fewer systems close to the Antarctic coast.
- The ACT in AMPS is located more south than in the re-analyses and in the satellite data.
- AMPS shows smaller systems in size than the re-analyses.
- Differences with the re-analyses are larger in winter than in summer.

Many other aspects are going to be communicated in a manuscript by Uotila et al. (2009). Our current work focuses on associating the mesoscale cyclogenesis and cyclone development with the surface energy exchange, upper level forcing and large scale circulation patterns.

REFERENCES

- Bromwich, D. H., F. M. Robasky, R. I. Cullather, and M. L. Van Woert 1995: The atmospheric hydrologic cycle over the Southern Ocean and Antarctica from operational numerical analyses, *Monthly Weather Review*, 123, 3518-3538.
- Bromwich, DH, Monaghan, AJ, Powers, JG, Cassano, JJ, Wei, HL, Kuo, YH and Pellegrini, A 2003, 'Antarctic mesoscale prediction system (AMPS): a case study from the 2000/2001 field season', *Monthly Weather Review*, vol.131, pp.412-434.
- Bromwich D.H, A.J. Monaghan, K.W. Manning, and J.G. Powers, 2005:, Real-Time Forecasting for the Antarctic: An Evaluation of the Antarctic Mesoscale Prediction System (AMPS), *Mon. Wea. Rev.*, 133, 579-603.
- Carleton, AM and Carpenter, DA 1990, 'Satellite climatology of polar lows and broad scale climate associations for the southern hemisphere', *International Journal of Climatology*, vol.10, pp.219-246.
- Cassano, J.J., P. Uotila, A.H. Lynch, 2006:, Changes in synoptic weather patterns in the polar regions in the 20th and 21st centuries, Part 1: Arctic. *Int. J. of Climatol.*, 26(8), 1027-1049.
- Kalnay et al., 1996: The NCEP/NCAR 40-year reanalysis project, *Bull. Amer. Meteor. Soc.*, 77, 437-470.
- Kanamitsu, M., W. Ebisuzaki, J. Woollen, S.-K. Yang, J.J. Hnilo, M. Fiorino, and G. L. Potter, 2002: NCEP-DEO AMIP-II Reanalysis (R-2), *Bul. of the Atmos. Met. Soc.*, 1631-1643, Nov 2002.
- Kohonen, T., 2001: *Self-Organizing Maps*, Springer, 501pp.
- Lim, E.-P., and I. Simmonds 2007:, Southern Hemisphere winter extratropical cyclone characteristics and vertical organization observed with the ERA-40 reanalysis data in 1979-2001. *Journal of Climate*, 20, 2675-2690.
- Lynch, A. H., J.P. Uotila, and J. J. Cassano, 2006:, Changes in synoptic weather patterns in the polar regions in the 20th and 21st centuries, Part 2: Antarctic. *International Journal of Climatology*, doi: 10.1002/joc.1305.
- Murray, R. J., and I. Simmonds, 1991a: A numerical scheme for tracking cyclone centres from digital data. Part I: Development and operation of the scheme, *Australian Meteorological Magazine*, 39, 155-166.
- Murray, R. J., and I. Simmonds, 1991b: A numerical scheme for tracking cyclone centres from digital data. Part II: Application to January and July general circulation model simulations, *Australian Meteorological Magazine*, 39, 167-180.
- Noone, D., and I. Simmonds 2002:, Annular variations in moisture transport mechanisms and the abundance of $\delta^{18}\text{O}$ in Antarctic snow, *J. Geophys. Res.*, 107, 4742, doi: 10.1029/2002JD002262.
- Onogi, K., J. Tsutsui, H. Koide, M. Sakamoto, S. Kobayashi, H. Hatsushika, T. Matsumoto, N. Yamazaki, H. Kamahori, K. Takahashi, S. Kadokura, K. Wada, K. Kato, R. Oyama, T. Ose, N. Mannoji and R. Taira, 2007: The JRA-25 Reanalysis. *J. Meteor. Soc. Japan*, 85, 369-432.
- Orlanski, I., 1975: A rational subdivision of scales for atmospheric processes, *Bull. Amer. Meteor. Soc.*, 56, 527-530.
- Powers, J.G., A.J. Monaghan, A.M. Cayette, D.H. Bromwich 2003: Real-time mesoscale modeling over Antarctica: The Antarctic Mesoscale Prediction System. *Bull. Amer. Meteor. Soc.*, 84, 1533-1545.
- Seefeldt, MW and Cassano, JJ 2008, 'An analysis of low-level jets in the greater Ross Ice Shelf region based on numerical simulations,' *Monthly Weather Review*, in press.
- Simmonds, I., R. J. Murray, and R. M. Leighton, 1999a: A refinement cyclone tracking methods with data from FROST. *Australian Meteorological Magazine (Special ed.)*, 35-49.
- Simmonds, I., and R. J. Murray, 1999b: Southern extratropical cyclone behavior in ECMWF analyses during the FROST Special Observing Periods. *Weather and Forecasting*, 14, 878-891.
- Simmonds, I., and K. Keay, 2000: Mean Southern Hemisphere Extratropical Cyclone Behavior in the 40-Year NCEP-NCAR Reanalysis, *J. Climate*, 13, 873-885.
- Simmonds, I., 2003a: Modes of atmospheric variability over the Southern Ocean, *J. Geophys. Res.-Oceans*, 108, 8078, doi:10.1029/2000JC000542.
- Simmonds, I., K. Keay and E.-P. Lim, 2003b: Synoptic activity in the seas around Antarctica, *Monthly Weather Review*, 131, 272-288.
- Simmonds, I., C. Burke, and K. Keay, 2008: Arctic climate change as manifest in cyclone behavior, *J. Climate*, 21, 5777-5796.
- Simmonds, I., and E. Lim, 2009: Biases in the calculation of Southern Hemisphere mean baroclinic eddy growth rate, *Geophys. Res. Lett.*, 36, L01707.
- Uotila, J.P., A.H. Lynch, J.J. Cassano, R.I. Cullather, 2007: Changes in Antarctic net precipitation in the 21st century based on Intergovernmental Panel on Climate Change (IPCC) model scenarios. *J. Geophys. Res.*, 112, 19 pages, D10107, DOI:10.1029/2006JD007482.
- Uotila, J.P., A. B. Pezza, J.J. Cassano, K. Keay and A.H. Lynch, 2009: A comparison of low pressure system statistics derived from a high resolution NWP output and three re-analysis products over the Southern Ocean, *J. Geophys. Res.*, in review.