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Katabatic winds, hydraulic jumps and wind flow over the Vestfold Hills, East Antarctica

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Abstract: This paper examines two strong or gale-force wind events which began suddenly at Platcha, near the Antarctic ice sheet edge in the Vestfold Hills of East Antarctica, and at a later time were recorded at Davis after progressing slowly across the intervening 25 km of relatively low hills.

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Introduction

Katabatic winds in Antarctica have been a source of scientific interest since first described by the early explorers. They are frequently characterized by a sudden onset and cessation, and associated drift snow if there is loose snow lying on the surface. Katabatic winds are caused by cooling of the layer of air next to the surface which then accelerates down the ice slope under the influence of gravity. Lied (1964) described 31 observations of hydraulic jumps at Platcha (see Fig. 1) in the 24 week period between 30 May–14 November 1961. In these cases the leading edge of the katabatic wind had become stationary, and formed a discontinuity between light winds on the downwind side of the jump and strong winds on the upwind side. This gives a frequency of jumps of more than one per week, suggesting them to be a regular and normal expression of the weather in that area.

Theoretical descriptions of this discontinuity, variously described as a hydraulic jump, pressure jump, wind jump or Loewe's phenomena, have been developed by Ball (1956), and more recently by Pettré & André (1991) and Gallee & Schayes (1992).

While katabatic winds are due to a colder layer of air near the surface moving downslope under gravity, researchers have tried to relate their onset and intensity to the overall synoptic situation. Streten (1963), Ball (1960) and Loewe (1972) related behaviour of katabatic winds to the overall synoptic environment and movement of pressure systems around the periphery of the Antarctic continent. Madigan (1929) and Shaw (1957) made observations about the position of the terminal end of the katabatic wind in relation to the coastline.

Lied (1964) showed that two thirds of stationary hydraulic jumps in the Platcha area occur when a trough is approaching or over the area. Callaghan (1991), in a study of strong winds at nearby Davis (see Fig. 1), noted that on 70% of occasions blizzard type winds begin at Davis near the time when the pressure bottoms out and rises, indicating the passage of a low pressure trough. Murphy (1993) in a modelling experiment of strong winds at Casey in coastal East Antarctica found that the model produced an enhanced inland high and inversion, some 48 hours before a strong wind event at the coast. Breckenridge *et al.* (1993) describe enhanced katabatic outflow through the Transantarctic Mountains due to accumulation of cold air over the Antarctic Plateau created by intense radiational cooling under the influence of high pressure ridging, the outflow being assisted by a low pressure area over the Ross Sea.

This paper examines two observations of strong wind events which began suddenly at Platcha, near the ice-slope edge in the Vestfold Hills of East Antarctica, and at a later time were recorded at Davis, after progressing slowly across some 25 km of intervening relatively low hills.

Two observations of the onset of strong winds at the ice-slope edge and later at Davis

Davis is an Australian Antarctic base situated in the Vestfold Hills. The Vestfold Hills are a roughly triangular area of ice-free rocky hills of some 600 km^2 in extent (see Fig 1). Davis is situated on the seaward side of the hills about 25 km from the edge of the Antarctic Plateau. One of these wind events was recorded in an ice-gully just inland of the ice-slope edge in the moraine line (see Fig 1). The second event was recorded at Platcha (Fig 1), a hut just next to the edge of the ice-slope, and the site of the "satellite" weather station at which Niels Lied made his observations of stationary hydraulic jumps in 1961 (Lied 1964).

Event 1. 20–21 January 1993

The data was collected by a party (of which the author was a member) led by D. Gore, who were investigating the origin and development of the ice-gullies. The data obtained from

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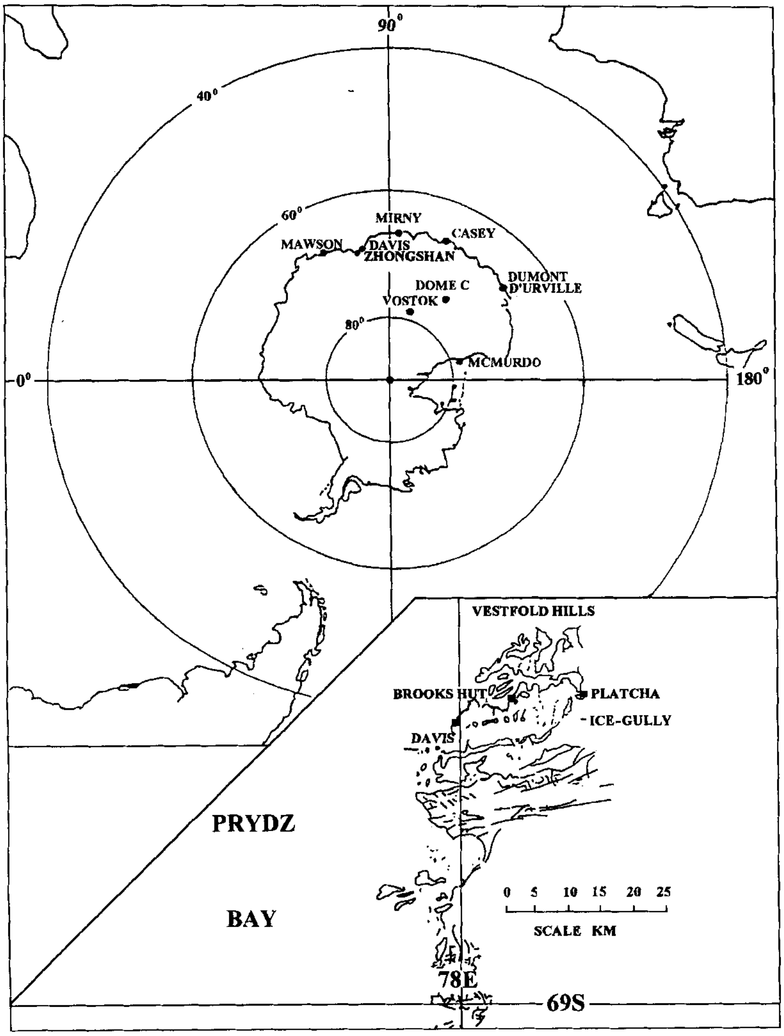

Fig. 1. The Antarctic continent with the locations of the East Antarctic stations. Inset, the Vestfold Hills with the location of Brooks Hut, Platcha and the ice-gully in relation to Davis.

the ice-gully consists of 30 hours of wind measurements taken at hourly intervals. The observations were taken under clear sky conditions, apart from several hours of thin cirrus towards the end of the period. Wind observations were terminated when cloud obscured the sun.

For some hours before the onset of strong winds in the ice-gully the wind could be heard in the distance, as described by Lied (1964). Figure 2 displays the wind observed in the ice-gully with respect to time, and the corresponding wind and pressure observed at Davis at the same time. This graph shows a delay between the onset of strong winds at the ice-gully, and later at Davis, with some eight hours separating maximum wind speeds at the respective sites. The clear skies and calm winds before the onset of strong winds at the ice-gully site are suggestive of the winds being of a katabatic nature. At this time in January there was no loose snow available to be lifted by the wind as the ice surface was glazed over by the summer warming. The pressure recorded at Davis for the same time shows a steady fall during this period, with the pressure reaching a minimum near the time of onset of strong winds. The slow nature of the pressure fall is suggestive of a synoptic scale trough passing over Davis as the reason for the fall and subsequent rise of pressure. Synoptic Mean Sea Level (MSL) charts prepared by the Antarctic Meteorological Centre at Casey for the period show a weak low pressure system passing to the north of Davis, and a persistent low pressure area east of Casey longitudes (110°E).

Before the onset of strong winds at Davis the winds reported by Automatic Weather Stations (AWSs) well to the south-east of Davis strengthened some 24–30 hours ahead of a strengthening at Davis. The wind at Zhongshan strengthened to 30 knots at least three hours ahead of the strengthening at Davis. Zhongshan is situated within a few kilometres of the ice-Plateau edge and about 100 km SSE of Davis (see Fig. 1).

On this occasion the wind observed at the ice-gully appeared to be katabatic in nature, and the leading edge of the strong winds progressed out from the ice-slope edge, passing over Davis some eight hours later.

The strengthening of winds over the Antarctic Plateau, and the earlier arrival of strong winds at Zhongshan, suggest a surge of air flowing from the interior towards the coast was at least a contributory cause of strengthening winds at Davis. However, the fall and subsequent rise of pressure at Davis suggest the passage of a trough, and this is supported by the

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analysis of a low pressure area to the north-west of Davis. The persistence of a low pressure area to the east of Casey leaves a ridging area westward towards Davis and a source of radiationally cooled air.

Support for the concept of a surge of continental air is lent by the increase of wind strength at the AWSs inland from Casey, and by the subsequent increase in wind strength at Mirny and Law Dome Summit to 25 and 30 knots at about the same time as Zhongshan increased to 30 knots. This explanation also provides a reason for the strong winds reaching the Plateau ice-edge and Zhongshan before Davis.

Event 2. 16–18 May 1993

The second event was recorded by A. Williams when he visited Platcha to survey the site for the installation of an anemometer as part of a more detailed study of the strong wind events currently under investigation. He recorded the onset and cessation of blizzard conditions that occurred at Platcha during his visit. The MSL synoptic charts for this period, produced by the Australian National Meteorological Centre (NMC), show an intense low pressure system moving close to Davis, with an associated frontal band near the station, while another low pressure system is in the vicinity of Casey.

Figure 3 shows the hourly observations at Davis and the onset and cessation of strong winds at Platcha. Again the wind speed increased rapidly at Platcha (vertical line on Fig. 3) some eight hours earlier than it rapidly rose at Davis. This event occurred as the MSL pressure was falling due to broadscale synoptic influences. It can be seen that the wind speed eventually decreases after the pressure trough had crossed the station and that the strong winds cease at Davis prior to the cessation at Platcha. It is notable that the wind direction at Davis reverses after the cessation of strong winds, a characteristic of hydraulic jumps described by Lied (1964). Hydraulic jumps have been reported progressing inland up the ice-slope by Pettré & André (1992) and Lied (1964).

The temperature at time of onset of the blizzard at Platcha was some seven degrees warmer than that at Davis (Fig. 3), with the Davis temperature subsequently warming to a similar value. This warming is most likely due to turbulent mixing of warmer air above a surface inversion; this means the warmer air flowing seaward from Platcha has to displace colder near-surface air over the Vestfold Hills. Lied (1964) reported temperature rises as hydraulic jumps were traversed from the

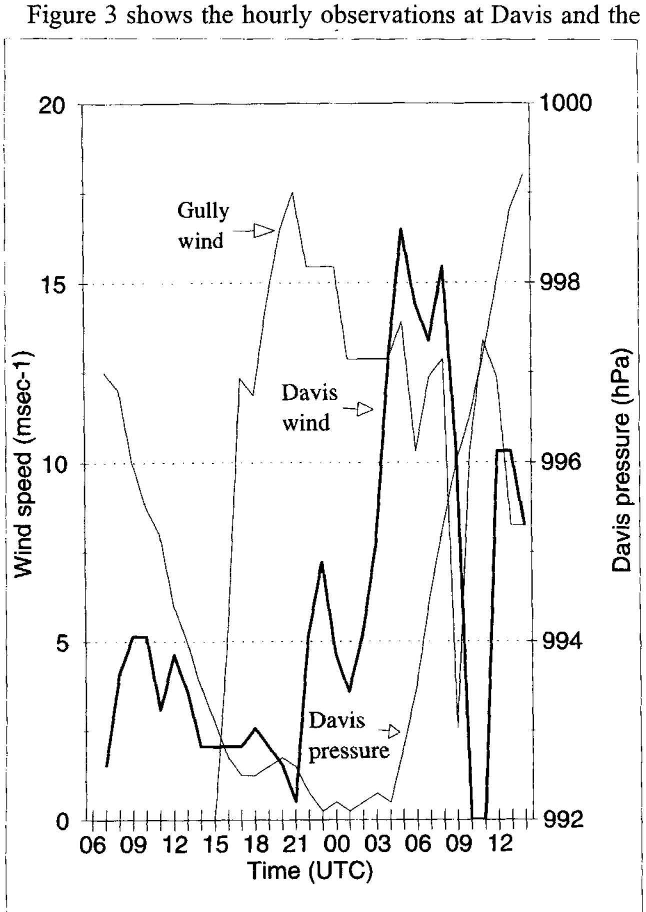

Fig. 2. Comparison of the wind speed between Davis and the ice-gully, and Davis pressure on 20–21 Jan 1993.

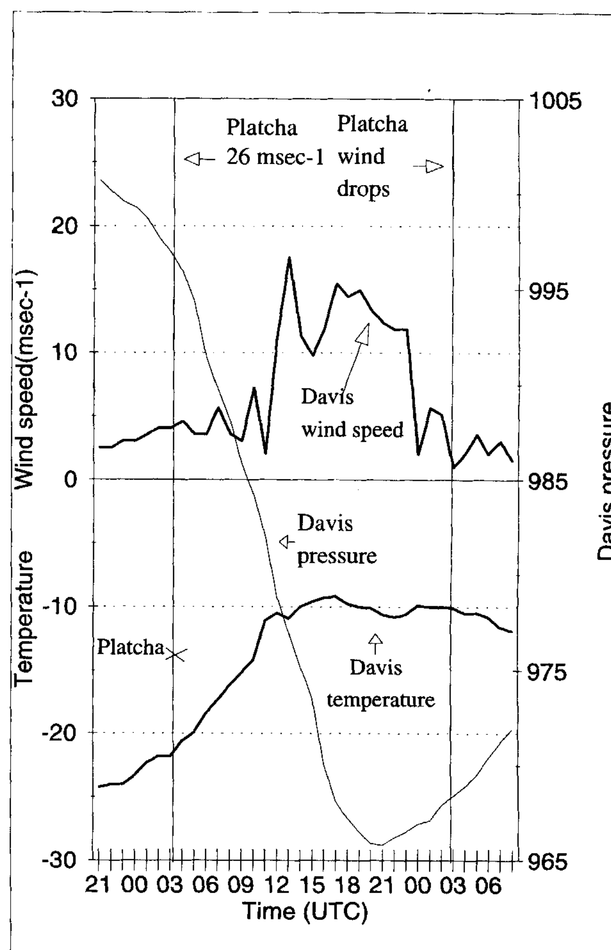

Fig. 3. Wind speed, temperature and pressure changes at Davis in relation to the onset and cessation of blizzard conditions at Platcha on 16–18 May 1993.

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tranquil seaward side to the turbulent upstream side.

An examination of MSL charts for the time of this event shows a low pressure system near Casey with a ridging area between this low and the upstream low approaching Davis longitudes.

Discussion

The two events described are cases where strong or gale force winds were observed at both the foot of the ice-slope and later at Davis. The events have a number features in common;

a) The time delay between the onset of strong winds at Platcha and later at Davis.

b) The sudden onset of strong or gale force winds at Platcha and Davis.

c) Steadily falling barometric pressure at Davis at the time of onset at Platcha.

d) The onset of strong winds at Davis close to the time of minimum barometric pressure.

e) The presence of a low pressure area near Casey longitudes for 24–48 hours before the onset at Platcha.

f) A low pressure system passing near or to the north of Davis.

g) A rise in temperature at both Platcha and Davis with the onset of strong winds.

An examination of the meteorological conditions at the time of an intense hydraulic jump observed by Lied (1964) on 12 August 1961 shows that the same features occurred in this event as described above. However, in Lied's case strong winds did not occur at Davis until some 24 hours after they occurred at Platcha.

Lied's (1964) paper described frequent stationary hydraulic jumps at Platcha, which is at the foot of the ice slope and where the force of gravity ceases to drive the katabatic wind.

The frequency seems very high compared to published data for other sites, and the topography of the area is most likely a major determining factor. Platcha is situated at the foot of the ice-slope so katabatic winds would lose gravity as their driving mechanism in this area. They would be expected to progress further only under the influence of their momentum without some additional driving mechanism. Lied's (1964) observations of more than one stationary hydraulic jump per week at Platcha suggests that momentum in many cases may not carry the jump past Platcha. Additionally the hills extending 25 km between Platcha and Davis, while rarely exceeding 100 m, are frequent and topographically rough, producing a frictional resistance impeding the progress of air towards Davis. The roughness of these hills and the ice free dark coloured rock would allow air to stagnate and cool in the many valleys, providing an additional barrier to the encroaching warmer surface air. The margin of the ice sheet runs roughly north–south behind the Vestfold Hills, so the airflow around an approaching low pressure system opposes katabatic air moving out from the ice-slope while it is assisted out towards the coast after the low passes.

Strong winds reported at the base of the plateau ice-edge during the summer of 1992–93 did not necessarily occur at Davis (personal observations). This suggests some mechanism is required to facilitate the movement of strong downslope winds at the base of the plateau across the 25 km of intervening terrain to Davis. The logical candidate for this is the overall synoptic environment as suggested earlier.

In lighter gradient situations where hydraulic jumps form they will move towards the coast, but slow down and become stationary near the foot of the ice-slope as they lose gravity forcing and encounter the higher friction and stagnant cold air over the Vestfold Hills. Stronger gradient situations would assist the hydraulic jump and associated strong winds to progress out to Davis. As hydraulic jumps require a decrease of MSL pressure from the interior towards the coast (Loewe 1972), it might be concluded that this pressure gradient is provided by the synoptic environment, and by the approach of a low pressure system in particular. This is consistent with data described in the two above events, and with the results of Callaghan (1991), who found 70% of blizzard type winds occur at Davis when the pressure bottoms out and rises, indicating the passage of a trough.

Conclusions

Two strong wind events have been described where strong winds were observed at Platcha and at a later time at Davis. A third event displaying similar characteristics was described by Lied (1964). In each of these three events there was a pre-existing low pressure area near or east of Casey longitudes and ridging westward to the Davis area providing conditions conducive to the development of katabatic wind flow. A low pressure system then moved north of Davis extending a trough over the area. The pressure gradient associated with the approaching low initially inhibits the seaward air flow at the surface. This, in conjunction with the loss of gravity forcing, colder denser air at the foot of the ice-slope and higher friction over the hills inhibits the seaward movement of hydraulic jumps. These and their associated winds move across the Vestfold Hills to Davis after the low pressure trough passes; the gradient then assists the movement of colder air away from the hills, and the stronger winds progress coastward.

While these three events manifested themselves with strong or gale-force winds, Lied (1964) also observed relatively light winds after the passage of hydraulic jumps. A flow of air from the continental interior to the coast is a persistent feature of the Antarctic atmosphere. Katabatic winds will flow towards the coast under the influence of gravity without any assistance from synoptic systems, as described by Gallee & Schayes (1992). In these cases a hydraulic jump may still form at the foot of the ice-slope, but the intensity would be weaker, and the hydraulic jump would lack the necessary mechanism to move far beyond the foot of the ice-slope.

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