The Mountain Barrier Effect and Modification of Tabular Iceberg Motion in a Coastal Ice Zone

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ABSTRACT ■

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A comparison was made between observed surface winds and geostrophic winds calculated from surface pressure maps, for the Arctic Ocean region near Axel Heiberg Island, during the May-September 1986 interval. For five distinct episodes, during which the geostrophic wind was directed from the west toward the mountain range, the surface wind, measured on Hobson's drifting ice island, 60 km west of the mountain barrier, was from the south. This is interpreted as additional experimental confirmation of the mountain barrier effect (PARISH, 1983). The effects on ice island motion near the Canadian Arctic coast are discussed.

ADDITIONAL INDEX WORDS: *Wind, iceberg, ice island, sea ice, geostrophic wind.*

INTRODUCTION

ALBRIGHT (1980) and THORNDIKE and COLONY (1982) stated that the geostrophic winds are related to the observed surface winds and pack ice motion in the central Arctic. Their observations showed large deviations in the directional relationships, indicating that wind shear in the central Arctic is a time-variable condition, as yet not thoroughly understood.

The classic approximate ratio of sea ice speed to surface wind speed (V_s) is about 2% (THORNDIKE and COLONY, 1982). The ratio of sea ice speed to geostrophic wind speed (V_s) is about 1% (ZUBOV, 1945). These were based upon annual ice floes free to move without restraint from adjacent land masses. ALBRIGHT (1980) found that the relationship between the geostrophic wind and the surface wind, using the Arctic Ice Dynamics Joint Experiment (AIDJEX) data from 1975 and 1976 in the Beaufort Sea, showed that the average ratios of surface wind speed to geostrophic wind speed are 0.55 in winter and 0.60 in summer. There was an average clockwise angle from surface wind to geostrophic wind of 30° in winter and 24° in summer.

However, the values obtained by ALBRIGHT

(1980) for the central Arctic should not be applied within 150 km of a mountain barrier if the geostrophic winds are directed either towards or away from the barrier. The effect of the mountains is to modify the direction and speed of the surface winds as compared with the geostrophic winds (SCHWERDTFEGER, 1975; PARISH, 1983; KOZO, 1980, 1988). A mountain barrier perpendicular to the geostrophic wind creates a surface wind component on the incoming side which is to the left (in the northern hemisphere) blowing parallel to the mountain chain, and extending up to 150 km away from it, as shown in Figure 1 (PARISH, 1983). In Figure 1, computed for a 10 m/sec geostrophic wind, the mountain parallel wind on the surface is 5 m/sec at a distance of 210 km from the base of the mountain.

In this paper, the observed surface wind data measured on Hobson's drifting ice island was used, and a comparison was made with the geostrophic winds calculated from surface pressure maps. The ice island was located near Axel Heiberg Island during the period of the study, May-September, 1986. The relationship between surface wind, geostrophic wind and ice island movement for large daily motion episodes are shown, and evidence is found for the mountain barrier effect; when the geostrophic wind was
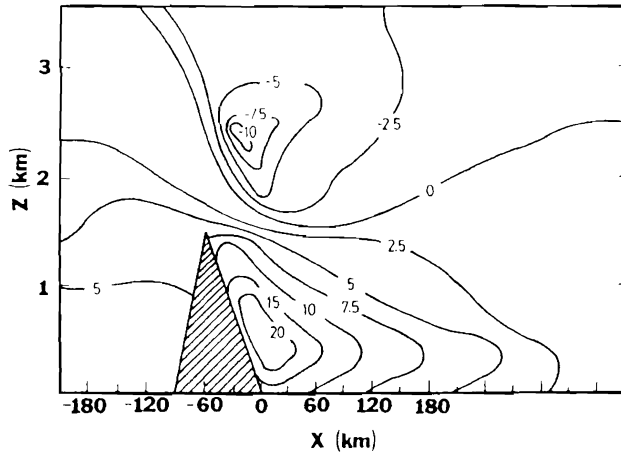
Figure 1   Mountain-parallel wind components (m/s) from calculations by Parish (1983) for a geostrophic wind of 10 m/s normal to the mountain barrier.
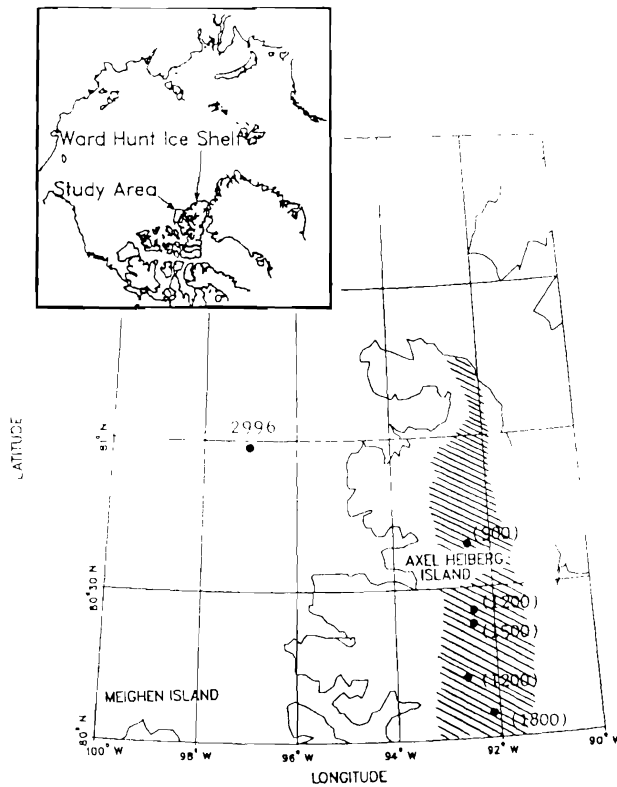

Figure 2.   The location of *Hobson's* Ice Island with buoy 2996 and its vicinity. The study area and Ward Hunt Ice Shelf are shown in the small map above. Crossed area on Axel Heiberg Island corresponds to surface elevation above 400 meters, and with peaks at 900, 1200, 1500 and 1800 meters.
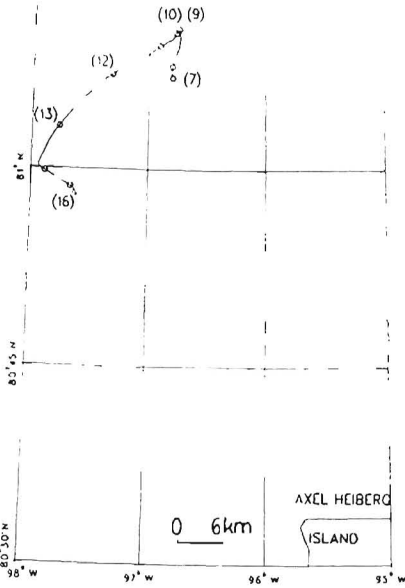
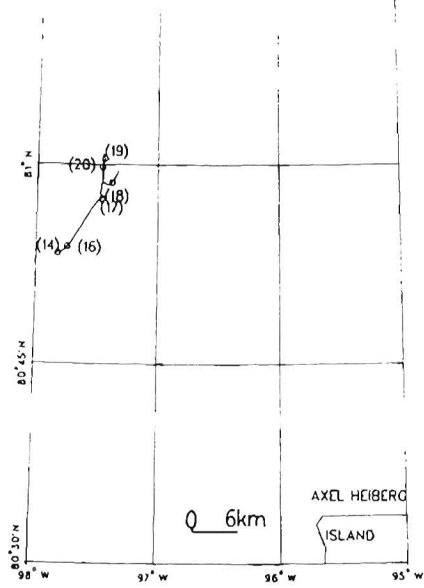Figure 3. Ice island positions in the period May 7th to 16th, 1986.

Figure 4. Ice island positions in the period June 14th to 21st, 1986

directed from the west toward the mountain range, the surface wind was from the south parallel to the mountain chain.

Observed Data, Hobson's Ice Island

Surface winds were measured at a height of 2 meters with Argos buoy 2996 deployed on Hobson's ice island. The velocity of the ice island movement was from Transit Satellite Geodetic Doppler Positioning System (SCHMIDT et al., 1987) and the geostrophic wind was calculated from the synoptic chart (Canadian Meteorological Center, Edmonton, Alberta, CMC). During the period of this study, May-September, 1986, the ice island was located about 60 km west of Axel Heiberg Island. On the island, there is a mountain barrier which has an average width of 30 km, with the heights of the ridge crests at 900 m, 1200 m, 1500 m and 1800 m, respectively, along a 110 km length, as shown in Figure 2.

Hobson's ice island is a tabular iceberg that broke off the Ward Hunt Ice Shelf in 1982-83, and is the largest ice island known in the Arctic Ocean at the present time with a length of
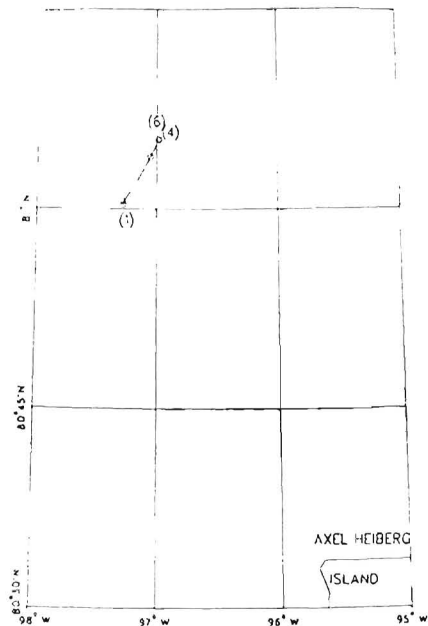

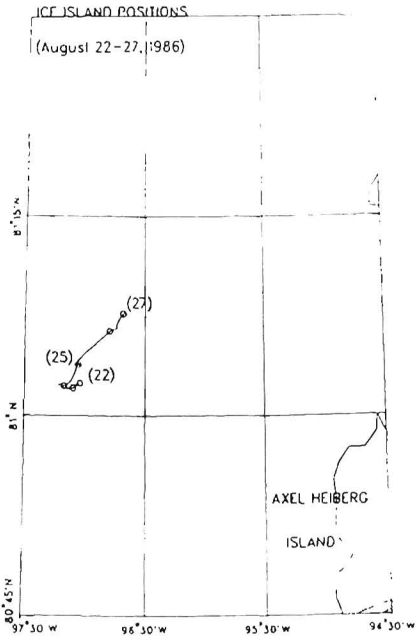Figure 5. Ice island positions in the period July 1st to 6th, 1986.

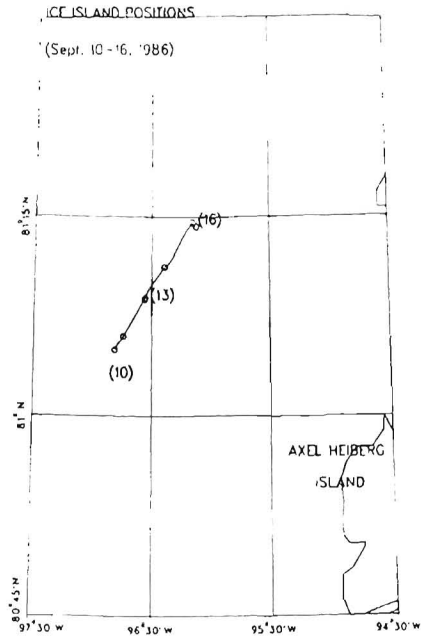Figure 6. Ice island positions in the period August 22nd to 27th, 1986.

Figure 7. Ice island positions in the period September 10th to 16th, 1986.

about 8.7 km, a width of about 5.7 km and a mean thickness of 42.5 m (JEFFRIES *et al.,* 1988). This particular ice island has been tracked by Argos buoys since 1983 (SACKIN-GER *et al.,* 1988), which have reported positions of the ice island, wind speed and direction, wind gusts, barometric pressure and air tempera-ture. These data have been used to calculate and analyze the ice island's movement.

Large Daily Movements from May to September 1986

The trajectories of Hobson's ice island in the period May 7-16, June 14-21, July 1-6, August 22-27 and September 10-16, 1986, for which large daily motions took place parallel to the coastline, are shown in Figures 3, 4, 5, 6 and 7, respectively. On May 7, May 9, June 14 and June 17 the motions are minor. It is interesting to note that large daily motion of the ice island was usually parallel to the coastline in the direction of the southwest or the northeast.

Relationship Between Surface Wind, Geostrophic Wind and Ice Island Movement

Data sets for surface wind, for the periods May 7-16 and June 14-21, 1986, are presented in Figures 8 and 9, and compared with the velocity of the ice island movement and the geo-strophic wind. It can be seen in Figure 8 that the ice island movement increased and decreased with the wind speed. The angle of the surface wind direction is smaller than the angle of the geostrophic wind direction from May 8 to 9, and from May 10 to 16, which indicates that the surface wind turns to the left of the geos-trophic wind due to the effect of surface friction. It is still seen from Figure 9 that the ice island movement increased and decreased with the wind speed, and the surface wind turned to the left of the geostrophic wind. The ice island motion direction was to the left of the geo-strophic wind, and to the right of the surface wind, as seen in Figures 8 and 9, for those times when large daily motions of the ice island took place.
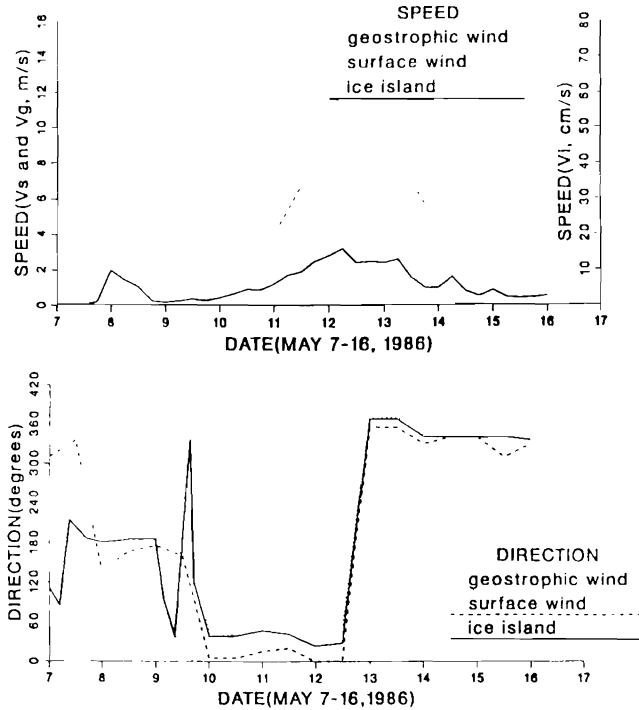
Figure 8. Direction and speed of surface wind, geostrophic wind and ice island movement in the period May 7-16, 1986.
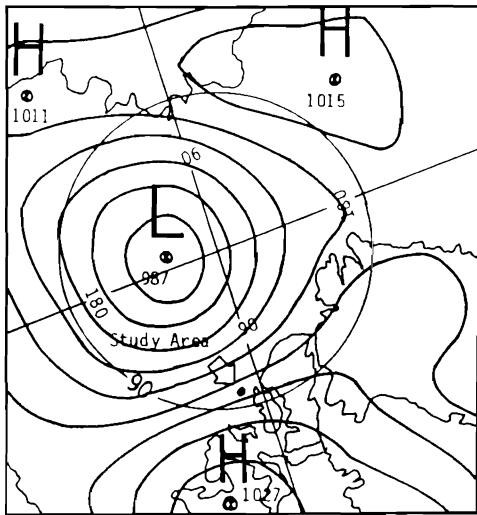

Figure 11. The Arctic surface weather map of 1200Z July 5th, 1986 (CMC).

However, on May 9 and June 17, the angle of the surface wind relative to the geostrophic wind was 90°. This was probably due to the mountain barrier effect, since the geostrophic wind was directed towards the mountain barrier, and details will be discussed in the next section. Because of the smaller wind speed on May 7 and May 9 (Figure 8), the movement of the ice island was also small and the direction of the movement changed significantly, probably due to tidal effects. The same phenomenon occurred also on June 14 and June 17 (Figure 9).

The results of the relationship between the velocity of ice island movement (V_i), the surface wind velocity (V_s) and the geostrophic wind velocity (V_g) for times of large movement episodes indicate that the average ratios of V_i/V_s, V_i/V_g and V_s/V_g are 1.4%, 0.86% and 0.62, respectively. These values, different from the classic ratios for sea ice as mentioned before, could be caused by the transient response due to the huge mass of the ice island, and by the
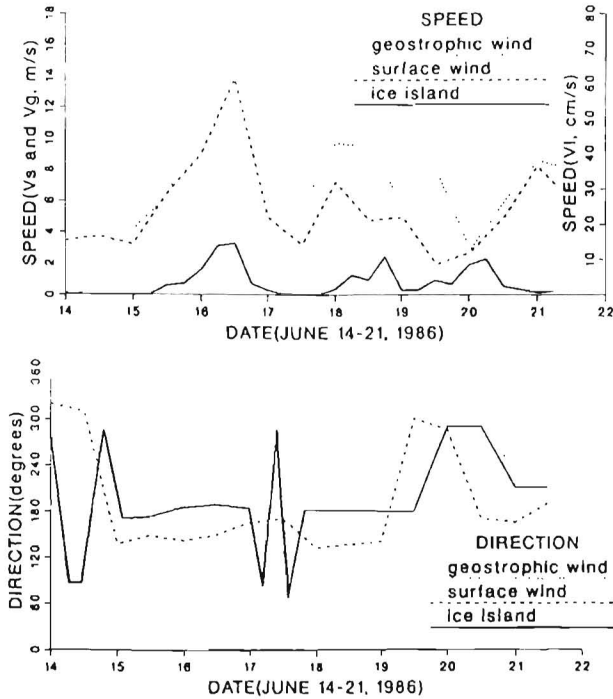
Figure 9.   Direction and speed of surface wind, geostrophic wind and ice island movement in the period June 14-21, 1986.

large form drag due to the great ice island thickness (LU, 1988). For large movement episodes, the ice island usually moves to the left of the geostrophic wind direction with an average angle of 25° ± 10°, to the right of the surface wind direction with an average angle of 20° ± 10°. The surface wind moves to the left of the geostrophic wind direction with an average angle of 36° ± 10° (LU, 1988).

Mountain Barrier Effect

As mentioned above, the location of Hobson's Ice Island was near Axel Heiberg Island in 1986. The surface elevation of Axel Heiberg Island rises very abruptly from sea level to over 400 meters with peaks at 900, 1200, 1500 and 1800 meters (Figure 2). This could cause a mountain barrier effect as computed by PARISH (1983).

The significant data on May 9 and June 17 show a turning angle from the surface wind to the geostrophic wind of greater than 90 degrees. This is probably due to the mountain

barrier effect, because the geostrophic wind was directed towards the mountain barrier from the west. Using the results of the model of Parish, it is reasonable to attribute the relationship between surface wind and geostrophic wind to the mountain barrier effect, as shown in Figure 1. However, since the speeds of the geotrophic wind and the surface wind were small on these two days, the ice island motion was not dominated by wind.

A more significant example occurred during the interval July 1-9 shown in Figure 10. On the first day of this episode, the geostrophic wind blew from the south parallel to the mountain barrier. The surface wind was also from the south on July 1 with a turning angle of about 30 degrees. The magnitude of the geostrophic wind was about 11.2 m/s, much larger than the surface wind, which was about 6 m/s. After the second day, on July 3-7, the geostrophic wind changed direction to southwest, blowing towards the mountain barrier, but the surface wind maintained its direction still parallel to the mountain barrier, from the south. The mag-
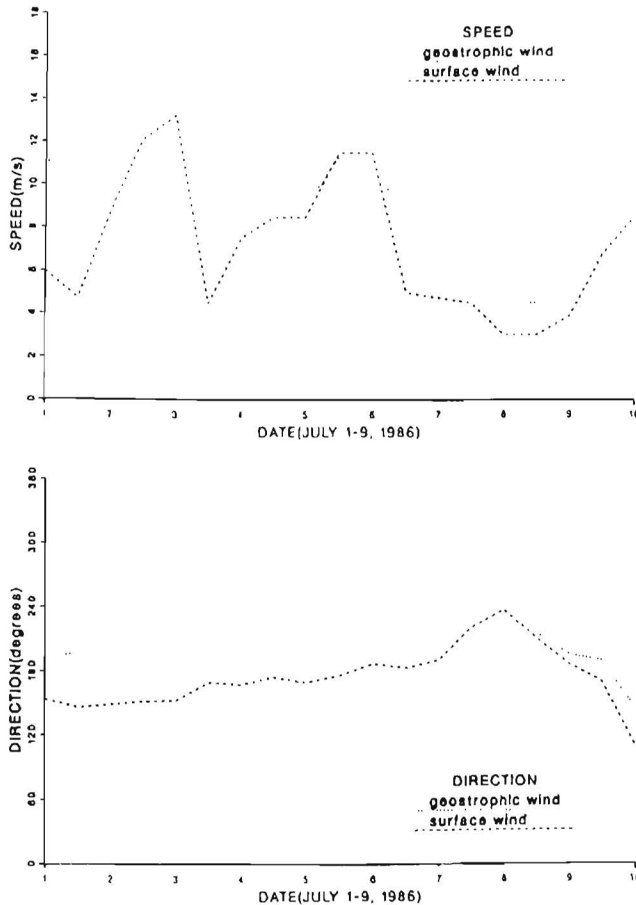
Figure 10. Direction and speed of surface wind and geostrophic wind in the period July 1-9, 1986.

nitude of the geostrophic wind approached that of the surface wind, especially on the day of July 5, when the surface wind was slightly larger than the geostrophic wind. This is likely evidence of the mountain barrier effect. In Figure 11, the corresponding surface weather map of 1200Z July 5th is presented. Ice island movement was large on July 2-3, but small thereafter, possibly due to the accumulation of pack ice around the island.

Evidence of mountain barrier effects were also observed for August and September, 1986. In Figure 12, the direction and magnitude of the geostrophic wind and surface wind is given for the period August 22-27, 1986. The mountain barrier effect occurred on August 26, which

is a case similar to that mentioned before. The geostrophic wind blew from the west towards the mountain barrier, and the surface wind was from the south, parallel to the mountain barrier. It is interesting to note that the speed of the geostrophic wind was slightly smaller than that of the surface wind during the onset of the mountain barrier effect. This is consistent with the results of PARISH (1983).

An additional episode of this type took place in the September 11-17, 1986 interval as shown in Figure 13. For the entire time, a geostrophic wind from the west produced a surface wind parallel to the mountain barrier. A noteworthy feature in Figure 13 is that small changes in geostrophic wind direction did not affect sur-
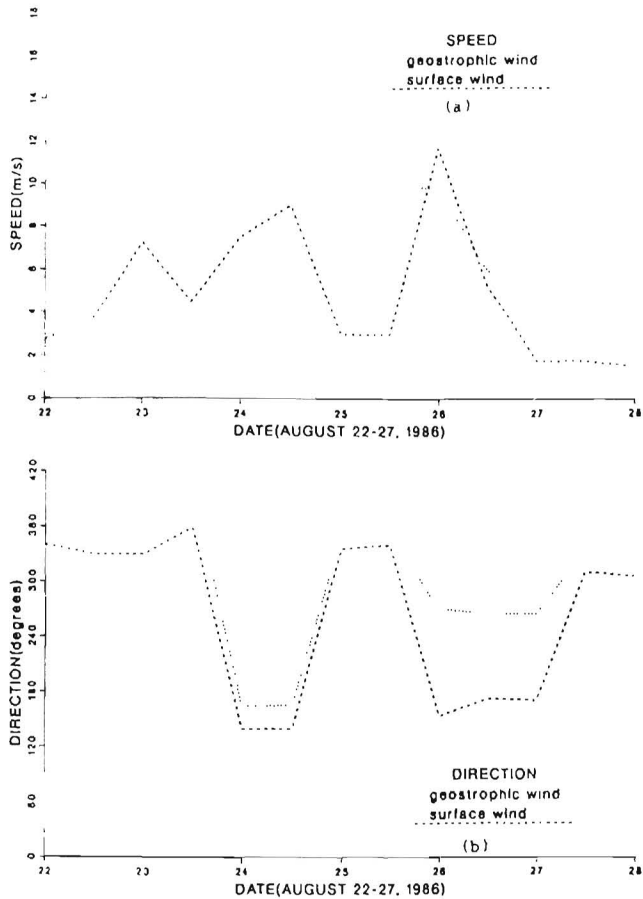
Figure 12.   The direction and speed of surface wind and geostrophic wind in the period August 22-27, 1986.

face wind direction, but they did affect the ratio of surface wind intensity to geostrophic wind intensity, as predicted by PARISH (1983).

The intensity of the surface wind was in the range 6-8 m/s on September 11-12, and in fact on September 14-15, in another intense wind event, the wind speed ranged from 6 to 10 m/s. These winds caused more rapid ice island motion, as shown in Figure 13, with velocity of 10-15 cm/s in a direction 25°–40° to the right of the surface wind. These events show specific evidence of how the mountain barrier effect can affect major ice island movements.

The relationships between surface wind direction and geostrophic wind direction for time segments 7–16 May, 14–21 June, 1–9 July, 22–27 August and 11–17 September, 1986, are plotted in Figure 14. Data points

within the small square show the influence of mountain barrier effect, for which the geostrophic wind is in the 270 degree direction (from the west towards the mountains) and the surface wind direction is about 180 degrees (parallel to the mountains). The turning angle between them is about 90 degrees in this case.

CONCLUSIONS

Trajectories of Hobson's ice island showed five large movement episodes in the intervals of May 1-16, June 14-21, July 1-4, August 22-27 and September 11-17, 1986, which were mainly towards a northeast direction along the coastline of Axel Heiberg Island. The relationships between the velocity of the ice island movement, the surface wind velocity and the geo-
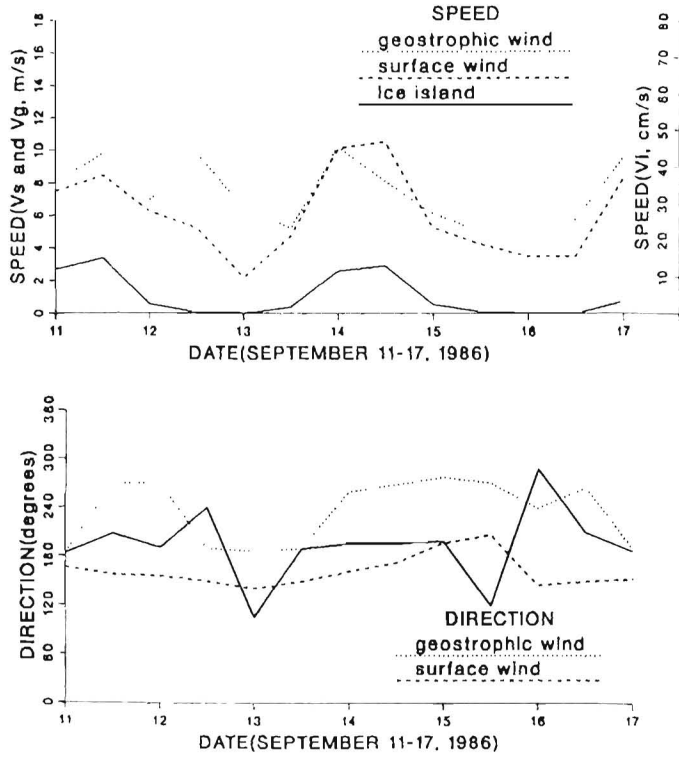
Figure 13. The direction and speed of surface wind, geostrophic wind and ice island movement in the period September 11-17, 1986.
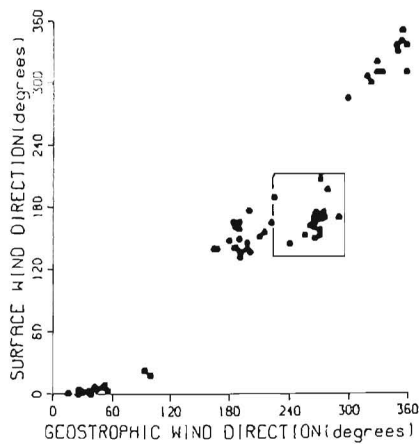

Figure 14. The geostrophic wind direction versus surface wind direction for time segments May 7-16, June 14-21, July 1-9, August 22-27 and September 11-17, 1986. Box area shows evidence of mountain barrier effect for North/South mountain chain on Axel Heiberg Island.

strophic wind velocity were obtained. Evidence
was found for the mountain barrier effect. The
surface wind produced by a geostrophic wind
blowing towards a mountain barrier was
directed to the left (in the Northern Hemi-
sphere). Episodes of coastward air flow from the
west induced a component of the surface wind
from the south. Ice island movement resulted,
at higher wind speeds. This movement implies
that the mountain barrier effect should be
taken into account when predicting ice island
movement near a mountainous coastline
extending up to 150 km away from it.

ACKNOWLEDGEMENTS

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