Polar Record, Vol 21, No 131, 1982, p 137–146
Printed in Great Britain

EXPERIENCES OF SCOTT'S NORTHERN PARTY: EVIDENCE FOR A RELATIONSHIP BETWEEN WINTER KATABATIC WINDS AND THE TERRA NOVA BAY POLYNYA

BY

DAVID H. BROMWICH AND DENNIS D. KURTZ*

[*Revised MS received February 1982*]

Contents

Introduction

The six men of Captain Robert Falcon Scott's Northern Party were stranded on Inexpressible Island (Fig 1) from late February to September 1912. During that period their lives were profoundly influenced by prevailing surface wind and sea ice conditions in Terra Nova Bay. Members of the party lived under the most primitive conditions, enduring more than seven months of strong, persistent winds. The western part of Terra Nova Bay remained largely free of ice in 1912, thus preventing the group from leaving until there was sufficient daylight to cross the Drygalski Ice Tongue. This open water, however, may also have assured their survival for it attracted enough seals and penguins to provide them with a continual though limited supply of food. Despite these adverse conditions some of the men, Raymond Priestley in particular, kept detailed journals which provide the only *in situ* wintertime observations for this area. Analysis of Priestley's wind and ice record provides strong confirmation of our model for the wintertime persistence of open water (a polynya) in Terra Nova Bay.

Terra Nova Bay appears to be a unique area in the western Ross Sea because the open water observed throughout the winter of 1912 probably recurs each year (Fig 2). Our model for the existence of this polynya (Bromwich and Kurtz, 1981)† requires that strong katabatic winds blow across the bay almost continually during winter. These surface winds collect over a large catchment area on the plateau and funnel into Terra Nova Bay primarily through the Reeves Glacier. Such a katabatic drainage pattern is suggested by numerical simulation of average winter winds (Parish, 1982), and by sastrugi information (David and Priestley, 1914, p 20; Stuart and Heine, 1961). Passage of this cold, dry air over the bay is accompanied by the formation of sea ice which is advected eastwards by the wind, thus maintaining the open water. An equally important factor influencing the polynya is the blocking effect of the Drygalski Ice Tongue. This feature probably prevents northward drifting pack ice from entering the bay.

The Terra Nova Bay polynya undergoes quasi-periodic areal oscillations (Bromwich and Kurtz, 1981) with a period of 15–20 days. These fluctuations probably reflect the interplay between coastal katabatic winds and synoptic-scale winds over the western Ross Sea which move

* Institute of Polar Studies, The Ohio State University, Columbus, Ohio 43210, USA.

† A pair of manuscripts dealing with polynya observations and a physical model have been submitted to the *Journal of Geophysical Research*.

sea ice into and out of the polynya. The present analysis of Priestley's (1913) diary reveals that the required coastal conditions certainly occurred during 1912, when moderate to strong katabatic winds kept western Terra Nova Bay largely free of ice.

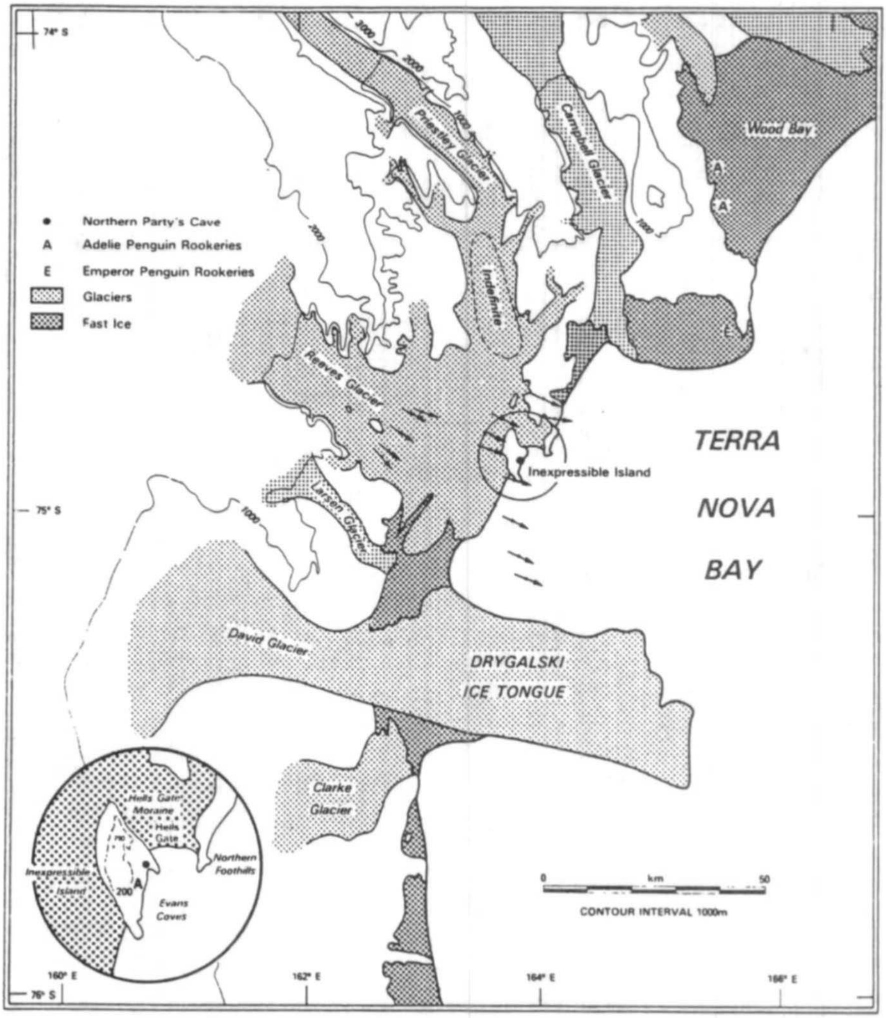

FIG 1. Location map of the Terra Nova Bay area showing the site of the Northern Party's snow cave. Sastrugi directions adapted from Wright and Priestley (1922); those in the present day ocean were measured on the Northern Party's 'homeward' journey.

Narrative

The men of Scott's Northern Party, Raymond E. Priestley, Lieutenant V. L. A. Campbell, Surgeon G. Murray Levick, Petty Officers G. P. Abbott and F. V. Browning, and Seaman H. Dickason, disembarked at what later became known as Hell's Gate Moraine on the evening of 8 January 1912. They intended to explore the area and conduct geological investigations until approximately 18 February when *Terra Nova* would return for them. It was agreed that if the ship did not appear by 15 March they would be forced to spend the winter there. This portion of the coast was thought to remain fairly open, because *Nimrod*, during Ernest Shackleton's expedition

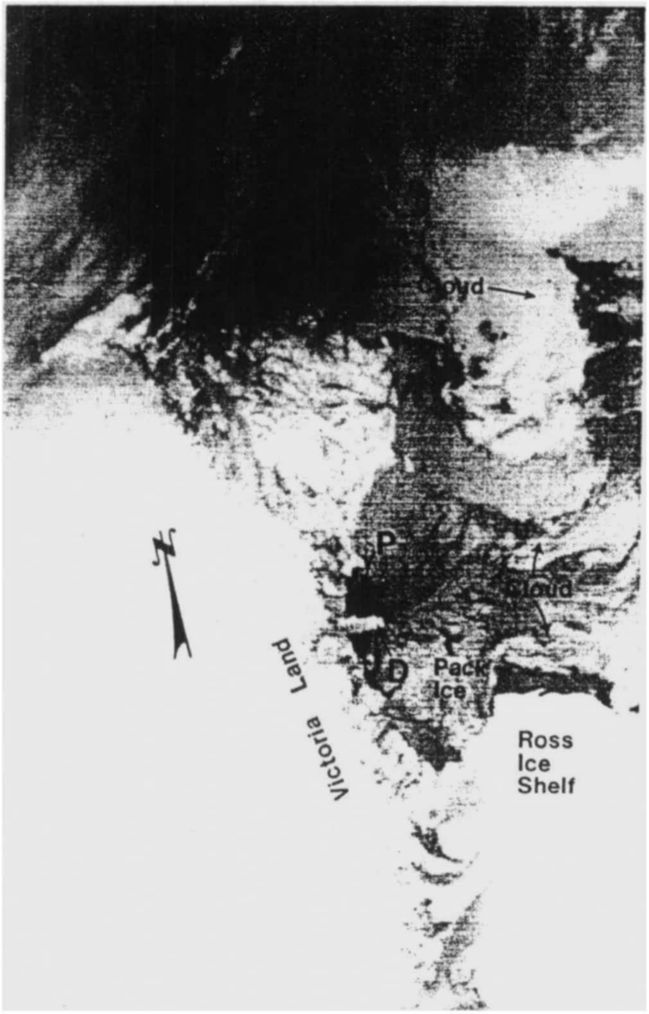

FIG 2. Infrared satellite image of the western Ross Sea, taken on 19 April 1979, showing the Terra Nova Bay polynya (P) and the Drygalski Ice Tongue (D).

in 1909, had encountered navigable ice conditions in Terra Nova Bay at this time of year. Consequently Lieutenant Campbell, the group's leader, did not feel compelled to offload the quantity and type of supplies needed for a winter stay.

Initially their time was spent pleasantly, with no hint of the conditions that would prevail the following winter. In addition, abundant seals and penguins lulled them into a false sense of security regarding the ready availability of food (Priestley, 1974, p 214). However Priestley (1974, p 216) recorded that on 8 February:

> . . . we first encountered the steady westerly plateau wind *blowing from the Reeves Glacier*, which was destined to be the bane of our existence during the winter. As yet it was only a moderate breeze that we had to face but, nevertheless, as it was blowing straight off the plateau, it was very galling, and we were very glad when we reached our objective and camped on a small drift to leeward of one of the moraines.

The party experienced this wind for two days, until they left the outlet region of the Reeves Glacier.

The party continued work until 17 February when they camped at Hell's Gate Moraine to await the return of *Terra Nova*. On the 18th a gale commenced which lasted until 23 February. After a period of lighter conditions the gale returned on the 27th and blew until the 29th. They were confined to the area in the immediate vicinity of their tents. During this period rationing was imposed. For the first time the men began to think that the ship might not return, and that they might be stranded.

Terra Nova did attempt to reach them during this time as well as on two other occasions, but was prevented from doing so by heavy pack ice. Her closest approach was 43 km. The men at Hell's Gate, however, saw no ice in the bay, and assumed that the ship had been blown north by the gales, or worse. Scott's chief meteorologist, George Simpson, was returning to India and on board *Terra Nova* during the last rescue attempt. Because of his departure from Antarctica in March 1912, and the later difficulties of communicating with other members of the expedition, he was apparently unaware of the meteorological conditions prevailing in Terra Nova Bay. Weather conditions for this region are not discussed in Simpson's (1919) treatise on Antarctic meteorology, and consequently never became widely known. Priestley's (1913) detailed meteorological observations are presented and discussed here for the first time.

The ill-timed storms were southerly blizzards. When they ceased on 29 February the party moved camp to Inexpressible Island.[1] The lull lasted for only a few hours, then the westerly plateau wind began. They now realized the urgency of securing a winter supply of food, and of constructing more permanent shelter. Labours were divided between two groups of three. One group began digging a cave in the only snow drift on the island, while the other hunted seals and penguins.

The hunting party camped at Hell's Gate during this period as they could watch more readily for the ship from there. On 19 March the bitter plateau wind intensified, destroying the hunting party's tent and pinning them beneath it for the entire day. At sunset the wind showed no signs of abating and, unable to walk against the wind, the men were forced to crawl and scramble across 2 km of windswept ice to the snow cave. From that time onwards the six men lived in a space roughly 4 m by 3 m, and only 1.7 m high (Priestley, 1974, p 315).

The wind blew throughout the winter; its constancy was frustrating, and astounding. Priestley (1974, p 325) on 15 August wrote:

> . . . the wind remained as exasperating as ever, and none of us had met anything approaching it before. It had now blown for 180 days without ever lulling for more than a few hours at a time.

During calm periods they obtained food, but the remainder of the time was spent in the snow cave. The plateau wind was a persistent westerly, ranging in speed up to Beaufort force 12. It was bitterly cold, and carried drift. Their observations indicate that the wind was primarily a surface phenomenon. Campbell at times noted that stars could be seen through the drift (Huxley, 1913, p 100).

The constant wind was not the only unexpected phenomenon that affected their existence; western Terra Nova Bay remained open throughout the winter. On 22 June Priestley (1974, p 311) noted 'I have seen to-day what I never exected to see—open water at 75°S latitude on Midwinter Day'. This open water apparently attracted penguins and seals. Except during May and June they were able to kill food regularly during lulls in the wind. Their diet was monotonous and sparse, but it enabled them to survive. Sea ice in Terra Nova Bay never consolidated to the degree that sledging was possible. Initially they had planned to depart for Cape Evans (on Ross Island) on 20 August, but by the end of June they had reconciled themselves to leaving, at the earliest, by the end of September. They did not want to cross the Drygalski Ice Tongue because of the problems T. W. Edgeworth David had experienced on his journey to the South Magnetic Pole (Priestley, 1914, p 13). But, if forced to do this, they would need reasonable light and benign weather conditions.

They left the snow cave on 30 September, with some of the men weak from sickness. As they travelled south the weather improved, and they crossed the Drygalski Ice Tongue without difficulty. Once past it the party never again experienced the frigid plateau wind that had plagued them during the winter. The Northern Party returned to Cape Evans on 6 November.

Physical conditions during 1912 and their implications

Raymond Priestley, the meteorologist in the Northern Party, was considered by Simpson (1919, p 128; 1923, p V) to be a careful and experienced observer. Priestley's (1913) diary allows a reconstruction of the physical circumstances in the vicinity of Inexpressible Island during 1912, especially the surface wind and ice cover in the western part of Terra Nova Bay. This document is, in part, an extension of his 1911 meteorological diary from Cape Adare which is printed in its entirety in Simpson (1923, p 470–551).

Figure 3 shows the daily time series of surface wind and ice conditions inferred from Priestley (1913). One or more summary notes about the wind were available for each day, and were apparently based upon at least two weather observations per day. Direction, to eight or more compass points, was usually stated explicitly. Beaufort force descriptions were not used for all observations, but Priestley was very conversant with this scale, having used it to estimate wind speed at Cape Adare during 1911 (Simpson, 1919, p 128); according to Simpson (1919, p 129) he was not inclined to overestimate the speed. Our determinations of Beaufort force were made by comparing the colloquial descriptions for winds of a given strength (List, 1971, p 119) with Priestley's notes, and assigning a minimum estimate.

Priestley noted the presence, absence, amount, location and type of sea ice every few days throughout the winter; these observations were qualitatively rated. Extremes of ice cover (ie, open water or solid pack ice) are of greatest interest with regard to the wind regime, and could be reliably identified. Intermediate ice conditions, occurring during transitions between the extremes, were rapidly changing and he did not describe them in detail. These we have ranked in a general fashion as partly open, estimating the relative amounts of ice from the diary entries. The limit of vision on a clear, bright day was probably 10–15 km.

Priestley's (1913) observations indicate a close correspondence between strong winds and open water. He noted for periods of gusting winds that the bay started to freeze during lulls, but that ice was blown away by each successive gust. Figure 3 reveals that the bay was often filled with pack ice when there were light winds (eg, mid March, late May, mid August, mid September). This connection between surface wind and sea ice conditions is an essential feature of our proposed model. However, a one-to-one correlation is not expected because many other factors, such as air temperature, duration of light winds, and sea ice advection from the Ross Sea, are also important.

Information contained in Priestley's diary indicates that katabatic winds[2] emanating from the Reeves Glacier (ie, his westerly plateau wind) were nearly always blowing at Inexpressible Island. Ninety per cent of the time winds blew from the west or south-west (Fig 4a), ie, from the general direction of the Reeves Glacier. This high directional constancy is characteristic of topographically controlled surface winds (Mather and Miller, 1967, p 44). Speeds (Fig 4b, Table 1) ranged up to Beaufort force 12, with 75 per cent being between force 3 and 7. This high frequency of moderate to strong winds is also noted in areas where a katabatic regime is well-documented (Mather and Miller, 1967, p 45). The resultant wind speed values given in Table 1 are similar to those measured at other Antarctic coastal stations influenced by katabatic winds (Parish, 1981).

In view of the harsh conditions experienced and the absence of quantitative observations, the derived winds (Table 1) provide an approximate picture only of the prevailing situation in the

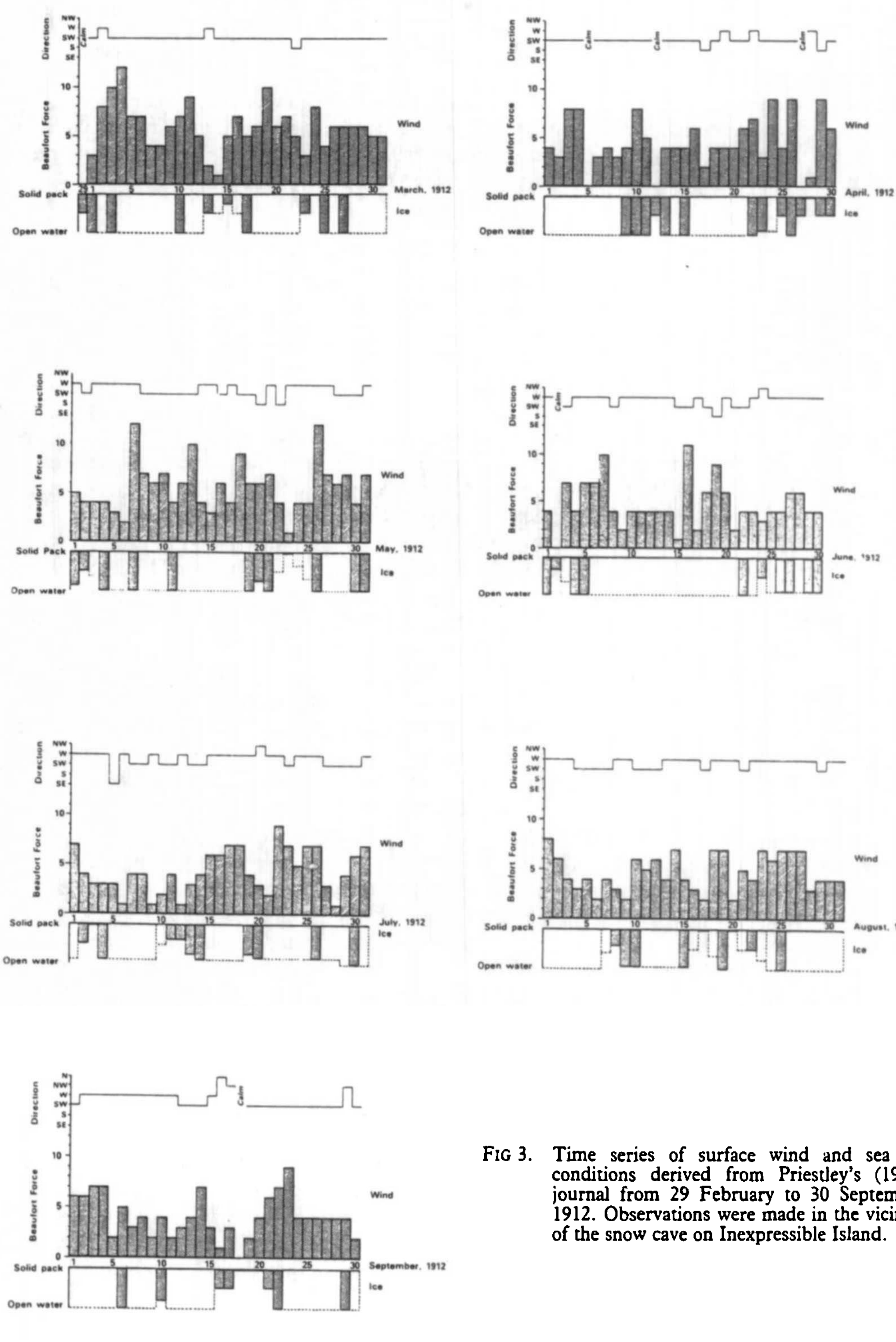

FIG 3. Time series of surface wind and sea ice conditions derived from Priestley's (1913) journal from 29 February to 30 September 1912. Observations were made in the vicinity of the snow cave on Inexpressible Island.

immediate vicinity of the Northern Party's snow cave. The partly sheltered nature of the site (Fig 1) has two consequences for this wind record. Firstly, the actual wind speeds are likely to be less than those that occur in places fully exposed to katabatic flow. Priestley (1923, p 71) wrote that throughout their stay in the vicinity of Inexpressible Island:

> . . . the same cold dry plateau wind, rarely reaching more than 60 miles an hour [27 ms^{-1} or force 10] and seldom falling below 30 miles an hour [13 ms^{-1} or force 6], scarcely ever ceased to blow. . . . Calms were as few as they were welcome, and were never of more than a few hours' duration.

This description suggests an average wind speed substantially stronger than our conservative estimate of 10 ms^{-1} (Table 1). Because Priestley (1913) often observed stronger winds at Hell's Gate Moraine and at the ice foot than at the snow cave, it is assumed that his comment described the unimpeded katabatic winds in the vicinity of Inexpressible Island.

TABLE 1. MEAN WIND CONDITIONS AT INEXPRESSIBLE ISLAND DURING 1912

Month	Resultant direction (degrees true)	Resultant speed (ms^{-1})	Mean speed (ms^{-1})	Maximum Beaufort force
February (18–28)	230	9	10	8
March	220	12	13	12
April	230	9	9	9
May	250	11	12	12
June	250	8	9	11
July	260	8	8	9
August	260	9	9	8
September	250	7	8	9
Whole period	240	9	10	12

The second consequence is that Inexpressible Island may deflect the impinging katabatic current, leading to a topographically modified resultant wind direction at the snow cave. Figure 1 contains sastrugi directions from Wright and Priestley (1922, p 16); sastrugi orientations coincide with the predominant wind direction (Mather, 1962). These data indicate that the undisturbed surface winds immediately upwind of Inexpressible Island blow from the west-north-west. As the average wind direction at the snow cave was west-south-west (Table 1), some deflection probably occurred.

It is likely that the 1912 conditions represent the usual winter-time coastal situation in Terra Nova Bay; the dominance of katabatic winds suggests that the year to year variations should be small. Caution is needed, however, because Simpson (1919, p 100) noted that, at Cape Evans (about 300 km south of Inexpressible Island), the winters of 1911 and 1912 were quite dissimilar. McMurdo Sound was frozen over during 1911 but remained open for most of the winter of 1912. These periods were characterized by markedly different mean winds and temperatures, as summarized in Table 2 (calculated from Simpson, 1919, p 96 and 99). Comparison with the

TABLE 2. AVERAGE MARCH TO SEPTEMBER TEMPERATURES AND WIND SPEEDS AT CAPE EVANS AND MCMURDO STATION

	Cape Evans		McMurdo station
	1911	1912	multi-annual average
Mean wind speed (ms^{-1})	7.4	11.4	6.8 (1956–65)
Mean temperature (°C)	−23.8	−20.8	−23.5 (1956–68)

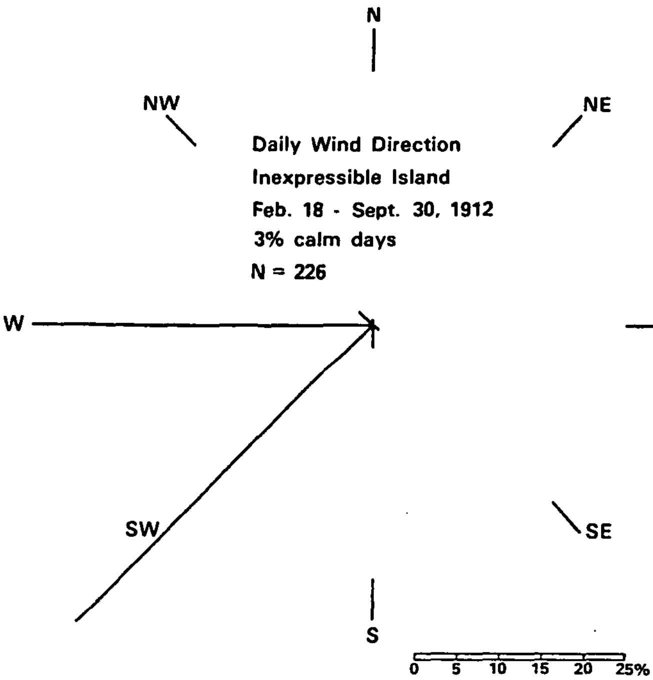

FIG 4a. Wind rose of daily surface winds at Inexpressible Island recorded in Priestley's (1913) journal. Vector length is proportional to the frequency of winds from that direction.

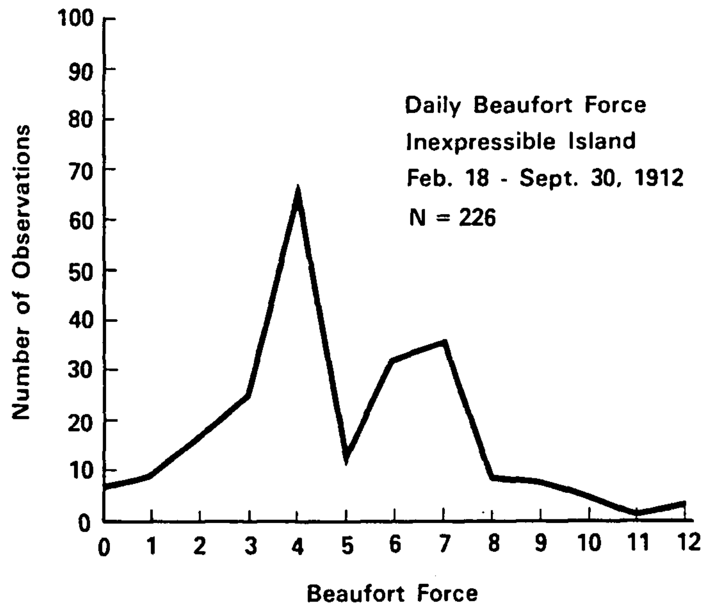

FIG 4b. Frequency distribution of estimated daily Beaufort force at Inexpressible Island, derived from Priestley's (1913) journal.

multi-annual averages for McMurdo Station (derived from Schwerdtfeger, 1970, p 337) suggests that the winter of 1912 was atypically warm and windy. However, the spatial extent of the anomalous McMurdo Sound conditions is unknown. Also, the likely existence of very different surface wind regimes at the two locations, 'barrier winds' at Cape Evans (Schwerdtfeger, 1979) and katabatic winds at Inexpressible Island, may result in uncorrelated interseasonal variations.

Numerical simulations of the East Antarctic wintertime surface wind field by Parish (1981; 1982) indicate that the very strong katabatic winds observed at Cape Denison (Mawson, 1915) originate in much the same fashion as those at Inexpressible Island. In both areas, winds from a large catchment area drain through a relatively narrow length of coastline. Though open water is present in winter in the immediate vicinity of Cape Denison, and larger leads occasionally form due to synoptic-scale atmospheric forcing (Knapp, 1972), no large, persistent polynya appears to form as a result of the katabatic outflow. The substantial area of open water illustrated in Madigan (1929, Fig 2) appears to be largely based upon sledging journeys during the *summer* of 1912–13. Furthermore, during our studies of infrared satellite images for the winter of 1979, coastal open water in this area was restricted to narrow shore leads which expanded briefly in response to synoptic events.

The absence of a large persistent polynya off the George V Coast reflects the importance of other factors besides the wind regime in affecting sea ice conditions. A major difference between the two areas is that no shielding effect, such as that exerted by the Drygalski Ice Tongue, is present near Cape Denison. No true embayment is present as in Terra Nova Bay, an area further protected by virtue of its position within the Ross Sea, and the Mertz and Ninnis glacier tongues do not extend far enough north to block sea ice markedly. The absence of sheltering from drifting sea ice is probably a main reason why no substantial polynya exists along this coast.

Though katabatic regimes are similar in the two areas important differences exist between them as well. So-called 'katabatic jumps', resulting from instability as the katabatic winds converge with relatively tranquil air over the sea, appear to be common at Cape Denison, but rare at Inexpressible Island. Mawson (1915) often observed the vertical vortices ('whirlies') associated with this phenomenon, but the men of the Northern Party rarely if ever saw them. Different terrain slopes in the two areas may explain why 'jumps' are more common at Cape Denison (Ball, 1957), but without more careful comparison of the two sites the importance of this difference cannot be evaluated. However, where 'jumps' occur, katabatic energy is dissipated very close to the coastline; thus effects of such winds on the sea ice field are minimized. Sea ice charts (Fleet Weather Facility 1975, 1977, 1979; Naval Polar Oceanography Center, 1981) do indicate that the George V Coast is consistently the site of early ice break-up in the spring, but the extent to which this reflects wintertime coastal wind conditions is not known.

Conclusions

Priestley's observations, recorded under such trying circumstances, are the only detailed, *in situ* wintertime data available from this region. The importance of these historical data cannot be over-emphasized, for they aid identifying the mechanisms responsible for wintertime open water in Terra Nova Bay. Raymond Priestley's journal entries indicate that a well developed katabatic regime persisted at Inexpressible Island throughout the winter of 1912, and that this area is one of the windiest in the Antarctic. Strong westerly surface winds were associated with open water or minimal ice cover in western Terra Nova Bay. This correlation strongly supports our physical model of polynya formation.

Acknowledgements

We thank the Scott Polar Library for supplying a copy of Priestley's diary, and Ms Terri Gregory of the Space Science and Engineering Center, Madison, Wisconsin for the loan of infrared satellite images. Jean Cothran typed the manuscript many times, and Yvonne Holsinger drafted the figures. This is contribution number 438 of the Institute of Polar Studies, The Ohio State University.

Notes

1. Priestley (1914, p 4) wrote: 'When discussing what name to give to the island on which we spent such an uncomfortable winter, we had great difficulty in deciding on one which would at once express our feelings with regard to the island and also be permissible in modern literature.'
2. There is evidence that katabatic winds frequently blow in this general area during the summer, exhibiting their characteristic diurnal variation (Mather and Miller, 1967, p 44). David and Priestley (1914, p 26) observed:

> When marching along the coast in October, November and December of 1908, we found that the plateau wind reached the coast between about 8 P.M. and 10 P.M. and would go on blowing until about between 9 A.M. and 10 A.M. the following morning. It would usually freshen a little after midnight. Its usual speed appeared to be 12 to 15 miles an hour [5 to 7 ms^{-1}]. . . . The immense sastrugi at the Drygalski Glacier [Drygalski Ice Tongue] show that towards winter the winds must blow from off the plateau with great fury . . .'.

David's party crossed the Drygalski Ice Tongue and ascended the Larsen Glacier on their way to the South Magnetic Pole.

References

BALL, F. K. 1957. The katabatic winds of Adélie Land and King George V Land. *Tellus*, Vol 9, No 2, p 201–08.
BROMWICH, D. H. *and* KURTZ, D. D. 1981. The Terra Nova Bay polynya: description and physical model. *EOS. American Geophysical Union Transactions*, Vol 62, No 45, p 902. (Abstract 02-1-A-10.)
DAVID, T. W. E. *and* PRIESTLEY, R. E. 1914. *Geology, Vol I. Glaciology, physiography, stratigraphy and tectonic geology of South Victoria Land. British Antarctic Expedition 1907–09. Reports on the scientific investigations.* London, Heinemann.
FLEET WEATHER FACILITY. 1975, 1977, 1979. *Antarctic ice charts, 1973–1974, 1975–1976, 1977–1978.* Suitland, Maryland, Fleet Weather Facility.
HUXLEY, L. *ed.* 1913. *Scott's last expedition, Vol II.* New York, Dodd, Mead and Co.
KNAPP, W. W. 1972. Satellite observations of large polynyas in polar waters. *In*: KARLSSON, T. *ed. Sea ice.* Reykjavik, Iceland, National Research Council, p 201–12.
LIST, R. J. 1971. *Smithsonian meteorological tables.* Washington, DC, Smithsonian Institution.
MADIGAN, C. T. 1929. Meteorological records of the Cape Denison station, Adélie Land. *Australasian Antarctic Expedition 1911–1914. Scientific Reports*, Series B, Vol 4.
MATHER, K. B. 1962. Further observations on sastrugi, snow dunes and the pattern of surface winds in Antarctica. *Polar Record*, Vol 11, No 71, p 158–71.
MATHER, K. B. *and* MILLER, G. S. 1967. *Notes on topographic factors affecting the surface wind in Antarctica with special reference to katabatic winds and bibliography.* Fairbanks, Geophysical Institute, University of Alaska. (Report UAG R-189.)
MAWSON, D. 1915. *The home of the blizzard.* London, Heinemann.
NAVAL POLAR OCEANOGRAPHY CENTER 1981. *Antarctic ice charts, 1979–1980.* Suitland, Maryland, Naval Polar Oceanography Center.
PARISH, T. R. 1981. The katabatic winds of Cape Denison and Port Martin. *Polar Record*, Vol 20, No 129, p 525–32.
PARISH, T. R. (in press). Surface airflow over East Antarctica. *Monthly Weather Review.*
PRIESTLEY, R. E. 1913. General diary, 1 January 1912–February 1913. (Unpublished manuscript in the Scott Polar Research Institute, Cambridge. MS 298/6/2.)
PRIESTLEY, R. E. 1914. Work and adventures of the Northern Party of Captain Scott's Antarctic Expedition, 1910–1913. *The Geographical Journal*, Vol 43, No 1, p 1–14.
PRIESTLEY, R. E. 1923. *Physiography (Robertson Bay and Terra Nova Bay regions). British (Terra Nova) Antarctic Expedition, 1910–1913.* London, Harrison and Sons.
PRIESTLEY, R. E. 1974. *Antarctic adventure.* Toronto, McClelland and Stewart.
SCHWERDTFEGER, W. 1970. The climate of the Antarctic. *In*: LANSBERG, H. E. *ed. World survey of climatology, Vol 14.* Amsterdam, Elsevier, p 253–355.
SCHWERDTFEGER, W. 1979. Problems and suggestions concerning synoptic and climatic data for the high southern latitudes. *In*: KUHN, M. *ed. Collections of contributions presented at CPM sessions, IAGA-IAMAP Assembly, Seattle, Washington, September 1977.* Boulder, Colorado, National Center for Atmospheric Research, p 84–100.
SIMPSON, G. C. 1919. *Meteorology. British Antarctic Expedition, 1910–1913. Vol I. Discussion.* Calcutta, Thacker, Spink and Co.
SIMPSON, G. C. 1923. *Meteorology. British Antarctic Expedition, 1910–1913, Vol III. Tables.* London, Harrison and Sons.
STUART, A. W. *and* HEINE, A. J. 1961. Glaciological work of the 1959–1960 US Victoria Land Traverse. *Journal of Glaciology*, Vol 13, No 30, p 997–1002.
WRIGHT, C. S. *and* PRIESTLEY, R. E. 1922. *Glaciology. British (Terra Nova) Antarctic Expedition, 1910–1913.* London, Harrison and Sons.