Analysis of Surface Winds at Mawson, Antarctica

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(Manuscript received 18 January 2000, in final form 1 March 2001)

ABSTRACT

An analysis is made of the wind regime at Mawson, Antarctica, to distinguish the meteorological characteristics leading to the gale force winds associated with blizzards as distinct from calm conditions or the relatively moderate and fairly steady surface katabatic winds. Investigation of relationships between the surface and midtropospheric winds over Mawson reveal that strong upper-level winds do not necessarily strengthen the surface wind, reinforcement of which varies with upper wind direction and season. Blizzard, katabatic, and calm wind categories and combinations of these are defined to allow investigation of different characteristics of winds. The importance of considering the katabatic near-surface jet component, which generally strengthens the surface wind, is demonstrated for categories of both weak and strong winds. Features of development in the midtropospheric flow during and 48 h prior to occurrences of blizzard, katabatic, and calm conditions are highlighted. Upper-level forcings associated with blizzard or calm conditions are related to slow-moving high pressure cells downstream. Similarities in forcing mechanisms of calm and katabatic periods suggest a relationship with the efficient drainage of low-level air, although there is evidence that upper-level opposition to the surface flow produces calm conditions.

1. Introduction

There have been numerous observations of strong downslope winds along short stretches of the Antarctic coast (e.g., Shaw 1957; Dzerdzeevskii 1960). At some locations, such as Mawson station (67°36′S, 62°53′E) on the East Antarctic coast (Fig. 1), the drainage flow is fairly constant (Streten 1962), which is attributed to the influence of inland and coastal topography. Picturing the East Antarctic continent as domelike in shape, with the interior plateau characterized by terrain heights exceeding 2000 m and terrain slopes less than 2 × 10⁻² (as defined by Dalrymple 1966), and bordered at its coastal margins by much steeper terrain, the drainage of cold, dense air from the interior toward the coast must be generally divergent because the “local circumference” of the dome increases with distance from the interior. However, this pattern of divergence is disturbed by the presence of terrain features that cause convergence of low-level air and formation (upstream of the coast) of a pool of cold air. When this negatively buoyant air flows toward the coast, it may cause strong and persistent winds (Bromwich and Kurtz 1984; Parish 1984).

Winds in the coastal region of East Antarctica are driven also by synoptic-scale systems (e.g., Rusin 1961; Streten 1961; Phillpot 1997) that superimpose gradient winds over the low-level mesoscale flow. The strongest winds are generally forced by offshore cyclonic vortices that move primarily “around the coast” from west to east, as components of the semipermanent trough of low pressure that encircles the Antarctic continent. When in the appropriate location, these depressions can reinforce the drainage flow at the coast (Ball 1960; Streten 1962). Prolonged periods of strong winds are associated with synoptic disturbances, in contrast to pure drainage flow, which does not persist for extended periods due to exhaustion of the upstream supply of air (Streten 1968).

With the two main forces that drive the winds in coastal East Antarctica identified (mesoscale katabatic and synoptic cyclonic), they shall be used in later sections to define categories of winds, analyze their accompanying meteorological characteristics, and investigate relationships that may be useful in forecasting winds at Mawson station. However, before detailed in-
vestigation of specific wind types, the first step, in section 2, is to investigate relationships between midtropospheric and surface winds using the Antarctic upper wind (AUW) data from the Australian Bureau of Meteorology observed over Mawson station from 1954 to 1987.

In section 3, nine categories of wind are defined and their respective characteristics are discussed, expanding on the analyses of winds presented in section 2. Analyses of AUW, surface, and Radiosonde data at Mawson, with an extensive meteorological record (1954–87), are carried out to establish climatological features of the three main wind categories: katabatic, blizzard, and calm. In section 4, the Australian Bureau of Meteorology’s Southern Hemisphere Analyses (SHANAL) covering a period of 16 yr (1972–87) are used to compute anomalous synoptic patterns corresponding to katabatic, blizzard, and calm conditions observed at Mawson. Anomalous patterns prior to these events are also examined, allowing identification of features that indicate potential development of each wind type. Results are summarized in section 5. Throughout the present work, the months of January and July are used as representatives of summer and winter, respectively.

2. Midtropospheric forcing of the surface wind

Streten (1990) showed that the average winds at 500 hPa over Mawson vary from strong westerlies during winter to relatively weak easterlies in the peak of summer. At the surface, however, analysis of observations at Mawson (Fig. 2) shows that the prevailing wind direction is close to slightly east of southeast throughout the year, similar to that found by Phillpot (1967). During winter the downslope flow of dense air is typically close to southeast, while during summer the flow is east of southeast, reflecting the greater cross-slope component, in agreement with seasonal patterns shown by van Meurs and Allison (1986). These variations may be explained by the katabatic force (Ball 1960), which is stronger during night/winter when the air is cool and the inversion strength is a maximum. While Fig. 2 may be used to imply weak synoptic support for the surface flow during summer, the relationship between the wind at 500 hPa and that at the surface is more complicated during winter, with the wind turning by about 120° between the surface and midtroposphere. It is well known that the underlying topography influences significantly the direction of the surface wind over the Antarctic continent, so it can reasonably be concluded that throughout the year the synoptic wind is a secondary influence on the direction of the surface wind at Mawson. The presence of a temperature inversion over Mawson complicates the scenario further by inhibiting vertical exchange of momentum. Also, the turning of the wind with height within the boundary layer is enhanced with greater atmospheric stability (Haltiner and Martin 1957).

The aim of the following analysis is to examine the influence of the midtropospheric wind on the surface wind. This may be useful in increasing predictability of winds at the surface. The difficulty in achieving this task has been noted previously; Shaw (1960), among others, found that the surface winds can be quite independent of synoptic forcing. However, it must be remembered that a situation that leads to generation of katabatic flow is itself a feature of a synoptic-scale system. For example, a high pressure cell imposing only light winds over the continent allows longwave radiational cooling of the surface and development of a pool of cold, dense air that is capable of supporting a strong gravity-driven downslope wind. In such a situation, there may be very little correspondence between the surface and upper-level winds, but there may be a relationship that can be identified. Therefore, a primary aim of the following analysis is to increase our understanding of the nature of the vertical profile of winds over Mawson.

For each wind speed, to the nearest integer in meters per second, at the 500-hPa level, mean corresponding wind speeds at the surface were computed for January and July, as representatives of summer and winter, respectively. Relating the surface and 500-hPa-level winds using linear regression results in

\[ V_{\text{SURFACE}} = a + bV_{500} \]

where \( V_{\text{SURFACE}} \) is the wind speed at the surface and \( V_{500} \) is the wind speed at the 500-hPa level. A positive gradient, \( b \), in Fig. 3a indicates that momentum is transported from the synoptic-scale flow to enhance the sur-
Fig. 2. Percentage frequencies of wind directions at the surface and 850, 700, and 500 hPa over Mawson during (a) Jan and (b) Jul. C denotes calm.

face-level flow; a stronger wind at 500 hPa implies a stronger wind at the surface. It is obvious that, for the mean monthly case, this occurs only during January. Otherwise, the winter and annual cases both show weak negative gradients. Loewe (1974), Wendler et al. (1993), and Parish (1992) noted that the strong inversions over Antarctica (Phillpot and Zillman 1970) can hinder the transfer of momentum from upper levels to the surface. Therefore, the presence of a strong inversion during winter and the relative lack of inversion over Mawson during summer may be used to partly explain the differences in these gradients. Further explanations are given below. Figure 3b shows that the highest occurrence of a wind speed at 500 hPa during winter is that corresponding to 11 m s$^{-1}$, while during summer the highest occurrence is for a 6 m s$^{-1}$ wind. However, Fig. 3a has shown that the influence of these winds on the surface wind differs with season and they are therefore not necessarily indicative of surface wind strengths. The analysis is now extended to account for wind direction.

Momentum transfer from the midtroposphere to the surface was examined in more detail by dividing the 500-hPa-level winds into categories defined by wind direction. Observed wind directions at the 500-hPa level during January and July were separated into octants and, as previously, for each integer wind speed at the 500-hPa level, mean corresponding wind speeds at the surface were computed for January and July. The first octant consists of winds from 0° to 44°, octant 2 of directions 45° to 89°, and so on, with each octant encompassing 45° of wind direction, up to octant 8, which covers directions 315° to 359°. Relationships between surface and midtropospheric winds were found to differ depending on the wind direction at 500 hPa as well as on the season. The gradients representing relationships between upper-level and surface winds for each octant, each station, and January and July are given in Table 1, summarizing the relations displayed in Figs. 4 and 5. The relative importance of each octant is indicated by the percentage frequency occurrence of wind direction falling within each sector, as shown in Fig. 6.

There is generally efficient transport of momentum from the midtropospheric level to the surface wind during summer over Mawson station, but differences are evident depending on the upper wind direction. When winds blow from octants 6 and 7 (southwesterly to northwesterly), the surface wind speed is not enhanced during summer. During winter the situation is clearly
different (Fig. 5). Octants 1, 2, 3, and 8 have corresponding positive gradients, while the remainder are negative (Table 1). The magnitudes of the positive gradients for octants 1 and 2 are larger than the gradients of any octants during summer, yet overall a negative gradient was found for winter (Fig. 3a). This is because the majority of the July 500-hPa wind directions are in octants 6 and 7 (Fig. 6) meaning significant westerly components and therefore opposition to the downslope flow, which is predominantly near southeasterly at Mawson. The deviations represented by the error bars in Figs. 4 and 5 demonstrate the difficulties in establishing relationships between synoptic and surface winds under highly variable atmospheric conditions, complicated further by the apparently independent (Shaw 1960) mesoscale-katabatic flow.

Negative gradients are less likely to be found during summer even for midtropospheric westerly winds because not only do such winds occur less frequently, but they are weaker in summer than in winter, when upper-level westerly winds are strengthened due to the strong circumpolar circulation. To generalize, during summer over Mawson, it appears that the surface wind speeds are enhanced by easterly winds, but unaffected by westerlies, and during winter the surface winds are strengthened by easterlies but weakened by westerlies.

Using the data in Table 1 and Figs. 4 and 5 to estimate the surface wind speed relative to the midtropospheric wind, the contribution of the mesoscale-katabatic flow can be implied. The nonzero surface wind speeds corresponding to the 500-hPa level wind speed of 0 m s⁻¹ in Figs. 4 and 5 (and parameters a in Table 1) show that synoptic forcing is not the only significant influence, the other being the drainage of cool, dense air from the interior of the continent. This drainage can account for surface wind speeds of 5–10 m s⁻¹ during summer, and about 10 m s⁻¹ during winter. These magnitudes indicate the need to examine the wind regime at Mawson in more detail, in particular, the near-surface katabatic flow. This section has demonstrated some simple relationships between surface wind strengths and the synoptic scale. Section 4 builds on these relationships, and on the wind regime discussed in the following section, to provide information that is potentially useful for prediction of winds at Mawson.

3. Characteristics of surface winds

In the previous section, only the wind speed, direction, and season were considered in the investigation of relationships between midtropospheric and surface winds at Mawson. In this section, the shape of the vertical profile and strength of winds are used to define distinct categories of wind in order to examine the nature of the different forcings (mesoscale katabatic and synoptic) and associated atmospheric characteristics. Three main wind types are defined—katabatic, blizzard, and calm—with six additional subcategories used to further describe the wind regime at Mawson.

There is a wide range of usage for the term “katabatic

![Fig. 3. (a) Wind speed (WS) at 500 hPa vs the mean corresponding surface wind speed for Jan (solid), Jul (dash), and annual (circle), at Mawson. (b) Percentage occurrences of wind speeds at 500 hPa for Jan (solid), Jul (dash), and annual (circle).](image-url)
wind” in the literature so here the following terminology is employed. The term katabatic is defined as a wind that flows downslope (due to negatively buoyant air being acted upon by gravity) with a vertical profile that possesses a near-surface jet, such that the wind speed measured at some level near the surface is greater than the wind speed at the adjacent level above. Generally, a katabatic wind’s low-level wind maximum is located within the lowest 100 m of the atmosphere, but the AUW dataset has only one measured level below about 370 m—the anemometer 9 m above the ground. Despite the lack of high spatial definition in the wind speed profile, it was felt that the available data were reasonably good indicators of the presence of katabatic winds.

Definition of the katabatic wind category is necessary because Mawson, located at the foot of an ice slope, is subject to predominant downslope airflow from the high
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Fig. 5. As in Fig. 4 but for Jul.

plateau interior. Such a location can be considered typical in regard to coastal katabatic winds, comparable with other Antarctic locations such as Mirny, Casey, Port Martin, and Cape Denison. Inclusion of the near-surface jet feature is important in consideration of the cold, dense gravity-driven downslope drainage currents that occur independently of vertical transfers of momentum from the synoptic scale.

Blizzard winds usually refer to strong winds accompanied by blowing snow, but here the term blizzard refers to wind speeds at the surface that equal or exceed 15 m s$^{-1}$, irrespective of whether blowing snow is observed at the station, which is at the edge of an extensive blue ice ablation zone that sometimes can be largely swept clear of loose snow. The blizzard wind category is selected to examine characteristics and forcings of the strongest winds; 15 m s$^{-1}$ is a somewhat arbitrary cutoff point, but it is reasonable for Mawson because the monthly mean January and July surface wind speeds are 9.0 and 10.6 m s$^{-1}$, respectively. Table 2 summarizes the January and July characteristics of the katabatic, blizzard, and calm (defined below) conditions, relative
to “average” conditions (all valid data regardless of wind characteristics) at Mawson station.

In general terms, blizzard winds at Mawson are usually relatively warm and moist and are associated with cyclones that are situated to the north or northeast of the station, directing upper-level air from the east, resulting in surface wind directions that are generally east of the southeast fall line by about 5°–10°. Winds are strong and the corresponding cloud amounts are large. In contrast, katabatic winds bring cool, dry air from over the continent, approaching Mawson from south of the fall line. There may be less cloud and greater visibility, although these characteristics are not statistically significant. Analysis of radiosonde data shows that the column of air at Mawson has greater thermal stability when katabatic winds are blowing.

“Calm” conditions are defined to be those of zero velocity surface winds. Calms are characterized by relatively high visibilities and low cloud amounts, but again these features are not supported by statistical significance tests. Temperatures are relatively high during summer because incoming solar radiation heats the surface and the lack of advection (from the interior plateau) prevents cooling. During winter, the combination of longwave radiative cooling and the lack of advection and mixing of air during calm conditions allows surface

<table>
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<th>Wind type</th>
<th>WD</th>
<th>WS</th>
<th>T</th>
<th>P</th>
<th>VIS</th>
<th>CLD</th>
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<td>Overall avg</td>
<td>121.6</td>
<td>126.2</td>
<td>9.0</td>
<td>10.6</td>
<td>0.3</td>
<td>−18.2</td>
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<td>Blizzard deviation</td>
<td>−5.9</td>
<td>−7.3</td>
<td>+8.6</td>
<td>+8.6</td>
<td>−0.3</td>
<td>+2.9</td>
</tr>
<tr>
<td>Katabatic deviation</td>
<td>+9.4</td>
<td>+2.6</td>
<td>+0.6</td>
<td>+1.8</td>
<td>−1.2</td>
<td>−1.2</td>
</tr>
<tr>
<td>Calm deviation</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>+0.8</td>
<td>−4.4</td>
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air temperatures to fall. It is expected that the pressure may rise when calm conditions are present at Mawson for both January and July, whereas during blizzard winds the pressure may be expected to fail.

Vertical profiles of wind speed corresponding to average, katabatic, blizzard, and calm conditions are shown in Fig. 7 for January and July. Although these profiles are largely determined, at least near the surface, by the definitions of the specific wind types, they provide useful information. During January, average, katabatic, and calm winds all have similar synoptic (5000-m level) strength forcings. Therefore it is difficult to predict the type of wind at the surface based on upper-level wind speeds. Katabatic and calm profiles are quite similar between 1000 and 5000 m above the surface, yet the difference in mean wind speeds at the surface is about 10 m s$^{-1}$. The average and blizzard profiles show nonkatabatic low-level wind maxima about 400 m above the surface. This feature is less defined during July, due to the contribution of the near-surface katabatic jet, which is stronger (Fig. 7b) and has a greater percentage occurrence than in January (Fig. 8). Although the wind is predominantly downslope at Mawson, the shapes of the average profiles show that the katabatic near-surface jet is not the usual characteristic (Fig. 7). During summer, the blizzard profile is stronger than any other at all levels but this clarity is somewhat absent during winter, with very similar mean wind speeds between 4000 and 5000 m for average, katabatic, and blizzard profiles. The difficulty in using midtropospheric winds to forecast surface winds during winter is further illustrated by the wind speed at 5000 m, which is greater corresponding to calm surface conditions than it is for profiles that exhibit blizzard conditions at the surface. In both January and July, the surface wind within the katabatic profile is stronger than at any other level up to 5000 m, again reflecting the mesoscale origin of the katabatic. Although the approach has been different, these results are in good agreement with those of section 2.

Figure 8 shows monthly mean surface wind speeds and percentage occurrences of various categories of wind at Mawson station. Time variations in surface wind speed presented by Russell-Head and Simmonds (1993) showed that very strong wind events occurred for only short periods. These winds fall into our blizzard category, which has an occurrence of around 20%–30% (Fig. 8). Calm winds occur 5%–10% of the time, with minima during autumn and spring when the mean monthly surface pressures are lowest and cyclones moving past Mawson are most frequent. The inclusion of these extreme (blizzard and calm) wind types in the average wind category prevents realistic representation of the “usual” strength of the wind at Mawson. An additional category of wind is defined that includes all winds but blizzards and calms: nonblizzard–noncalm. This is shown in Fig. 8c to have a high percentage occurrence, from about 60% to 80%. Blizzard, calm, and nonblizzard–noncalm wind types are mutually exclusive and their percentage occurrences per month add to 100%. The monthly mean wind speeds of the nonblizzard–noncalm category are below those of the average by 1–2 m s$^{-1}$ (Fig. 8a), suggesting that the inclusion of strongest winds in computing the mean wind speed may overestimate the strength of what may be considered the typical surface wind at Mawson.

To further examine properties of the katabatic near-surface jet in relation to mesoscale and synoptic forcings, subsets of the blizzard and katabatic categories are defined. Winds of blizzard strength are separated into two sets depending on the presence of a near-surface katabatic jet: blizzard–katabatic and blizzard–nonkatabatic. Figure 8b shows that consideration of the near-surface jet allows clear separation of the monthly mean
wind speeds of these blizzard subcategories. The blizzard–katabatic is stronger than the blizzard–nonkatabatic throughout the year with greatest differences during midwinter of 2–3 m s\(^{-1}\). It is interesting that the (strong wind) blizzard category is linked to cyclonic forcing yet it is strongest when it features the near-surface jet, which is characteristic of a mesoscale contribution. However, the blizzard with near-surface jet occurs about half as often as does the blizzard–nonkatabatic case (Fig. 8d) suggesting that a combination of cyclonic and katabatic winds is not the usual cause of strong winds but is certainly not rare, with an occurrence of about 10% of all observations during winter. The blizzard–katabatic wind has the greatest monthly mean wind speed of any category considered here. This wind is forced to some degree by cyclones, but it also possesses some characteristics of the katabatic, in addition to the obligatory presence of a near-surface jet. The surface wind direction has a more southerly component of flow than that associated with the mean blizzard wind type, but more easterly than the pure katabatic.

The analysis is extended by dividing winds below blizzard strength into two categories. Neglecting calm conditions, the resultant categories may be labeled nonblizzard–noncalm with near-surface jet and nonblizzard–noncalm without near-surface jet. Again it is found that winds are strongest when the vertical profile of wind speed exhibits a near-surface katabatic jet (Fig. 8b). Also, winds without the near-surface jet are most common for the types considered in Fig. 8d.

When forecasting at Mawson, it is necessary to consider the katabatic contribution, in addition to winds driven by passing cyclones. It is therefore important to be able to recognize the large-scale forcing patterns that lead to both blizzard and katabatic winds. Additionally, given that the katabatic component is important, it is necessary to differentiate the fairly similar patterns associated with katabatic and calm conditions. These problems are discussed in the following section.
Fig. 9. Percentage frequencies of wind directions at 500 hPa during Jan and Jul, calculated from the AUW dataset for categories of wind at Mawson: (a) and (b) average, (c) and (d) blizzard ($\geq 15$ m s$^{-1}$), (e) and (f) katabatic (nearsurface jet), and (g) and (h) calm (0 m s$^{-1}$). C denotes calm.

4. Large-scale patterns corresponding to blizzard, katabatic, and calm surface winds

In this section, relationships between 500-hPa-level winds and three specific types of surface wind, blizzard, katabatic, and calm, are investigated. This expands on section 2, where relationships between midtropospheric and surface winds were examined, and section 3, which contains a climatology of various categories of surface wind and related mesoscale katabatic and synoptic forcings. The AUW and SHANAL datasets are used to compute climatological mean 500-hPa-level wind direction frequencies and synoptic pattern composites corresponding to the three wind categories. Mean anomalous synoptic conditions are illustrated and variations in synoptic fields 48 h prior to the occurrence of each surface wind category are described.

The important link between the direction of the midtropospheric wind and the surface wind speed was demonstrated in section 2. Figure 9 expands on this earlier analysis by relating wind directions at the 500-hPa level to different types of surface wind. For both January and July the upper-level wind directions associated with surface blizzard conditions are generally easterly (Figs. 9c and 9d), although this pattern is less certain during winter, with relative reductions in frequencies of directions ranging from northeasterly to southeasterly and small increases in frequencies of directions ranging from southwesterly to northerly. The predominant midtropospheric wind directions present during both katabatic and calm surface conditions are southwesterly to westerly (Figs. 9e-h). During January, upper-level wind directions corresponding to the average wind category (Fig. 9a) show signals indicative of blizzard, katabatic, and calm wind types but this changes to largely westerly during winter (Fig. 9b). This suggests that conditions at the surface during July are well represented by the katabatic and calm types relative to the occurrence of cyclonically forced blizzards during January. This may be so because although there is evidence that blizzards are forced mainly by cyclones (shown by the easterly signal in Fig. 9d, in agreement with section 3), the strength of the katabatic is greater during July than January, which must partly account for an increase in the average category’s monthly mean wind speed (Fig. 8a), regardless of direct cyclonic forcing.

Superimposed on the mean atmospheric circulation
Fig. 10. (a) The 500-hPa-level anomalous heights 2 days prior to occurrence of blizzard conditions at Mawson station during Jan. (b) The 500-hPa-level anomalous heights corresponding to blizzard conditions at Mawson station during Jan. Contour interval is 5 m. Stippled regions indicate statistically significant differences from average/all-wind conditions at the 95% confidence level, as computed using Student’s *t*-test. The solid square shows the location of Mawson station.

Fig. 11. As in Fig. 10 but for Jul.

are synoptic variations associated predominantly with the movement of offshore cyclones around the continent from west to east concentrated in the region of the mean sea level pressure trough. The synoptic variations associated with these systems can be represented by anomalies from mean heights of the 500-hPa level showing the patterns of transient high and low pressure cells varying around the continent and the Southern Ocean. The AUW dataset was used to determine the dates and times of each of the three wind types at Mawson station. Composites were then constructed from the SHANAL dataset based on these dates and times.

Mean anomalous heights of the 500-hPa surface prior, to, and corresponding to, blizzard conditions are shown in Figs. 10 and 11 for summer and winter, respectively. As found in section 3 from analysis of observations over Mawson, the mean situation during blizzard conditions is easterly flow over the station associated with the approach from the west of a deep cyclonic pattern. Figure
10 shows the movement of a cyclonic anomaly from about 50°E, northwest of Mawson, to about 70°E, north of the station, at the time of the blizzard event, in general agreement with the findings of Phillpot (1997). This is accompanied by an anomalous high pressure region north of the coast at around 110°–120°E, with a ridge extending over the Antarctic interior to the south of Mawson. This feature is statistically significant and offers the potential for the forecasting of blizzard type winds at Mawson. As the low moves eastward throughout the 48-h period, the anomalous ridge is approximately stationary, although it weakens. The presence of this pattern has the effect of strengthening the gradient easterlies directed over the station. Throughout this period, the wind direction suggested by the anomalous 500-hPa-level field is maintained close to easterly. Unfortunately, the highly variable nature of the atmosphere in this region limits the establishment of statistical significance, particularly in relation to events involving cyclones, which are frequently observed features around the Antarctic coast. The difference in definitions of times of wind events between the AUW and SHANAL datasets is also a limitation.

There are similarities with summer (Fig. 10) in the pattern of development during winter (Fig. 11), except that neither the ridge nor the anomalous low are as well defined 2 days prior to the event. Again, a low anomaly in the height of the 500-hPa surface approaches from the west (40°–70°E) and deepens over the 48-h period. The wind direction turns from approximately northeast to east. A high anomaly to the east, over the continent at around 90°E, supports a tightening of the synoptic gradient. The easterly winds shown by the anomalous 500-hPa-level fields during blizzard conditions (Figs. 10 and 11) are in good general agreement with the AUW dataset (Figs. 9c and 9d).

Summarizing for the blizzard case, anomalous ridging over the continent is important during summer 48 h prior to a blizzard event (Fig. 10a), while during winter, an anomalous low (Fig. 11b) north of Mawson, along with an extensive trough far to the east are significant signals. Generally, the movement of a low from the northwest to northeast, accompanied by anomalous ridging over the continent suggests the possibility of blizzard conditions at Mawson, in agreement with the work of Ball (1960), Stretten (1990), Parish et al. (1993), and Phillpot (1997). Complementary consideration of statistically significant features identified here offers the potential for improved forecasting of blizzard winds.

In contrast to the blizzard situation, the anomalous 500-hPa height fields corresponding to katabatic winds show practically a complete reversal (Figs. 12 and 13), with a statistically significant eastward-moving anomalous high north of Mawson, a weakening in the easterly flow, and a low anomaly to the southwest extending over the continent. During January, southwesterly flow turns to westerly as a high anomaly moves eastward to a position north of the station (Figs. 12a and 12b). The eastward movement of a high anomaly also occurs in July. Differences are that, at the beginning of the 48-h period, the high anomaly at about 30°E was relatively weak, as was the 500-hPa-level wind over the station (Fig. 13a). Importantly, though, there is a statistically significant anomalous trough oriented north–south over Mawson during this time prior to the katabatic event.
This is linked to the low anomaly centered on the coast at around 5°E, far west of Mawson (Fig. 13a), which deepens and is partly responsible for the westerly flow over the station in combination with the high to the north at around 60°E at the time of the event (Fig. 13b). There is reasonably good agreement between the SHANAL (Figs. 12 and 13) and AUW (Fig. 9) midtropospheric wind directions corresponding to katabatic wind events. Despite this agreement and the identification of a number of significant features, the apparent independence of strong near-surface katabatic winds (Shaw 1960; Streten 1963) limits establishment of statistical significance using midtropospheric anomalies.

For calm conditions, the anomalous 500-hPa-level flow is approximately westerly with a high pressure anomaly north of Mawson for both January and July (Figs. 14 and 15). Similarities with the katabatic case can be seen in the approach of high anomalies from the west. During January a statistically significant high anomaly at around 40°E (Fig. 14a) moves southeastward
to about 65°E during the 48 h prior to a calm event, while intensifying and developing a relatively strong westerly flow over Mawson (Fig. 14b). In contrast, the case for the January katabatic case shows neither intensification of the anomaly nor the very strong westerly flow (Fig. 12). This is interesting because the pattern corresponding to the calm conditions does not have the benefit of a low anomaly positioned to the southwest, as in the katabatic situation, which may be expected to reinforce the westerly flow. During July, both the katabatic and calm cases (Figs. 13 and 15, respectively) show approach from the west, and intensification, of a relatively weak high anomaly during the 48-h period. Westerly flow is statistically well supported over Mawson during the July calm event by the presence of an extensive anomalous trough over the continent. It may be conjectured that the calm conditions follow the katabatic conditions, with the position of the high anomaly corresponding to the calm about 10°–20° of longitude farther downstream than in the case of the katabatic, at both 48 h prior (30° vs 50°E) and during the respective events (60° vs 70°E). There is also the possibility that calm conditions develop due to exhaustion of the inland supply of cold air necessary for katabatic flow. However, there are significant differences elsewhere in the anomalous 500-hPa-level patterns to suggest that calm and katabatic events occur under quite unrelated synoptic conditions.

Up to this point, synoptic features that are related to the various categories of wind at Mawson have been shown to approach from the west. In the case of the blizzard it was useful to also consider features located to the east. Mean anomalous 500-hPa heights corresponding to calm events show slow-moving cells as far away as 180° and beyond. During January (Fig. 14), statistically significant anomalous highs are located north of the Antarctic coast at 165° and 230°E. Over the 48 h prior to the calm, these cells are steady in terms of both location and intensity. This near-stationary pattern appears to slow the movement of the anomalous low (125°E), which may slow the movement the high north of Mawson, which is associated with the calm. During July (Fig. 15), a similar pattern of blocking is suggested except that the distant high anomaly is centered at about 175°E and statistically significant anomalous reductions in 500-hPa-level heights are widespread over much of continental Antarctica. Consideration of these features may allow clearer differentiation between development of katabatic and calm conditions than may be possible based on signals present in the AUW dataset alone.

The validity of the results in this section is strengthened by their agreement with the findings of the different analyses in sections 2 and 3, which were based on different datasets. Many of the present results also show statistically significant differences in 500-hPa-level heights to the 95% confidence level. Additionally, the strong wind cases appear to be in broad general qualitative agreement with the observational and modeling results for Adélie Land (140°–145°E) by Parish et al. (1993), the GCM analyses in the region of Casey (66°15′S, 110°32′E) by Murphy and Simmonds (1993), and the observational analyses by Phillpot (1997) for Mawson.

5. Summary and conclusions

The predominant physical factors that directly influence the surface winds in the region of the Antarctic coast at Mawson include the katabatic forcing (which
involves the strength and depth of the inversion layer over the catchment region, and the surface slope), the Coriolis acceleration, the frictional resistance, and the synoptic-scale pressure gradient. Of these the principal forcing factors that change with time are the synoptic pressure gradient and the inland inversion strength. This is because the surface topography is constant and the Coriolis and frictional effects are inherently determined as part of the flow.

The surface and upper air data from Mawson combined with the hemispheric analyses archived by the Australian Bureau of Meteorology have been used to determine clear patterns of forcing for the principal wind regimes at Mawson. The synoptic forcing has a strong annual variation with prevailing midtroposphere (500 hPa) westerlies during winter and a short summer period of mean easterly winds. These different regimes have been portrayed here by results for January and July. The effect of the wind at the 500-hPa level on the surface wind is not limited, or indeed necessarily directly proportional, to the speed, but was found to vary with both direction and season. Division of a set of winds into subsets defined by the presence or lack of a near-surface katabatic jet showed that winds are strongest when the vertical profile of wind speed contains the jet, indicating drainage flow from the continental interior.

Different surface wind regimes (blizzard, katabatic, and calm) are clearly distinguished by the composite anomaly patterns for the 500-hPa level corresponding to the occasions of the different surface wind regimes. These composites were constructed from observational analyses. The results indicate that the strength of the surface wind depends largely on the extent to which the midtroposphere synoptic gradient reinforces or opposes the surface drainage flow. Associated statistically significant features were also identified that offer the potential for improving the forecasting accuracy of the analyzed wind types. Strong surface winds are associated with an anomalous low pressure center north of the station and a ridge of high pressure extending from over the inland plateau region to east of the low. The ridge appears to cause a slowing in the eastward movement of the low and an increase in the horizontal pressure gradient. This causes a strengthening of the midtropospheric easterly flow, with an implied increase in transfer of momentum toward the surface. The average katabatic flow is associated with practically a reversal of that anomalous pattern but, notably, relatively weak upper-level horizontal pressure gradient. Therefore, the near-surface southeasterly katabatic is able to flow without significant opposition from the relatively weak upper westerly wind. Calm surface winds are associated with stronger westerly midtroposphere flow, which opposes the drainage flow, effectively reducing the surface winds to near zero. Reinforcement of this westerly flow appears to be related to slow-moving high pressure cells as far away as 180°E. These cells slow the eastward movement of the low anomaly located at around 120°E. Consequently, there is an increase in the horizontal pressure gradient between the high anomaly approaching Mawson station and the near-stationary low, which produces a strong westerly wind. Although the weather at Mawson is largely determined by the approach of synoptic patterns from the west, consideration of features hundreds of kilometers to the east of the station may allow clearer differentiation between development of katabatic and calm conditions and also aid in prediction of strong winds.

The clear patterns of development of these anomalous synoptic regimes over the period of 2 days prior to the events are also apparent. Similar general types of patterns and developments of strong winds were also found by Murphy and Simmonds (1993) in the region of Casey, near 110°E. However, further work is required to establish with certainty the generality of these results, which may in the future provide additional insight into the prior conditions leading to the different wind regimes, which could be used for forecast guidance and provide a basis for the use of analog regression techniques in local forecasting for coastal regions of Antarctica.

Acknowledgments. We thank Professor B. W. Atkinson and Dr. M. J. Pook for reading the manuscript and for their constructive comments. We also thank Dr. U. Radok and the other two anonymous reviewers for their constructive comments.

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