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Fall Ice Drift in Nares Strait, as Observed by Sideways-Looking Airborne Radar

MOIRA DUNBAR[1]

ABSTRACT. From Sideways-Looking Airborne Radar (SLAR) imagery of sea ice obtained on three flights during the week of 19 to 26 Oct. 1976 it is possible to track floes throughout Nares Strait over periods of days and, on one occasion, hours. The data are interpreted in the light of available information on ice drift, winds, and currents. The results are believed to give a fairly typical picture of ice drift characteristics in periods of northerly air flow, which is the dominant pattern in this area.
The suitability of the method for acquiring drift information in other areas is also demonstrated.

RÉSUMÉ. Des clichés SLAR de glace de mer, pris lors de trois vols, pendant la semaine du 19 au 26 octobre 1976, permettaient de suivre de près des glaces flottantes dans la détroit de Nares pendant des jours et des heures à une occasion. Certainement les résultats donnent une image typique correcte des proprietés de la dérive des glaces pendant les périodes où le vent du Nord souffle, ce qui est le cas gènèralement dans cette région. C'était un bon exemple de crédibilité de la méthode à appliquer dans l'autres régions pour acquérir de l'information sur la dèrive des glaçes.
Traduit par Alain de Vendegies, Aquitaine Co. of Canada Ltd.

INTRODUCTION

The imagery on which this study is based was obtained by a Canadian Forces Argus aircraft as part of a joint Canadian/UK exercise designed primarily to provide top and bottom profiles of ice in the Arctic Ocean. A report on the interpretation of ice characteristics in this SLAR imagery has already been published (Dunbar, 1978).

As the aircraft was based at Thule in northwest Greenland, the opportunity was taken to image Nares Strait (Fig. 1) as often as possible enroute to and from the Arctic Ocean. The resulting imagery provided a considerable amount of information on ice drift in the strait through tracking of floes from one flight to the next, and this information is presented and discussed in this report.

The aircraft made three flights, on Oct. 19, 21 and 26. Nares Strait was covered on all three flights; once, from north to south, on 19 Oct., twice on 21 Oct. and twice on 26 Oct. Three of these traverses were straight up and down the channel, and two, on 21 Oct., followed a direct line between Thule and Alert, giving an oblique and less complete coverage of the strait.

The radar used was a Motorola AN/APS-94D, a real-aperture SLAR which images on either or both sides of the track, at ranges of 25 and 50 km a side. The non-imaged strip below the aircraft has a width of about twice the flight altitude. The range resolution is about 30 m, and the azimuth resolution is 40

[1]Defense Research Board/DREO, National Defence HQ, Ottawa K1A 0Z4

m at 5 km from the track, deteriorating down-range at a rate of 8 m/km. This is quite adequate to allow identification of floes from one image to another.

The radar was operated in the mode just described on 26 Oct. only; on the other two flights it was in a Doppler beam-sharpened (DBS) mode designed by the Communications Research Centre for the Department of National Defence (Barnes *et al.*, in press). This modification produces the same sort of image as the original mode but with an improved azimuth resolution. For the purposes of this study, however, it has two important drawbacks: It images on one side at a time only, and is extremely sensitive to aircraft movement. Thus the imagery for 19 and 21 Oct. covers only half the channel, and that for 21 Oct. has the additional disadvantage of being largely spoiled by instability.

THE DATA

The drift information obtainable from the imagery is of two kinds: the longer-term data tracing individual floes from one flight to the next, some of them over the whole seven-day period; and short-term drift covering the 8 to 11 hour period between the up and down channel flights on 26 Oct. These drifts have been plotted on Figs. 2 to 5. No very exact measurements are possible owing to variations in SLAR geometry — it is impossible to overlay one image on another and match the coastlines, chiefly because any change of aircraft heading, however small, introduces distortions in the imagery. However, the general picture gained of drift speed and direction is valid and gives a good deal of useful information on conditions in the channel. It is the first time that near simultaneous drift observations of the whole of Nares Strait have been made. For this reason, and as an illustration of what can be done with consecutive SLAR passes, it seems worthwhile to publish the results.

Long-Term Drift

Examination of the imagery afforded a total of 18 floes that could be recognized on two or all three dates. These are designated by letters from A to U and are plotted on Figs. 2-4. In Figs. 2 and 3 they are divided by date for clarity of presentation, though many appear on both. Fig. 4 shows those that could not be found in the imagery for 21 Oct., but were seen on the first and third dates. Table 1 shows the dates of observation of each floe as well as the distance and speed of drift, and Table 2 divides the floes by drift speed and area. Fig. 9 shows some of the floes on 26 Oct.

More floes could undoubtedly have been tracked if the imagery had been more complete. However, on the first two flights parts of the channel were not seen, and in addition on 21 Oct. much of the imagery was wiped out by aircraft movement. Figs. 6-8 show the limits of observation on the three dates. The imagery on 26 Oct. (Fig. 8), when the SLAR was imaging on both sides, has a blind strip immediately below the aircraft with a width of twice the aircraft altitude, or 1829 m (6000 ft) on the northbound track and 3658 m (1200 ft) on the southbound.

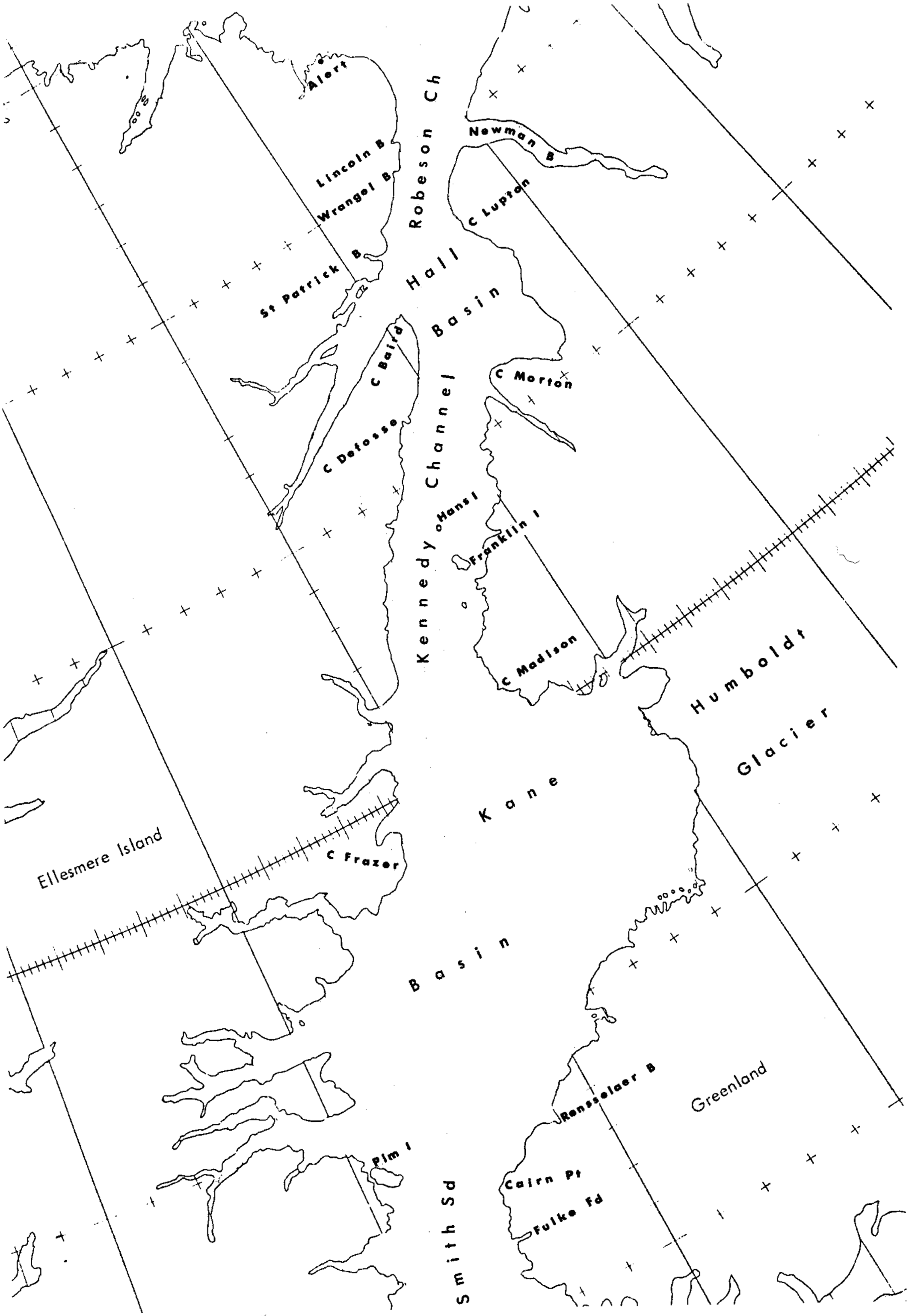

FIG. 1. Map of Nares Strait.

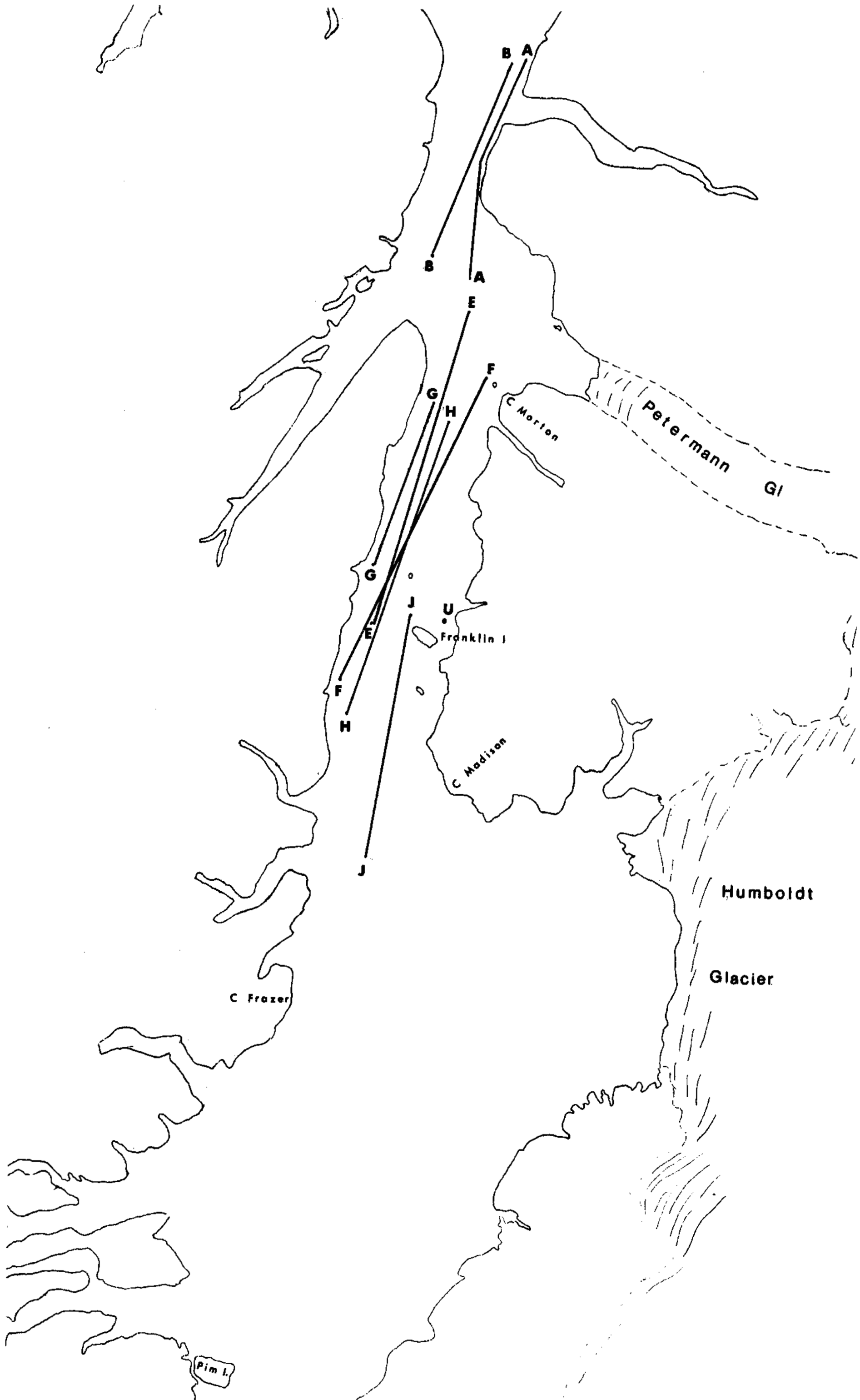

FIG. 2. Drift of floes tracked between 19 and 21 October.

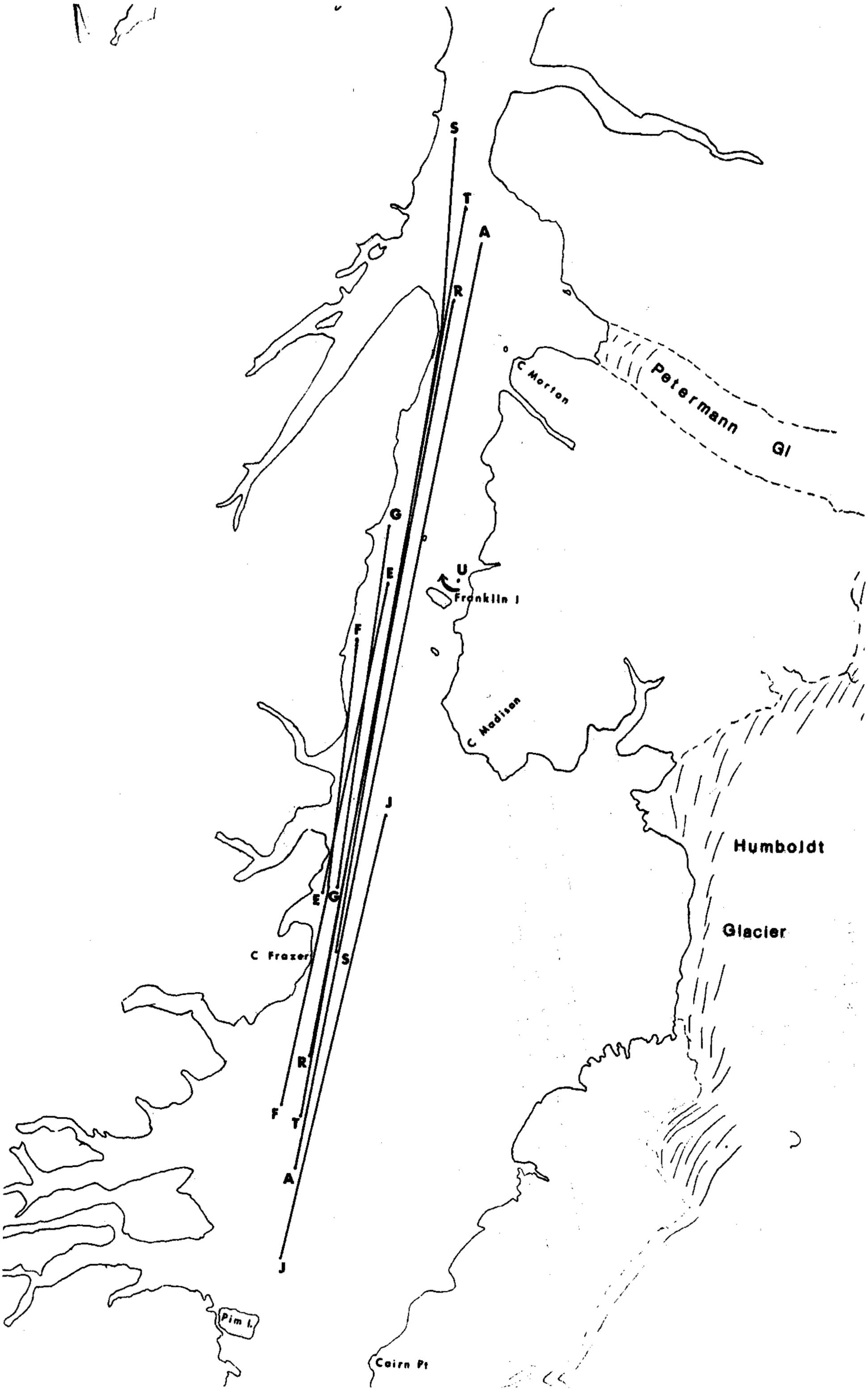

FIG. 3. Drift of floes tracked between 21 and 26 October.

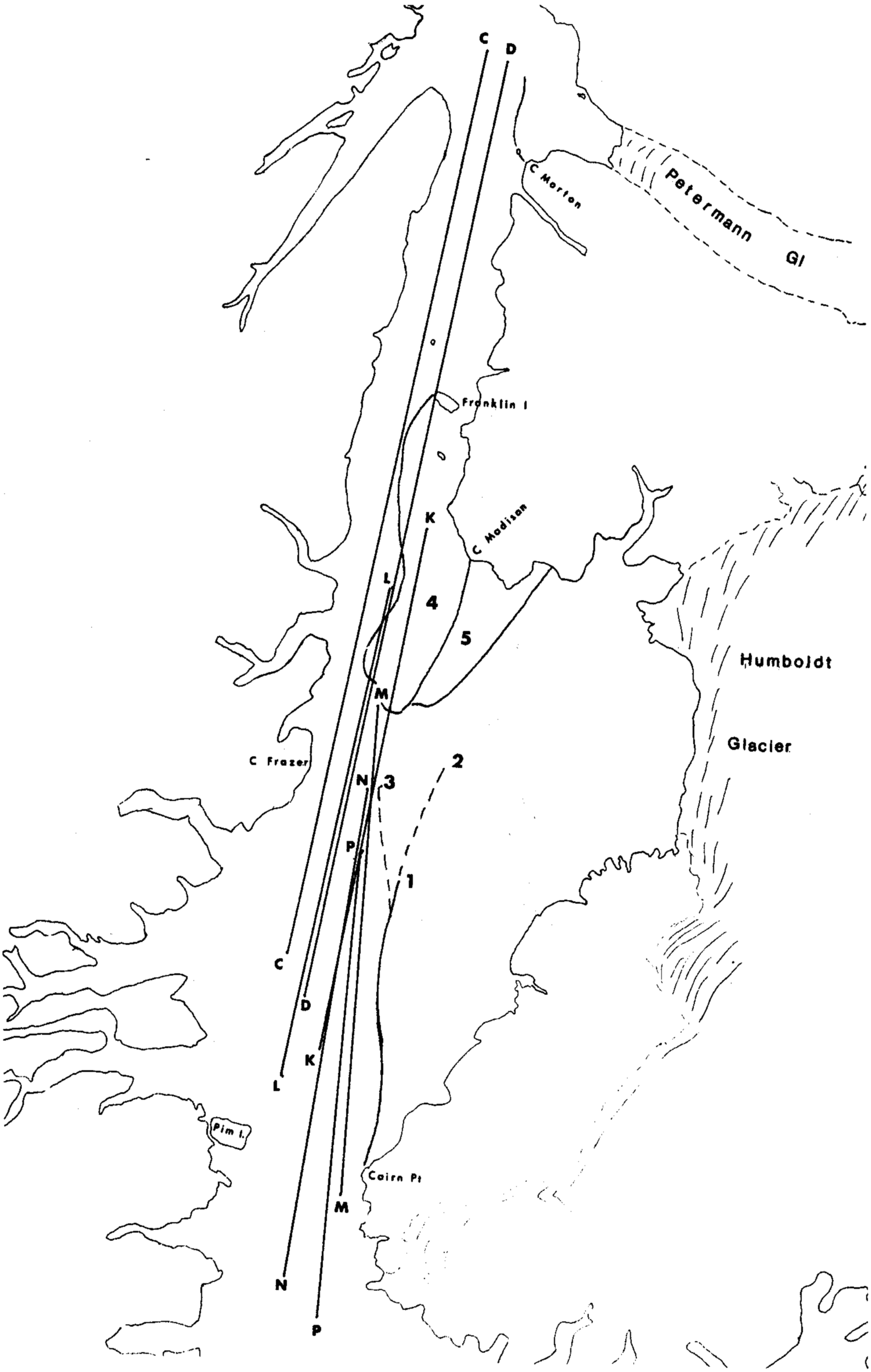

FIG. 4. Floes tracked between 19 and 26 October, but not seen on 21 October. The lines running north from C. Morton and Cairn Pt show fast ice limits, and areas 4 and 5 the open water and brash ice on 21 October.

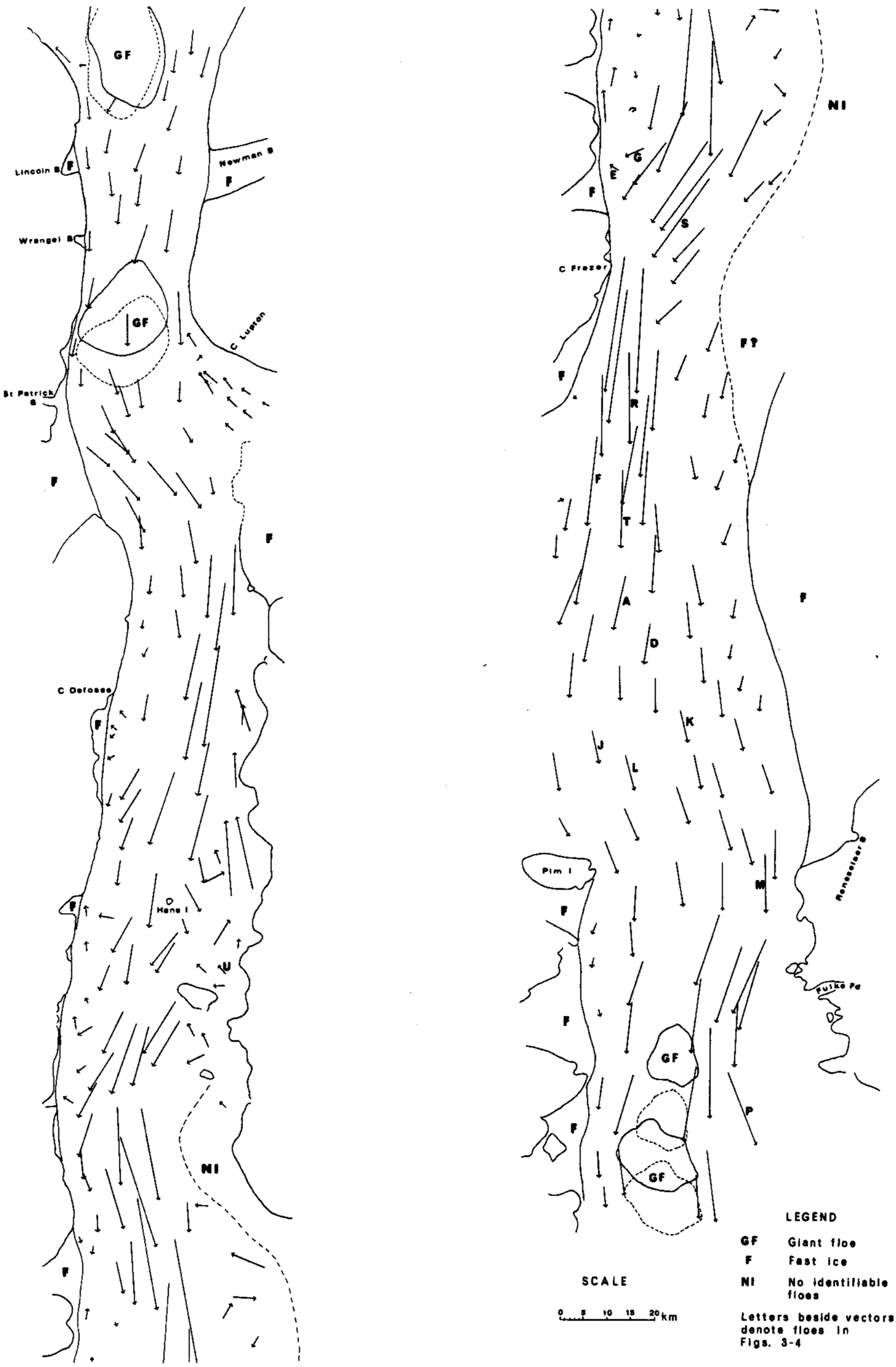

FIG. 5. Drift of floes on 26 October. There is a slight overlap between the strips showing the north half of the channel (left) and the south (right).

TABLE 1. Drift of Floes 19 October to 26 October 1976

Floe	Dates Observed			19 Oct to 21 Oct			21 Oct to 26 Oct			19 Oct to 26 Oct		
	19 Oct	21 Oct	26 Oct	Distance (km)	Time (hours)	Speed (m/sec)	Distance (km)	Time (hours)	Speed (m/sec)	Distance (km)	Time (hours)	Speed (m/sec)
A	X	X	X	78	39.42	0.55	324	129.67	0.70	402	169.09	0.66
B	X	X		70	39.43	0.50	—	—	—	—	—	—
C	X		X	—	—	—	—	—	—	313	168.83	0.51
D	X		X	—	—	—	—	—	—	326	168.85	0.54
E	X	X	X	109	38.85	0.78	111	129.67	0.24	220	168.52	0.36
F	X	X	X	113	38.77	0.81	165	129.93	0.35	278	168.70	0.46
G	X	X	X	59	38.82	0.42	128	129.62	0.27	187	168.44	0.31
H	X	X		104	38.77	0.74	—	—	—	—	—	—
J	X	X	X	83	38.35	0.60	159	130.25	0.34	242	168.60	0.40
K	X		X	—	—	—	—	—	—	183	168.35	0.30
L	X		X	—	—	—	—	—	—	172	168.40	0.28
M	X		X	—	—	—	—	—	—	167	168.33	0.27
N	X		X	—	—	—	—	—	—	167	168.38	0.27
P	X		X	—	—	—	—	—	—	157	168.35	0.26
R		X	X	—	—	—	265	129.59	0.57	—	—	—
S		X	X	—	—	—	287	129.30	0.62	—	—	—
T		X	X	—	—	—	321	129.55	0.69	—	—	—
U	X	X	X	Nil	—	—	Negligible (Rotated)	—	—	—	—	—

TABLE 2. Drifts by Speed and Area

	19 - 21 October			21 - 26 October			19 - 26 October	
Floe	Speed (m/sec)	Area of Drift	Floe	Speed (m/sec)	Area of Drift	Floe	Speed (m/sec)	Area of Drift
F	0.81	Kennedy	A	0.70	Kennedy-Kane	D	0.54	Hall-Kane
E	0.78	Kennedy	T	0.69	Hall-Kane	C	0.51	Hall-Kane
H	0.74	Kennedy	S	0.62	S Robeson-Kane	K	0.30	Kane
J	0.60	S Kennedy*	R	0.57	Kennedy-Kane	L	0.28	Kane
A	0.55	Robeson	F	0.35	S Kennedy-Kane+	M	0.27	Mid Kane-N Smith
B	0.50	Robeson	J	0.34	Kane	N	0.27	Mid Kane-Smith
G	0.42	Kennedy+	G	0.27	Mid Kennedy-Kane+	P	0.26	Mid Kane-Smith
			E	0.24	Mid Kennedy-Kane+			

* May have been caught behind Franklin Island at start
\+ Very close to coast

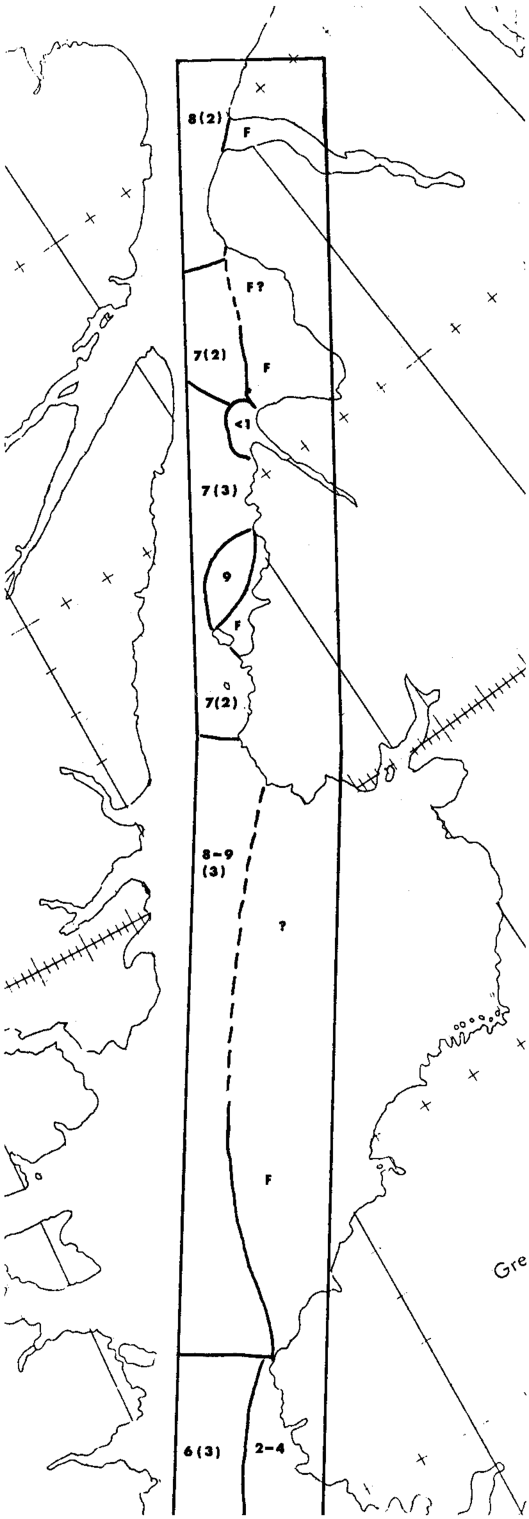

FIG. 6. Ice conditions on 19 October, from the SLAR imagery, in tenths of total cover, tenths of young ice in brackets. Absence of a figure for young ice does not necessarily mean there was none, just that it could not be determined from the imagery. Queries indicate difficulty in interpretation and the outer lines the limits of SLAR coverage.

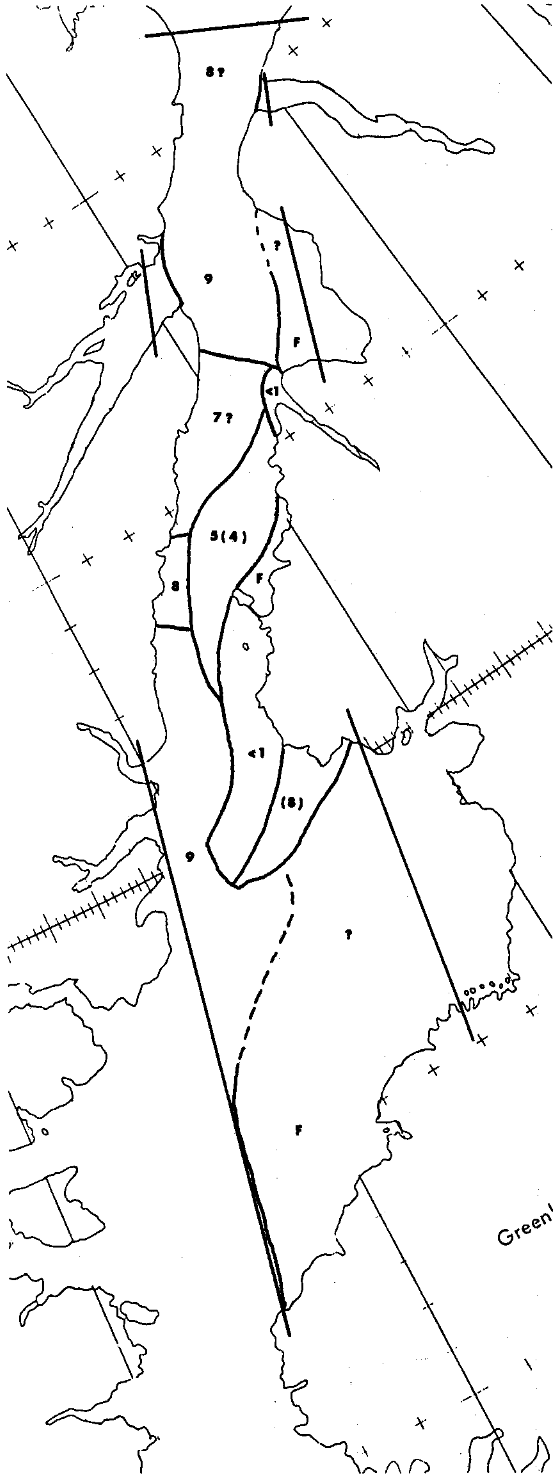

FIG. 7. Ice conditions on 21 October. The uneven limits of coverage reflect differences in flight track on the two passes.

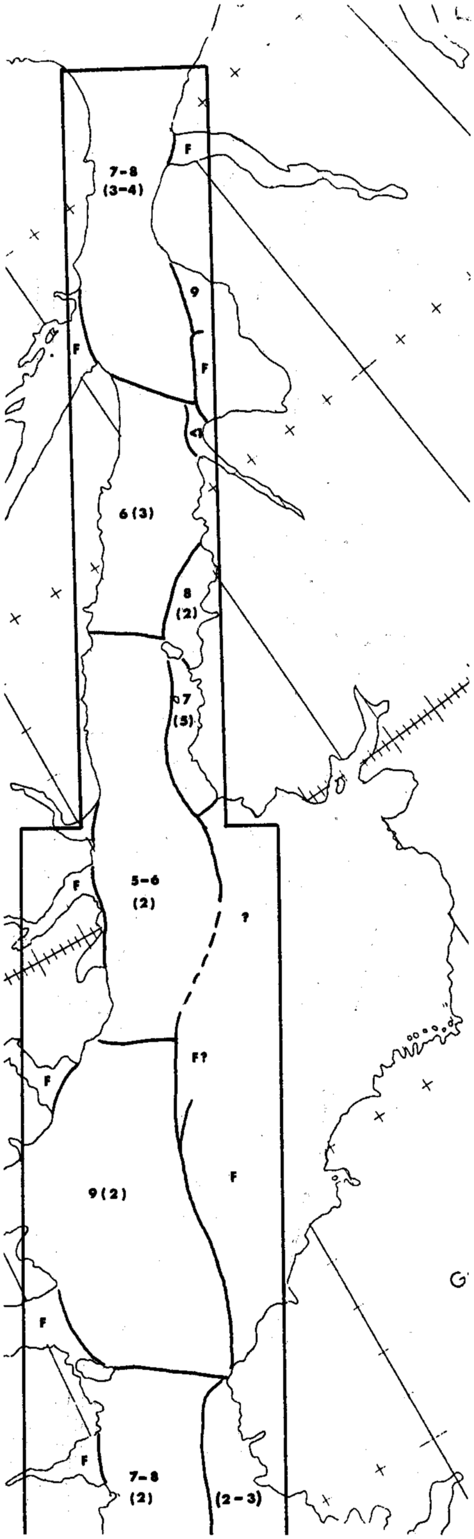

FIG. 8. Ice conditions on 26 October. The widening of the coverage south of Kennedy Channel is the result of changing from the 25 km to the 50 km range on the return flight.

For the two days with two passes over the area a choice had to be made as to which pass to use for plotting. In the case of 26 Oct. the second pass was used for all floes. For 21 Oct. the first pass was chosen, as the positions of all the floes could be recognized on the imagery, whereas not all of them appeared on the second pass.

The recognition of floes from one flight to the next was not difficult, and no example was accepted without reasonable certainty as to identification. The consistency of the data seems to confirm the accuracy of identification.

Short-Term Drift

The two flights up and down the strait on 26 Oct. made it possible to plot the movement of 235 floes over a period of from 7.75 hours at the north end of the strait to 10.45 hours at the south. The resulting vectors are shown on Fig. 5. The coastlines in this map are inexact, as they are traced directly off the SLAR imagery and thus subject to problems of radar shadow and, as already mentioned, of geometric distortions due to slight heading adjustments and differences in aircraft track and attitude on the two passes. For the same reason the vectors, which are measured in relation to coastal points, must be regarded as approximations only. They do, however, give a valid picture of drift directions and relative speeds.

A note of explanation of the fast-ice limits on the east side of Hall and Kane basins is required. Fig. 4 shows these in more detail. In both these areas, where the strait widens to form eastward embayments, the main current and ice drift keep to the west side of the strait, and fast ice forms early in the eastern parts. In both basins in October 1976 there was a very clear fast-ice edge running north from the southeast points (Cape Morton in Hall Basin, Cairn Point in Kane Basin). These lines remained firm throughout the week of the operation, but both petered out and became hard to interpret less than halfway across the basin and it was not possible, owing partly to incomplete SLAR coverage, to see what the limit was beyond these points.

The situation in Kane Basin was particularly interesting. On 19 Oct. the fast ice extended to Point 1 on Fig. 4 and then became fuzzy, but what looked like an incipient boundary could be traced in a fairly straight line to Cape Madison, with smooth continuous ice to the east and about 8-9/10 pack ice to the west of it (see also Figs. 6 and 9). On 21 Oct. the firm line to Point 1 remained intact and appeared to continue to Point 2, while the strong northerly winds had opened up a tongue of open water from Franklin Island and Cape Madison down into Kane Basin, with an area of brash ice to the east of it, probably the wreckage of much of the thin fast ice that had been in the area before (see also Fig. 7). By 26 Oct. most of this open water had gone and a new fast-ice line appeared to be forming west of the line from Point 1 to Point 2; floes east of this line showed no movement at all. North of Point 3 the line was lost, but to the east of the continued dotted line on Fig. 5 the ice appeared young, without identifiable floes.

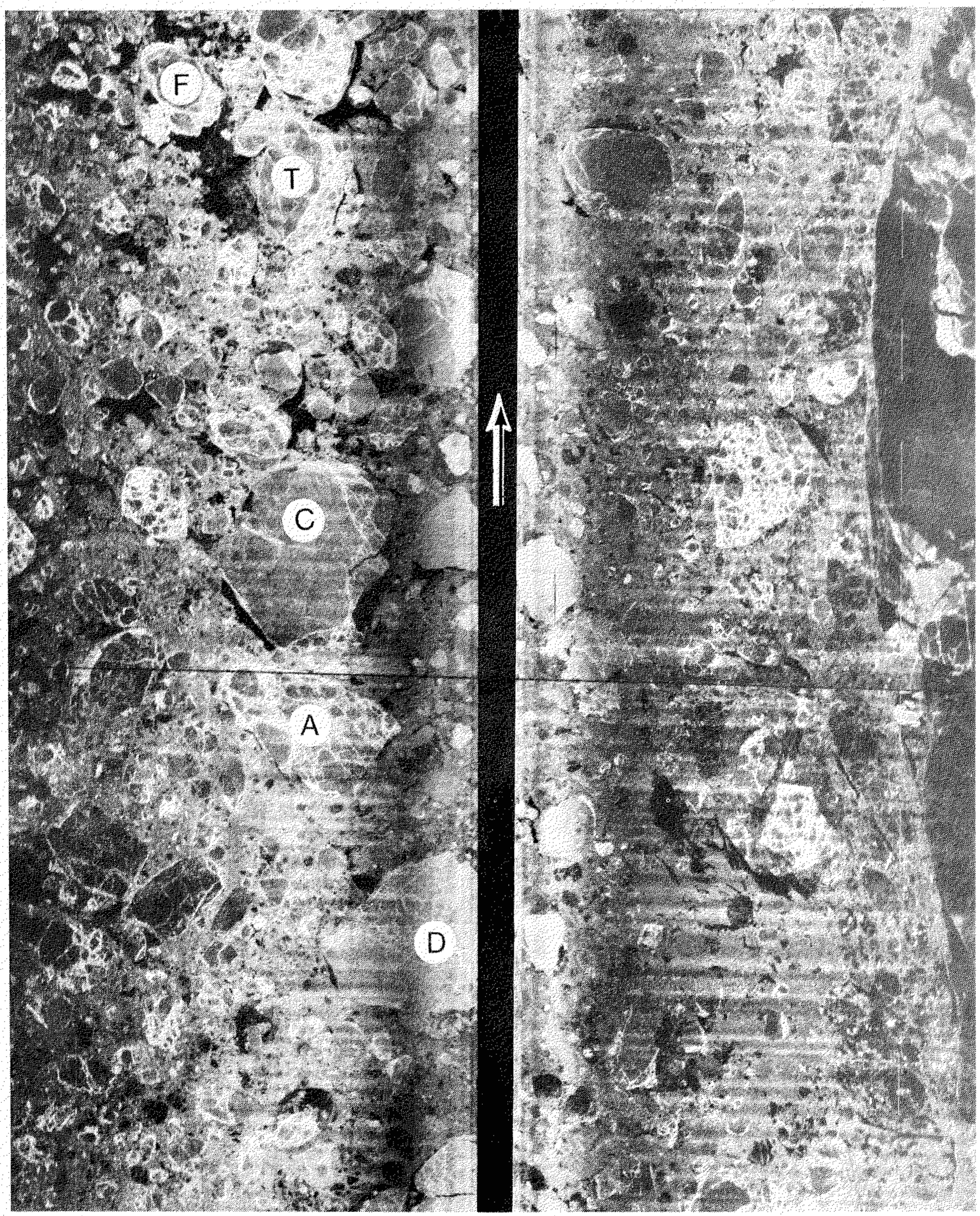

FIG. 9. Part of southern Kane Basin on the northbound flight, 26 October, showing some of the tracked floes. On the right can be seen the fast-ice edge, which remained unchanged throughout the operation (Point 1 on Figure 4 is just north of this picture). Altitude 915 km (3000 ft), range 25 km. The arrow shows flight direction.

FACTORS INFLUENCING ICE DRIFT

The drift of ice floes is influenced by both wind and current, and for most areas the wind has long been accepted as by far the more important. In a narrow channel like Nares Strait, however, currents might be expected to play a larger than normal role, and this was indeed found to be so in a drift study carried out in Robeson Channel in the summers of 1972 (Keys *et al.*, 1974) and 1974 (report in preparation). Strong currents were found to exist, which, though largely tidal, have a predominating southwesterly, or down-channel, direction.[1] Thus in periods of calm or near calm the ice moved steadily down-channel, making much more progress on the flood tide (towards the southwest) than on the ebb. With a northerly wind the southerly drift was intensified, and the reaction time to the onset of a northerly wind was fast. A strong southerly wind did eventually overcome the current but the reaction time was much longer and it had to blow harder to produce a comparable effect. In the summer of 1972 the winds were mainly from the north, and the ice moved fairly steadily down-channel. The tracked flows seldom remained within radar range (20 nautical miles) for more than two days. In 1974 the situation was quite different. Southerly winds predominated, and floes would often remain in range for days or even weeks as the opposed wind and current worked on them.

To summarize, it appears that in day-to-day variations the wind remains the controlling factor, inasmuch as it is more variable in both speed and direction than the current, and if strong enough can always dominate; but that the current nevertheless plays a large role, greatly enhancing the effect of a northerly wind and reducing that of a southerly wind.

TABLE 3. Mean Daily Winds at 1000-mb Level

	Nares Strait			
	South Half		North Half	
Date	Direction	Speed (m/sec)	Direction	Speed (m/sec)
Oct 17	050	4	050	4
18	040	12	065	10
19	035	10	090	Light
20	060	26	080	21
21	070	18	070	18
22	040	5	065	13
23	085	15	085	15
24	Variable	Light	080	10
25	Variable	Light	080	Light
26	060	8	050	10

[1]The channel axis varies from NE-SW to NNE -SSW. In the interest of simplicity the terms "northerly" and "southerly" will be used to indicate up-and -down-channel direction.

Wind Conditions

Throughout the period of 19-26 Oct. 1976, and at least two days before it, the winds as interpreted from the daily 1000-mb charts were in the northeast sector. Experience has shown that the high coasts of Nares Strait have a strong effect, so that any wind with an appreciable down-channel (northeasterly) component blows down channel at the surface. Thus the winds were down-channel, and for most of the time they were fairly strong. Table 3 gives the approximate speed and direction of the 1000-mb winds; actual speeds at the surface may be expected to be a little higher, especially in the narrow parts of the channel, owing to the funnelling effect.

In-flight winds were not recorded with any frequency or regularity, but such evidence as there is agrees reasonably well with Table 3. Close agreement would not be expected, as apart from the difference between surface and flight altitude, it must be remembered that the 1000-mb charts are 24-hour means. On 19 Oct. winds at 1830 m (6000 ft) were light and variable in the north half of the channel (down to the south end of Kennedy Channel) becoming 050° at 12 m/sec (24 knots) by the middle of Kane Basin. Unfortunately there are no measurements between these points, but aircraft drift increased steadily from 1.7° starboard at the south end of Kennedy Channel to 3.4° at the time of the Kane Basin wind record, and continued high through Smith Sound, while the ground speed went up from 182 to 202 knots.

On 21 Oct. there is only one wind observation, 045° at 18 m/sec (15 knots) in Robeson Channel.

On 26 Oct. in-flight information is available only from the Smith Sound area. On the northbound flight, at 915 m (3000 ft) the wind was directly on the nose at 6 m/sec (12 knots) decreasing to 2.5m/sec (5 knots) as the aircraft emerged from the narrows into Kane Basin. This increase of wind speed in Smith Sound, due to funnelling, is very frequently observed when flying at low levels, and is undoubtedly one of the causes of the existence of the North Water, the well-known polynya in Smith Sound which remains open or partly open all winter.

On the return flight, at 1830 m (6000 ft) a wind reading of 080° at 8 m/sec (15 knots) was obtained in Smith Sound, and, as on 19 Oct., drift and ground speed increased steadily through Kane Basin into Smith Sound. The direction of this wind is significant. In the narrow parts of Nares Strait a wind of 080° will be redirected and funnelled down the channel at the surface but in Kane Basin it may be expected to blow straight and with increased velocity down the Humboldt Glacier and across the basin, which could account for some of the drift characteristics in this area. This will be referred to later.

Currents

Few direct measurements of current in Nares Strait have been made except in Robeson Channel, where measurements were made from the ice in May 1971 and 1972 (Chow, 1975; Sadler, 1976). In 1971 Chow found mean velocities of .03 m/sec at 2.25 m and .04 m/sec at 7.25 m; in 1972 Sadler had 28-day means of up to .1m/sec at 5 and 10 m depths. Apart from these we know only that the residual current in the entire strait is down-channel, though the tidal currents flow strongly in both directions and there are known to be at least occasional incursions of Baffin Bay water into Smith Sound and probably Kane Basin (Sadler, 1976; Tidmarsh, 1973).

From visual observations it appears that the current in Kennedy Channel may be faster than in Robeson Channel and Hall Basin. Evidence for this is the frequent appearance of open water at the head of Kennedy Channel, suggestive of an increase in current speed, and the common occurrence of patterns of brash ice lined up in strings, which are characteristic of rapid movement. Both phenomena can of course also be explained by acceleration of wind speeds, such as has already been described for Smith Sound. It is probable that an acceleration of both wind and current occurs in both channels, but this has not been definitely established.

Little is known of the currents in Kane Basin.

Ice Concentration

A third factor influencing drift speed might be called the traffic-jam factor, or the extent to which the drift is impeded by the overall ice concentration and resulting pressure of one floe against another. Figures 6-8 give an indication of the total observed ice cover in tenths, with, in brackets, the tenths of young ice included in the total. In general at this time of year all the ice in Nares Strait that is not young may be assumed to be either multi-year or highly deformed ice of unidentifiable age. The information is taken entirely from the imagery, as cloud and darkness combined to prevent visual observation most of the time. Where there are question marks after the concentration figures (21 Oct., Robeson Channel and north Kennedy Channel) it is because poor imagery made it impossible to give a firm estimate. The question marks in eastern Hall and Kane basins refer to the problem of interpreting the extent of the fast ice.

The maps show that throughout the period there was a high concentration of ice in Kane Basin, and that on 26 Oct., when the short-term vectors were measured, the southern part of Kane Basin had the highest concentration in the whole channel (Fig. 9). The lowest concentrations were in Smith Sound and in Kennedy Channel, extending into the extreme north of Kane Basin.

This pattern of low concentration in Kennedy Channel and Smith Sound and high concentration in Kane Basin is a frequent and typical occurrence, presumably caused by the speeding up of wind and current in the narrows and their slowing down in the wider basins. The effect is exaggerated by the ice itself, as freer movement is possible where the concentration is less. Robeson Channel, although it often displays the same characteristics as the other two narrows, is also often subject to high ice concentrations (as on this occasion) especially with northerly winds. One reason for this may be that Robeson Channel is funnel-shaped, narrowing from north to south, whereas Kennedy Channel and Smith Sound are narrow at the north end. This factor, combined with the very large floes which frequently enter the channel from the Arctic Ocean, tends to cause jams and slow the drift.

The early formation of fast ice over the eastern parts of Hall and Kane basins has already been referred to. This fast ice in effect acts as an extension of the coast of Greenland, straightening it out and reducing the main channel to a fairly uniform width throughout its length (Fig. 8). Obviously it is not the fast ice which causes the width of the main path of the current to be reduced but the other way round — the lack of current in the eastern embayments is one of the causes for the formation of fast ice. Therefore it may be assumed that the main drift stream keeps to this narrow path even in the season when the fast ice is absent (roughly August and September).

Floe Size

Floe size did not appear to be a factor in drift speed. Floes of different sizes in the same area tended to move at the same speed, those of the same size in different areas often at different speeds. The floes tracked varied considerably in size, most of them falling between 2 and 10 km (1 and 5.4 nm) across. Below this size they were hard to track, the features being too small for the radar resolution; some few were larger. The largest by far were the four giant floes shown in Fig. 5. From north to south their longer dimensions were 28, 21, 16 and 15 km respectively (15, 11, 8.6 and 8 nm).

DISCUSSION

Long-term Data

The most striking feature of the long-term data is the high overall speed of drift, or to put the same thing another way, the remarkable distances covered by the floes in one week (Table 1). The longest and fastest total distance plotted was for Floe A, which covered 402 km (217 nautical mi) in 169.08 hr; at an average speed of 0.66 m/sec (1.28 knots). This was the highest speed over the whole period, but not the highest speed recorded, which was 0.81 m/sec (1.57 knots) for Floe F from 19 to 21 Oct. Floes E and H, in the same area, had very similar speeds over this period.

A second characteristic emerges if the drifts are arranged in order of speed (Table 2), namely that the highest speeds all involve drifts wholly or partly in Kennedy Channel. Next highest are in Robeson Channel, while the lowest speeds are almost all in Kane Basin. This is true throughout the observation period and is also reflected to some extent in the short-term drift vectors (Fig. 5). The only floes in Kennedy Channel which do not show high drift speeds are Floe G, and Floes E and F after 21 Oct. All were located very close to the coast of Ellesmere Island for all or part of their drift, an area of high concentration on 21 Oct., and where they might also tend to be slowed down either by getting directly hung up on the coast, or by being caught in inshore gyres. Floe E illustrates this very strikingly. Having been one of the fastest moving floes from 19 to 21 Oct. (0.78 m/sec or 1.52 knots) it became the very slowest from 21 to 26 Oct. (0.24 m/sec or 0.46 knots). Fig. 5 confirms that, on the last day of the period at least, it was in fact caught in an inshore gyre.

Floe U, also in Kennedy Channel, hardly moved at all, but it was in a dead area behind Franklin Island. From 19 to 21 Oct. it was apparently in fast ice; by 26 Oct. it had rotated through 45° and moved slightly to the west.

With such inexact wind data and inadequate knowledge of the currents it is perhaps futile to attempt to relate these drifts to the driving forces, and it is certainly dangerous to draw conclusions of a general nature from such a short sample period. It is nevertheless useful to examine the data in more detail.

Table 3 shows that the highest winds were on 20 and 21 Oct., exactly the period between the first and second flights, which took place late on 19 and shortly after noon on 21 Oct. respectively. It is thus not surprising that the highest drift speeds were registered in this period, by Floes F, E and H (Table 2). For the period from 21 to 26 Oct. the drift speeds in Kennedy Channel were appreciably lower, reflecting the reduced wind speeds. It is also worth noting that on all three flights ice conditions in Kennedy Channel were rather more open than in the waters north and south of it, allowing the floes to move more freely.

In Robeson Channel there were only two drifts recorded, both from 19 to 21 Oct., and they are considerably slower than those in Kennedy Channel, although the winds appear to have been similar. One factor that was not the same is the ice concentration, which increased over the period in Robeson Channel and decreased quite markedly in Kennedy Channel, and this alone might account for the difference in drift speeds. It may also be that the current is indeed stronger in Kennedy Channel, or merely that the wind was stronger, as it may well have been. It is also possible that coastal friction may have delayed the floes in Robeson Channel.

There are six drift tracks that are almost wholly within Kane Basin: Floes K, L, M, N and P from 19 to 26 Oct. (Fig. 4), and Floe J from 21 to 26 October (Fig. 3). All are among the slowest drifts recorded, between 0.26 and 0.34 m/sec. if we exclude the three floes which appear to have been caught up on the coast or in inshore eddies (Floes E, F and G) these in fact represent the slowest speeds of all. The fastest of the six was J, which had one of the shortest trajectories but took nearly two days less to cover it, and the rest follow in alphabetical order (Table 2). It is perhaps significant that the three fastest, J, K and L, all start in the extreme north of Kane Basin, where the open water appeared between 19 and 21 Oct. (Fig. 7) and where high drift speeds were recorded on 26 Oct. in contrast to the slow speeds farther south (Fig. 5). Thus the first parts of their drifts were likely to have been the fastest. Floe M also started in the northern part of Kane Basin, while Floes N and P, starting in central Kane Basin, speeded up somewhat on entering Smith Sound. Both were tracked here on 26 Oct. (although only Floe P is shown on Fig. 5), at which time they were both making 0.43 m/sec. It is probable therefore that all these floes slowed down south of Cape Frazer, in the same way as appears in Fig. 5.

This is perhaps not surprising. It has already been pointed out that the funnelling effect on the winds and also on the currents will be less in the wider area of Kane Basin, and in addition the wind situation must be complicated by katabatic flow from the Greenland icecap across the Humboldt Glacier and the relatively low ice-free area between the Humboldt and Smith Sound. The high ice concentration observed on this operation, which is quite characteristic of most of Kane Basin, is an expression of the general falling off of driving forces, and at the same time it becomes itself a slowing factor by impeding movement.

The northern part of Kane Basin is somewhat different. On 26 Oct. at least it was functioning as an extension of Kennedy Channel, the drift maintaining or even increasing its speed (Fig. 5) and clinging to a narrow band off the coast of Ellesmere Island.

Short-Term Data

A comparison of Figs. 2-4 wit the short-term data in Fig. 5 does much to support the deductions made from the long-term data, and Fig. 5 shows in general the same pattern. In assessing Fig. 5 allowance must be made for the time difference; the Smith Sound vectors do not really represent speeds as much faster than Robeson Channel as might at first appear, because the elapsed time in Smith Sound is between 10.5 and 10.75 hrs. as compared with between 7.8 and 8.25 hrs for Robeson Channel. Calculated drift speeds are however comparable, and maximum and typical vector speeds for each part of the channel are given in Table 4. It will be seen that the fastest speeds were in the northern part of Kane Basin, followed by Kennedy Channel, Smith Sound and Robeson Channel in that order, and the slowest were in southern Kane Basin. The order agrees well with the long-term data except that Smith Sound replaces Robeson Channel in second place. The long-term data do not in fact provide any figures for Smith Sound as separate from Kane Basin, but Floes N and P on 26 Oct. were making 0.43 m/sec., or about the typical speed for their position in the channel and rather slower than Floes A and B in Robeson Channel from 19 to 21 Oct. The difference is probably not significant, being largely due to the different wind speeds on the dates concerned. The contrast of conditions between north and south Kane Basin does not show up in the long-term data, though it probably would if there were more observations.

In this connection it is significant to note the incipient fast-ice line, which approaches to within 25 km (13.5 nm) from the coast at Cape Frazer, and reduces the effective width of the channel to a figure comparable to the narrowest parts of Kennedy Channel (28 km (15 nm) overall, or 22 km (12 nm) west of Franklin Island) and Robeson Channel (20 km (11 nm)). The sudden

TABLE 4. Drift Speeds 26 October

	Speeds (m/sec)	
Area	Max	Typical
Robeson Channel	0.39	0.24
Kennedy Channel	0.76	0.51*
Kane Basin N	0.83	0.59
Kane Basin S	0.32	0.22
Smith Sound E	0.50	0.42
Smith Sound W	0.41	0.26

* In main stream

falling off of drift speeds eastwards towards the fast-ice line in Fig. 5 is quite dramatic.

Winds: the estimated wind on 26 Oct. was down-channel at the moderate speed of 8-10 m/sec (Table 3). It was certainly not a strong driving wind, and as it followed two days of generally very light winds it is quite probable that it played a smaller than normal part in the ice drift. The in-flight winds of 6 m/sec and 2.5m/sec at 915 m altitude above Smith Sound and Kane Basin respectively and 8 m/sec at 1830 m above Kane Basin suggest that the estimates may even have been too high. On the other hand, if there was a strong katabatic effect, the winds off the Humboldt Glacier might have been considerably higher, and these, upon being met and deflected by the coast of Ellesmere Island, might account for the increased drift speeds in northern Kane Basin.

Currents: If the wind influence was relatively slight, then it should follow that the current was exerting a relatively strong influence and that the drift pattern should give some valid information on the currents. However the information is not easy to interpret because over the short period of observation tidal variations as well as residual currents must be considered, and tidal information is scarce, except for Robeson Channel, where five stations were maintained over one tidal cycle in recent years. For the rest there is one station in north Kennedy Channel, at Cape Defosse, and three in the Smith Sound area, at Rensselaer Bay (SE Kane Basin), Pim Island and Fulke Fiord. The absence of stations in northern Kane Basin is particularly unfortunate, as this is an area where two tides meet, the tidal stream in the northern part of the strait originating in the Arctic Ocean and that in the southern part in Baffin Bay.

Data obtained from the Department of Fisheries and Environment show that for all these points except those in Smith Sound the period between passes was characterized by a preponderance of falling over rising tide of over three hours, and the tide was either falling or just on the turn (low) at the time of the second pass. In Smith Sound the picture is confused owing to an apparently large tidal time-lag between the two sides of the channel. The tides were at the spring phase.

The tidal influence is hard to interpret, especially for the southern area where there is less information and where the tide runs in the opposite direction than in the slightly better known northern part of the strait. Experience in Robeson Channel suggests that from there as far as the south end of Kennedy Channel the down-channel vectors would have been longer if the rising tide had predominated. The rather complex current pattern observed in Kennedy Channel, with eddies and counter-currents, may be partly due to the state of the tide at that time, but the partial obstruction of the channel by islands is also a factor likely to cause such features. In Hall Basin the counter-drift rounding Cape Lupton was probably due to the falling tide. Floes running east on the rising tide in this area would be stopped by the fast or near-fast ice and there would therefore be no predominance of drift in the down-channel, or rising tide direction, as was the case for the main drift-stream.

Ice concentration and floe size: The effect of ice concentration (Fig. 8) is clearly seen in Kane Basin and western Smith Sound, where the concentrations are highest. However, as already mentioned, this is a two-way street, since the higher concentrations may in turn be due to a slacking off of wind or current. Both Smith Sound and Robeson Channel may also have been affected by the presence of very large floes (Fig. 5), but the nature of this effect is not clear. Large floes react more slowly to a change of direction than smaller ones, but once under way they tend to move as fast or faster, unless their drift is impeded, when they can cause jams. In this case all four large floes recorded were moving at much the same speed as their neighbours. The only one that shows any real sign of differential movement is the one at the north end of Robeson Channel, which appears in Figure 10 to be lagging behind the floes to the south. However, this may have as much to do with the speeding up of driving forces at the entrance of the channel as with floe size. Both the large floes noted in Robeson Channel, incidentally, were large enough to become hung up on Hans Island in Kennedy Channel, which is less than 19 km (10 nm) from the coasts on each side. Such a situation has been observed twice in recent years and it can exercise a strong influence on ice conditions from Hans Island south.

Persistence Of Observed Pattern

To summarize, it is clearly not possible from the data available to pinpoint the precise part played by the various influences in the observed ice drift. Even if it were possible, the results would be valid for one set of conditions only, and generalizations from one set of conditions, though too often made, are to be deplored. It may be assumed, however, that the conditions observed are fairly typical of periods of northerly air circulation in the season when the ice is in motion. This statement is based not only on the results of this operation but on two summers of continuous observation of the northern half of the strait and many flights in the area. Conditions in periods of southerly air flow are very different and much more variable, as was found in Robeson Channel in 1974, the opposition of wind and current leading to confused and changeable conditions. A strong up-channel wind persisting over several days can completely reverse the direction of drift in all or part of the channel and open up a wide area in the Lincoln Sea to the north of Robeson Channel.

The question of relative frequency of air circulation patterns is therefore important, and a study by Bradley and England (1977) has provided the means to attempt an answer. These authors developed a classification of 22 synoptic types for the High Arctic in North America (Queen Elizabeth Islands plus northern Greenland) and have generated a catalogue of these types for every day from 1946 to 1974, a period of 29 years. From this catalogue it was possible to deduce approximate wind directions and strengths in Nares Strait and so to calculate mean monthly and annual frequencies. The figures should

FIG. 10. Robeson Channel on the northbound flight, 26 October, showing one of the giant floes and part of the other. Altitude 915 m, range 25 km. The arrow shows flight direction.

TABLE 5. Percentage of Winds in Nares Strait by Direction

Period	Down Channel	Up Channel	Other*	Calm	No Data
January	65	20	5	7	3
February	60	24	6	6	4
March	58	22	8	9	3
April	51	26	8	12	3
May	49	28	7	12	4
June	51	26	7	11	5
July	40	35	5	17	3
August	37	34	11	15	3
September	56	26	8	7	3
October	52	26	7	10	5
November	55	26	6	9	4
December	61	22	7	8	2
Year	53	26	7	10	4
July-Aug	39	34	8	16	3
Aug-Sept	48	30	8	11	3
Aug-Dec	52	27	7	10	4
Aug-Jan	54	26	7	9	4

* For explanation see text

however be treated with caution, as the small scale of the synoptic charts makes the accuracy of the deduced winds questionable.

Monthly frequencies by direction are shown in Table 5, together with percentages for various periods of the year. To allow for the funnelling effect, winds were classified as down-channel if they were between 330° and 100°, up-channel if they were 150° to 280°, and "other" if outside these limits.

It will be seen that there is a strong preponderance of down-channel winds over the year, but that in the summer months of July and August up-channel winds are almost as frequent. On balance for these two months they also tend to be stronger than the down-channel winds, which are stronger in the winter months.

Break-up in Nares Strait is usually late in July, so the percentages for August and September, the most open months, are given, showing that down-channel winds begin to dominate again in September. The figures for August-December and August-January are included because this is the normal period during which the ice continues to move. It will be seen that those two periods show very little difference and that both are very close to the annual mean. For any calculation of net ice export or direction of drift, therefore, it appears that the pattern observed in the course of this exercise is the dominant one. Nevertheless the incidence of up-channel winds is considerable, and more information on their effect is needed to complete the picture.

CONCLUSION

The purpose of this paper has been to extract information on ice drift in Nares Strait from SLAR imagery repeated on three flights over a period of one week. In so doing it has also shown the value of such repeated imagery for obtaining detailed drift data, a method that could be effective in areas where detailed information is needed for off-shore drilling or other operations. By correlating the flights with typical air circulation patterns a great deal of drift information could be acquired with relatively little flying.

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