P4.13 Observations and numerical modelling of an ordinary katabatic wind regime in Coats Land, Antarctica

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1. Introduction

Recently a number of studies have started to re-evaluate the premise of a katabatic-forcing being the primary driver of Antarctic winds. Parish and Cassano (2001) examined the surface winds in one year of the NCEP/NCAR reanalysis and indirectly calculated the terms of the horizontal momentum equations. They found that the 'pure' katabatic and the 'synoptic-scale' pressure-gradient terms account approximately equally for the surface wind pattern generated by the model. They concluded that the adjustment of the synoptic pressure distribution to the Antarctic topography caused a high degree of directional constancy in the surface wind field of the model. Parish (2001) presents a series of numerical modelling experiments of an idealised sloped terrain, initialised with different synoptic-scale basic states and model conditions. He found qualitatively similar flow fields over the continent for a surprisingly broad variety of initial conditions. For example, simulations of katabatically-driven surface winds were remarkably similar to simulations of non-katabatic winds forced by a meridional pressure gradient or a synoptic-scale low pressure system. This suggests that, in his model at least, the topography is moulding the surface wind pattern, and the forcing mechanism cannot be deduced from the direction and magnitude of the winds alone.

Reviewing the above, one is under the impression that there is currently a shift in the perception of what drives Antarctic surface winds. It is within this context that we present a climatology of Coats Land, a region of Antarctica that is typical of much of the coastal fringes of the continent. Indeed the surface winds here could be described as 'ordinary', in contrast to the regions of katabatic convergence that yield extraordinarily strong surface winds (e.g. Bromwich 1989b, Wendler *et al.* 1993). The topography of Coats Land is broadly two-dimensional and smooth, rising from around 50 m on the Brunt Ice Shelf to around 1700 m approximately 150 km inland. The slopes are typical of the continent's fringe, about 5% at the steepest point, decreasing with distance inland. The British Antarctic Survey's Halley station is located close to the coast on the Brunt Ice Shelf and marks the end point of a transect of AWSs running down the fall line of Coats Land. The AWS data, along with upper air and surface-based data from Halley, and some satellite remotely-sensed data, form the basis of this study.

2. Geographic setting and data coverage

The topography of Coats Land, as extracted from the Antarctic Digital Database Version 3, is shown in Fig. 1 (BAS *et al.* 1993). The map also shows Halley and four AWS sites: Coats Land AWS sites abbreviated to C1 - C4. At the Coats Land sites an AWS records hourly station pressure; air temperature and humidity at two heights (nominally 1 and 2.5 m); and winds at one height (nominally 3 m). For data coverage and instrumental details please see the full paper.

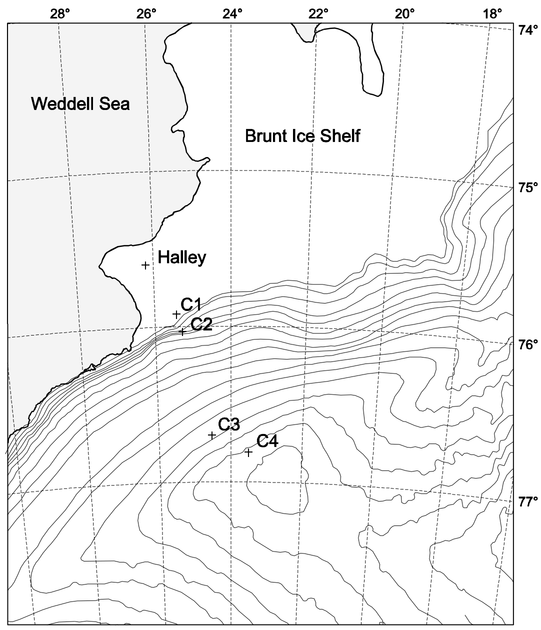

Figure 1 A topographic map of Coats Land, Antarctica, based on the Antarctica Digital Database Version 3. The contour interval is 100 m. The location of Halley and the four AWS sites are marked (C1 to C4).

3. Surface climatology

The climatology is broken down into seasons: denoted DJF (summer), MAM (autumn), JJA (winter) and SON (spring). In every season the strongest mean winds are at C2, followed by those at C3, with the weakest mean winds on the ice shelf (at either Halley or C1). The vector-mean wind direction is from the SE at

C2, from the ESE at Halley, C3 & C4, and from the E at C1. Recall the fall line is ~150° (i.e. from the SSE), so the vector-mean wind directions are to the east of the fall line. In general the wind is more southerly during the winter, and the equinoctial seasons than during the summer season. The surface wind regime is illustrated in Fig. 2 which shows wind roses for DJF and JJA for all five sites.

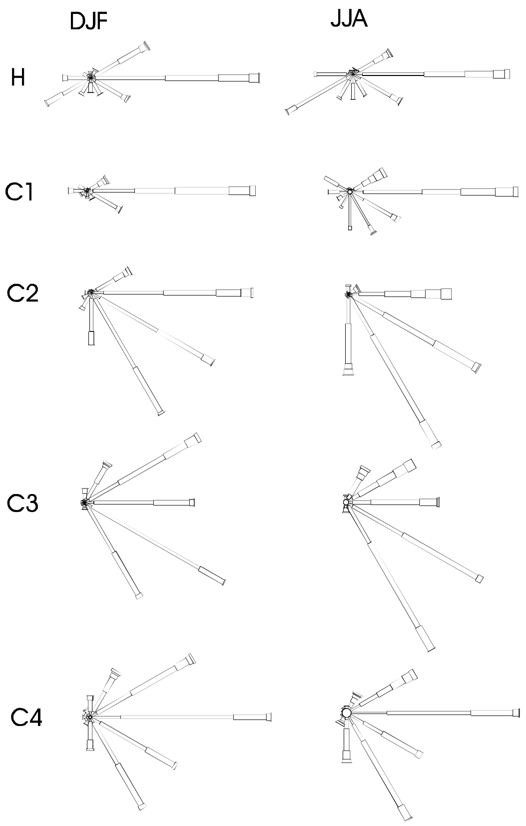

Figure 2 Wind roses for Halley (H) and C1 to C4 as marked, for summer (DJF) and winter (JJA). The wind directions are divided into 30° bins and the wind speeds into 5 m s^{-1} bins from 0.1 to 30 m s^{-1}. The size of the centre circle is proportional to the number of calm observations.

The JJA (winter) wind roses are qualitatively representative of the MAM and SON seasons (not shown). At Halley there is a bimodal distribution with winds most frequently from the E, ESE or ENE; or from the W or WSW. There are relatively few periods of southerly winds and northerlies are rare; the strongest winds are always from the E or ENE. The winds at C1, 37 km inland, are similar to Halley, although with a greater number of weak southerlies and less westerlies; again the strongest winds are from the east or ENE. In contrast, at C2, C3 & C4 on the continent, the winds are most frequently from the south-east quadrant, with no winds from the west and rarely from the north. At C2 there are strong winds from throughout the south-east quadrant, but most frequently from the east. The wind roses at C3 and C4 appear similar to C2 except rotated through ~30°. Strong southerly flow only occurs at C2. Comparing the summer and winter wind roses, there are few qualitative differences. On the ice shelf, there are more frequently winds from the south during the winter. At C2 there are occasionally winds from the ENE in summer, but rarely in winter. In general there is a greater frequency of stronger winds during the winter. Illustrated as wind roses it is clear that the ice shelf sites are under a qualitatively different surface-flow regime than the continental sites. A fact all the more remarkable when one considers that the C1 and C2 sites are only 10 km apart. This downslope change in flow regime was first hypothesised by King (1993) on the basis of wind data from two ice shelf sites. Examining the complete transect of wind data, we have now shown this hypothesis to be true.

During the summer the near-surface air temperature (t_a) generally decreases with elevation (i.e. moving inland). However during the non-summer months the warmest temperatures are at C2 (C1 during SON), rather than Halley. These sites are located within the 'thermal belt', a band of warm surface brightness temperatures observed in remote-sensing studies such as Nakagawa and Shimodoori (1994). This thermal structure is a product of strong surface-atmosphere coupling. Over the flat ice shelf, there are many periods of calm or very light winds (see Fig. 2): periods of quiescent flow allow a strong surface-layer inversion to develop, driven by long-wave radiational cooling of the surface. Thus the cold t_a's of the ice shelf are caused by the close coupling of the surface and near-surface air temperatures. In contrast, on steeply sloped surfaces, for example at C2, there are fewer periods of calm or very light winds (Fig. 2), hence there is generally a greater degree of turbulent mixing and downward turbulent heat transfer. The higher downward surface heat flux, leads to higher surface temperatures and thus higher near-surface air temperatures. In short, over the ice shelf, there is a tendency for relatively cold near-surface air temperatures and a very stable surface layer; over the steeper slopes of the continent there is a tendency for warmer near-surface air temperatures and a less stable surface layer.

In terms of potential temperature (θ), the above equates to a potentially-cold surface layer over the ice shelf and a potentially-warmer surface layer over the continent; a demarcation that is particularly clear in the winter season. This potential temperature picture is consistent with that sketched in King *et al.* (1998) of an approximately adiabatic surface-layer over the continental slope, book-ended by cold and strongly stable surface-layers over the ice shelf and over the plateau. In that sketch only *clear-sky* surface temperatures (from remotely sensed infra-red satellite imagery) and contemporaneous free-atmosphere temperatures (from upper air soundings at Halley) were used. Hence the climatological data from that study are conditionally sampled as clear-sky conditions. Here an augmented *clear-sky* boundary-layer thermal structure is illustrated as θ versus height in Fig. 3.

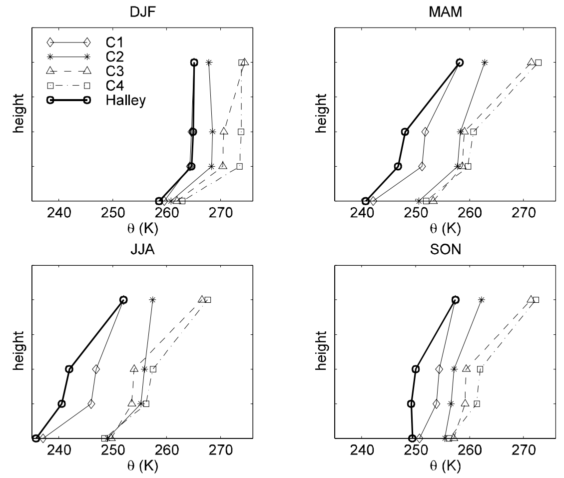

Figure 3 Illustrations of the mean boundary-layer thermal structure for each season during conditionally-sampled clear sky conditions. The vertical scale is nominal: the four heights represent the surface, approximately 1 and 2.5 m above the surface, and the free atmosphere (perhaps 50 to 200 m above the surface). The potential temperatures at the surface are from infra-red brightness temperatures (remotely-sensed from space); the 1 and 2.5 m potential temperatures are from the lower and upper AWS sensors; and the free-atmosphere potential temperatures are taken from a set of upper air soundings.

The figure illustrates a division of the surface layer into potentially-cold over the ice shelf (at Halley & C1) and potentially-warm over the continent (at C2, C3 & C4) for clear skies. This is true for all four seasons, but is most marked in MAM and JJA; during SON and DJF incoming solar radiation affects the more northerly ice shelf sites to a greater degree than the continental sites. In addition, the surface-layer is approximately adiabatic in the horizontal between C2 and C4 during MAM and JJA. In the non-summer months, the strongest clear-sky surface-layer stabilities are at Halley, C1 and C4. Note that the jump in θ between the surface-layer and the free-atmosphere is much greater at C3 & C4 than at Halley or C1. At C2 there is little jump in θ between the surface layer and the free atmosphere, perhaps due to a greater degree of turbulent mixing due to the higher winds at this site.

In short, the climate of Coats Land is clearly divided into two regimes. Over the slopes of the continent the winds are from the east to south quadrant with the strongest winds at the steepest part of the slope, and wind speeds tending to be moderate to strong. The surface layer is approximately adiabatic, but becomes more moist (although drier in terms of RH_{ice}) moving down the slope. On the adjoining ice shelf, only a few kilometres north, the surface climate is startlingly different, there is a bimodal wind distribution with winds from either the eastern or western sectors, and with wind speeds much more skewed; i.e. periods of calm to low winds interrupted by moderate to strong wind events.

4. Fingerprinting katabatic flow

It is clear from the surface climatology and the cases studies (see full paper) discussed in the previous sections that Coats Land does not experience solely katabatic flows, but rather a mix of katabatics and winds primarily forced by other types of weather system. Here we refer to katabatics, or katabatic flows, as those believed to have been dominated by a downslope buoyancy forcing.

To start we define three simple criteria to obtain a subset of the AWS observations that are, in some sense, pure katabatic conditions. This is illustrated by Fig. 4 and explained in detail in the full paper. The black dots in Fig. 4 represent ‘pure katabatic’ data. It is apparent that this procedure selects a coherent subset of the data at C2, C3 and to a lesser extent at C4, at least in terms of wind speed and wind direction characteristics. The mean pure katabatic wind is 7.5 m s^{-1} & from 153º at C2; and is 5.1 m s^{-1} & from 139º at C3. These wind directions are approximately 10º to the east of the fall line. The bimodal wind speed distribution at C4 means the wind constancy is lower (0.73) and the wind shape parameter is more skewed (1.6). At C4 the katabatic criteria appear to pick out two regimes a more quiescent flow from the east and a more dynamic flow from the SSE. The mean wind direction is still around 10º to the east of the fall line.

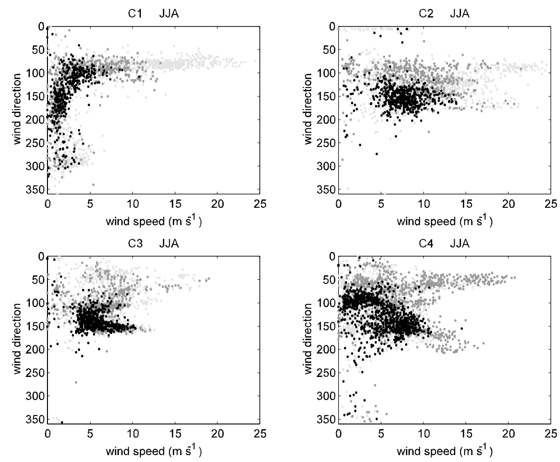

Figure 4 An illustration of the ‘pure katabatic’ selection criteria via scatter plots of wind speed versus wind direction. The light grey dots show all matching JJA data. Over-plotted as dark grey dots are the subset of data where ∇p’ is between the 1/4 and 3/4 quartile of the ∇p’ distribution, where ∇p’ is between the station and Halley. Then over-plotted in black are the subset of data where $\Delta\theta/\Delta z > 2/4$ quartile of the $\Delta\theta/\Delta z$ distribution, where $\Delta\theta/\Delta z$ is at the station. The black dots shows the distribution of pure katabatic flows in wind speed and wind direction space.

So far we have characterised pure katabatic flow on Coats Land by applying our criteria locally at the station. One could ask another question: what does the atmosphere look like when the flow is katabatic at (for example) C2? We choose C2 as this site has the strongest and most coherent katabatics. To this end, Fig. 5 summarises data from Halley, C2 and C4 *when there are pure katabatic conditions at C2*.

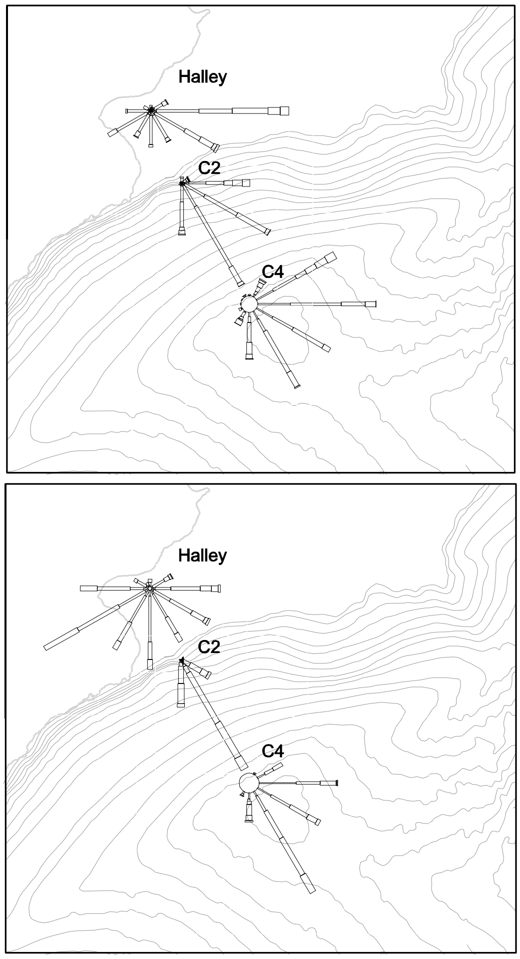

Figure 5 Wind roses for Halley, C2 and C4: (a) for all matching winter time observations, and (b) during katabatic conditions at C2. Plotted as a background is the 100 m topography from Fig. 1.

Examining Fig. 5 we see the high wind speed observations (at Halley) from the east and ENE have been deselected. However the low wind constancy (0.37) and the large spread in the wind rose indicate the flow is not 'coherent' in any sense. The surface layer during katabatic conditions is 1^{o}C colder, and there is a smaller total cloud amount; in other words, katabatic conditions on the continent tend to occur when the skies are clearer than average. However in general, there is no distinctive signature at Halley of katabatic flow on the continent. At C2, as discussed above, selecting pure katabatic conditions results in a tightly-constrained wind rose. At C4, during katabatic conditions at C2, the flow appears to fall into three clusters: periods of calm, periods of low wind speeds from the east, and periods of moderate winds from the ESE to south. The latter two clusters are also seen in Fig. 4, when the katabatic criteria are applied at C4. The first cluster shows that strong katabatic winds may be blowing at C2 while it is flat calm at C4. Comparing directly the pure katabatic and all data conditions at C4: there is an increase in wind constancy but the wind shape parameter remains similar. Most of the winds from the NE are deselected, including all the high wind speeds.

6. Conclusions

A surface-based climatology of Coats Land, Antarctica, has been presented. There are clear seasonal differences, so for simplicity here we remark upon winter conditions only; although we note that these are also relevant for the equinoctial seasons. The region can be divided into two dynamical regimes: the slopes of the continent, and the Brunt Ice Shelf. The continent is frequently subject to moderate katabatic winds from about 10^{o} to the east of the fall line. Mean katabatic wind speeds are 7.5 m s^{-1} at the steepest part of the slope (at the C2 site) and 5.1 m s^{-1} higher up the slope (at the C3 site). Katabatic winds rarely exceed 15 m s^{-1} in this region; although winds stronger than this are frequent, they are associated with synoptic-scale low pressure systems. The adjoining Brunt Ice Shelf is generally unaffected by katabatic winds, instead receiving low to moderate winds with no preferred direction during periods when the flow is katabatic on the continent.

The two different dynamical regimes also have a clear thermal signature. Moving up the continental slope the surface layer is generally close to adiabatic and about 10 K warmer, in terms of potential temperature, than the surface layer over the ice shelf. This scenario is most apparent for conditionally-sampled clear-sky conditions, or katabatic conditions, when the surface can cool unhindered. It would appear that the slope of the ice surface is crucial in determining the surface-layer thermal structure: where the slopes are smallest, on the ice shelf and high up the slope (at the C4 site), there is a high frequency of calm or low wind-speed conditions. Such conditions imply there is little turbulent transport of heat through the surface layer, which leads to very strong surface-layer stabilities and very cold potential temperatures on the ice shelf.

References

For references please see the full paper on this topic accepted for publication in Tellus A, subject to minor revisions. Please contact *i.renfrew@bas.ac.uk*