P.1.9 CYCLOGENESIS NEAR THE ADÉLIE COAST AND INFLUENCE OF THE LOW-LEVEL WIND REGIME

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1. INTRODUCTION

Cyclones are an important component of the Southern Hemisphere climate. Meridional motions associated with cyclones transport mass, moisture, and momentum between mid-latitude and polar regions. The resulting wind field and precipitation from cyclones impact the interactions within the atmosphere-ocean-ice system. Besides their role in the overall Southern Hemisphere climate, cyclones also have practical implications upon commercial and research activities in the Southern Ocean and Antarctica.

Previous studies have indicated that the Adélie Coast and George V Coast regions of Antarctica, near 150°E, feature a high frequency of cyclogenesis (Carleton and Fitch 1993, Simmonds et al. 2003, Hoskins and Hodges 2005). However, little explanation has been given towards the physical mechanisms responsible for the high frequency of cyclogenesis. Hoskins and Hodges (2005) suggest that cyclone development is associated with dissipating systems that decay upstream of 150°E. Lim and Simmonds (2007) indicate that the Antarctic coastal region near 150°E features the strongest time-averaged baroclinicity in the Southern Hemisphere, primarily due to the low-level meridional temperature gradient. Little mention has been made of a possible connection to the intense Adélie Land katabatic wind regime, as inferred by Parish and Walker (2006). This wind regime is highlighted by Mawson's 1912-13 Australasian Antarctic Expedition that measured an annual mean wind speed of 19.4 m s^{-1} (Madigan 1929, Parish and Walker 2006).

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This study discusses the physical mechanisms responsible for cyclogenesis along the Antarctic coast near 150°E from three years (2003-2005) of model output from the Antarctic Mesoscale Prediction System (AMPS, Powers et al. 2003, Bromwich et al. 2005). Composites and case study events are presented to analyze the physical mechanisms involved in cyclone development. Automated cyclone tracking is done using the University of Melbourne Automatic Cyclone Finding and Tracking Scheme (Murray and Simmonds 1991a,b, Simmonds and Murray 1999).

2. CLIMATOLOGY

As mentioned, previous studies utilizing reanalysis products have located a high frequency of cyclogenesis along the Antarctic Coast near 150°E (Steinhoff 2008). These same studies have shown that cyclolysis is prominent upstream along the coast near 120°E. Both of these cyclogenesis and cyclolysis patterns are found in the 2003-2005 AMPS annual average cyclogenesis and cyclolysis statistics, shown in Fig. 1a-b. A cyclogenesis maximum is centered near 140°E, with a weaker maximum located east of 160°E. Seasonally, these maxima vary in location and intensity, but the patterns in Fig. 1a are generally representative of all seasons outside of summer, which features a sharp reduction in cyclone activity, due to the more zonal storm track around Antarctica. Cyclolysis (Fig. 1b) is found in a belt from 120°E to 160°E. Seasonally (including summer), more defined maxima are generally found west of 130°E and between 150°E and 160°E.

Uotila et al. (2009) show that AMPS better resolves smaller-scale systems near the Antarctic coast compared to reanalysis products. Compared to reanalyses, AMPS has higher spatial resolution, allowing it to better the represent effects of Antarctic topography on cyclone activity. Also, parameterization schemes and surface characteristics in AMPS are optimized for polar conditions, so it will better simulate

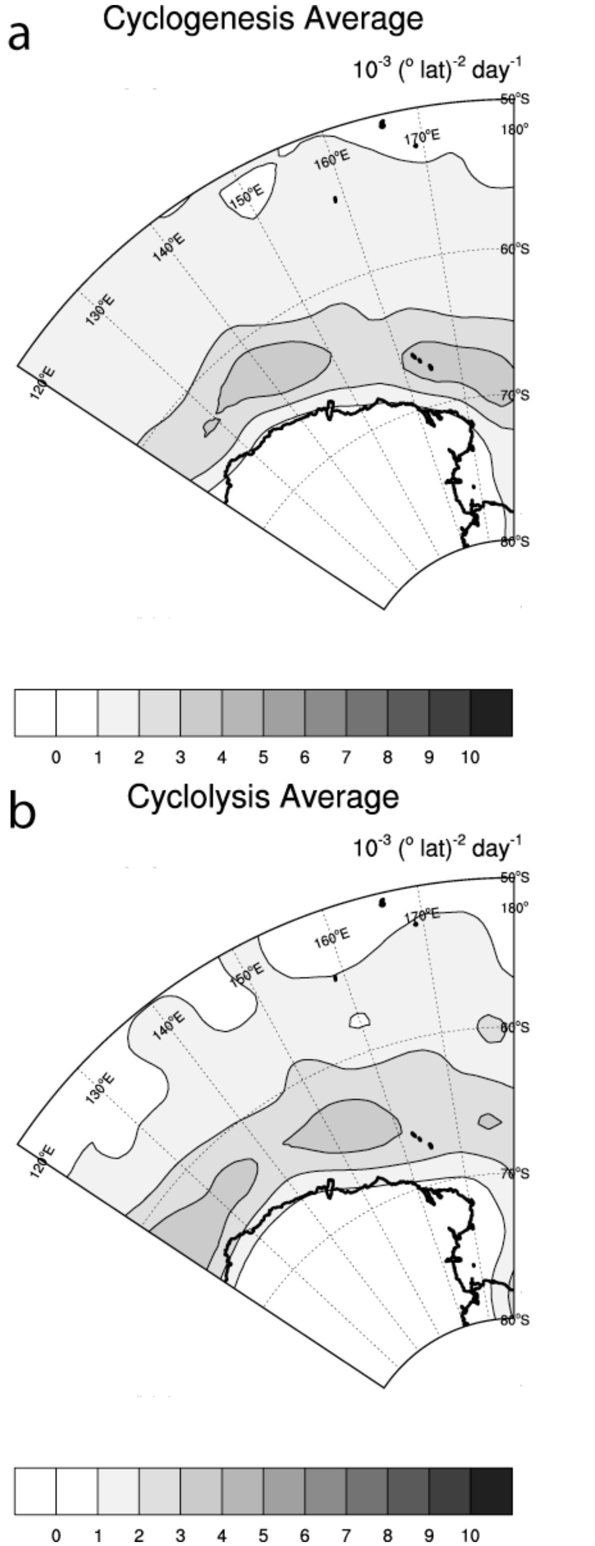

Figure 1. a) 2003-2005 AMPS cyclogenesis (10^{-3} $(°lat)^{-2}$ day^{-1}) and b) 2003-2005 AMPS cyclolysis (10^{-3} $(°lat)^{-2}$ day^{-1}).

the effects of sea ice on surface heat and moisture fluxes, for instance. The greater detail in the cyclogenesis and cyclolysis products shown in Fig. 1a-b compared to corresponding quantities from reanalysis products in other studies shows that AMPS is better suited for a study focusing on the development mechanisms of systems around the Antarctic coast.

3. SYSTEM DEVELOPMENT

Data from the 30-km resolution Domain 2 of AMPS from 2003-2005 at 6-hourly intervals is used for this study, obtained from both the AMPS database located at Ohio State and the more extensive AMPS archive at the NCAR mass storage system (MSS). A simplified manual identification of cyclogenesis is undertaken, with cyclones that develop at least 2 closed surface pressure isobars (2 hPa contour interval), and are sustained for 12 hours, in the region bounded by 140°E-160°E and 60°S-coast being identified as undergoing genesis.

A total of 132 cyclogenesis events are manually identified (MAN) over the three-year period, compared with 202 systems identified with the automatic tracking scheme (AUTO). The systems identified in MAN are real, as only 5 are not accounted for in AUTO. The systems in MAN not found in the study area in AUTO are generally found west, north, or east of the study area, depending on the development pattern of the system. Those systems found in AUTO not identified in MAN are either weaker, less-defined systems, or can be described as “open wave” systems.

Therefore, the systems in MAN are a subset of well-defined systems that can be used to study the physical mechanisms involved in cyclogenesis. For the most part, the systems can be described by four patterns of development. Two of these development patterns occur near the coast, and are discussed further here.

a. Type I Development

Fifty-three Type I cases are identified throughout the three-year study period. Figure 2 shows the composite surface pressure field for Type I cyclogenesis cases. These systems form on the leading edge of dissipating systems to the west. The new systems propagate in a general easterly direction while the existing system remains nearly stationary and continues to dissipate. The composite surface wind field 6 hours prior to cyclogenesis is shown in Fig. 3. Southerly winds are prominent over Adélie Land near 142°E, associated with the persistent katabatic wind regime, although modified by the synoptic-scale weather systems in the area. Offshore, an easterly jet of almost 20 m s^{-1} is situated along the coast. Calculations of the Froude Number for the region and analysis of the momentum forcing terms from the horizontal equations of motion (not shown) indicate that the forcing for the easterly jet results from the development of barrier winds and from the offshore adjustment of katabatic winds.

The development of an easterly jet along the Antarctic coast, associated with generally westerly flow to the north in the northern sector of the developing cyclone, leads to enhanced values of low-level vorticity. Figure 4a shows a cross-section of relative vorticity at 1800 UTC 8 July 2005. The strongest values of cyclonic vorticity are restricted to the lowest 1 km height, consistent with the vertical extent of barrier wind forcing. Therefore, it is apparent that the development of a coastal low-level easterly jet through barrier wind and katabatic wind forcing leads to enhanced cyclonic vorticity and cyclone development.

Other factors are also involved in cyclone development along the Antarctic coast at 150°E. To explore more detailed features, a case study has been selected from July 2005. Figure 4b shows the potential temperature, pressure, and wind field at 150 m height at 1800 UTC 8 July 2005, with cyclogenesis deemed to occur 6 hours later. The meridional temperature gradient is strengthened in the vicinity of the cyclone development. This is the result of cold air entrained into the easterly jet along the coast, both from the east and from drainage flow off of Adélie Land, and from warm air advection from the northwest in the northern sector of the developing cyclone. These temperature advection patterns are likely responsible for the strong time-averaged baroclinicity and meridional temperature gradient in this region from Lim and Simmonds (2007). The strong low-level baroclinicity is supportive of cyclone development in the region through baroclinic instability. Upper-level effects, analyzed through 500 hPa vorticity advection and mid-tropospheric Q-vector convergence, show that upper-level support is often present in cyclogenesis events (not shown). However, case study analysis shows that the magnitude of upper-level support varies, and is not necessary for initial cyclone development.

Figure 5 shows the evolution of the 53 Type I systems as depicted by the automatic tracking scheme. Twenty-seven systems form to the west of the study area (west of 140°E), and 40 systems form as "open" systems. Hence, identification of Type I systems in the automatic tracking scheme occurs in the barrier wind-modulated pressure gradient on the leading (eastern) edge of a dissipating cyclone. Manual identification of these systems occurs farther to the east, once they have closed off and separated from the dissipating system. Some of the new systems are short-lived, and contribute to the cyclolysis region west of 160°E in Fig. 1b. Otherwise, these systems generally spiral southeastward into the Ross Sea and coastal Marie Byrd Land.

b. Type II Development

Thirty Type II cases are identified throughout the three-year study period. Figure 6 shows the composite

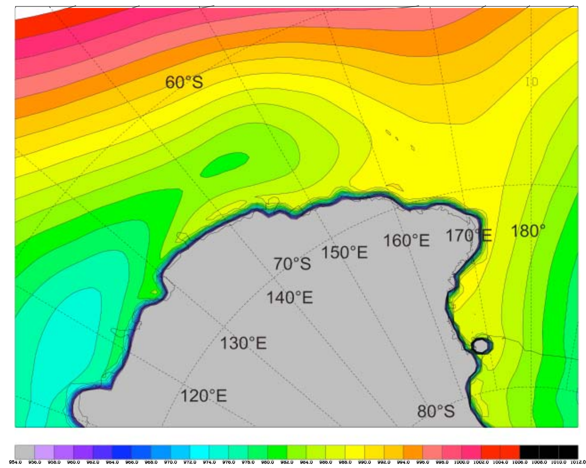

Figure 2. AMPS Type I 53-case composite surface pressure (hPa) at cyclogenesis.

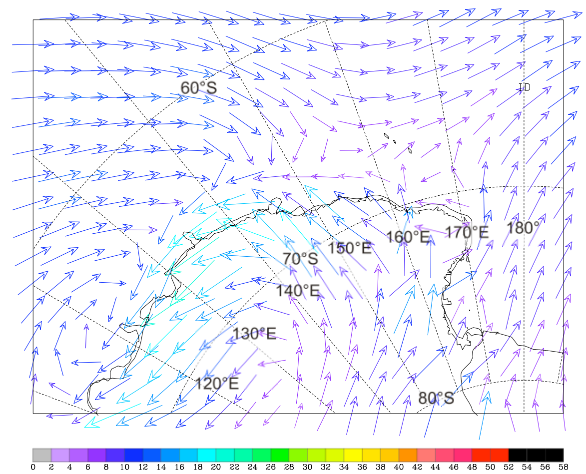

Figure 3. AMPS Type I 53-case composite surface wind vectors and speed (m s^{-1}) 6 hours prior to cyclogenesis.

surface pressure field for Type II cyclogenesis cases. The systems form along the immediate coast, in what appears to be a lee-trough that extends eastward into the Ross Sea. Figure 7 shows the composite surface wind field 6 hours prior to cyclogenesis. Strong winds of about 25 m s^{-1} are found over Adélie Land, which, based on Fig. 6, are likely synoptically supported katabatic winds.

The primary development mechanism responsible for Type II development is lee cyclogenesis. Figure 8 shows the 500 hPa geopotential height and surface pressure composites for Type II development. It can be seen that the surface system forms in association with an upper-level trough just to the south. Lee cyclogenesis occurs in conjunction with an increase in relative vorticity as flow descends sloping terrain (vortex stretching). However, the generation of low-level cyclonic vorticity in association with the katabatic winds may ultimately provide the most favorable location for cyclogenesis to occur. Cyclone development occurs on the cyclonic-shear side of the katabatic jet. The result is a mechanical “spin-up” of low-level vorticity along the coast. Baroclinic development does not occur for Type II development, at least not in the initial stages, as an equivalent barotropic environment is often established.

Figure 9 shows the evolution of the 30 Type II systems as depicted by the automatic tracking scheme. Eleven of the 30 systems form to the east of 160°E in the automatic tracking scheme. In contrast to Type I systems, Type II systems are manually identified earlier in development than in automatic tracking. At initiation, these systems often have weaker pressure gradients compared to Type I systems, and will not be identified in the automatic tracking scheme, which measures the Laplacian of the sea-level pressure. Four of the five unmatched systems fall into this category.

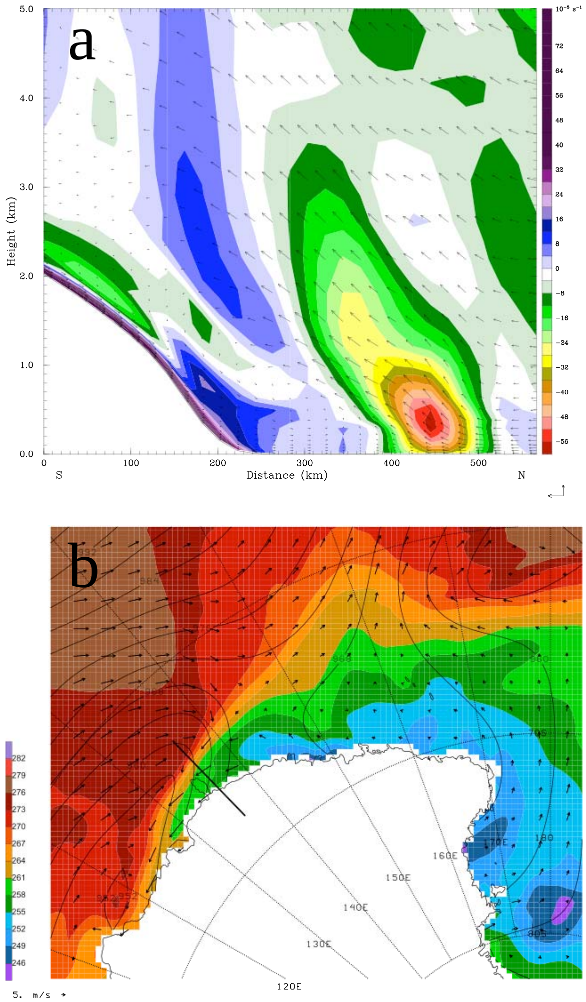

Figure 4. a) Vertical cross-section of circulation vectors (black arrows) and relative vorticity (10^{-5} s^{-1}, color shaded) at 1800 UTC 8 July 2005. b) Pressure (hPa, black contours), potential temperature (K, color shaded), and wind vectors (m s^{-1}, black arrows) at 1800 UTC 8 July 2005. Cross section line used in a).

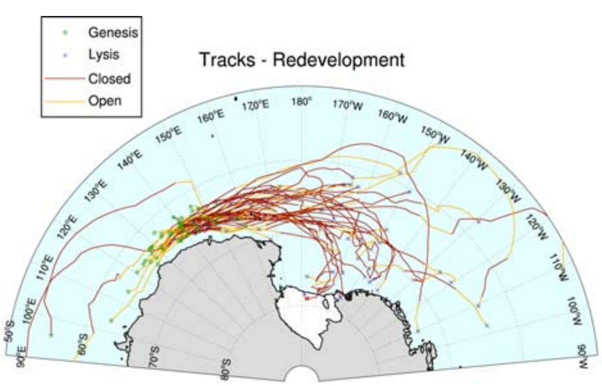

Figure 5. Tracks of Type I systems.

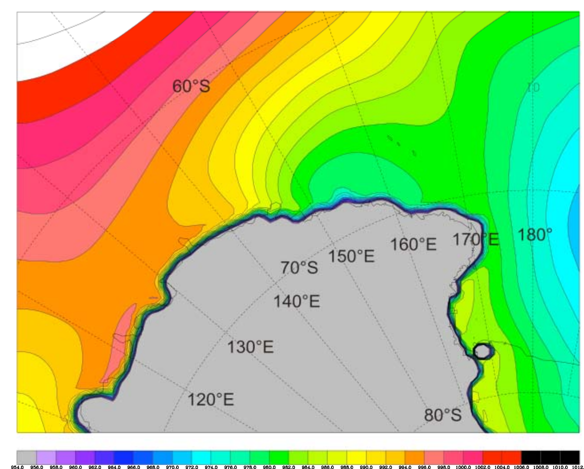

Figure 6. AMPS Type II 30-case composite surface pressure (hPa) at cyclogenesis.

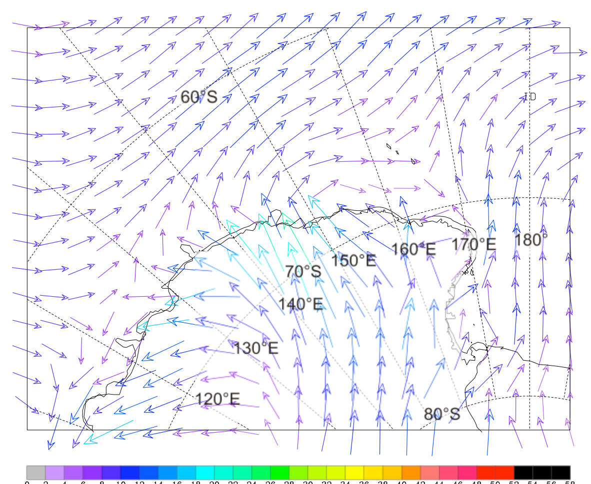

Figure 7. AMPS Type II 30-case composite surface wind vectors and speed (m s^{-1}) 6 hours prior to cyclogenesis.

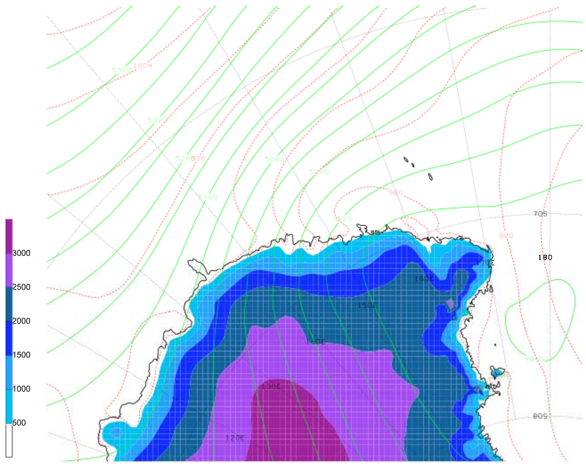

Figure 8. AMPS Type II 30-case composite 500 hPa geopotential height (gpm, solid green contours) and sea level pressure (hPa, dashed red contours) at cyclogenesis.

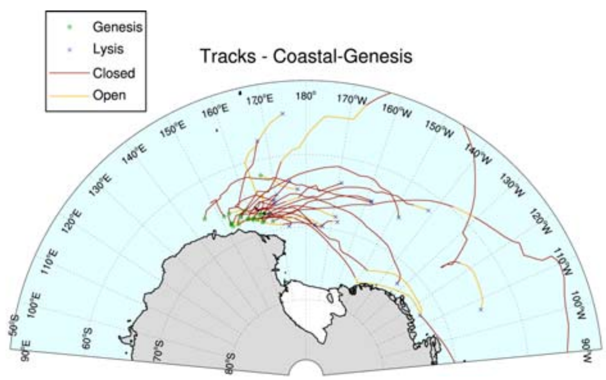

Figure 9. Tracks of Type II systems.

These systems tend to have shorter tracks than Type I systems, with most dissipating in the northern Ross Sea.

4. CONCLUSIONS

The low-level wind regime is a prominent factor in cyclone development for both Type I and Type II cases. For Type I development, barrier winds and katabatic winds interact to form a low-level easterly jet along the Antarctic coast that leads to enhanced regions of low-level vorticity and baroclinicity that are favorable for cyclone development. In Type II development, low-level vorticity is enhanced on the cyclonic-shear side of the Adélie Land katabatic jet. The inference that cyclogenesis occurs in conjunction with an existing system is supported for both types of development, as upper-level support is present. However, at least for Type I systems, the initial cyclone development can be restricted to low levels, with vertical development only required for further development and propagation of the system. The use of AMPS, a mesoscale model tailored for the polar environment, is necessary in order to study the physical development mechanisms associated with cyclogenesis in coastal Antarctica. Automated cyclone tracking studies utilizing global reanalyses can only infer possible reasons for cyclone development based on the time-averaged basic meteorological conditions.

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