THE UNIVERSITY OF CALGARY

MULTIVARIATE ANALYSIS OF ICEBERG DATA COLLECTED FOR THE LABRADOR SHELF FROM 1973-1980

by

Alvin Eric Simms

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

CALGARY, ALBERTA

August, 1986

ISBN 0-315-32718-9

THE UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Multivariate Analysis of Iceberg Data Collected for the Labrador Shelf from 1973-1980" submitted by Alvin Eric Simms in partial fulfillment of the requirements for the degree of Master of Science.

Supervisor, Dr. Nigel Waters

Dept. of Geography

Nigel Michael Waters

Dr. Mario Giovinetto

Dept. of Geography

Mario Giovinetto

External Examiner

Dr. Ian Jordaan

I Jordaan

ABSTRACT

The primary objective of this study was to compare both spatially and temporally the physical dimensions and motion attributes of iceberg data. This data were recorded by iceberg observers using marine radar located on the bridges of drillships operating on the Labrador Shelf from 1973 to 1980.

Iceberg position data files were recoded to contain the following information: (i) geographical area code (from south to north the areas are: Hamilton Bank, Cartwright Saddle, Makkovik Bank, Hopedale Saddle, Nain Bank and Saglek Bank); (ii) wellsite identification code; (iii) month of operation (July, August, September and October); (iv) iceberg size class code (small, medium, large and extra large); (v) iceberg shape (tabular or non-tabular); (vi) deflection code (iceberg towed or not towed); (vii) iceberg mass (tonnes); (viii) daily average drift direction (degrees true); and (ix) iceberg drift speed (m/sec). Furthermore, the iceberg data was grouped for statistical analyses by geographical area, month of operation and iceberg size class . Descriptive statistics, composite rank scores, Spearman's rho, Kruskal-Wallis one-way analysis of variance and discriminant analysis were used to examine between group differences.

The results of the data analyses indicates that there were differences in iceberg variables from south to north along the Labrador Shelf. However, the statistical evidence indicates a more significant difference between the Bank and Saddle areas. Furthermore, there appears to be a possible crude summer and autumn division in the observed iceberg variables. Finally, there is a negative correlation (-0.50) between iceberg mass and drift speed.

ACKNOWLEDGMENTS

I wish to acknowledge those people whose contributions made the writing of this thesis possible.

To Dr. Nigel Waters, my sincere thanks and appreciation for his time and especially his patience during the writing of this thesis. Also, sincere thanks to Dr. Mario Giovinetto and Dr. Ian Jordaan for their participation as committee members and for their suggestions.

Appreciation is also extended to the **Centre for Cold Ocean Resources Engineering (C-CORE)**, Memorial University, St. John's, Newfoundland, for its support and permission to reprint valuable information in this study.

Thanks to the Geography Department staff - Donna Limbert, Debbie Snow and Anne Syndmiller for accommodating me during a very busy time of the year. A special thank you to Joyce Rowden whose help and encouragement let me see the light at the end of the tunnel.

Thanks to the **Rat Pack** - Jan Clark, Karen Marion and Sharon Chomyn who kept me civilized when I wanted to pillage and plunder. Appreciation is also given to the **Calgary Irish Rugby Club** who let me pillage and plunder both on and off the field.

Finally, I wish to express my indebtedness to my 'girlfriends' Audrey, Alexandria, Genevieve and Erica for their understanding, encouragement and patience.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

ICEBERGS: A HAZARD TO OFFSHORE OIL EXPLORATION ON THE LABRADOR SHELF

1.0 Introduction

> "Some of our company have reported that in the month of May they were stuck for sixteen whole days on end in so much ice that some of the icebergs were sixty fathoms thick; and when their sides facing the sun melted, the entire mass was turned over, as it were on a sort of pivot, in such a way that what had previously been facing upwards was then facing down, to the great danger of any people at hand, as you can well imagine (Parmenius, 1583)[1]."

Although icebergs have always been considered a hazard by mariners, intensive research and observation of icebergs did not begin until the sinking of the Titanic on April 14, 1912. After the sinking of the Titanic the International Ice Patrol (IIP) was formed by the United States Coast Guard. The IIP was responsible for monitoring the number of icebergs present in the major shipping lanes of the North Atlantic, and the number of icebergs crossing the 48th parallel.

From 1971 to the present iceberg observers have been stationed on all oil exploration drillships operating off the Canadian east coast and have kept a record of all icebergs drifting in the vicinity (i.e. the maximum range of the drillships' radar system usually 25 to 30 n.m.) of the drillships. Research on icebergs has increased tremendously since the beginning of oil exploration programs off Canada's east coast. This increase in iceberg research is directly related to the hazards posed by icebergs drifting into areas where offshore oil exploration wells are being drilled. The hazards presented by icebergs are twofold: (i) there is the potential for a direct collision with an offshore structure; and (ii) there is the likelihood of crushing and ploughing of subsea installations such as wellheads, mooring systems and pipelines by grounding and scouring icebergs (Figure 1.1).

[1] *The New Found Land of Stephen Parmenius.* ed. by D.B. Quin & N.M. Cheshire (Toronto: University of Toronto Press, 1972).

1.1 Study Objectives

The primary objective of the proposed research is to compare both spatially and temporally the physical dimensions and motion attributes of iceberg data collected at eighteen offshore oil exploration wellsites located on the Labrador Shelf (Figure 1.2). Previous studies have contributed to a better understanding of iceberg behaviour, however the present study is required for two reasons:

(i) previous studies tend to concentrate on either single iceberg behaviour patterns or aggregated data analysis, thus comparisons between distinct geographical areas on the Labrador Shelf were not studied.

(ii) although some of the Labrador Shelf wellsite iceberg data have been analyzed, the results were aggregated and no spatial or temporal variations were examined.

The study on iceberg data collected on the Labrador Shelf can be subdivided into three components: (i) determination of whether or not there are differences in the behaviour and management problems associated with small, medium and large icebergs; (ii) determination of seasonal variations in the behaviour, physical dimensions and management problems associated with icebergs observed on the Labrador Shelf; and (iii) determination of differences between iceberg behaviour, physical dimensions and management problems of icebergs observed at six geographical areas on the Labrador Shelf.

1.2 Previous Iceberg Studies

Current and past iceberg studies have focused on understanding iceberg hazards and preventing the occurrence of the hazards outlined in the preceding section through iceberg management programs. Thus iceberg studies have generally focused on the following categories: (i) approximation of physical dimensions and hazards associated with physical

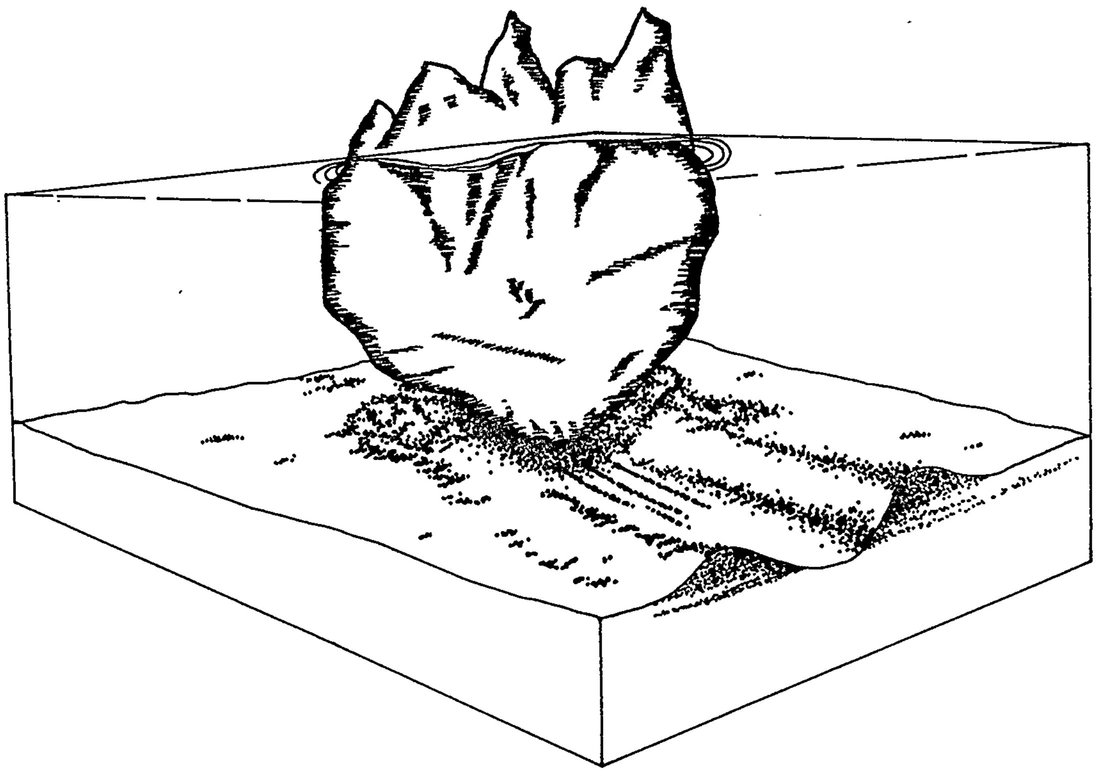


Figure 1.1 A conceptual drawing of a scouring iceberg
(Source: C.M.T. Woodworth-Lynas, 1984. C-CORE News, Vol. 9, No. 1)

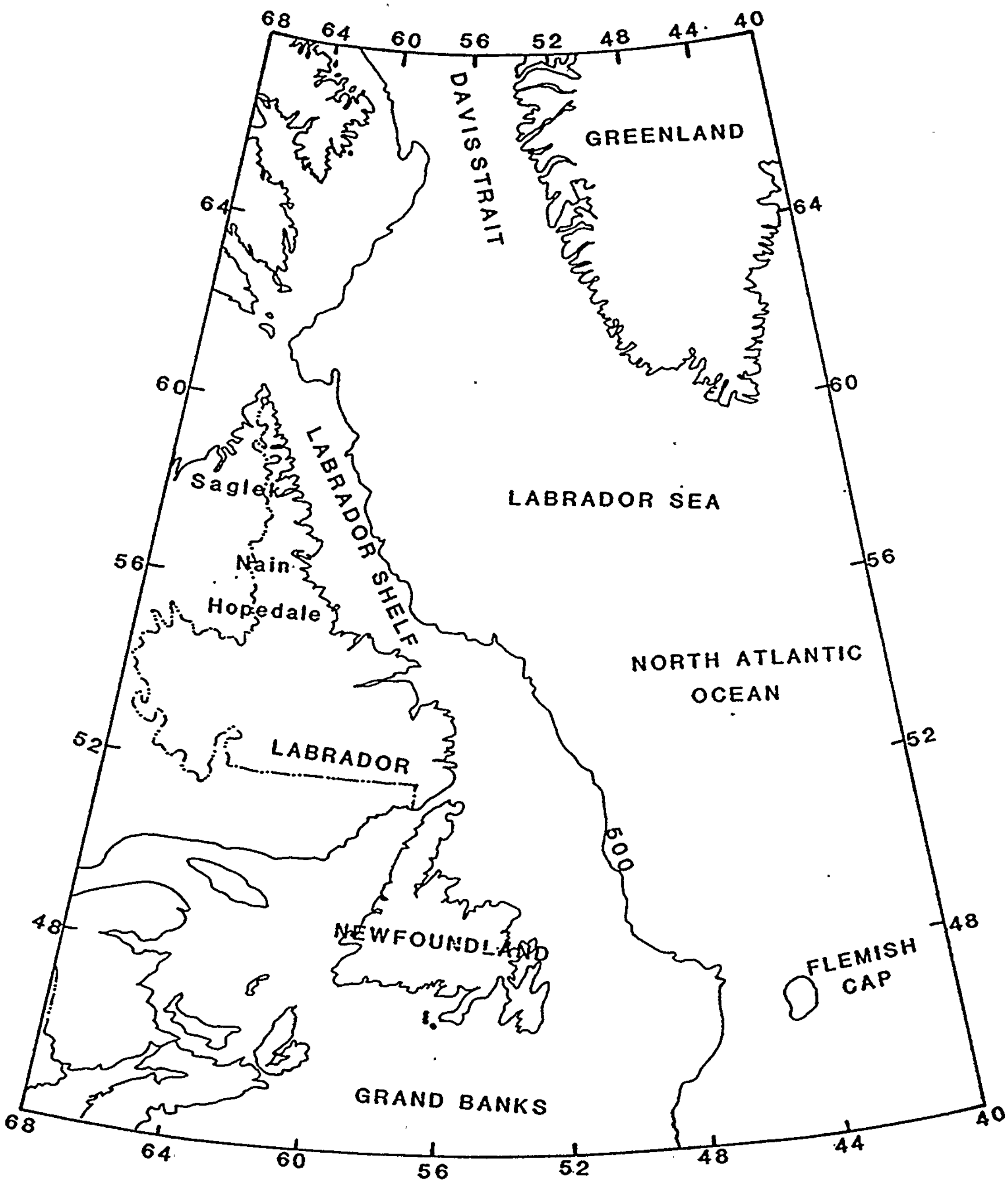


Figure 1.2 Shelf and Bank areas off the Canadian East Coast.
(Source: C-CORE, St. John's, Nfld., 1982)

dimensions and (ii) motion studies (i.e. drift direction, kinetic energy and drift velocity). The following review of selected iceberg studies is presented according to these categories.

1.3 Physical Dimensions

The physical dimensions of an iceberg refer to its height, length, width and draft. Icebergs drifting onto the Labrador Shelf originate from floating portions of glaciers in Greenland. According to Robe (1982) the physical dimensions of icebergs vary with the size and structure of the parent glacier. Usually icebergs produced by Greenland glaciers are initially kilometers in length. Robe argues that for a Greenland glacier to be a major producer of icebergs it must exhibit the following characteristics: "(i) the flow of ice must be great enough to produce an active calving front, (ii) the terminus of the glacier must be floating, (iii) the terminus must be thick enough and broad enough to produce an iceberg capable of surviving long months on the open sea, and (iv) the icebergs produced must have access to the open water of Baffin Bay."

Robe's (1982) report suggests that of the seventy coastal glaciers in western Greenland only sixteen can produce icebergs one kilometer long and 250 meters thick. Furthermore, of the sixteen major iceberg producing glaciers, only nine have sufficient access to offshore waters, through channels, at least 350 meters deep (Figure 1.3). However, by the time an iceberg drifts onto the Labrador Shelf the iceberg mass may be reduced (by deterioration or break-up) to between 20 to 50 percent of its original size.

Research on iceberg morphometric data has focused on methodologies to approximate draft and mass. Robe (1975) recognized that the draft of icebergs was of considerable interest for several reasons: (i) iceberg draft can be used to estimate the probability of collision between an iceberg keel and subsea cables or pipelines; and (ii) iceberg draft may also provide information on drift, grounding and deterioration. The objective of Robe's (1975) study was to calculate height to draft ratios for a variety of iceberg types. If height is measured for an iceberg one may easily calculate an approximate draft.

Robe (1975) separated icebergs into four distinct categories:

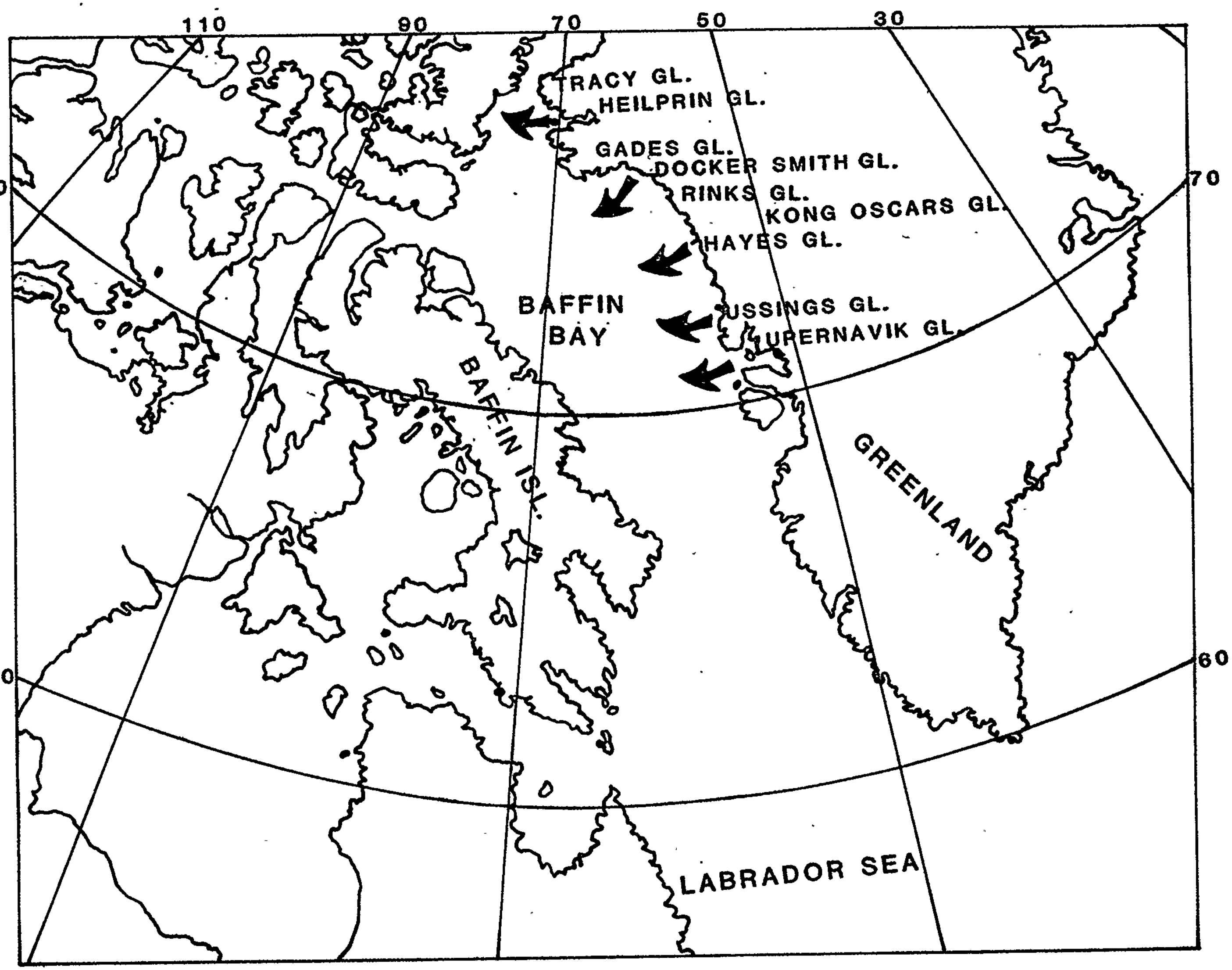


Figure 1.3 Location of major iceberg producing west Greenland glaciers which have ready access to the sea. (Source: Adapted from Q.R. Robe, 1982)

(i) icebergs that were horizontal, and flat-topped were classified as "tabular".

(ii) icebergs which had a large central spiral or a series of spirals dominating the shape were classified as "pinnacled".

(iii) icebergs with a large smooth rounded top which had been at one time submerged were referred to as "domed".

(iv) icebergs with an eroded u-shaped slot formed by wave action and surrounded by high vertical walls or pinnacled were classified as "drydock" (Figure 1.4 illustrates typical profiles of drydock, domed and tabular icebergs).

Robe (1975) calculated the average height to draft ratio for all four classes of icebergs. The calculated ratios were: (i) tabular icebergs 1:4.46, (ii) pinacled icebergs 1:2.31, (iii) domed icebergs 1:6.30, and (iv) drydock 1:2.41. To determine whether a generalized height to draft ratio could be used to obtain the draft of an iceberg given the height, Robe used a Kruskal-Wallis one-way analysis of variance test. His hypothesis was that "the average ratio for icebergs was not significantly different for the gross visual shape classes." The conclusion of Robe's study (for the sampled icebergs) was that there were no significant differences between the classes. According to the author the average ratio of all iceberg classes, i.e. 1:3.95, can be used to describe the height to draft ratio of icebergs regardless of shape.

Hotzel and Miller (1983) also investigated the physical dimensions of icebergs, but they examined the functional relationships between the linear dimensions as well as ratios. Like Robe (1975) the authors' considered draft as well as mass as important parameters. Hotzel and Miller suggested that accurate draft measurements are important because they permit the calculation of depths needed to bury subsea equipment in order to protect it from collision with iceberg keels. The authors' main objective was to determine the functional relationships between the various iceberg dimensions. Evaluation of the functional relationships is important for several reasons: (i) measurement of icebergs is dangerous, time consuming and expensive, and (ii) it is possible to obtain above water iceberg dimensions easily. When this data is combined with suitable

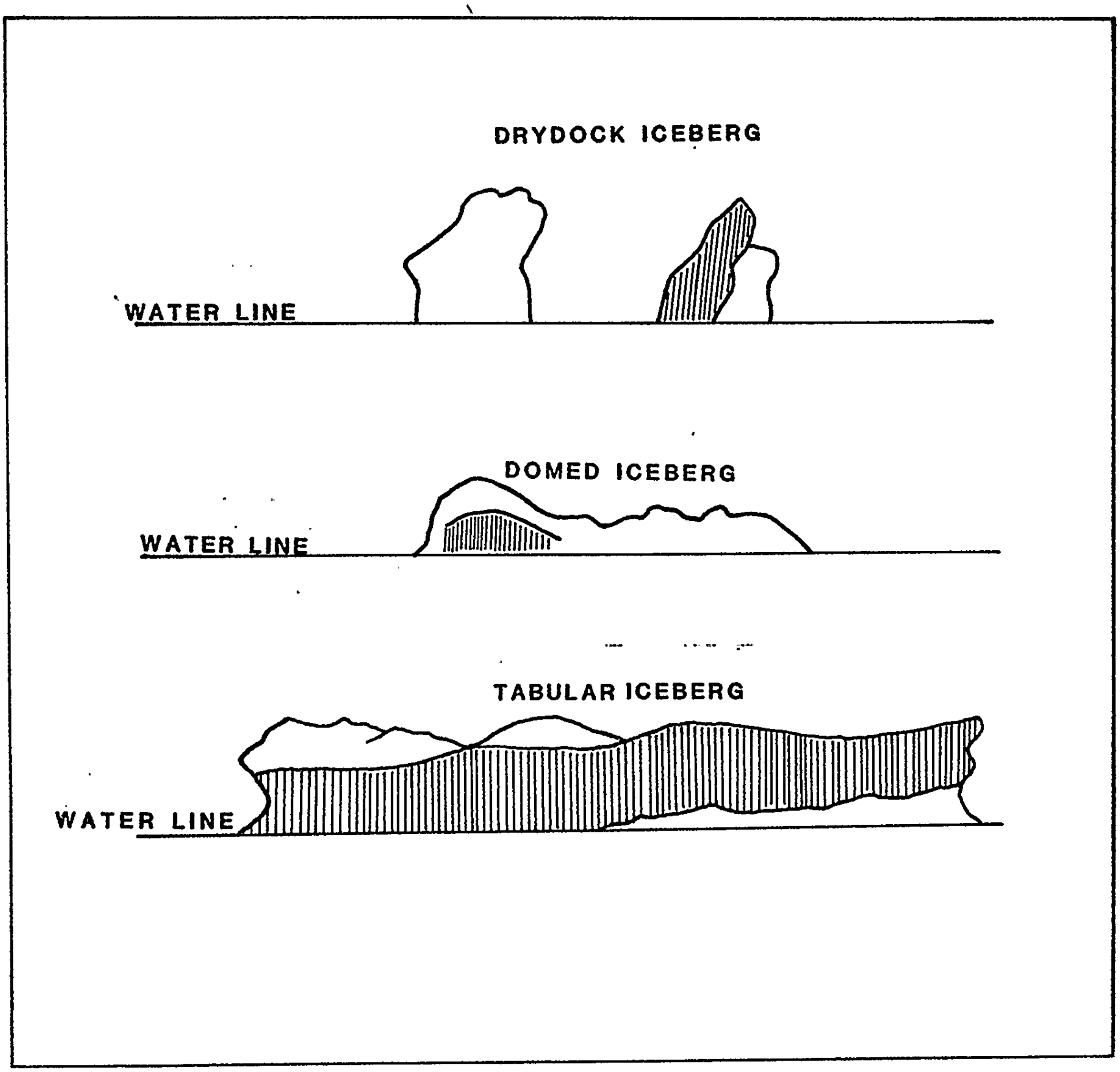


Figure 1.4 Profiles of drydock, domed and tabular icebergs
(Source: Adapted from J.H. Allen, 1972)

functional relationships it is possible to approximate the dimensions of other variables such as draft and mass.

Hotzel and Miller defined the functional relationships in terms of a regression of the logarithmically transformed values. A power function, $y = ax^b$ (where y and x are iceberg parameters; and a and b are regression equation parameters), was used to define the relationship between the various physical dimensions of icebergs. The authors found that length rather than height could be used to estimate iceberg draft, where draft= $3.78*length^{0.63}$. According to the authors this equation is suitable for icebergs observed on the Labrador Shelf. In addition to calculating draft estimates the authors suggested that length or draft may be used to estimate iceberg mass. For example, mass=$0.002009*length^{2.68}$ or mass=$0.0147*draft^{2.5}$. These equations are usually required to approximate draft and mass values because in a majority of cases height, length and width are the only iceberg morphometric data collected. Table 2.1 contains the results of the Hotzel and Miller study.

Table 1.1 Functional relationships between parameters of iceberg dimensions

Type	y	x	n	r	a	b
All icebergs	Draft	Length	75	0.74	3.781	0.63
	Width	Length	67	0.94	0.7118	1.00
	Height	Length	230	0.83	0.4025	0.89
	Mass	Length	168	0.90	0.0020	2.68
	Mass	Draft	55	0.78	0.0147	2.50
	Draft	Mass	55	0.78	17.245	0.232

y, x = Iceberg dimension
a, b = Regression equation parameters
n = Number of data pairs
r = Correlation coefficient
(all regressions are of the form $y = ax^b$)

Source: Hotzel and Miller (1983)

The approximation of mass and draft values for icebergs is also supported by Manor and Zorn (1983). These authors recognized that a maximum draft value is required to determine the safe level for subsea installations and mass is the governing parameter for towing operations.

However, Manor and Zorn also stressed the need for width values. They discovered that the stability of an iceberg generally decreases with decreasing width to draft ratio (W/D). Furthermore, icebergs will only roll when the stability ratio is near or less than1.0 and it will always roll to a more stable position. This means that the W/D ratio will increase. For example, icebergs with a stability ratio of 2.0 would be considered a stable ice mass, while icebergs with a stability ratio of 1.2 would be considered unstable and likely to roll.

Manor and Zorn argue that stability ratios are important for two reasons. First, if an iceberg rolls during a towing operation (i.e iceberg being deflected away from the wellsite) the tow line would be disconnected from the iceberg. This would pose a potential collision hazard to the drillship if this occurs near the wellsite. Second, studies have demonstrated that icebergs can increase their draft significantly by rolling up to 90°. Research on iceberg dynamics by Lewis and Bennett (1984), and Bass and Peters (1984) showed that rolling may increase draft by as much as 50 percent with an average of 25 percent. Under certain conditions, decreases in draft are as likely as increases (Lewis and Bennett, 1984). This is especially true when large icebergs calve (i.e split into two smaller icebergs) and roll.

1.4 Iceberg Motion Studies

Iceberg motion studies usually concentrate on kinetic energy, drift velocity and drift trajectory prediction. Lever et al (1984) differentiated the magnitude of hazards posed by small and large icebergs. The authors noted that icebergs up to 2×10^6 tonnes may be deflected away from drillships using established towing techniques, but smaller icebergs may pose a greater hazard. This is due to the smaller icebergs' relatively small above water dimensions and usually rounded shape which may not be detected by marine radar until they are too close to a drillship[2]. Lever et al suggested that the hazard posed by smaller icebergs is increased during storm conditions because these relatively small icebergs are influenced by heavy seas whereby they

[2]Heavy seas, rain and snow storms usually mask a radar signal, thus smaller icebergs cannot be detected by radar under storm conditions.

obtain velocities far greater than their average drift speeds. The kinetic energy[3] associated with this increased speed creates a potential impact energy equal to that of a 1 X 10^6 tonne iceberg moving at a moderate drift speed (i.e. 0.10 to 0.30 m/sec.). A collision between these small icebergs and a drillship during storm conditions could result in serious damage or total loss of the drillship.

Wave and iceberg interaction studies conducted by Lever and his associates under simulated conditions suggest first that:

> "ice masses, which were small compared to a wave length, essentially moved as particles of fluid in finite amplitude waves. Maximum full scale velocities of 4.5 m/sec would be possible for a 2,300 tonnes bergy bit[4] in a 14m, 12 sec storm wave. The resulting kinetic energy of 4 X 10^7 joules represents approximately a third of the kinetic energy of a million tonne iceberg drifting at 0.5 m/sec, secondly for larger ice masses up to 7 X 10^5 tonnes, diffraction effects in storm waves may result in maximum velocities in the 3 m/sec range, with corresponding kinetic energies in excess of 10^9 joules. A plot of full scale kinetic energy versus ice mass, as determined from these tests is shown in Figure 1.5." (Lever et al, 1984).

Finally, during a simulation test in a wave tank the authors observed an ice/structure impact which in full scale would be a 4.5 m/sec collision between 1,500 tonnes bergy bit (kinetic energy = 10^7) and a 7.6m diameter column. According to the authors this type of collision could cause serious structural damage.

Smith and Banke (1982) demonstrated that the time required for the largest icebergs to approach an equilibrium drift velocity after a change in winds and currents is only a few hours. Smaller icebergs reach equilbrium drift in less than an hour. The relatively quick response (i.e. change in drift trajectory and speed) of smaller icebergs indicates that smaller icebergs are as great a threat as larger icebergs.

According to Robe (1982) icebergs drifting along the Labrador Shelf have typical drift speeds of 0.10 to 0.40 m/sec, with speeds of 0.40 m/sec being quite common. Wright and Berenger (1980) studied iceberg drift trajectories and speeds using marine radar. The authors computed average drift speeds of 0.10 to 0.30 m/sec with maximum speeds of 0.50 to 1.2 m/sec.

---

[3] Kinetic energy is computed as: 1/2 * mass * velocity^2.

[4] Bergy bits are icebergs ranging in size from 100 to 2500 tonnes.

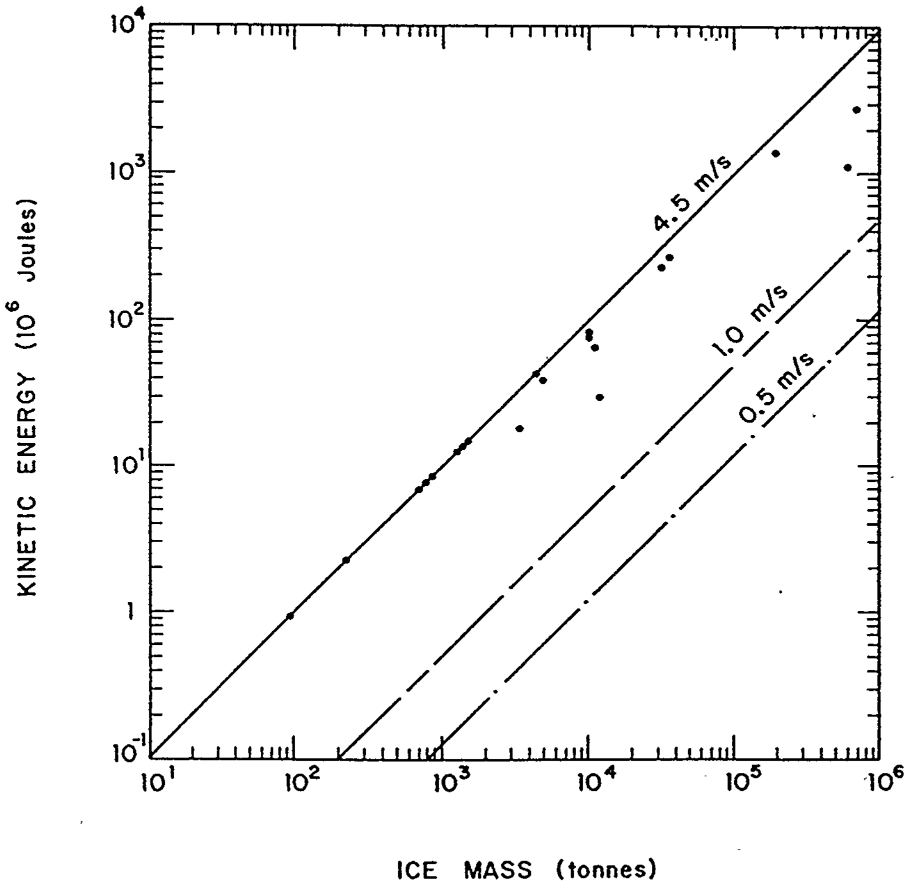


Figure 1.5 Maximum full scale kinetic energy versus mass for icebergs in 14m, 12 sec. storm waves as determined from wave tank tests (Source: J. Lever et al, 1984. C-CORE News, Vol. 9, No. 1)

Wright and Berenger (1980) also investigated a 3 X 10^6 tonne iceberg which had an average drift speed of 0.80 m/sec suggesting that large icebergs can reach relativley high drift speeds.

A study by Allen (1972) on iceberg motions on Saglek Bank found that the strength of the ocean currents in the area was very weak. Therefore, iceberg movements were subject to influences from surface conditions such as wind and low pressure regions passing over the area. Furthermore, icebergs in the weak offshore current generally moved in a spiralling manner with the diameter being approximately 1.6 kilometers and of a 12.5 hour period. According to Allen this was due to the semi-diurnal tidal effect.

Allen's (1972) iceberg study on Saglek Bank also demonstrated the impact of a low pressure system moving over the area. As the storm system moved through the area on August 21, 1972 and after the weather system had moved over the Saglek area, a distinct change in the drift patterns of icebergs was observed. This is illustrated in Figures 1.6 and 1.7, where the drift pattern in Figure 1.6 is different fron the drift pattern observed in Figure 1.7. The author suggested that the change in drift pattern after the storm was caused by a situation where "low pressure regions will raise the surface level of the sea and induce currents similar in nature to tidal currents. As the sea surface rises, currents are generated which are superimposed on the steady state current pattern and these have some effect on drift of icebergs in the region."

Hsuing and Aboul-Azm (1982) also investigated the impact of environmental forces on iceberg drift patterns. Specifically, the authors studied the effect of wave action on small and medium size icebergs. Water drag, wind drag, coriolis effect and geostropic effect were also considered. Table 1.2 illustrates the magnitude of different environmental forces acting on a 200,000 ton tabular iceberg. In all cases wave action exerted greaterforces than any other environmental forces. Therefore, examining the drift direction of small and medium size icebergs for a specified time period should indicate prevailing wave directions in a wellsite area. Sodhi and El-Tahan (1980) also studied medium size iceberg drift patterns during a storm. They found that direct action of the wind and waves is evident because the icebergs would move back and forth as the wind direction changed as the storm centre moved through the area.

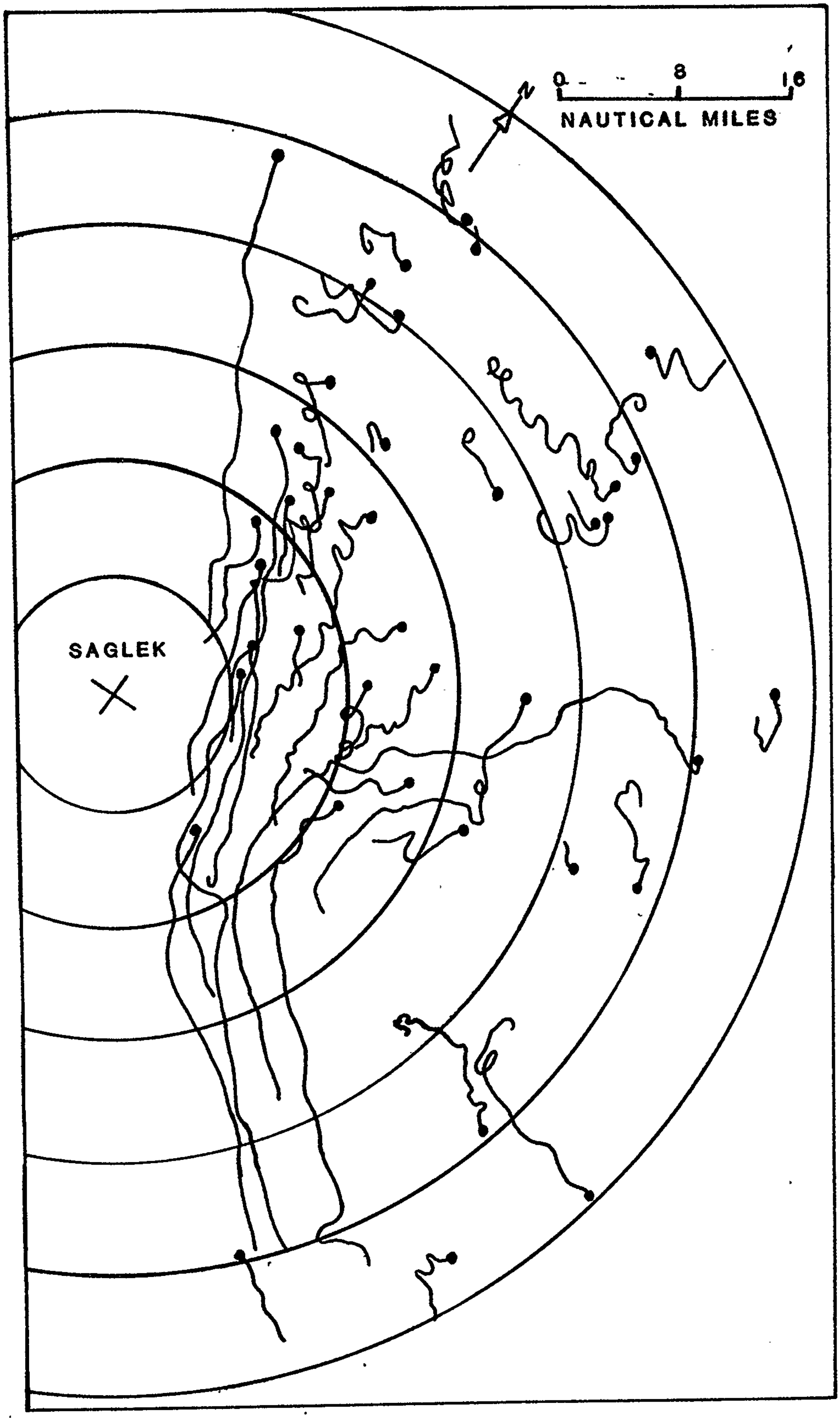


Figure 1.6 Iceberg movement through Saglek Bank as tracked by marine radar prior to August 21 storm (dots indicate beginning of track)
(Source: Adapted from J.H. Allen, 1972)

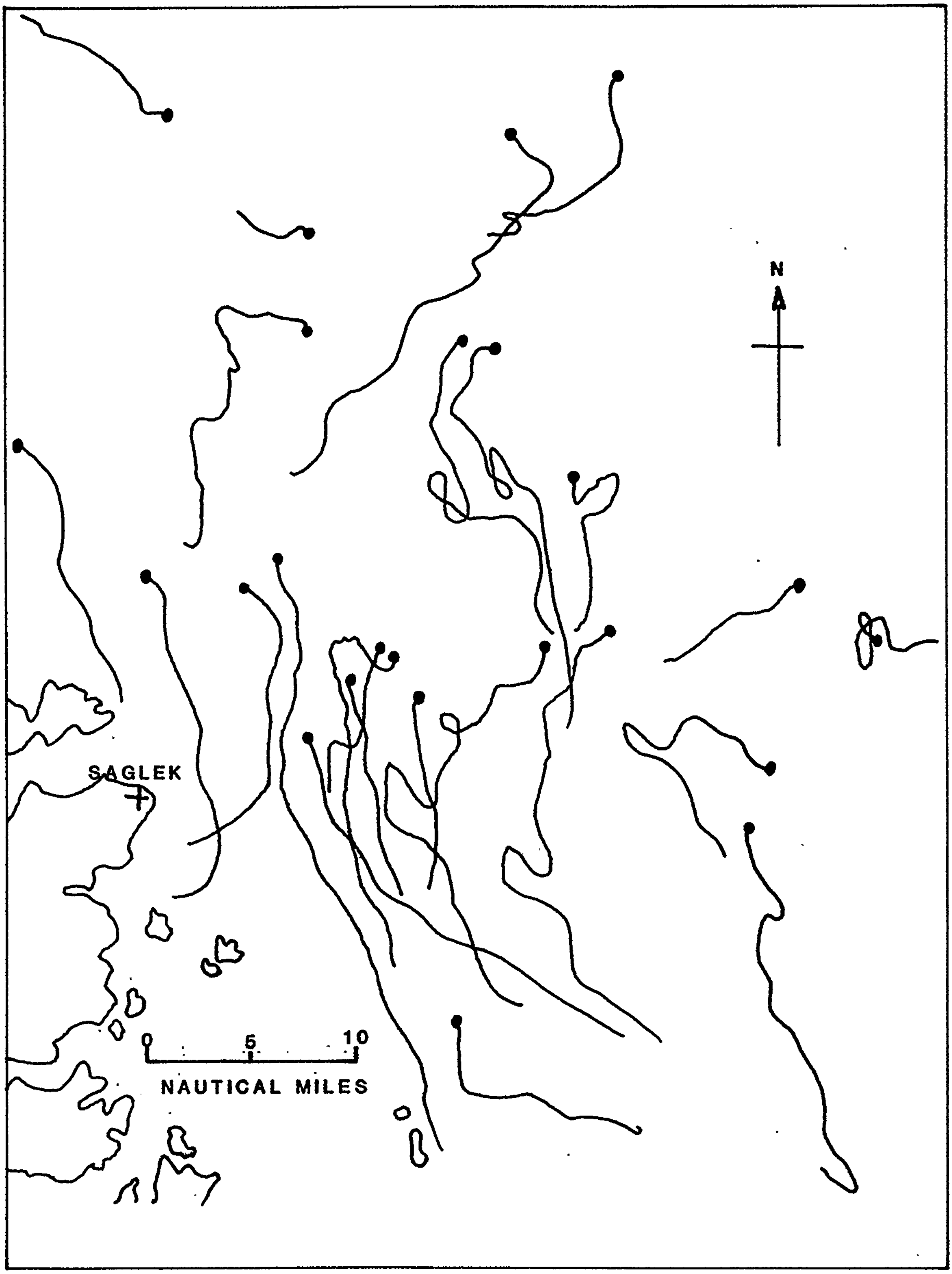


Figure 1.7 Iceberg movement through Saglek Bank as tracked by marine radar after August 21 storm (dots indicate beginning of track) (Source: Adapted from J.H. Allen, 1972)

Table 1.2 Comparsion between the magnitude of different environmental forces acting on a 200,000 ton tabular iceberg

Force components	Force (tons)	Condition	Force (tons)	Condition	Force (tons)	Condition
Water drag	5.35	Relative vel. =0.2 m/sec	15.12	Relative vel. =0.4 m/sec	34.02	Relative vel.
Wind drag	1.95	Wind speed =20 knots	7.8	Wind speed =40 knots	17.55	Wind speed =60 knots
Coriolis effect	0.76	Latitude x 55^o Rel. vel.=0.2 m/sec	1.52	Latitude X 55^o Rel. vel.=0.4 m/sec	2.27	Latitude x 55^o Rel. vel.=0.6 m/sec
Geostropic effect	4.0	Acceleration= $2 x 10^{-5}$ m/sec^2	8.0	Acceleration= $4 x 10^{-5}$ m/sec^2	12.0	Acceleration= $6 x 10^{-5}$ m/sec^2
Wave drift effect	8.11	Wave amp.=0.5m Wave period =12 sec	32.45	Wave amp=1.0m Wave period =12 sec	73.0	Wave amp=1.5 Wave period =12 sec

Source: C.C. Hsiung and A.I. Aboul-Azm (1982)

Gaskill and Rochester (1982) examined how iceberg motion data (i.e. velocity and drift direction) in conjunction with environmental data may be used to derive integrated surface currents over an extended surface area about the wellsite. The results of Gaskill and Rochester's study demonstrated that "the principal determinant of local iceberg motion is the ambient current driving that motion." Ball et al (1981) also concluded that "the complexities seen in the iceberg motion were due primarily to the spatial and temporal variability in the current regime and not to variation in the individual iceberg parameters such as mass and shape."

1.5 Summary

The preceding literature illustrates the importance of determining the physical dimensions of icebergs since these parameters have been shown to influence iceberg management decisions (i.e. to tow or not to tow an iceberg away from the wellsite). Therefore, any spatial and temporal variation in iceberg mass observed on the Labrador Shelf will be an important consideration when planning offshore oil exploration.

Studies by Allen(1972), Ball et al (1982), Hsuing and Aboul-Azm (1982), Lever et al (1984) among others demonstrate that differences in iceberg motion between geographical areas are a direct result of local environmental and current conditions in the area. Furthermore, the influence of wave action and storms on drift patterns is especially evident in areas where offshore currents are weak. It is also apparent that one may use iceberg motion data as a surrogate measurement of environmental and current differences between geographical areas on the Labrador Shelf. Finally, studies have indicated that small and medium size icebergs are greatly affected by wave and wind action and pose just as great a threat to offshore structures as large icebergs.

The study is organized into six chapters. Chapter 2 presents a description of the seabed topography, oceanography, climate and potential iceberg hazards associated with the study area. Chapter 3 presents the methodology pertaining to the study and the data sources used in the study. Chapter 4 contains the results of the descriptive and non-parametric statistical analysis of the iceberg data. Chapter 5 discusses the results of the discriminant analyses on iceberg data grouped by geographical area, months of operation and iceberg size class, and chapter 6 summarizes the results of the study and provides recommendations for future studies.

CHAPTER 2

THE PHYSICAL GEOGRAPHY OF THE STUDY AREA

2.0 Introduction

The study area is restricted to six geographical areas on the Labrador Shelf where offshore oil exploration activity has occurred since 1971. From south to north these areas are: Hamilton Bank, Cartwright Saddle, Makkovik Bank, Hopedale Saddle, Nain Bank and Saglek Bank. The areas extend linearly from approximately 52^{o} N to 60^{o} N (Figure 2.1). This chapter will present a brief description of seabed topography, oceanography, climate and potential iceberg hazards on the Labrador Shelf.

2.1 Topography

The topography of the Labrador Shelf is a linear combination of small banks: the Hamilton, Makkovik, Nain, and Saglek Banks. In addition, a discontinuous longitinudal trough (which reaches depths of 600 m) separates the inshore waters from the outer bank areas. The bank areas on the Labardor Shelf are relatively shallow (200 m); however, they are separated by transverse channels (i.e. Hopedale Saddle and Cartwright Saddle) that are up to 500 m in depth (Figure 2.1).

The seafloor of the outer shelf areas is a smooth surface with the exception of the deep channels. The outer shelf areas are covered with glacial drift, probably the result of glacier excavation in the longitudinal trough (Gustajtis, 1979a). Gustajtis (1979a) also indicated that the transverse troughs are a result of glacial erosion. Research by Loken and Hodgson (1971) on transverse troughs off western Greenland and Baffin Island supports the concept that glacial erosion followed the pre-existing fluvial system. Another feature common on the Labrador Shelf is boulder beds. The boulder beds are quite varied in thickness and extent and are considered to

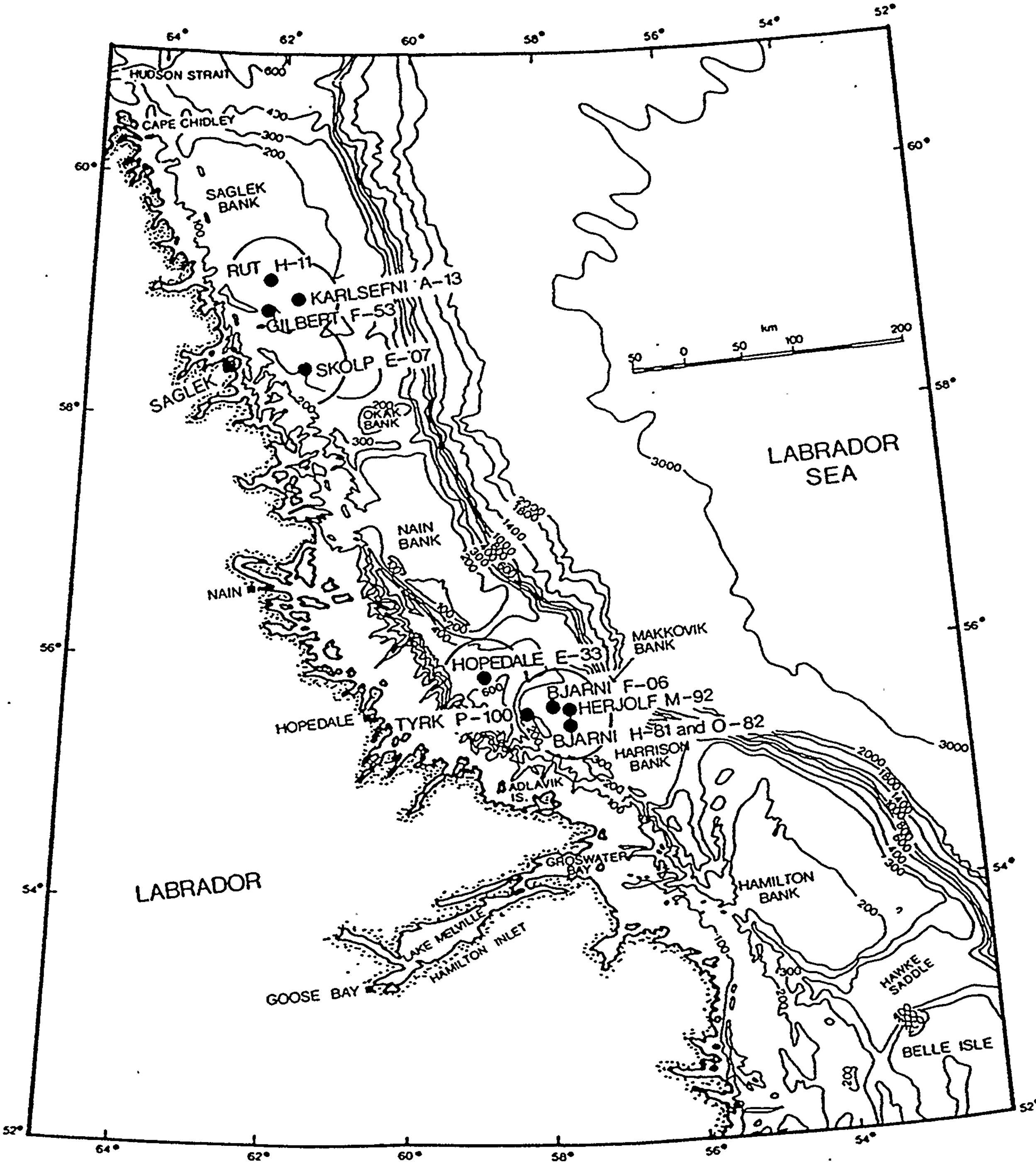


Figure 2.1 Drilling activity: Labrador Shelf
(Source: C-CORE, 1985)

be glacial in origin. Furthermore, the boulder beds create problems when starting an exploration well because the drill has problems penetrating the boulder beds (Gustajtis, 1979a).

2.2 Physical Oceanography

The Labrador Current dominates the waters off the Labrador coast. The current flows south over the Labrador Shelf to the Newfoundland Grand Banks. According to Dunbar (1951) it is the most southerly extension of the cold Arctic water mass. Specifically the Labrador Current is an aggregation of the Baffin Island and West Greenland Current, with added momentum from waters moving out from Hudson Bay and Fox Channel through Hudson Strait (Figure 2.2).

Research on current velocities associated with the Labrador Shelf is sparse. A study on Saglek Bank by Allen (1972) during August, 1972 documented the influence of the movement of a low pressure storm through the area. Current speeds on the surface (to a depth of approximately 13 m) increased from 0.20 to 0.50 m/sec during the advance of the storm, and velocities reached 0.75 m/sec as a direct influence of the storm. At a depth of greater than 155 m the current velocity was 0.15 m/sec and the deep currents were not affected by the storm. However, at depths from 120 m to 140m, velocities averaged 0.15 to 0.20 m/sec and reached a maximum velocity of 0.35 m/sec as a result of the storm. The effects of the storm on current velocities at various depths is presented in Figure 2.3.

Allen's (1972) study was probably the most detailed work on surface currents for a specific geographical area on the Labrador Shelf. Dunbar (1951) also investigated surface currents on the Labrador Shelf during ice free periods. The author suggested that with the coming of winter the current velocities would be reduced as a result of decreased land drainage:" and as land drainage increased during the summer, the volume of coastal water would grow. The dynamic height of currents especially close to shore rises and the velocity of the current consequently increases."

Research on surface current velocities by NORCDO, (Newfoundland Oceans Research and Development Corporation, 1977) supports Dunbar's (1951) hypothesis that as drainage increases from the spring to summer surface current velocities increase until you get a peak

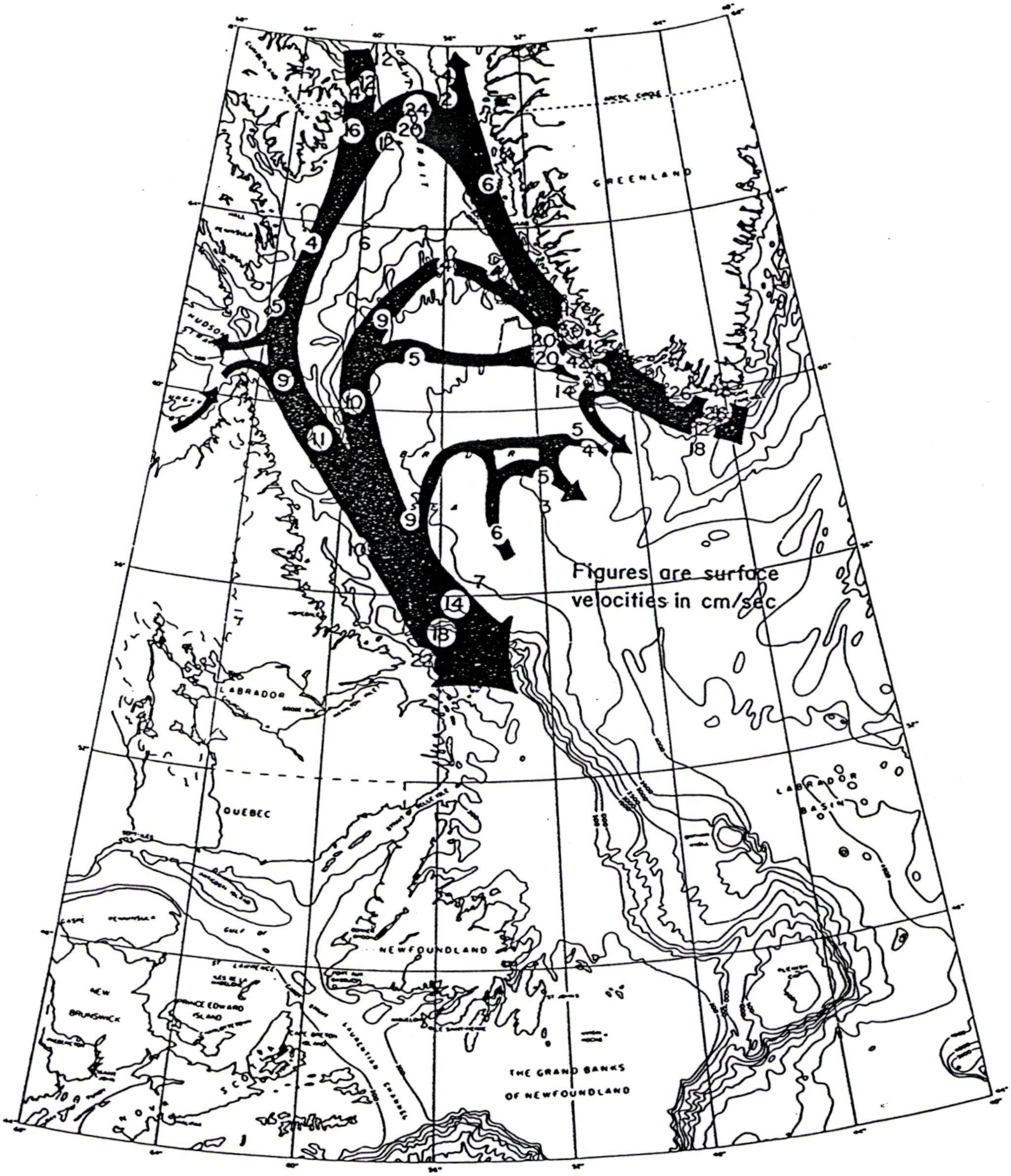


Figure 2.2 Surface currents for the Labrador Sea August-September
(Source: Gustajtis, 1979b)

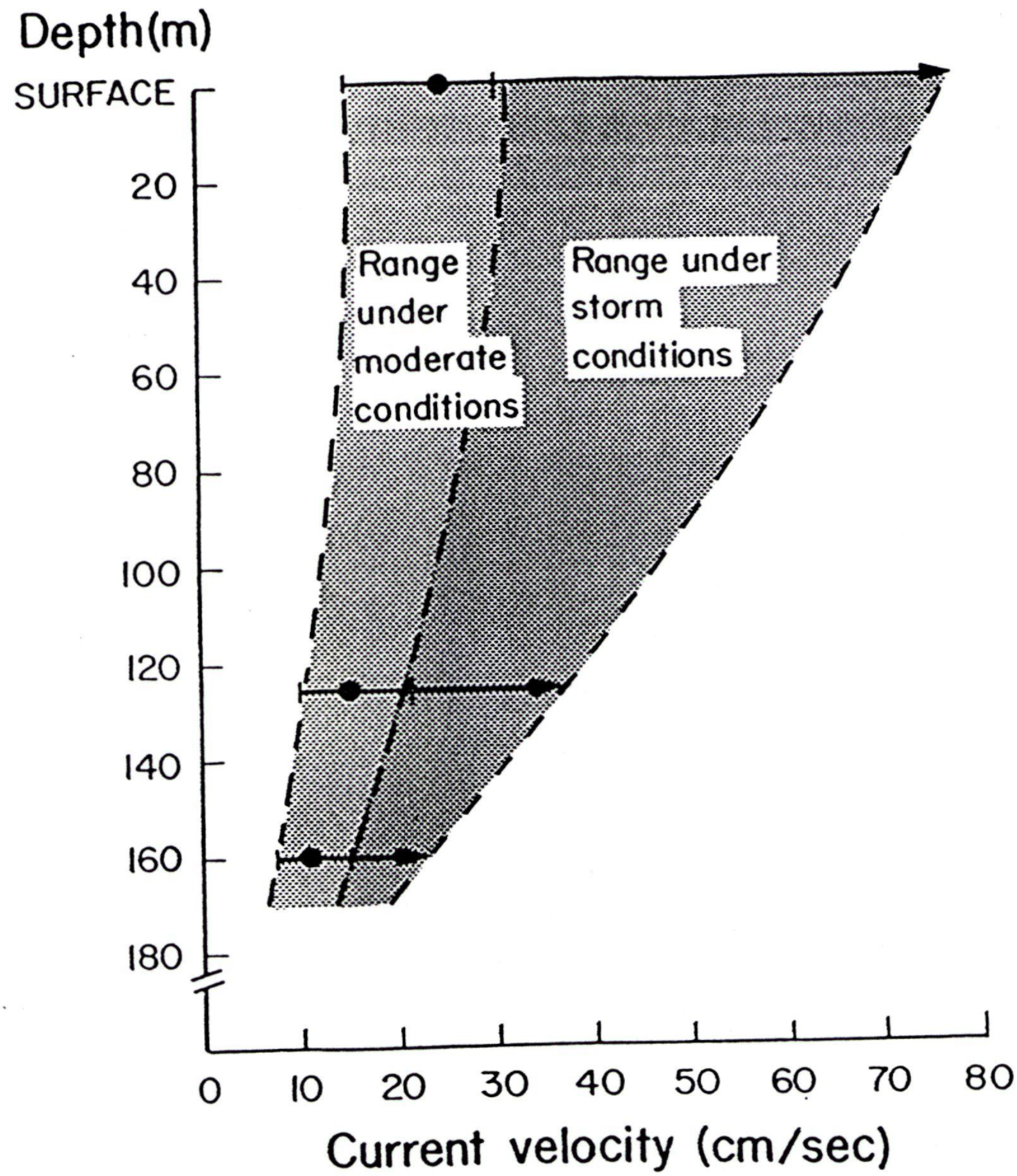


Figure 2.3 Current profile on Saglek Bank, Labrador: August, 1972
(Source: Gustajtis, 1979b)

velocity in the fall. Figures 2.4 to 2.7 show surface currents increasing from spring to summer and peaking in the fall with a subsequent decrease in the winter. NORDCO's (1977) study supports Dunbar's argument that terrestial drainage is an important contributor to sea surface current velocities.

Sea state information like the current data for the Labrador Shelf is also limited. The most detailed studies have been completed by Neu (1972, 1976). According to Neu (1972) the water depth over the Shelf varies between 150 and 200 m, and the wave propagation is as "deep water waves", which are unaffected by bottom topography. Furthermore, Neu's (1976) study indicated that the sea state along the Labrador Shelf is non-uniform both spatially and temporally. In late fall and early winter strong northwest winds have the potential to produce large seas; however the intrusion of pack ice into the area reduces the sea state significantly. Neu, also computed the 10 and 100 year recurring wave heights for the Labrador Shelf. The estimated recurring wave heights for 10 and 100 year periods were 20 and 26 m respectively.

Gustajtis (1979b) assimilated wave rider buoy data (Table 2.1) and the results indicated that the period of time waves are less than 0.75 m decreases from a high of 43.5 per cent in July, 1976 to 0.0 per cent in late fall. For the same period, wave heights greater than 3 m increase in October[1], however the formation of pack ice damps out wave energy levels in December and January. The author also constructed a pie chart (Figure 2.8) which indicates that weather (i.e. sea state) is the major factor causing stoppage of drilling operations on the Labrador Shelf.

2.3 Climate

The Labrador Sea is colder for longer periods than other parts of the world in the same latitude. The seasonal distributional of these temperature differences can be seen in Figure 2.9. During the summer (July) the area is colder than other zones in the same latitude, however the winter period (January) is somewhat milder. According to Gustajtis (1979) the seasonal variability

[1]According to the author wave heights of 3 m or more cause significant problems for dynamically positioned drillships operating on the Labrador Shelf.

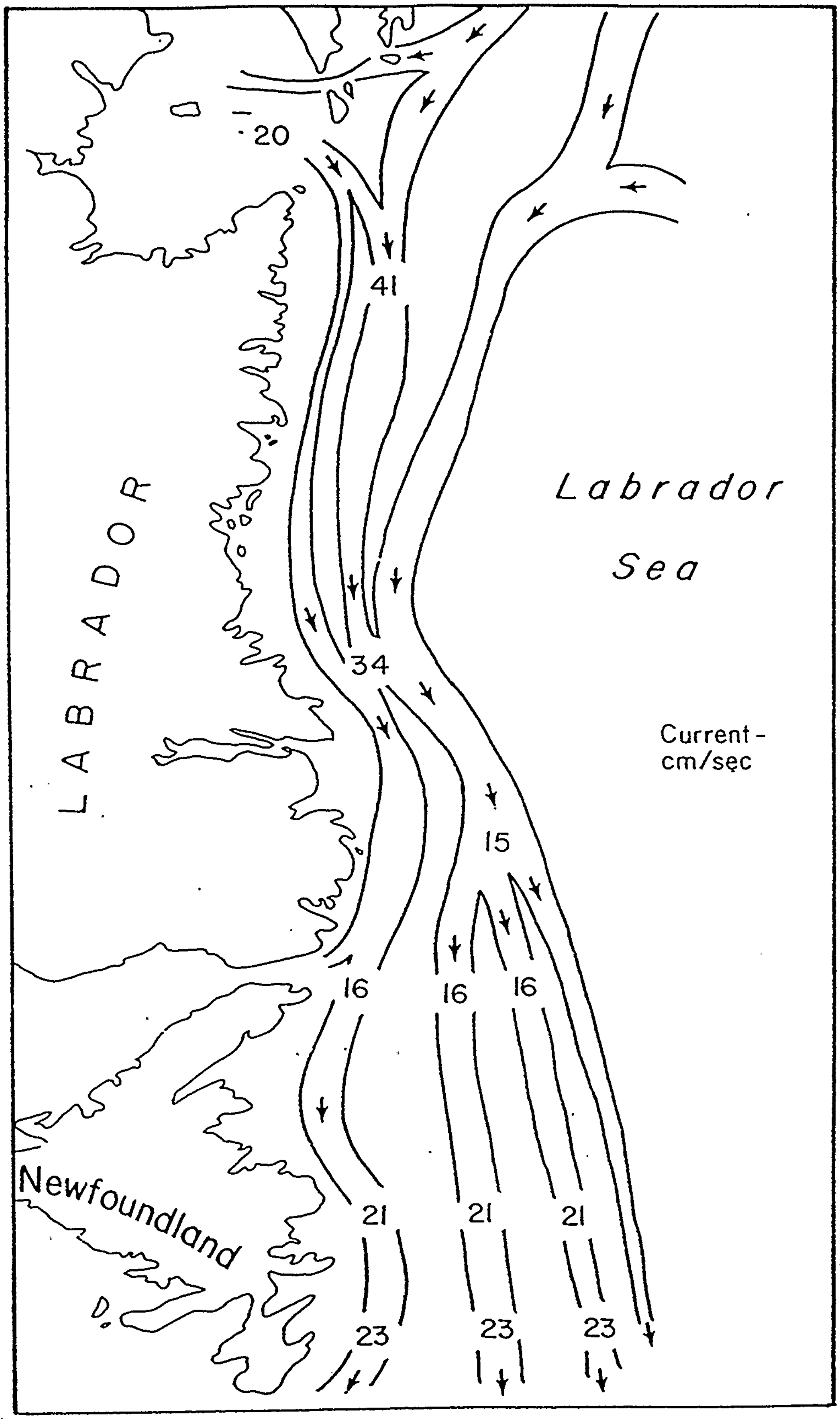


Figure 2.4 Spring surface current velocities: Labrador Current
(Source: Gustajtis, 1979b)

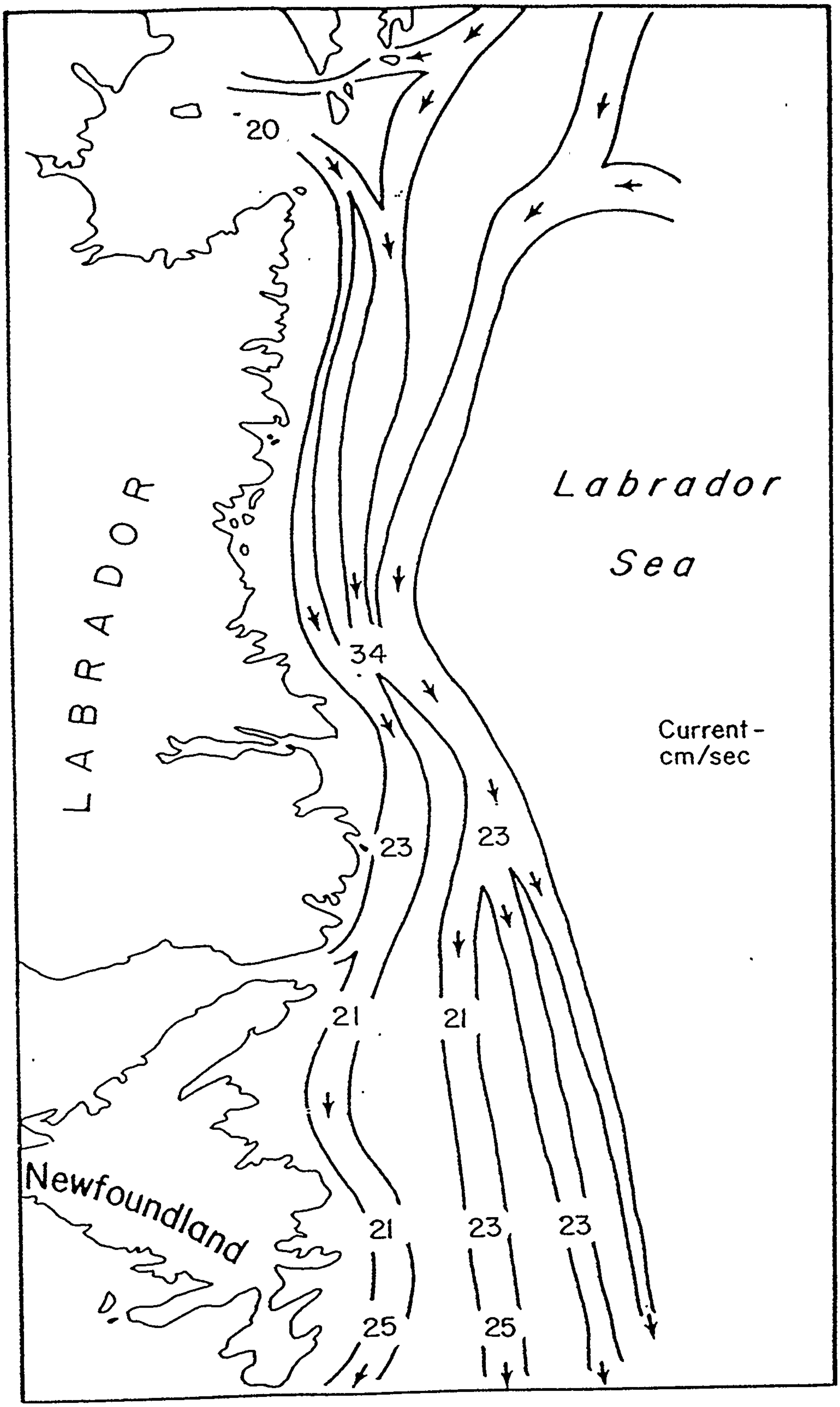


Figure 2.5 Summer surface current velocities: Labrador Current
(Source: Gustajtis, 1979b)

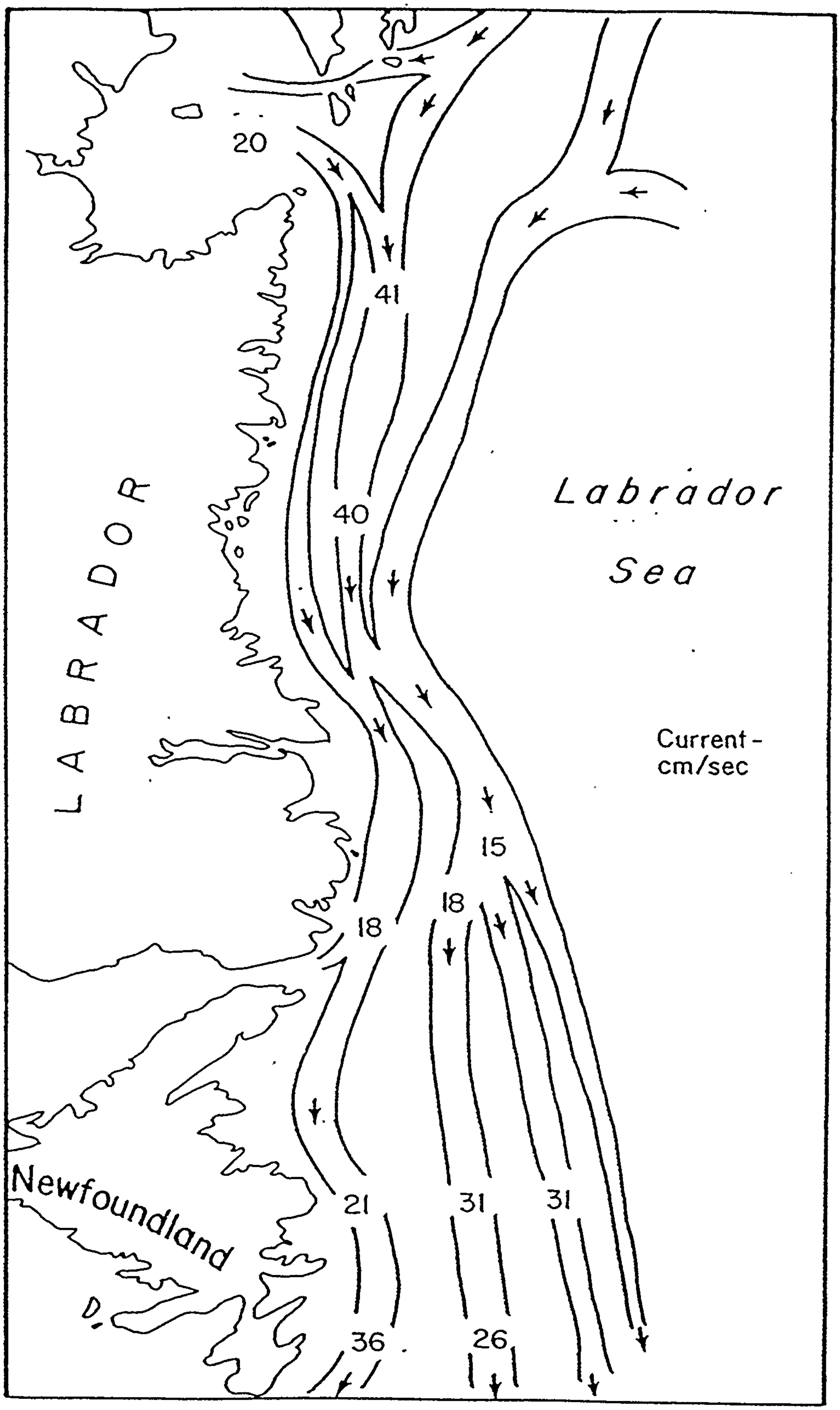


Figure 2.6 Fall surface current velocities: Labrador Current
(Source: Gustajtis, 1979b)

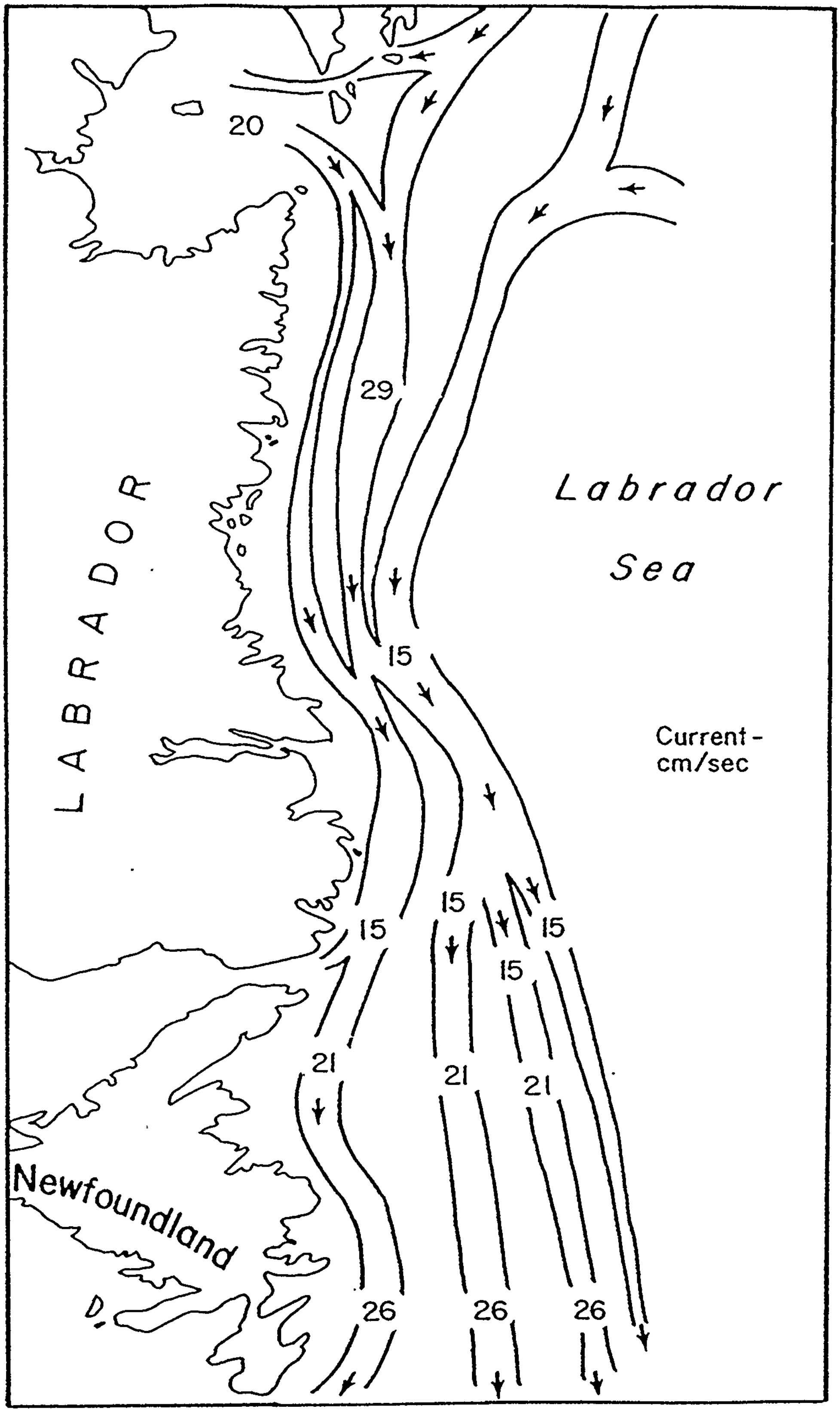


Figure 2.7 Winter surface current velocities: Labrador Current
(Source: Gustajtis, 1979b)

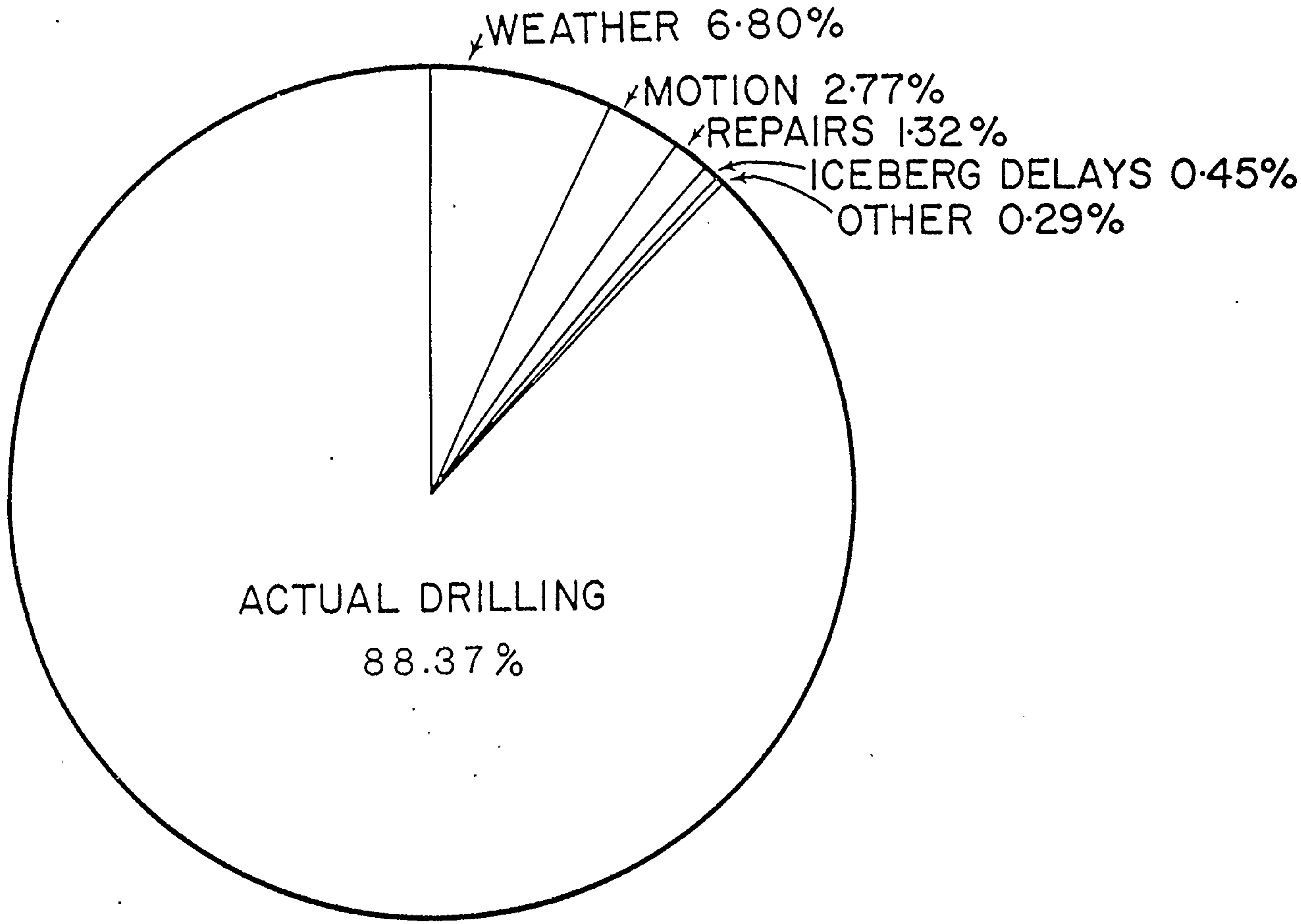


Figure 2.8-Total time involved in offshore Labrador drilling program: 1973-1975 inclusive (Source: Gustajtis, 1979b)

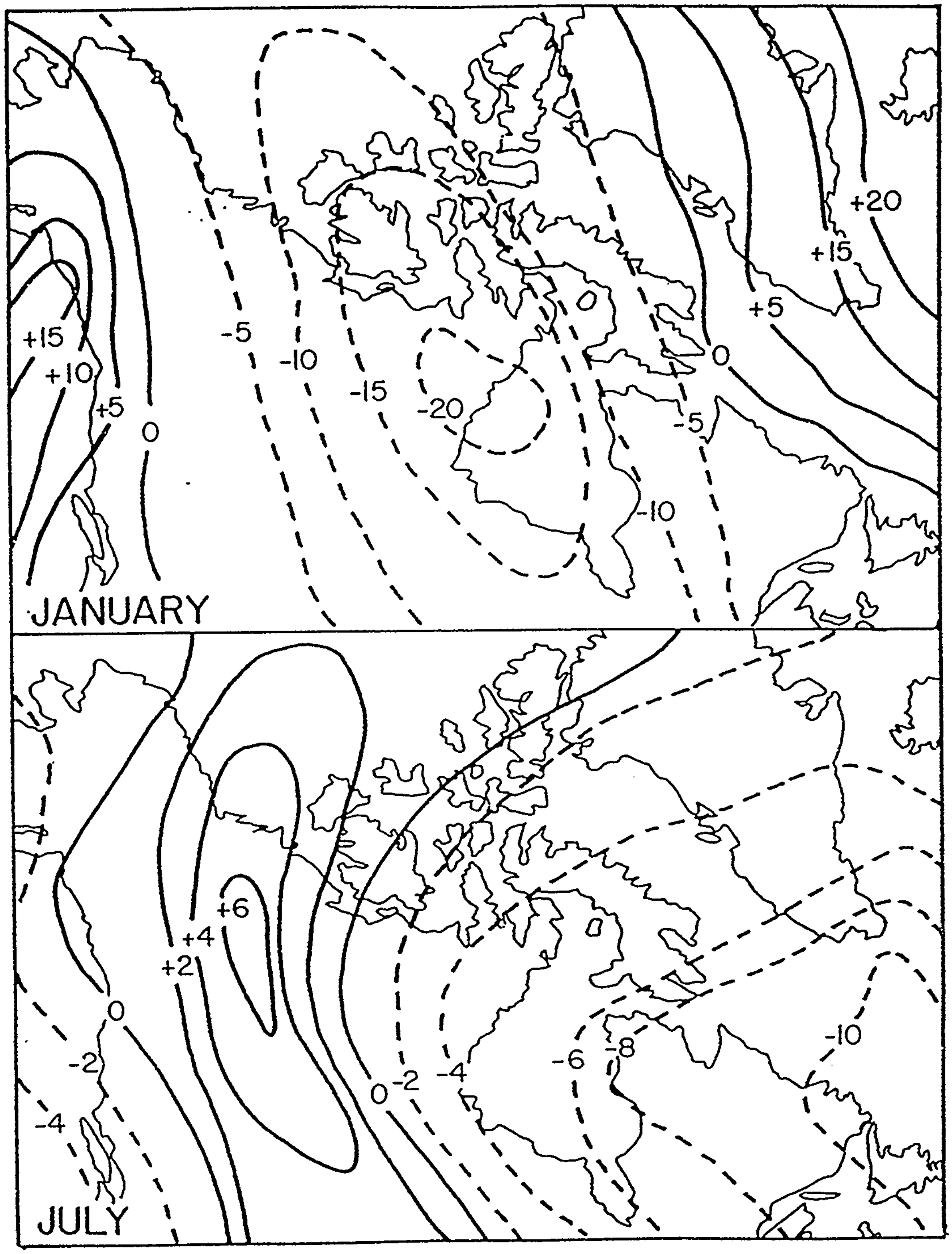


Figure 2.9 Canadian temperature anomalies (°F)
(Source: Gustajtis, 1979b)

is the direct result of Labrador's geographical position in relation to " (i) the surrounding disposition of the continental and ocean areas, and (ii) the prevailing physical charcateristics of the adjacent ocean water masses, especially temperature."

Table 2.1 Wave rider results: Labrador Shelf

MEDS* Station Number	Year	Month	Wave height less than 0.75 m (% of total time)	Wave height greater than 3.0 m (% of total time)
17	1973	August	28.5	27.5
17		September	14.0	30.0
17		October	0.0	22.6
94	1974	July	12.5	22.1
94		August	6.7	23.6
94		September	6.7	27.8
17	1975	July	37.0	22.9
17		August	10.0	20.6
17		September	7.5	26.6
17		October	0.0	26.6
18	1975	August	4.6	30.0
18		September	2.9	30.0
94	1976	July	43.4	21.8
94		August	4.1	23.4
94		September	5.2	28.9
94		October	0.0	17.6
17	1976	September	1.0	22.4
17		October	3.6	21.8
24	1976	September	2.1	28.9
24		October	1.12	29.9
24		November	0.9	18.7
23	1976	August	47.2	21.89
23		September	0.0	18.3

* Marine Environment Data Service, Environment Canada
(Source: Gustajtis ,1979b)

Sea surface temperatures of the central areas of the Labrador Sea in August and September usually reach 9 to 10^{o} C, while areas of the central and northern coast can be less than 4^{o} C. During the summer the winds blow offshore and the cold ocean temperatures have little effect on land temperatures (Bursey et al, 1977).

The entire Labrador area is influenced by the westerly jet stream, but at the surface the mean pressure patterns are predominantly influenced by the Icelandic flow. During the winter months a strong northwesterly gradient dominates a major portion of eastern Canada (Figure 2.10). In addition, the Labrador area is influenced by the Icelandic low during this period. The low usually produces stormy, unsettled weather with predominantly northwesterly winds and is a common feature of Labrador winters. The Icelandic low migrates westward to southern Baffin Island and weakens during late winter and summer (Figure 2.10). By July the circulation around the low is weak resulting in less frequent storms and prevailing westerly winds (Bursey et al ,1977). Figure 2.11 illustrates the transition from northwesterly winds in the winter to a south and southwesterly pattern in the summer, and the increased number of calm periods during the summer months.

Mean annual precipitation on the Labrador Shelf increases from 310 mm over the northern areas to 750 mm in the southern areas of the Shelf. The various types of precipitation are summarized in Figure 2.12. Forty-three percent of the annual precipitation is snow, and the period of maximum snowfall is between October and March. Maximum monthly rainfall occurs between May and October. Forty to fifty percent of the rain falls through July and September in the southern areas while 73 percent falls in the northern areas during the same period.

2.4 Iceberg Hazards

Icebergs are present year round on the Labrador Shelf with the maximum number of icebergs being observed in late spring and early summer. Farmer (1982) suggests that the seasonal variation of iceberg flux results "from the greater survival rate of bergs making the passage in spring, buffered from wave action by the pack ice and protected from melting by ocean water temperatures below 0^0 C". Greater solar heating and higher water and air temperatures later in the season (i.e. summer and fall) accelerate iceberg decay thus reducing the number of icebergs observed during summer and fall (Farmer, 1981). For example, the size of icebergs (observed during the drilling season) ranges from 100,000 tons to 20×10^6 tons. The physical

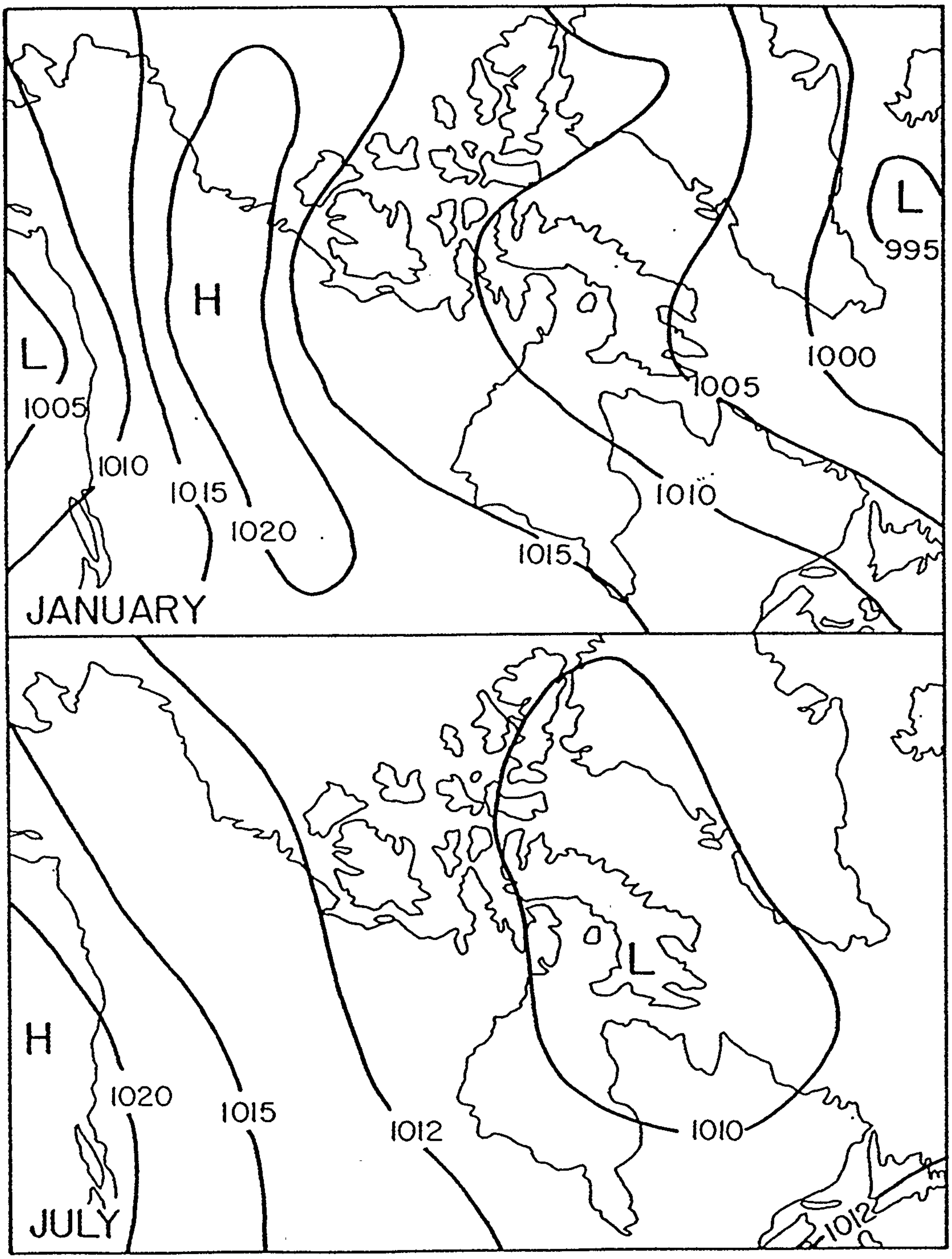


Figure 2.10 Mean surface pressure distribution (mb)
(Source: Gustajtis, 1979b)

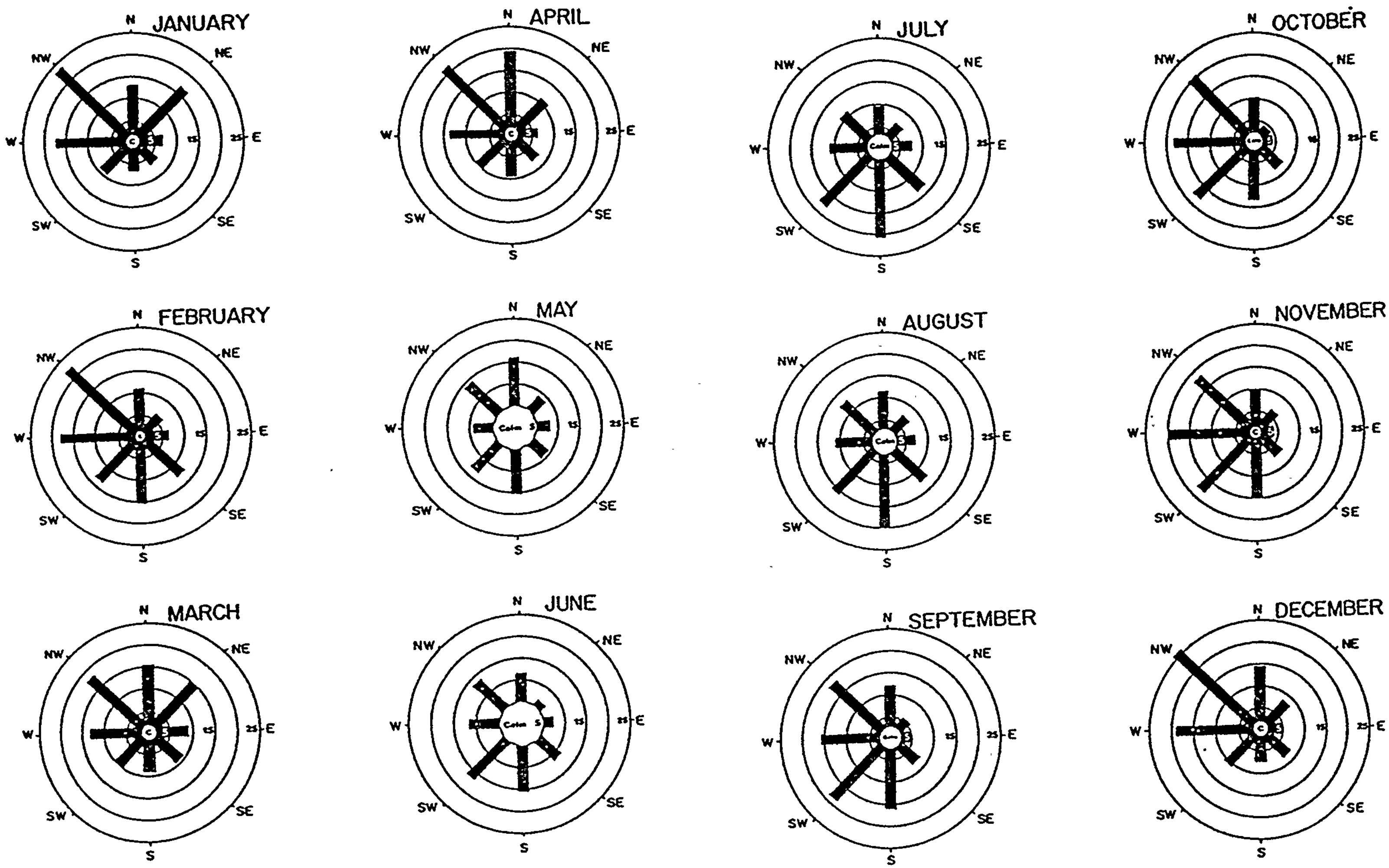


Figure 2.11 Monthly change in wind direction: Labrador offshore area
(Source: Gustajtis, 1979b)

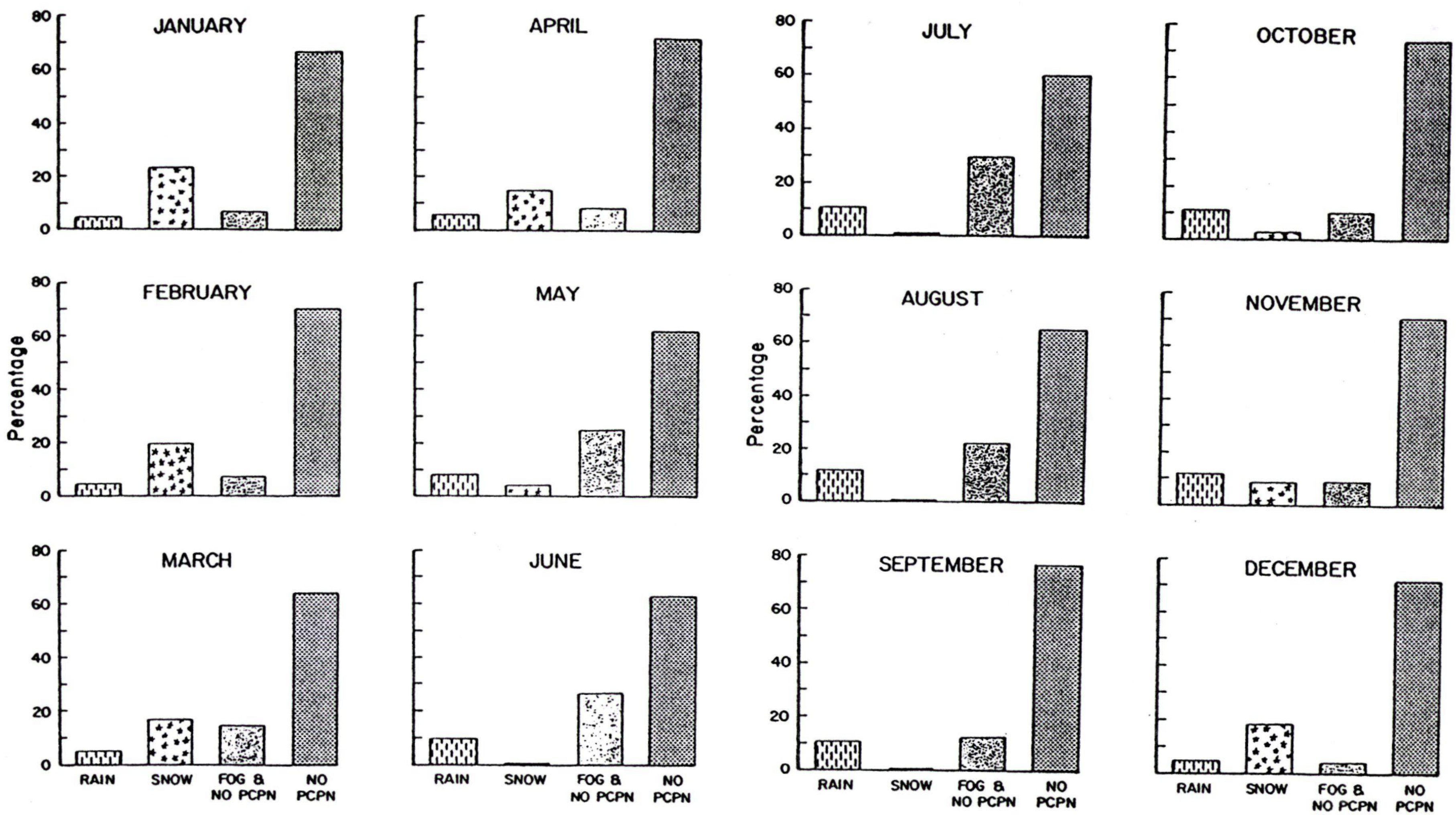


Figure 2.12 Monthly precipitation patterns: Labrador offshore area
(Source: Gustajtis, 1979b)

dimensions of a 10 X 10^6 ton iceberg will be approximately: sail height 50 to 75 m; keel depth 200 to 300 m.

Gustajtis and Buckley (1977) compiled a series of iceberg density maps (i.e number of icebergs observed per km^2) from observation data collected by the International Ice Patrol (IPP - see Figures 2.13 to 2.16). The results of their study indicate that the number of icebergs along the Labrador Shelf is relatively low during the winter (Figure 2.16). The southern boundary limit of icebergs during the winter months appears to be 55 to 57° N, which corresponds with the sea ice boundary over the Shelf area. During the spring icebergs can be found along the entire Labrador Continental Shelf with the largest number being concentrated in a central area along the outer continental shelf (Figure 2.13). Very few icebergs are present landward or seaward. With the advent of summer, the melting of sea ice and warming of sea surface temperatures, icebergs begin to deteriorate. Murray (1969) produced estimated deterioration times for various size icebergs (Table 2.2). Small icebergs (20 m high and 50m long) will deteriorate in 5 days in seawater with a temperature of 4° C while a large iceberg (greater than 40 m high and 100m long) will deteriorate in 15 days.

Table 2.2 Iceberg deterioration time (in days)

Type of Iceberg	Seawater Temeprature (°C) 2	4
Small (20 m high and 50 m long)	8 days	5 days
Medium (35 m high and 100 m long)	16 days	10 days
Large (> 40 m high and > 100 m long)	24 days	15 days

(Source: Murray, 1969)

Finally, by late fall iceberg densities along the shelf are reduced to a few icebergs (Figure 2.15).

Analysis of IIP iceberg data by Gustajtis and Buckley (1977) indicates that the total number and size of individual icebergs decreases from north to south on the Labrador Shelf (Table 2.3). For example, growlers (1 to 100 tonne icebergs) increase in numbers from 6.4

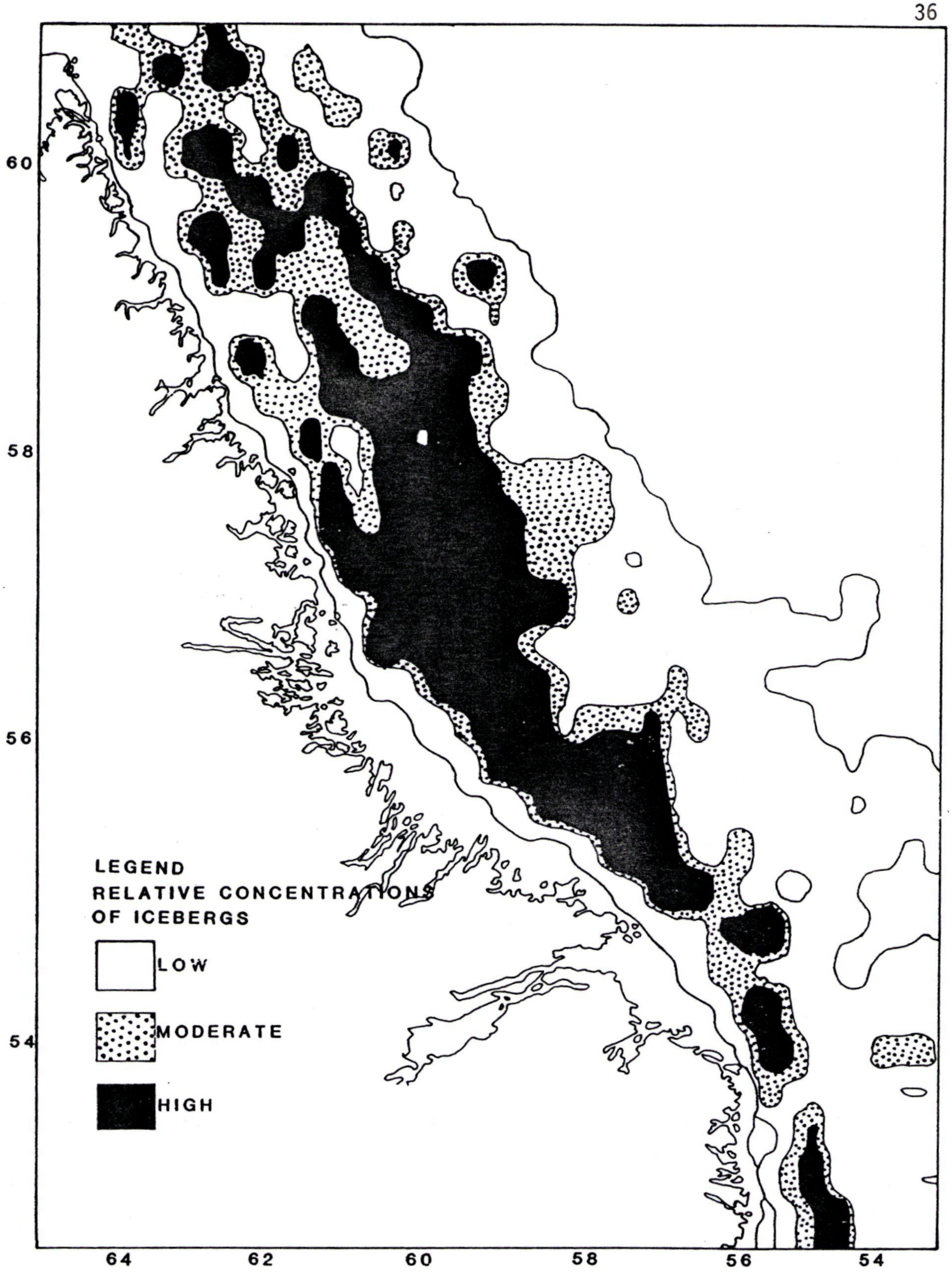


Figure 2.13 An average spring iceberg density distribution along the Labrador coast (Source: Adapted from Gustajtis, 1979c).

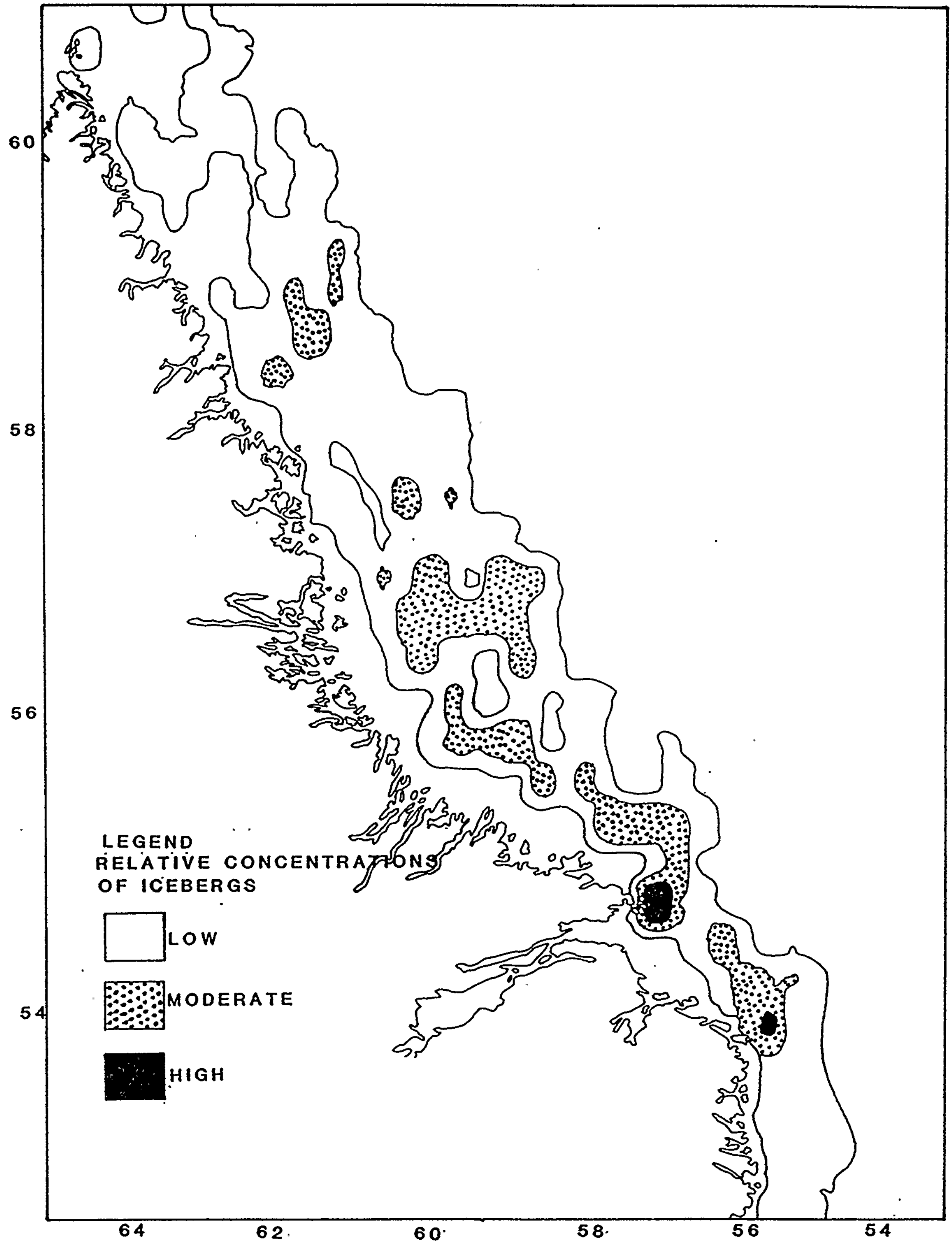


Figure 2.14 An average summer iceberg density distribution along the Labrador coast (Source: Adapted from Gustajtis, 1979c).

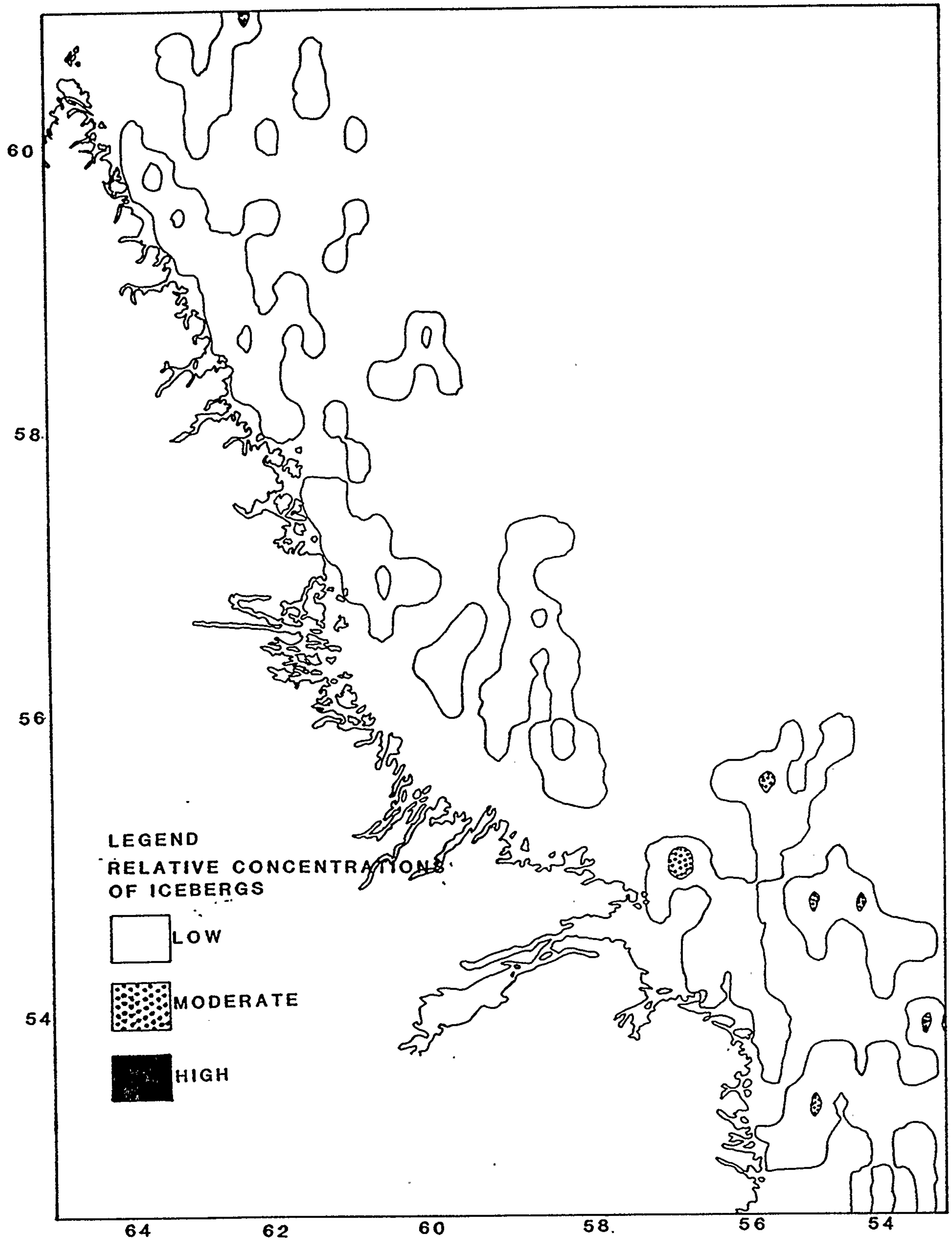


Figure 2.15 An average fall iceberg density distribution along the Labrador coast (Source: Adapted from Gustajtis, 1979c).

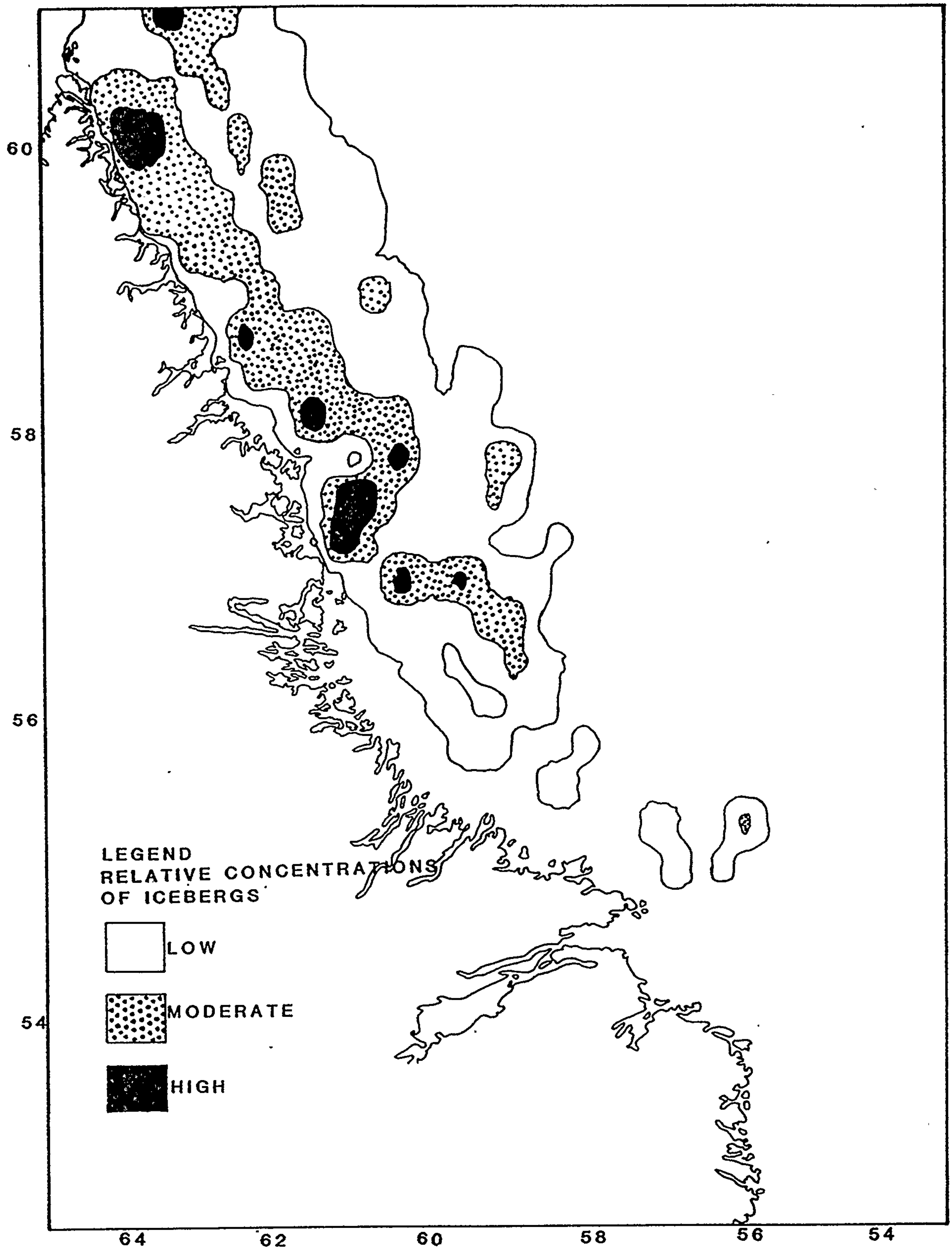


Figure 2.16 An average winter iceberg density distribution along the Labrador coast (Source: Adapted from Gustajtis, 1979c).

percent at 60° N to 16.7 percent at 52° N, whereas large icebergs (750,000 to 4 X 10^6 tonnes) decrease in numbers from 16.8 percent of the total number observed at 60° N to 6.5 percent at 52° N.

Table 2.3 Size distribution of icebergs reported by the International Ice Patrol (1963-1977) per degree latitude (percent distribution)

°N	Growlers	Small	Medium	Large
60	6.4	43.3	33.5	16.8
59	4.2	49.9	29.4	15.5
58	4.2	48.0	36.6	11.2
57	4.3	41.9	42.2	11.7
56	5.1	51.6	34.1	9.3
55	3.9	61.4	27.8	7.0
54	16.6	52.3	24.5	6.7
53	10.2	52.4	26.5	10.9
52	16.7	52.2	24.6	6.5

(Source: Gustajtis, 1979)

Anderson's (1971) compilation of average monthly iceberg flux data supports Gustajtis and Buckleys' (1977) study where the total number of icebergs crossing 61° N annually is 1206 while only 263 icebergs are expected on average to cross 50° N (Table 2.4).

Table 2.4 Monthly average fluxes of fcebergs across each degree of latitude

Flux Across	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
61°N	106	95	134	135	145	138	122	86	60	49	49	87	1206
60°N	103	95	128	131	144	142	124	87	51	40	40	74	1159
59°N	97	94	122	130	142	141	129	90	53	26	36	59	1119
58°N	87	92	115	129	139	140	135	95	62	21	26	43	1084
57°N	73	88	112	128	132	137	127	99	56	20	16	31	1019
56°N	49	77	112	112	133	134	122	106	68	28	10	19	966
55°N	31	59	99	105	126	130	120	118	75	35	11	10	909
54°N	17	39	82	98	116	118	91	81	49	32	15	6	744
53°N	12	30	73	93	111	107	64	54	33	23	11	2	613
52°N	9	23	62	89	106	102	42	34	22	14	9	0	512
51°N	4	14	40	76	86	67	37	11	2	5	5	0	347
50°N	3	8	35	66	75	32	22	5	1	2	3	0	263

(Source: Anderson, 1971)

The general trend is that the iceberg hazard is greater in the northern shelf areas than in the southern areas. This is reinforced by Gustajtis' (1979c) computation of annual probability of iceberg impact with an offshore structure (Table 2.5).

Table 2.5 Annual probability of iceberg impact P(A)[2] for the Labrador offshore (distance from shore 1° longitude)

	1°		2°		3°		4°	
	No.	P(A)	No.	P(A)	No.	P(A)	No.	P(A)
60°N	347	0.81	486	1.13	231	0.54	93	0.22
59°N	504	1.1	325	0.75	224	0.52	67	0.16
58°N	455	1.04	412	0.94	184	0.42	33	0.08
57°N	580	1.32	275	0.63	132	0.30	31	0.07
56°N	29	0.07	240	0.54	346	0.78	250	0.57
55°N	318	0.72	418	0.94	109	0.25	55	0.12
54°N	60	0.13	357	0.80	74	0.17	97	0.22
53°N	190	0.43	141	0.32	74	0.17	80	0.18
52°N	271	0.60	123	0.27	61	0.14	15	0.03

(Source: Gustajtis, 1979c)

The results of Gustajtis' computations indicate that the more northerly areas have, overall, a higher probability of impact (from 0.81 to 0.22 at 60°N) than the southern areas (from 0.60 to 0.03 at 52°N).

2.5 Summary

The combination of weather and icebergs indicates that the Labrador Shelf is a hazardous environment for offshore drilling operations. The evidence suggests that drillships involved in offshore drilling in the northern areas are at a greater risk in terms of iceberg hazards than those operating in the southern areas of the Shelf. Furthermore, the weather and iceberg data suggest that at best any offshore oil exploration activity will remain a seasonal venture.

[2] P(A) is expressed as percentages.

CHAPTER 3

METHODS FOR COMPILING THE ICEBERG DATA SET

3.0 Introduction

The study area was selected on the basis of the availability of iceberg observation data. Iceberg observation data for eighteen offshore wellsites located on the Labrador Shelf was obtained from Canada Oil and Gas Lands Adminstration (COGLA), Ottawa for the period 1973 to 1980 (Table 3.1). The data was stored on magnetic tape and is publicly available.

Table 3.1 Drillsite Locations and Geographical Areas on the Labrador Shelf

YEAR DRILLED	WELL NAME	LATITUDE	LONGITUDE	GEOGRAPHIC AREA*
1973	Leif E-38	54.2914	55.0978	Hamilton Bank (1)
1973	Leif M-48	54.2961	55.1222	Hamilton Bank (1)
1975	Indian M-52	54.3642	54.3975	Hamilton Bank (1)
1976	Indian M-52 RE	54.3642	54.3642	Hamilton Bank (1)
1980	Roberval C-02	54.8597	55.7431	Cartwright Saddle(2)
1975	Gudrid H-55	54.9083	55.8756	Cartwright Saddle(2)
1979	Tyrk P-100	55.4969	58.2306	Makkovik Bank (3)
1973	Bjarni H-81	55.5081	57.7014	Makkovik Bank (3)
1974	Bjarni H-81 RE	55.5081	57.7014	Makkovik Bank (3)
1979	Bjarni O-82	55.5300	57.7094	Makkovik Bank (3)
1976	Herjolf M-92	55.5314	57.7481	Makkovik Bank (3)
1978	Hopedale E-33	55.8733	58.8478	Hopedale Saddle (4)
1975	Snorri J-90	57.3289	59.9622	Nain Bank (5)
1976	Snorri J-90 RE	57.3289	59.9622	Nain Bank (5)
1978	Skolp E-07	58.4400	61.7692	Saglek Bank (6)
1975	Karlsefini A-13	58.8708	61.7783	Saglek Bank (6)
1976	Karlsefini A-13 RE	58.8708	61.7783	Saglek Bank (6)
1979	Gilbert F-53	58.8739	62.1397	Saglek Bank (6)

* Numbers in brackets are numeric codes for the geographical areas (1 indicates the most southerly geographical area and 6 indicates the most northerly area)

The primary objective of this study is to determine if there are any spatial and temporal variations in iceberg data collected on the Labrador Shelf. In addition, differences in the behaviour of various size icebergs were also thought to be worth investigating. In order to develop a logical sequence of procedures to examine these potential relationships it is desirable to identify: (i) the characteristics of the data set, and (ii) the statistical procedures required to evaluate the possible relationships. The former are, of course, essential for determining the latter.

3.1 Iceberg Data

Iceberg data used in this particular study were collected by iceberg observers located on the bridges of drillships operating on the Labrador Shelf. The observers recorded the hourly positions of icebergs using marine radar on the bridges of drillships. For each individual iceberg, the time, range and bearing was entered in an iceberg logbook. Occasionally, the height, length, width and draft of individual icebergs were also recorded. These combined physical dimensions were used to calculate approximate iceberg mass. After the conclusion of the drilling season the data entered in the iceberg logbook were keypunched and stored on magnetic tape.

A typical iceberg data file stored on magnetic tape is organized in the following format:

(i) record 1: wellsite name, latitude and longitude;

(ii) record 2: iceberg identification number; first month, day and time, and last month, day and time iceberg observed; iceberg shape, height, length, width, mass draft, and towing status (yes or no);

and (iii) record three: time, range and bearing.

Record two is repeated for each iceberg stored in the data file, while record three is repeated for each hour an individual iceberg was observed (i.e. anywhere from 2 to 500 hours of observation). Iceberg shape refers only to whether an iceberg was tabular or non-tabular, and all physical dimensions are measured in metres while mass is expressed in tonnes. Range is measured in nautical miles and bearing is degrees true (i.e. 0^0 indicates geographical north).

3.2 Required Iceberg Data

The objective of this study is to investigate the possible spatial and temporal differences in iceberg motions and physical dimensions, as well as variations in the behaviour of various sizes of icebergs. In addition to examining variations in iceberg motions and physical dimensions variations in iceberg shape and deflection (i.e. the number of icebergs towed versus not towed in a particular area) were also investigated.

In order to examine variations in iceberg data according to space, time and various size icebergs, iceberg data had to be grouped according to these subdivisions. Prior to grouping iceberg data into the three subdivisions the iceberg variables were defined and coded. For the purpose of this study space refers to the six distinct geographical areas[1] where the eighteen oil exploration wells were drilled. These areas from south to north are: Hamilton Bank, Cartwright Saddle, Makkovik Bank, Hopedale Saddle, Nain Bank and Saglek Bank. Wellsites located on Hamilton Bank were coded as geographical area 1 (the most southerly location), while wellsites located on Saglek Bank were coded 6 (the most northerly location)[2].

Time refers to month of operation. For example, iceberg data observed in July were given the number code 7 while data observed in October were coded 10. Initial examination of the iceberg data indicated that July, August, September and October had sufficient data for analysis. However, data for June and November were limited to just a few observations (i.e. 1 to 3 observations) and were omitted from the analysis.

Iceberg data grouped by iceberg size class is based on a standardized classification index utilized by the oil industry and research scientists[3] to group icebergs of different masses into six categories and they are: (i) growler - 1 to 100 tonnes, (ii) bergy bit - 100 to 2500 tonnes, (iii) small - 2500 to 120,000 tonnes, (iv) medium - 120,000 to 750,000 tonnes, (v) large - 750,000 to 4×10^6 tonnes, and (vi) extra large - greater than 4×10^6. Preliminary evaluation of the iceberg data showed that only one or two observations fell into either the growler or bergy bit class, thus these two classes were excluded from the study. The four iceberg size classes used in the study were: small - coded 1; medium - coded 2; large - coded 3; extra large - coded 4.

---

[1] For the preliminary data analysis in Chapter 4 the eighteen wellsites were also defined as distinct spatial entities, however for the overall analysis the six geographical areas were the primary spatial divisions.

[2] See Table 3.1 for wellsite names and geographical area codes.

[3] Personal communication with John Miller, Petro Canada (Calgary, Feb., 1986).

Initial examination of the iceberg physical dimension data[4] indicated that only length and height dimensions were measured consistently. However, mass was measured more often than either draft or width . Given that (i) mass is a combination of length, height, width and draft, and (ii) mass can be estimated using Hotzel and Millers' (1983) equation:

$$\text{mass} = 0.002009 * \text{length}^{2.68},$$

mass will be used as a surrogate measure of physical dimensions. For example, the height, length and width of an observed non-tabular 300,000 tonne iceberg was 24 m, 68 m, and 58 m, respectively, while a 2.5 X 10^6 non-tabular iceberg has a height of 85 m, a length of 230 m and a width of 180 m. Therefore any significant differences in mass are also assumed to represent significant differences in other physical dimensions.

Iceberg deflection and shape variables are available from the iceberg data files. Deflection is associated with the original tow variable, where 0 indicates that a particular iceberg was not deflected away from the drillsite, while 1 indicates that the iceberg was deflected away. Iceberg shape is coded 1 for tabular icebergs and 2 for non-tabular icebergs. The inclusion of deflection will provide insight into iceberg management problems both spatially and temporally, while the inclusion of shape will provide information on possible variations in the shape of icebergs observed along the Labrador Shelf.

Iceberg motion data, drift direction and velocity had to be computed from the time, range and bearing parameters of individual icebergs. Iceberg position data is stored as polar coordinates. To make the computation of drift direction and velocity a relatively simple task the position data were transformed into cartesian coordinates. The traditional calculation of x and y from r (range in nautical miles) and Ø (bearing in degrees true) where:

$$x = r * \text{cosine}(Ø); \quad \text{and } y = r * \text{sine}(Ø)$$

---

[4] A check on the physical dimension data using a program written in Fortran 77 indicated that draft and width were measured less than 1 percent of the time.

is not applicable with iceberg data. The problem is related to the fact that marine radar has 0 degrees on the y-axis while conventional circle geometry has 0 degrees on the x-axis. The solution to the problem is to calculate:

$$x = r * \text{sine}(\varnothing); \quad \text{and } y = r * \text{cosine}(\varnothing)$$

where the definition of x and y is reversed (Woodworth-Lynas et al, 1985).

After the data were converted from polar to cartesian coordinates, drift direction and velocity were calculated. Velocity is defined as the rate of shift from position x_i, y_i to x_{i+1}, y_{i+1} during a specified time period and is presented as m/sec. Computed velocity is an hourly average rather than an instantaneous velocity. Velocity V_i is expressed as:

$$V_i = DXY_i / DT_i * 3600$$

$$DXY_i = [(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2]^{1/2}$$

$$DT_i = T_{i+1} - T_i$$

where x_i, y_i = position of an iceberg in a cartesian system at time T_i

x_{i+1}, y_{i+1} = position of iceberg at time T_{i+1}

T_i = time iceberg in position x_i, y_i

T_{i+1} = time iceberg in position x_{i+1}, y_{i+1}

DXY_i = magnitude of shift (in metres) from position x_i, y_i to position x_{i+1}, y_{i+1}.

DT_i = elapsed time from T_i to T_{i+1}

3600 = a constant which converts velocity from hours to seconds.

Iceberg drift direction was calculated in two stages. First, the NS (north/south) and EW (east/west) vector components were calculated where:

$$NS_i = V_i * \text{cosine}(\varnothing + 180^\circ), \text{ and } EW_i = V_i * \text{sine}(\varnothing + 180^\circ).$$

Second drift direction was computed as:

$$DRIFT_i = \text{ARCTAN}((EW_i / NS_i) * 180^\circ / \text{pi})$$ [5].

[5] The calculation, coding and transformation of iceberg variables was performed by a computer program written in Fortran 77. For the program listing see Appendix A.

The iceberg data files for the eighteen wellsites contained approximately 22,000 hourly observations for 1046 icebergs. To reduce computer computational time for the data analysis the data set was reduced. Reduction in the size of the iceberg data set was achieved by computing daily averages for drift direction and speed because under normal conditions the hourly changes in drift direction and speed are not significantly large. For example, an iceberg observed for 48 hours would have two records of drift direction and velocity rather than n-1 observations (where n is total number of observations and might be as high as 48). This procedure reduced the data set from 22,000 hourly observations to 1167 daily average observations[6]. The reduction of the data set was such that no data class or group (i.e. geographical area, month of operation and iceberg size class) had less than 50 observations. The reorganized iceberg data set contained the following information for each iceberg: (i) geographical area (coded 1-6), (ii) wellsite identification (coded 1-18), (iii) month of operation (coded 7-10), (iv) iceberg size class (coded 1-4), (v) iceberg shape (coded 1-2), (vi) deflection (coded 0-1), (vii) iceberg mass (tonnes), (viii) daily average drift direction (degrees true), and (ix) daily average drift velocity (m/sec).

3.3 Statistical Analysis

Statistical analysis of iceberg data has been limited in the past because much of the research has focused on modeling and predicting iceberg behaviour. However, Robe (1975) used one-way analysis of variance to evaluate the physical dimensions of differently shaped icebergs, while Hotzel and Miller (1983) used regression analysis. Gustajtis (1979c) and Robe (1982) used descriptive statistics to summarize iceberg drift direction, mass and speed in terms of average and standard deviation.

The statistical procedures used in this study to evaluate iceberg data can be classified as (i) descriptive, (ii) non-parametric and (iii) parametric. Descriptive statistics (average, standard

[6]Preliminary discriminant analysis by wellsite indicated that the classification results were similar (approximately 35 percent correctly classified) for both the original and the daily average data sets. Appendices B and C contain frequency polygons of original and daily average iceberg speed data, respectively.

deviation, median, skewness and range) were computed for each wellsite, geographical area, month of operation and iceberg size class using the SPSS subprogram DESCRIPTIVE (SPSS Manual, 2nd Edition, 1975). Skewness was computed because in positively skewed distributions averages are inflated and the median is generally considered to be a better measure of central tendency (Yeates, 1974). Futhermore, composite rank scores were computed for each wellsite to compare iceberg conditions between the southern and northern locations (see Chapter 4 for a detailed discussion on descriptive statistics and composite rank scores).

The non-parametric test used in this study was the Kruskal-Wallis one-way analysis of variance. The one-way analysis of variance was used to determine if iceberg variables (deflection, drift direction, mass, shape, and speed) grouped by geographical area, iceberg size class, month of operation and wellsite were derived from the same population (the Kruskal-Wallis test is discussed in detail in Chapter 4 and is described in Hammond and McCullagh, 1978). The Kruskal-Wallis test results were computed using the SPSS subprogram NPAR TESTS.

To determine which of the iceberg variables contributed significantly to the spatial, temporal and iceberg class size differences discriminant analysis was performed on the grouped iceberg data. Discriminant analysis predicts group memberships and selects predictor variables which contribute significantly to discriminating between the various group memberships (discriminant analysis is discussed in Chapter 5). The SPSS subprogram DISCRIMINANT (SPSS Manual, 2nd Edition, 1975) was used to compute the test results.

The combined results of descriptive statistics, non-parametric and parametric tests will provide a statistical summary of iceberg conditions on the Labrador Shelf. This statistical summary will also indicate which sectors of the Labrador Shelf experienced the best and worst iceberg conditions during the drilling season.

CHAPTER 4

ICEBERG DATA: CLASSIFICATION AND DESCRIPTION

4.0 Introduction

Having classified the iceberg data by space, time and iceberg size class, various calculations were performed to provide a concise description of variations in the data set. The characteristics of the grouped iceberg data were examined in terms of: (i) central tendency, (ii) dispersion; and (iii) shape. Furthermore, additional information was obtained by ranking the grouped data (to determine composite rank scores) and performing a non-parametric test to determine whether the observed differences among the grouped data warranted further investigation.

4.1 Classification

The iceberg data was classified according to geographical area, iceberg size and month of operation. Geographical area refers to six specific Shelf and Saddle areas located on the Labrador Shelf (Table 4.1). Drillsite data sets associated with a specific geographical area were aggregated for statistical analysis. In addition, drillsite data were also grouped according to iceberg size. Iceberg size is a classification index utilized by the oil industry to group icebergs of various masses into six distinct catergories. These categories are: (i) growler - 1 to 100 tonnes, (ii) bergy bit - 100 to 2500 tonnes, (iii) small - 2500 to 120,000 tonnes, (iv) medium - 120,000 to 750,000 tonnes, (v) large - 750,000 to 10^6 X 4 tonnes, (vi) extra large - > 10^6 X 4 tonnes.

The preceding classification procedures permit the statistical evaluation of the iceberg data by: month, drillsite, geographical area or iceberg size. The iceberg data set also contains additional information for individual icebergs on : (i) average daily speed (m/sec), (ii) average daily drift direction (degrees true), (iii) iceberg mass (tonnes), (iv) deflection (yes or no), and (v) shape (tabular or non-tabular).

Table 4.1 Drillsite Locations and Geographical Areas on the Labrador Shelf.

YEAR DRILLED	WELL NAME	LATITUDE	LONGITUDE	GEOGRAPHIC AREA
1973	Leif E-38	54.2914	55.0978	Hamilton Bank
1973	Leif M-48	54.2961	55.1222	Hamilton Bank
1975	Indian M-52	54.3642	54.3975	Hamilton Bank
1976	Indian M-52 RE	54.3642	54.3642	Hamilton Bank
1980	Roberval C-02	54.8597	55.7431	Cartwright Saddle
1975	Gudrid H-55	54.9083	55.8756	Cartwright Saddle
1979	Tyrk P-100	55.4969	58.2306	Makkovik Bank
1973	Bjarni H-81	55.5081	57.7014	Makkovik Bank
1974	Bjarni H-81 RE	55.5081	57.7014	Makkovik Bank
1979	Bjarni O-82	55.5300	57.7094	Makkovik Bank
1976	Herjolf M-92	55.5314	57.7481	Makkovik Bank
1978	Hopedale E-33	55.8733	58.8478	Hopedale Saddle
1975	Snorri J-90	57.3289	59.9622	Nain Bank
1976	Snorri J-90 RE	57.3289	59.9622	Nain Bank
1978	Skolp E-07	58.4400	61.7692	Saglek Bank
1975	Karlsefini A-13	58.8708	61.7783	Saglek Bank
1976	Karlsefini A-13 RE	58.8708	61.7783	Saglek Bank
1979	Gilbert F-53	58.8739	62.1397	Saglek Bank

4.2 Data Set Characteristics

Prior to making any statistical inference on the two hypotheses outlined in Chapter 1, concise decriptions of the iceberg data sets are required for two reasons: (i) measures of central tendency and dispersion reduce the description of the major attributes of a data set to a few numbers, and (ii) decisions on whether to use parametric or non-parametric statistical inference tests are dependent upon these characteristics.

The decision to use parameteric or non-parametric statistics is usually based on the skewness of a particular distribution. For example, the skewness value of a symmetrical distribution is zero whereas a distribution with a high degree of skewness would have a skewness value of ±0.3 (Yeates, 1974). If a particular data set is found to be highly skewed there are several important factors that must be considered. First, the validity of applying a parametric statistical test on the data is questionable, because a high degree of skewness indicates that the data is not normally distributed. Therefore, the data is likely to come from a population that is not normally distributed, and the assumption of parametric statistical tests that the data is normally distributed cannot be maintained. Second, descriptive statistics (i.e. average, standard deviation, variance, etc.) can be misleading if used to describe a highly skewed distribution because a majority of the data lies to the left or the right of the average. The median is considered a more relevant measure of central tendency in a skewed distribution and non-parametric tests are more applicable (Yeates,1974).

4.3 Descriptive Statistics By Drillsite

Measures of central tendency and dispersion were computed for drift direction, speed and mass data grouped by drillsite, geographical area, iceberg size and month using the "FREQUENCIES" program in SPSS[1]. Specifically, average, standard deviation, range, median, and skewness were computed for each group. Tables 4.2 to 4.4 present the descriptive statistics for speed, drift direction and mass for each drillsite. The most notable feature for all three variables is the moderate to high skewness for a majority of the drillsite data sets. Skewness values for iceberg speed (Table 4.2) range from 0.025 at Skolp to 4.029 at Gudrid. Sixteen out of the eighteen data sets had positively skewned values that would be considered moderate to high. Therefore, a majority of the iceberg speed data are less than the average and the median is a more appropriate measure of central tendency. Median iceberg speeds ranged from 0.154 at Bjarni H-81 to 0.361 m/sec at Indian M-52. The skewness of the 18 drillsite data sets is also apparent when descriptive statistics are computed for aggregated iceberg speed data (i.e. combined data sets inTable 4.2) where computed skewness is 2.302. The median speed for the aggregated data is 0.197 m/sec.

The computed statistics for drift direction (Table 4.3) are similar to the speed statistics because a majority of the data is moderately or highly skewed. Skewness for drift direction data sets ranges from -1.249 to +0.944 and median drift direction ranges from 152.971° at Hopedale to 237.826° at Gudrid. In addition, the median iceberg drift direction values suggest a fluctuation from a southeasterly to a southwesterly direction. The computed skewness for the aggregated

---

1 Statistical Package for the Social Sciences, Version 9.1.

Table 4.2 Descriptive statistics iceberg speed (m/sec)

Drillsite	Mean	S.D.	Range	Median	Skew	N
Leif E-38	0.182	0.059	0.185	0.180	0.151	12
Leif E-48	0.188	0.090	0.457	0.172	2.790	28
Indian M-52 RE	0.272	0.093	0.348	0.257	0.803	11
Roberval K-92	0.226	0.107	0.997	0.208	2.533	245
Gudrid H-55	0.217	0.136	1.455	0.186	4.029	245
Tyrk P-100	0.184	0.121	0.729	0.163	1.936	65
Bjarni H-81	0.142	0.098	0.341	0.154	0.375	21
Bjarni H-81 RE	0.428	0.189	0.342	0.336	1.675	3
Bjarni O-82	0.204	0.106	0.514	0.195	0.669	170
Herjolf M-92	0.323	0.251	1.148	0.311	1.825	23
Hopedale E-33	0.293	0.152	0.625	0.258	0.968	83
Snorri J-90	0.233	0.119	0.516	0.196	1.851	49
Snorri J-90 RE	0.259	0.077	0.226	0.222	0.655	9
Skolp E-07	0.168	0.084	0.363	0.161	0.025	107
Karlsefini A-13	0.263	0.087	0.316	0.268	0.339	19
Karlsefini A-13 RE	0.176	0.131	0.432	0.190	0.194	42
Gilbert F-53	0.283	0.153	0.495	0.321	-0.641	16
Combined Data Sets	0.218	0.127	1.455	0.197	2.302	1167

S.D. = standard deviation   Skew = skewness   N = number of observations

Table 4.3 Descriptive statistics iceberg drift direction

Drillsite	Mean	S.D.	Range	Median	Skew	N
Leif E-38	180.230	73.864	270.298	190.45	-1.249	12
Leif E-48	204.506	51.997	288.841	204.507	0.125	28
Indian M-52	191.296	70.738	189.313	209.302	-0.267	6
Indian M-52 RE	171.380	25.588	84.65	170.529	-0.053	11
Roberval K-92	167.855	66.909	359.5	166.58	0.083	246
Gudrid H-55	160.843	54.689	350.176	159.734	0.278	245
Tyrk P-100	186.652	62.645	264.919	188.514	0.027	66
Bjarni H-81	191.964	58.308	242.802	193.67	0.944	22
Bjarni H-81 RE	223.293	14.036	27.897	225.097	-0.569	3
Bjarni O-82	177.018	55.925	313.879	177.529	-0.152	171
Herjolf M-92	130.649	75.383	228.117	154.971	-0.969	23
Hopedale E-33	160.572	58.988	352.169	152.485	0.513	83
Snorri J-90	190.652	59.698	330.611	180.323	-0.252	49
Snorri J-90 RE	204.633	36.749	101.368	193.305	0.382	9
Skolp E-07	204.312	44.268	276.457	202.042	0.135	107
Karlsefini A-13	211.014	45.084	173.406	220.452	-0.244	19
Karlsefini A-13 RE	203.995	51.217	212.038	202.884	0.483	45
Gilbert F-53	232.066	69.686	204.958	237.826	-0.328	22
Combined Data Sets	177.185	60.852	359.500	177.529	-0.038	1167

S.D. = standard deviation Skew = skewness N = number of observations drift direction data is -0.038. This low negative skewness value is also reflected in the small difference between the average (177.185°) and median (177.529°) drift direction.

The iceberg mass data for each drillsite (Table 4.4) exhibits the same high skewness displayed by the speed data sets. Skewness for the mass data sets range from -1.706 to +2.609. Median iceberg mass ranges from a low of 0.300 X 10^6 tonnes at Snorri J-90 to a high of 12 X 10^6 tonnes at Karlsefini A-13. The high skewness associated with the iceberg mass data sets is evident from the differences between the average and median mass values for each drillsite. For example, at Gudrid the average mass is 4.151 X 10^6 tonnes, while median mass is 1.5 X 10^6 tonnes, a difference of 3 X 10^6 tonnes. The positively skewed values have pulled the average up to an unusually high level. This difference between the average and median mass values computed for each drillsite is also true for the aggregated mass data set where computed skewness is 2.486 with an average of 3.492 X 10^6 tonnes and a median of 1.5 X 10^6 tonnes.

4.4 Descriptive Statistics By Geographical Area, Month And Size

Iceberg speed, mass and drift direction data for each drillsite were aggregated by geographical area, month of operation and iceberg size class size (Tables 4.5, 4.6 and 4.7, respectively) and descriptive statistics were computed for each aggregated data set. The computed statisctics again suggest that researchers should examine median vaules rather than average values because of the skewness of the various data sets. For example, in Table 4.5 skewness for iceberg speed ranges from 0.256 at Saglek to 3.565 at Cartwright. All bank areas (except for Nain) have a lower median speed than either Hopedale Saddle (0.258 m/sec) or Cartwright Saddle (0.199 m/sec). Another interesting result presented in Table 4.5 is that both Hopedale and Cartwright have strong southeasterly median iceberg drift directions while all Bank areas maintain a more southerly or southwesterly drift direction. A factor which also appears to separate the Bank and Saddle areas is the median iceberg mass. Both Hopedale (1.6 X 10^6 tonnes) and Cartwright (1.5 X 10^6 tonnes) are more than twice the median mass computed for

Nain (0.300 X 10^6 tonnes) and Hamilton (0.7 X 10^6 tonnes) Banks (Table 4.5). The water depth in the Saddle areas reaches a maximum depth of 500 m while on the Bank areas the water depth does not exceed 200 m. The deeper water in the Saddle areas would permit larger icebergs (i.e. with drafts exceeding 200 m) to drift into the Saddle areas. There is one exception however, Saglek Bank has the largest computed median mass (2 X 10^6 tonnes) and is the most northerly geographical area. Gustajtis and Buckley (1977) suggest that the largest icebergs are usually found on the northern areas of the Labrador Shelf.

The median iceberg speed, drift direction and mass computed for each month (Table 4.6) present some interesting trends. For example, median iceberg speed increases from 0.173 m/sec in July to 0.282 m/sec in October, suggesting a seasonal variation in iceberg behaviour. This is also supported by the change in iceberg drift direction from southerly (180.205°) in July; southeasterly, in August (176.478°) and September (170.813°); southwesterly, (208.649°) in October. However, median iceberg mass (Table 4.6) does not change drastically from July to September (1.4 X 10^6 to 1 X 10^6 tonnes). The median iceberg mass for October (5 X 10^6 tonnes) however, suggests that iceberg mass does not necessarily decrease from the beginning to the end of a drilling season on the Labrador Shelf. This is supported by the computed range for iceberg mass in Table 4.6 where range has a small fluctuation from July to October (i.e. 34.127 X 10^6 to 24.992 X 10^6 tonnes). Gustajtis (1979c) indicated that large icebergs are present in the fall but the number of large icebergs is significantly less than in the spring.

The grouping of iceberg mass data into small, medium, large, and extra large size classes permits comparsions to be made between the various size classes. Table 4.7 presents the descriptive statistics for each iceberg size class on speed, drift direction and mass. Again one should note the skewness present in the various iceberg size class data sets. The most notable result is the difference in the median speed of small (<0.12 X10^6 tonnes) and extra large (>4 X 10^6 tonnes) icebergs. Median speed for small icebergs is 0.236 m/sec while extra large icebergs have a median speed of 0.167 m/sec. This indicates that small icebergs will probably drift approximately 20 km. during a 24 hour period, while an extra large iceberg will travel approximately

Table 4.4 Descriptive statistics iceberg mass (10^6 tonnes)

Drillsite	Mean	S.D.	Range	Median	Skew	N
Leif E-38	3.800	4.788	13.97	2.000	1.987	12
Leif E-48	2.667	4.744	16.01	0.975	2.609	28
Indian M-52	1.035	1.194	3.399	0.700	2.128	6
Indian M-52 RE	0.302	0.475	1.470	1.040	2.069	11
Roberval K-92	1.668	1.855	6.499	1.000	1.387	246
Gudrid H-55	4.532	6.078	30.12	2.000	2.180	245
Tyrk P-100	0.843	0.674	2.935	1.000	0.762	66
Bjarni H-81	8.027	3.300	9.998	10.00	-1.706	22
Bjarni H-81 RE	0.500	0.000	0.000	0.500	0.000	3
Bjarni O-82	4.151	4.691	12.24	1.150	0.660	171
Herjolf M-92	1.151	1.524	7.498	1.000	3.487	23
Hopedale E-33	2.910	3.639	14.98	1.600	2.368	83
Snorri J-90	1.322	1.402	4.990	0.300	1.050	49
Snorri J-90 RE	1.418	3.47	9.950	0.163	2.821	9
Skolp E-07	3.946	3.817	13.97	2.200	0.776	107
Karlsefini A-13	0.752	0.885	1.995	0.170	0.760	19
Karlsefini A-13 RE	14.53	10.75	24.99	12.00	-0.27	45
Gilbert F-53	2.138	1.583	4.955	2.000	0.795	22
Combined Data Sets	3.492	5.170	30.12	1.500	2.486	1167

Table 4.5 Descriptive statistics - geographical area

Parameter	Hamilton	Cartwright	Makkovik	Hopedale	Nain	Saglek
Speed (m/sec)						
Average	0.222	0.221	0.207	0.293	0.229	0.189
S.D.	0.110	0.122	0.136	0.152	0.114	0.110
Range	0.473	1.000	1.000	0.625	0.516	0.501
Median	0.191	0.199	0.191	0.258	0.201	0.183
Skew	1.597	3.565	2.188	0.968	1.716	0.256
N	57	491	285	83	58	193
Direction (degrees true)						
Average	191.612	164.35	177.148	160.572	192.821	208.06
S.D.	55.949	61.156	60.819	58.988	56.716	49.833
Range	350.65	359.50	343.888	352.169	330.611	276.45
Median	193.14	163.60	178.693	152.485	183.730	204.79
Skew	-0.443	0.187	-0.281	0.513	-0.305	0.242
N	57	491	285	83	58	193
Mass (mega tonnes)						
Average	2.282	3.097	3.387	2.900	1.300	5.893
S.D.	4.128	4.709	4.264	3.639	1.787	7.661
Range	16.00	30.12	12.249	14.98	9.990	24.99
Median	0.700	1.500	1.000	1.600	0.300	2.000
Skew	2.834	3.058	1.026	2.368	2.496	1.601
N	57.000	491.000	285.000	83.000	58.000	193.00

Skew = skewness

Table 4.6 Descriptive statistics - month

Parameter	July	August	September	October
Speed (m/sec)				
Average	0.190	0.221	0.270	0.259
S.D.	0.099	0.114	0.169	0.183
Range	0.660	1.000	1.000	0.898
Median	0.173	0.194	0.249	0.282
Skewness	1.463	2.185	2.303	-0.949
N	256	665	197	47
Direction (degrees true)				
Average	178.660	175.789	172.867	207.175
S.D.	67.623	56.147	64.840	62.877
Range	359.500	353.657	343.888	316.000
Median	180.205	176.478	170.813	208.649
Skewness	-0.024	-0.046	0.009	-0.578
N	258	665	197	47
Mass (mega tonnes)				
Average	3.512	3.115	3.237	9.909
S.D.	5.632	3.867	5.516	10.590
Range	30.127	24.990	24.000	24.992
Median	1.400	1.600	1.000	5.000
Skewness	2.718	1.760	2.485	0.622
N	258	665	197	47

Table 4.7 Descriptive statistics - iceberg size class

Parameter	Small	Medium	Large	Extra large
Speed (m/sec)				
Average	0.254	0.226	0.236	0.170
S.D.	0.113	0.106	0.151	0.109
Range	0.583	0.646	1	0.643
Median	0.236	0.199	0.203	0.167
Skewness	0.681	1.45	3.217	0.952
N	151	319	396	301
Direction (degrees true)				
Average	181.406	180.309	171.169	179.443
S.D.	69.671	58.239	62.172	57.634
Range	352.169	353.5	359.5	299.417
Median	190.59	180.082	171.011	178.572
Skewness	-0.553	-0.16	0.065	0.384
N	151	319	396	301
Mass (mega tonnes)				
Average	0.051	0.38	1.963	10.448
S.D.	0.035	0.178	0.754	5.903
Range	0.118	0.628	3.2	25.928
Median	0.047	0.34	1.8	8
Skewness	0.369	0.392	0.614	1.562
N	151	319	396	301

14 km. during the same period. Medium and large size icebergs maintain similar median speeds; 0.199 and 0.203 m/sec respectively. Furthermore, small, medium and large size icebergs exceed the aggregated median speed of 0.197 m/sec, while iceberg median speed (0.167 m/sec) for extra large icebergs is less.

The differences in the drift speeds of small, medium, large and extra large icebergs are generally the result of the environmental forces driving the various size icebergs (Ball et al, 1982). According to Lever et al (1984), and Hsuing and Aboul-Azm (1982) the drift speed and trajectory of small and medium size icebergs are influenced by increases in wind speeds, wave heights and surface currents and would result in a significant increase in drift speeds. Robe (1982), and Smith and Banke (1982) suggest that extra large icebergs are driven by deep sea currents (which are generally slower than surface currents[2]) and do not respond to the same degree to surface conditions as smaller icebergs. Robe (1982) also reported that observed extra large icebergs were in contact with the seabed approximately 60 percent of the time. This contact between the iceberg keel and seabed material would produce a braking action whereby the drift speed of the iceberg would be reduced (in some instances the iceberg comes to a complete stop until its draft is reduced by deterioration or an increase in water depth caused by incoming tide).

Small and medium size icebergs have a southwesterly (190.6°), and a southerly (180.1°) median drift direction respectively, while large and extra large have an apparent southeasterly median drift direction: large icebergs 171.0° and extra large 178.6°.

Computed descriptive statistics on mass in Table 4.7 serve only to differentiate the iceberg mass between the various iceberg size classes. For example, median mass ranges from 0.047×10^6 tonnes for small icebergs to 8×10^6 tonnes for extra large size icebergs. The mass data is also highly skewed for all size classes which indicates that a majority of the mass data is to the left of the mean. This is exemplified by the difference between the average mass (3.492×10^6 tonnes) and the median mass (1.5×10^6 tonnes) for the aggregated mass data.

---

[2] See Figure 2.3 in Chapter 2 to examine the differences between surface currents and deep sea currents under various surface conditions.

4.5 Ranked Data

Computing descriptive statistics for each drillsite, geographical area, month of operation, and iceberg size class provided general information on the spatial and temporal differences between iceberg speed, drift direction and mass. Additional information on: (i) the number of icebergs observed; (ii) the number of icebergs deflected; and (iii) the number of icebergs drifting within 1.6 km. (one mile) of the drillsite (hereafter referred to as hazardous icebergs). When icebergs drift within 1.6 km. of a semi-submersible drilling rig there are two possible courses of action: (i) deflect the iceberg away from the rig with established towing techniques; and (ii) stop the drilling operations and move the rig off the wellsite until the iceberg has moved out of the drilling area. This analysis would enhance the information on iceberg management problems encountered at various wellsite locations and would possibly lead to a reduction in the second more drastic course of action.

Data available on the number of icebergs observed, deflected and considered hazardous are discrete data, although speed and mass are interval data. An effective method of organizing data sets with different measurement scales is to rank the data. Ranking the iceberg data permits one to make meaningful comparisions between iceberg parameters. Another advantage to ranking the data is that it provides the ability to produce comparable aggregates by adding ranks scored for each variable. This procedure makes it possible to (i) produce aggregate rank scores for each drillsite, geographical area or month of operation, and (ii) make comparisions between the various drillsites, geographical areas, or months of operation and iceberg parameters. The aggregated rank scores for individual locations or months will provide information on which locations or months experience the best or worst iceberg conditions (Hammond and McCullagh, 1978). Reducing interval data (speed and mass) to an ordinal level causes some loss of information, however, it should not adversely affect the results to any great extent since many of the non-parametric ranking procedures are almost as powerful as their parametric equivalents (see Siegel, 1956).

4.6 Ranking Iceberg Data By Drillsite And Geographical Area

The drillsite data was sorted in ascending order from the most southerly location to the most northerly location on the Labrador Shelf. In Table 4.8 Leif E-38 is the most southerly location with a rank of 1 and Gilbert F-53 is the most northerly with a rank of 18. In addition, the number of icebergs observed, deflected and considered hazardous were counted for each drillsite. The median speed and mass for each drillsite were also included in the ranking procedure (Table 4.8). Each column of raw data in Table 4.8 was ranked separately from lowest to highest (i.e. a drillsite with the lowest speed is ranked 1 while the drillsite with the highest speed is ranked 18). Ranks scored by a drillsite were aggregated to give a composite score for each drillsite's status in terms of iceberg attributes included in the ranking procedure (column 7 Table 4.9) It is obvious from the composite scores in Table 4.9 that Gudrid H-55, Roberval K-92, Bjarni O-82, Hopedale E-33 and Skolp E-07 have overall more of an iceberg problem than the other drillsites.

When the drillsites are grouped by geographical area and composite scores averaged (Figure 4.1) it becomes apparent that the Cartwright and Hopedale Saddle areas present the greatest iceberg problem, while the Bank areas are relatively similar in terms of iceberg problems. Saglek, the most northerly of the Bank areas, has the highest average composite score for Bank areas, whereas Hamilton Bank, the most southerly area, has the lowest average composite score.

An examination of bargraphs presented in Figures 4.2 to 4.8 for each drillsite by geographical area indicates that a possible relationship between iceberg speed and mass rank exists. For example, in Figure 4.2 the low speed rank for Leif 38 is associated with a high mass rank, while a high speed rank for Indian (M-52) has a correspondingly low mass rank. This indicates a possible inverse relationship between median iceberg mass and speed, where on average larger icebergs drift more slowly than smaller icebergs.

Table 4.8 Iceberg parameters: discrete and interval data

Drillsite	Location Rank	No. Obs.	No. Deflected	No. Hazardous	Speed (m/sec)	Mass (10^6 tonnes)
Leif E-38	1	12	1	9	0.18	2
Leif E-48	2	34	2	23	0.172	0.975
Indian M-52	3	12	0	8	0.361	0.7
Indian M-52 RE	4	10	7	8	0.257	1.04
Roberval K-92	5	161	55	138	0.208	1
Gudrid H-55	6	225	20	199	0.186	2
Tyrk P-100	7	138	19	118	0.163	1
Bjarni H-81	8	6	1	4	0.154	10
Bjarni H-81 RE	9	6	0	4	0.336	0.5
Bjarni O-82	10	114	32	97	0.195	1.15
Herjolf M-92	11	29	7	22	0.311	1
Hopedale E-33	12	73	5	65	0.258	1.6
Snorri J-90	13	61	21	44	0.196	0.3
Snorri J-90 RE	14	13	4	11	0.222	0.163
Skolp E-07	15	71	24	51	0.161	2.2
Karlsefini A-13	16	25	6	24	0.19	0.17
Karlsefini A-13 RE	17	32	17	24	0.19	12
Gilbert F-53	18	24	7	20	0.321	2
Combined Data Sets		1,046	228	869	0.197	1.5

Table 4.9 Iceberg rank data: ascending order

Drillsite	Location Rank	No. Obs.	No. Deflect	No. Hazard	Speed (m/sec)	Mass (10^6 tonnes)	Composite Rank
Leif E-38	1	4.5	3.5	5	5	14	32
Leif E-48	2	11	5.5	9	4	7	36.5
Indian M-52	3	4.5	1.5	3.5	18	6	33.5
Indian M-52 RE	4	3	10	3.5	12	1	29.5
Roberval K-92	5	17	18	17	10	8	70
Gudrid H-55	6	18	14	18	6	14	70
Tyrk P-100	7	16	13	16	2	9	56
Bjarni H-81	8	1.5	1.5	1.5	17	5	26.5
Bjarni H-81 RE	9	1.5	3.5	1.5	1	17	24.5
Bjarni O-82	10	15	17	15	8	11	66
Herjolf M-92	11	9	5.5	8	15	10	47.5
Hopedale E-33	12	14	8	14	13	12	61
Snorri J-90	13	12	15	12	9	4	52
Snorri J-90 RE	14	6	7	6	11	2	32
Skolp E-07	15	13	16	13	3	16	61
Karlsefini A-13	16	8	9	10.5	14	3	44.5
Karlsefini A-13 RE	17	10	12	10.5	7	18	57.5
Gilbert F-53	18	7	11	7	16	14	55

Figure 4.1

AVERAGE COMPOSITE RANK SCORES BY GEOGRAPHICAL AREA

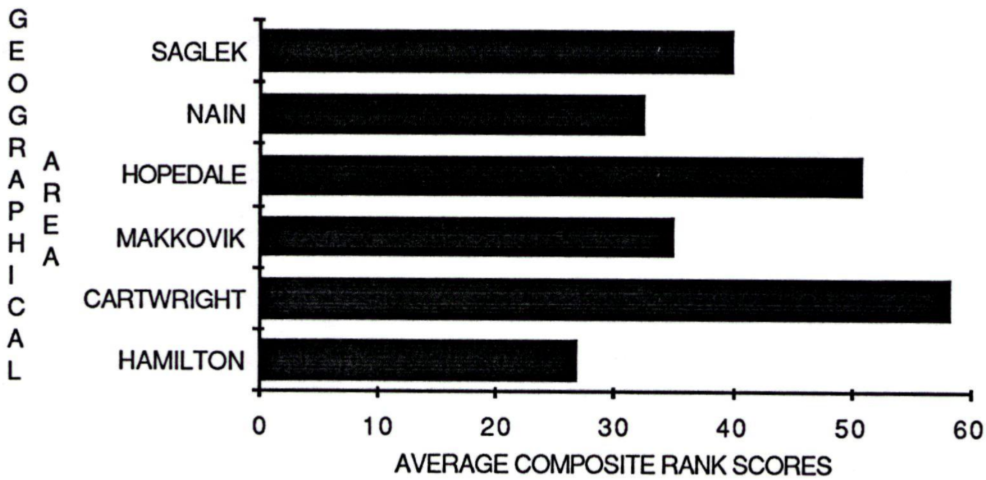


Figure 4.2

RANK SCORES FOR DRILLSITES LOCATED ON HAMILTON BANK

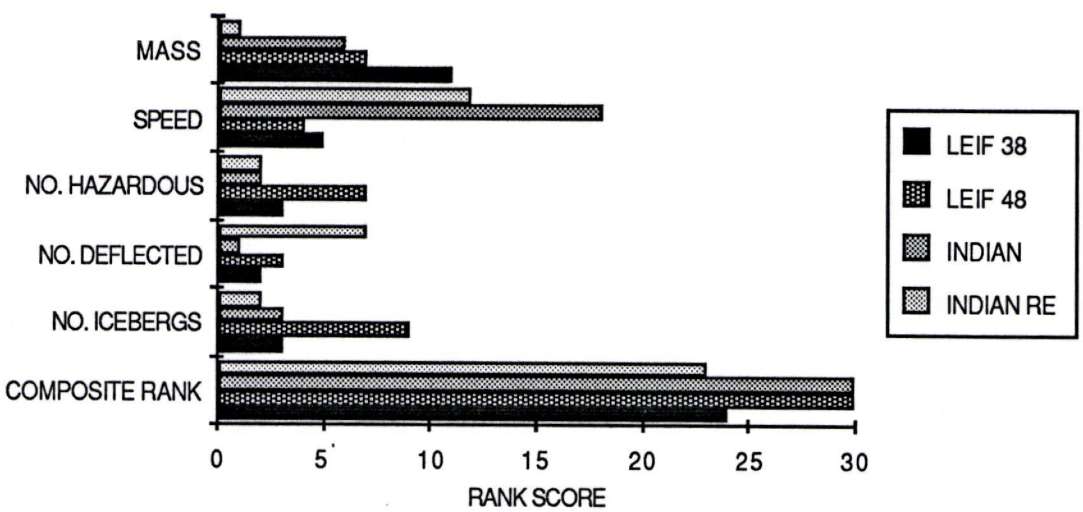


Figure 4.3

RANK SCORES FOR DRILLSITES LOCATED ON CARTWRIGHT SADDLI

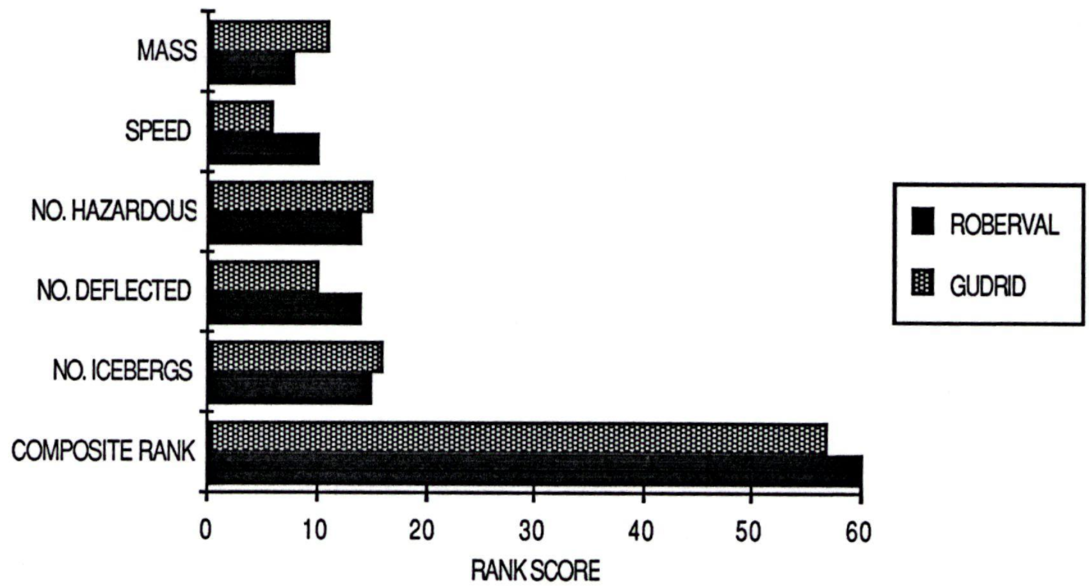


Figure 4.4

RANK SCORES FOR DRILLSITES LOCATED ON MAKKOVIK BANK

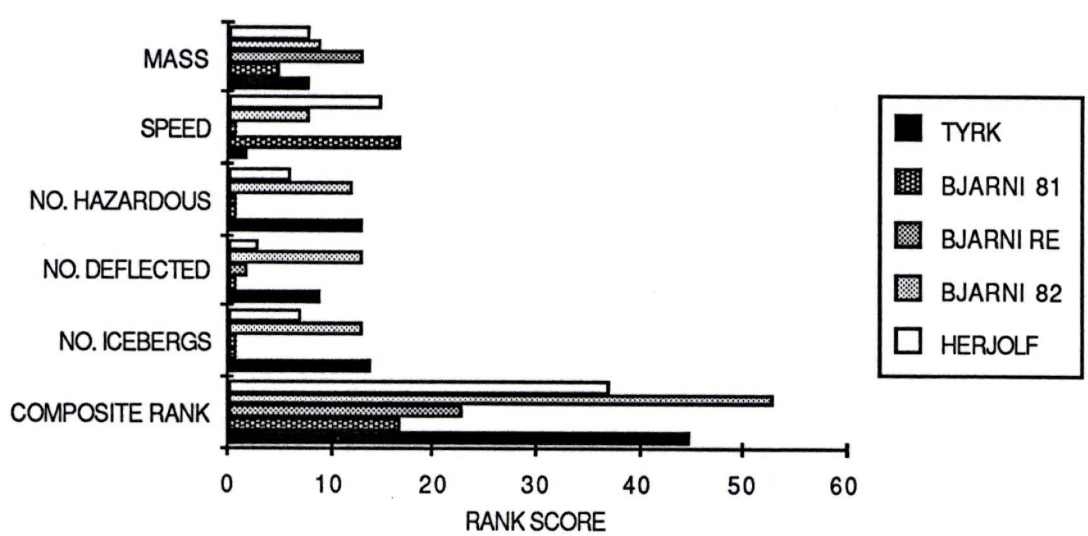


Figure 4.5

RANK SCORES FOR DRILLSITE HOPEDALE LOCATED ON HOPEDALE SADDLE

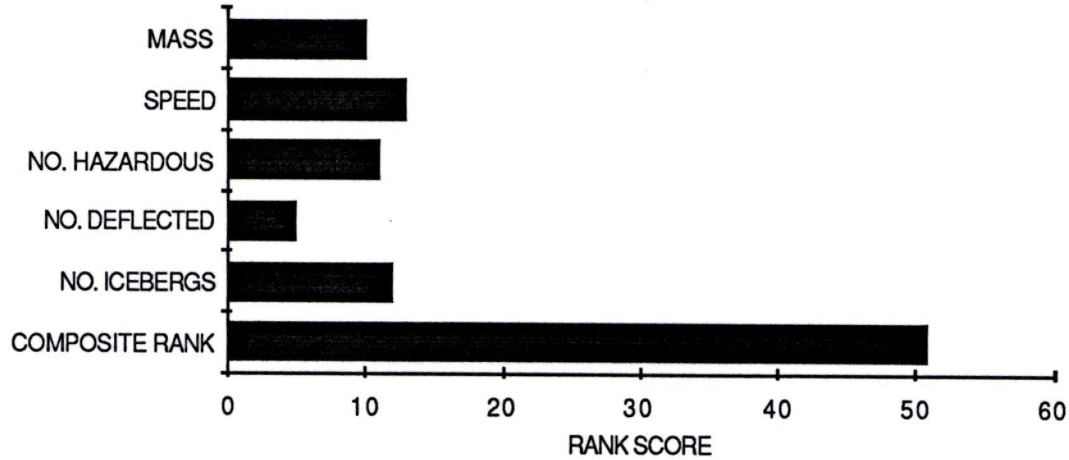


Figure 4.6

RANK SCORES FOR DRILLSITES LOCATED ON NAIN BANK

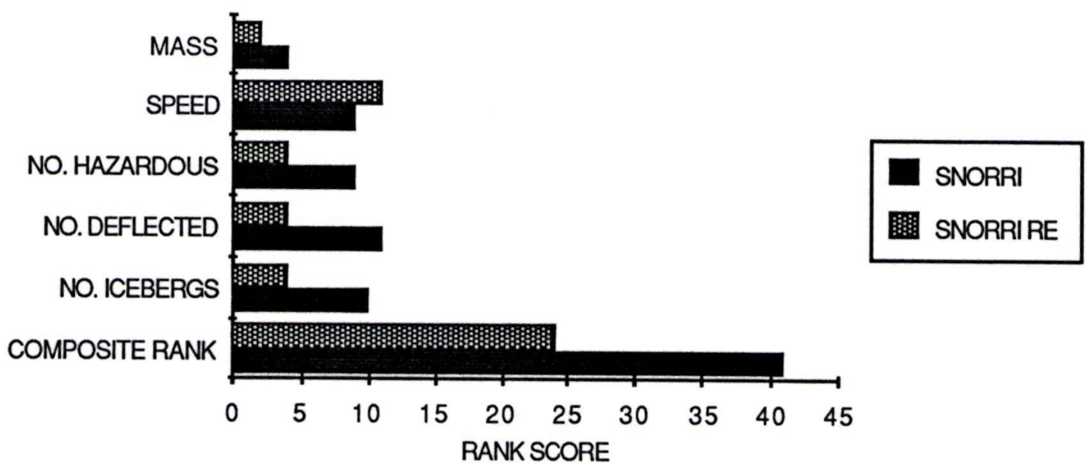


Figure 4.7

RANK SCORES FOR DRILLSITES LOCATED ON SAGLEK BANK

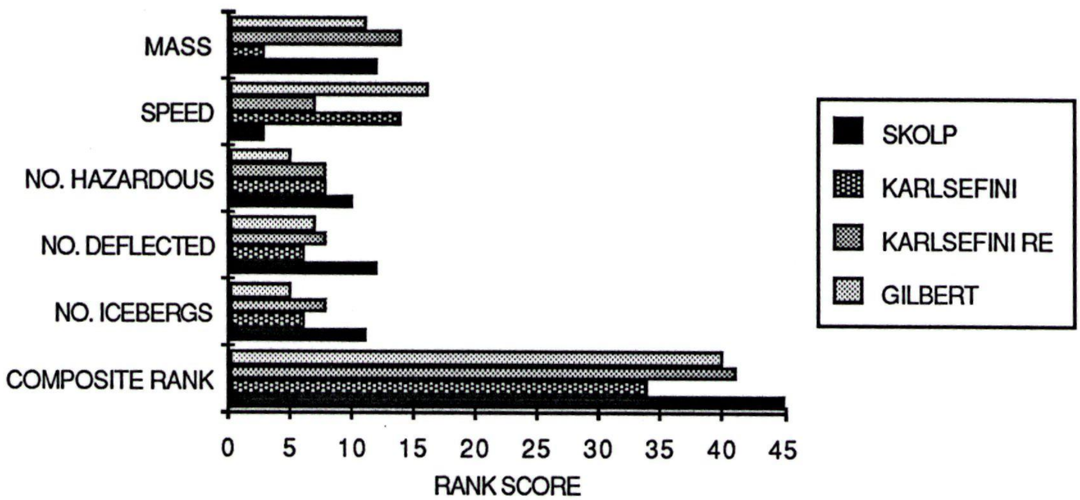
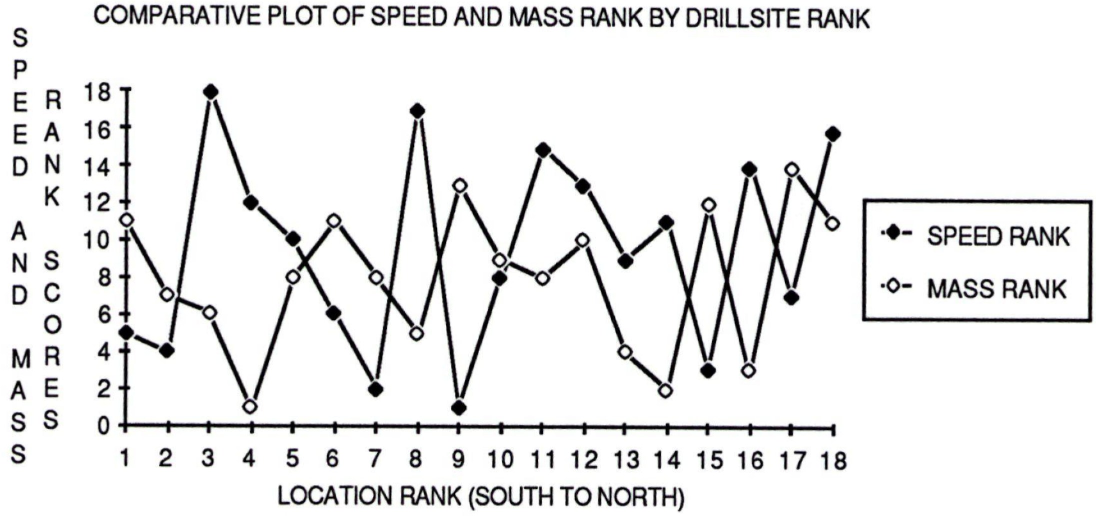


Figure 4.8 is a plot of iceberg speed and mass ranks by drillsite and it is apparent that high speed ranks are generally associated with low mass ranks and vice versa.

Figure 4.8

COMPARATIVE PLOT OF SPEED AND MASS RANK BY DRILLSITE RANK

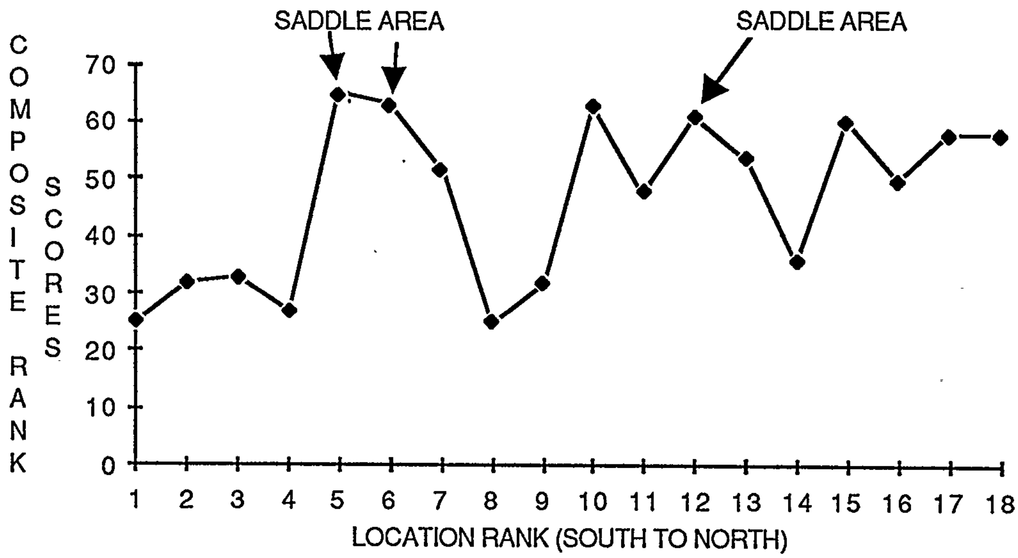


A computed Spearman's rho of -0.50 (significant @ 0.01) for mass and speed verifies that there is a negative relationship between these two iceberg variables, whereby larger icebergs will generally drift at slower speeds than smaller icebergs. This finding is also supported by the literature and descriptive statistics presented in the preceding section.

A comparative plot of composite rank scores (y-axis) and drillsite location rank (x-axis) (Table 4.9 and Figure 4.9) reveals an interesting trend, where composite rank scores increase from south to north.

Figure 4.9

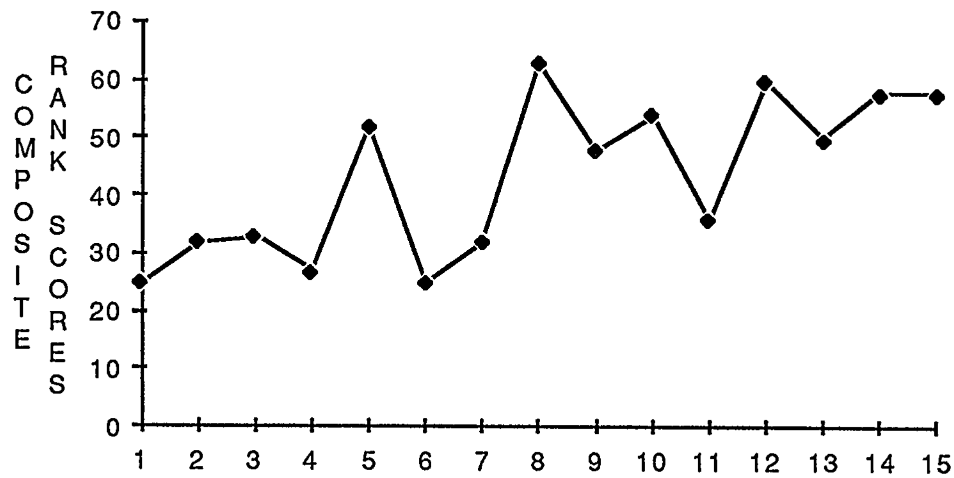
COMPARATIVE PLOT OF COMPOSITE RANK SCORES AND DRILLSITE LOCATION RANK



A Spearman's rho of 0.509 (significant @ 0.01) for composite scores and location rank signifies an increase in composite rank scores from south to north (i.e. south ranked lowest and north ranked highest). Therefore, drillsites located in the northern part of the Labrador Shelf would potentially have more of an iceberg problem than those drillsites located further south. An exception to this trend are those drillsites located in the Cartwright and Hopedale Saddle areas which tend to have more of an iceberg problem than a majority of the drillsites located in the Bank areas. Figure 4.10 is a plot of composite scores with the two Saddle areas removed. The increase in iceberg problems from south to north is quite evident.

Figure 4.10

COMPARATIVE PLOT OF COMPOSITE RANK SCORES AND DRILLSITE LOCATION RANK (WITHOUT SADDLE AREAS)



The recalculated value of 0.73 (significant @ 0.005) for Spearman's rho suggests that the Saddle areas are special problem areas and tend to distort trends in the iceberg data associated with Bank areas. A change in Spearman's rho from 0.509 to 0.73 (with only a minor decrease in N from 18 to 15) also supports the concept that the Saddle areas tend to distort south to north trends with regards to iceberg problems at drillsites located on the Banks. The concept that drilling operations are more hazardous on the northern areas of the Labrador Shelf is also supported by Gustajtis (1979c), where the probability of iceberg impact with an offshore structure increases from south to north.

4.7 Non-parametric Variance Test

When iceberg drift direction, mass and speed data are grouped by geographical area, month and size class, the grouped data can be defined as independent samples. For example, iceberg speed data grouped by month (i.e. July, August, September and October) are defined as four independent samples. Both the descriptive statistics and rank score data indicate variations in iceberg drift direction, mass and speed: (i) during the drilling season (i.e. July, August, September, October); (ii) between the six geographical areas, and (iii) between iceberg size classes. Therefore, one must determine whether the differences among the various samples are actually population differences or whether they are chance variations which might be expected among random samples from the same population.

The Kruskal-Wallis one-way analysis of variance will be used to determine whether the independent samples are from the same population. There are several reasons for selecting the Kruskal-Wallis test: (i) the moderate to high skewness of the data sets, and (ii) the lack of assumptions regarding the normality and homogeneity of variance associated with parametric tests. The Kruskal-Wallis technique tests the null hypothesis that k samples came from the same population with respect to averages (Kruskal and Wallis, 1952).

The computation of the Kruskal-Wallis test involves the substitution of individual observations with ranks, where k samples are aggregated and ranked in a single series. Therefore, the lowest value in the aggregated samples is ranked 1 and the largest value is ranked N (N is the total number of independent observations in k samples). The Kruskal-Wallis test is computed using the formula:

$$H = [12/N(N+1)] \sum_{j=1}^{k} R_j^2/n_j - 3(N+1) \qquad (4.1)$$

where, k = number of samples

n_j = number of cases in j^{th} sample

N = n_j, the number of cases in all samples combined

R_j = sum of ranks in j^{th} sample (column)

$\sum_{j=1}^{k}$ = directs one to sum over the k samples (columns).

Furthermore, H approximates a chi square disrtribution with df=k-1 for large sample sizes. This is true when k=3 and $n_j > 5$ (Kruskal-Wallis, 1952). When ties occur between two or more rank scores, each observation is given the average of the rank for which it is tied. H is affected by ties, and has to be corrected for ties (i.e. H usually increases when corrected for ties). Correction for ties is achieved by dividing formula 4.1 by:

$$1- \Sigma T/N^3-N$$

where $T= t^3-t$ (t is the number of tied observations in a tied group of scores)

N = number of observations in all k samples ($N= \Sigma n_j$)

ΣT = directs one to sum over all groups of ties.

Correcting H for ties increases its value and makes the result more significant. According to Kruskal and Wallis (1952) the effect of the correction is negligible if no more than 25 percent of the observations have tied ranks. In this particular study all Kruskal-Wallis test results are corrected for ties.

4.8 Kruskal-Wallis Test Results

The results of the Kruskal-Wallis test are presented in Tables 4.10 to 4.25, and the results were computed by the SPSS, subprogram NPAR.

Table 4.10 Kruskal - Wallis test results: speed by iceberg size class.

	Small	Medium	Large	Extra-Large
n_j	140	319	396	301
Average Rank	702.93	600.57	601.98	439.99

Chi square corrected for ties = 74.955 significant @ .001

Table 4.11 Kruskal - Wallis test results: drift direction by iceberg size class.

	Small	Medium	Large	Extra-Large
n_j	140	319	396	301
Average Rank	622.94	600.87	542.73	581.18

Chi square corrected for ties = 8.479 significant @ .05

Table 4.12 Kruskal - Wallis test Results: speed by month.

	July	August	September	October
n_j	256	662	193	42
Average Rank	494.50	564.89	704.61	684.35

Chi square corrected for ties = 49.300 significant @ .001

Table 4.13 Kruskal - Wallis test results: drift direction by month.

	July	August	September	October
n_j	258	665	197	46
Average Rank	593.37	575.89	554.97	760.33

Chi square corrected for ties = 14.659 significant @ .01

Table 4.14 Kruskal - Wallis test results: iceberg mass by month.

	July	August	September	October
n_j	258	659	196	46
Average Rank	584.06	588.59	498.30	782.30

Chi square corrected for ties = 28.953 significant @ .001

Table 4.15 Kruskal - Wallis test results: iceberg deflection by month

	July	August	September	October
n_j	258	665	197	46
Average Rank	614.67	556.90	616.91	650.04

Chi square corrected for ties = 13.474 significant @ .01

Table 4.16 Kruskal - Wallis test results: iceberg shape by month.

	July	August	September	October
n_j	258	665	197	46
Average Rank	596.04	601.88	522.77	507.52

Chi square corrected for ties = 23.497 significant @ .001

Table 4.17 Kruskal - Wallis test results: iceberg speed by geographical area.

	Hamilton	Cartwright	Makkovik	Hopedale	Nain	Saglek
n_j	57	490	282	83	58	184
Average Rank	580.59	588.22	540.85	747.23	607.51	518.13

Chi square corrected for ties = 31.759 significant @ .001

Table 4.18 Kruskal - Wallis Test Results: iceberg drift direction by geographical area.

	Hamilton	Cartwright	Makkovik	Hopedale	Nain	Saglek
n_j	57	491	285	83	58	193
Average Rank	681.21	507.39	590.11	473.86	675.98	760.88

Chi square corrected for ties = 96.549 significant @ .001

Table 4.19 Kruskal - Wallis test results: iceberg mass by geographical area.

	Hamilton	Cartwright	Makkovik	Hopedale	Nain	Saglek
n_j	57	491	279	83	57	193
Average Rank	508.51	577.18	559.35	615.75	431.48	669.6

Chi square corrected for ties = 29.666 significant @ .001

Table 4.20 Kruskal - Wallis test results: iceberg deflection by geographical area.

	Hamilton	Cartwright	Makkovik	Hopedale	Nain	Saglek
n_j	57	491	285	83	58	193
Average Rank	446.79	549.20	679.09	395.48	796.08	594.40

Chi square corrected for ties = 113.556 significant @ .001

Table 4.21 Kruskal - Wallis test results: iceberg shape by geographical area.

	Hamilton	Cartwright	Makkovik	Hopedale	Nain	Saglek
n_j	57	491	285	83	58	193
Average Rank	492.84	554.38	629.69	709.02	520.30	554.65

Chi square corrected for ties = 50.951 significant @ .001

Table 4.22 Kruskal - Wallis test results: speed by deflection.

	Not-Towed	Towed
n_j	561	593
Average Rank	554.28	599.47

Chi square corrected for ties = 5.299 significant @ .05

Table 4.23 Kruskal - Wallis test results: drift direction by deflection.

	Not-Towed	Towed
n_j	564	601
Average Rank	564.30	602.49

Chi square corrected for ties = 3.740 significant @ .1

Table 4.24 Kruskal - Wallis Test Results: Speed by Shape.

	Non-Tabular	Tabular
n_j	926	228
Average Rank	590.80	523.49

Chi square corrected for ties = 7.462 significant @ .01

Table 4.25 Kruskal - Wallis test results: drift direction by shape.

	Non-Tabular	Tabular
n_j	939	228
Average Rank	583.12	587.64

Chi square corrected for ties = .033 not significant

Information presented in the tables are: n_j (number of cases per sample), average rank, N (total number of cases for all samples), chi square corrected for ties, and significance level for rejection of H_0 or conversely acceptance of H_1. Furthermore, "speed by iceberg size class" in the title of Table 4.10 indicates that the H_0 is "the average speed of icebergs does not vary by size class, and H_1 is "the average speed of icebergs does vary by size class". The results presented in Table 4.10 indicate that the H_0 can be rejected at the .001 level of significance or one may state with 99.9 percent confidence that H_1 is true. Tables 4.11 to 4.25 maintain the same format as Table 4.10. The results of the Kruskal-Wallis test presented in Tables 4.10 to 4.25 can be summarized as follows: (i) there is a significant difference in the average speed (99.9% confidence) and drift direction (95% confidence) of small, medium, large and extra-large icebergs (Tables 4.10 to 4.11); (ii) there is a significant difference (99.9% confidence for all iceberg parameters) in the average speed, drift direction, mass, deflection and shape of icebergs observed during the drilling season (i.e. July, August, September and October; Tables 4.12 to 4.16); (iii) there is a significant difference (99.9% confidence for all iceberg parameters) in the average speed, drift direction, mass, deflection and shape of icebergs observed at six geographical areas on the Labrador Shelf (Tables 4.17 to 4.21); (iv) the average speed of towed and non-towed icebergs are significantly different (95% confidence, Table 4.22); (v) the average speed of tabular and non-tabular icebergs are significantly different (99% confidence, Table 4.24).

The following inferences (from average rank scores) may be derived from the test results.

1. Small icebergs drift faster than medium, large or extra large icebergs, while extra large icebergs drift more slowly than small, medium or large.
2. Icebergs drift faster in September and October than in July and August.
3. Iceberg mass decreases from July to September, however October has the highest average rank for iceberg mass.
4. Iceberg deflection does not decrease from July to October.
5. Iceberg drift speeds on Saddle areas are faster (except for Nain Bank) than drift speeds on the Bank areas.
6. Icebergs are generally larger on the Saddle areas, however Saglek Bank has the highest average rank for iceberg mass.

4.9 Summary

The descriptive statistics, composite rank scores and Kruskal-Wallis one-way analysis of variance suggest that there are spatial and temporal variations in iceberg conditions along the Labrador Shelf. Furthermore, there is also statistical evidence that there are differences in the behaviour of the various sizes of icebergs.

The results of the Kruskal-Wallis test present several conclusions about icebergs observed (by marine radar on the bridges of drillships) on the Labrador Shelf. First, iceberg speed is dependent upon iceberg size. Second, there is a spatial and temporal variation in observed iceberg variables (i.e. speed, drift direction, mass etc.).

The differences in iceberg mass and speed are documented in studies by Lever et al (1984), Smith and Banke (1982), Hsuing and Aboul-Azm (1982), and Sodhi and El-Tahan (1980) where the authors demonstrated that the behaviour of small and medium size icebergs was more dependent on surface conditions and that there was a tendency from them to drift at faster speeds than larger icebergs. Robe (1982) suggested that larger icebergs were in contact with the seabed more than 60 percent of the time. This contact with seabed material usually resulted in a braking action resulting in more slowly drifting icebergs. The preceding authors also suggest that the drift speed and trajectory of larger icebergs (with their greater draft) were influenced more by deep sea currents than by surface conditions. However, extreme surface conditions have been shown to influence the movement of the larger icebergs as well.

The temporal differences in the iceberg variables may be due to changes in the frequency of storms and surface currents from July to October. For example, NORDCO's study of surface currents on the Labrador Shelf indicates that surface currents increase in velocity from July to October. Gustajtis's (1979) report on weather conditions on the Labrdaor Shelf indicated that: (i) weather prevented drilling operations 6.8 percent of the time, and (ii) the frequency of calm periods decreases from July to October.

The spatial differences in the iceberg variables are supported by studies completed by Anderson (1971), Gustajtis (1979), and NORDCO (1977) where these authors demonstrated that: (i) surface currents are faster in the northern areas of the Shelf than on the southern areas, (ii) more icebergs are observed in the northern areas than in the southern areas and (iii) the probability of collision between an offshore rig and an iceberg is greater in the northern areas than in the southern areas.

These temporal and spatial variations in the iceberg data suggest that location and month of operation may be important considerations when planning offshore operations on the Labrador Shelf.

CHAPTER 5

DISCRIMINANT ANALYSIS OF ICEBERG DATA GROUPED BY GEOGRAPHICAL AREA, MONTH OF OPERATION AND ICEBERG SIZE CLASS

5.0 Introduction

Both descriptive statistics and Kruskal-Wallis one way analysis of variance indicated that there are significant spatial and temporal variations in iceberg deflection, drift direction, mass, shape and speed. There was also statistical evidence that these variations exist between iceberg size classes. However, the Kruskal-Wallis test could not rank the variables in order of the importance of their contribution to the spatial, temporal and size class differences. Therefore, a more sophisticated multivariate statistical methodogly is required to identify those iceberg variables which contribute to the differences among: (i) geographical areas, (ii) months of operation, and (iii) iceberg size classes. Discriminant analysis is a statistical technique which not only predicts group membership, but will also identify important predictor variables for discriminating group memberships. Tabachnick and Fidell (1983) state that "the primary function of discriminant analysis is to predict group membership on the basis of a variety of predictor variables or to determine the best combination of predictor variables to maximize differences among groups".

5.1 Discriminant Analysis

According to Klecka (1975) discriminant analysis can differentiate between geographical areas, months of operation or iceberg size classes by forming one or more linear combinations of the discriminating variables (i.e. iceberg drift direction, mass, speed, among others). These linear combinations of the discriminating variables are referred to as "discriminant functions" and are expressed by the formula:

$$D_i = d_{i1} Z_1 + d_{i2} Z_2 + \ldots\ldots\ d_{ip} Z_p$$

where D_i = the score on the discriminant function i

d = weighting coefficient

p = number of discriminating variables used in analysis

Z = standardized values of p discriminating variables.

The number of discriminating functions that may be computed is usually one less than the maximum number of groups or equal to the number of discriminating variables. The functions are derived so as to maximize the separation of the groups (Klecka, 1975).

After the discriminant functions are computed a researcher can evaluate the analysis and classification components of the discriminant procedure. The analysis component provides statistical tests for intrepretation of the data. This includes tests for measuring the ability of the predictor variables to discriminate when aggregated into a discriminant function. Once the interpretation phase is completed a set of classification functions can be compared which will facilitate the classification of new cases with previously unknown memberships. Quality control can be enforced on the discriminant function by classifying the original set of data to determine how many observations are correctly grouped by the predictor variables. The classification procedure is based on a separate linear combination of the discriminating variables for each group. This produces a probability of membership in a particular group, and the observation is assigned to the group with the highest probability.

The iceberg data set may also present a situation where there are more predictor variables than necessary to achieve adequate discrimination between geographical areas, months of operation and other groups. This problem can be eliminated by using a stepwise procedure in the discriminant analysis. The stepwise procedure used in this particular study selects the single best discriminating variable which has the highest F ratio and smallest Wilks's lamdba (Klecka, 1975). A second discriminating variable is selected as the variable which most improves the value of the discriminating criterion in association with the first variable. The third and subsequent variables are also selected on their ability to improve the discrimination. At the beginning of each step variables previously selected are evaluated to determine if they still have sufficient discriminating power. If any of the variables are now considered to be insufficient they are removed, although a variable can be re-entered at another step if it meets the selection criterion at that time (Klecka, 1975). Finally, at a point where all the variables have been chosen, or where the remaining variables do not contribute to improve discrimination, the stepwise procedure stops and additional analysis is performed exclusively using the selected variables.

5.2 Discriminant Analysis Results: Geographical Areas

Using the "DISCRIMINANT" subroutine in SPSS stepwise discriminant analysis was performed on iceberg data associated with six geographical areas (Hamilton Bank, Cartwright Saddle, Makkovik Bank,Hopedale Saddle, Nain Bank and Saglek Bank). The geographical areas were coded 1 to 6, where 1 represented the most southerly geographical area (Hamilton Bank) and 6 represented the most northerly area (Saglek Bank). The initial predictor variables used in the analysis were iceberg deflection, drift direction, mass, months of operation, shape and speed.

Prior to performing discriminant analysis on the iceberg data a $\log_{10}$ transformation was performed on the data associated with iceberg drift direction, mass and speed because preliminary data analysis in Chapter 4 indicated that these three predictor variables came from positively skewed distributions. The skewness was removed from the three predictor variables because discriminant analysis is a parametric technique which assumes data is normally distributed. A $\log_{10}$ transformation will tend to normalize positively skewed data sets (Gardiner and Gardiner, nd).

The coding scheme for the predictor variable, month of operation, was coded such that the variable was non-linear with respect to the remaining variables. Given that month of operation had been originally coded into four levels: July (7), August (8), September (9) and October (10) there was no reason to expect a linear relationship with the other predictor variables on the basis of coding (Tabachnick and Fidell, 1983). Therefore, the variable was recoded into three dummy variables: July, August, and September (i.e k-1 dummy variables where k is the original number of levels (4) coded)[1].

The results of the SPSS subprogram DISCRIMINANT are presented in Tables 5.1a to 5.1d. A stepwise discriminant analysis was performed using the six iceberg variables as predictors of membership in six geographical areas. A summary of results (Table 5.1a) indicates that seven predictors were entered in the analysis. Iceberg mass was excluded from the analysis suggesting that spatially there is very little variation in iceberg mass. Gustajtis' (1979c) analysis of IIP iceberg data also indicated that there was little variation in iceberg mass from north to south on the Labrador Shelf, although there are generally more large icebergs observed in the northern areas of the Shelf than in the southern areas.

Table 5.1a. Summary of results: geographical areas

Step	Entered	Variables In	Wilks Lambda	Significance
1	Deflection	1	0.90	0.001
2	July	2	0.85	0.001
3	Speed	3	0.81	0.001
4	Shape	4	0.77	0.001
5	August	5	0.74	0.001
6	September	6	0.71	0.001
7	Drift Direction	7	0.68	0.001

Deflection, July[2] and speed were entered in the first, second and third steps respectively, while shape, August, September and drift direction were entered fourth, fifth, sixth and seventh respectively.

According to the results in Table 5.1b three discriminating functions were derived for the geographical area data. The first discriminating function has significant discriminating power, indicated by X^2 (35)=411.7 , and p=0.001 (where p is the probability that this value of X^2 would have been observed if there were no differences between the six geographical areas).

[1] See Chapter 21 in SPSS Manual, 2nd Edition, 1975 for a discussion on the use of dummy variables in linear models.

[2] July, August and September are the recoded dummy variables for month of operation variable.

Table 5.1b Canonical discriminant functions: geographical areas

Fn	Eig	%Var.	C.C.	After Fn	Wilk's	X^2	DF	Sig
1	0.22	52.64	0.42	1	0.68	411.7	35	0.001
2	0.10	24.63	0.30	2	0.83	211.9	24	0.001
3	0.06	17.49	0.26	3	0.91	104.7	15	0.001

Fn=function Eig=eigenvalue C.C.=canonical correlation Sig=significance

The other two functions are statistically significant and represent an additional dimension in separating the geographical areas. The amount of predictable (between group) variability contributed by each discriminant function is evident in the relative size of the eigenvalues associated with discriminant functions 1,2 and 3. This is signified by the relative proportion of between group variability contributed by each function. For the geographical area data (Table 5.1b) 52.64 percent of the between group variability is attributed to the first linear combination of variables, 24.63 percent to the second linear combination and 17.49 percent to the third combination. The canonical correlation coefficient for function 1 is 0.42, while functions 2 and 3 have coefficients of 0.30 and 0.26 respectively.

The standardized canonical discriminant function coefficients presented in Table 5.1c signify that July, August, September, deflection, and speed with coefficients of 1.41, 1.47, 0.86, -0.56 and -0.51 are the five most important predictor variables for function 1. Iceberg drift direction with a coefficent of 0.33 also contributes moderately to function1. The coefficients computed for July (1.41) and August (1.147) suggest that there are a greater number of icebergs observed in the northern areas than in the southern areas of the Labrador Shelf during those months of operation. This result is supported by Anderson's (1971) computed monthly average flux for 59° N (the most northerly extent of the geographical areas) and 54° N (the most southerly extent). The computed monthly average flux for July and August for 59° N is 219 icebergs, while at 54° N it is 164. However, the decrease in the coefficient for September (0.86) indicates that <u>the difference</u> between the number of icebergs observed in the northern and southern areas has decreased. Again Anderson's (1971) flux data supports this trend where the expected monthly flux for September at 59° N is 53 icebergs and at 54° N the expected flux is 49 icebergs. A coefficient of -0.51 for iceberg speed indicates that icebergs tend to drift at slower speeds in the northern areas. The strong negative coefficient of -0.56 associated with iceberg deflection signifies that as you move further north (given the highest numeric code) along the Labrador Shelf the number of icebergs required to be towed away from the wellsite decreases.

Table 5.1c Standardized canonical discriminant function coefficients: geographical areas

	Function1	Function 2	Function 3
Speed	-0.51	0.12	-0.07
Drift Direction	0.33	0.07	0.45
Shape	0.04	-0.59	0.36
Deflect	-0.64	0.26	0.73
July	1.41	1.04	0.69
August	1.47	0.36	1.09
September	0.86	0.42	0.73

Iceberg shape (with a coefficient of 0.04) contributes very little to function 1, which accounts for almost 53 percent of the between group variability. However, the important variables in function 2 are July and shape with coefficients of 1.04 and -0.59 respectively, whereas in function 3 August (1.09), September (0.73), July (0.69) and deflection (0.73) are the dominant predictor variables.

The stability of the classification procedure was checked by cross-validation (Table 5.1d), and there was a 32.2 percent correct classification rate. This signifies a low degree of consistency in the classification scheme. For example, Saglek Bank had only 25.4 percent correctly classified, while 26.4 percent of the data was classified as being similar to Nain Bank, and 22.8 per cent similar to Hamilton Bank. Geographical areas which had more than a 50 percent correctly classified result were Hamilton (63.2), Hopedale (51.8) and Nain (67.2).

The inconsistency in the classification procedure may be the result of similar iceberg conditions in the four Bank areas. To determine if these suggested similarities in the Bank areas caused the inconsistency in the classification procedure the geographical area data were grouped into Bank and Saddle locations. Iceberg data associated with Hamilton, Makkovik, Nain and Saglek Banks were aggregated into the group "Bank" (coded 2), whereas Cartwright and Hopedale Saddle data were aggregated into the group "Saddle" (coded 1).

Table 5.1d Classification results: geographical areas

Actual Group	No. of Cases	(1) Hamilton	(2) Cartwright	(3) Makkovik	(4) Hopedale	(5) Nain	(6) Saglek
(1)	57	36 63.2%	2 3.5%	7 12.3%	3 5.3%	9 15.8%	0 0.0%
(2)	491	126 25.7%	144 29.3%	15 3.1%	58 11.8%	133 27.1%	15 3.1%
(3)	285	25 8.8%	50 17.5%	65 22.8%	24 8.4%	94 33.0%	27 9.5%
(4)	83	22 26.5%	3 3.6%	3 3.6%	43 51.8%	12 14.5%	0 0.0%
(5)	58	2 3.4%	8 13.8%	2 3.4%	4 6.9%	39 67.2%	3 5.2%
(6)	193	44 22.8%	22 11.4%	12 6.2%	17 7.8%	51 26.4%	49 25.4%

Percent of grouped cases correctly classified: 32.2%

The results of the stepwise discriminant anlysis performed on the Bank and Saddle area iceberg data (Tables 5.2a to 5.2d) produced better results than the analysis on the six geographical areas. All eight variables were entered (Table 5.2a) in the analysis.

Table 5.2a Summary of results: Bank and Saddle areas

Step	Entered	Variables In	Wilk's Lambda	Significance
1	Deflection	1	0.95	0.001
2	July	2	0.93	0.001
3	Speed	3	0.91	0.001
4	August	4	0.90	0.001
5	September	5	0.88	0.001
6	Shape	6	0.87	0.001
7	Mass	7	0.86	0.001
8	Drift Direction	8	0.86	0.001

One discriminant function was derived for the Bank and Saddle data and with $X^2(8)=142.1$ (Table 5.2b) the discriminant function has significant discriminating power at $p=0.001$. Furthermore, 100 percent of the between group variability is accounted for in the linear combination of variables, however the canonical correlation is low at 0.37. This is expected since the data is divided into two super groups which have greater internal variability, therefore the canonical correlation between the resulting discriminant function for each group will be lower.

Table 5.2b Canonical discriminant function: Bank and Saddle areas

Fn	Eig	%Var.	C.C	After Fn	Wilk's	X^2	DF	Sig
1	0.15	100	0.37	0	0.86	142.2	8	0.001

Fn=function Eig=eigenvalue C.C=canonical Correlation Sig=significance

The canonical discriminant coefficients (Table 5.2c) computed for July (2.04), August (1.92) and September (1.30) indicate that there are more icebergs observed on the Bank areas than on the Saddle areas. However, negative coefficients for speed (-0.50) and deflection (-0.68) indicate that: (i) icebergs tend to drift at faster speeds on the Saddle areas than on the Bank areas, and (ii) there is a tendency for more icebergs to be towed away from wellsites located on the Saddle areas than wellsites located on the Banks. This suggests there is potentially a greater iceberg management problem on the Saddle areas of the Labrador Shelf. Drift direction (0.19), mass (-0.21) and shape (0.30) contribute moderately to the function. However the negative coefficient for mass suggests that larger icebergs are generally observed on the Saddle areas, while a positive coefficient for iceberg shape indicates that non-tabular icebergs are the dominant iceberg shape on the Bank areas.

Table 5.2c Standardized canonical discriminant function coefficients: Bank and Saddle areas

	Function 1
Speed	-0.50
Mass	-0.21
Drift Direction	0.20
Shape	0.30
Deflection	-0.70
July	2.04
August	1.92
September	1.30

An evaluation of the classification procedure was performed by a cross-validation run (Table 5.2d). The computed correct classification rate was 65.81 percent, signifying a high degree of consistency, although with a two group classification problem one would expect some improvement in the results.

Table 5.2d Classsification results: Bank and Saddle

Actual Group	No. of Cases	Saddle	Bank
Saddle	574	378 65.9%	196 34.1%
Bank	400	137 34.3%	263 65.8%

Percent of the grouped cases correctly classified: 65.81%

The results of this classification procedure suggest that the iceberg data differences between Bank and Saddle areas along the Labrador Shelf would make it worth investigating the two types of areas separately.

5.3 Discriminant Analysis: Months of Operation

Preliminary analysis of the iceberg data in Chapter 4 demonstrated that there were significant monthly variations in the average and median values of iceberg attributes. To determine which variables are contributing significantly to the monthly variations a stepwise discriminant analysis was performed on the data. Months of operation (July, August, September and October) were defined as the groups for the analysis, while iceberg deflection, drift direction, mass, shape, speed and wellsite location were used as the six predictor variables.

According to the results in Table 5.3a all six predictor variables were entered in the analysis. Wellsite location, iceberg mass and shape were the first three variables entered, while speed, deflection and drift direction were, respectively, the final three variables entered.

Table 5.3a Summary results: month of operation

Step	Entered	Variable In	Wilk's	Significance
1	Wellsite	1	0.88	0.001
2	Mass	2	0.87	0.001
3	Shape	3	0.86	0.001
4	Speed	4	0.85	0.001
5	Deflection	5	0.84	0.001
6	Heading	6	0.83	0.001

Two discriminating functions were computed for the monthly iceberg data (Table 5.3b). Function 1, with $X^2(10)=52.7$ and $p=0.001$ has significant discriminating power. However, function 2 is somewhat less significant with $X^2(4)=16.4$ and $p=0.003$. For the monthly data 75.6 percent of the between group variance is attributed to the first function, while the second function accounts for 16.5 percent of the between group variance.

Table 5.3b Canonical discriminant functions: month of operation

Fn	Eig	% Var.	C.C.	After Fn	Wilk's	X^2	DF	Sig
1	0.14	75.6	0.35	1	0.95	52.7	10	0.001
2	0.03	16.9	0.18	2	0.98	16.4	4	0.003

Fn=function Eig=eigenvalue C.C.=canonical coefficient Sig=significance

The canonical correlations are somewhat low for both functions, 0.35 and 0.18 for functions 1 and 2, respectively.

A standardized canonical discriminant function coefficient (Table 5.3c) of 0.93 for wellsite location signifies that this variable is a dominant predictor when discriminating monthly iceberg data.

Table 5.3c Standardized canonical discriminant function coefficients: month of operation

	Function 1	Function 2
Speed	-0.30	0.32
Mass	-0.23	-0.76
Drift Direction	-0.12	-0.30
Shape	-0.33	0.22
Deflection	0.04	0.04
Wellsite	0.93	-0.02

Iceberg shape (-0.33) , speed (-0.30) and mass (-0.23) contribute moderately to function 1. The negative coefficients for mass and speed indicate a trend toward somewhat smaller and slower drifting icebergs. However, a negative coefficient of -0.76 for mass in function 2 indicates that iceberg mass decreases from July (coded 7) to October (coded 10) while a positive coefficient of 0.32 for speed indicates a general increase in iceberg drift speed during the same perioid. The scenario presented in Function 2 is more likely because studies by Nordco (1977) and Gustajtis (1979) show that surface currents reach their peak velocity in the fall. Furthermore, the frequency of calm periods decreases in the fall and the probability of getting wave heights greater than 3 m also increases during this period (see Chapter 2 for more information on surface currents and sea state). The combination of increased surface currents and wind generated waves would more likely produce faster drifting icebergs than slower drifting icebergs (Hsiung and Aboul-Azum, 1982). The results presented in Table 5.3c suggest that wellsite location, iceberg mass, shape,speed, and drift direction are the best discriminating variables for investigating monthly variations in iceberg hazards on the Labrador Shelf.

An evaluation of the classification procedure by cross-validation (Table 5.3d) produced a 36.11 percent correct classification rate[3]. This low degree of consistency is probably due to similar surface conditions that exist in July and August compared to September and October. An examination of the classification results partially supports this concept. For example, for July 50 percent of the cases were correctly grouped, while 26 percent of the cases were incorrectly grouped as August. Therefore, 76 percent of the cases were grouped in the two summer months. A similar disparity exists for the October data, where 65.2 percent of the cases were correclty classified and 15.2 percent were classified for September. Thus 80.4 percent of the October data was classified in the two autumn months. However, September appears to be an anomaly because 51.7 percent of the data is classified for autumn months while

[3]A similar classification rate was obtained for data grouped by year (1973 to 1980). See Appendix D for discriminant analysis results for data grouped by year.

48.2 percent is classified in the two summer months. The overall results suggest a crude summer and autumn division rather than a monthly grouping of the iceberg data.

Table 5.3d Classification results: month of operation

Actual Group	No. of Cases	July	August	September	October
July	258	129 50%	67 26%	37 14.3%	25 9.7%
August	665	249 37.4%	203 30.5%	113 17%	100 15%
September	197	55 27.9%	40 20.3%	59 29.9%	43 21.8%
October	46	3 6.5%	6 13%	7 15.2%	30 65.2%

Percent of the grouped cases correctly classified: 36.11%

To test the possible differences in iceberg attributes between summer and autumn a second, stepwise discriminant analysis was performed on data grouped as summer (July and August coded 1) and autumn (September and October coded 2). The predictor variables used in the first analysis (month of operation data) were also used in the second analysis. Five of the six predictor variables were entered in the stepwise discriminant analysis (Table 5.4a). Wellsite location, iceberg shape and speed were the first three variables entered, while drift direction and deflection were entered at the fourth and fifth steps respectively. Iceberg mass was not included in the analysis.

Table 5.4a Summary of results: summer and autumn

Step	Entered	Variables In	Wilk's	Significance
1	Wellsite	1	0.95	0.001
2	Shape	2	0.93	0.001
3	Speed	3	0.92	0.001
4	Drift	4	0.91	0.001
5	Deflection	5	0.91	0.001

Wellsite location, iceberg shape and speed were the first three variables entered, while drift direction and deflection were entered at fourth and fifth steps respectively. Iceberg mass was not included in the analysis.

A single discriminant function was derived for the iceberg data grouped by seasons (Table 5.4b). This function had a X^2=96.9 with a p=0.001, indicating that the function has siginificant discriminating power. However, the canonical correlation coefficient (0.30) is low.

Table 5.4b Canonical discriminant functions: summer and autumn

Fn	Eig	%Var.	C.C.	After Fn	Wilk's	X^2	DF	Sig
1	0.09	100	0.30	0	0.92	96.9	5	0.001

Fn=function Eig=eigenvalue C.C.=canonical correlation Sig=significance

An examination of the standardized canonical discriminant function coefficients (Table 5.4c) signifies that wellsite location (-0.83), iceberg shape (-0.45) and speed (-0.40) are the most important variables in the discriminant function. A high negative coefficient for wellsite location suggests that there is a decrease in the number of icebergs observed between July and October. This trend is supported by Anderson's (1971) computation of expected monthly average fluxes of icebergs for the study area where the number of icebergs expected decreases from 724 in July to 162 in October.

Table 5.4c Standardized discriminant function coefficients: summer and autumn

	Function 1
Speed	-0.40
Drift Direction	0.23
Shape	-0.45
Deflection	0.13
Wellsite	-0.83

Drift direction (-0.23) and deflection (0.13) contribute very little to the discriminating function. The exclusion of mass from the analysis suggests there is no significant seasonal variation in iceberg mass.

A check for consistency in the classification procedure (Table 5.4d) indicated that 69.75 percent of the summer and autumn data were correctly classified.

Table 5.4d Classification results: summer and autumn

Actual Group	No. of Cases	Summer	Autumn
Summer	923	682 73.9%	241 26.1%
Autumn	244	112 45.9%	132 54.1%

Percent of grouped cases correctly classified: 69.75%

The high degree of consistency associated with the summer data (73.9%) signifies that overall iceberg characteristics in July and August have little variability. However, the autumn months (54.1% correctly classified) tend to demonstrate more variable iceberg characteristics. A possible cause of the variability in the Autumn months may be the result of weather characteristics which can alternate frequently between calm and stormy periods. Furthermore, the discriminant analysis on data grouped by seasons indicates that monthly variations are not as critical as seasonal variations.

5.4 Discriminant Analysis: Iceberg Size Class

Studies by Lever et. al (1984) and Hsiung and Aboul-Azm (1982) recognized that the behaviour of icebergs of various sizes was at times significantly different. This was especially true during storm conditions when the speeds and drift directions of small and medium size icebergs were dominated by sea surface conditions and wind. To determine if differences in speed and drift direction can be detected in the various sizes of icebergs observed by marine radar a stepwise discriminant analysis was performed on iceberg data grouped by iceberg size class (small

- coded 1, medium - coded 2, large - coded 3 and extra large - coded 4). The predictor variables used in the analysis were: deflection, drift direction, wellsite location (latitude of wellsite), months of operation (July, August and September), shape and speed.

Iceberg shape, speed and deflection were entered in the first, second and third steps, respectively, and wellsite location, month of operation and drift direction were entered in the fourth, fifth and sixth steps, respectively (Table 5.5a). One discriminant function was derived for the iceberg size class data. The function is significant with X^2=344.4 and p=0.001 (Table 5.5b); 90.1 percent of between group variance is explained by the linear combination of variables.

Table 5.5a Summary results: iceberg size class

Step	Entered	Variables In	Wilk's	Significance
1	Shape	1	0.89	0.001
2	Speed	2	0.83	0.001
3	Deflection	3	0.79	0.001
4	Wellsite	4	0.76	0.001
5	September	5	0.75	0.001
6	August	6	0.74	0.001
7	July	7	0.74	0.001

Table 5.5b Canonical discriminant function: iceberg size class

Fn	Eig	%Var.	C.C.	After Fn	Wilk's	X^2	DF	Sig
1	0.30	90.1	0.48	1	0.97	344.4	10	0.001

Fn=function Eig=eigenvalue C.C.=canonical correlation Sig=significance

The standardized canonical discriminant function coefficients (Table 5.5c) indicate that iceberg shape (-0.70), speed (-0.56) , months of operation (July (0.53) and August (0.65)) and deflection (0.41) are the important predictor variables when discriminating iceberg size class data. Drift direction (0.10) contributes very little to the discriminating function while wellsite location (0.-26) contributes a moderate negative influence on the function. According to the results in Table 5.5c iceberg shape (for this study shape was coded as being tabular or non-tabular) is the most important predictor variable.

Table 5.5c Standardized canonical discriminant function coefficients: iceberg size class data

	Function 1
Speed	-0.56
July	0.53
August	0.65
September	0.44
Drift Direction	0.10
Shape	-0.70
Deflection	0.40
Wellsite	-0.26

The negative coefficient for shape (-0.70) indicates a trend where larger icebergs are predominantly tabular. However, the negative coefficient for speed (-0.57) signifies a decrease in drift speed as iceberg mass increases. This is an expected result since the preliminary data analysis in Chapter 4 indicated that drift speed generally decreased with increased iceberg mass. A positive coefficient of 0.41 for deflection suggests that as iceberg mass increases the frequency of towing also increases. This suggests that the larger icebergs were perceived to present more problems to drilling operations than smaller icebergs during the drilling season.

An evaluation of the classification procedure by cross-validation (Table 5.5d) produced a 39.7 percent correct classification rate. Extra large size icebergs (64.8 percent) had the best classification result. The medium iceberg data had 29.2 percent classified as small and 22.3 percent in the large group. Likewise, the large iceberg group had 27.8 percent correctly classified and 23.5 percent classified in the small group. However, a majority of the small iceberg data (66.4%) was classified in the small and medium iceberg group data. Furthermore, a majority of the medium iceberg data (60.2%) was grouped in the small and medium iceberg size classes. This suggests that there are significant similarities between the movement characteristics of small and medium size icebergs. Studies by Smith and Bank (1982), and Hsiung and Aboul-Azm (1982) support this interpretation because the results of those studies indicate that: (i) small and medium size icebergs react more quickly (in terms of drift speed and direction) to changes in sea surface conditions, and (ii) wind and wave action have a greater on influence the drift patterns and speed of small and medium icebergs than on the larger sizes (which tend to be influenced more by deep sea currents).

Table 5.5d Classification results: iceberg size classes

Actual Group	No. of Cases	Small	Medium	Large	Extra Large
Small	140	55 39.3%	38 27.1%	27 19.3%	20 14.3%
Medium	319	93 29.8%	99 31.0%	71 22.3%	56 17.6%
Large	396	93 23.5%	117 29.5%	110 27.8%	76 19.2%
Extra Large	301	40 14.3%	35 9.6%	31 13.3%	195 64.8%

Percent of the grouped cases correctly classified: 39.7%

Therefore, the behaviour of small and medium size icebergs as indicated by the classifications is similar. However, overall there is a low degree of consistency in the classification procedure. A possible reason for the low consistency is that during periods of relative calm seas all icebergs, regardless of size, tend to behave in a similar manner.

To determine if a more generalized grouping of the data would produce better results a second stepwise discriminant analysis was performed on iceberg data grouped as small (small and medium) and large (large and extra-large).

The results of the second discriminant analysis (Table 5.6a) indicate that iceberg shape, speed, deflection and months of operation (July, August and September) were entered in the analysis, whereas drift direction and wellsite were excluded from the discriminant analysis. The derived discriminant function (Table 5.6b) has significant discriminating power with X^2=90.3, p=0.001 and 100 percent of the between group variance attributed to the linear combination of shape, speed and deflection.

Table 5.6a Summary of results: small versus large icebergs

Step	Entered	Variables In	Wilk's Lambda	Significance
1	Shape	1	0.97	0.001
2	Speed	2	0.95	0.001
3	Deflection	3	0.94	0.001
4	July	4	0.93	0.001
5	September	5	0.93	0.001
6	August	6	0.92	0.001

Table 5.6b Canonical discriminant function: small versus large icebergs

Fn	Eig	%Var.	C.C	After Fn	Wilk's	X^2	DF	Sig
1	0.08	100	0.27	1	0.94	90.3	6	0.001

Fn=function Eig=eigenvalue C.C.=canonical correlation Sig=significance

The discriminant function coefficients for shape, speed and deflection (Table 5.6c) are similar to the results presented in Table 5.5c in terms of importance in the discriminant function. The negative coefficient for speed (-0.43) indicates that the drift speed of the large icebergs is slower than that of smaller icebergs. A negative coefficient for shape (-0.61) indicates that smaller icebergs tend to be non-tabular while the larger icebergs tend to be tabular in shape.

Table 5.6c Standardized canonical discriminant function coeifficients: small versus large icebergs

	Function 1
Speed	-0.50
July	0.38
August	0.77
September	0.68
Shape	-0.61
Deflection	0.50

The positive coefficient for deflection (0.50) signifies that there are more large icebergs deflected than small icebergs.

The check for consistency in the classification procedure (Table 5.6d) produced a 60.47 percent correct classification rate which is considerably better than the result of 38.41 percent obtained in the discriminant analysis on four iceberg size classes (although it should again be noted that when data is reduced from four groups down to two groups the classification results are generally better - see Table 5.5d). The small iceberg data has a 66.2 percent correct classification rate, however 35.1 percent of the data were grouped in the large category. Furthermore, the classification of the large iceberg data was even more variable with 56.7 percent of the data being correctly classified and 43.3 percent classified in the small iceberg group.

Table 5.6d Classification results: small versus large icebergs

Actual Group	No. of Cases	Small	Large
Small	459	304 66.2%	155 33.8%
Large	697	302 43.3%	395 56.7%

Percent of the grouped cases correctly classified: 60.9%

5.5 Summary and Conclusion

A common trend in the discriminant analyses was the greatly improved classification results when the number of groups were reduced from either six or four to two[4]. For example, when discriminant analysis was used to predict group membership in six geographical areas there was only a 32.2 percent correct classification rate. When the data was reorganized into two groups (Bank and Saddle areas) the classification rate was 65.8 percent. This improvement in the classification rate can be attributed to two possible factors; (i) resolution of the data set will not permit the classification of the data into six discrete geographical areas which really do exist as discrete entities, or (ii) iceberg characteristics of the Bank areas are similar and the discriminating procedure confirms the similarities between the four Bank areas.

The large improvement in the classification rate after reducing the number of groups is also true for month of operation and iceberg size class data. Using the four months of operation as groups produces only a 36.11 percent classification rate, whereas reducing the number of groups to two (summer and autumn) produces a 69.75 percent classification rate.

---

[4] In each case theoretical justification based on the observed physical geography was provided for the reduction in the number of groups.

For the iceberg size class data, a subdivision into small, medium, large, and extra large produced a correct classification rate of 39.7 percent, however, iceberg size data grouped as small and large had a correct classsification rate of 60.47 percent.

The classification rates produced obvious anomalies in the discriminant analysis, however the standardized discriminant function coefficients supported a majority of the findings from the preliminary data analysis presented in Chapter 4. For example, in Chapter 4 preliminary iceberg data analysis indicated that: (i) iceberg drift speeds were faster in the Saddle areas than in the Bank areas, (ii) larger icebergs drift more slowly than smaller icebergs, (iii) iceberg drift speeds were slower in the summer than in the autumn, and (iv) combined iceberg hazards generally increased as one moved from south to north on the Labrador Shelf.

According to the discriminant function coefficients for predictor variables associated with iceberg data grouped by six geographical areas iceberg speed (with a coefficient of -0.51) indicates that as one moves from the more southerly wellsites to the more northerly locations iceberg drift speed decreases. For example, the computed median iceberg speed for Hamilton Bank (the most southerly area) was 0.191 m/sec while the median speed for Saglek Bank (the most northerly area) was 0.183 m/sec. Futhermore, a coefficient of -0.56 for deflection siginifies that more icebergs are towed away from wellsites located in the southern areas of the Labrador Shelf.

The preliminary data analysis in Chapter 4 indicated that Saddle areas generally had more of an iceberg management problem than the Bank areas, and the discriminant function coefficients support this intrepretation. A coefficient of -0.68 for iceberg deflection signifies that more icebergs are towed on the Saddle areas than on the Bank areas. Furthermore, a coefficient of -0.46 indicates indicates that iceberg drift speeds are faster on the Saddle areas than on the Bank areas.

An anomaly in the discriminant function coefficients was found with data grouped by the four months of operation (July, August, September and October). When discriminant analysis was performed on data grouped by month of operation a coefficient of -0.30 for drift speed suggests a decrease in iceberg drift speed from July to October. Grouping of the data as summer and autumn produced the same results. The results of the data analysis in Chapter 4 indicated that iceberg drift speeds generally increased from summer to autumn.

Discriminant analysis on the iceberg size class data had results which supported the findings in Chapter 4. Stepwise discriminant analysis performed on iceberg data grouped by four size classes produced a discriminant function coefficient of -0.57 for iceberg drift speed. This coefficient signifies that the drift speeds of smaller icebergs are faster than the speeds of larger icebergs. This finding was also true when the data were grouped as small and large icebergs the computed coefficient of -0.50 for drift speed indicated that smaller icebergs drifted faster than larger icebergs.

The results of the discriminant analyses generally support the Kruskal-Wallis test results and identify which iceberg variables contribute significantly to the spatial and temporal variation in the data. According to the Kruskal-Wallis test iceberg data grouped by six geographical areas were significantly different in terms of iceberg deflection, drift direction, mass, shape, and speed. The discriminant analysis supports these findings but not to the same degree as the Kruskal-Wallis test. This is also true for month of operation and iceberg size class data.

CHAPTER SIX
SUMMARY AND CONCLUSION

6.0 Introduction

The primary objectives of this study were outlined in Chapter 1 as being: (i) determination of whether there are differences in the behaviour and management problems associated with small, medium and large icebergs; (ii) determination of seasonal variations in the behaviour, physical dimensions and management problems associated with icebergs observed on the Labrador Shelf; and (iii) determination of differences between iceberg behaviour, physical dimensions and management problems of icebergs observed at six geographical areas on the Labrador Shelf.

6.1 Review of Literature

Both empirical and theoretical studies on the physical dimensions, behaviour and environmental influences on icebergs were available.

Physical dimension studies tend to investigate the functional relationships between the linear dimensions of icebergs as well as ratios. Furthermore, these studies tend to use regression analysis and one-way analysis of variance to examine the functional relationships. For example, Hotzel and Millers' study indicated that a strong relationship existed between iceberg mass and length (correlation coefficient of 0.90) and also between iceberg draft and mass (correlation coefficient of 0.78).

Literature on iceberg behaviour was also reviewed. These studies focused on kinetic energy, drift velocity and trajectory prediction. Theoretical studies on small and medium size icebergs demonstrated that these icebergs are significantly influenced by heavy seas whereby they reach velocities far greater than their average drift speeds. One of the major conclusions of one particular study was that a small 4,300 tonne iceberg being driven by 14 m, 12 sec storm waves would produce one third of the kinetic energy of a 1 X 10^6 tonne iceberg drifting at 0.5 m/sec (Lever et al, 1984).

Empirical studies on iceberg motion indicate that smaller icebergs react more quickly to changes in wind and currents than larger icebergs. Other studies have indicated that in areas where ocean currents are weak iceberg movements were greatly influenced by surface conditions and low pressure weather systems moving through the area. Furthermore, studies have also demonstrated that wave action in storm conditions have the most siginificant impact on the drift speed and trajectories of small and medium size icebergs.

The literature presented in this study led to the following conclusions:

(i) differences in iceberg motion between geographical areas are the result of local weather and ocean currents;

(ii) iceberg motion data can be used as a surrogate measure of environmental and current differences between geographical areas on the Labrador Shelf;

(iii) the drift speed and trajectory of small and medium size icebergs are siginificantly influenced by wave and wind action;

and (iv) the potential for collision between large icebergs and sub-sea installations suggests that any spatial and temporal variation in iceberg mass observed on the Labrador Shelf will be an important consideration when planning drilling operations.

6.2 Summary of Procedures

The analyses of the iceberg data was completed in four steps: (i) the computation of descriptive statistics (average, standard deviation, median, skewness and range) for each wellsite, geographical area, month of operation and iceberg size class using the SPSS subprogram DESCRIPTIVE (SPSS Manual, 2nd Edition, 1975); (ii) the derivation of composite rank scores for each wellsite to compare iceberg conditions between the southern and northern locations on the Labrador Shelf; (iii) the use of the Kruskal-Wallis test to determine if the iceberg variables (deflection, drift direction, mass, shape and speed) grouped by geographical area, iceberg size class and month of operation were derived from the same population; and (iv) the use of discriminant analysis to determine which of the iceberg variables contributed significantly to the spatial, temporal and iceberg size class differences.

6.3 Discussion of Results

According to the results of the data analysis there is a spatial variaton in iceberg variables observed along the Labrador Shelf. This is especially true for the Bank and Saddle areas. The computed median iceberg drift speed for the Bank areas was 0.191 m/sec while the median drift speed for the Saddle areas was 0.229 m/sec.

The composite rank scores, however indicated a trend where iceberg problems for offshore drilling areas increases from south to north. An initial computation of 0.51 (significant @ 0.01) for Spearman's rho (for all wellsites) indicated that generally icebergs were: deflected more often and were faster and larger in the northern areas of the Labrador Shelf. A recomputation of Spearman's rho with the Saddle areas removed produced a coefficient of 0.73 which indicated that: (i) there is an obvious increase in iceberg management problems from south to north; (ii) the Saddle areas tend to distort (i.e. reduce) the potential differences between the southern and northern Bank areas; and (iii) the differences between the Bank and Saddle areas are such that in future these areas should be investigated separately.

The finding that southern and northern areas are different with respect to iceberg management problems is also supported by a study completed by Gustajtis (1979c) who suggested that generally the probability of impact between iceberg and offshore drill rigs was higher in the northern areas of the Labrador Shelf (i.e. Nain and Saglek Banks). Furthermore, the author also indicated that there were more, larger icebergs observed in the northern areas than in the southern areas of the Shelf.

The Kruskal-Wallis one-way analysis of variance also indicated that there was significant spatial variation in the iceberg variables. Furthermore, the discriminant analysis of the data grouped by six geographical areas indicated spatial differences in the data but the trends indicated by the descriptive statistics and composite rank scores were not entirely supported by the subsequent discriminant analysis. For example in function 1 iceberg speed and deflection had standardized canonical correlation coefficients of -0.51 and -0.64 respectively indicating a decrease in iceberg speed and the number of icebergs deflected from south to north. When the stability of the classification procedure was checked by cross-validation there was only a 32.2 percent correct classification rate. A further examination of the classification results revealed that the Bank areas exhibited considerable intra-group consistency.

To determine if the similarities in the Bank areas influenced the results a stepwise discriminant analysis was performed on the data grouped as Bank and Saddle areas. The results of the analysis indicated that: (i) icebergs tend to drift faster in the Saddle areas; (ii) icebergs observed in the Saddle areas are generally larger than those observed in the Bank areas; (iii) icebergs were deflected more often in the Saddle areas; and (iv) the number of grouped cases correctly classified were 65.8 percent. The results of the analysis indicated that there was a greater difference between the Saddle and Bank areas than between the various Bank locations on the Labrador Shelf.

The descriptive statistics indicated that there were variations in iceberg speed for July (median speed 0.173) and October (median speed 0.282 m/sec). In addition, the Kruskal-Wallis test (significant @ 0.001) also indicated a significant variation in iceberg speed, mass, deflection and shape from July to October. However, when the discriminant analysis was performed on the iceberg data there were anomalies between the results of the discriminant and descriptive analyses results. The coefficients of -0.23 and -0.30 for mass and speed, respectively, indicated a trend where mass and speed decrease from July to October (the descriptive statistics indicated the reverse). However, coefficients in function 2 for mass (-0.76) and speed (0.32) indicated that mass decreased and drift speed increased during the same period. This scenario is more likely because research by NORDCO (1977) and Gustajtis (1979b) demonstrated that the combination of increased surface currents and wind generated waves during the fall would produce faster drifting icebergs rather than more slowly drifting icebergs. The difference between the results of the discriminant analysis and descriptive statistics can be explained by the fact that in a multivariate analysis with two functions each variable is only providing a portion of the discrimination and in neither case is iceberg speed one of the key variables.

The classification results for the data grouped by month of operation indicated a possible crude summer and fall division rather than a monthly division of data. For example, for July 50 percent of the data were correctly grouped, while 26 percent of the data were incorrectly grouped as August (76 percent of the data grouped as July and August).

To determine if a summer and autumn division of the data existed in the iceberg data a second stepwise discriminant analysis was performed on the data grouped as summer (July and August) and autumn (September and October) and a single function was derived by the discriminant analysis. A negative coefficient of -0.40 for drift speed indicated a decrease in speed from summer to autumn, however the Kruskal-Wallis test results indicate that iceberg drift speed generally increases from summer to autumn. The exclusion of mass from the analysis suggests that iceberg mass does not significantly vary during the drilling season.

Sixty-nine percent of the summer and autumn data were correctly classified. The summer data was 73.9 percent correctly classified while the autumn data was 54.1 percent correctly classified. The relatively high consistency associated with the summer data siginifies that there is little variability in the overall iceberg characterictics during July and August. The autumn months demonstrated more variable iceberg conditions.

The descriptive statistics for data grouped by iceberg size class indicated that there was a significant difference in the drift speed of small and extra large icebergs. The computed median speed for small and extra large icebergs was 0.236 and 0.167 m/sec respectively. Furthermore, a computed Spearman's rho of -0.50 (significant @ 0.01) for speed and mass indicates that as mass increases speed decreases.

To determine which of the iceberg variables contributed significantly to the differences between the various sizes of icebergs discriminant analysis was performed on the data, and a single discriminant function was derived for the iceberg size class data. A negative, canonical discriminant function coefficient of -0.70 for iceberg shape indicated that large icebergs were predominantly tabular, and a negative coefficient for speed (-0.57) signifies a decrease in drift speed as iceberg mass increases. The positive coefficient of 0.41 for deflection suggests that larger icebergs were deflected more often than smaller icebergs. Until recently offshore drillship operators perceived larger icebergs as a greater hazard to drilling operations than relatively small icebergs (i.e. < 10,000 tonnes). However, research by Lever et al (1984) indicated that under extreme storm conditions smaller icebergs could reach velocities and kinetic energy levels that would cause serious structual damage if the small iceberg collided with an offshore structure.

A check on the efficiency of the classification procedure produced a 39.7 correct classification rate, and extra large icebergs (64.8 percent) had the best classification rate. However, a majority of the small iceberg data (66.4 percent) was classified in the small and medium iceberg data groups, and a majority of the medium iceberg data (60.2 percent) was grouped in the small and medium iceberg size classes. This grouping suggested possible similarities between iceberg data grouped as small and medium. Studies by Smith and Banke (1982), and Hsuing and Aboul-Azm (1982) indicated that small and medium size icebergs respond in a similar manner to changes in sea surface conditions.

To determine if a more generalized grouping of the data would produce better classification results a second stepwise discriminant analysis was performed on iceberg data grouped as small (small and medium icebergs) and large (large and extra large icebergs). The discriminant function coefficients for shape, speed and deflection were similar to the results derived in the first discriminant anlaysis. However, an evaluation of the classification procedure produced a 60.9 percent classification rate which is siginificantly better than the 39.7 percent obtained in the discriminant analysis performed on data grouped as small, medium, large and extra large icebergs.

In this study descriptive statistics, non-parametric and parametric tests indicated that spatial and temporal variations exist in the speed, mass, deflection and shape of icebergs observed on the wellsites located on the Labrador Shelf. Furthermore, statistical analyses also indicate that significant differences exist in iceberg data associated with various sizes of icebergs.

In the past iceberg management programs were generally a reaction to a potential collision between an iceberg and a drillship. The spatial and temporal variation in iceberg density and deflection suggest that consideration should be given to location and month when planning offshore drilling operations on the Labrador Shelf. Although iceberg density decreases from summer to autumn iceberg mass does not vary significantly during this period, therefore a collision between a drillship or subsea installations and a large iceberg is still possible during the fall. Furthermore, the frequency of storms along the Labrador Shelf increases during the fall, thus if icebergs are present in a wellsite area the operators will likely have to contend with bad weather and icebergs simultaneously. In this particular situation icebergs are rarely deflected from the wellsite and the only alternative is for the drillship to move out of the way of the iceberg. The information presented by the data analysis and the literature suggest that on the Labrador Shelf drillship operators are continually experiencing problems with icebergs and weather. Gustajtis (1979b), demonstrated that the combination of weather, sea state and icebergs resulted in approximately a 10 percent loss of total drilling time.

6.4 Summary of Conclusions

The results of the iceberg data analyses appears to support the following conclusions.

1. Although the results of the data analyses indicated that there were differences in iceberg characteristics from south to north along the Labrador Shelf, the statistical evidence suggests a more significant difference between the Bank and Saddle areas.
2. The differences between the Saddle and Bank areas warrant that these two types of areas should be investigated separately.
3. Icebergs observed in the Saddle areas are generally larger, faster and deflected more often than icebergs observed on the Bank areas.

4. There appears to be a crude summer and autumn division in observed iceberg characteristics (speed, shape, deflection, drift direction and number of icebergs).

5. There is no significant variation in observed iceberg mass during the drilling season along the Labrador Shelf.

6. The number of icebergs observed along the Labrador Shelf decreases from summer to autumn.

7. There is a negative correlation between iceberg mass and drift speed (i.e. as mass increases speed decreases).

8. Large icebergs (i.e. > 1×10^6) are predominantly tabular while smaller icebergs (i.e. < 1×10^6) are generally non-tabular.

6.5 Implications for Future Research

The results of this study appear to have implications for future research on iceberg behaviour using wellsite observation data collected by marine radar.

Primarily, this study indicated that the radar data is useful for examining general trends in iceberg characteristics. For example, a common trend in the discriminant analysis was the significantly improved results when the number of groups were reduced from either six or four to two. Furthermore, descriptive statistics and non-parametric tests suggested that there were significant spatial and temporal variations in the iceberg data, however the more refined discriminant analysis supported the initial findings but not to the same degree.

There were two findings that were suppported by all statistical procedures used in the study and they were: (i) the differences between the Saddle and Bank areas, and (ii) the differences between the various sizes of icebergs. Although it has been demonstrated that the Saddle areas are different from the Bank areas there is almost no mention of their differences in the literature, however this is probably due to the lack of oceanographic and climatic data for the areas. This is typical of much of the research on the Labrador Shelf where no detailed spatial and temporal differences in ocean currents, and weather patterns and other variables are available, thus any future research on the Shelf should involve compiling a database which will provide this detailed information. Although the differences between the various size icebergs are evident from the data analysis, the lack of appropriate environmental information does not permit detailed explanation of why these differences exist.

A major problem in the study was finding detailed oceanographic and weather information for the four Bank and two Saddle areas on the Labrador Shelf, thus correlation between local ocean current and weather conditions and iceberg behaviour was not possible. Therefore, future research on spatial and temporal behaviour of icebergs would be greatly improved if local ocean currents and weather (i.e. sea state, wind speed and direction) were recorded simultaneously with iceberg position data.

BIBLIOGRAPHY

Allen, J. H. (ed.) (1972). Iceberg Study Saglek Bank, labrador. Memorial University, Faculty of Engineering, St. John's, Nfld.

Anderson, C. (1971). The Flow of Icebergs Along the Canadian East Coast. In *Proc. Canadian Seminar on Icebergs*, December 6th and 7th, Maritime Command Headquarters, Halifax, N.S., pp. 52-61.

Ball, P., Gaskill, H.S., and Lopez, R.J. (1982). An analysis of two data sets collected at drill sites in the Labrador Sea *C-Core Publication*, St. John's, Nfld.

Banke, E.G. and Smith, S.D. (1984). A hindcast study of iceberg drift on the Labrador Coast. *Canadian Technical Report of Hydrography and Ocean Seminars*, No. 49.

Bass, D.W., and Peters, G.R. (1984). Computer simulation of iceberg insability. *Cold Regions Sci. Technol.*, 9(2): 163-169.

Bendat, J.S. and Piersol, A.G. (1971). Random data: Analysis and measurement procedures. John Wiley & Sons, Inc., Toronto.

Bercha, F.G. (1984). The state of art of statistical approaches to ice mechanics. *IAHR Ice Symposium,* Hamburg, West Germany.

Bursey, J.O., Sourdes, W.J., Gates, A.D., and C.L. Blackwood (1977). The climate of the Labrador Sea. *Proceedings from the Fourth International Conference on Port and Ocean Engineering under Arctic Conditions.* St. John's, Newfoundland, pp. 1122-1131.

Chari, T.R. (1978). Model studies of iceberg scouring. *The 4th International conference on Port and Ocean Engineering under Arctic Conditions*, St. John's, Nfld.

Coachman, L.K. and Aagoard, K. (1974). Physical oceanography of the Arctic and Subarctic seas. In, *Marine Geology and Oceanography of the Arctic Seas*, Y. Herman (ed.). Springer Verlog, New York, pp. 1-72.

Dempster, R.J. (1974).The measurement and modelling of iceberg drift. *IEEE International Conference on Engineering in Ocean Environment,* Halifax, N.S.

Dunbar, M.J. (1951). Eastern Arctic Waters. *Bull. Fish. Res. Bd. Can. 88.*

Farmer, G.H. (1981). The cold ocean environment of Newfoundland. *In The Natural Environment of Newfoundland Past and Present.* Edited by A.G. Macpherson and J.B. Macpherson, Department of Geography, Memorial University, St. John's, Newfoundland.

Gardiner, V. and Gardiner G. (nd). Analysis of frequency distributions. The Invicta Press, London, England.

Gaskill, H.S. and Rochester, J. (1982). Ocean currents derived from iceberg drift: A tool for iceberg drift prediction. *Newfoundland Institute for Cold Ocean Sciences*, St. John's, Nfld.

Gaskill, H.S., Terry, B., and Riggs, N. (1984). Forecasting iceberg drift: A comparative study. Department of Mathematics & Statistics, Memorial University, St. John's, Nfld.

Gustajtis, K.A. and Buckley, T.J. (1977). A seasonal iceberg density distribution along the Labrador Coast. Proceedings from the *Fourth International Conference on Port and Ocean Engineering under Arctic Conditions.* St. John's, Newfoundland, pp. 1122-1131.

Gustajtis, K.A. (1979a). Geology and Hydrocarbon Potential of the Labrador Continental Margin. *In Oil Spill Scenario for the Labrador Sea.* Edited by B.R. Ledrew and K.A. Gustajtis. Canada, Dept. Environment, Environment Impact Control Directorate Report, EPS 3-EC-79.

Gustajtis, K.A., (1979b). Oceanography and Climatology of the Labrador Sea. *In Oil Spill Scenario for the Labrador Sea.* Edited by B.R. Ledrew and K.A. Gustajtis. Canada, Dept. Environment, Environment Impact Control Directorate Report, EPS 3-EC-79.

Gustajtis, K.A. (1979c). Iceberg Hazard. *In Oil Spill Scenario for the Labrador Sea* . Edited by B.R. Ledrew and K.A. Gustajtis. Canada, Dept. Environment, Environment Impact Control Directorate Report, EPS 3-EC-79.

Gustajtis, K.A. (1979d). Iceberg population distribution study in the Labrador Sea. *C-CORE Publication,* St. John's, Nfld.

Hammond, R. and McCullagh, P.S. (1978). Quantitative Techniques in Geography. Oxford University Press, Oxford, England.

Hotzel, S.I. and Miller, J.D. (1983). Icebergs: Their physical dimensions and the presentation and application of measurement data. *Annals of Glaciology, 4.*

Hsiung, C.C. and Aboul-Azm, A.F. (1982). Iceberg drift affected by wave action. *Ocean Engineering,* Vol. 9, No. 5.

Klecka, W.R. (1975). Discriminant Analysis. In SPSS: Staistical Package for the Social Sciences, 2nd Edition, McGraw Hill Book Company, New York.

Kruskal, W.H. and Wallis, K.A. (1952). Use of ranks in one-criterion variance analysis. J. Amer. Statist. Ass., 47, pp. 583-621.

Lever, J.H., Reimer, E. and Diemand, D. (1984). A model study of wave-induced motion of small icebergs and bergy bits. *Third International Offshore Mechanics and Arctic Engineering*, Halifax, N.S.

Lewis, J.C. and Bennett, G. (1984). Monte carlo calculations of iceberg draft changes caused by roll. *Cold Regions Sci. Technol.,* 10(1): pp. 1-10.

Loken, O. and Hodgson, D.H. (1971). On the submarine geomorphology along the east coast of Baffin Island. *Can. J. Earth Sci. 8,* pp. 185-195.

Lopez, R., Chari, T.R., Moore, E., Peters, G.R. and Zielinski, A. (1981). Hydrodynamic effects on iceberg gouging. *Cold Region Sci. Technol., 4.*

Mangor, K. and Zorn, R. (1983). Iceberg conditions offshore Greenland. Iceberg Research, No. 4, Scott Polar Institute, Cambridge, England.

Mountain, D.G. (1980). On predicting iceberg drift. *Cold Regions Sci. Technol., 1.*

Murray, J.E. (1969). The drift, deterioration and distribution of icebergs in the North Atlantic Ocean. *CIM Special Vol. 10. The Ice Seminar, 3-18.*

Napoleni, J.G. (1979). The dynamics of iceberg drift. M.sc Thesis., Department of Geophysics and Astronmy, University of British Columbia.

Neu, H.J.A. (1972). Extreme wave height distribution along the Canadian Atlantic Coast. *Ocean Industry,* July, pp. 45-49.

Neu, H.J.A. (1976). Wave climate of the North Atlantic - 1970. Bedford Institute of Oceanography, Dartmouth, Nova Scotia. Report Series /BI-R-76-10/ November.

NORDCO Ltd. (1977). Preliminary Offshore Environmental Study. Vol. 1. Report to Dept. Mines and Energy, Government of Newfoundland and Labrador.

Robe, Q.R. (1975). Physical properties of icebergs. U.S. Coast Guard Research and Development Center, Bulletin No. 61.

Robe, Q.R. (1982). Iceberg Climatology. *Seminar on Iceberg Management in offshore Exploration, Production and Transportation,* Memorial University, St. John's, Nfld., Nov. 8 -10.

Siegel, S. (1956). Non parametric statistics for the behavioral sciences. McGraw Hill, New York.

Smith, S.D. and Banke, E.G. (1982). The influence of winds, currents and towing forces on the drift of icebergs. Atlantic Oceanographic Laboratory, Bedford Institute of Oceanography, Dartmouth, N.S.

Sodhi, D.S. and Demspter R.T. (1975). Motions of icebergs due to changes in water currents. *IEEE Ocean 75.*

Sodhi, D.S. and El-Tahan (1980). Prediction of an iceberg drift trajectory during a storm. *Annals of Glaciology, 1.*

Tabachnick, B.G. and Fidell, L.S. (1983). Using multivariate statistics. Harper and Row Publishers, New York.

Talley, L.D. and McCartney, M.S. (1982). Distribution and circulation of Labrador Sea water. Woods Hole Oceanographic Institute, Woods Hole, MA 02543.

Woodworth-Lynas, C.M.T., Simms, A., and Rendell, C.M. (1985). Iceberg grounding and scouring on the Labrador Continental Shelf. *Cold Regions Sci. Technol., 10.*

Woodworh-Lynas, C.M.T., Simms, A., and Rendell, C.M. (1984). Grounding and scouring icebergs on the Labrador Shelf. *Iceberg Research No. 7,* Scott Polar Institute, Cambridge, England.

Woodworth-Lynas, C.M.T. and Simms, A. (1984). Iceberg grounding and scouring frequency, Labrador Sea. *Oceans '84 Conference*, Washington D.C. Sept. 10-12 Conference Record, pp. 259-262.

Wright, B. and Berenger D. (1980). Ice conditions affecting offshore hydrocarbon production in the Labrador Sea. Proc. *Workshop on Research in the Labrador Coastal and Offshore Region.* Memorial Univ. Newfoundland, St. John's, pp. 307-319.

APPENDIX A

The following Fortran 77 program was used to caculate variables and reorganize the iceberg data set for statistical analyses.

```
C   This program performs a number of functions.
C Options are selected by entering the integer number
C which is the sum of the idex of the desired options.
C    'List' provides a listing of grounded bergs, which
C can be used with Select, allows the user to
C process only grounded bergs for Ovrly or Trax.
C    'Statistics' does some elementary statistics on velocity,
C kinetic energy, mass, and draft, and outputs the
C calculated values for each observation into a data
C file if 'Output' is specified.
C    'Range' calculates the average range when each berg
C is first sighted, last sighted, and maximum. If 'Output'
C is specified, the individual values for first, last,
C and max for each berg are written into the output file.
C
      %global ansi77 fold card
      real lx,ly,ltime,ke,max,mps,mn,min,del,x1,y1,ang
      integer draft,towed,grnd,GD,ichoice,shape,deflect
      INTEGER FD,FM,FT,LD,LM,LT,HGHT,LNGHT,WDTH,TYP,MASS
      CHARACTER*20 SHIP
      real LAT,LONG,LT1,LG1,L4,LN4,GPOS
      INTEGER L1,L2,L3,LN1,LN2,LN3,site,lmonth,lday,bergs
      character*7 id,trim,null*80,file*10,file2*10,file3*10
      logical list,stat,output,ranges
      data mps,DLAT/1852.0,1.66E-27
      std(s,sq,rn) = sqrt(sq/rn-(s/rn)**2)
      open(1,mode="inout",form="formatted",
     *file=">udd>GGeog>Simms>iceberg>berg")
      open(12,mode="inout",form="formatted",
     *file=">udd>GGeog>Simms>iceberg>data")
      print 01,'Enter month data collected or 99 for season='
      read 500,imonth
      print *,'Enter run number='
      read *,site
  500 format(i2)
      print *,'(1) - List grounded'
      print *,'(2) - Statistics'
      print *,'(8) - Range averages'
      print 01,'   Enter option(s) > '
      read *,ians
      if (ians.ge.8) then
         ranges = .true.
         ians = ians - 8
      end if
      if (ians.ge.2) then
         stat = .true.
         ians = ians - 2
      end if
      if (ians.eq.1) list = .true.
      read (1,03) SHIP,L1,L2,L3,L4,LN1,LN2,LN3,LN4
      LAT=L1+L2/60.+L3/3600.+L4/360000.
      LONG=LN1+LN2/60.+LN3/3600.+LN4/36000.
      DLNG=DLAT/57.29578/cos(LAT/57.29578)
      print *,SHIP,LAT,LONG
      count=0
   10 READ(1,04,END=30) ID,N,FM,FD,FT,LM,LD,LT,TYP,HGHT,
     +LNGHT,WDTH,MASS,DRAFT,TOW,GD
      towed=0.0
      grnd=0.0
      sv=0.0
      sn=0.0
      sv2=0.0
      ske=0.0
      ske2=0.0
      sm=0.0
      mn=0.0
      sm2=0.0
      sy3=0.0
      sy4=0.0
      sx3=0.0
      sx4=0.0
      sh=0.0
      sh4=0.0
      sd=0.0
      dn=0.0
      sd2=0.0
          bergs = bergs + 1
      if (mass.ne.0) then
         mn = mn + 1
         sm = sm + mass/1.0E6
```

```
        sm2 = sm2 + (mass/1.0E6)**2
     end if
     if (draft.ne.0) then
        dn = dn + 1
        sd = sd + draft
        sd2 = sd2 + draft*draft
     end if
     if (tow.eq.1hT) towed = towed + 1
     if(tow.eq.1hT) deflect=1
     if(tow.eq.1hN) deflect=0
     if(typ.eq.1hD) shape=0
     if(typ.eq.1hT) shape=1
     if(typ.eq.1hN) shape=0
     read (1,05) imnth,iday,time,range,bearing
     first = range
     sf = sf + range
     max = 0.0
     min = 99.0
     t1=0.0
     g1=0.0
     icode=icode+1
     x=((mps*range*sin(bearing/57.29578))-((1852.*range)*
    +sin(1.5/57.29578)))
     y=((mps*range*cos(bearing/57.29578))-((1852.*range)*
    +sin(1.5757.29578)))
     T1=range*cos(bearing/57.29578)*DLAT+LAT
     G1=-range*sin(bearing/57.29578)*DLNG+LONG
     do 60000 i=1,n-1
     K=K+1
       lmonth=imnth
       lday=iday
        ltime = time
        lx = x
        ly = y
        read (1,05) imnth,iday,time,range,bearing
        brgd=brgd+bearing
        if(bearing.eq.0.0) bearing=360.0
        if (bearing.eq.0.0) print *,id,imnth,iday,time
        del=(1852.*range)*sin(1.5/57.29578)
        if (range.gt.max) max = range
        if (range.lt.min) min = range
        x = (mps*range*sin(bearing/57.29578))-del
        y = (mps*range*cos(bearing/57.29578))-del
        LT1=range*cos(bearing/57.29578)*DLAT+LAT
        LG1=-range*sin(bearing/57.29578)*DLNG+LONG
        dtime=time-ltime
        if (dtime.le.0.0) dtime = dtime + 24.0
        dxy=sqrt(((lx-x)**2)+((ly-y)**2))
        v = dxy / (dtime*3600.0)
        if(v.gt.0.0) then
        x2=((x-lx)/(dtime*3600.))
        y2=((y-ly)/(dtime*3600.))
        heading=(atan2(x2,y2))*57.29578
          head2=(atan2(x,y))*57.29578
        if (heading.lt.0.0) then
        heading=360.+heading
        else
        heading=heading
        end if
        if(heading.eq.0.0) heading=360.0
        if (head2.lt.0.0) then
        head2=360.+head2
        else
        head2=head2
        end if
        x3=x2
        y3=y2
        else
        x3=0.0
        y3=0.0
        end if
        ke = (0.5*mass*v*v)/1.0E6
c      write(12,15003) id,hght,lnght,wdth,mass,draft,tow,typ,
c    *imnth,iday,time,x/1000.,y/1000.,v,heading,shape,deflect
       if((imnth.eq.lmonth).and.(iday.eq.lday)) then
        sh4=sh4+heading*heading
        sh=sh+heading
        sh2=sh2+head2
        sx3=sx3+x3
        sy3=sy3+y3
```

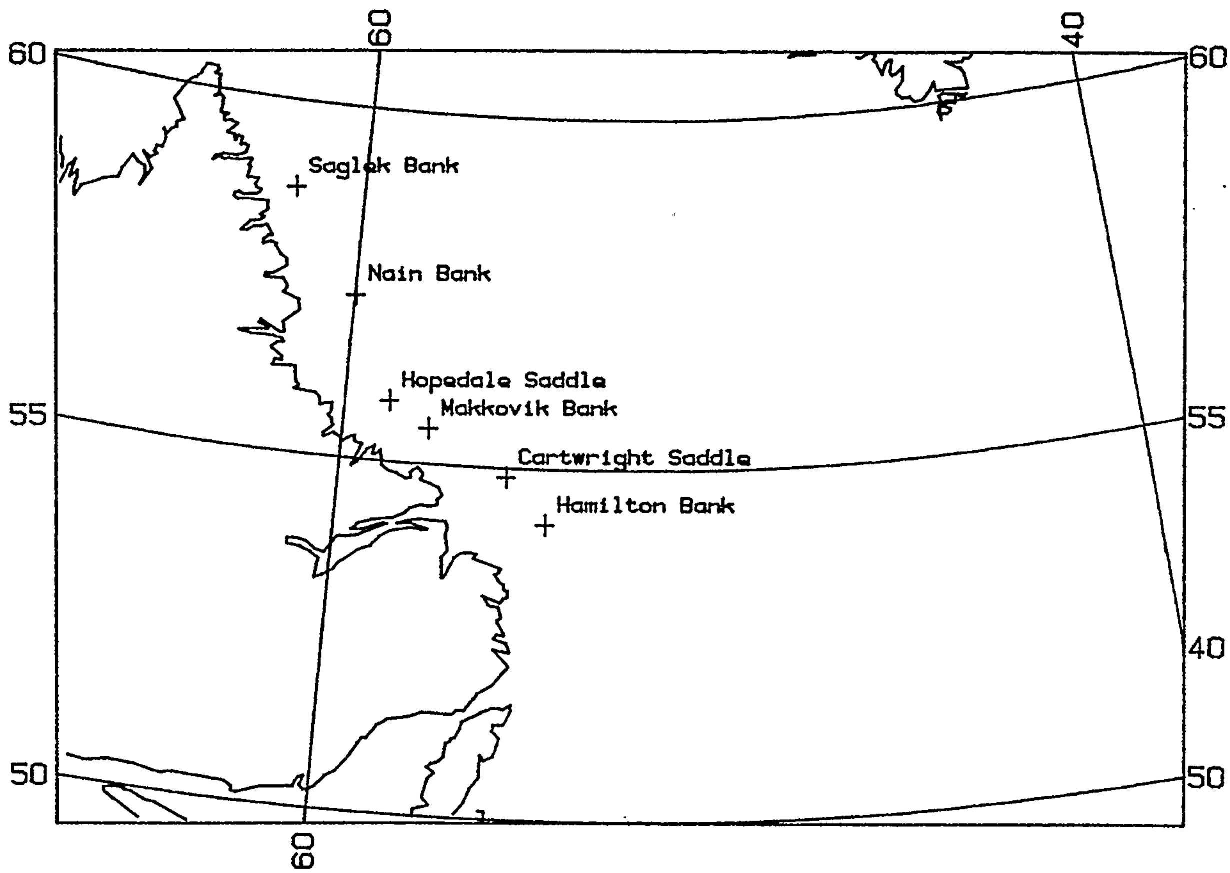
```
          sx4=sx4+x3*x3
          sy4=sy4+y3*y3
          sn = sn + 1
          sv = sv + v
          sv2 = sv2 + v*v
          ske = ske + ke
          ske2 = ske2 + ke*ke
       else
       write(12,15003) (month,lday,shape,deflect,site,lat,long,
      +mass/1000000.,sv/sn,sh/sn,ske/sn
       count=count+1
       sn=0.0
       sv=0.0
       sh=0.0
       sv2=0.0
       sh4=0.0
       ske=0.0
       endif
          if (dxy.lt..09) then
             ttime = ttime + dtime
          else if ((ttime.ge.12.0).and.(ig.ne.bergs)) then
             print *,imnth,iday,time,id
             if (list) print *,id,'  grounded'
             grnd = grnd + 1
             ig = bergs
             ttime = 0.0
          else
             ttime = 0.0
          end if
60000  continue
       sl = sl + range
       smax = smax + max
       smin = smin + min
       if (output.and.ranges) write (2,08) id,first,range,max

       if (ranges) then
          print *,' '
          print *,'Average first sighted range ',sf/bergs
          print *,'Average last sighted range  ',sl/bergs
          print *,'Average maximum range       ',smax/bergs
          print *,'Average minimum range       ',smin/bergs
       end if
       if (stat) then
       if(sn.eq.0) then
       print *,'NO DATA AVAILABLE FOR COMPUTATION'
       else
       print *,'ICEBERG',id
       end if
       end if
       goto 10
01     format (1x,a60,$)
15003  format(5i3,6f8.4)
02     format (a10)
03     format(A20,1X,I2,1X,I2,1X,I2,F3.3,1X,I2,1X,I2,1X,I2,F3.3)
04     FORMAT(2X,A6,I4,5X,I2,I2,I4,1X,I2,I2,I4,1X,A1,1X,I3
      +,1X,I3,1X,I3,1X,I8,1X,I3,1X,A1,I1)
05     format (2i2,f5.2,1x,f5.2,1x,f5.1)
06     FORMAT (3F8.3)
07     format (1x,a30,' - ',2f10.4,2x,a)
08     format (2x,a7,4(1x,f4.1))
30     print *,'FINISHED PROCESSING DATA OUTPUT IN FILE "DATA"'
       print *,'NUMBER OF OBSERVATIONS FOR THIS RUN IS  ',count
       close(1)
       close(12)
       stop
       end
```

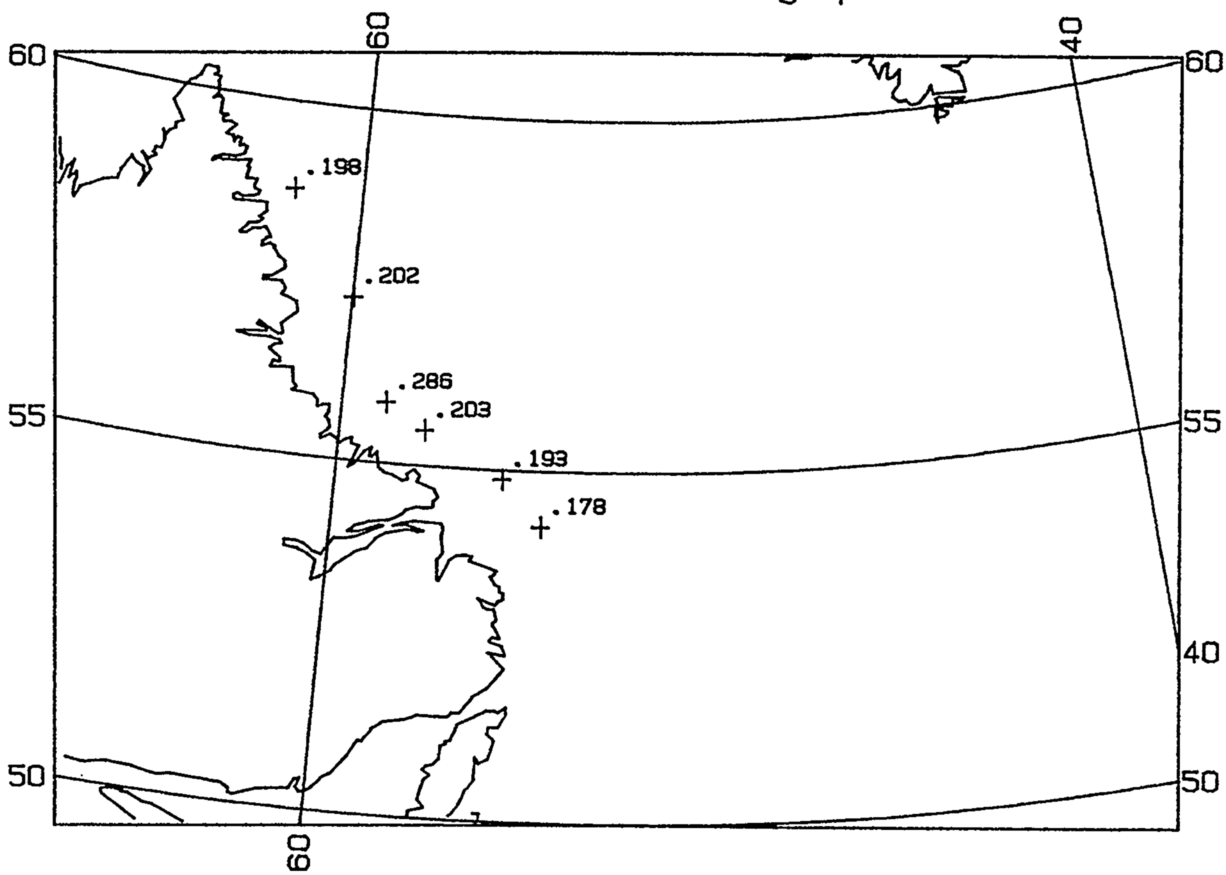
APPENDIX B

Frequency polygons and cumulative plots of iceberg speed data grouped by geographical area (original data set).

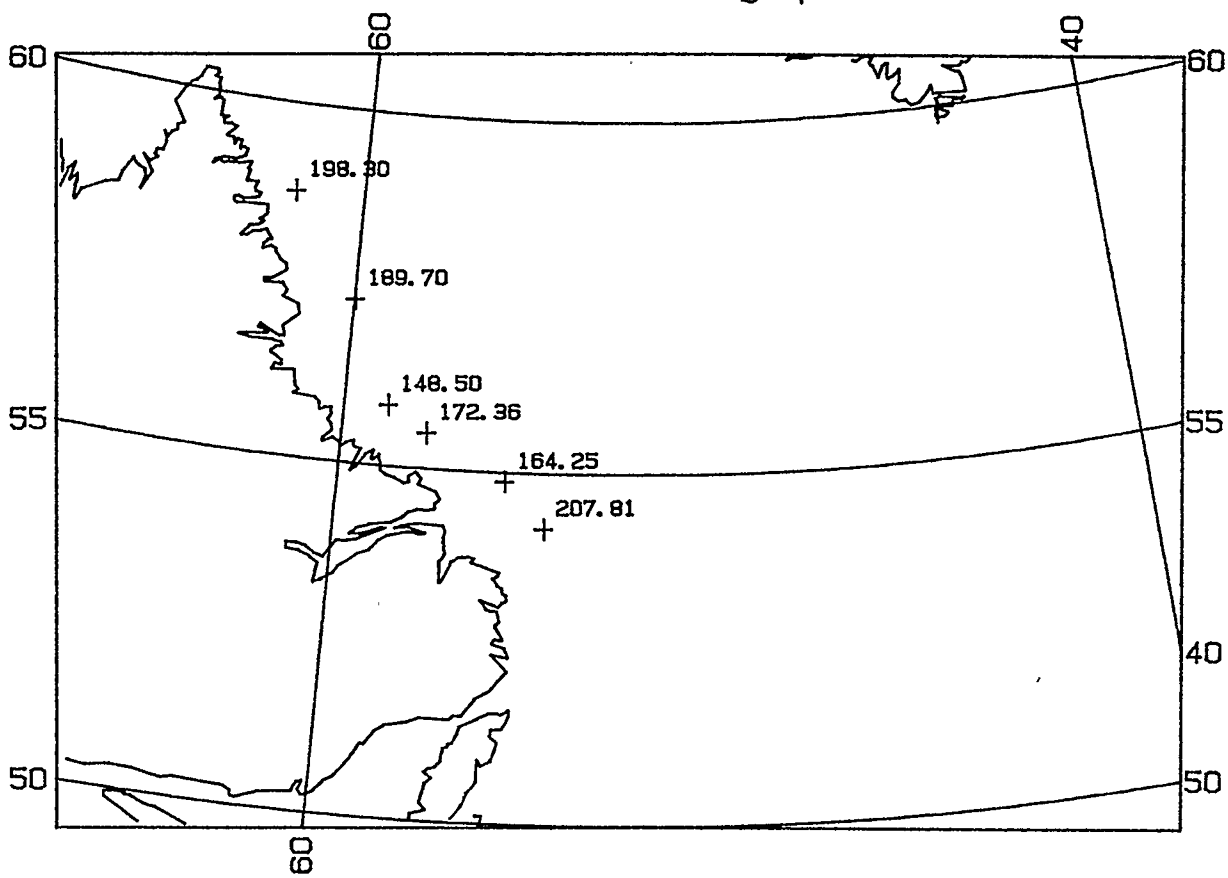
Labrador Sea - Bank and Saddle Locations



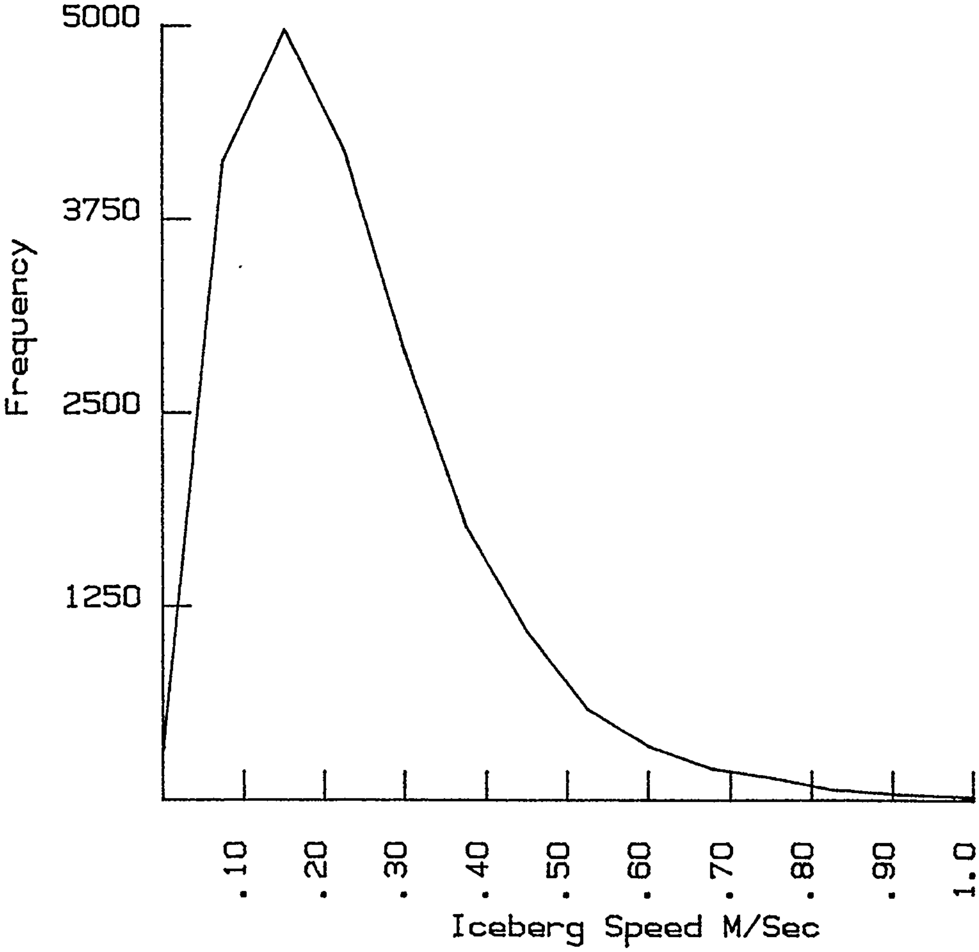
Labrador Sea - Combined Median Iceberg Speed M/Sec

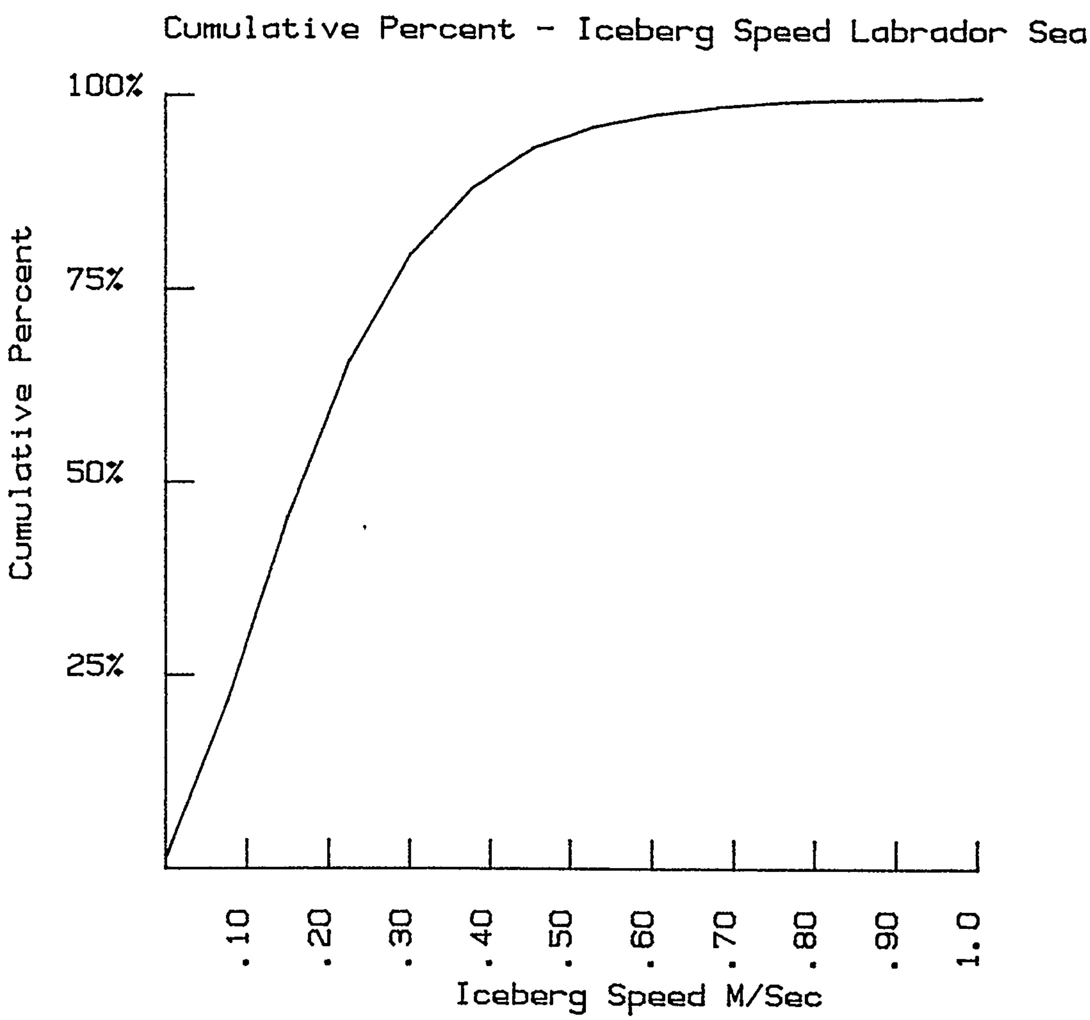


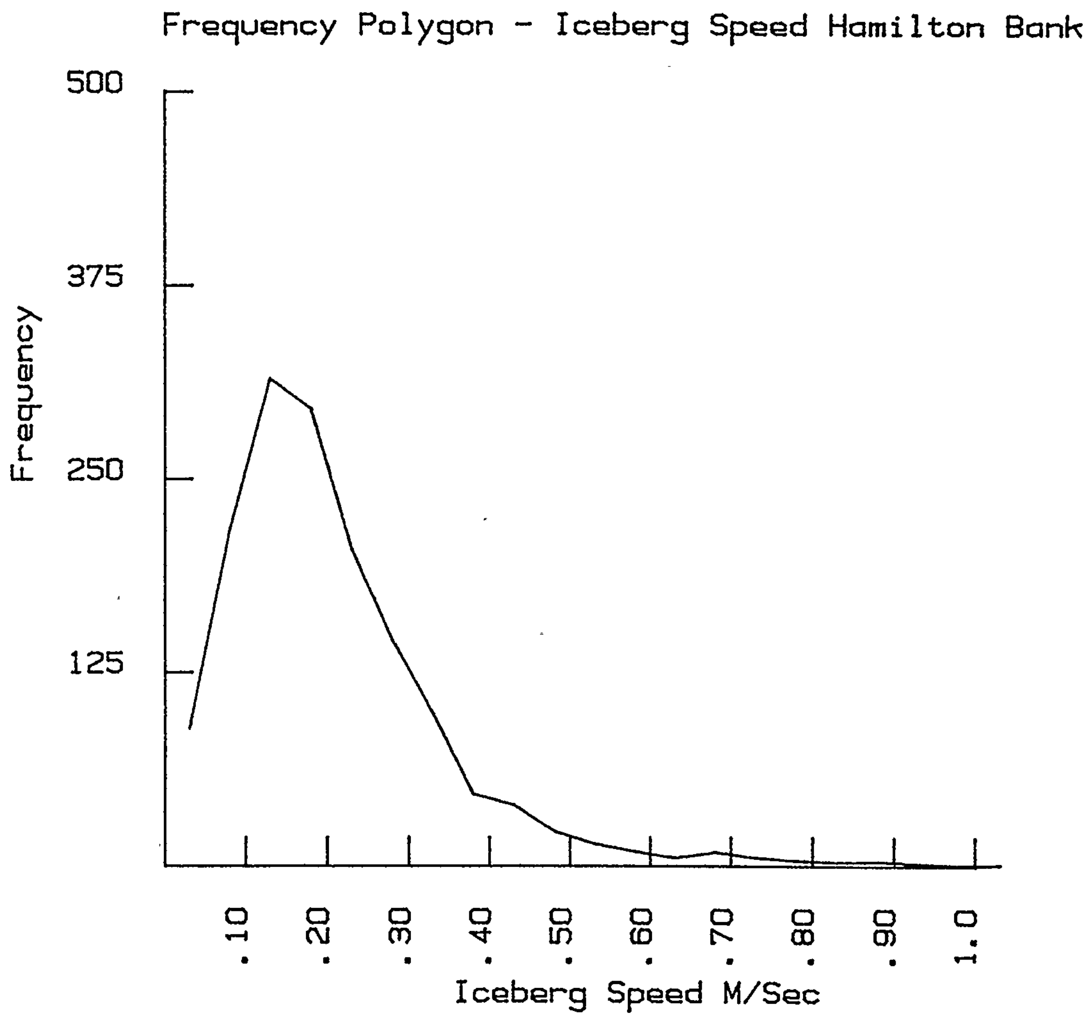
Labrador Sea - Combined Mean Iceberg Speed Direction

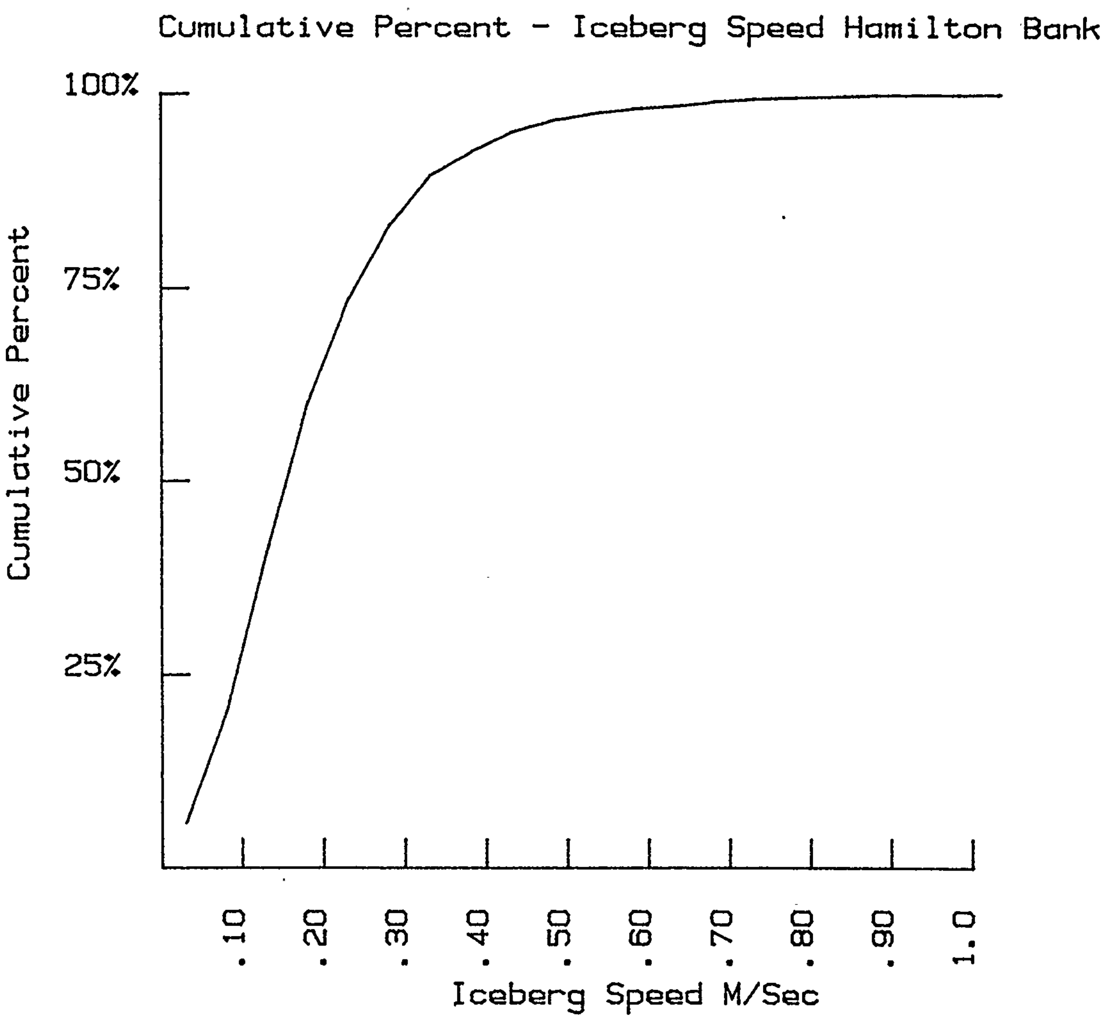


Frequency Polygon - Iceberg Speed Labrador Sea

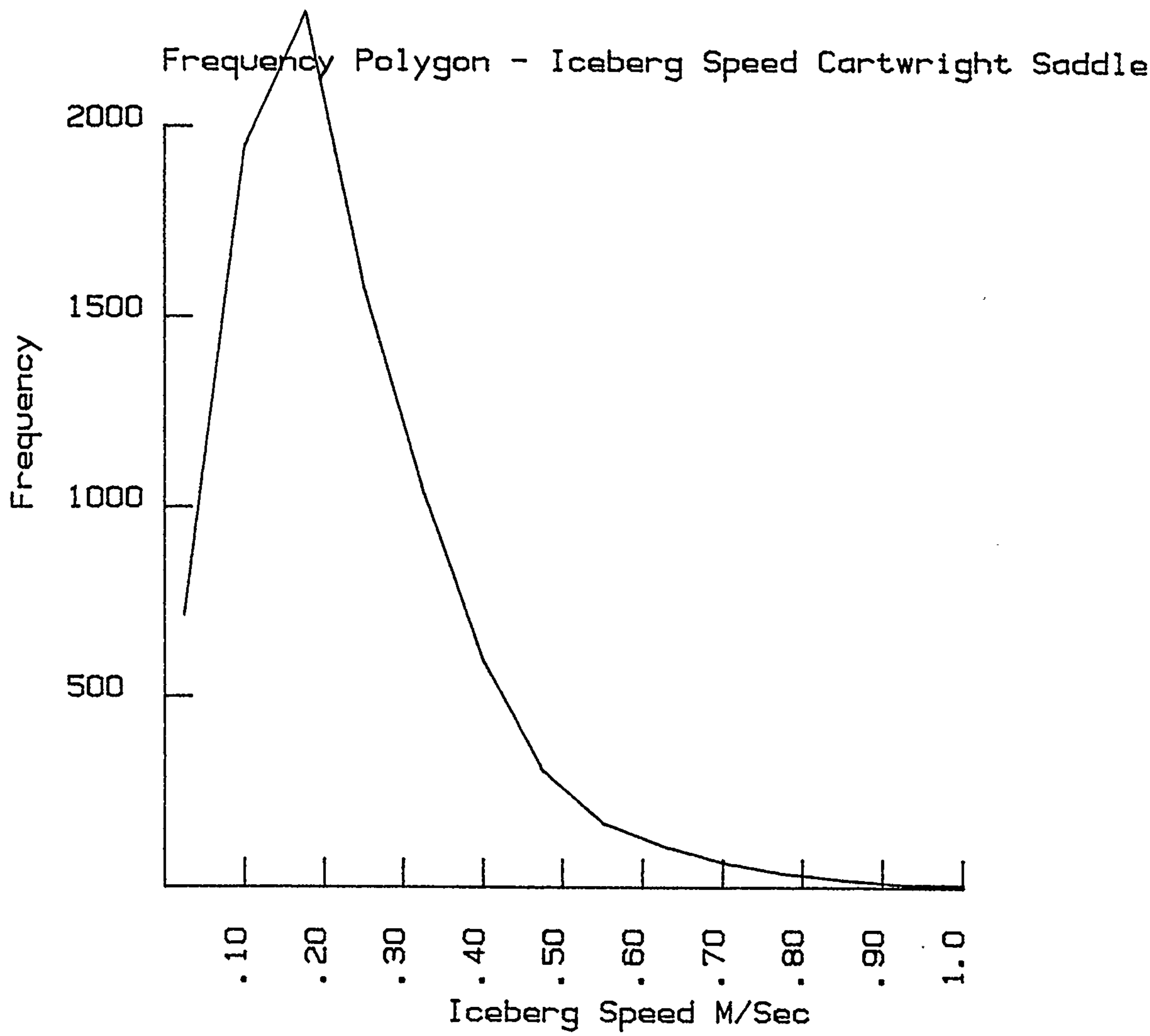


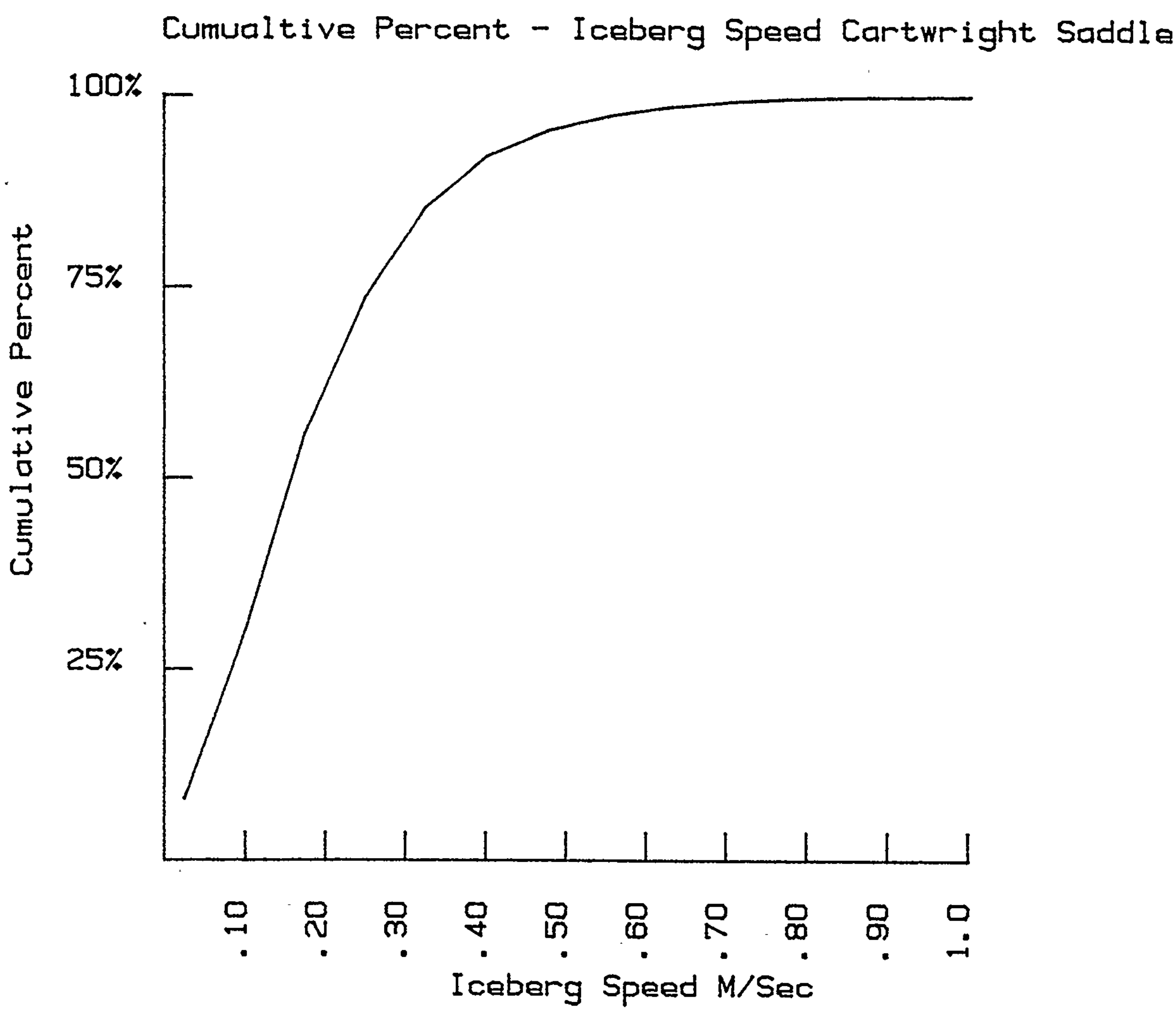

Cumulative Percent - Iceberg Speed Labrador Sea
100%
75%
50%
25%
Cumulative Percent
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec


Frequency Polygon - Iceberg Speed Hamilton Bank
500
375
250
125
Frequency
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

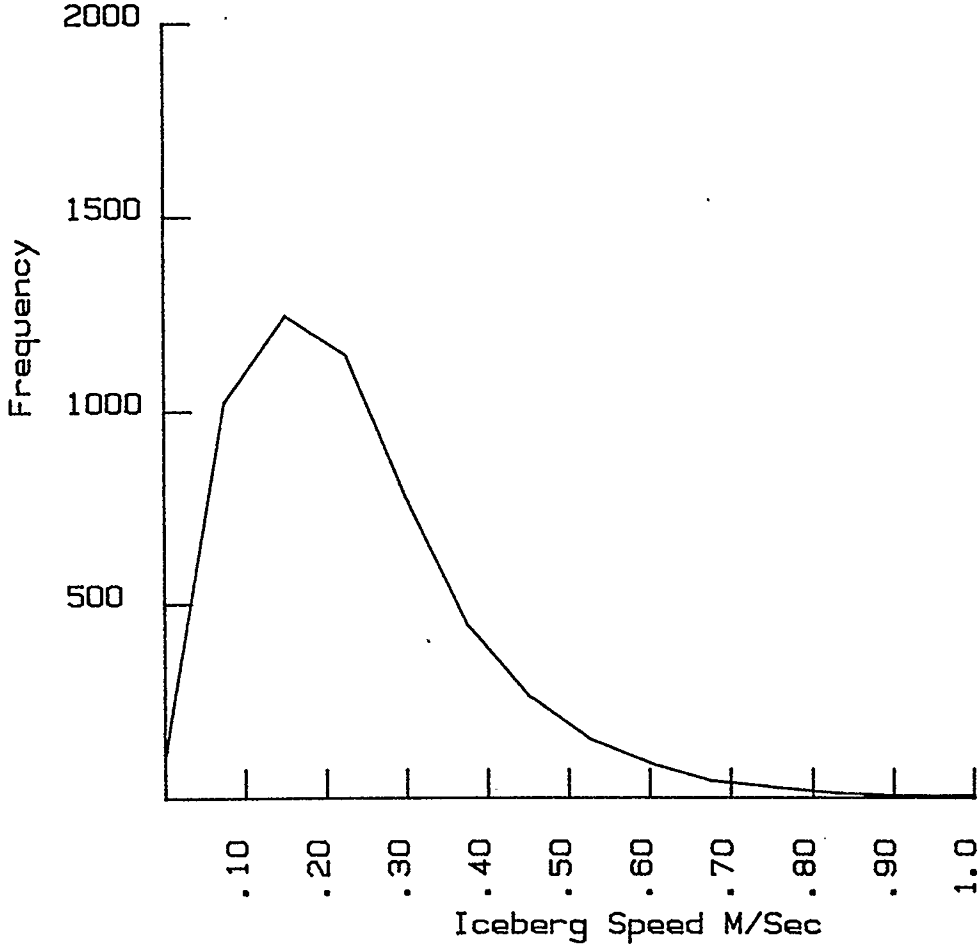


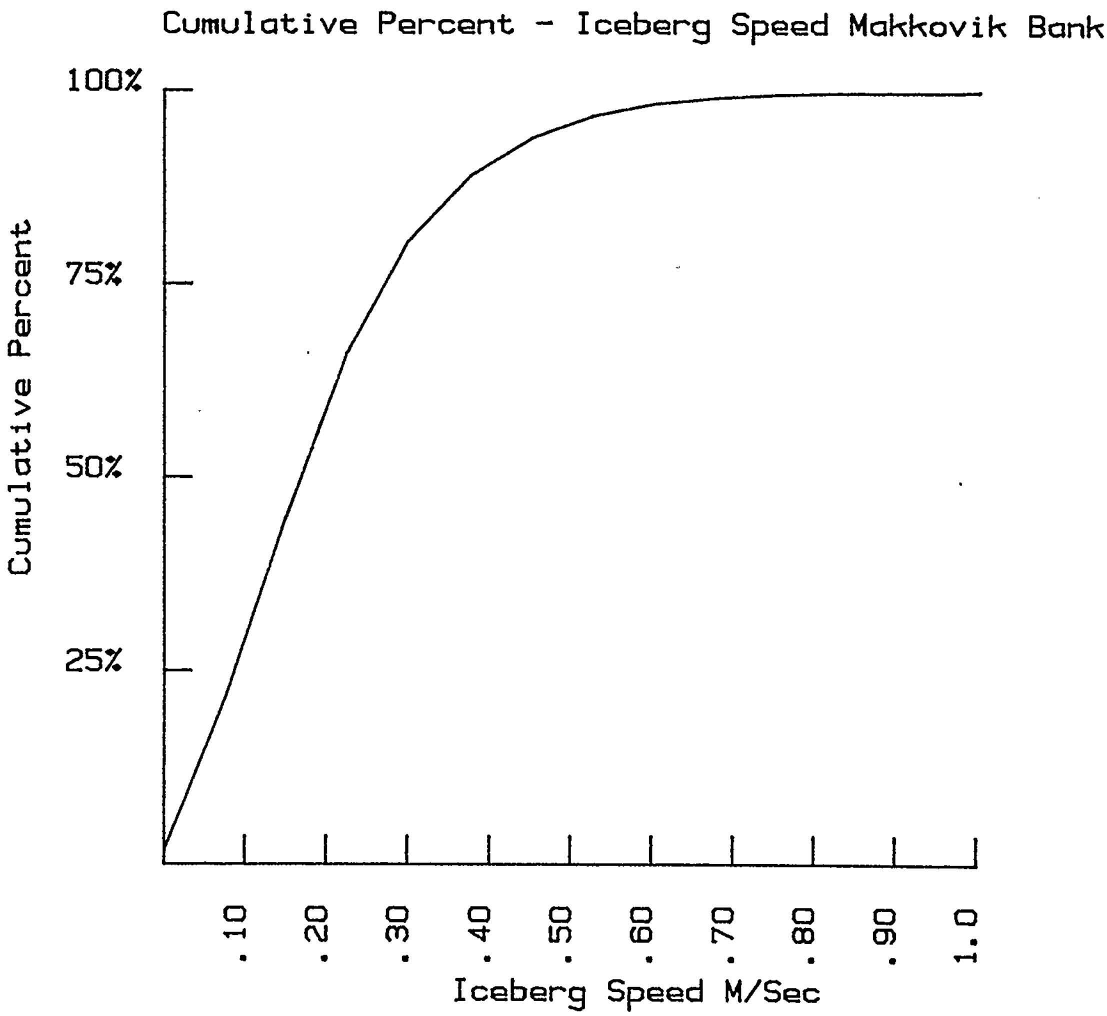
Cumulative Percent - Iceberg Speed Hamilton Bank
100%
75%
50%
25%
Cumulative Percent
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec


Frequency Polygon - Iceberg Speed Cartwright Saddle
Frequency
2000
1500
1000
500
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

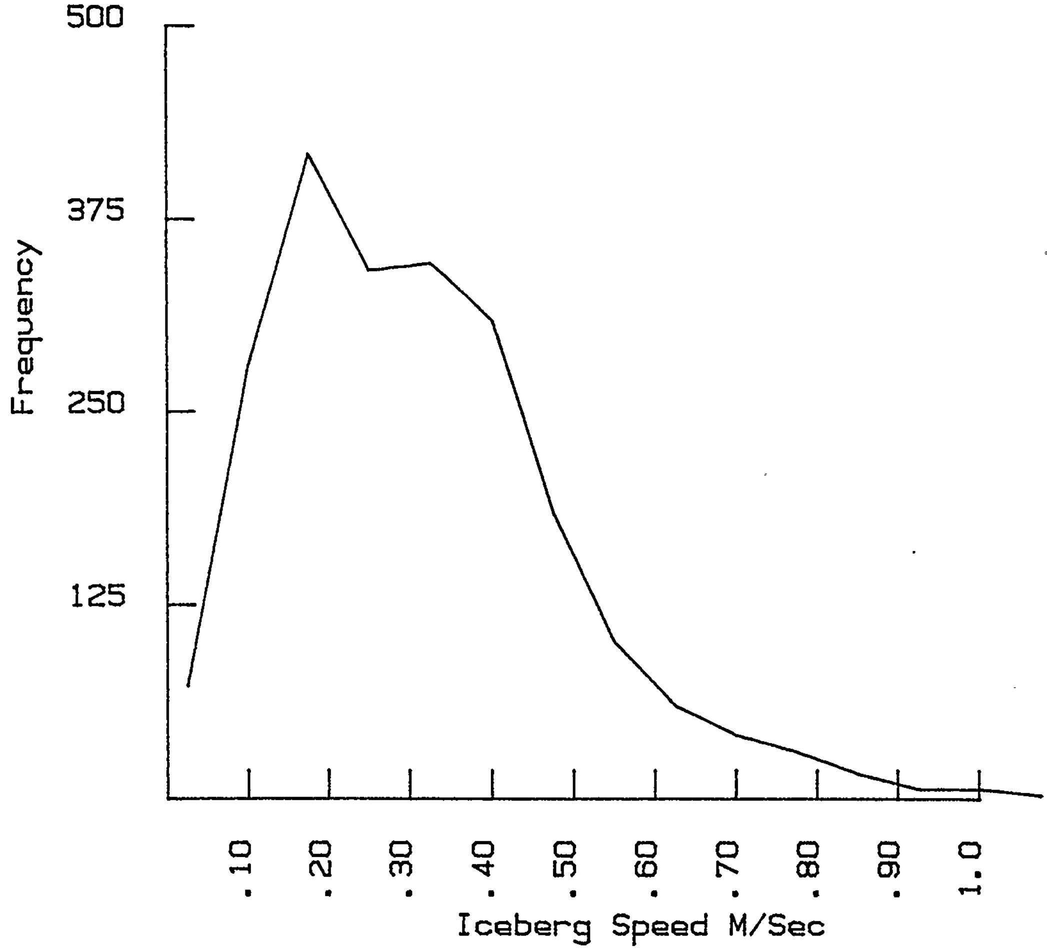

Cumualtive Percent - Iceberg Speed Cartwright Saddle
100%
75%
50%
25%
Cumulative Percent
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

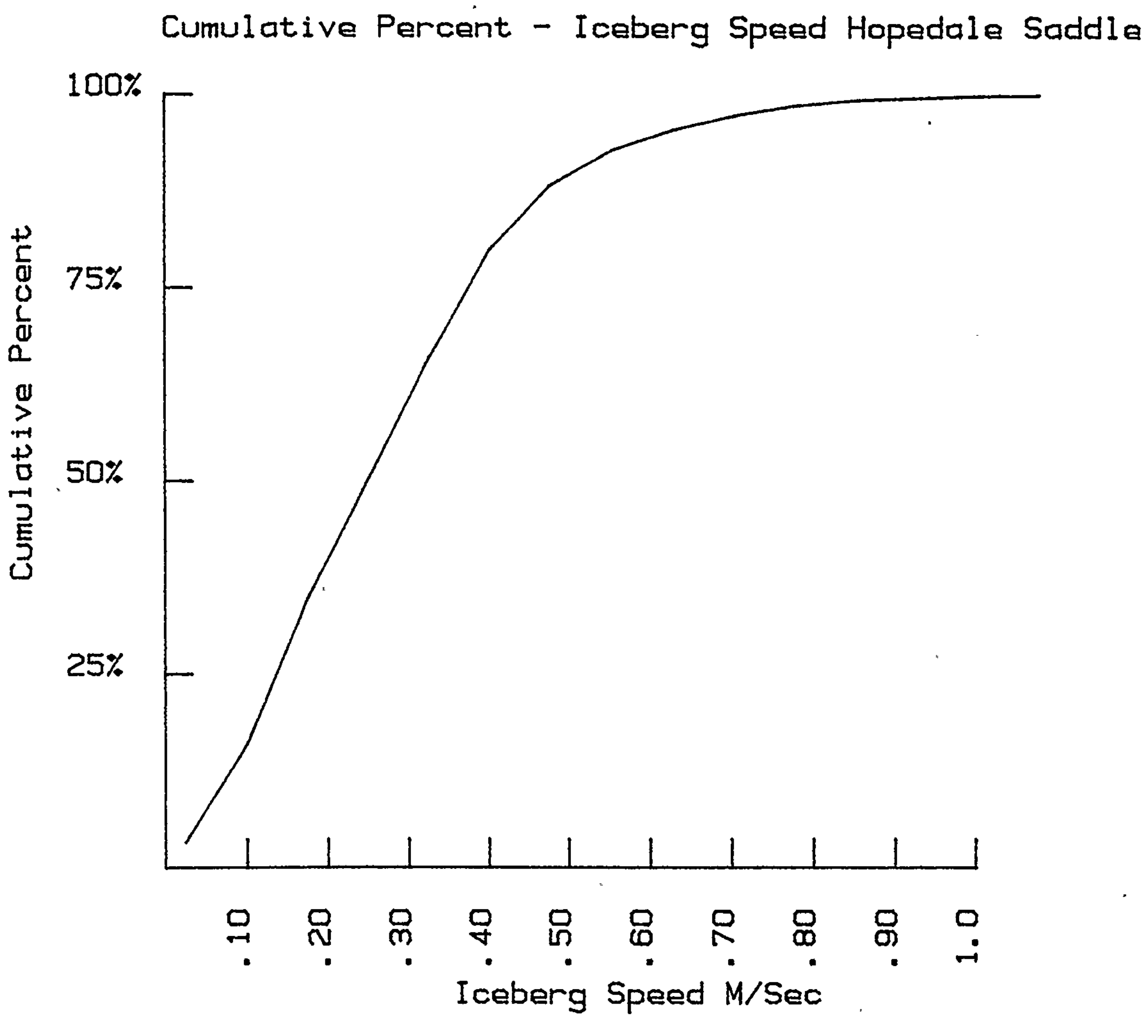
Frequency Polygon - Iceberg Speed Makkovik Bank

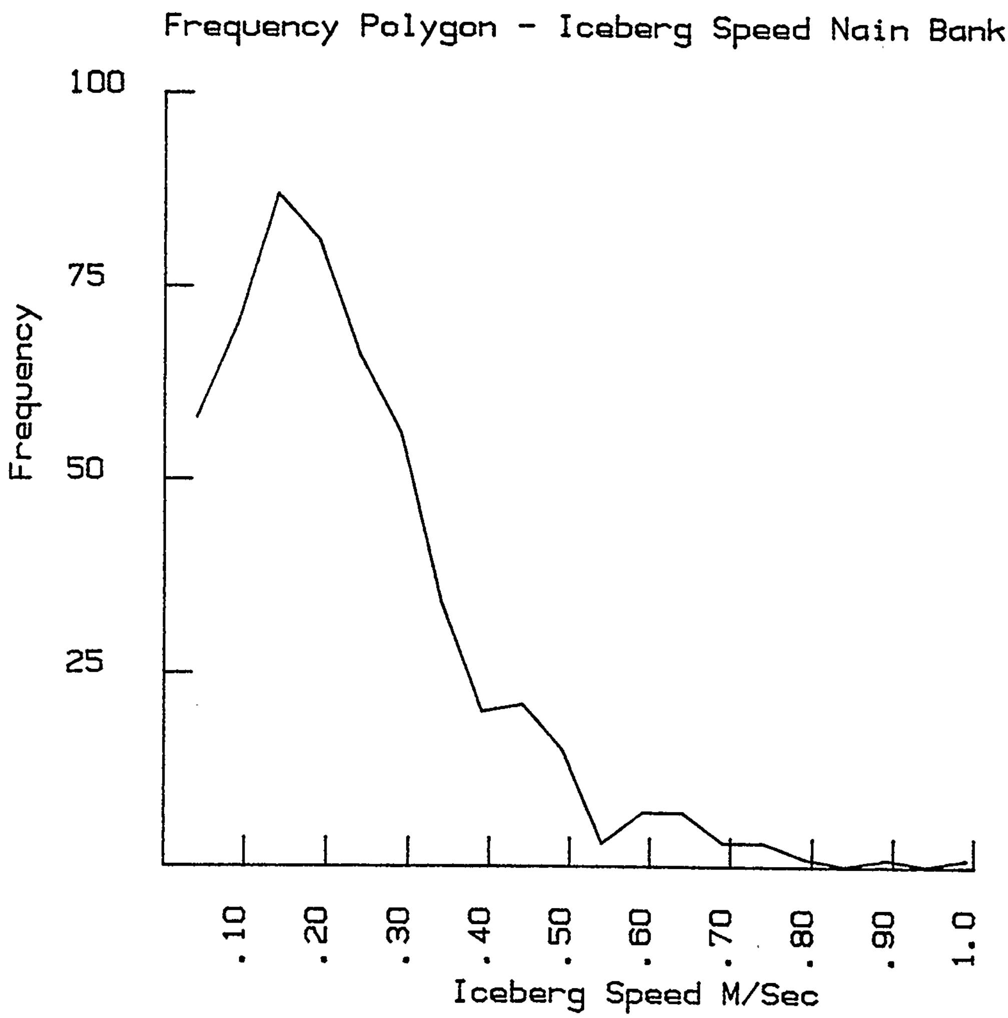



Cumulative Percent - Iceberg Speed Makkovik Bank
100%
75%
50%
25%
Cumulative Percent
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

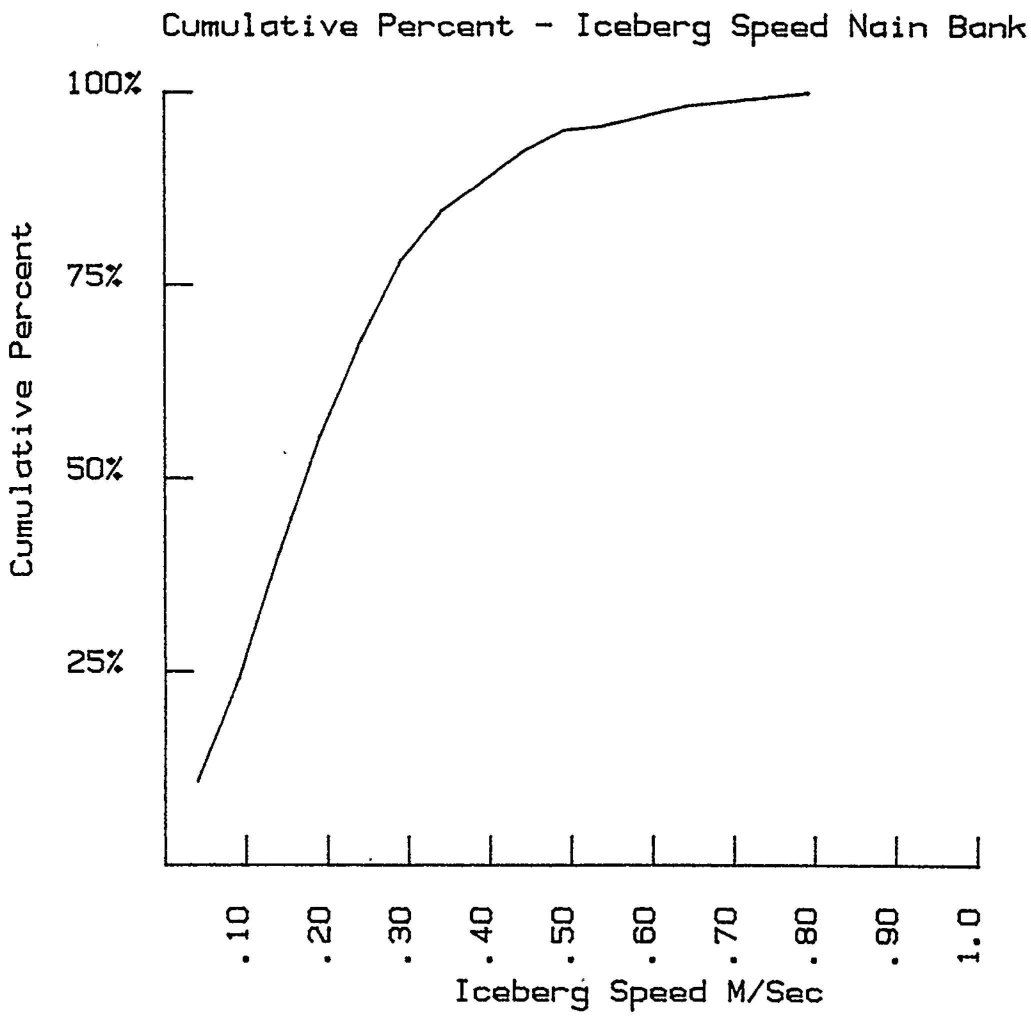
Frequency Polygon - Iceberg Speed Hopedale Saddle

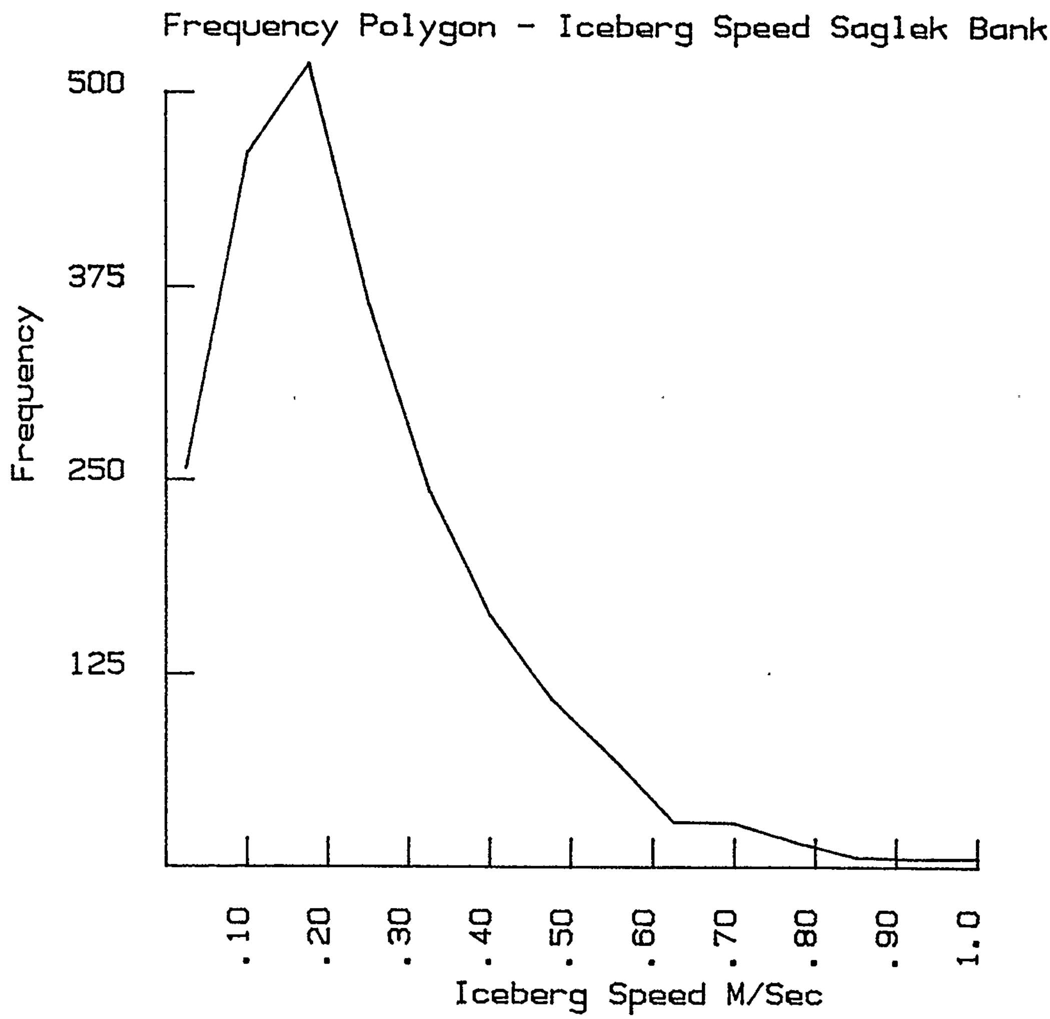


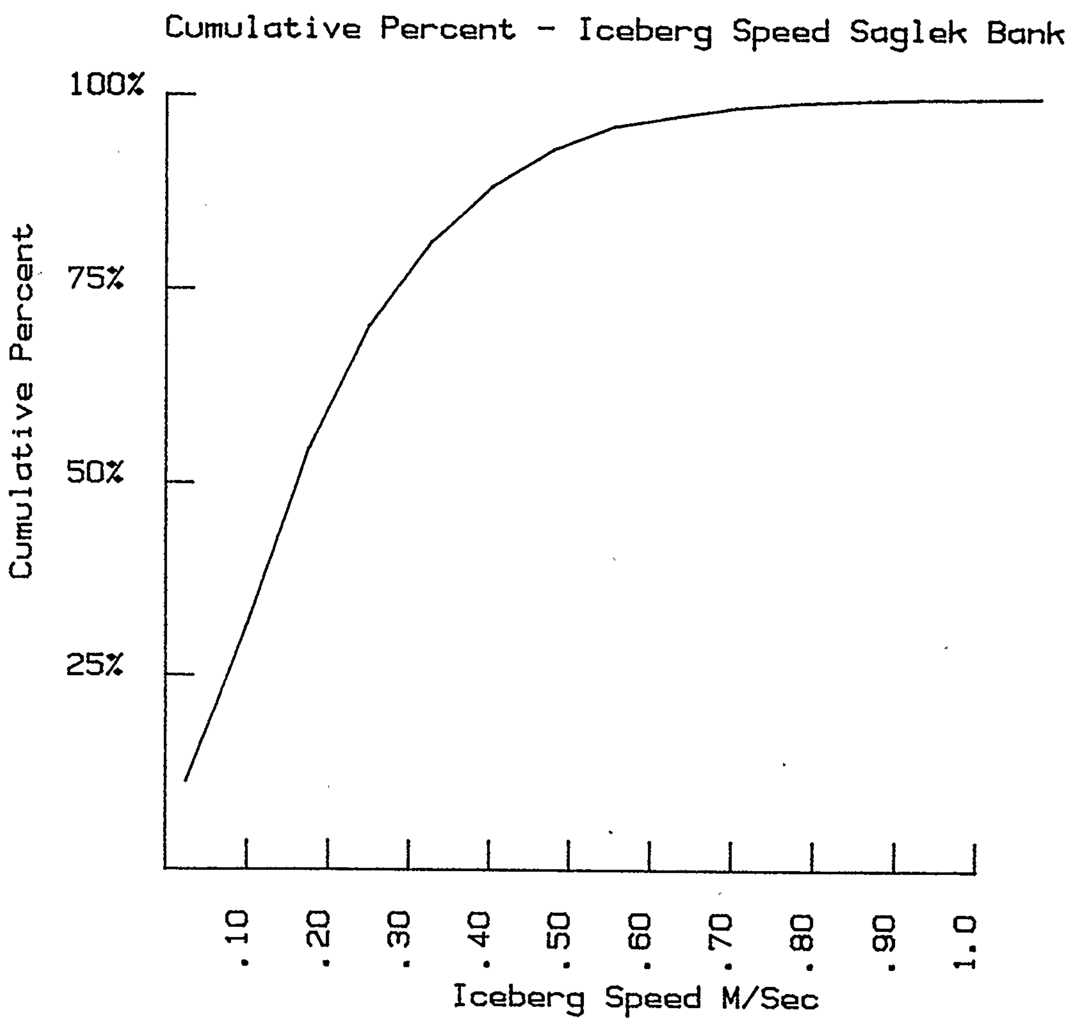

Cumulative Percent - Iceberg Speed Hopedale Saddle
100%
75%
50%
25%
Cumulative Percent
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec



Frequency Polygon - Iceberg Speed Nain Bank
100
75
50
25
Frequency
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

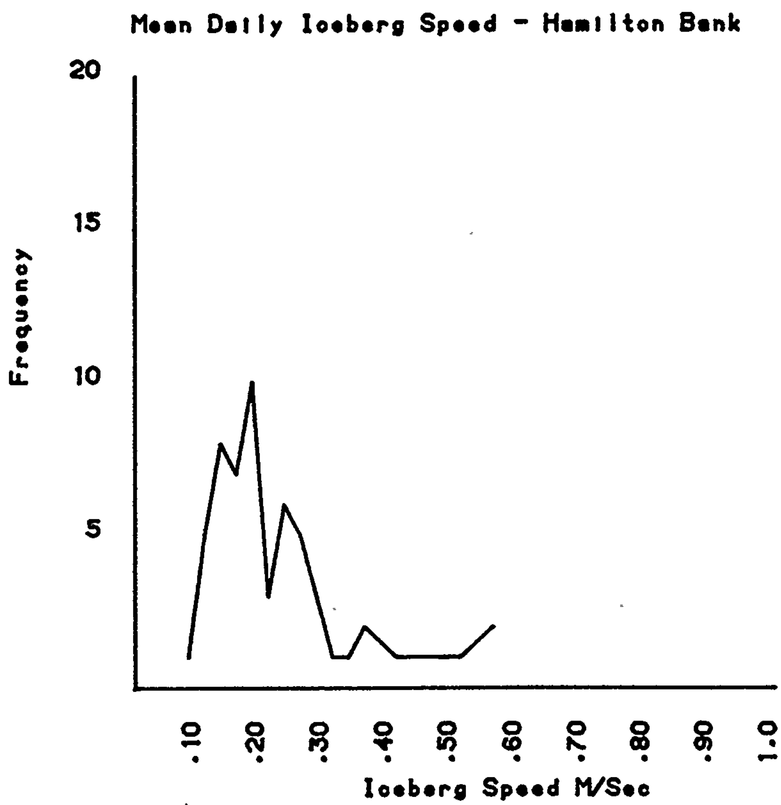

Cumulative Percent - Iceberg Speed Nain Bank
100%
75%
50%
25%
Cumulative Percent
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

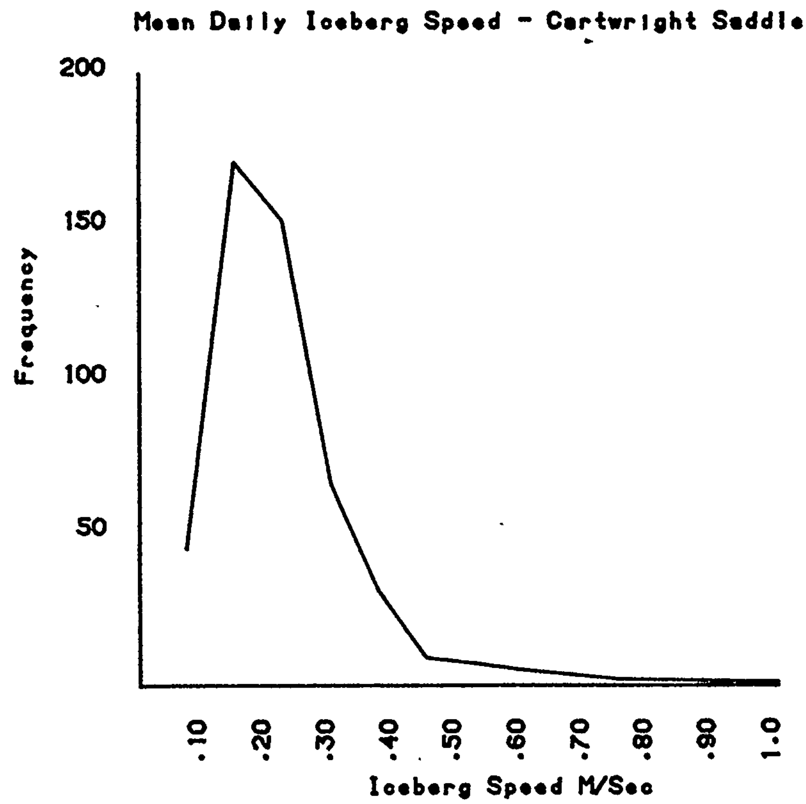

Frequency Polygon - Iceberg Speed Saglek Bank
500
375
250
125
Frequency
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

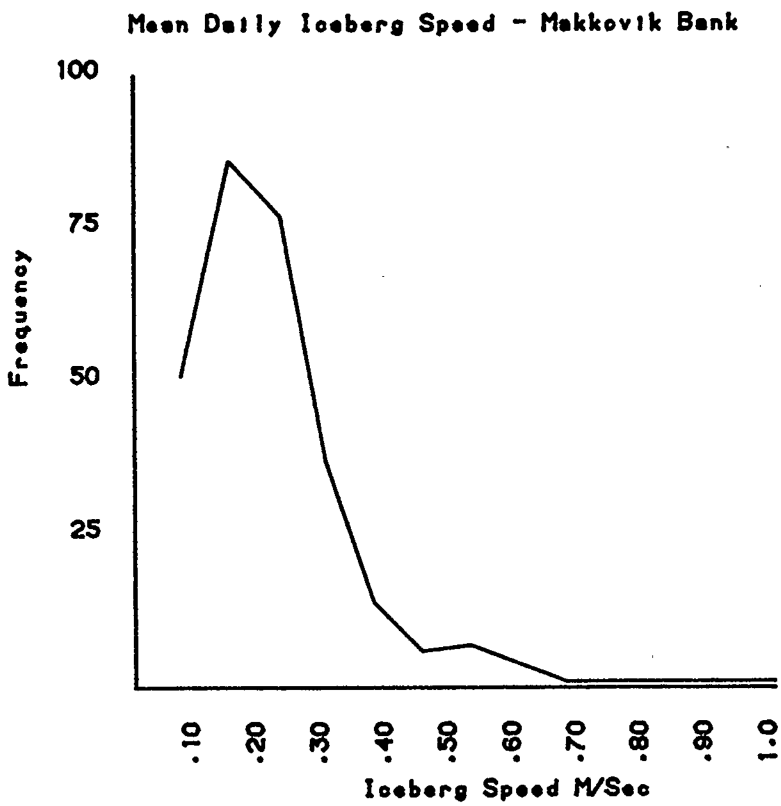

Cumulative Percent - Iceberg Speed Saglek Bank
100%
75%
50%
25%
Cumulative Percent
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

APPENDIX C

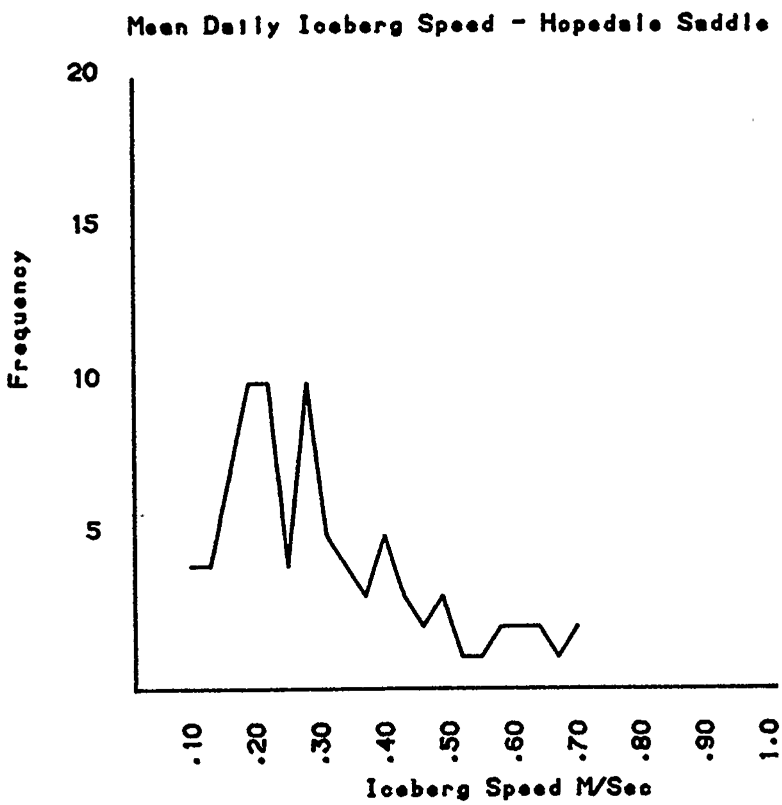
Frequency polygons - mean daily iceberg drift speed by geographical area (reduced data set).

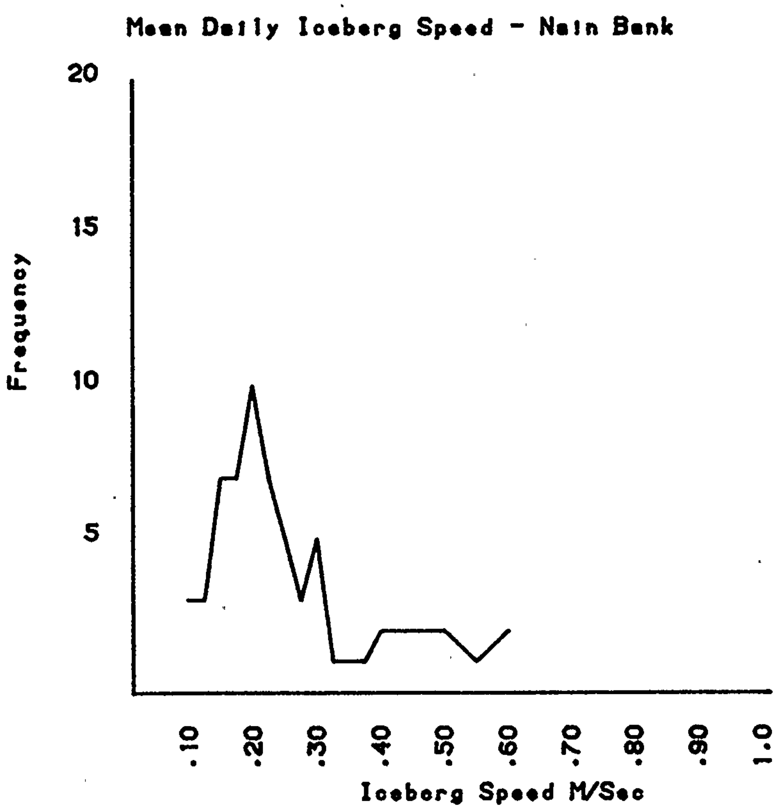

Mean Daily Iceberg Speed - Hamilton Bank
20
15
10
5
Frequency
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

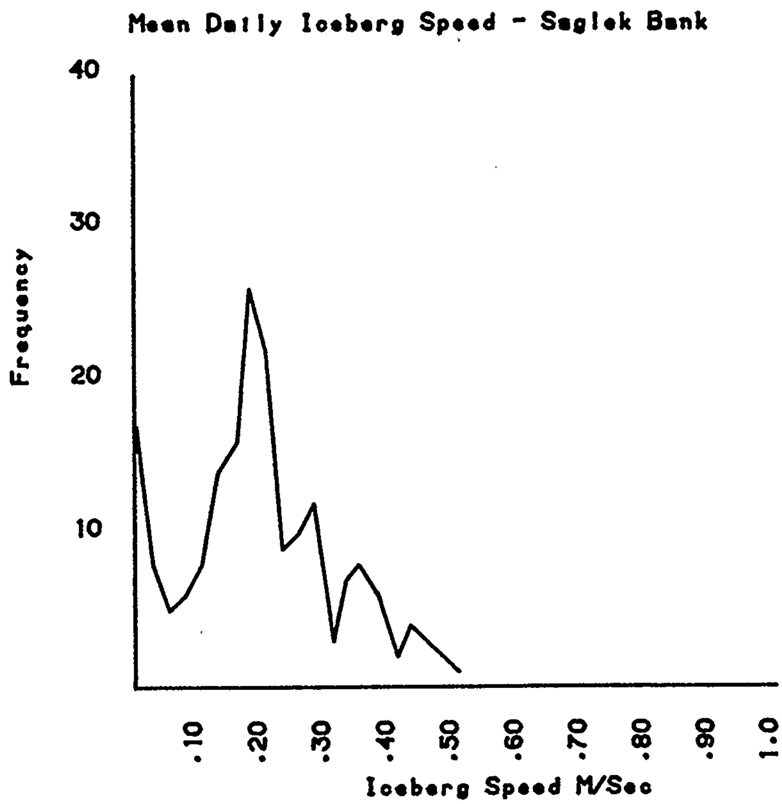

Mean Daily Iceberg Speed - Cartwright Saddle
200
150
100
50
Frequency
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec



Mean Daily Iceberg Speed - Makkovik Bank
100
75
50
25
Frequency
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec


Mean Daily Iceberg Speed - Hopedale Saddle
20
15
10
5
Frequency
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec


Mean Daily Iceberg Speed - Nain Bank
20
15
10
5
Frequency
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec


Mean Daily Iceberg Speed - Saglek Bank
40
30
20
10
Frequency
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.0
Iceberg Speed M/Sec

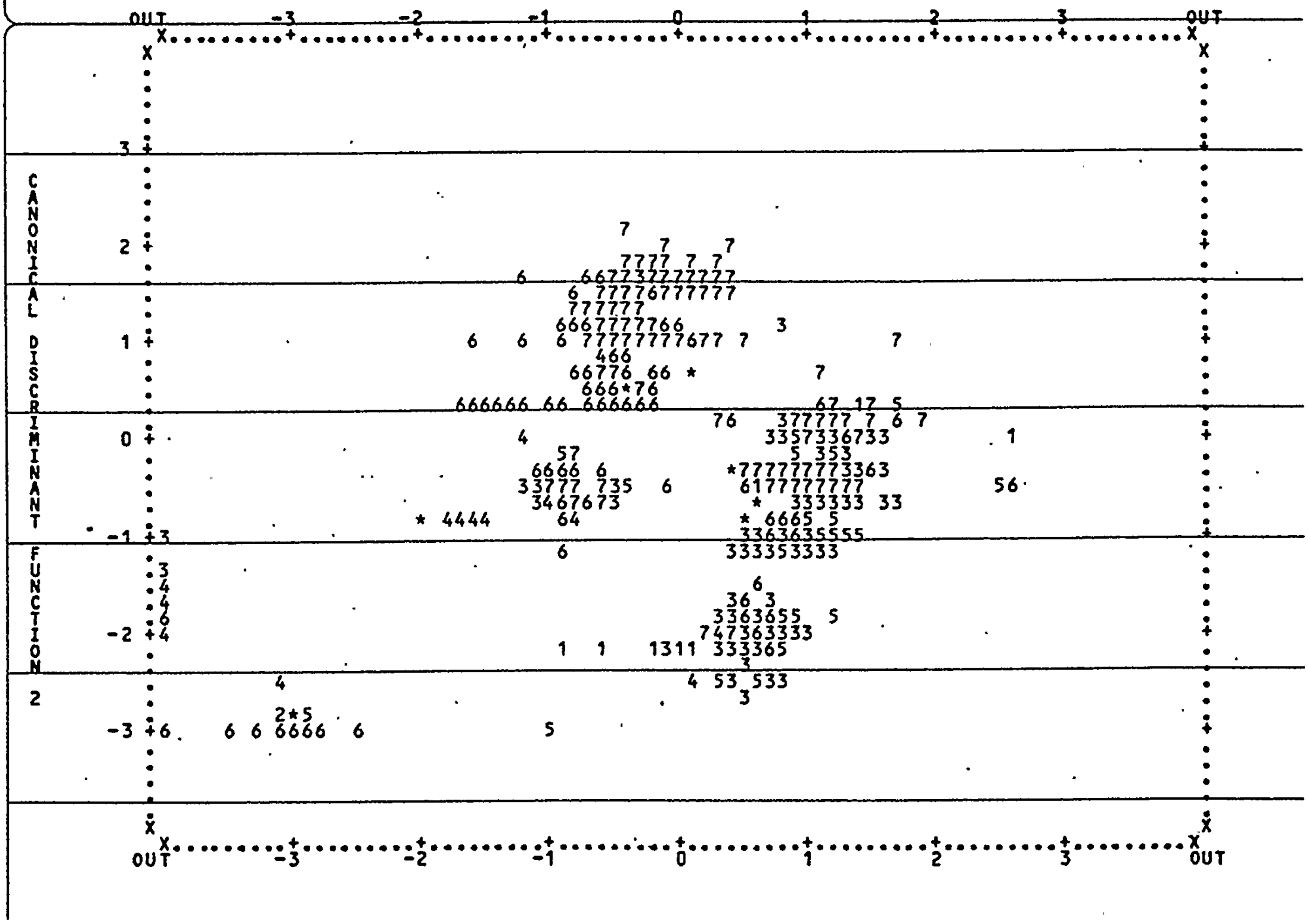
APPENDIX D

Discriminant analysis results - all groups scatterplot and classification results. Both the all-groups scatterplot and classification results (35.75 per cent correctly classified) indicates a high degree of inconsistency in the classification procedure. This signifies that the main sources of variation occur within each year and not between the years.

DISCRIMINANT ANALYSIS BY YEAR (1973 - 1980) 08/18/86

ALL-GROUPS SCATTERPLOT - * INDICATES A GROUP CENTROID

CANONICAL DISCRIMINANT FUNCTION 1



DISCRIMINANT ANALYSIS BY YEAR (1973 - 1980) 08/18/86

CLASSIFICATION RESULTS -

ACTUAL GROUP		NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3	4	5	6	7
GROUP 1973	1	62	45 72.6%	0 0.0%	5 8.1%	0 0.0%	3 4.8%	7 11.3%	2 3.2%
GROUP 1974	2	3	0 0.0%	3 100.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%	0 0.0%
GROUP 1975	3	319	112 35.1%	4 1.3%	46 14.4%	39 12.2%	62 19.4%	29 9.1%	27 8.5%
GROUP 1976	4	65	5 7.7%	15 23.1%	1 1.5%	28 43.1%	3 4.6%	10 15.4%	3 4.6%
GROUP 1978	5	106	17 16.0%	5 4.7%	10 9.4%	1 0.9%	55 51.9%	12 11.3%	6 5.7%
GROUP 1979	6	259	19 7.3%	13 5.0%	14 5.4%	11 4.2%	18 6.9%	121 46.7%	63 24.3%
GROUP 1980	7	246	56 22.8%	0 0.0%	15 6.1%	6 2.4%	11 4.5%	77 31.3%	81 32.9%

PERCENT OF "GROUPED" CASES CORRECTLY CLASSIFIED: 35.75%

CLASSIFICATION PROCESSING SUMMARY

1167 CASES WERE PROCESSED.
107 CASES WERE EXCLUDED FOR MISSING OR OUT-OF-RANGE GROUP CODES.
1060 CASES WERE USED FOR PRINTED OUTPUT.