

# STATIONARY HYDRAULIC JUMPS IN A KATABATIC FLOW NEAR DAVIS, ANTARCTICA, 1961

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Abstract: A description is given of standing hydraulic jumps, also called "Loewe's Phenomenon", on the slopes of the Polar Ice Cap behind the satellite weather station, established by the Australian National Antarctic Research Expeditions (ANARE) for the study of katabatic winds at Vestfold Hills during 1961. This includes measurements of temperature, pressure and wind made just outside and inside the curtain of drift marking the jump, relevant upper air data for the satellite station and Davis, and the synoptic situations in which the phenomena were observed.

## 1. INTRODUCTION

Apart from the intense cold, the most dramatic feature of the coastal climate of Antarctica is doubtless the katabatic wind. A relatively thin layer of air above the ice slopes of the polar plateau is cooled by radiation and this denser air flows down the slope by gravitation, accelerating to its maximum speed near the foot of the slope.

The contour of the slope, the Coriolis effect, and local topographical features further determine the strength and direction of the katabatic wind. Given the right combination of slope, temperature inversion, and synoptic situation, i. e. a cyclonic depression near the coast to the right of the line of katabatic outflow, the wind can attain the almost unbelievable velocities recorded at Adelie Land, and less frequently at other points of observation, such as Mawson, Mirny and the Vestfold Hills satellite station, where the strongest wind recorded in 1961 was 132 m.p.h. over a 15 minute period.

Theoretical treatment of the mechanism of the katabatic wind and its relationship to topography has been made by Madigan (1929), Defant (1933) and by Ball (1956, 1957, 1959). Ball (1957) derived theoretically various types of katabatic flow discontinuities, or "jumps", including a "standing jump" which should be observable upslope from an observing station. This type of jump has been described by Valtat (1959) at Dumont d'Urville, and called "Loewe's Phenomenon".

Until the establishment of the ANARE Satellite Weather Station at Vestfold Hills, no physical measurements of elements through such a jump had been obtained, and this paper is an attempt to describe the phenomenon with actual measurements of wind, temperature, and pressure changes through the line of discontinuity. Some upper air data from both the satellite station and Davis are given in addition to the surface observations.

## 2. THE SATELLITE WEATHER STATION

A "satellite" weather station for the study of the katabatic wind was established at Vestfold Hills, Princess Elizabeth Land, during 1961 (Lat.  $68^{\circ} 31' S$ , Long.  $78^{\circ} 30' E$ ) and manned continuously by meteorological staff and other expedition members from the ANARE station at Davis ( $68^{\circ} 35' S, 77^{\circ} 59' E$ ) from 25 May 1961 to 15 January 1962.

Vestfold Hills constitute one of the largest single, continuous bare rock areas in Antarctica, some 300 square miles in extent. The satellite station was approximately 18 miles inland from Davis, at the foot of the ice cap where it abuts the bare rock.

From ice cliffs 150 metres east of the satellite station the ice plateau rises smoothly in stepped ridges to a height of 1300 metres at a point 50 miles inland and due east from the station (see Fig. 1). The plateau is steepest near the coast and flattens out from approximately 30 miles inland.

The contour lines near the coast are orientated in a N-S direction, but from 30 miles inland there is a gradual swing in contours from N-S to NE-SW at 50 miles inland (see Fig. 2).

### 3. THE STANDING KATABATIC JUMP WITH SOME EXAMPLES OF MEASUREMENTS OBTAINED

Apart from the sudden onsets and cessations of the katabatic wind, its most spectacular aspect is the standing jump observed on the coastal slopes of the ice cap. Nearly all standing jumps observed from the satellite station took the form of a wall of drift snow 100 to 300 feet high.

Between 30 May and 14 November 1961, a total of 31 occasions were recorded when the standing jump was seen or heard. Twenty of these occasions were seen with walls of drift snow, and 11 had sudden wind discontinuities only. Many more cases could have been present during the dark winter months or at night, when no visual observations could be made.

The formation of the standing jump would frequently happen after the katabatic at the satellite station had persisted for several hours, presumably with the jump then situated somewhere between the satellite station and Davis. A cessation would be recorded at the station, and the wind retreat upslope to form a standing jump on the lower slopes of the plateau. On other occasions the katabatic would not reach the station, but advance downslope, there to be observed as a standing jump within sight, and approximately  $\frac{1}{4}$  to  $\frac{1}{2}$  mile from the station (Lied 1963).

The wall of snow appeared vertical, often with a flattish, or plumed top. Frequently small fracto-type roll clouds were seen at the top of the wall, rapidly forming and just as rapidly dissipating, slightly downslope, and above the wall. Times of a complete cycle from formation to dissipation of the roll clouds varied from 30 seconds to 3 minutes on a number of occasions. Madigan (1929) observed a similar behaviour.

When the standing katabatic jump was observable with a wall of drift snow, it could be seen along the plateau edge distributed over a distance of 10-12 miles. On a number of occasions gaps were noted in this distribution of the jump, mostly near prominent topographical features such as ice domes, moraines, and nunataks.

On a few occasions only, the distribution was confined to a width of 1-2 miles upslope from the satellite station.

The greatest drift density in the jump was found in areas where the more pronounced funnel effects on wind were normally observed.

However, it was found that a wall of drift snow did not always accompany the standing jump. The distinctive roar of the wind upslope, similar to the passing of a distant express train, was always a feature of the standing jump. This agrees with the fact that onsets of katabatic wind at the satellite station were not always accompanied by drifting snow.

The reason for the existence of the jump without drift snow is lack of loose surface snow in the catchment area inland, particularly later in the year. After a period of some days with little or no precipitation, either inland or along the coast, the persistent drift snow would gradually disappear near the satellite station but the roar of wind would indicate the presence of the katabatic. Only exceptionally strong winds would then raise drift in the area.

However, the most common examples of a standing jump were accompanied by a wall of drift snow, varying in height from approximately 100 to 300 feet.

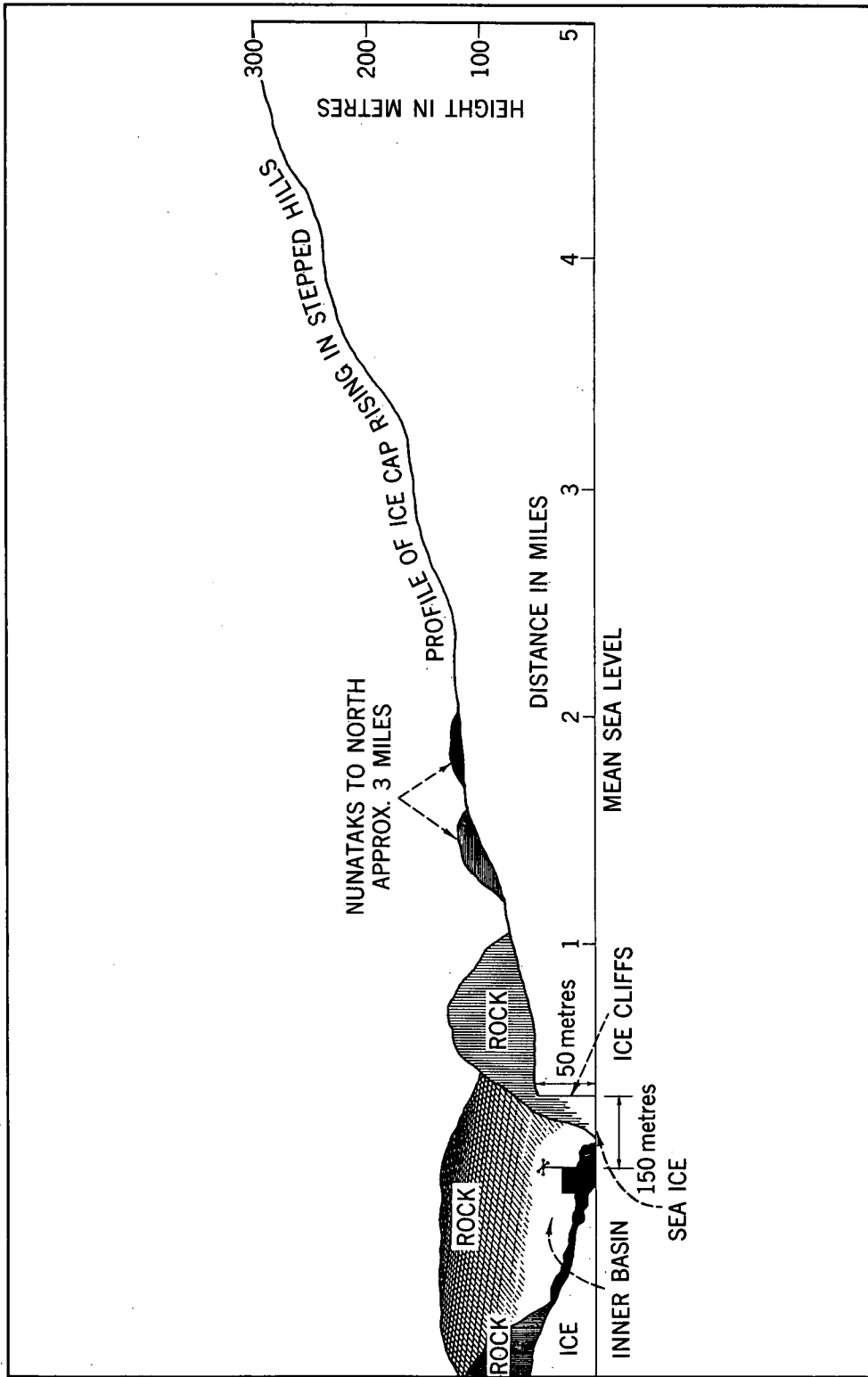


Fig. 1 Profile of ice cap east of Satellite Station and features north of the station.

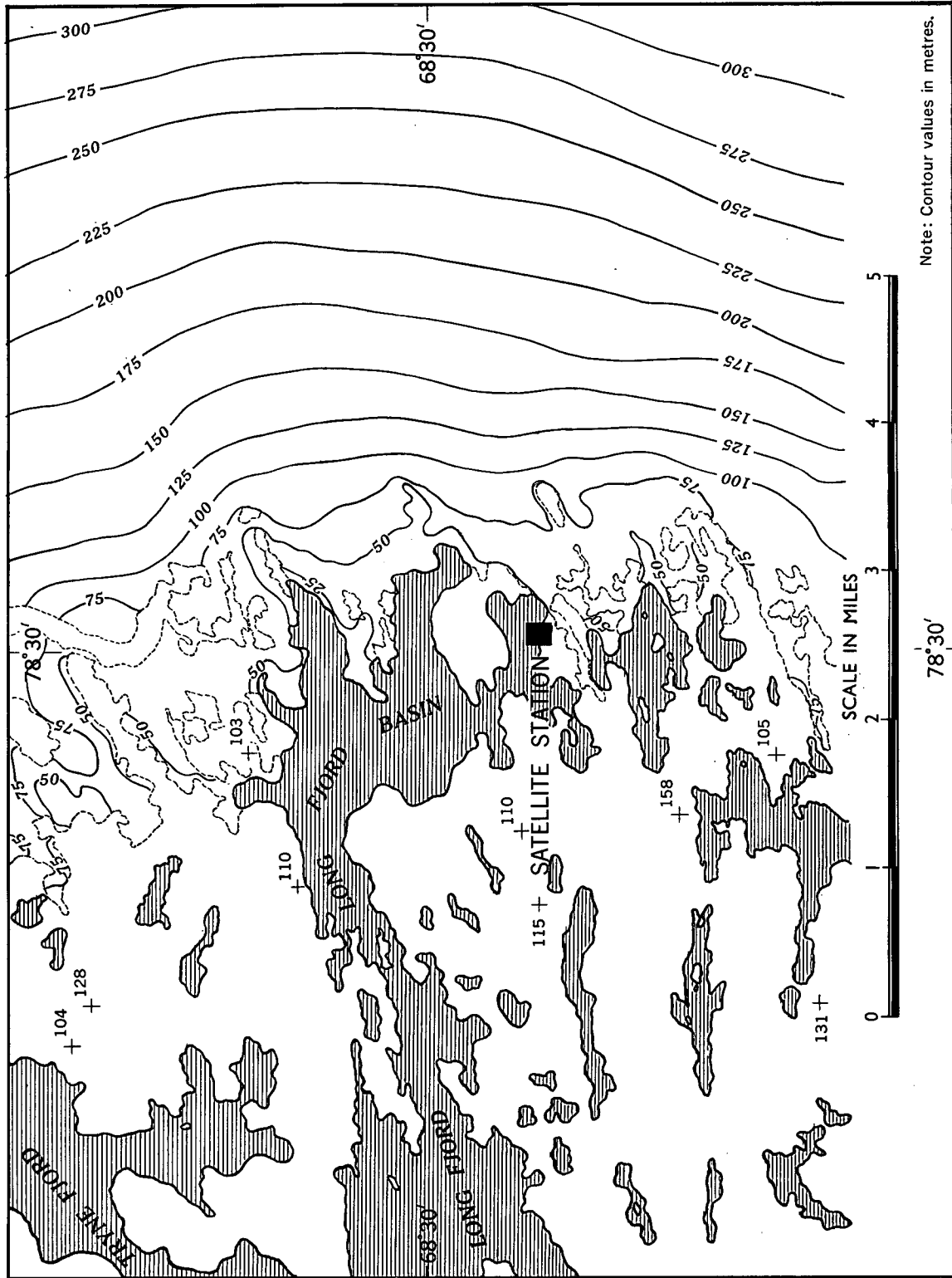


Fig. 2 Locality map of the vicinity of Satellite Station showing contours of ice cap.

The experience of actually walking through a standing katabatic jump is somewhat unusual. Invariably the following sequence of events took place:-

- (i) The observer walked upslope in calm conditions, or with light and variable winds.
- (ii) Taking measurements of pressure, temperature, and wind-speed and direction downhill from the jump while still in the calm air, the observer had the odd sensation of approaching a strongly roaring wall of drift snow, which was neither retreating nor advancing, and towering up to 300 feet above him.
- (iii) Series of measurements were taken immediately outside the edge of the jump, whereafter the observer stepped into a totally different world, like walking through a door opening out into a full blizzard. At the very edge of the jump violently rotating swirls of wind and snow, with strong updrafts and downdrafts alternately forced snow up into his nostrils and eyes and at the next moment blew it down his neck. A severe buffeting was experienced.
- (iv) At this point further measurements were taken. These showed a sudden drop in pressure, an immediate rise in temperature, and just inside the very turbulent edge of the jump, a violent increase in wind speed, blowing downslope with strong gusts, and accompanied by moderate to dense drift snow.
- (v) To make sure of his measurements the observer passed in and out of the jump a number of times repeating his observations on either side of it. He then walked upslope into the wind to obtain measurements well behind the turbulent edge of the jump.
- (vi) Upslope the wind was usually stronger than near the edge, with denser drift, and the differences in pressure and temperature from the values obtained in the calm air also increased upslope.
- (vii) Walking downslope with the wind behind him the observer could determine the standing edge of the jump by the sudden increase in turbulence. On leaving the jump, the transition from highly turbulent to calm, or light and variable conditions usually occurred over a distance of only about 5 yards.

#### 4. METEOROLOGICAL MEASUREMENTS THROUGH A STANDING HYDRAULIC JUMP

Four sets of measurements of pressure, temperature and wind were made through standing jumps (see Table 1).

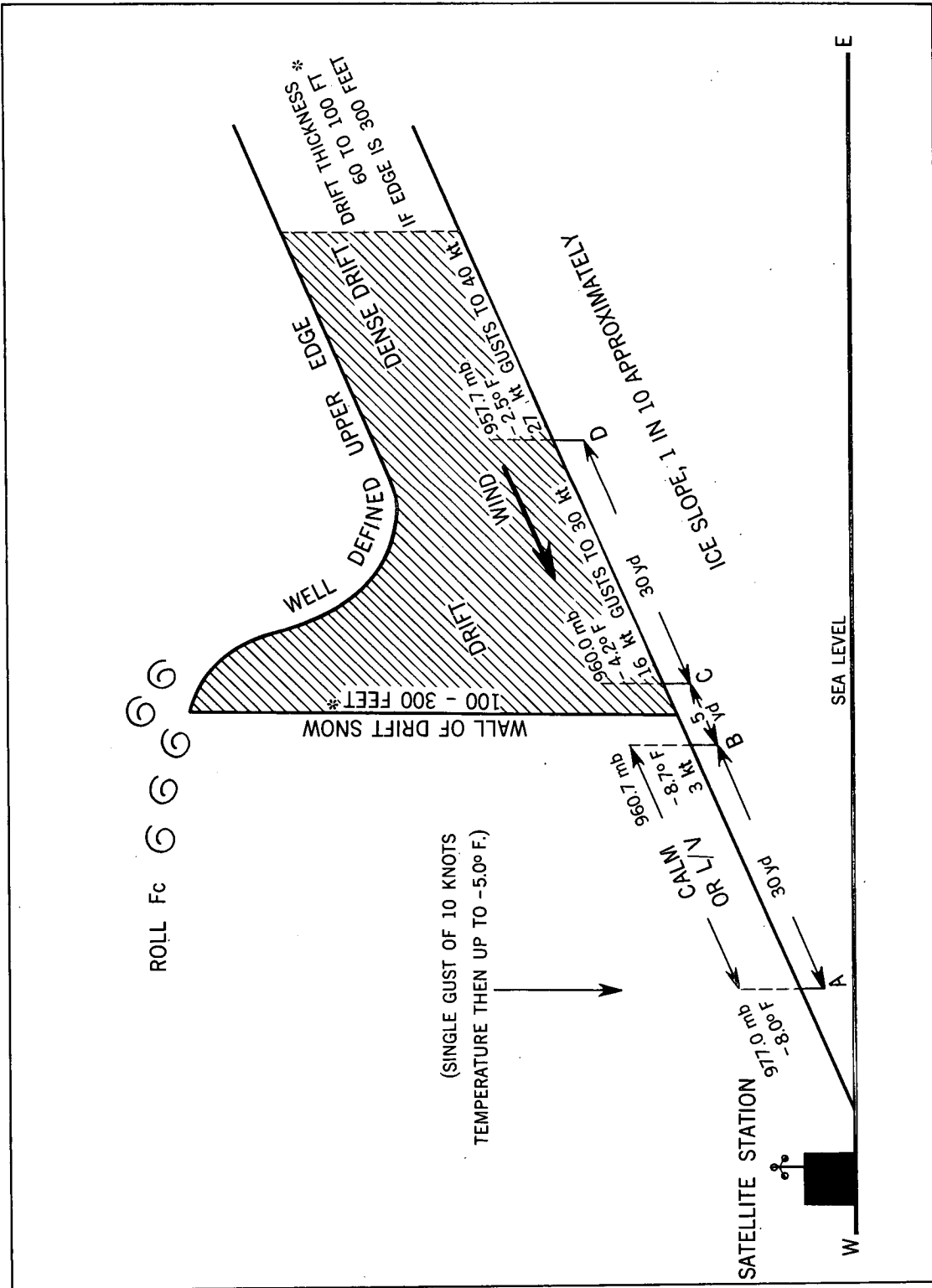
Three related to jumps upslope from the satellite station, while one related to a jump to the west of the station with a katabatic blowing at the station.

One example, for 12 August 1961, is presented in the form of a sketch (Fig. 3) for better clarity. This example is also amplified by a photograph.

Fig. 4 is a photograph of this standing jump taken looking up the ice slope.

An interesting feature of this case is the very large pressure difference across the jump, i. e. over a distance of only about 60-70 yards. The pressure observations of the points furthest apart differ by nearly 20 mb, which is about ten times as great as the changes in pressure normally seen on a station barograph under a moving jump or a katabatic onset.

Part of the 20 mb pressure difference would be due to the altitude difference of the two points, although this difference is extremely small over a distance of only 60-70 yards approximately, and part may be due to house effect on the hand-held surveying aneroid barometer. The observations were checked and repeated on the spot, and there seems no reason to doubt them.



\* Approximate heights

Fig. 3 Observations made through standing jump, 12 August 1961.

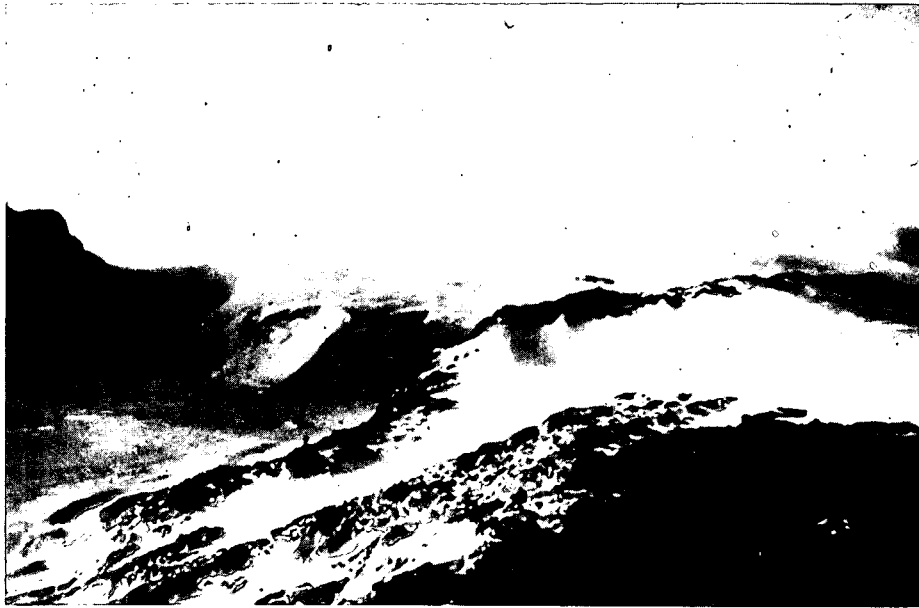


Fig. 4 Photograph of standing jump of 12 August 1961 taken looking up the ice slope.



Fig. 5 Onset of a katabatic with wall of drift snow approaching on plateau close to Satellite Station. Onset here approximately 7 to 10 miles inland.

Table 1. Measurements Through Standing Jumps in 1961

Date and time	Position of jump	Elements before and close to jump				Elements in edge of jump				Elements behind edge of jump			
		Wind	Press.	Temp.	Drift	Wind	Press.	Temp.	Drift	Wind	Press.	Temp.	Drift
31 July 1961 1000 GMT	230 metre contour line	170°/02 kt or L/V	962.7	-5.2° F	Nil	080°/20 kt	961.7	-3.3° F	Mod.	030° 20kt	961.7	-3.3° F	Mod.
7 August 1961 0700 GMT	200 metre contour line	Calm	954.5	-10.0	Nil	080°/12 kt	952.1	-8.2	Slt.	060°/ 08 kt	952.1	-8.0	Slt.
8 August 1961 0630 GMT	Ridge ½ mile west of station. Elevation 20 metres	Calm or L/V	979.8	-11.5	Nil	080°/18 kt	977.9	-11.0	Mod.	080°/ 18 kt	977.5	-11.0	Mod. / hvy.
12 August 1961 0700 GMT	¾ mile upslope	Calm or L/V	977.0	-8.0	Nil	080°/16 kt. Gusts to 30 kt	960.0	-4.2	Mod. / heavy	080°/ 27kt	957.7	-2.5	Heavy, dense

L/V = Light and variable; Slt. = Slight; Mod. = moderate; Hvy. = Heavy

If one assumes a depth for the shallow cold layer upstream and a higher temperature aloft above a sharp inversion, the depth of the deep, cold layer downstream can be calculated from the surface pressure difference, assuming hydrostatic balance.

Using a pressure difference of 20 mb, a surface pressure of 950 mb, a cold layer depth of 100 metres and an inversion strength of 10 degrees centigrade, the depth of the deep layer comes to about 4000 metres, which, on the evidence of temperature and wind soundings, is far too large.

However, the hydrostatic assumption would not apply near the jump; but even so, the contrast with changes recorded with moving jumps during an onset of katabatic wind still needs to be explained.

In most cases the onset of a downslope katabatic, with a moving jump passing through the satellite station, was easily detectable by visual observations of the accompanying wall of drift snow. Fig. 5 is a photograph of a typical moving katabatic front upslope on the plateau. A rough time/distance calculation established that generally the speed of the advancing jump would be 15-20 m.p.h., but frequently more, and would agree closely with the mean wind-speed recorded after the passage of the jump through the station. Onset of a moving katabatic wind at the satellite station would rarely show a pressure difference of more than 2-3 mb, if one discounts occasional violent gusts and the marked house-effect on the barograph.

In fact, on 12 August 1961, the jump, after remaining stationary  $\frac{3}{4}$  mile east of the satellite station from 0600 GMT until 1245 GMT rapidly moved downslope, and passed the satellite station at 1250 GMT.

The onset registered on the autographic traces, and showed marked gustiness. During one gust the barograph trace showed a drop of 6.5 mb, and there were several other gusts of slightly less magnitude.

After the relatively calm period at the station prior to the onset, when the thermograph trace had registered rapid fluctuations of up to 4° F, the onset brought about a steadying of the autographic trace, with variations of no more than 0.5° F for the next three hours, then a steady rise of 7.0° F. (The instrument was subsequently blocked by snow.)

The onset was accompanied by an increasing roar and a dense wall of snow which reduced visibility to 25 yards with zero visibility in the gusts. The conditions rapidly deteriorated to a blizzard, with mean wind 40-45 knots with gusts 60-70 knots, which lasted through 13 August, until 0800 GMT 14 August, when a pilot balloon sounding was made in 30 kt surface winds at release. The balloon was tracked to 3500 ft when it entered the cloud base.

The result of the sounding showed winds of 080° 35 kt to 400 ft, then a gradual decrease and backing to 030° 20 kt (mean) above the layer of strong winds. At 3500 feet the wind was 030° 05 kt.

## 5. SYNOPTIC AND UPPER AIR CONDITIONS

The Bureau of Meteorology 0600 GMT surface analyses for the Southern Ocean were used to classify the synoptic situation over the waters to the north of Vestfold Hills. The situations were classified into four types, according to the position of ridges and troughs in the general easterly gradient flow over the area:

- A - a ridge over the area,
- B - a ridge to the east and a trough to the west,
- C - a trough over the area,
- D - a trough to the east and a ridge to the west of the area.

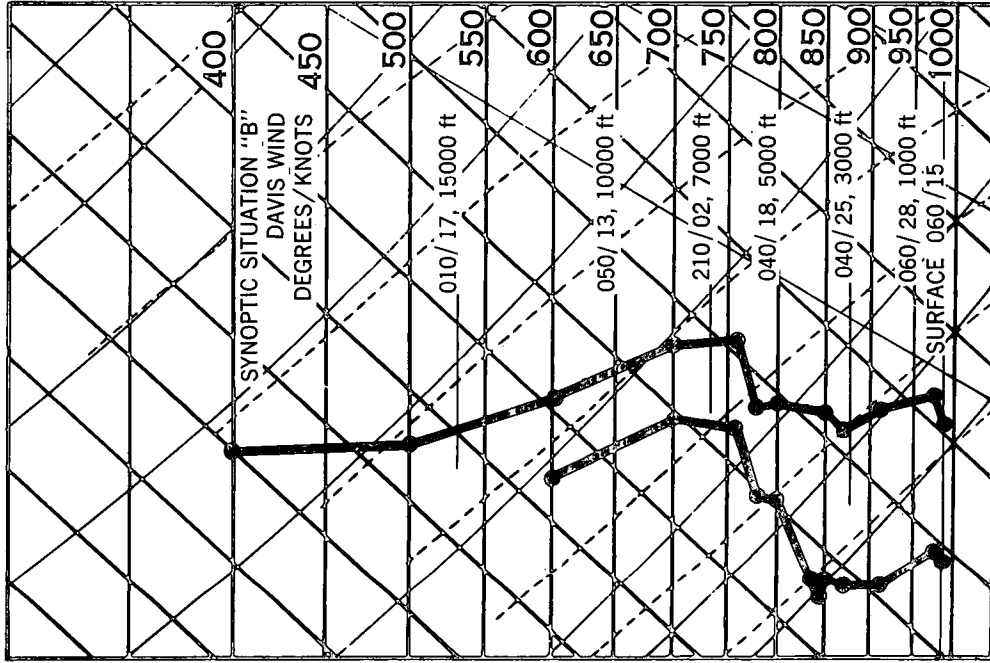


Fig. 6 (b) Davis radiosonde and upper wind data at  
0001 GMT 12 August 1961.

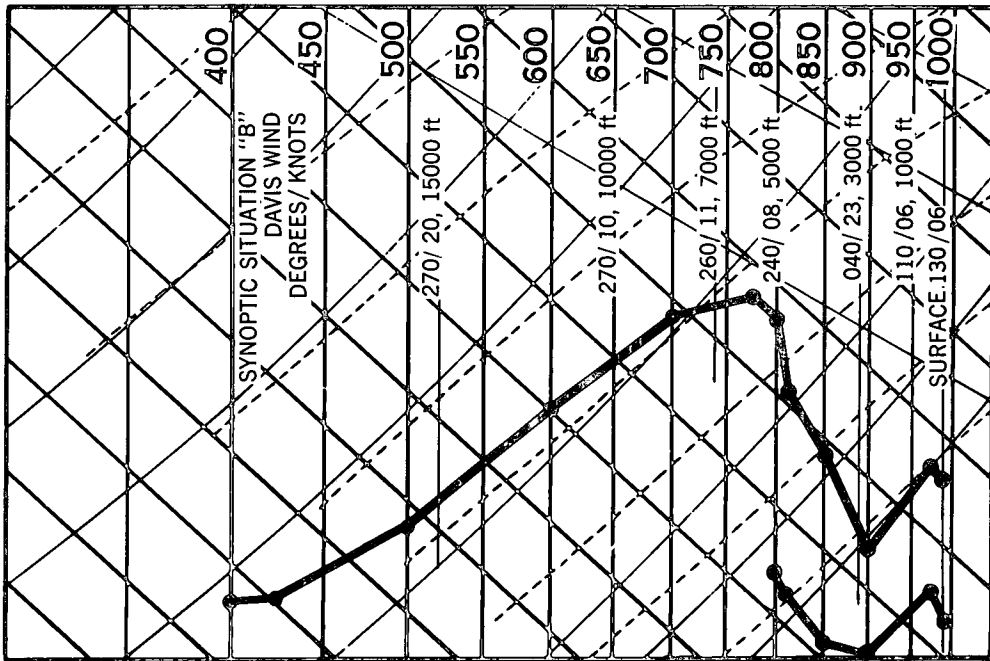


Fig. 6 (a) Davis radiosonde and upper wind data at  
0001 GMT 31 July 1961.

Of the 31 cases of standing katabatic jumps examined, six were type "A", 12 were type "B", 10 were type "C" and only four were type "D".

Ball's theory (Ball 1957) regarding katabatic flow suggests that the jump is downstream from the coast when the wind is strong, and upstream when the wind is lighter.

According to Ball's (1959) theory regarding flow lines produced by a depression situated to the north of the Antarctic coast, the wind should be strongest in situation "D". The fact that only 4 cases (13 per cent) were observed in situation "D", while the greatest number recorded in any one of the other sectors were found during situation "B", (12 cases), seems to be consistent with this hypothesis.

An examination of upper air data on days with a standing jump shows a strong, over-riding wind, both at the satellite station and at Davis, 18 miles to the west. A temperature inversion also appeared on the sounding at Davis on the same days. Similar observations have been recorded by Shaw (1957) and Streten (1961) at Mawson, and by Tauber (1959) at Mirny.

Typical soundings at Davis for days when a standing jump was observed upslope from the satellite station are presented in Fig. 6 (a) and (b). Generally the base of the inversion on such days was located between 2000 and 7000 ft. The layer of strongest wind showed no uniform relation with the inversion, being either in, or below the inversion layer, as far as could be judged from wind observations over 1000 ft layers.

## 6. CONCLUSIONS

Katabatic jumps have been shown as a definite, narrow zone of large changes in wind speed, pressure and temperature, stationary on the ice cap slope, or moving up or down. Observations confirm that it is the zone between a shallow strong wind layer, and a deeper light wind layer downstream which may contain a shallow high speed layer in or below an inversion layer. In most cases the pressure changed by 1 to 3 mb through the jump but on one occasion a mysteriously large change of nearly 20 mb was measured.

The wall of snow clearly marks the downstream edge of the strong wind zone, but drifting snow may not be present after a long, fine spell with little or no precipitation in the catchment area near the coast and for some distance inland.

It is hoped that in the future more comprehensive upper air measurements will be made through the discontinuity in this locality, which seems particularly apt to produce hydraulic standing jumps.

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