Environmental
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048 Long-Range Prediction of Grand Banks Iceberg Season Severity:

A Statistical Approach

Canada

October 1986

Environmental Studies Revolving Funds

Report No. 048

October 1986

Long-Range Prediction of Grand Banks Iceberg Season Severity: A Statistical Approach

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The correct citation for this report is:

Davidson, L.W., W.I. Wittmann, L.H. Hester, W.S. Dehn, J.E. Walsh and E.M. Reimer, 1986. Long-Range Prediction of Grand Banks Iceberg Season Severity: A Statistical Approach. Environmental Studies Revolving Funds, Report No. 048. Ottawa.

Published under the auspices
of the Environmental Studies
Revolving Funds

ISBN 0-920783-47-3

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ACKNOWLEDGEMENTS

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The technical direction of the ESRF scientific authority Mr. Oleh Mycyk is gratefully acknowledged, as is the beneficial technical commentary provided by J.D. Miller of Petro-Canada and J.R. Marko of Arctic Sciences Ltd. Appreciation is also expressed for insights provided by the external reviewers, A.H. El-Shaarawi (of the National Water Research Institute, Canada Centre for Inland Waters) and Clement Chouinard (of Recherche en Prévision Numérique, Service de L'environnement Atmosphérique).

Executive Summary

Two complementary statistical methods have been applied to develop long-range prediction models for the occurrence of icebergs on the Grand Banks. The annual flux of icebergs across latitude 48°N is predicted on the basis of correlations between the historical (1951-1984) iceberg flux and selected atmospheric pressure and temperature fields.

Firstly, a statistical correlation approach isolates geographical locations from a 540 point northern hemispheric grid where particular time averages of mean sea level pressure anomaly and 700 mb geopotential height anomaly are highly correlated with the iceberg severity index. Rigorous Monte Carlo tests are imposed to ensure the statistical significance of selected predictors. These predictors are then input to a multiple regression equation to forecast iceberg severity.

Three-point multiple regression models are applied for groupings of October to March mean sea level pressure (MSLP) and December to January 700 mb height. A coarse measure of predictive skill is obtained by dividing the forecast domain (of 30 years duration) into terciles (10 least severe, 10 moderate, and 10 most severe years), and considering tercile errors in the hindcast. Using a dependent verification scheme, in which the hindcast is tested for those same years which contributed data to the model development, the two illustrated cases yield tercile errors as noted following:

6 months March MSLP	Tercile Errors	2 months, January 700 mb Height
22 cases	0 category error	18 cases
8 cases	1 category error	12 cases
0 cases	2 category error	0 cases

Secondly, the method of Empirical Orthogonal Function (EOF) analysis is applied to fields of monthly mean sea level pressure (MSLP), 700 mb height (HEIGHT), 700-1000 mb thickness (THICK) and surface air temperature (SAT). Again correlations are sought between dominant EOF modes for selected time groupings of the atmospheric parameters and the iceberg severity index. Multiple regression models are constructed from

sets of predictors which individually are highly correlated with the ice index but which possess low cross correlations. Employing a fully independent verification scheme, in which the predictive model is tested for years which did not contribute data to the model development, the EOF analysis yields the following tercile error distributions:

2 months Jan MSLP E(1) 2 months Oct HEIGHT E(3) 2 months Dec THICK E(4)		2 months Oct HEIGHT E(3) 2 months Jan MSLP E(1)
	Tercile Errors	
17 cases	0 Category Error	15 cases
10 cases	1 Category Error	12 cases
2 cases	2 Category Errors	2 cases

(The notation E(i) denotes the ith eigenvector).

Both the statistical correlation and the EOF methods show considerable promise in being able to accurately predict Grand Banks iceberg season severity. The EOF methods are shown to be particularly successful in the prediction of extreme ice years.

A secondary investigation considers the role of pack ice in the Davis Strait, Baffin Bay, Labrador Sea region in influencing the occurrence of icebergs on the Grand Banks. This work concludes that although pack ice and iceberg occurrence are correlated, the actual direct effect of pack ice on icebergs is weak. This result lends further credence to the selection of statistical techniques for the forecasting of iceberg season severity.

RESUME

Deux méthodes statistiques complémentaires ont été utilisées pour élaborer un modèle de prédiction à long terme de l'abondance des icebergs sur les Grands Bancs. Ce modèle prédit le flux annuel d'icebergs vers le sud à la latitude 48°N à partir de corrélations entre des données historiques (s'étalant de 1951 à 1984) et des paramètres tirés des champs de pression atmosphérique et de température de l'air.

En premier lieu, une étude de corrélations statistiques permet d'identifier, parmi un réseau de 540 points recouvrant l'hémisphère nord, certains endroits où des moyennes temporelles de l'anomalie de pression atmospherique au niveau de la mer (MSLP) et de celle de l'attitude de l'isobare 700 mb présentent une forte corrélation avec un indice d'abondance des icebergs. Des tests Monte Carlo serrés ont été utilisés pour assurer la significativité des prédicteurs ainsi sélectionnés. Ces prédicteurs sont ensuite insérés dans une equation de régression multiple qui prédit la sévérité en icebergs de la saison prochaine.

Des modèles de régression multiple impliquant trois positions géographiques sont appliqués à des ensembles de données de pression au niveau de la mer (MSLP) allant d'octobre à mars et de données de l'altitude de l'isobare 700 mb portant sur les mois de décembre et janvier. Un index assez grossier du succès des prédictions est obtenu en divisant la période d'intérêt (trente ans) en tiers (les dix années les plus sévères, dix années modérées, les dix années avec le moins d'icebergs) et en se limitant à prédire la position d'une année donnée parmi ces trois classes. Un système de vérification non-indépendant, òu les mêmes années qui ont servi à l'élaboration du modèle servent à en vérifier les prédictions, donne les résultats suivant pour les deux variables prédictives:

MSLP oct-mar.	erreurs de catégorie	alt. 700 mb, dec.-jan.
22 cas	aucune	18 cas
8 cas	erreur d'une catégorie	12 cas
0 cas	erreur de deux catégories	0 cas

En second lieu, nous avons appliqué la méthode des Fonctions Orthogonales Empiriques (EOF) aux champs de pression atmosphérique moyenne au niveau de la mer (MSLP), d'altitude du niveau 700 mb (HEIGHT), d'épaisseur entre les niveaux 700 mb et 1000 mb (THICK) et de la température de l'air au niveau du sol (SAT). De nouveau, nous avons cherché des corrélations entre les modes dominants des EOF des différents paramètres atmospheriques portant sur des périodes de quelques mois d'une part et la valeur du flux d'icebergs d'autre part. Des modèles de régression multiple ont été élaborés à partir d'un ensemble de fonctions prédictives peu corrélées entre elles mais toutes fortement corrélées avec l'indice de l'abondance en icebergs. Un système de vérification indépendant, où le modèle prédictif est testé pour des années n'ayant pas servi à son élaboration donne les résultats suivants, encore une fois pour la prédiction par tiers:

MSLP E(1) dec.-jan. HEIGHT E(3) sep.-oct. THICK E(4) nov.-dec.	erreurs de catégorie	HEIGHT E(3) sep.-oct. MSLP E(1) dec.-jan.
17 cas	aucune	15 cas
10 cas	erreur d'une catégorie	12 cas
2 cas	erreur de deux catégories	2 cas

(Le symbole E(n) dénote le $n^{ième}$ vecteur propre)

Les corrélations statistiques et la méthode des EOF s'avèrent donc toutes deux fort prometteuses pour prédire le flux d'icebergs vers les Grands Bancs. La méthode EOF rencontre un succès particulièrement remarquable à prédire les années de glaces extrêmes (aucune erreur de catégorie).

Une étude secondaire s'est penchée sur l'influence de la présence de glace flottante dans le détroit de Davis, la mer de Baffin et la mer du Labrador sur le nombre d'icebergs parvenant jusqu'aux Grands Bancs. Notre travail conclut que bien que l'on trouve une corrélation entre l'abondance de glace flottante et le nombre d'icebergs, l'influence directe de la glace sur ces derniers est faible. Ce résultat ajoute à la confiance que l'on peut porter à notre choix de méthodes statistiques pour prédire le flux d'icebergs.

1.0 INTRODUCTION

1.1 Statement of Problem

Numerous icebergs calved from the glaciers of western Greenland and the eastern Canadian arctic islands are ultimately advected southwards by winds and currents along the Baffin Island and Labrador coasts. Many of these pieces of glacial ice survive the journey to eventually reach the Grand Banks region where they subsequently decompose. These icebergs constitute a geographically unique threat to exploratory drilling operations at any point along their trajectory. Recent increases in drilling activity on the Grand Banks have rekindled interest in the possibility of being able to accurately forecast the annual flux of icebergs through the region.

As a result of annual surveillance and analysis of iceberg sightings in the North Atlantic throughout this century, by the International Ice Patrol (IIP) of the United States Coast Guard, there exist annual estimates of the flux of icebergs across latitude 48°N. Visual aerial surveillance was introduced in about 1948 and was the primary method of iceberg observation until 1983 when Side Looking Airborne Radar (SLAR) was first employed as a routine operational tool. The consequence is that a reasonably homogeneous data set exists for the years 1948 to 1982. It is accepted that the more recent 1983 to 1985 data are biased high due to the increased detection capability of SLAR. In summary, availability of a time series of annual flux values, of greater than thirty years duration, which illustrates real variability in the severity of iceberg flux at 48°N is noted. It is this signal which a successful forecast (hindcast) method must reproduce.

The premise of this work is that the number of icebergs which reach 48°N in any given year is determined or at least affected by the regional meteorological and oceanographic circulation and temperature fields which influence the bergs during their southward transit. Intuitively, the atmospheric pressure distributions (and hence circulations) are regarded as most important factors. Three dominant physical conditions or processes affecting the abundance of icebergs on the Grand Banks are:

(a) the distribution of icebergs in the Baffin Bay/Davis Strait/etc. source regions in the pre-season (say October to January).

(b) the deterioration of icebergs en route from the source region to the Grand Banks. Clearly, increased rates of deterioration correspond to decreased flux values at 48°N.

(c) the advection or transport efficiency of icebergs from the source regions to the Grand Banks.

At least the latter two of these are intimately connected to the atmospheric and oceanographic conditions encountered by icebergs en route.

The thrust of this study then is to seek quantified relationships between atmospheric conditions and iceberg transport and survival, and to derive a predictive method on the basis of these relationships.

1.2 Historical Perspective

The drift of icebergs from the Arctic to the Grand Banks has been the subject of scientific investigation since the nineteenth century. Rodman (1890) discussed iceberg production and the factors involved in the drift of icebergs from Baffin Bay to the Grand Banks. He identified ocean currents, sea ice and groundings as key factors regulating the arrival time and numbers of icebergs on the Grand Banks. In the first decade of this century there were a number of investigations of the factors responsible for the variations in iceberg population on the Grand Banks (Schott, 1904; Mecking, 1906 and 1907; and Meinardus, 1905). Mecking (1907) proposed the first method for forecasting iceberg populations on the Grand Banks. He identified atmospheric circulation patterns in the previous summer as the key factor responsible for the annual variations in the number of icebergs drifting into the North Atlantic during the following spring.

Smith (1931), after a review of all the previous research and analysis of 50 years of ice and meteorological data, concluded that "an abnormal amount of northwesterly wind during the winter on the American coast south of Baffin Land results in a heavy iceberg season past Newfoundland". After an investigation of a number of factors, Smith developed a regression equation for forecasting purposes which was based on:

(a) the atmospheric pressure difference between Ivigtut (Greenland) and Belle Isle in November to April, preceding the iceberg season off Newfoundland, and

(b) the atmospheric pressure difference between Stykkisholm (Iceland) and Bergen (Norway) in August to January, preceding the iceberg season off Newfoundland.

When used from 1926-1930 to forecast the iceberg population on the Grand Banks, a month prior to the inauguration of the berg season, this methodology gave good results in four of the five years. The only failure was 1929, which later studies (Schell, 1961 and Corkum, 1971) have shown to be an exceptional year. In an analysis of the longer (50 years) record Smith points out that there are occasional great iceberg seasons such as 1909, 1912 and 1929 which come without meteorological warning.

Schell (1952), in one of the few studies to consider the role of ocean currents, concluded that "it would appear that the changes in the current alone are not likely satisfactory to account for all the variations in the berg count. It is worth noticing too that the values of the berg count computed with the aid of the meteorological formula are in about as good an agreement with the actual berg count as the results that may be deduced from the Labrador current". The lack of good long term records of ocean currents has generally excluded this factor from consideration in subsequent studies.

Schell (1962) developed a statistical model for predicting iceberg populations on the Grand Banks using the December to March pressure gradient between Ivigtut and Belle Isle and the temperature at St. John's during the same period. A test of the formula, on a data set separate from the one used to develop the formula, indicated that the method will give the correct sign of the departure from normal in over 80 percent of cases and that the average magnitude of the error on a scale of iceberg populations from 1 to 10, was 1.4. A later test of this formula on a longer data set (Corkum 1971) gave similar results. It should be noted that the largest errors were during World War II when iceberg counting methods were doubtful and 1929 which Smith (1931) identified as an exceptional year.

There are a number of weaknesses in the methods proposed by Smith (1931) and Schell (1962). The main disadvantage for their use in long range forecasting is that they require reliable long range forecasts of pressure patterns before they can be used early in the season (December to February). In addition neither method considers the population and distribution of icebergs in the source areas prior to the start of the season. This was mainly due to the fact that Smith (1931) had no comprehensive surveys of iceberg population at his disposal and Schell had only three years of data from the 1940's. The use of a single Labrador Sea pressure gradient in both methods is also a potential source of error since synoptic patterns exist which can give strong Belle Isle to Ivigtut gradients, yet not be conducive to iceberg transport to the Grand Banks and vice versa.

In the early 1960's the International Ice Patrol (IIP) started to collect regular data on the preseason iceberg population in Baffin Bay and Davis Strait. As early as 1963 (Corwin et al., 1963) the IIP proposed a method for predicting the severity of the coming season based on the preseason populations of icebergs. However, this methodology was questioned in subsequent reports. An analysis of eight years of pre-season flights by Delaney (1971) indicates that there is a good correlation between the iceberg population south of 61°N in February and the subsequent number of icebergs crossing 48°N, however, there is only a weak correlation with the January pre-season data.

The promising results presented in the 1971 report were soon overshadowed by the failure of this method in 1972 and 1973. In 1972 a record number of icebergs drifted south of 48°N while the pre-season flight in January indicated less than average numbers of icebergs south of Cape Dyer, which was the normal area checked by these flights (Scobie, 1975). Unfortunately for the forecasters, the 1972 season was characterized by exceptionally strong pressure gradients along the Labrador coast which transported large numbers of bergs south from areas north of Cape Dyer. A similar situation occurred in 1973 with the added possibility of icebergs from southwest Greenland having been advected south. Circumstances in these two years reveal the main disadvantage of forecasts based on pre-season iceberg populations as being their failure to accomodate years with exceptional transport conditions.

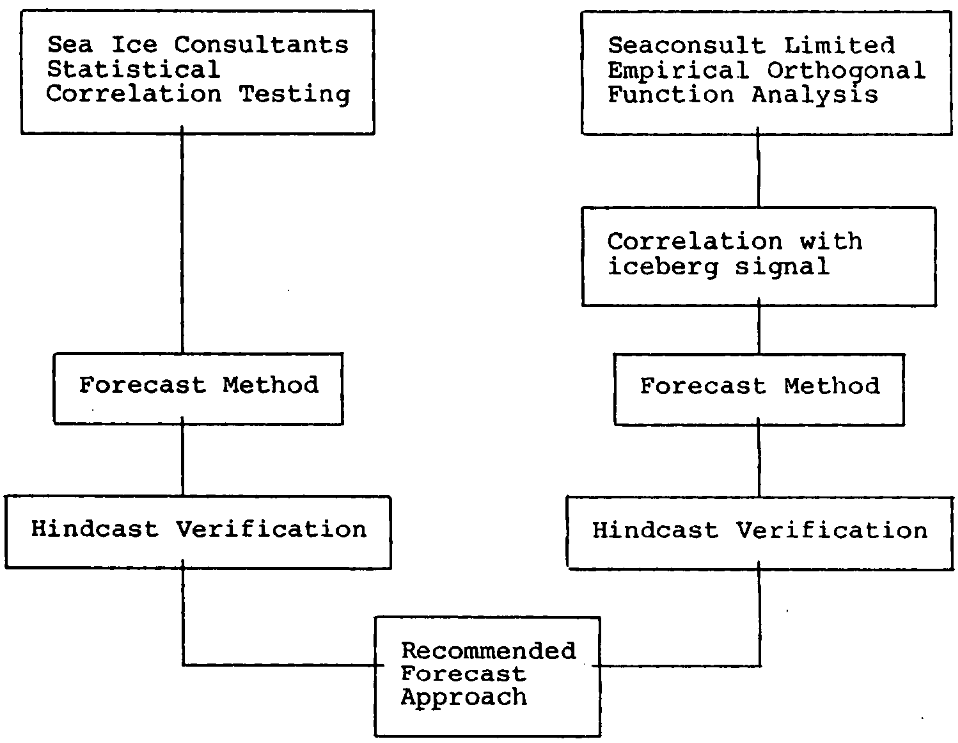
Murty and Bolduc (1975) presented the results of a statistical analysis which attempted to combine the effects of transport and pre-season conditions. They claimed that some of the correlations explain up to 50% of the variance, however no significance levels were quoted. These investigators used as the summer air temperature at Upernavik, Greenland, an indirect index of iceberg supply. Notably, Smith (1931) considered this factor in his analysis and discarded it as unimportant.

Rogers and van Loon (1978) correlated the severity of the Grand Banks iceberg season with the frequency of Greenland above (GA) and Greenland Below (GB) winters (circulation index based on temperatures in Greeland and northwest Europe). They found a statistically significant difference, with GB winters having more severe ice conditions. These results are in agreement with observations made by Smith (1931) regarding the pressure patterns associated with good and bad iceberg years. Smith found that years with a weak Icelandic Low (GA years) have lower iceberg populations on the Grand Banks. The significance of the paper by Rogers and Van Loon lies in showing how this relationship is related to hemispheric circulation patterns through teleconnections.

1.3 Two Complementary Approaches

The conceptual statistical methods employed in this study evolved through an association between Seaconsult Limited of St. John's, Newfoundland and Sea Ice Consultants Inc. of Camp Springs, Maryland. Initial funding allocated to the project was such that Sea Ice

Consultants were to provide subcontract assistance to Seaconsult, the prime contractor. As the technical task assignments were being formulated in early 1985, it became apparent that certain statistical methods which had previously been well researched by Sea Ice Consultants Inc., as well as Empirical Orthogonal Function methods applied by Seaconsult Limited both held considerable promise as forecasting tools. A strategic decision was taken to pursue both approaches in a cooperative, complementary attempt to develop useful predictors. The assigned distribution of responsibilities is best depicted in the following simplified schematic diagram:



Results of the Sea Ice Consultants Inc. investigation of statistical correlation methods constitute Chapter 3 of this report. An independent verification of the resulting forecast method is presented for the 1985 ice season. The empirical orthogonal function methods applied by Seaconsult Limited are documented in Chapter 4 and numerous hindcast verifications of the resulting forecast methods are presented. It is finally in Chapter 5 that the recommended forecast methods are summarized. An operational 1986 forecast appears in Chapter 6. The greater detail in reporting, and the more extensive model verification testing presented by Seaconsult in Chapter 4 than by Sea Ice Consultants in Chapter 3 is fully consistent with the distribution of project funds between the two groups of investigators. Sea Ice Consultants Inc. has in fact contributed a substantial investment of internal research and development funding to complete the investigation documented in Chapter 3 of this report.

An ancilliary question which has been addressed in the course of this study is the role of pack ice in determining the advection and deterioration of icebergs. This investigation, undertaken by Canpolar Consultants Ltd. of St. John's, Newfoundland is documented as Chapter 7 of this report.

2.0 DATA RESOURCES

2.1 Atmospheric Data

Through the courtesy of Dr. John Walsh of the University of Illinois at Urbana-Champaign, the present investigation of long range iceberg forecast methods has benefited from a set of digital atmospheric parameter data bases previously compiled at the National Centre for Atmospheric Research (NCAR). Specifications of these data sets are as follows:

Parameters:	Mean sea level pressure (MSLP) 700 mb geopotential height (HEIGHT) 700-1000 mb thickness (THICK) Surface air temperature (SAT).
Time Interval:	January 1951 to December 1980 (MSLP, HEIGHT and THICK). January 1951 to December 1982 (SAT only).
Frequency:	Monthly.
Spatial Grid:	5° latitude by 10° longitude extending 20°N to 90°N latitude and 0°E to 350°E (10°W) longitude. Each complete grid thus contains 15 x 36 = 540 points .

2.2 Iceberg Data

In response to the sinking of the liner Titanic in 1912 following collision with an iceberg, a patrol of sea ice and iceberg conditions in the northwest Atlantic was initiated. The formal agency tasked with the collection, collation and dissemination of ice information became known as the International Ice Patrol (IIP). Initially, as today, the patrol maintained an almost totally operational mandate. The prime purpose for the collection and collation of iceberg data was for rapid dissemination to real-time users, the foremost of these being North Atlantic merchant vessels.

Enormous uncertainties affect the collection of iceberg distribution data over a region as large and as severe as the North Atlantic. These can be classified primarily as surveillance problems and as uniqueness problems. The surveillance aspects which affect the ability to confirm the presence of ice at a particular location and a particular time are two fold:

- was the given location surveyed (aircraft or vessel) at or near the given time?
- what were the local visibility conditions at that location and time?

Thus, the absence of an iceberg sighting at a given location and time could evolve from any number of circumstances including:

- the location was surveyed with acceptable visibility and no iceberg was present
- the location was surveyed, however poor visibility precluded any assessment of ice presence
- the location was not surveyed.

It is important to note that the data available from the IIP do not resolve these differences: the data explicitly denote those times and locations where targets were sighted, but provide very little if any information about where targets were not located.

Any user of iceberg sighting data must also be familiar with the concept of uniqueness. Simply stated, it is desirable to know if a target sighted at a given location and time has previously been observed, and if so, where and when was this observation made. Even when repeat sightings are noted, it is seldom possible to link a given observation to a specific earlier observation. That is, it may be reported that a given target had earlier been observed, but it is seldom reported where or when that earlier observation took place. A further complication evolves on occasions when numerous vessels or aircraft may be operating in a particular region. In such instances the presence of one iceberg may be reported over some short time interval by more than one observer. Due to navigational errors which are potentially large, such duplicate sightings may actually be reported at distinctly different locations.

Since 1978, assessment of the uniqueness of any individual target has been done operationally. In these more recent years the IIP has maintained a computerized numerical iceberg drift model. All sightings are seeded into the model and forecasts of future positions of these targets are generated. Objective, quantitative criteria are employed to make a preliminary assessment of whether or not a given sighting is to be considered a resighting of a previously identified target or is to be designated as a unique (new sighting). These criteria are specified as follows:

- assume a target is sighted at location P at time T. At a later time, $T + \Delta t$, another target is sighted at a location separated from P by the distance x. Assume in this simplest case that no size or shape information is recorded for either of these sightings.

- the initial sighting is seeded into the IIP drift model and future predicted positions are generated. A 10 nautical mile radius circle is defined around the original sighting location P and is considered valid for the first 24 hours following the initial sighting time T. This radius expands by five nautical miles per day through days two to five to a maximum value of 30 nautical miles.

- if the distance x is less than the radius pertaining to the time $T + \Delta t$, then the second sighting is considered to potentially be a resighting of the first target. In this simplest hypothetical case, with the absence of any information other than time and position, the decision would objectively be made.

- in a more complex situation, assume that shape, size or other ancilliary information were available for the two sightings. If the objective criteria indicated that the second sighting was a repeat of the first, then these ancilliary data would be manually reviewed and a subjective decision would be made to either accept or reject the objectively reached uniqueness conclusion.

- in either instance, the final outcome is a designation of the second sighting as being unique or as being a repeat sighting.

A number of factors have potentially hampered the continuity of IIP practices and procedures. Firstly, it is noted that the agency has undergone various organizational changes and physical relocations during its existence. During the 1950's and early 1960's the Office of Commander, International Ice Patrol operated during the ice season from the United States Naval Station at Argentia, Newfoundland. In 1967, the permanent Office of Commander, IIP was established at Governors Island New York, and the Patrol was directed from Governors Island, still staging from Argentia. The use of Argentia as a primary base was altered somewhat in 1970 when the patrol redeployed to Summerside PEI in mid-season. These two locations were both employed in the ensuing years until 1974 when for the first time the Ice Patrol utilized St. John's almost entirely as its base of operations. Finally, in 1982 the operations base was moved to Gander Newfoundland. Then in 1983 the Office of Commander, IIP was reloated from Governors Island New York to Groton CT.

Secondly, it is recognized that IIP staffing is extremely transient. Coast Guard personnel serve assignments to the IIP of generally less than four years duration. The role of Commander, International Ice Patrol rotates with similar regularity. A practical consequence of this policy is that personnel responsible for determining changes to operational procedures or to data interpretation procedures at a given time would have little or no personal access to those individuals responsible for the collection and analysis of data in earlier years. As all policies, methods, assumptions etc., pertaining to data collection in the earlier years were not rigorously documented, there remains little practical assistance available today to resolve any questions or ambiguities affecting the early data.

One of the interpretive data products provided each season by the International Ice Patrol is an estimate, based upon its analysis of all observational data, of the number of unique icebergs crossing 48°N latitude during the season. The IIP attempts to account for duplicate sightings and for iceberg deterioration in calculating this estimate from its season-long collection of iceberg sighting reports. The 1978 introduction of the drift model into operational use marks the most evident procedural change in the 1950-1985 interval, however discussions with IIP personnel (Commander N. Edwards, 1985 pers. comm.) would suggest that other more subtle changes also took place from year to year. One example is the threshold value for iceberg mass used in defining the number of ice pieces crossing 48°N. A change in this value in 1966 is offered as a possible explanation for the fact that the 1966 Bulletin clearly identifies the presence of pieces of ice south of 48°N and yet quotes a zero value for annual flux across 48°N.

It is this sequence of estimated annual flux values for 48°N latitude which is the root of the iceberg severity index in the present study.

3.0 THE STATISTICAL CORRELATION APPROACH

3.1 Overview

The statistical correlation approach to long-range prediction of iceberg season severity, as developed by Sea Ice Consultants Inc. under subcontract to Seaconsult Limited, is documented in this chapter. The methods are based primarily on a systematic use of surface and 700 mb atmospheric data. Several considerations dictate this reliance upon atmospheric parameters:

(1) **Availability of Data:** Reliable, gridded atmospheric data are far more readily available than are either oceanographic or sea ice cover data. Unlike the oceanographic or sea ice parameters, 30 or more years of monthly atmospheric data are available for the region. This provides a sample large enough for the systematic application of statistical significance testing.

(2) **High Correlation:** Atmospheric variability can be expected to correlate well with oceanic variability at the spatial and temporal scales considered here, as it does in the Bering Sea (Niebauer, 1983). Therefore, atmospheric fields should implicitly describe large portions of the thermal and current regimes.

(3) **Scope of Project:** The funding and manpower constraints of the project demand a highly focused effort toward development of a forecast system capable of straightforward implementation. Many potentially attractive avenues of research are excluded by temporal and fiscal constraints.

The statistical treatments of both predictand and predictor data sets are complicated by several factors. The distribution of the annual iceberg count, for instance, is non-linear and non-normal, while the atmospheric data fields are known to contain high levels of spatial and moderate levels of temporal correlation on the monthly time scale. These and other factors require that statistical procedures be carefully formulated with respect to sample selection, filtering, and regression analysis. To address these difficulties this study has relied heavily on

Monte Carlo testing procedures. These preserve the spatial and temporal dependences of the data in the determination of significance thresholds. Although such an emphasis on significance testing is computationally demanding, it is mandatory in this type of situation, where potentially useful signals may be masked by the large natural variability of the physical system under investigation. For this reason, the following sections contain particularly detailed documentation of the statistical significance tests in addition to examples of the levels of skill achievable by the approach formulated here.

3.2 Procedures

3.2.1 Indexing the Predictand

The annual number of icebergs estimated by the IIP to have crossed south of 48°N latitude for each year from 1947 through 1984 is available as discussed in Chapter 2. The period of the annual count is from 1 September through 31 August. That the distribution of annual values possesses large year-to-year variability and is non-linear and non-normal has previously been stated. For example, while the annual totals range from 0 to more than 2000, 22 of the 38 years have values of less than 160. Assuming that correlative statistics based on this distribution would be biased heavily toward (and dominated by) the few years with large totals, a rank index has been selected for the predictand. This index is derived as shown in Table 3.1. The 30 years, 1955 through 1984, were assumed to be a sample of adequate size for testing, while also having available the most accurate corresponding atmospheric data sets. The most severe case (2204 icebergs in 1984) was arbitrarily assigned a rank of 1, while the mildest year (0 icebergs in 1966) was assigned a rank equal to the sample size of 30. This approach has applied no adjustment to the IIP iceberg totals for the SLAR-supported surveillance years 1983 and 1984.

Due to the obviously non-linear distribution of the predictand, log-normal and power transformations were applied to the predictand. In preliminary tests, such transformations produced correlations generally similar to, but not significantly better than, those obtained with the

Table 3.1

Severity Index (Rank) of Iceberg Years

(1 = most severe)

Year	IIP Iceberg Count	Severity Index (Rank)
1984	2204	1
1972	1584	2
1974	1386	3
1983	1351	4
1957	931	5
1973	846	6
1959	689	7
1967	441	8
1964	369	9
1960	256	10
1968	226	11
1982	188	12
1979	152	13
1976	151	14
1962	121	15
1961	114	16
1975	100	17
1970	85	18
1956	80	19
1965	76	20
1978	75	21
1971	73	22
1981	63	23
1955	61	24
1969	53	25
1963	25	26
1980	24	27
1977	22	28
1958	1	29
1966	0	30

NOTE: The IIP has estimated the 1985 iceberg count to be 1031, which would make it fifth (of 31 cases).

IIP berg counts are from 1 September through 31 August annually.

rank index. The rank index has the advantage that errors in forecast rank can be readily interpreted within a categorical framework (e.g., terciles, quintiles, etc.).

3.2.2 Selecting the Predictors

This procedure is predicated on the assumption that atmospheric circulation data represent the most effective source of predictive information. This assumption is valid insofar as the dynamic and thermodynamic forcing of oceanic and sea ice fluctuations are atmospheric in origin. The essential element of atmospheric forcing is the large-scale circulation, which determines the surface thermal regime (via temperature advection) as well as the dynamic regimes of sea ice, icebergs, and the near-surface ocean layer. The dynamic role follows from the fact that wind stress is the primary motive force for sea ice and for surface currents in the ocean. Such considerations dictate the use of sea level pressure data. It is noted that the use of grids of sea level pressure (or of geopotential height in upper air fields) are implicitly equivalent to the use of wind or circulation data, as the geostrophic winds are directly proportional to the gradients in these fields.

The requirement for lead times of several months or seasons in long-range forecasting introduces a reliance on large-scale atmospheric teleconnections as a forecast tool (Namias, 1972). Teleconnections to remote regions have recently been shown to represent predictive signals at lead/lag times of up to several seasons (the Southern Oscillation for example, (Horel and Wallace, 1981)). These teleconnections are most readily detectable in data for the upper air, where surface-induced perturbations of large-scale signals are minimal. Gridded data for the geopotential height of the 700 mb level have been used in this application. This is generally considered to be most representative of the vertically averaged tropospheric circulation.

The monthly gridded data, as discussed in Chapter 2, were obtained from the National Center for Atmospheric Research (NCAR) in a 5° latitude by 10° longitude format spanning the area from 20°N to the North Pole. Each grid thus contains a total of 540 data points. Monthly NCAR grids are available through 1982. Grids for the years 1983 and 1984 were derived from the National Weather Service/NOAA monthly printouts.

Two distinct predictor selection techniques were applied. First, a linear correlation of each grid point with the iceberg index over the 30-year sample was computed. In a second and separate approach, a composite difference of the grid data between the mild and severe iceberg years was constructed. Each of the two approaches was applied to both the sea level (MSLP) and 700 mb grids. Numerous periods and lag times were considered in that the atmospheric data were averaged over all periods of 1-7, 9, 12, and 24 months ending each month from May of the preceding year through April of the current year. The data were staggered in this fashion to meet operational requirements, because forecasts issued after April are of little practical value to users.

The statistical significance of the predictor field was of overriding concern in the development of the forecast system. Specifically, if field significance could not be demonstrated, then the existence of a predictive signal (and the validity of any derived forecast model) was considered highly uncertain. Therefore, each grid of point correlations or of composite differences was tested for field significance as follows:

(1) The statistical significance of each grid point value in the field was determined. For the linear correlations, the significance test was based on the sample size and on the null hypothesis of zero correlation. In the case of composite difference fields, significance level was obtained from a two-tailed t-test and the null hypothesis of zero difference.

(2) The areal fraction of the domain over which the point values were statistically significant was computed. The number of point values was converted to an areal fraction by the application of a latitudinal cosine weighting factor. The areal fractions were computed for an Arctic subset (65°N - 90°N) of the grid as well as for the entire grid.

(3) The probability of achieving the areal fractions obtained in step (2) by chance was evaluated with a series of from 100 to 500 Monte Carlo trials. The element of chance was introduced into the Monte Carlo trials by randomly reordering the predictand time series. Any desired significance level could then be determined by ordering the Monte Carlo results in order of decreasing areal fractions of point significance (e.g., in a trial of 100 runs, the 5th highest areal fraction corresponds to the 5% level of significance). Although they introduce substantial computational requirements, Monte Carlo tests represent the most rigorous estimates of significance because of their fidelity to the statistical forecasting procedure and to the distribution of the data, whether normal or otherwise, (Livezey and Chen, 1983).

Once a given field passed the Monte Carlo test, the individual grid point values were evaluated to select a number of individual predictor points for inclusion in the multiple regression. This subsampling of available predictor points was necessary both because of the spatial and temporal coherence of the data (i.e. the relatively high correlation between adjacent points) and because of the prohibitively large numbers of predictors (540) in each grid. Various objective criteria were employed, in attempting to maximize the spatial and temporal independence of the subjectively selected predictors. These criteria were:

(1) To insure spatial independence, a point was required to be a relative maximum or minimum (correlator or t-value) within its field.

(2) The point was required to exceed the threshold values for significance in its own right.

(3) When an otherwise successful point predictor occurred in two fields having overlapping periods, only that predictor with the higher correlation and/or t-value was selected.

This rule could, however, be superceeded by an operational requirement for greater forecast lead time: although a particular time combination would not yield the best possible prediction from a given point, it may have been the best predictor available at the time the forecast had to be issued. For example, a point may correlate at 0.74 for the 6-month period ending in April, while the 3-months ending in February for the same point correlates at 0.68. In this case, the additional lead time between February and April (when the data become available) more than offsets the difference in predictability implied by the lower correlation.

3.2.3 Multiple Regression

The procedure described above generally extracted from two to five points. These were then used as the predictor points for the iceberg rank index in a multiple linear regression equation obtained by running the International and Mathematical Software Library (IMSL) subroutine RLMUL. The equation thus produced was used to generate hindcasts of the iceberg index for the 30 years in the sample, and to predict the next year's rank. Numerous combinations of potential predictors were tested. Results for only the most successful of these predictor combinations are presented.

3.3 Results

3.3.1 The 30-Year (1955-1984) Correlation Sample

Following the above described procedures, correlations between iceberg rank and MSLP (as well as 700 mb) were computed for various periods ending in each month from the preceding May through the current April. The locally significant areal fraction of each grid and its Arctic subset were computed, as quoted in Tables 3.2(a) and 3.2(b). The Arctic subset was included for procedural consistency with experiments performed for the Alaskan North Slope. A possibly more suitable approach would have been to use a subset of grid points centered on the Baffin Bay-Davis Strait area to determine a local signal in the correlation grids.

Table 3.2(a)

Areal Fraction (percent) of MSLP Grids having Statistical Significance where N = 30

Prestige elite = entire grid (20-90N)

Italics = Arctic Subset (65-90N)

# Months in Period	Ending month of period											
	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
1	3.7	0.3	0.2	0.3	0.0	5.8	0.0	1.5	17.8	0.5	0.8	0.5
	1.1	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*27.9*	*2.8*	*0.0*	*0.0*
2	0.5	1.9	0.0	0.0	0.0	2.6	3.6	2.4	12.1	14.3	2.4	1.3
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*9.1*	*28.3*	*6.7*	*0.0*
3	0.9	0.7	1.2	0.0	0.0	0.9	2.4	5.2	12.2	14.4	13.6	3.1
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*4.9*	*15.8*	*31.9*	*5.3*
4	0.8	0.6	1.0	1.3	0.0	1.1	1.1	3.1	13.1	15.9	14.6	13.3
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*19.9*	*23.2*	*24.7*
5	1.4	0.4	0.3	1.0	1.0	0.0	1.0	2.6	10.9	17.6	14.2	15.7
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.4*	*13.3*	*28.4*	*21.0*
6	2.0	1.6	0.4	0.3	0.5	1.0	0.5	1.3	9.6	15.1	19.0	14.9
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*2.7*	*13.7*	*27.9*	*24.2*
7	3.5	1.9	0.8	0.0	0.3	0.4	1.0	1.1	7.0	15.4	15.5	17.2
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*5.1*	*18.0*	*28.2*	*24.7*
9	2.4	2.4	3.3	0.9	0.2	0.2	0.9	0.8	9.0	11.5	15.9	16.6
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.3*	*12.0*	*33.6*	*31.1*
12	1.9	2.3	2.8	1.8	1.0	1.7	0.5	0.2	4.8	9.0	9.8	15.0
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*12.6*	*20.3*	*28.7*
24	1.5	1.5	1.2	1.2	1.2	0.6	1.4	0.9	0.9	1.4	2.1	1.0
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*

Table 3.2(b)

Areal Fraction (percent) of 700 mb Grids having Statistical Significance where N = 30

Prestige Elite = entire grid (20-90N)

Italics = Arctic Subset (65-90N)

# Months in Period	Ending month of period											
	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
1	2.8	0.5	0.4	1.4	0.1	5.7	0.0	1.4	14.7	0.0	2.6	0.2
	0.0	*0.0*	*0.0*	*0.7*	*0.9*	*1.8*	*0.0*	*0.0*	*21.7*	*0.0*	*0.9*	*0.0*
2	1.0	1.2	0.5	0.7	0.2	1.5	2.1	0.9	8.5	13.7	3.5	3.1
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*5.7*	*26.3*	*6.3*	*1.8*
3	1.0	1.6	1.4	0.0	0.6	1.1	2.8	2.7	11.0	11.3	15.8	6.1
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*4.0*	*0.0*	*0.0*	*10.4*	*15.7*	*2.9*	*7.0*
4	0.4	0.8	1.1	0.8	0.0	0.7	1.8	2.5	10.0	12.8	13.0	14.2
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*4.5*	*3.2*	*0.0*	*6.4*	*17.0*	*17.7*	*23.8*
5	0.4	0.4	0.7	0.8	0.7	0.0	1.0	3.0	10.8	13.5	13.7	12.3
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*3.2*	*0.0*	*6.6*	*18.2*	*19.5*	*17.7*
6	1.7	0.7	0.2	0.5	0.5	0.0	0.0	1.8	10.5	11.8	14.9	13.2
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*9.0*	*15.5*	*22.0*	*20.3*
7	1.5	0.9	0.3	0.0	0.5	0.0	0.0	1.1	8.0	12.8	15.3	15.2
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*10.3*	*17.4*	*20.0*	*23.1*
9	0.5	0.5	0.5	0.5	0.2	0.0	0.0	1.1	7.7	8.4	15.0	15.5
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*9.7*	*13.2*	*26.4*	*25.6*
12	0.5	0.5	0.2	0.0	0.0	1.1	0.8	0.0	3.3	8.1	10.5	13.5
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*6.9*	*15.2*	*18.3*	*19.7*
24	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	3.6	2.7
	0.0	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*7.5*	*2.5*

In Tables 3.2(a) and 3.2(b), a general lack of skill is apparent in the early months (May - October of the previous year). Most entries for these months are at or near zero, but the values rise noticeably during winter. This tendency is generalized in Fig. 3.1, which shows the average areal fraction of all periods for each month for the MSLP grid and its Arctic subset. Although only the MSLP plot is shown, a corresponding plot for 700 mb height produces quite similar results.

The lag between the abrupt jump in predictability and the occurrence of maximum monthly iceberg totals (i.e., the lag between the December-February period in Fig. 3.1 and the April-June period) indicates that the achievable range of predictability in the system is probably on the order of 4 to 6 months.

The most promising entries from Tables 3.2(a) and 3.2(b) were subjected to Monte Carlo testing. Monte Carlo thresholds for 10%, 5%, 2%, and 1% significance are compared against observed areal fractions for selected grids in Fig. 3.2. One hundred trials were run for each case except for the 6-months ending in March MSLP, where 500 trials were run. While several of the tested fields clearly fail the Monte Carlo tests (e.g., 1-month 700 mb ending in May), other fields pass the test, even at the 1% significance level (e.g. 6-month MSLP ending in March and 2-month 700 mb ending in January). These Monte Carlo trials led to the selection of two fields for predictive application:

(1) 6-month MSLP ending in March

(2) 2-month 700 mb height ending in January

For purposes of illustration, the 6-month MSLP-March case is emphasized in the following discussion. In this case Fig. 3.2 shows that the field exceeds the Monte Carlo threshold at 1% significance by a wide margin. The second case (2-month 700 mb-January) narrowly exceeds the 1% threshold; but it provides two months additional forecast lead time, and is valuable for that reason.

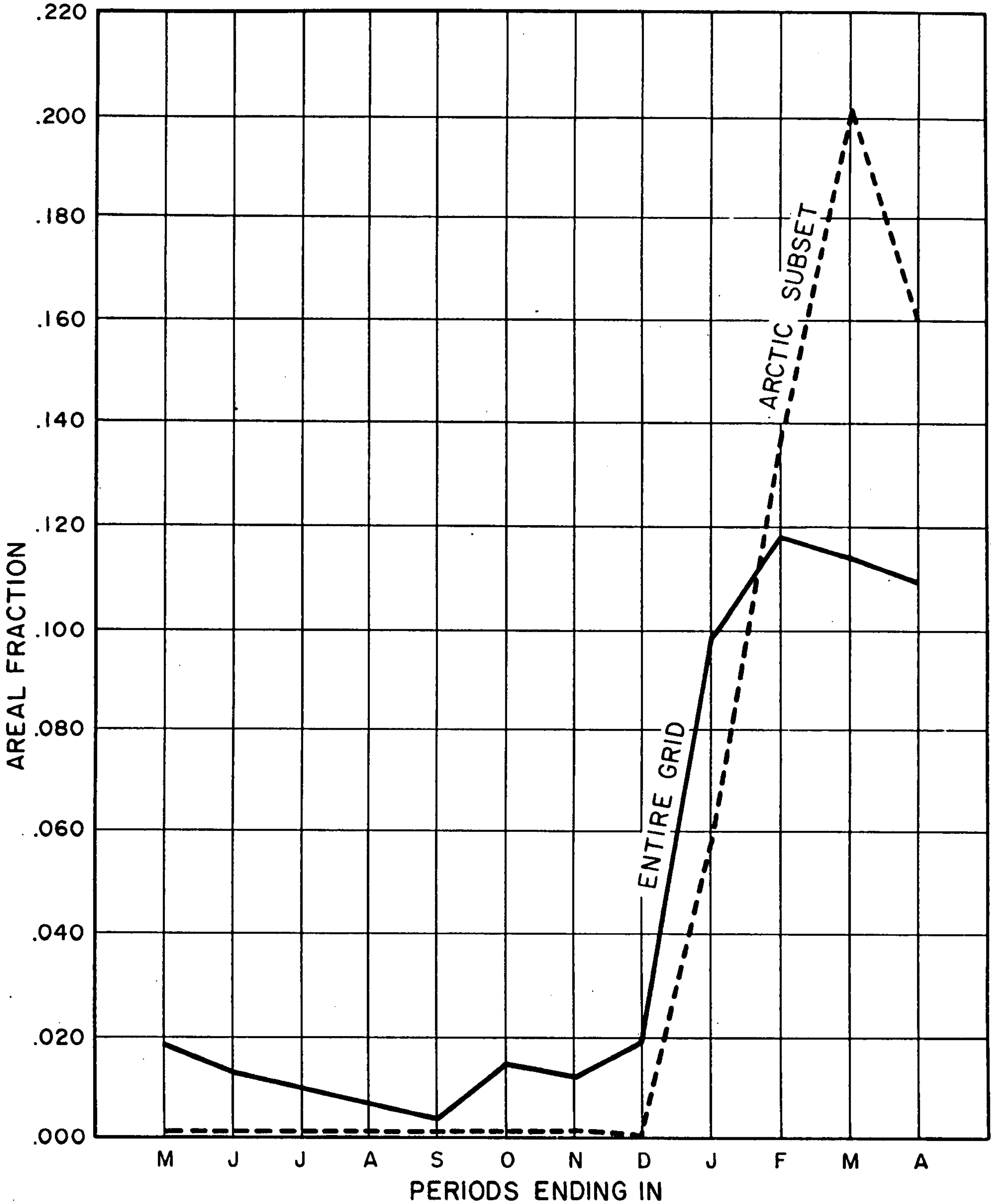


Fig. 3.1 Areal fraction of grid region possessing significant correlation with ice index as a function of lead time.

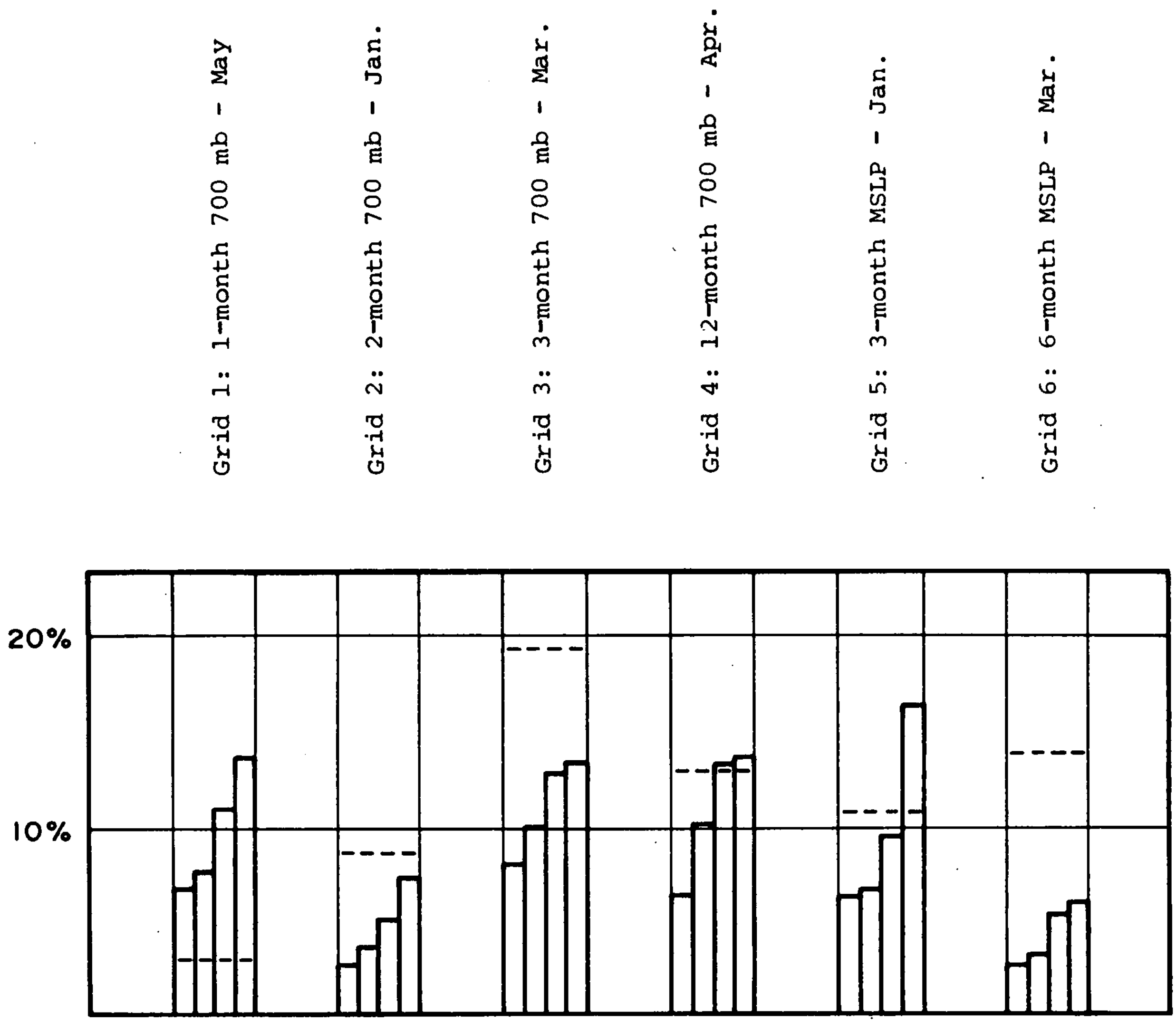


Fig. 3.2 Monte Carlo Thresholds vs. Observed Areal Fractions

In Fig. 3.2, the four bars for each grid represent the areal fraction thresholds obtained from the respective Monte Carlo run. For each grid, the thresholds are (from left to right): 10%, 5%, 2%, and 1% significance. There were 100 Monte Carlo trials run for each of grids 1 through 5, while there were 500 trials run for grid 6. The dashed line across all 4 bars represents the observed areal fraction for that grid. When, for a given grid, the dashed line lies at a higher areal fraction than does a given bar, it is interpreted that the observed correlations are statistically significant, at the indicated level.

Correlation grids for the two selected predictor fields are included as Tables 3.3(a) and 3.3(b). (In the original computer runs, the order of the iceberg rank was reversed. Although this changes the sign of the correlation, the absolute value and the significance levels of the correlation are unaffected.)

Case 1. 6-Month MSLP-March Correlation Field

This correlation grid (Table 3.3(a)) is characterized by significant negative correlations (low MSLP in severe iceberg years) in Canadian Arctic and the North Atlantic subarctic areas, and by significant positive correlations (high MSLP in severe iceberg years) in the subtropical and mid-latitude Atlantic. This north-south Atlantic anomaly gradient corresponds to the North Atlantic seesaw documented by van Loon and Rogers (1978) and by others.

Applying the criteria of Section 3.2.2 yields the following points as predictors for use in the regression equation:

(a) 40°N 330°W: $r = +.70$ (high MSLP in severe iceberg year)
(b) 45°N 340°W: $r = +.70$ (high MSLP in severe iceberg year)
(c) 40°N 60°W: $r = +.65$ (high MSLP in severe iceberg year)

The behaviour of the three-point multiple regression model developed using these points is summarized in Table 3.4. Regression statistics are quoted and the 30 years of observed and predicted iceberg rank are compared. Absolute hindcast error statistics derived from the predictions in Table 3.4 include:

Hindcast Errors	
Mean absolute rank error	4.73 ranks
Median absolute forecast rank error	4.50 ranks
Correlation (forecast versus observed rank)	0.77

A coarse measure of predictive skill is obtained by dividing the forecast domain into terciles (10 least severe, 10 moderate, 10 most severe years) and considering the tercile errors in the hindcast. From Table 3.4, for the 6-month MSLP-March predictor, these are:

Table 3.3(a)

6-months MSLP ending March: 30-year (1955-84) correlation grid results.

LONG	20N	25N	30N	35N	40N	45N	50N	55N	60N	65N	70N	75N	80N	85N	90N
360W	.50	.52	.46	.47	.56	.54	.49	.29	-.03	-.32	-.47	-.55	-.55	-.55	-.48
350W	.39	.45	.56	.58	.63	.60	.55	.30	-.08	-.20	-.35	-.52	-.56	-.54	-.48
340W	-.40	.34	.58	.66	.67	.70	.57	.24	.01	-.25	-.35	-.51	-.57	-.54	-.48
330W	.36	.33	.51	.61	.70	.65	.38	.08	-.06	-.23	-.34	-.47	-.56	-.53	-.48
320W	.34	.39	.40	.46	.67	.52	.11	-.07	-.17	-.24	-.35	-.46	-.55	-.53	-.48
310W	-.08	-.04	.48	.51	.34	.23	-.08	-.23	-.28	-.33	-.41	-.46	-.51	-.52	-.48
300W	.16	.27	.24	.40	.28	.05	-.24	-.33	-.35	-.48	-.46	-.46	-.49	-.51	-.48
290W	.32	.34	.34	.35	.37	.15	-.28	-.33	-.34	-.38	-.44	-.45	-.48	-.50	-.48
280W	.08	.20	.28	.29	.32	.19	-.28	-.31	-.31	-.34	-.43	-.45	-.48	-.49	-.48
270W	.18	.25	.14	.15	.31	.10	-.16	-.26	-.27	-.30	-.40	-.44	-.46	-.47	-.48
260W	.17	.35	.17	.16	.26	.33	.07	-.09	-.23	-.32	-.35	-.42	-.45	-.45	-.48
250W	-.02	-.10	.12	.18	.20	.36	.17	-.06	-.23	-.38	-.38	-.40	-.42	-.43	-.48
240W	.19	.37	.35	.39	.44	.30	.19	.00	-.15	-.18	-.36	-.36	-.39	-.41	-.48
230W	.09	.20	.43	.25	.39	.06	.23	.12	-.19	.00	-.29	-.34	-.38	-.40	-.48
220W	.12	.14	.13	.25	.15	.20	.00	.06	.19	-.21	-.24	-.34	-.37	-.38	-.48
210W	.19	.18	.07	.12	.09	.00	.20	.37	.28	-.13	-.14	-.32	-.36	-.38	-.48
200W	.13	.03	-.12	-.15	-.12	-.09	.12	.32	.31	.07	-.03	-.29	-.35	-.38	-.48
190W	.07	-.08	-.16	-.18	-.13	-.07	.18	.33	.37	.02	-.07	-.24	-.34	-.39	-.48
180W	.12	-.03	-.10	.12	.00	.03	.14	.28	.33	.12	.05	-.19	-.34	-.40	-.48
170W	.09	.00	-.04	.00	.05	.09	.19	.28	.36	.37	.15	-.16	-.34	-.41	-.48
160W	.23	.15	.04	.08	.10	.10	.20	.25	.26	.39	.27	-.15	-.35	-.43	-.48
150W	.27	.31	.25	.24	.21	.19	.23	.29	.29	.32	.36	-.16	-.38	-.45	-.48
140W	.26	.32	.29	.27	.22	.19	.16	.15	.12	.25	.31	-.19	-.41	-.48	-.48
130W	.15	.16	.10	.10	.17	.22	.13	-.06	-.10	.10	.15	-.27	-.44	-.50	-.48
120W	.19	.25	.13	.06	.00	.00	-.11	-.19	-.05	.05	-.04	-.37	-.48	-.52	-.48
110W	.26	.26	.30	-.20	-.19	-.17	-.22	-.24	-.19	-.22	-.29	-.43	-.51	-.54	-.48
100W	.05	.12	.26	-.15	.29	.25	-.21	-.21	-.21	-.28	-.36	-.42	-.51	-.56	-.48
90W	-.13	-.21	-.27	-.23	-.02	.15	.08	-.03	-.06	-.26	-.39	-.44	-.53	-.57	-.48
80W	.11	-.11	.09	.34	.45	.55	.46	.28	.03	-.26	-.43	-.48	-.55	-.58	-.48
70W	.19	.44	.50	.58	.59	.62	.51	.26	.01	-.33	-.47	-.45	-.55	-.59	-.48
60W	.24	.45	.56	.60	.65	.63	.49	.23	.11	-.38	-.45	-.49	-.56	-.59	-.48
50W	.22	.35	.49	.58	.61	.55	.37	.02	-.34	-.48	-.50	-.49	-.55	-.57	-.48
40W	.21	.35	.44	.53	.58	.49	.30	-.12	-.56	-.67	-.59	-.48	-.53	-.55	-.48
30W	.15	.32	.43	.52	.52	.44	.32	.05	-.40	-.62	-.65	-.57	-.54	-.55	-.48
20W	.37	.42	.49	.52	.51	.45	.36	.17	.29	-.69	-.65	-.62	-.55	-.55	-.48
10W	.40	.53	.48	.48	.48	.48	.43	.23	-.18	-.53	-.60	-.58	-.54	-.55	-.48

Table 3.3(b)

2-months 700mb ending January: 30-year (1955-84) correlation grid results.

LONG	20N	25N	30N	35N	40N	45N	50N	55N	60N	65N	70N	75N	80N	85N	90N
360W	.00	.08	.31	.30	.36	.41	.38	.26	.07	-.09	-.12	-.09	-.06	-.13	-.01
350W	.04	.09	.24	.41	.51	.51	.43	.30	.12	.01	-.04	-.03	-.01	-.10	-.01
340W	.14	.18	.31	.48	.53	.47	.35	.23	.11	.04	.01	.00	02	-.09	-.01
330W	.06	.05	.18	.35	.43	.30	.17	.08	.03	.01	.00	.01	.04	-.07	- 01
320W	-.05	-.16	-.31	-.15	-.02	-.05	-.16	-.17	-.14	-.08	-.02	.01	.04	- 06	-.01
310W	-.14	-.33	-.43	-.37	-.26	-.34	-.39	-.35	-.28	-.16	-.05	.03	.04	- 06	- 01
300W	.10	.03	-.24	-.38	-.34	-.42	-.43	-.40	-.31	-.18	- 06	.02	04	-.06	- 01
290W	.47	.20	-.06	-.26	-.35	-.33	-.31	-.30	-.22	-.14	-.06	-.01	.03	.06	- 01
280W	.22	.11	-.10	-.22	-.08	-.06	-.07	-.11	-.10	-.09	-.07	-.04	.00	-.07	-.01
270W	.16	.02	-.17	-.10	.08	.12	.12	.03	-.01	-.05	-.06	-.07	-.03	- 08	- 01
260W	-.11	-.18	-.07	.11	.28	.28	.29	.25	.11	.04	-.03	-.09	-.06	- 09	-.01
250W	-.12	-.03	-.03	.08	.38	.44	.45	.35	.15	.04	-.04	-.10	-.08	- 10	-.01
240W	-.08	.04	.19	.29	.40	.52	.56	.38	.13	-.03	- 09	-.14	-.10	- 12	- 01
230W	.00	.10	.24	.33	.38	.43	.50	.29	.02	-.11	-.16	-.17	-.11	-.13	- 01
220W	.10	.20	.18	.20	.25	.25	.20	.01	-.16	-.19	-.22	-.20	-.12	- 13	-.01
210W	.15	.14	.17	.14	.13	.09	.01	-.09	-.18	-.18	-.23	-.19	-.11	-.14	-.01
200W	.18	.18	.17	.12	.03	.01	-.06	-.10	-.12	-.14	-.19	-.17	-.10	- 15	- 01
190W	.17	.18	.15	.09	.01	-.01	-.06	-.07	-.08	-.09	-.13	-.12	-.08	-.16	-.01
180W	.05	.18	.14	.07	.03	.01	-.02	-.02	-.02	-.02	-.04	-.05	-.05	- 16	-.01
170W	.08	.14	.12	.08	.02	.03	.02	.04	.04	.04	.04	-.01	-.05	-.17	- 01
160W	.20	.20	.13	.08	.00	.04	.05	.10	.12	.11	.09	.04	-.03	-.18	- 01
150W	.23	.32	.25	.19	.12	.13	.12	.15	.20	.16	.10	.03	- 05	- 19	-.01
140W	.30	.41	.41	.33	.24	.18	.14	.11	.15	.15	.09	.01	-.06	- 20	- 01
130W	.25	.25	.32	.28	.16	.08	.02	.01	.02	.07	-.02	-.07	-.10	- 20	- 01
120W	.29	.15	.20	.06	.00	-.04	-.05	-.05	-.10	-.15	-.14	-.13	- 13	- 21	- 01
110W	.13	.17	.01	-.20	-.25	-.22	-.21	-.27	-.39	-.37	-.27	-.20	-.16	- 22	-.01
100W	.27	.17	.02	-.09	-.07	-.11	-.22	-.36	-.43	-.41	-.35	-.26	-.20	- 23	-.01
90W	.28	.45	.45	.40	.34	.18	-.10	-.29	-.37	-.39	-.37	-.30	- 24	- 24	-.01
80W	.52	.57	.62	.59	.50	.30	-.07	-.29	-.42	-.44	-.44	-.37	- 29	- 25	- 01
70W	.46	.66	.69	.68	.01	.41	.03	-.33	-.49	-.51	-.47	-.39	-.30	- 24	-.01
60W	.33	.59	.69	.67	.55	.32	-.09	-.46	-.60	-.58	-.51	-.41	-.31	- 24	- 01
50W	.16	.32	.41	.65	.44	.17	-.19	-.52	-.61	-.57	-.50	- 41	- 31	-.23	-.01
40W	.02	.12	.34	.45	.36	.12	-.17	-.46	-.54	-.51	-.45	-.38	-.28	-.22	- 01
30W	.06	.13	.31	.30	.29	.12	-.06	-.30	-.44	-.44	-.39	-.33	-.24	-.20	-.01
20W	.12	.14	.30	.35	.27	.18	.09	-.09	-.28	-.35	-.32	-.24	-.18	-.18	- 01
10W	.03	.12	.23	.30	.31	.28	.22	.09	-.10	-.24	-.22	-.17	-.12	-.16	- 01

Table 3.4

Multiple Regression of 6-Month MSLP
March Field Vs. Iceberg Rank (1955-1984)

Regression Statistics:

Coefficient of Determination(r^2)...	0.59
Coefficient of Multiple Correlation .	0.77
Standard Error of Estimate	5.90
F-Ratio (Regression)	12.83
Probability of Chance	0.00009
Number of Cases	30

Regression Coefficients:

	Variable	Mean MSLP (mb-1000)	S.D.	Coefficient
	Constant			89.8174
(a)	40°N 330°W	17.25	1.67	- .9567
(b)	45°N 340°W	18.39	1.61	- 2.1266
(c)	40°N 60°W	14.43	2.10	- 1.2969

Regression Equation: $\text{index} = 89.82 -(.95)P_a -(2.13)P_b -(1.30)P_c$
where P_i = MSLP at location i

Table 3.4 Cont'd

Hindcast:

YEAR	OBSERVED RANK	PREDICTED RANK	RANK ERROR	TERCILE ERROR
1955	24	30	6	0
1956	19	28	9	1
1957	5	8	3	0
1958	29	26	3	0
1959	7	7	0	0
1960	10	20	10	1
1961	16	14	2	0
1962	15	24	9	1
1963	26	21	5	0
1964	9	9	0	0
1965	20	19	1	0
1966	30	25	5	0
1967	8	11	3	1
1968	11	17	6	0
1969	25	27	2	0
1970	18	29	11	1
1971	22	15	7	1
1972	2	4	2	0
1973	6	2	4	0
1974	3	3	0	0
1975	17	10	7	1
1976	14	1	13	1
1977	28	22	6	0
1978	21	13	8	1
1979	13	12	1	0
1980	27	18	9	1
1981	23	23	0	0
1982	12	16	4	0
1983	4	5	1	0
1984	1	6	5	0

Tercile Errors

0 category error:	22 cases
1 category error:	8 cases
2 category error:	0 cases.

Case 2. 2-month 700 mb -January Correlation Field

The major North Atlantic features of the correlation grid in Table 3.3(b) are quite similar to those of Case 1. That is, low heights over southern Greenland and high heights in the subtropical North Atlantic are associated with severe iceberg years. This field, however, produces an additional feature. A region of significant positive values (high 700 mb heights associated with severe iceberg years) is identified over northeastern Asia. The points selected from the 700 mb predictor field for the regression were:

(a) 50°N 240°W: r = +.56 (high 700 mb in severe iceberg year)

(b) 30°N 70°W: r = +.69 (high 700 mb in severe iceberg year)

(c) 60°N 50°W: r = -.61 (low 700 mb in severe iceberg year)

Actually, five points of interest were produced by the method. However, two sets of points were adjacent and of equal correlation. The process of multiple regression effectively eliminates (i.e., assigns very low coefficients to) such irrelevant points. These points were, therefore, excluded as predictors for the final regression equation. Thirty years of hindcast ranks for this regression model are compared with observed ranks in Table 3.5. Measures of hindcast skill are summarized as follows:

Hindcast Errors

Mean absolute rank error	5.23 ranks
Median absolute forecast rank error	4.00 ranks
Correlation (forecast versus observed rank)	0.74

Tercile Errors

0 category error:	18 cases
1 category error:	12 cases
2 category error:	0 cases

Table 3.5

Multiple Regressionof 2-Month 700 MB
January Field Vs. Iceberg Rank (1955-1984)

Regression Statistics:	**Coefficientof Determination(r^2)...**			**0.56**
	Coefficient of Multiple Correlation .			**0.75**
	Standard Error of Estimate			**6.12**
	F-Ratio (Regression)			**11.27**
	Probability of Chance			**0.00016**
	Number of Cases			**30**

Regression Coefficients:	**Variable**	**Mean Height (dam -200)**	**S.D.**	**Coefficient**
	Constant			**264.74**
(a)	**50°N 240°W**	**83.92**	**2.01**	**- .9486**
(b)	**30°N 70°W**	**112.57**	**2.51**	**- 1.6917**
(c)	**60°N 50°W**	**74.74**	**5.35**	**.2705**

Regression Equation: $\text{index} = 264.74 - (.94)H_a - (1.69)H_b - (.27)H_c$
where H_j = 700 mb height at location j

Table 3.5 Cont'd

Hindcast:

YEAR	OBSERVED RANK	PREDICTED RANK	RANK ERROR	TERCILE ERROR
1955	24	22	2	0
1956	19	30	11	1
1957	5	1	4	0
1958	29	25	4	0
1959	7	17	10	1
1960	10	19	9	1
1961	16	23	7	1
1962	15	8	7	1
1963	26	24	2	0
1964	9	10	1	0
1965	20	18	2	0
1966	30	29	1	0
1967	8	14	6	1
1968	11	13	2	0
1969	25	28	3	0
1970	18	27	9	1
1971	22	11	11	1
1972	2	3	1	0
1973	6	5	1	0
1974	3	2	2	0
1975	17	4	13	1
1976	14	9	5	1
1977	28	26	2	0
1978	21	12	9	1
1979	13	20	7	0
1980	27	16	11	1
1981	23	21	2	0
1982	12	15	3	0
1983	4	7	3	0
1984	1	6	5	0

The January prediction, as might be expected, does not perform quite as well as the March prediction. It does, however, compare favorably with the accuracy of long-range forecasts of weather elements, such as temperature and precipitation, which are forecast to be above or below normal 55-60% of the time with a lead time of only 30 days. The corresponding chance expectation is 50%.

3.3.2 The Composite Difference Approach

For the 6-month MSLP fields ending in March, composite anomaly fields were constructed for the five most severe and the five mildest iceberg years by calculating means for 1957, 1972, 1974, 1983, 1984 and for 1958, 1963, 1966, 1977, 1980 respectively. These are shown as Figures 3.3(a) and 3.3(b). The difference between the two mean grids is shown as Fig. 3.3(c).

The anomaly centers near southern Greenland and in the mid-latitude Atlantic are spatially coincident in Figures 3.3(a) and 3.3(b). This implies that the same pattern of anomalies dominates both sets of extremes: only the sign changes. The reciprocal nature of the two composites does not extend to the North Pacific, however, where the mid-latitude anomalies are negative in both cases. Note that the North Atlantic pattern is also extremely consistent with the correlation grid in Table 3.3(a).

Over the iceberg source regions of Baffin Bay and the Labrador Sea, the geostrophic wind patterns implied by Fig. 3.3(a) and 3.3(b) provide a physically plausible explanation for the extreme iceberg conditions in the respective composites. The anomalous airflow component is southward (with cold advection) during severe years and northward (with warm advection) during mild years. Statistical constraints on the system do not dictate the dramatic contrast between these patterns. Instead, the contrast argues for the existence of a physical control over both types of iceberg extremes.

In Figs. 3.4(a) and 3.4(b) are shown and the actual mean MSLP for the same period as Figs. 3.3(a) and 3.3(b) on an expanded scale centered

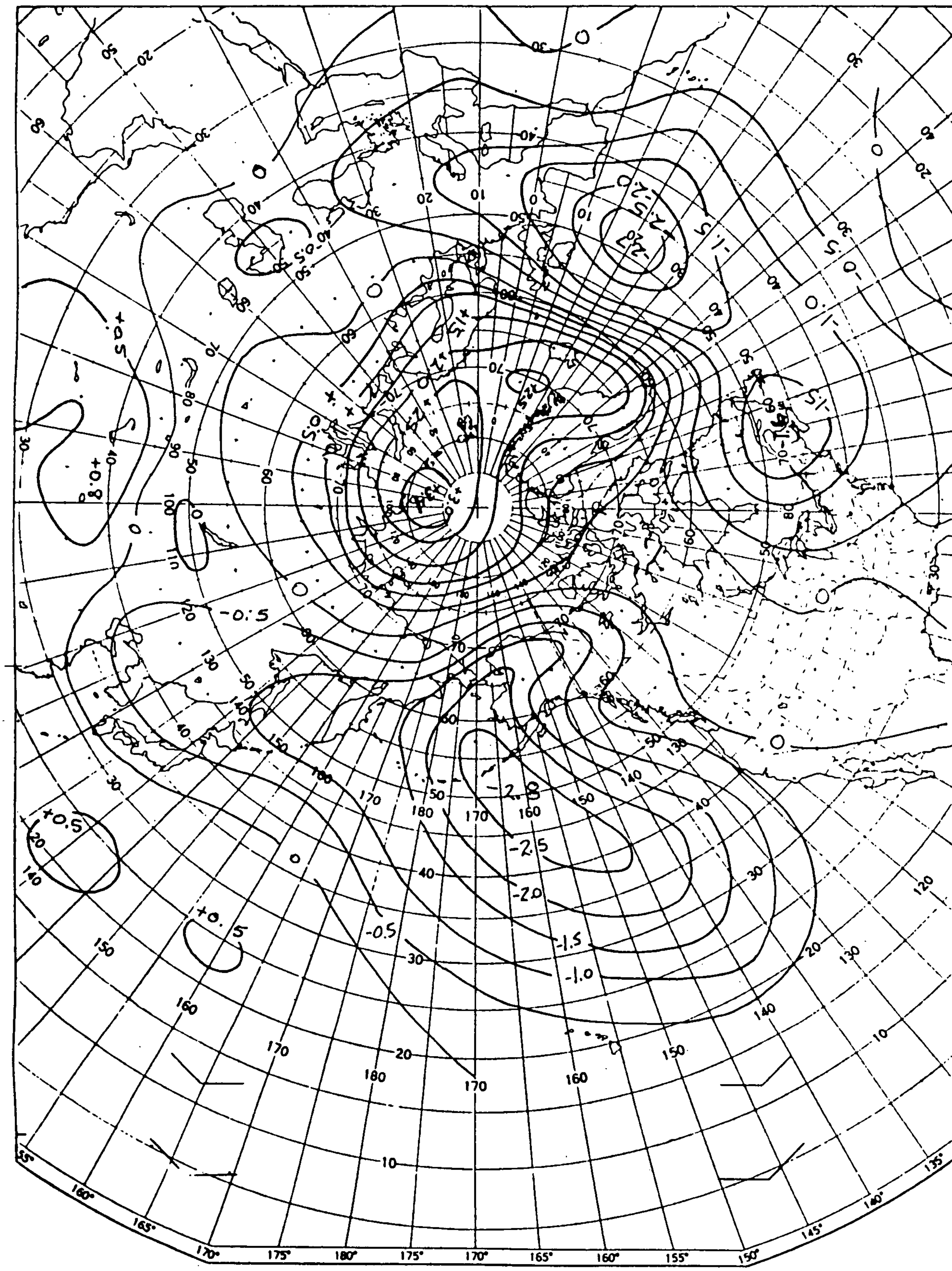


Fig. 3.3(a) 6-months ending in March MSLP anomaly field: Mean of the 5 mildest iceberg years (1958, 63, 66, 77, and 80). Isopleths are drawn for 0.5 mb departure from the 30-year mean (1951-80).

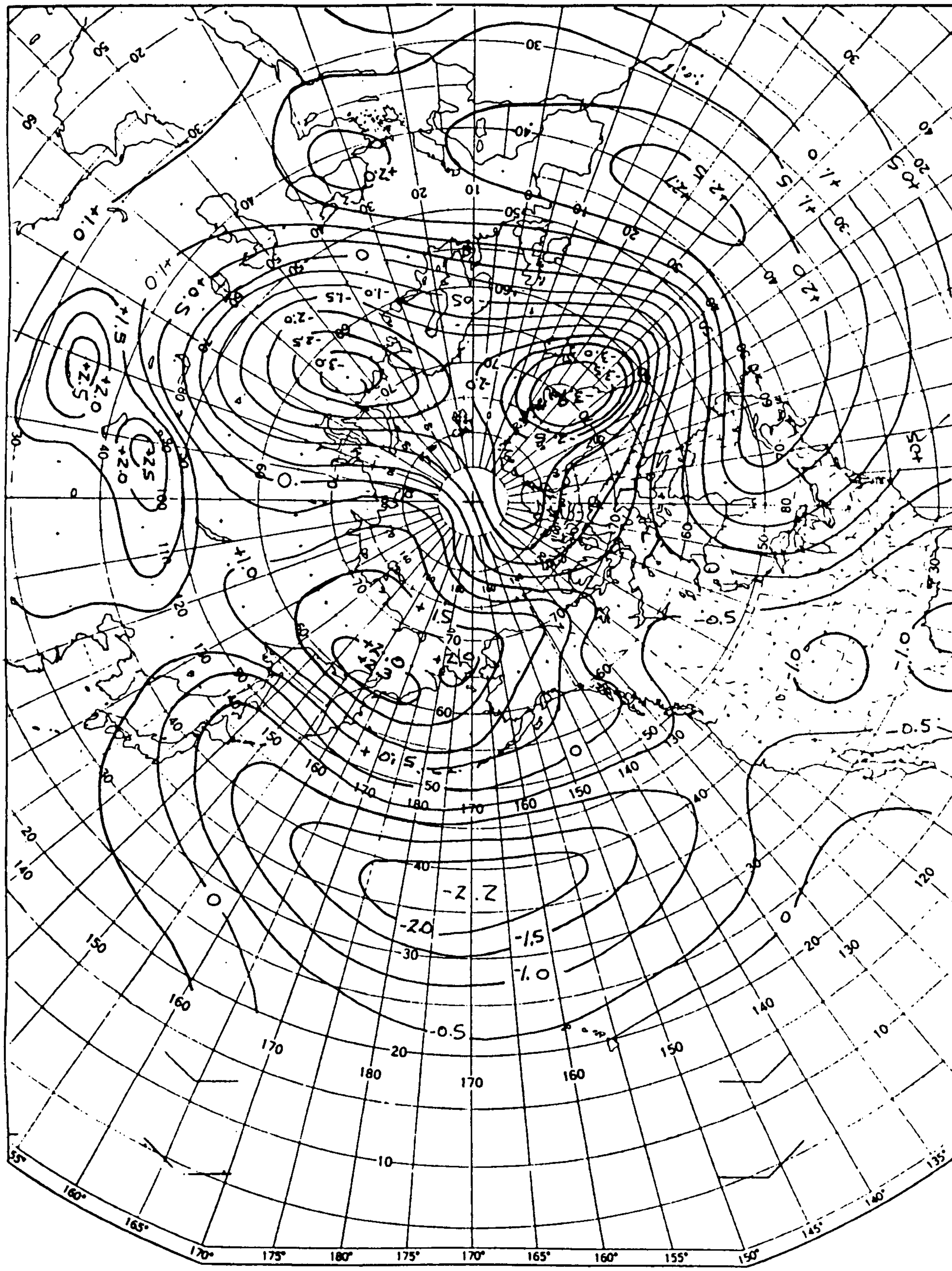


Fig. 3.3(b) 6-months ending in March MSLP anomaly field: Mean of the 5 most severe iceberg years (1957, 72, 74, 83, and 84). Isopleths are drawn for 0.5 mb departure from the 30-year mean (1951-80).

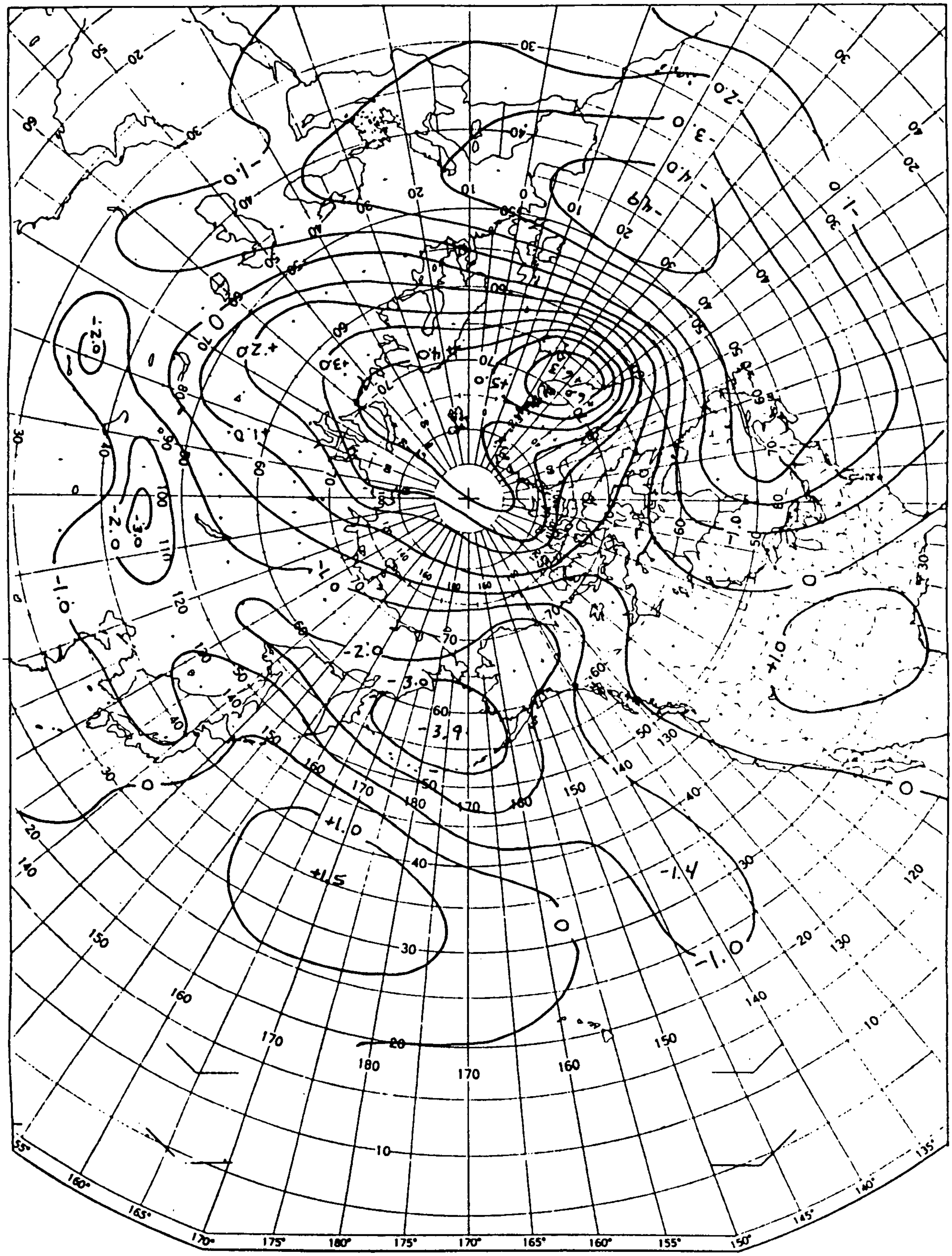


Fig. 3.3(c) 6-months ending in March MSLP: Difference between mild and severe iceberg years. The mean of the 5 most severe years (Fig. 3.3(a)) has been subtracted from the mean of the 5 mildest years (Fig. 3.3(b)). Isopleths have been drawn for each 1 mb difference.

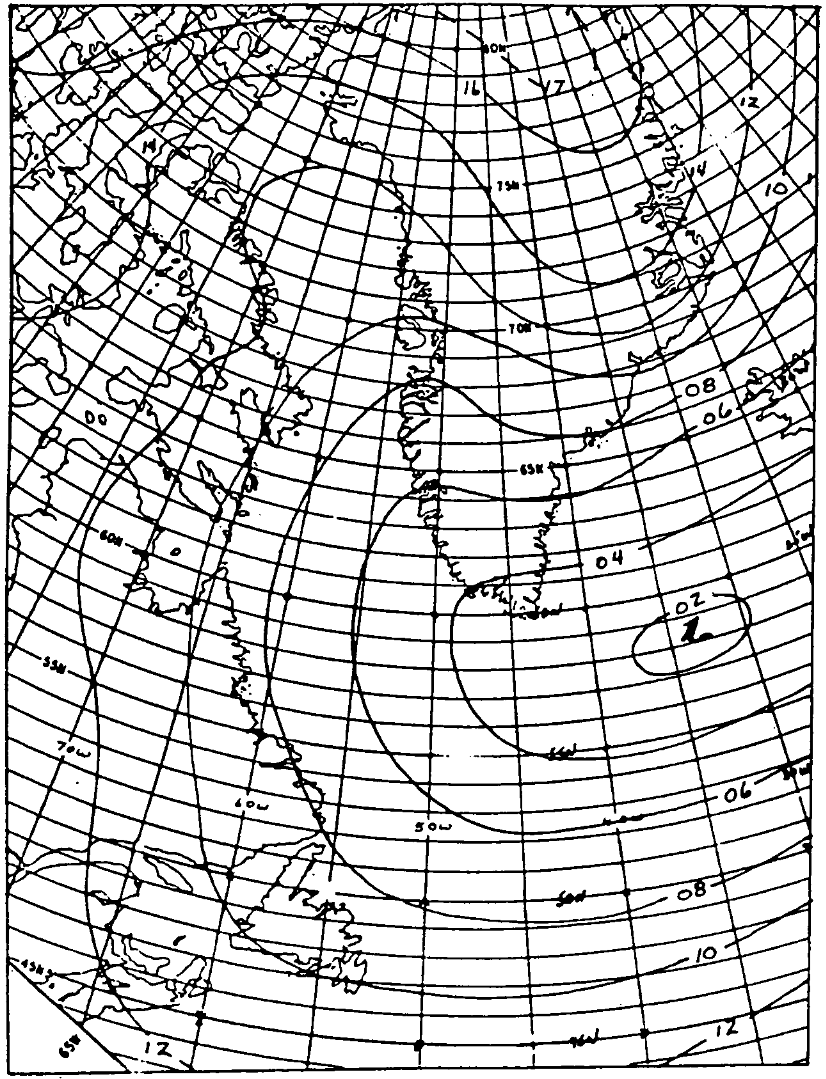


Fig 3.4(a) 6-months ending in March: Mean MSLP for the five mildest iceberg years. (1958, 63, 66, 77, 80)

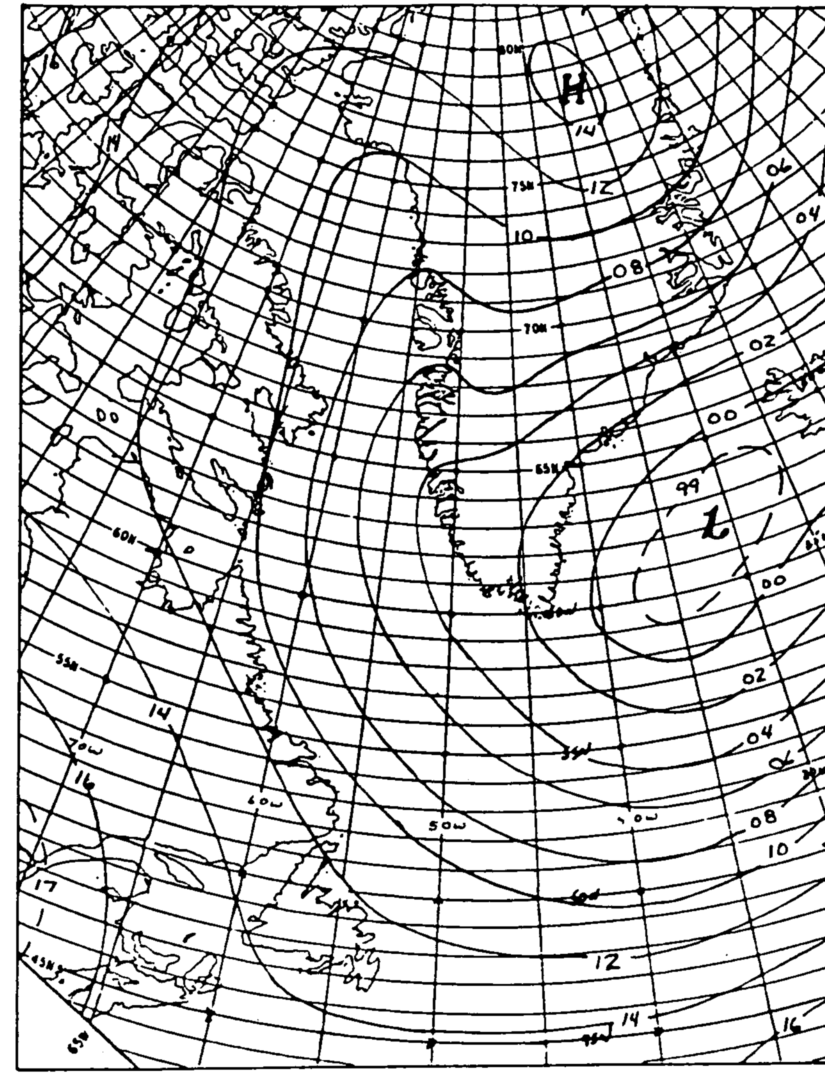


Fig. 3.4(b) 6-months ending in March: Mean MSLP for the five most severe iceberg years. (1957, 72, 74, 83, 84)

over the area of interest. The primary impact of the anomalies is seen upon the magnitude of, rather than the direction of, airflow. In both cases, the net airflow is southerly over the region. However, the airflow is much weaker in mild than in severe years. This situation is expected to result in longer iceberg transit times and a greater likelihood of iceberg melt in the mild years. It is also expected to permit intrusions of greater amounts of warmer ocean water by surface currents into the Labrador Sea.

3.3.3 The 1985 Forecast

Predictive methods developed using 6-month MSLP-March and 2-month 700 mb - January predictors as discussed above have been applied in forecast mode to predict the March to August 1985 iceberg season severity. This application can be considered to be an independent verification test of the predictive model as the data contributing to the development of the model exclude 1985 observations.

The International Ice Patrol preliminary report for the year ending 31 August 1985 is 1031 icebergs, which yields a 1985 severity ranking of 5th most severe (of 31 cases 1955-1985).

(a) Forecast by 2-Month 700 mb Data Ending in January 1985

The following are the 700 mb heights(*) for the 2-month period ending in January 1985 for the three 700 mb predictor points previously selected from the "Case 2." correlation field:

a. 50°N 240°W: H_a = 2831 m = 83.1
b: 30°N 70°W: H_b = 3132 m = 113.2
c. 60°N 50°W: H_c = 2702 m = 70.2

(*) For computational purposes, values are converted to decameters minus 200.

Insertion of these values in the regression equation from Table 3.5 yields:

$$\text{index} = 264.74 - (.94)(H_a) - (1.69)(H_b) + (.27)(H_c)$$
$$\text{index} = 264.74 - 78.11 - 191.31 + 18.95$$
$$\text{index} = 14.27$$

which is the 11th most severe (of 31 cases). Therefore, the difference between forecast and observed ranks is 6, which is slightly less than 1 standard error of estimate (6.2) for the 30-year sample. The forecast is for fewer icebergs than were actually observed.

(b) Forecast by 6-Month MSLP Ending in March, 1985

The following are the MSLP values(*) for the 6-month period ending in March, 1985 for the three MSLP predictor points selected from the "Case 1." correlation field:

a. 40°N 330°W: P_a = 1018.5 mb = 18.5
b. 45°N 340°W: P_b = 1019.8 mb = 19.8
c. 40°N 60°W: P_c = 1914.5 mb = 14.5

(*) For computation purposes, 1000 mb is subtracted from each value.

From Table 3.4, the regression equation yields:

$$\text{index} = 89.82 - (.95)(P_a) - (2.13)(P_b) - (1.3)(P_c)$$
$$\text{index} = 89.82 - 17.56 - 42.17 - 18.85$$
$$\text{index} = 11.19$$

which is the 9th most severe (of 31 cases). The forecast is in the correct tercile, but differs from the observed by 4 ranks. This is within the median and mean errors, and well within the standard error of estimate (5.9 ranks) for the 30-year sample. Again in this case, the forecast is for fewer icebergs than were actually observed.

It is noted, for comparison, that chance expectation is a standard error of estimate of 9 ranks, with a standrd deviation of 1 rank. This was determined by two separate 100-trial Monte Carlo runs.

4. THE EMPIRICAL ORTHOGONAL FUNCTION APPROACH

4.1 Overview

The statistical methods introduced in Chapter 3 to correlate long time-series of atmospheric field data with an annual Grand Banks ice index are computationally very demanding. The requirement to conduct Monte Carlo simulations to test the reliability of apparently good predictors expands the computational effort required to isolate such predictors by at least two orders of magnitude. The method of Empirical Orthogonal Function Analysis (EOF), which is also known variously as characteristic function analysis, factor analysis, or as the method of principal components, provides a practical tool by which to efficiently isolate predictors from the enormous volumes of available atmospheric data.

Early research in the use of empirical orthogonal functions for statistial weather prediction is discussed in detail by Lorenz (1956). A later overview paper by Stidd (1967) is also comprehensive. A more generic description of EOF analysis methods and interpretations is provided by Rummel (1967). The very practical description of EOF methods provided by Davis (1976) as an appendix to his study of north Pacific sea surface temperature and sea level pressure anomalies serves as a model for the EOF application in this study.

The essential features and merits of empirical orthogonal functions are well described by Walsh and Sater (1981). Describing the large volumes of sea level pressure (SLP) and sea surface temperature (SST) data which they had prepared for use in studying sea ice/atmosphere interactions, these authors note that,

> "In view of the large volume of SLP and SST data, much of the analysis and discussion is based on the dominant patterns of variability of the data fields. These patterns are empirical orthogonal functions (EOF's), which are also referred to as eigenvectors or principal components. The first eigenvector of a set of data fields is the dominant mode of variability in the sense that it describes a greater precentage of the variance of the data fields than does any other pattern. Each succeeding eigenvector describes a maximum of the variance that is unexplained by the previous eigenvectors. The coefficient or amplitude of an eigenvector is a measure of the extent to which that eigenvector pattern is present in a particular anomaly field.
>
> Among the advantages of the eigenvector representation are the effective compression of the data and the orthogonality (independence) of the patterns in space and time."

4.2 Derivation of Empirical Orthogonal Functions

It is desired to calculate the characteristic functions of a set of atmospheric data such as the mean sea level pressure, 700mb height, 700mb - 1000mb thickness, surface air temperature, or some other parameter. Suppose that the data are symmetrically organized on a geographical latitude/longitude grid, and that data values at each grid point are available over some routinely spaced series of times. Such values can be considered as a regular time-series of (spatially varying) data fields. Let the data values for points of fixed latitude define the rows of a matrix and similarly let the data values for points of fixed longitude define the columns of this same matrix. One such matrix (or grid) exists for each time.

By summing such matrices for a selected number of times and dividing by the appropriate number of cases it is a simple matter to compute the time averaged or mean representation of these fields. Then by subtracting this mean from the measured fields, it is possible to compute anomaly fields. In the present application the time step is monthly and data fields span at least 30 years. Hence, for example, the January mean is computed from 30 individual measured January fields and is subtracted from each measured field to yield 30 individual January anomaly fields.

Such zero-mean anomaly fields (for any selected scalar parameter) can be represented as:

$$P = P(x, y, t) \qquad (4.1)$$

where $x = x_1, x_2 \ldots x_{N_1}$ $\quad N_1$ = number of columns (longitude)

$y = y_1, Y_2 \ldots Y_{N_2}$ $\quad N_2$ = number of rows (latitude)

$t = t_1, t_2 \ldots t_M$ $\quad M$ = number of time intervals

Combining the two spatial dimensions into one spatial parameter $\underline{x}$, the field can be represented as:

$$P = P(\underline{x}, t) \qquad (4.2)$$

where $\underline{x} = \underline{x}_1, \underline{x}_2 \cdots \underline{x}_{N_1N_2}$

Following the arguments of Davis (1976), the time averaged correlation matrix of the anomaly fields can be computed as follows:

$$R_{ij} = \frac{1}{M} \sum_{k=1}^{M} P(\underline{x}_i, t_k)\, P(\underline{x}_j, t_k) \qquad (4.3)$$

The matrix R_{ij} is dimensioned $N_1N_2 \times N_1N_2$.

The eigenvectors $E_n(\underline{x})$ of R_{ij} are the empirical orthogonal functions of the data fields: the associated eigenvalues λ_n describe the contribution of each eigenvector to the total variance in the data fields. Those $E_n(\underline{x})$ with the largest λ_n are the principal modes of the data fields.

While there exist N_1N_2 eigenvectors, it is usually true that a small number of these describe a large percentage of the variance in the signal. To what extent this is true can be determined by examining the parmeter λ'_T defined as:

$$\lambda'_T = \sum_{n=1}^{R} \lambda'_n \quad \text{for } R << N_1N_2 \qquad (4.4)$$

(The primed quantities simply denote normalized values.)

As λ'_T approaches 1.0, the number of important eigenvectors (R) can be determined.

It is thus possible to reconstruct any of the observed fields $P(\underline{x}, t)$ as a superposition of $E_n(\underline{x})$. Formally,

$$P(\underline{x}, t) = \sum_{n=1}^{R} a_n(t) E_n(\underline{x}) \qquad (4.5)$$

Using the dot product operator, it is possible to determine the $a_n(t)$ as:

$$a_n(t) = P(\underline{x}, t) \cdot E_n(\underline{x}) \qquad n=1, R \qquad (4.6)$$

The net result is a reduction of M grid patterns of observed data of dimension N_1N_2, to R time-series of scalar coefficients $a_n(t)$, with

$R \ll N_1N_2$, typically less than ten. These $a_n(t)$ are the "coefficients or amplitudes" of the eigenvectors, as described by Walsh and Sater (1981). They describe the extent to which the particular eigenvector is present in any particular measured anomaly field.

In the present application, the data fields are organized on a geographical grid of 10° longitudinal and 5° latitudinal spacing. A domain extending from 10°W to 100°W longitude and 45°N to 90°N latitude is employed to describe atmospheric conditions over the entire north Atlantic including all of Greenland and the eastern Canadian arctic. By virtue of this domain definition the spatial counters N_1 and N_2 associated with Equation 4.1 both have the value 10. Hence the correlation matrix R_{ij} defined in Equation 4.3 has dimension $N_1N_2 \times N_1N_2$ or 100 x 100.

Temporally the data fields typically span 30 years at monthly time step. Thus for the computation of eigenfunctions for a particular month, the number of contributing data fields (M) is 30.

Computationally, the necessary matrix inversions and calculations of eigenvectors and eigenvalues are accomplished using the real symmetric version of the International Mathematical and Statistics Library (IMSL) eigenvector routine "EIGRS".

4.3 Procedures

4.3.1 Indexing of Predictand

The stated objective is to predict the annual flux of icebergs onto the Grand Banks. It has previously been noted that historical data maintained by the International Ice Patrol provide estimates of the annual flux across latitude 48°N. This scalar time-series of annual values represents the most basic iceberg index or predictand available for the present investigation.

Various other indices can be computed from the annual flux parameter. Four such indices investigated in this study include:

- iceberg severity rank, derived by simply ranking or ordering the years from least severe (1) to most severe (30), based upon the annual flux

- square root of annual flux
- logarithm of annual flux
- iceberg severity class defined by Table 4.1.

Table 4.1

Definition of Iceberg Severity Classes

Class	Annual Flux
1	0 - 50
2	50 - 100
3	100 - 200
4	200 - 400
5	400 - 800
6	800 - 1200
7	>1200

The class definitions presented in Table 4.1 are somewhat arbitrary but were rationalized as an attempt to smooth the otherwise erratic iceberg signal. The frequency distribution of occurrence of iceberg severity by class is illustrated in Figure 4.1 for the 30 years 1951-1980. This histogram indicates that one half of the years (15) are grouped in classes 1 and 2 with annual flux less than or equal to 100 icebergs. An additional nine years occupy classes 3 and 4 at an annual flux of 100-400 icebergs. The remaining six high flux years are evenly distributed between classes 5, 6 and 7 at two occurrences per class.

The majority of the correlation studies reported in this investigation employ measurements from the 30 year interval 1951 to 1980. Certain studies involving surface air temperature extend this interval through 1982; however, the basic list of iceberg indices, as presented in Table 4.2(a) (sorted by flux) and Table 4.2(b) (sorted by year), is restricted to the former 30 years. These are the scalar indices employed in the correlation tests against selected series of $a_n(t)$ output from eigenfunction derivations. The iceberg indices are referred to in subsequent chapters as the predictand, while the $a_n(t)$ are described as being the predictor.

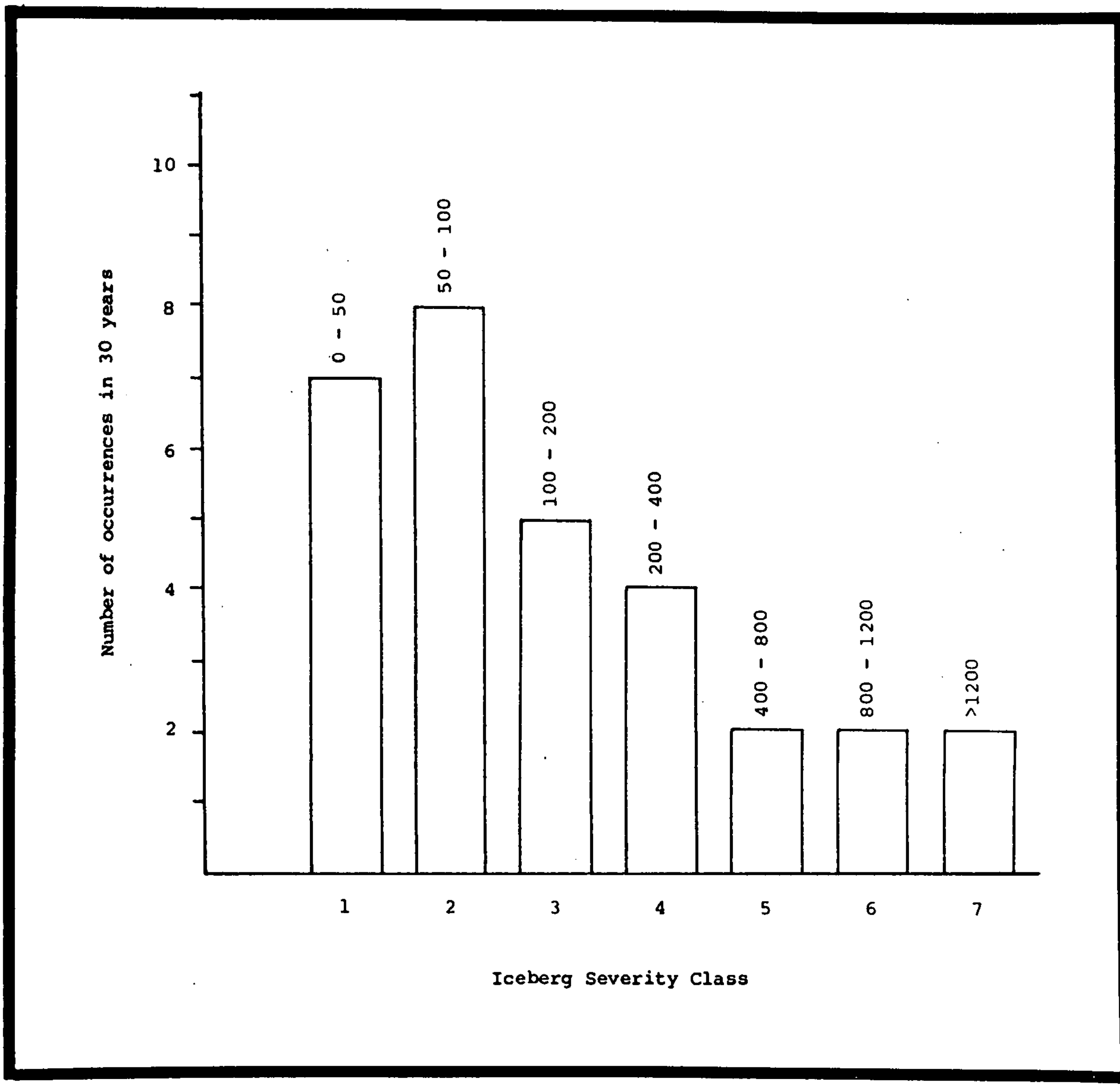


Fig. 4.1 Frequency Histogram of Iceberg Class Occurrence in the 30 Years 1951-1980

Table 4.2(a)

Annual Values of Five Iceberg Indices, Sorted by Flux

Year			Index		
	Flux	Rank	$(Flux)^{1/2}$	log(flux)	Class
1966	0	1	0.0	0.00	1
1958	1	2	1.0	0.00	1
1951	9	3	3.0	0.95	1
1952	15	4	3.9	1.18	1
1977	22	5	4.7	1.34	1
1980	23	6	4.8	1.36	1
1963	25	7	5.0	1.40	1
1953	56	8	7.5	1.75	2
1969	57	9	7.5	1.76	2
1955	61	10	7.8	1.79	2
1971	73	11	8.5	1.86	2
1978	75	12	8.7	1.88	2
1965	76	13	8.7	1.88	2
1956	80	14	8.9	1.90	2
1970	85	15	9.2	1.93	2
1975	101	16	10.0	2.00	3
1962	112	17	10.6	2.05	3
1961	114	18	10.7	2.06	3
1976	151	19	12.3	2.18	3
1979	182	20	13.5	2.26	3
1968	226	21	15.0	2.35	4
1960	258	22	16.1	2.41	4
1954	312	23	17.7	2.49	4
1964	369	24	19.2	2.57	4
1967	441	25	21.0	2.64	5
1959	689	26	26.2	2.84	5
1973	850	27	29.2	2.93	6
1957	931	28	30.5	2.97	6
1974	1386	29	37.2	3.14	7
1972	1584	30	39.8	3.20	7

Table 4.2(b)

Annual Values of Five Iceberg Indices, Sorted by Year

Year	Index				
	Flux	Rank	$(\text{Flux})^{1/2}$	log(flux)	Class
1951	9	3	3.0	0.95	1
1952	15	4	3.9	1.18	1
1953	56	8	7.5	1.75	2
1954	312	23	17.7	2.49	4
1955	61	10	7.8	1.79	2
1956	80	14	8.9	1.90	2
1957	931	28	30.5	2.97	6
1958	1	2	1.0	0.00	1
1959	689	26	26.2	2.84	5
1960	258	22	16.1	2.41	4
1961	114	18	10.7	2.06	3
1962	112	17	10.6	2.05	3
1963	25	7	5.0	1.40	1
1964	369	24	19.2	2.57	4
1965	76	13	8.7	1.88	2
1966	0	1	0.0	0.00	1
1967	441	25	21.0	2.64	5
1968	226	21	15.0	2.35	4
1969	57	9	7.5	1.76	2
1970	85	15	9.2	1.93	2
1971	73	11	8.5	1.86	2
1972	1584	30	39.8	3.20	7
1973	850	27	29.2	2.93	6
1974	1386	29	37.2	3.14	7
1975	101	16	10.0	2.00	3
1976	151	19	12.3	2.18	3
1977	22	5	4.7	1.34	1
1978	75	12	8.7	1.88	2
1979	182	20	13.5	2.26	3
1980	23	6	4.8	1.36	1

4.3.2 Methodology of Predictor Selection

The derivation of empirical orthogonal functions or eigenfunctions of the anomaly fields of atmospheric data has previously been discussed. In applying the EOF methods to the present study, it has been stated that the finest temporal resolution employed was monthly. That is, given the available long time-series of monthly mean pressure, temperature, height or thickness data, eigenfunctions have been derived to describe variability in these fields on a monthly basis. The series of $a_n(t)$ derived as the dot product of the eigenvectors with the measured data fields thus also pertain to a particular month. While this monthly time step is the finest employed in the present study, it has been possible to consider time intervals more coarse than monthly. This has been done by incorporating some specific number of sequential months from each year into the eigenfunction calculation. The procedure is best clarified by Figure 4.2 which illustrates the set of 120 possible cases investigated for any given parameter. The one case of 3 months ending March is isolated and described in the figure caption.

A series of computations is required to assess the potential value of predictors derived from any one of these 120 cases for a particular parameter. For a selected parameter and case (say 3 months ending March as in Figure 4.2) it is first necessary to compute the correlation matrix R_{ij} from the appropriate anomaly data, and then to find the eigenvectors of R_{ij} with their associated eigenvalues. A subset of the most important eigenvectors $E_n(\underline{x})$ is isolated and the series of $a_n(t)$ are computed. A linear regression of the $a_n(t)$ series against the selected iceberg index (Section 4.3.1) is performed and the correlation coefficient "r" between these two scalar parameters is computed. An equal-tails test of the significance of the correlation coefficient, as described by Neville and Kennedy (1966), is applied. Given the number of variables in the regression (2) and the number of data pairs (30), the number of degrees of freedom is calculated (30-2=28). The threshold value of the correlation coefficient "r" at a given level of significance (in this case 1%) is determined. A value of $|r|$ falling below this threshold suggests the null hypothesis that there is no association between the variables. For the present case of two variables

	ENDING (End of)											
Number of Months	January	February	March	April	May	June	July	August	September	October	November	December
1												
2												
3												
4												
5												
6												
7												
9												
12												
24												

Figure. 4.2 Matrix Illustrating 120 Possible Temporal Groupings of Atmospheric Data for Eigenfunction Calculations.

The illustrated case of 3 months ending March would dictate that data from January, February and March of each year would contribute to the eigenfunction calculation for a selected parameter. The $a_n(t)$ would be calculated for each year as the dot product of the n^{th} eigenvector with the time averaged January, February, March data field for that parameter.

with 28 degrees of freedom, the threshold value for $|r|$ at the 1% signficance level is 0.46. Hence any linear regression of a given $a_n(t)$ against a selected iceberg index which yields $|r| > 0.46$ isolates a potentially useful predictor.

Tables such as the one illustrated in Figure 4.2 are employed to record the results of selected investigations. One table is maintained for each input data parameter (mean sea level pressure, 700mb height, 700mb - 1000mb thickness, surface air temperature). Table entries for each case (such as 3 months ending March) are the index of the eigenvector "n" and the associated correlation coefficient. For example, an entry in the MSLP table for 3 months ending March could read (2) -0.61. It would be interpreted that the linear regression of $a_2(t)$ versus iceberg flux, derived from the second eigenvector of 3 months MSLP ending March, yielded a correlation coefficient $r = -0.61$. Since this value meets the threshold condition that $|r| > 0.46$, the parameter 3 months MSLP ending March would be regarded as a potentially valuable predictor.

While Figure 4.2 is organized on a calendar basis (January through December), it should be noted that the iceberg season is defined as August through July. It follows then that a predictor based on say 3 months ending December would correlate a_n values for a given calendar year (1951) against iceberg index values for the subsequent year (1952). A predictor based on 6 months ending March would employ measured data from October 1951 through March 1952 to calcualte the value of a_n for correlation with the 1952 iceberg index.

4.3.3 Time Averaged and Composite Approaches

There exist two options for deriving eigenvectors for any of the Figure 4.2 cases involving two or more months of input data. This includes 90% of the 120 illustrated cases, with only those cases in the first row of the table being exempt.

Consider the simple case of 2 months ending February for a given parameter. Assume, as is the case, that available data for the selected parameter commence in January 1951. The first steps in deriving the eigenfunctions for this case are to compute the monthly anomaly fields and to develop the corelation matrix R_{ij} as defined in Equation 4.3. It is necessary to input both the January 1951 and the February 1951 anomaly fields into the computation of R_{ij}. One approach, termed in this study as the "Time Averaged Approach" is to calculate the mean anomaly pattern for 2 months ending February 1951. This is simply the sum of January 1951 and February 1951 anomaly values divided by two. The resulting time averaged pattern contributes to the calculation of R_{ij}. The alternate approach is to employ both the January 1951 and the February 1951 anomaly patterns individually in the derivation of R_{ij}. This approach is termed the "Composite Approach", as R_{ij} is developed from the composite of all contributing anomaly fields. In this latter instance the divisor "M" in Equation 4.3 increases from the number of years (30) to the product of the number of years times the number of contributing months per year (in this case 2). Hence in this example $M = 30 \times 2 = 60$.

The eigenfunctions evolving from these two approaches differ; hence the $a_n(t)$ differ and hence the regression of $a_n(t)$ against iceberg index yields different regression equations and different correlation coefficients for the two approaches. Comparative results to illustrate these cases appear in Section 4.4.2.

4.3.4 Linear and Multiple Regression Options

It has been noted in the immediately preceding section that simple two parameter linear regressions between selected $a_n(t)$ and iceberg index are performed to isolate potentially useful predictors. From each such regression evolves an equation of the form:

$$(\text{iceberg index}) = (\text{slope}) \cdot (a_n(t)) + (\text{intercept}) \qquad (4.7)$$

One such combination can be derived for each combination of parameter (MSLP, 700mb height, etc.), index (flux, rank, etc.), case (1 month ending January, 3 months ending March, etc.), eigenvector coefficient ($a_n(t)$, n=1,100), and approach (Time Averaged or Composite). Using the 120 case definitions in Figure 4.2, this yields a total of 4 (parameter) x 5 (index) x 120 (case) x 100 (a_n) x 2 (approach) = 480,000 possible predictive equations simply from the linear regression approach. The number of potentially meaningful predictors is orders of magnitude smaller than this for the following reasons:

- a sensitivity analysis can be performed to isolate the most effective iceberg indices and as is shown in Section 4.4.2 the choice of five indices can readily be reduced to two.

- for practical purposes it is necessary to issue iceberg season forecasts in the early winter, before any substantial flux occurs. Typically the earliest icebergs arrive in February and hence the search for effective predictors spans only the immediately preceeding months of about November to February. March and April predictors are of more academic interest. Certainly the priority investigation can be restricted to at most six of the 12 calendar months.

- the EOF theory dictates that only a small number of the eigenfunctions of a particular data set are significant. It will be seen in later sections that certainly less than 10 of the 100 available eigenvectors of any data set are of consequence. The imposition of statistical significance tests for "r" ($|r| > 0.46$) again reduces the number of important eigenvectors by half an order of magnitude.

- comparison of Time Averaged versus Composite Approach results can be used (Section 4.4.3) to isolate one or the other of these as a best predictor.

In later sections (4.4), the results of promising linear regression analyses are presented. In each case, a relation of the form of Equation 4.7 is used to either forecast or hindcast iceberg occurrence, and the skill of the prediction is assessed.

By introducing the option for multiple regression analysis, it can be seen that again an enormous number of possibilities arise. Series of $a_n(t)$ representing different eigenvectors for a given parameter, case, and approach can be introduced to a multiple regression against iceberg index. In a more complicated case, it is possible to select several $a_n(t)$ for different parameters, cases, eigenvectors, and approaches for multiple regression against iceberg index. The combinations are much too exhaustive to allow a systematic evaluation of multiple regression cases in this study. The results of selected cases appear in Section 4.4.

4.3.5 Measures of Forecast Skill

In the linear regression case, two bulk parameters are employed to sense the skill of a particular prediction. Two simple indices are also employed to evaluate the skill of flux or rank and class forecasts respectively. Relevant parameters and indicators include:

$$\text{mean absolute error} = \frac{1}{M} \sum_{i=1}^{M} |(P_i - O_i)| \qquad (4.8)$$

$$\text{mean absolute rank error} = \frac{1}{M} \sum_{i=1}^{M} |P_i^r - O_i^r| \qquad (4.9)$$

where M = number of years

P_i = predicted iceberg index

O_i = observed iceberg index

P_i^r = predicted iceberg rank (derived from index)

O_i^r = observed iceberg rank

When iceberg flux or rank is employed as the iceberg index, a tercile classification is used to indicate skill. The 30 years of predictions are ranked by increasing flux (see Table 4.2(a)) and are separated into three sets of rank 1 to 10, 11 to 20 and 21 to 30. Tercile errors are then computed. For example, years with observed rank 1 to 10 and predicted rank 1 to 10 would yield an error of 0. On the printed results appearing in Section 4.4, these are termed "Category Errors". Pursuing this same example, a prediction of 21 to 30 for an observed rank of 1 to 10 would yield a Category Error of 2. The distribution of Category Errors expected by chance for a case with 30 years of predictions is quoted in Table 4.3.

Table 4.3

Expected Chance Distribution of Tercile (Category) Errors for 30 Years of Predictions

Category Error	Chance Expectation (Years)	Chance Expectation (Fraction)
0	10	30/3
1	13	40/3
2	7	20/3

In cases where iceberg class (Table 4.1) is employed as the iceberg index, it is possible to illustrate the skill of a prediction using Absolute Class Error as an indicator. This is simply the numerical value of the absolute value of the difference between predicted and observed class. The distribution of Class Errors expected by chance, for the case with 30 years of predictions having an observed distribution as per Fig. 4.1, is quoted in Table 4.4.

Table 4.4

Expected Chance Distribution of Class Errors for 30 years of Predictions

Class Error	Chance Expectation (Years)	Chance Expectation (Fraction)
0	4	30/7
1	7	51/7
2	6	41/7
3	5	34/7
4	4	26/7
5	3	19/7
6	1	9/7

These same indicators are useful in assessing the forecast skill in a multiple regression case. In this instance, the correlation coefficient calculated between predicted and observed iceberg index is also useful.

4.3.6 Verification Options

Having developed models by which to predict iceberg index on the basis of measured atmospheric data it remains to test the predictive capability of these models. A dependent verfication test is implicit in the selection of the predictive model, as is now described. A total of at least 30 years of atmospheric data contribute to the development of any of the possible regression equations. From the hundreds of available cases, a selected few cases are isolated on the basis of particularly good correlation between $a_n(t)$ and observed iceberg index. The regression equations (models) associated with these cases are used to predict iceberg index as a linear function of $a_n(t)$ for the same 30 years which contributed data to the development of the model. It is in this sense that this first order verification is dependent. Those same years which contributed data to the development of the model are hindcast to evaluate the dependability of the model. Results are quantified as described in the immediately preceding section.

A much more important verification test is the evaluation of model performance on independent cases. Two methods of independent verification testing are employed in this study.

Firstly, it is possible to restrict the model development to 29 of the 30 years of available data and to apply the resulting model to the one remaining year. In this way the verification test for the one excluded year is truly independent. Now it is clear that the choice of which year to exclude from the eigenfunction calculation is totally arbitrary. Hence it is seen that there are actually 30 possible cases whereby a model is constructed using 29 years of data and the model is employed to hindcast only the one excluded year. The first of the independent verification tests employed to assess the performance of models presented in section 4.4 is this "one year out" method. The results of 30 separate regression model developments are presented in terms of Category Error and/or Class Error tables as discussed in Section 4.3.5.

For some parameters (notably MSLP and 700mb height) it has been possible to compile complete data sets beyond 1980. These provide appropriate resources for the additional independent testing of models. The predictive equations are derived using data for the 30 years 1951-1980 and are applied to predict iceberg flux, rank or class for one or more of the years 1981-1985.

4.3.7 Result Presentation Format

Prior to introducing actual quantitative results it is advantageous to illustrate and describe the format in which subsequent results are presented. Tabular formats are adopted for results of both the linear and the multiple correlation tests. Samples of these appear as Table 4.5 and 4.6 respectively. The numerical content of these particular tables is of marginal interest: it is the format and generic content, as now described, which is of consequence.

The output typical of a linear regression test appears as Table 4.5. The title line identifies the test as being either dependent or independent (see Section 4.3.6) and specifies the predictand employed (see Section 4.3.1). The parameter used as a predictor is identified in the second title line and subsequent labels identify the number of months and the end month contributing to the test. Additional captions discriminate between Time Averaged and Composite approach (see Section 4.3.3) and quote the linear regression correlation coefficient. The body of the table includes the following columns:

YEAR: ice season year for which the prediction applies

a(n): numerical value of the eigenfunction coefficient

OBSERVED: value of observed ice flux derived from observed index, or observed rank or class

PREDICTED: value of predicted ice flux derived from observed index, or predicted rank index or class

(P-O): numerical difference between predicted and observed ice flux, rank or class, as derived from observed and predicted index values

(P-O/SD): numerical value of (P-O) divided by standard deviation in observed flux

OBS RANK: rank of observed index (replaced by OBS CLASS when index is iceberg class)

PRED RANK: rank of predicted index (replaced by PRED CLASS when index is iceberg class)

Table 4.5

Sample of Presentation Format for Results of Linear Regression Hindcast

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

Parameter : 700 - 1000 MB THICKNESS TIME AVERAGED APPROACH

Number of Months: 1 Correlation Coefficient r: .72
Ending in : JANUARY

YEAR	a(1)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	-136.46	0.	51.	51.	.12	1.	9.	8.
1958	-219.68	1.	0.	-1.	-.00	2.	3.	1.
1951	-34.64	9.	221.	212.	.52	3.	13.	10.
1952	69.85	15.	395.	380.	.93	4.	22.	18.
1977	-142.61	22.	41.	19.	.05	5.	8.	3.
1980	-65.74	23.	169.	146.	.36	6.	10.	4.
1963	-6.53	25.	268.	243.	.59	7.	19.	12.
1953	71.91	56.	399.	343.	.84	8.	23.	15.
1969	-151.02	57.	27.	-30.	-.07	9.	6.	-3.
1955	-225.12	61.	0.	-61.	-.15	10.	2.	-8.
1971	-147.26	73.	33.	-40.	-.10	11.	7.	-4.
1978	-32.16	75.	225.	150.	.37	12.	14.	2.
1965	-39.31	76.	213.	137.	.34	13.	12.	-1.
1956	-256.96	80.	0.	-80.	-.20	14.	1.	-13.
1970	34.81	85.	337.	252.	.62	15.	20.	5.
1975	144.07	101.	519.	418.	1.02	16.	25.	9.
1962	89.84	112.	429.	317.	.78	17.	24.	7.
1961	58.56	114.	377.	263.	.64	18.	21.	3.
1976	-8.61	151.	264.	113.	.28	19.	17.	-2.
1979	-176.81	182.	0.	-182.	-.45	20.	5.	-15.
1968	-25.22	226.	237.	11.	.03	21.	15.	-6.
1960	-24.60	258.	238.	-20.	-.05	22.	16.	-6.
1954	153.98	312.	536.	224.	.55	23.	26.	3.
1964	-45.93	369.	202.	-167.	-.41	24.	11.	-13.
1967	-6.86	441.	267.	-174.	-.43	25.	18.	-7.
1959	-217.55	689.	0.	-689.	-1.69	26.	4.	-22.
1973	198.14	850.	610.	-240.	-.59	27.	27.	0.
1957	314.12	931.	803.	-128.	-.31	28.	28.	0.
1974	462.96	1386.	1052.	-334.	-.82	29.	30.	1.
1972	364.84	1584.	888.	-696.	-1.70	30.	29.	-1.
MEAN		279.	279.					
STD. DEV.		409.	293.					
MEAN OF ABSOLUTE VALUES				204.0	.50			6.7
STD. DEV. OF ABSOLUTE VALUES				176.4	.43			5.8

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	15
1	12
2	3

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	6
1	12
2	8
3	3
4	1
5	0
6	0

Table 4.6

Sample of Presentation Format for Results of Multiple Regression Hindcast

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	a(n)	r
700 MB HEIGHTS	1	JANUARY	1	-.50
MEAN SEA LEVEL PRESSURE	3	MARCH	1	-.52
SURFACE AIR TEMPERATURE	4	MARCH	1	-.67

Correlation Coefficient (Observed vs Predicted): .68

YEAR	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	0.	70.	70.	.17	1.	8.	7.
1958	1.	0.	-1.	-.00	2.	2.	0.
1952	15.	302.	287.	.70	3.	17.	14.
1977	22.	0.	-22.	-.05	4.	3.	-1.
1980	23.	40.	17.	.04	5.	6.	1.
1963	25.	147.	122.	.30	6.	11.	5.
1953	56.	0.	-56.	-.14	7.	4.	-3.
1969	57.	0.	-57.	-.14	8.	1.	-7.
1955	61.	166.	105.	.26	9.	12.	3.
1971	73.	313.	240.	.58	10.	18.	8.
1978	75.	325.	250.	.61	11.	19.	8.
1965	76.	245.	169.	.41	12.	15.	3.
1956	80.	120.	40.	.10	13.	9.	-4.
1970	85.	63.	-22.	-.05	14.	7.	-7.
1975	101.	633.	532.	1.29	15.	26.	11.
1962	112.	123.	11.	.03	16.	10.	-6.
1961	114.	568.	454.	1.10	17.	24.	7.
1976	151.	640.	489.	1.19	18.	27.	9.
1979	182.	170.	-12.	-.03	19.	13.	-6.
1968	226.	223.	-3.	-.01	20.	14.	-6.
1960	258.	25.	-233.	-.56	21.	5.	-16.
1954	312.	493.	181.	.44	22.	21.	-1.
1964	369.	505.	136.	.33	23.	22.	-1.
1967	441.	484.	43.	.10	24.	20.	-4.
1959	689.	300.	-389.	-.94	25.	16.	-9.
1973	850.	727.	-123.	-.30	26.	28.	2.
1957	931.	523.	-408.	-.99	27.	23.	-4.
1974	1386.	597.	-789.	-1.91	28.	25.	-3.
1972	1584.	957.	-627.	-1.52	29.	29.	0.
MEAN	288.	288.					
STD. DEV.	413.	281.					
MEAN OF ABSOLUTE VALUES			203.	.49			5.4
STD. DEV. OF ABSOLUTE VALUES			212.	.51			4.0

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	16
1	12
2	1

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	8
1	11
2	8
3	2
4	0
5	0
6	0

DELTA RANK: numerical difference between predicted and observed rank (replaced by DELTA CLASS when index is iceberg class)

Subsequently, the mean and standard deviation of the observed and predicted flux are quoted as are the mean absolute error with its standard deviation and the mean absolute rank error with its standard deviation. Similar values for the scaled parameter (P-O/SD) are also quoted.

Finally, two tables defined as "Category Errors: Discrepancy Between Observed and Predicted Categories" and "Class Errors: Discrepancy Between Observed and Predicted Classification", are presented. As it is impossible to compute class from rank, this latter table is eliminated when rank is employed as the iceberg index.

Output from multiple regression tests, as illustrated in Table 4.6 contains additional caption information and excludes the a(n) column from the body of the Table.

One additional variation occurs in the case of an independent test of the linear regression prediction. In this instance a different correlation coefficient evolves for each excluded year. These are quoted in a column labelled "r" in the appropriate tables.

4.4 Results

4.4.1 Eigenvector Results and Rankings

One set of plotted eigenvectors is analyzed at the commencement of this presentation of results to illustrate the independence or orthogonality of eigenfunctions, to confirm the postulate that small numbers of eigenfunctions contain a large portion of the field variance, and to illustrate the interpretation of eigenfunction coefficients relative to numerical temperature anomalies. The case selected for illustration is 4 months ending March surface air temperature, which will later be shown to be a potentially important predictor. Additional eigenvectors for other parameters and time groupings are discussed in later sections.

The mean field of air temperature for 4 months ending March, based on 32 years 1951-1982 appears as Fig. 4.3. The mean pattern is dominated by a -40°C minimum centered over the Greenland ice cap. The -30°C and -20°C contours conform to this feature over Greenland. This latter contour extends from Davis Strait across southern Baffin Island and arcs to circumscribe Hudson Bay. The -10°C and 0°C contours possess a southwest to northeastward orientation from Labrador and Newfoundland respectively to the Denmark Strait and Iceland. The +10°C contour maintains this same orientation in the central North Atlantic.

The first four modes of temperature anomaly for this same interval of 4 months ending March are described by eigenvectors E(1) through E(4) as displayed in Fig. 4.4(a) through Fig. 4.4(d). The independence or orthogonality of these patterns is graphically evident. The dominant mode E(1) exhibits a maximum centered over northern Quebec and southern Baffin Island and a pronounced gradient across Davis Strait and Baffin Bay where contours are oriented directly north/south. The curvature of the -0.05 contour is suggestive of a minimum centered to the east of the study domain. In distinct contrast, the second mode E(2) exhibits an east/west contour orientation across Davis Strait in the center of the domain. This pattern is relatively featureless over mainland Canada and has a minimum over northeastern Greenland. The third E(3) and fourth E(4) modes exhibit contours with northwest/southeast and southwest/northeast orientations respectively, each being independent of the other three primary modes. These latter two modes also suggest the presence of complementary cells to the northeast of the present domain with positive values in the E(3) mode and negative values in E(4).

The postulate that small numbers of eigenvectors explain a large fraction of the field variance is confirmed by the eigenvalues quoted in Table 4.7.

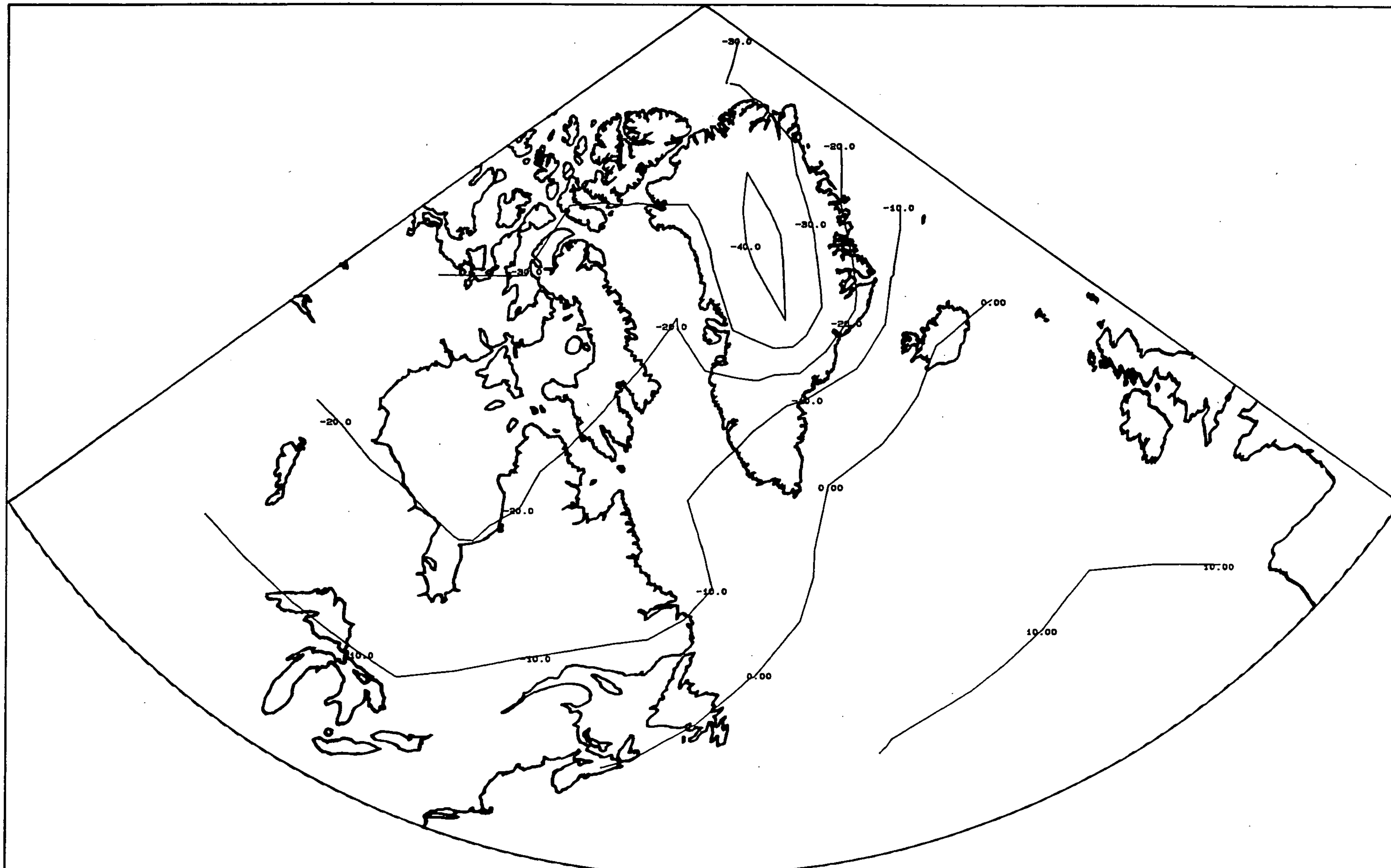


Fig. 4.3 Mean Field of Surface Air Temperature 4 months ending March 1951-1980

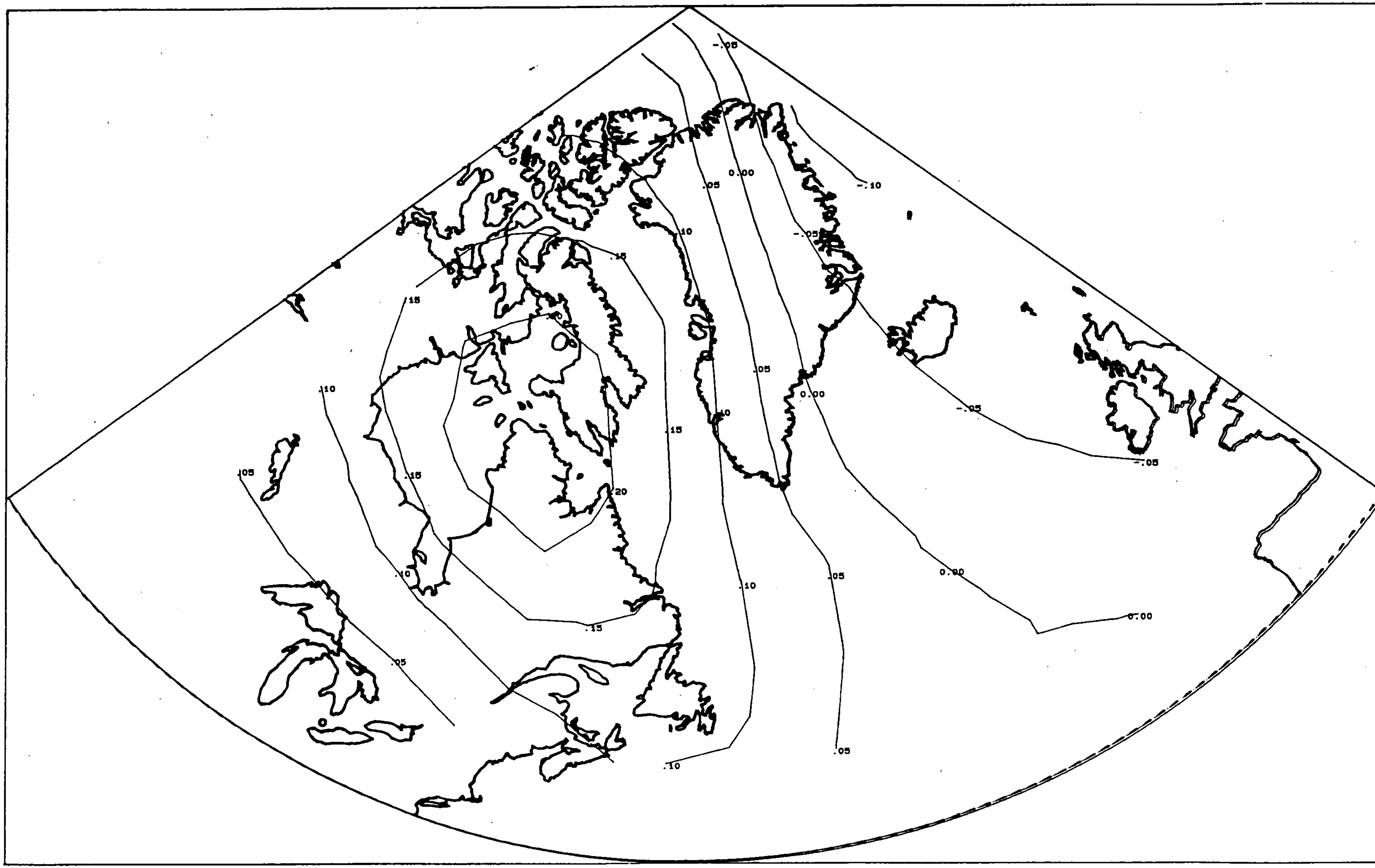


Fig. 4.4(a) 4 months March Air Temperature, Time Averaged Approach
Eigenvector E(1) Eigenvalue $\lambda_1' = 0.41$

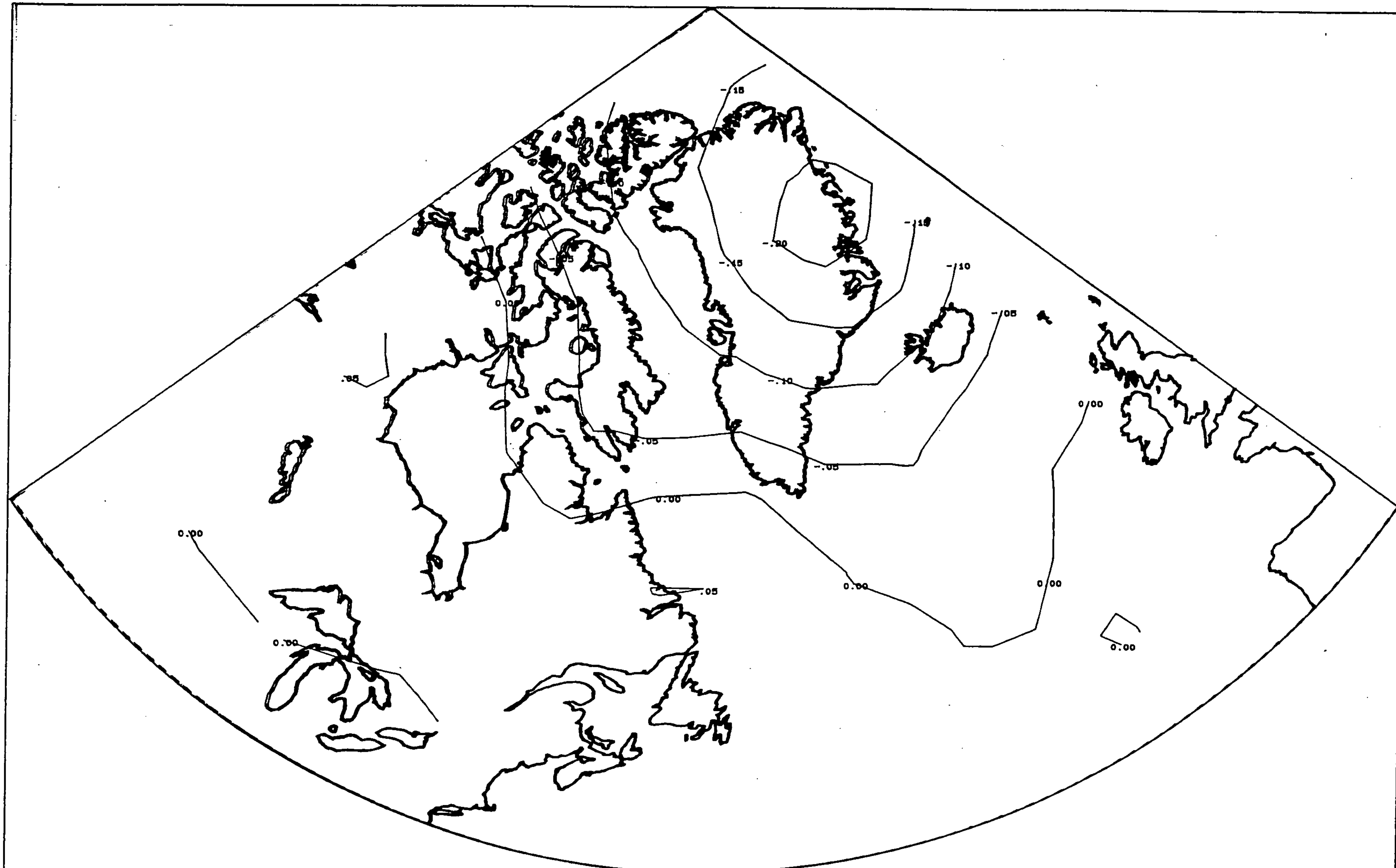


Fig. 4.4(b) 4 months March Air Temperature, Time Averaged Approach
Eigenvector E(2) Eigenvalue $\lambda_2' = 0.20$

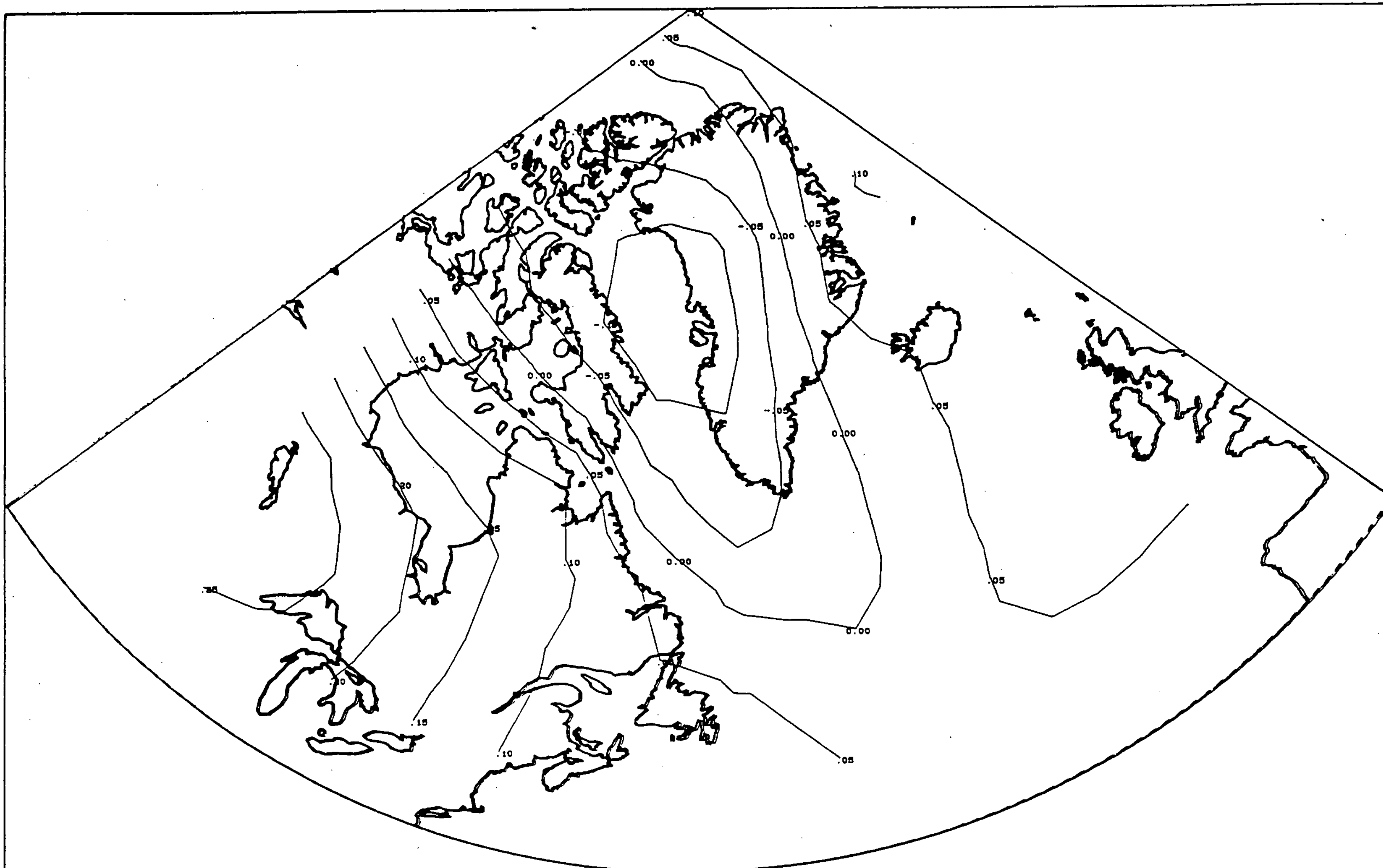


Fig. 4.4(c) 4 months March Air Temperature, Time Averaged Approach
Eigenvector E(3) Eigenvalue $\lambda_3' = 0.14$

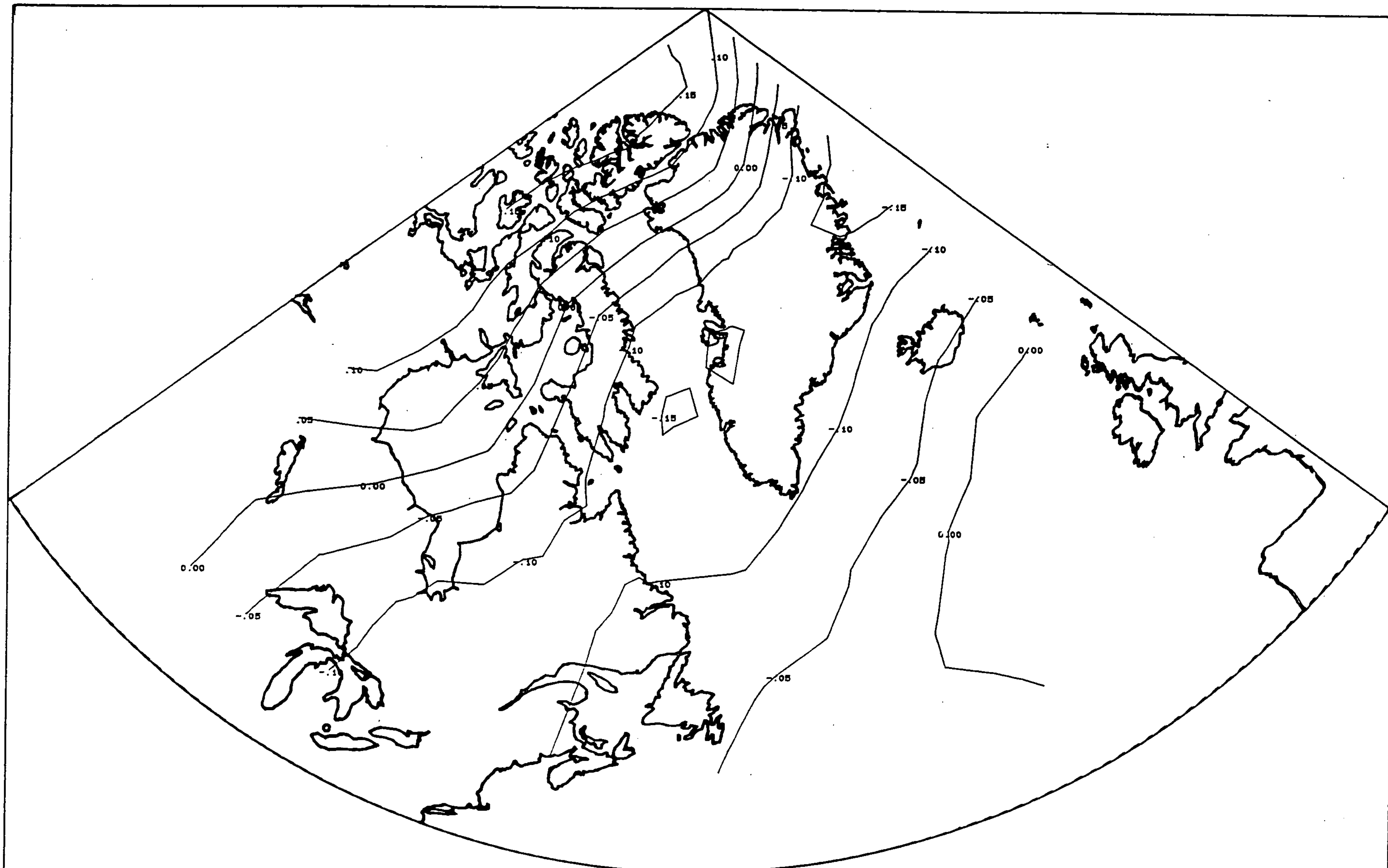


Fig. 4.4(d) 4 Months March Air Temperature, Time Averaged Approach
Eigenvector E(4) Engenvalue $\lambda_4^{'} = 0.08$

Table 4.7

Ranked Eigenvalues Showing Dominance of Primary Modes

Parameter:	SURFACE AIR TEMPERATURE
Number of Months:	4
Ending in:	March (Time Averaged Approach)

EIGENVALUE (NUMBER)	RANK	EIGENVALUE	NORMALIZED	CUMULATIVE NORMALIZED
100	1	68.82	.41	.41
99	2	33.91	.20	.62
98	3	23.14	.14	.76
97	4	13.36	.08	.84
96	5	8.52	.05	.89
95	6	5.33	.03	.92
94	7	3.36	.02	.94
93	8	2.69	.02	.96

In this table are listed the eight most significant eigenfunctions with their associated eigenvalues. Normalized and cumulative normalized eigenvalues also appear. It is seen that modes E(1) through E(4) contain 84% of the field variance with the dominant mode E(1) containing 41% itself. The additional four modes listed (E(5) throught E(8)) contribute an additional 12% to a total of 96% for the first eight functions. The remaining 4% of the field variance is described by an additional 92 inconsequential eigenvectors.

The sign convention assigned to eigenvector elements is determined by the computational technique employed. To determine the physical implication of these functions it is necessary to also inspect the sign of the eigenvector coefficient for a specific physical circumstance. Actual fields of 4 months ending March surface air temperature anomaly are displayed in Fig. 4.5(a) and 4.5(b) for the years 1972 and 1958 respectively. Associated coefficients of eigenvector E(1) are:

December 1971 - March 1972   a(1) = -21.12

December 1957 - March 1958   a(1) = +12.46

These coefficients applied to E(1) as plotted in Fig. 4.4(a), are readily interpreted in light of measured anomalies as displayed in Fig. 4.5. The 1972 data (Fig. 4.5(a)) illustrate an intense negative

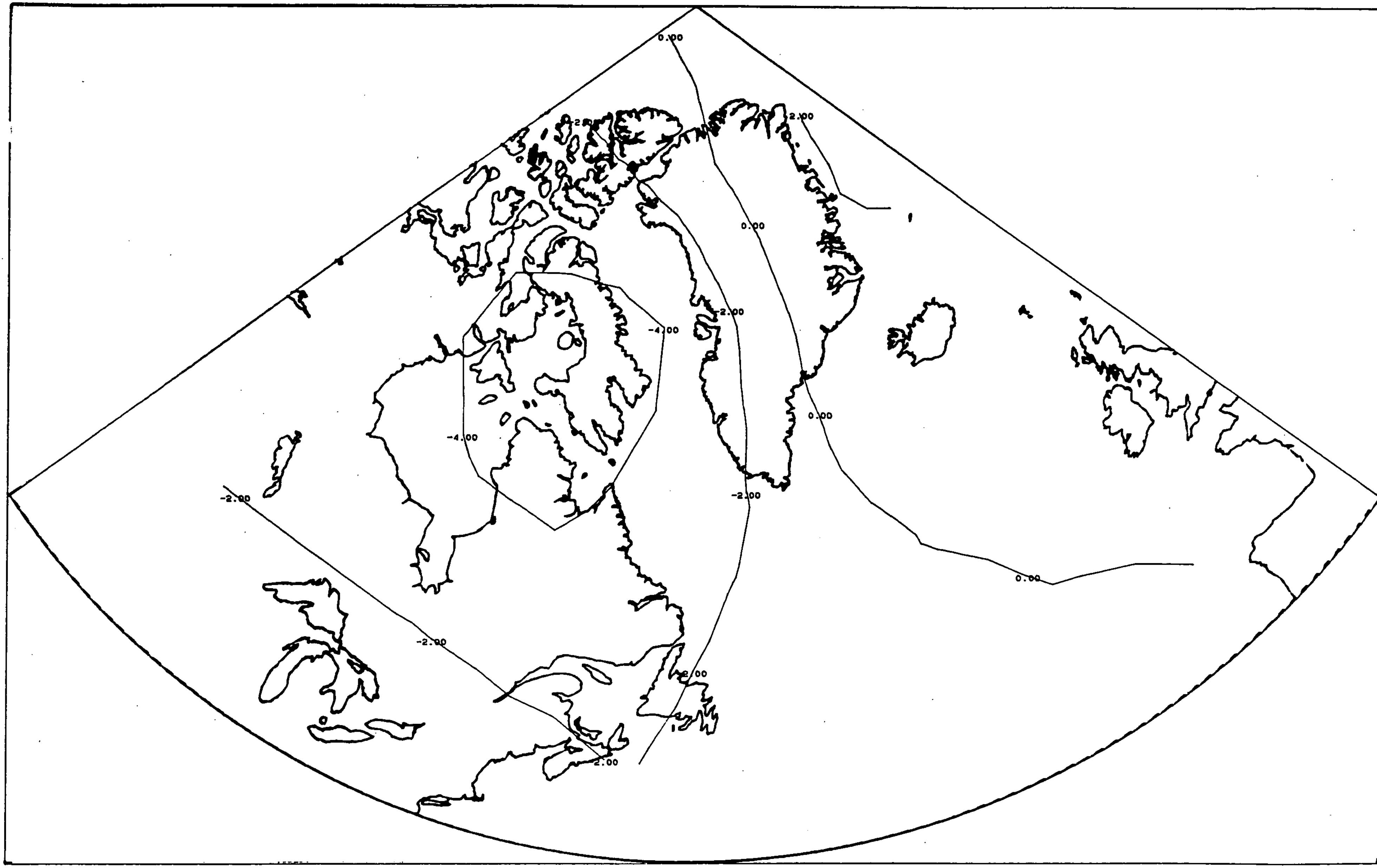


Fig. 4.5(a) Surface Air Temperature Anomaly 4 Months Ending March, Time Averaged Approach December 1971 - March 1972,

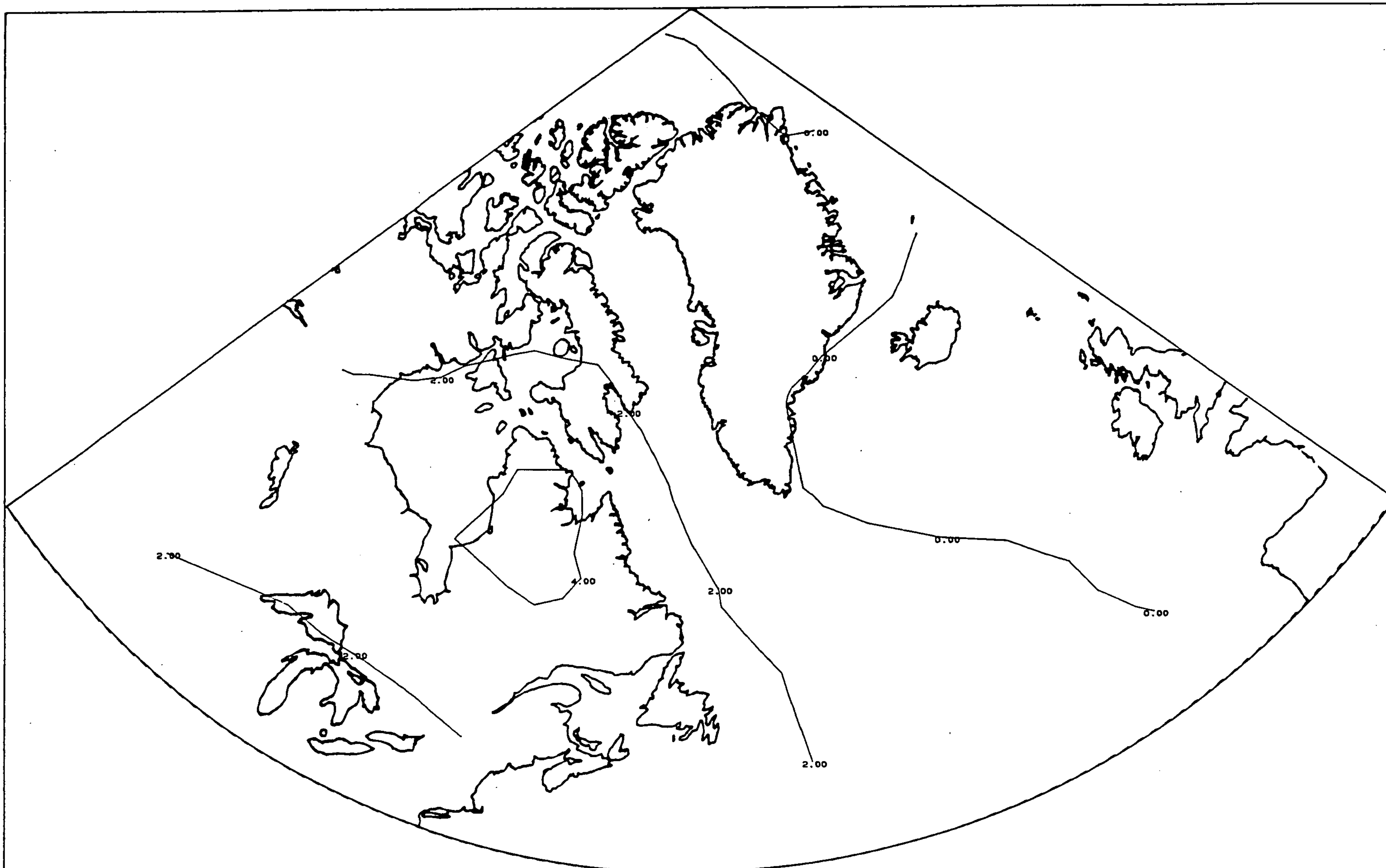


Fig. 4.5(b) Surface Air Temperature Anomaly 4 Months Ending March, Time Averaged Approach
December 1957 - March 1958

temperature anomaly centered over northern Quebec and southern Baffin Island. The 0.0°C anomaly contour stretches across central Greenland and curves toward southern Europe. The pattern correspondance between this measured field and the principal eigenvector E(1) (Fig. 4.4(a)) is unmistakable. It is the negative coefficient a(1) for E(1) in 1972 which indicates from the eigenvector analysis that the 1972 anomaly is negative. In a like manner, Fig. 4.5(b) displays the measured anomaly for December 1957 to March 1958. In this instance the pattern features again distinctly match E(1). However, it is a cell of positive anomaly which lies over northern Quebec. This is accurately described by the 1958 coefficient of E(1) which has a large positive value. Physically, it is clear from Fig. 4.5 and from observed iceberg fluxes that large negative temperature anomalies corresponding to E(1) for 4 months ending March surface air temperature are associated with high iceberg fluxes (1584 icebergs in 1972). Conversely, the occurrence of positive temperature anomalies in the pattern of E(1) for 4 months ending March are associated with low iceberg fluxes (1 iceberg in 1958).

4.4.2 Selection of Predictand Indices

Two linear and one multiple regression cases, arbitrarily selected from a large number with significant correlations, are employed to illustrate the effect of altering the iceberg severity index. Other cases (not here presented) have also been investigated and yield similar conclusions to those annunciated below. The selected cases are:

Case (a): 4 months ending March surface air temperature E(1)
Time averaged approach
Dependent linear regression hindcast results appear in Table 4.8(a)

Case (b): 1 month ending January 700-1000 mb thickness E(1)
Time averaged approach
Dependent linear regression hindcast results appear in Table 4.8(b)

Case (c): 2 months ending January mean sea level pressure E(1)
2 months ending October 700 mb height E(3)

Table 4.8

Comparison of Tercile and Class Errors for Five Different Ice Indices

(a) Case (a) 4 months ending March surface air temperature E(1)

ice index	r value	Category Errors			Class Errors						
		0	1	2	0	1	2	3	4	5	6
1	-.67	20	10	1	9	10	11	1			
2	-.70	20	10	1							
3	-.71	20	10	1	8	12	10	1			
4	-.64	20	10	1	9	15	4	3			
5	-.71				7	17	6	1			

(b) Case (b) 1 month ending January 700-1000 mb height E(1)

ice index	r value	Category Errors			Class Errors						
		0	1	2	0	1	2	3	4	5	6
1	.72	15	12	3	6	12	8	3	1		
2	.56	15	12	3							
3	.68	15	12	3	5	15	8	1	1		
4	.55	15	12	3	9	12	7	1	1		
5	.67	15	12	3	6	16	7	0	1		

(c) Case (c) 2 months ending January mean sea level pressure E(1)
2 months ending October 700 mb height E(3)
2 months ending December 700-1000 mb thickness E(4)

ice index	r value	Category Errors			Class Errors						
		0	1	2	0	1	2	3	4	5	6
1	.78	18	10	1	4	16	6	3			
2	.68	16	12	1							
3	.77	18	10	1	5	16	8				
4	.63	16	12	1	10	11	7	1			
5	.74				8	13	8				

Ice Index	Definition
1	flux
2	rank
3	square root of flux
4	log (base 10) flux
5	class (Table 4.1)

2 months ending December 700-1000 mb thickness E(4)
Time averaged approach
Dependent multiple regression hindcast results appear in Table 4.8(c)

Thirty year dependent hindcasts were executed for each case using the following five ice indices:

Index Number	Definition
1	flux
2	rank
3	square root of flux
4	log (base 10) flux
5	class (Table 4.1).

In the single predictor cases (Table 4.8(a) and (b)) the expected result is verified: linear transformations of flux cannot improve skill as evaluated on a tercile rating system. In contrast, the introduction of predictand variations in the multiple predictor case (Table 4.8(c)) can cause a different weighting of predictors in the multiple regression equation and hence can alter the tercile ranking of results. In this case, flux and $[flux]^{1/2}$ show marginally greater skill in the distribution of category errors than do rank or log(flux). On the strength of this and other non-illustrated observations, and noting from Case (a) and Case (b) that category errors for rank (index 2) are at best the same as those for all transformations of flux, it is concluded that using rank as a predictand index has no substantial advantage. It further has the disadvantage that hindcast skill cannot be unambiguously evaluated using the class error indicator, as class cannot be unambiguously determined from rank. Hence the predictand index of rank (index = 2) is eliminated from consideration in this attempt to isolate the most useful predictand.

The hindcast skill obtained using the remaining four indices (rank excluded) can be evaluated using the class error method. The specific distributions of class errors appear in Tables 4.8(a), (b) and (c). These results appear in alternate form in Table 4.9 which illustrates

Table 4.9

Comparison of Class Error Exceedance for Various Ice Indices: Cases (a), (b) and (c)

Number of events with class error exceeding indicated value.

	Ice Index	>0	>1	>2	>3	>4	>5	>6
Case (a):	flux	22	12	1				
Max = 31	$(flux)^{1/2}$	23	11	1				
	log(flux)	22	7	3				
	class	24	7	1				
Case (b):	flux	24	12	4	1			
Max = 30	$(flux)^{1/2}$	25	10	2	1			
	log(flux)	21	9	2	1			
	class	24	8	1	1			
Case (c):	flux	25	9	3				
Max = 29	$(flux)^{1/2}$	24	8					
	log(flux)	19	7	1				
	class	21	8					

class error exceedance for Cases (a), (b) and (c) using each of four ice indices. Table entries are number of events (years) with class errors exceeding indicated values. The more skillful hindcasts have the smaller numbers of events at each successive level of class error. As the predictor skill and the total number of events varies between Cases (a), (b) and (c) it is appropriate to compare class errors only within cases and not from case to case. The number of events with class error >0 is high in every case and for every index. Generally greater than 70% of the 29-31 events (years) tested yield class errors >0 for every index. Only in Case (c) does the use of log(flux) as a predictand yield less than 20 events with class error >0. This threshold then is a poor indicator to use in isolating the most efficient predictand.

The number of events with class error >1 emerges as a much more useful indicator. In all three cases illustrated in Table 4.9, the use of class (index ≐ 5) as an ice index yields the most skillful hindcasts. The square root and log transformations of flux are seen to yield better results than obtained by using flux directly. It is hence determined to employ iceberg class (index = 5) as the predictand in the forecast method developed via the Empirical Orthogonal Function approach. Flux, and various transformations of flux, remain useful and are subsequently employed in comparing the skill of various predictors, however quantitative forecasts are developed using class as the predictand index.

4.4.3 Comparison of Time Averaged and Composite Approaches

Hindcast skills achieved using the time averaged and the composite data input formulations described in Section 4.3.3, are compared for three cases among a larger number investigated. The cases here presented include:

Case (a): 3 months ending March surface air temperature E(1)
Case (b): 2 months ending January 700-1000 mb thickness E(2)
Case (c): 4 months ending March mean sea level pressure E(1)

Comparisons of dependent time averaged (TA) and composite (C) approach hindcasts are presented in Table 4.10. Category errors are compared for

Table 4.10

Comparison of Tercile and Class Errors for
Time Averaged (TA) and Composite Approaches (C)

(a) Case (a) 3 months ending March surface air temperature E(1)

TA C	ice index	r value	Category Errors			Class Errors						
			0	1	2	0	1	2	3	4	5	6
TA	1	-.60	21	10	1							
C	1	-.50	18	12	2							
TA	5	-.67				6	15	10	1			
C	5	-.59				8	13	9	2			

(b) Case (b) 2 months ending January 700-1000 mb thickness E(2)

TA C	ice index	r value	Category Errors			Class Errors						
			0	1	2	0	1	2	3	4	5	6
TA	1	.54	13	12	4							
C	1	-.63	12	14	3							
TA	5	.46				6	14	5	4			
C	5	-.54				6	13	7	3			

(c) Case (c) 4 months ending March mean sea level pressure E(1)

TA C	ice index	r value	Category Errors			Class Errors						
			0	1	2	0	1	2	3	4	5	6
TA	1	-.49	18	10	1							
C	1	-.52	18	10	1							
TA	5	-.56				3	18	4	4			
C	5	-.58				3	19	4	3			

hindcasts based on iceberg flux (index = 1) and class errors are compared for hindcasts based on iceberg class (index = 5). The results presented in Table 4.10 are compatible with those from other tests, and indicate a marginal degrading in skill for composite approach hindcasts compared to time averaged approach hindcasts. Variations of only one or two events per error category or class are common, and odd cases are noted where composite approach results show even fractional improvements (Table 4.10(c)) over time averaged counterparts. The basic tendancy through the various cases tested is for the time averaged approach to yield the more accurate hindcasts.

Physically, there are contradictory arguments as to the merit of one approach versus the other. One perspective suggests that the calculation of time averages prior to evaluation of eigenvectors effectively smoothes the atmospheric signal and results in a loss of real variability as represented by the eigenfunctions. The contrasting argument suggests that it is in fact the integrated or time averaged behaviour of the atmospheric field which this method seeks to isolate as a predictor of iceberg flux, and hence that time averaging is a most appropriate action. No decisive physical arguement has been formulated to justify selection of one approach as being more suitable than the other.

Hence on the basis of marginally better performance in a number of hindcast tests, it has been determined to employ the time averaged approach in the forecast method devised in this study.

4.4.4 Linear Regression Cases

4.4.4.1 Isolating Potential Predictors

The matrix format illustrated as Fig. 4.2 specifies 120 possible temporal groupings of atmospheric data for eigenfunction calculations. This same matrix format is employed to quote correlation coefficient values derived in the numerous linear regression tests performed. In this summary of correlation test results, each matrix entry (some number of months ending in specified month) consists of the values of the correlation coefficient r for selected regression of a(n) versus iceberg severity index. In all instances the index employed is flux. The values displayed were selected on the following basis:

(a) the correlation coefficient r determined from the regression of the primary eigenfunction coefficients a(1) against ice index is always quoted

(b) correlation coefficients for regression of a(n) n=2, 3,...8, are also quoted provided $|r| \geq 0.46$. This is the significance threshold quoted in Section 4.3.2.

(c) only the largest value of the significant correlation coefficient for a(n) N=2,3,...8 is quoted (besides the a(1) value).

Correlation coefficient matrices appear as Fig. 4.6, 4.7, 4.8 and 4.9 for the parameters mean sea level pressure, 700 mb height, 700-1000 mb thickness and surface air temperature respectively.

The mean sea level pressure correlations (Fig. 4.6) are particularly poor through the October to December period. The only three values which have apparent significance in this interval are for fifth and sixth mode eigenfunctions and hence are not spontaneously considered likely to identify high quality predictors. These same high correlations are evident for E(5) and E(6) in selected January cases: the utility of such predictors warrants investigation. Primary eigenfunction correlations are apparently significant for a number of cases in the January to March interval for groupings of one to four months. The utility of these will be evaluated.

The 700 mb height correlations exhibit a similar behaviour (Fig. 4.7) with E(5) and E(6) being important in the December and January columns for groupings of four to nine months. Values for two months ending October and November are also of interest. Primary mode correlations show promise for one and two months ending January and for a number of February and March cases. Of particular interest is the case of four months ending March where both the E(1) and E(2) correlations exceed the significance threshold, though only marginally.

ENDING (End of)

Number of Months	January	February	March	April	May	June	July	August	September	October	November	December
1	(1)-.55	(1)-.18	(1)-.38								(1) .09	(1)-.10
2	(1)-.49	(1)-.48	(1)-.31							(1)-.05 (6) .54	(1) .04	(1) .00
3	(1)-.39 (5) .49	(1)-.46	(1)-.52							(1)-.11	(1) .01	(1).00
4	(1)-.35 (6) .56	(1)-.39	(1)-.49							(1)-.07	(1)-.05	(1)-.05 (5) .55
5	(1)-.35 (5) .48	(1)-.38	(1)-.44								(1)-.03	(1)-.10 (5)-.50
6	(1)-.36 (5)-.46	(1)-.37	(1)-.44								(1) .01	(1)-.08
7	(1)-.31	(1)-.38	(1)-.42								(1)-.11	(1)-.04
9	(1)-.33	(1)-.29	(1)-.39									
12	(1)-.23	(1)-.31	(1)-.34									
24	(1)-.12	(1)-.21	(1)-.31									

Fig. 4.6 Matrix of Correlation Coefficients for Iceberg Flux versus Mean Sea Level Pressure

ENDING (End of)

Number of Months	January	February	March	April	May	June	July	August	September	October	November	December
1	(1)-.50	(1)-.24	(1)-.27								(1)-.05	(1)-.17
2	(1)-.44	(1)-.48	(1)-.30							(1)-.21 (3)-.57	(1)-.11 (2) .46	(1)-.16
3	(1)-.38	(1)-.47	(1)-.48							(1)-.26	(1)-.16	(1)-.17
4	(1)-.39 (5)-.51	(1)-.42	(1)-.49 (2) .47							(1)-.21	(1)-.22	(1)-.23
5	(1)-.38 (5)-.49	(1)-.42	(1)-.45								(1)-.19	(1)-.27 (5)-.58
6	(1)-.39 (5)-.56	(1)-.41	(1)-.46								(1)-.13	(1)-.24 (5)-.54
7	(1)-.34 (5) .51	(1)-.42	(1)-.44								(1)-.23	(1)-.17 (6) .49
9	(1)-.36 (6) .55	(1)-.34	(1)-.42									
12	(1)-.27	(1)-.34	(1)-.36									
24	(1)-.13	(1)-.24	(1)-.37									

Fig. 4.7 Matrix of Correlation Coefficients for Iceberg Flux versus 700 mb Height

ENDING (End of)

Number of Months	January	February	March	April	May	June	July	August	September	October	November	December
1	(1) .72	(1)-.29	(1)-.18 (6)-.48								(1)-.17 (3) .50	(1)-.25
2	(1)-.51 (2) .55	(1) .64	(1)-.31								(1)-.23	(1)-.30 (4)-.55
3	(1)-.52	(1) .63	(1) .65								(1)-.35	(1) .25 (4) .54
4	(1) .48	(1) .53	(1)-.64								(1)-.35	(1) .34
5	(1) .47	(1) .51	(1) .58 (3)-.48								(1) .31	(1) .35
6	(1) .43	(1) .49	(1) .56								(1) .25	(1) .34
7	(1) .40	(1) .47	(1) .54								(1) .29	(1) .29
9	(1) .33	(1) .39	(1) .48									
12	(1) .26	(1) .29 (4)-.49	(1) .31									
24	(1) .05 (2) .53	(1) .12 (2) .50	(1) .20 (2)-.55									

Fig. 4.8 Matrix of Correlation Coefficients for Iceberg Flux versus 700-1000 mb Thickness

ENDING (End of)

Number of Months	January	February	March	April	May	June	July	August	September	October	November	December
1	(1)-.39 (2) .55	(1)-.33	(1)-.27								(1) .13	(1)-.26
2	(1)-.46 (2)-.49	(1)-.51	(1)-.42								(1) .11	(1)-.20
3	(1)-.48	(1)-.62	(1)-.60								(1) .12	(1) .19
4	(1) .41	(1)-.58	(1)-.67								(1) .06	(1) .19
5	(1) .38	(1)-.48	(1)-.62								(1) .05	(1) .17
6	(1) .36	(1)-.47	(1)-.53								(1) .05	(1) .17
7	(1) .36	(1) .46	(1)-.52								(1) .13	(1) .16
9	(1) .33	(1) .42	(1) .51									
12	(1) .27	(1) .35	(1) .41									
24	(1) .29	(1) .34	(1) .42									

Fig. 4.9 Matrix of Correlation Coefficients for Iceberg Flux versus Surface Air Temperature

At 0.72, the correlation coefficient value for January 700-1000 mb thickness (Fig. 4.8) is the largest yet noted. November to December values are higher than those for MSLP or 700 mb height but still do not generally meet significance criteria. Many potential predictors are evident in the January to March interval at one to nine month time groupings. Correlation values exceeding ±0.5 are also noted in E(2) for 24 month groupings ending January through March.

Finally, the surface air temperature eigenvector correlations are summarized in Fig. 4.9. November and December values are particularly poor, but improve substantially in the January to March interval. The primary mode for four months March (which was used to illustrate Section 4.4.1). has promise. Numerous January and particularly February predictors require investigation.

In summary, these matrices of correlation coefficients identify a large number of potentially skillful predictors for the January to March interval. Clearly the operational constraints argue for the use of the earliest of these which might yield well verified hindcasts. Potentially useful early winter (October to December) predictors are limited, but because of their temporal attractiveness must be carefully evaluated.

4.4.4.2 Dependent Hindcast Tests

The preparation of these matrices of correlation coefficients necessitated the performance of linear regressions for each of the eight highest ranked eigenvectors for each parameter and time interval. By storing and maintaining the results of these regressions it became simply and efficiently possible to dependently test the hindcast performance of any single predictor. The dependent hindcast software simply required input of the a(n) series and the regression equation slope and intercept, all of which were stored in binary disc files. The information required for any single-parameter dependent hindcast could readily be displayed, and was readily accessed by the hindcast prediction software.

The consequence of this computational simplicity by which dependent hindcasts could be executed is that numerous such tests were performed.

Output in each case was of the form described and illustrated in Section 4.3.7. Hindcast skill was assessed in terms of category and class errors for each case investigated.

Results of some 50 such tests (representing a subset of about one half of those tests performed) are summarized in Table 4.11. The following notes pertain to the interpretation of this table:

Column 1:	sequential case number
Column 2:	D=Dependent I=Independent All results presented in Table 4.11 are for dependent hincasts
Column 3:	L=Linear M=Multiple All results presented in Table 4.11 are for linear, or single-parameter hindcasts
Column 4:	TA = Time Averaged C = Composite All results presented in Table 4.11 are for time averaged cases
Column 5:	#P = Number of Parameters #P = 1 for single-parameter tests #P > 1 for multiple-parameter tests
Column 6:	Parameter Name MSLP = mean seal level pressure HEIGHT = 700 mb height THICK = 700-1000 mb thickness SAT = surface air temperature
Column 7:	#mon = number of months
Column 8:	End mon = end month of #mon
Column 9:	a(n) = eigenfunction coefficent number
Column 10:	ice index = predictand 1 = flux 2 = rank 3 = square root flux 4 = log (base 10) flux 5 = class
Column 11:	r = correlation coefficient
Columns 12-14:	Category Errors
Columns 15-21:	Class Errors

On the basis of operational utility and favourable category and class error statistics (Table 4.11), and coupled with inspection of actual hindcast flux values, a set of five linear regression hindcasts were selected (from the more than 100 cases investigated), for full display. These results and selected others which follow are displayed in Appendix I. These apparently good single predictors, referenced by their

Table 4.11

Summary of 30 Year Hindcast Iceberg Severity Predictions

Case Num	D I	L M	TA C	# P	Param. Name	# mos	End mon	a (n)	ice index	r value	Category Errors			Class Errors						
											0	1	2	0	1	2	3	4	5	6
1	D	L	TA	1	MSLP	1	Jan	1	1	-.55	16	10	4	4	9	13	2			
2	D	L	TA	1	MSLP	3	Jan	1	1	-.39	16	8	5	5	10	7	7			
3	D	L	TA	1	MSLP	4	Jan	1	1	-.35	16	8	5	4	12	7	7			
4	D	L	TA	1	MSLP	2	Oct	1	1	-.05	14	12	4	4	7	11	8			
5	D	L	TA	1	MSLP	2	Nov	1	1	-.04	11	8	11	4	7	11	8			
6	D	L	TA	1	MSLP	2	Dec	1	1	.00	9	12	9	4	7	11	8			
7	D	L	TA	1	MSLP	2	Jan	1	1	-.49	15	12	2	3	12	10	3	1		
8	D	L	TA	1	MSLP	2	Feb	1	1	-.48	17	10	3	4	9	13	4			
9	D	L	TA	1	MSLP	2	Mar	1	1	-.31	19	8	3	3	8	13	6			
18	D	L	TA	1	MSLP	1	Nov	3	1	.39	9	16	5	6	4	13	6			
21	D	L	TA	1	MSLP	1	Nov	3	5	.34				4	14	8	3	1		
19	D	L	TA	1	MSLP	2	Nov	2	1	.42	14	12	4	4	10	10	5	1		
22	D	L	TA	1	MSLP	2	Nov	2	5	.41				5	12	10	3			
20	D	L	TA	1	MSLP	3	Nov	2	1	.43	15	10	5	3	9	13	4	1		
23	D	L	TA	1	MSLP	3	Nov	2	5	.40				4	14	9	3			
24	D	L	TA	1	HEIGHT	1	Nov	3	1	.45	8	16	6	5	9	7	7	2		
28	D	L	TA	1	HEIGHT	1	Nov	3	5	.34				7	10	8	5			
25	D	L	TA	1	HEIGHT	2	Oct	3	1	-.57	15	12	3	5	10	10	5			
29	D	L	TA	1	HEIGHT	2	Oct	3	5	-.56				6	14	9	1			
26	D	L	TA	1	HEIGHT	2	Nov	2	1	.46	12	14	4	3	10	11	5	1		
30	D	L	TA	1	HEIGHT	2	Nov	2	5	.41				5	12	9	4			
27	D	L	TA	1	HEIGHT	3	Nov	2	1	.43	15	10	5	1	11	11	4	1		
31	D	L	TA	1	HEIGHT	3	Nov	2	5	.38				3	13	11	3			
32	D	L	TA	1	THICK	1	Nov	3	1	.50	15	12	3	7	7	10	4	2		
33	D	L	TA	1	THICK	1	Nov	3	5	.40				6	12	6	6			

Table 4.11 Cont'd

Summary of 30 Year Hindcast Iceberg Severity Predictions

Case Num	D I	L M	TA C	# P	Param. Name	# mos	End mon	a (n)	ice index	r value	Category Errors 0	1	2	Class Errors 0	1	2	3	4	5	6
73	D	L	TA	1	HEIGHT	5	Dec	5	1	-.58	11	14	5	6	8	7	8	1		
74	D	L	TA	1	HEIGHT	1	Jan	1	1	-.50	16	10	4	3	8	13	4	2		
75	D	L	TA	1	HEIGHT	2	Feb	1	1	-.48	17	12	1	6	7	14	3			
76	D	L	TA	L	HEIGHT	3	Feb	1	1	-.47	14	14	1	2	13	10	4			
77	D	L	TA	1	HEIGHT	4	Mar	1	1	-.49	16	12	1	5	8	13	3			
78	D	L	TA	1	HEIGHT	4	Mar	2	1	.47	11	14	4	3	11	7	6	2		
79	D	L	TA	1	MSLP	2	Oct	6	1	.54	14	12	4	3	9	13	4	1		
80	D	L	TA	1	MSLP	4	Dec	5	1	.55	10	16	4	4	7	12	6	1		
81	D	L	TA	1	MSLP	3	Mar	1	1	-.52	18	10	2	7	9	10	4			
82	D	L	TA	1	MSLP	4	Mar	1	1	-.49	18	10	1	5	10	11	3			
83	D	L	TA	1	THICK	2	Dec	4	1	-.55	12	14	4	6	9	7	7	1		
84	D	L	TA	1	THICK	1	Jan	1	1	.72	15	12	3	6	12	8	3	1		
85	D	L	TA	1	THICK	2	Jan	1	1	-.51	14	12	3	3	12	9	4	1		
86	D	L	TA	1	THICK	2	Jan	2	1	.55	13	12	4	6	10	8	3	2		
87	D	L	TA	1	THICK	2	Feb	1	1	.64	17	12	1	8	9	9	4			
88	D	L	TA	1	THICK	4	Mar	1	1	-.64	16	12	1	6	11	10	2			
89	D	L	TA	1	THICK	6	Mar	1	1	.56	16	12	1	8	7	11	3			
90	D	L	TA	1	THICK	24	Mar	2	1	-.55	12	12	4	7	7	9	5			
91	D	L	TA	1	SAT	2	Jan	1	1	-.46	12	14	5	3	14	9	3	2		
92	D	L	TA	1	SAT	2	Jan	2	1	-.49	15	12	4	6	11	11	2	1		
93	D	L	TA	1	SAT	2	Feb	1	1	-.51	18	12	2	7	11	10	4			
94	D	L	TA	1	SAT	4	Feb	1	1	-.58	18	10	3	4	15	7	5			
95	D	L	TA	1	SAT	4	Mar	1	1	-.67	20	10	1	9	10	11	1			
96	D	L	TA	1	SAT	6	Mar	1	1	-.53	16	12	3	6	10	10	5			
97	D	L	TA	1	SAT	9	Mar	1	1	.51	16	12	3	7	12	8	4			

CASE NUMBERS from Table 4.11 include:

Case 7	2	months	January	MSLP	E(1)	Table I.1 (a) and (b)
Case 25	2	months	October	HEIGHT	E(3)	Table I.2 (a) and (b)
Case 82	4	months	March	MSLP	E(1)	Table I.3 (a) and (b)
Case 87	2	months	February	THICK	E(1)	Table I.4 (a) and (b)
Case 95	4	months	March	SAT	E(1)	Table I.5 (a) and (b)

Dependent mode hindcast results for these predictors using flux (index = 1) and class (index = 5) are presented as Table I.1(a) to Table I.5(a) and Table I.1 (b) to Table I.5(b) respectively for the five selected cases.

Each pair of tables is accompanied by one figure (Fig. I.1 to Fig. I.5) which is a log-log representation of observed versus predicted flux values. Class predictions are not graphed. Each datum on these figures is labelled with the latter two digits of the year to which the point applies. Observed or predicted values less than 10 are excluded from the plotted display but are readily identified in Tables I.1(a) to I.5(a).

The first two of the illustrated cases are of interest primarily because of their potential as early season operational predictors, while the latter three are of more scientific interest as the best of all predictors investigated.

4.4.4.3 Independent Hindcast Tests

Two modes of independent verification testing for predictive regression models were introduced in Section 4.3.6. The principal method involves the sequential elimination of one of the 30 available years of data in 30 different iterations of model development. In each case the model is used to hindcast only the one excluded year. The second method involves the use of a predictive model developed from 1951-1980 data to hindcast iceberg fluxes in the ensuing years 1981-1985.

Independent tests to sequentially exclude each of 30 years are computationally very demanding. Such tests required eight to ten hours elapsed time on the HP1000/A700 computer system employed in this study.

The results of two such tests are presented and compared to their dependent hindcast counterparts. Cases presented include:

(a) 2 months January mean sea level pressure E(1)
Independent hindcast results appear in Appendix I as Table I.6 and are to be compared with dependent hindcast results in Table I.1(a).

(b) 2 months October 700 mb height E(3)
Independent hindcast results appear in Appendix I as Table I.7 and are to be compared with dependent hindcast results in Table I.2(a).

These comparisons, as summarized in Table 4.12 show only a marginal decrease in hindcast skill between dependent and independent tests. The mean absolute rank error degrades by 0.5 and 0.4 units respectively in cases (a) and (b). The tercile error distribution actually improves in the independent test for case (b) but the class error distribution is marginally degraded by a shift of two events from Class Error < 2 to Class Error = 2. Overall, the summary in Table 4.12 is most encouraging and suggests that apparent hindcast skill demonstrated in dependent mode hindcasts has true statistical significance.

Independent hindcast tests for the interval 1981-1985 are affected by the previously noted change in iceberg observing technique which resulted from the operational introduction of SLAR in 1983. Seeking to approximate compatibility between the pre and post-SLAR observation totals, the 1983, 1984 and 1985 IIP totals of 1351, 2204 and 1031 have been reduced by a factor of 3 to yield adjusted observed counts of 450, 735 and 343. These adjusted values are used in the following coarse assessment of independent hindcast results for the 1981-1985 interval. Again the two early season predictors tested above are employed.

Results of these independent 1981-1985 tests for 2 months January MSLP E(1) and 2 months October HEIGHT E(3) are summarized in Table 4.13. The case (a) results are again most encouraging as severity classes for each of 1983, 1984 and 1985 are accurately predicted. The years 1981 and 1982 suffer overprediction and underprediction by two and one classes

Table 4.12

Comparison of Dependent and Independent Hindcast Results for Two Linear Regression Cases

Case (a) 2 months January MSLP E(1)			Case (b) 2 months October HEIGHT E(3)	
Dependent	Independent	Category Errors	Dependent	Independent
15	14	0	15	17
12	12	1	12	10
2	3	2	3	3
		Class Errors		
3	3	0	5	6
12	11	1	10	7
10	11	2	10	12
3	2	3	5	5
1	2	4		
		5		
		6		
254	270	Mean Absolute Flux Error	232	249
6.9	7.4	Mean Absolute Rank Error	6.5	6.9

Table 4.13

Comparison of Observed and Hindcast 1981-1985
Iceberg Fluxes for Two Linear Regression Cases

Case (a)			Case (b)	
2 months January MSLP E(1)			2 months October HEIGHT E(3)	
		Iceberg Flux		
Observed	Hindcast	Year	Observed	Hindcast
63	391	1981	63	312
188	62	1982	188	0
450	545	1983	450	0
735	452	1984	735	437
343	362	1985	343	0
		Iceberg Class		
		Year		
2	4	1981	2	4
3	2	1982	3	1
5	5	1983	5	1
5	5	1984	5	5
4	4	1985	4	1

CLASS ERRORS (Case (a))

Error	Number of Years
0	3
1	1
2	1
3	
4	
5	
6	

CLASS ERRORS (Case (b))

Error	Number of Years
0	1
1	0
2	2
3	1
4	1
5	
6	

respectively. The case (b) results suggest little if any skill. Zero flux is predicted in three of five years in spite of observed large fluxes in two of these three years. Only 1984 achieves an accurate class prediction, while 1981 is again overpredicted by two classes.

4.4.5 Multiple Regression Cases

4.4.5.1 Dependent Hindcast Tests

Review of the performance of a large number of single-parameter predictors (Section 4.4.4) has isolated a number of these as potentially useful. It now remains to test various combinations of these to assess their combined performance in improving forecast skill. Prior to employing multiple predictors in a multiple regression approach it is necessary to assess the degree of cross correlation between the predictors. Such correlations are known to be zero between the coefficients of any pair of eigenvectors for a given parameter and time grouping. This is a necesary condition of the orthogonality of the eigenfunctions. The same is not necessarily true between selected pairs of predictors in which the parameter or the time grouping varies, and hence such cross correlations must be tested. Low absolute values of the correlation coefficient computed between sets of predictors are necessary to justify the joint use of such predictors in a multiple regression model.

Again those results which are formally presented represent a subset of the many cases which have been tested. The six cases selected for presentation are summarized in Table 4.14. The initial column in Table 4.14 identifies the Table Number(s) of the subsequent tables, located in Appendix I, which fully present the dependent mode hindcast results. In all cases, the (a) table in any sequence presents the cross correlation results for the appropriate set of parameters. The (b) table presents dependent hindcast results for flux (ice index = 1) and where necessary, the (c) table presents the corresponding dependent hindcast results for class (ice index = 5).

Each of the first four illustrated multiple regression cases (Tables I.8 to I.11) possesses one or more problems which precludes the utilization

Table 4.14 Summary of 30 Year Hindcast Iceberg Severity Predictions for Multiple Regression Cases

Table Num	D I	L M	TA C	# P	Param. Name	# mos	End mon	A (n)	ice index	r value	Category 0	Category 1	Category 2	Class 0	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
I.8	D	M	TA	3	HEIGHT	1	Jan	1	1	-.50	16	12	1	8	11	8	2			
(a),(b)					MSLP	3	Mar	1	1	-.52										
					SAT	4	Mar	1	1	-.67										
I.9	D	M	TA	2	MSLP	4	Mar	1	1	-.49	15	14	0	4	14	8	2	1		
(a),(b)					MSLP	4	Mar	2	1	.45										
I.10	D	M	TA	5	MSLP	2	Jan	1	1	-.49	16	12	1	7	12	6	4			
(a),(b)					HEIGHT	5	Dec	5	1	-.58										
					HEIGHT	2	Oct	3	1	-.57										
					THICK	2	Dec	4	1	-.54										
					MSLP	4	Dec	5	1	.55										
I.11	D	M	TA	5	MSLP	2	Jan	1	1	-.49	16	12	1	6	11	9	3			
(a),(b)					HEIGHT	2	Oct	3	1	-.57										
					MSLP	4	Mar	1	1	-.49										
					THICK	2	Feb	1	1	.63										
					SAT	4	Mar	1	1	-.67										
I.12	D	M	TA	3	MSLP	2	Jan	1	1	-.49	18	10	1	4	16	6	3			
(a),(b)					HEIGHT	2	Oct	3	1	-.57										
					THICK	2	Dec	4	1	-.54										
I.12	D	M	TA	3	MSLP	2	Jan	1	5	-.49				8	13	8				
(c)					HEIGHT	2	Oct	3	5	-.57										
					THICK	2	Dec	4	5	-.54										
I.13	D	M	TA	2	MSLP	2	Jan	1	1	-.49	16	12	1	7	9	10	3			
(a),(b)					HEIGHT	2	Oct	3	1	-.57										
I.13	D	M	TA	2	MSLP	2	Jan	1	5	-.49				6	14	9				
(c)					HEIGHT	2	Oct	3	5	-.57										

of that set of predictors to formulate an operational forecast model. As seen from Table I.8(a), the three individual predictors in this test are cross-correlated at 0.55, 0.68 and 0.70, which is regarded as too high for operational use. Besides, two of the three pertain to periods ending in March which is too late in the season for the preparation of operational forecasts. The case illustrated by Table I.9 clearly shows the independence of eigenfunctions for a given parameter and time grouping, but again is based upon March predictors. The group of five early season predictors tested in the third multiple regression case exhibits certain cross-correlations (Table I.10(a)) which are unacceptably high, although most absolute values are less than 0.4. Category and class error statistics for this case are encouraging in spite of the parameter interdependences. Similar comments apply again to the fourth case (Table I.11) with further difficulty imposed by two March predictors.

The most successful of the multiple regression cases tested are displayed via Tables I.12 and I.13. In the first of these, the independence of the three predictors is verified via Table I.12(a) which exhibits cross-correlation coefficients of only 0.08, 0.27 and 0.37. The operational utility of the predictors is confirmed, with the latest being the 2 months ending January pressure distribution. Finally the dependent hindcast performances for flux (Table I.12(b)) and for class (Table I.12(c)) are as impressive as any observed. It is particularly noted from Table I.12(b) that highly credible absolute flux values are predicted for the more severe years (1967, 1959, 1973, 1957, 1974 and 1972). Even more importantly, the ranks of the four most severe years are almost exactly predicted, and only two of the eight most severe years experience absolute rank errors greater than 1. The class error distribution (Table I.12(c)) illustrates errors of 0 or ± 1 in 21 of 29 case, with the remaining eight cases all having errors of ± 2. This cases stands as the most successful of all those investigated.

By eliminating the 2 months December 700-1000 mb thickness E(4) parameter, a subset of the predictors employed in this most skillful case was also tested. Results for the multiple regression test of 2 months January mean sea level pressure E(1) and 2 months October 700 mb height E(3) appear as Table I.13. Predictive skill is degraded only slightly from the three parameter case (Table I.12).

4.4.5.2 Independent Hindcast Tests

As was discussed in Section 4.3.6 and illustrated for linear regression cases in Section 4.4.4.3, two methods of independent verification are available. The first involves the sequential elimination of one of the 30 available years of data in 30 different iterations of model development. The second method involves the use of a predictive model developed from 1951-1980 data to hindcast iceberg fluxes in the ensuing years 1951-1985.

Results of complete 30 year independent hindcast tests for the latter two multiple regression groupings discussed above (Tables I.12 and I.13) are presented. These cases are:

(a) 2 months January mean sea level pressure E(1)
2 months October 700 mb height E(3)
2 months December 700-1000 mb thickness E(4)

Independent hindcast results appear as Table I.14 and are to be compared with dependent hindcast results in Table I.12(b).

(b) 2 months January mean sea level pressure E(1)
2 months October 700 mb height E(3)

Independent hindcast results appear as Table I.15 and are to be compared with dependent hindcast results in Table I.13(b).

The decrease in hindcast skill between dependent and independent hindcast tests in these multiple regression cases, as summarized in Table 4.15, is greater than was observed in corresponding linear regression tests (Table 4.12). Category errors do not degrade substantially in the present case (a) but class errors in this instance are notably worse. Dependent hindcasts yield 20 of 29 cases having class errors ≤ 1 while the independent hindcast accounts for only 15 of 29 events in this low error state. Again in case (a) the mean absolute flux error increases by 23% from 179 to 220 and the mean absolute rank error

Table 4.15

Comparison of Dependent and Independent Hindcast Results for Two Multiple Regression Cases

Case (a)

2 months January MSLP E(1)
2 months October HEIGHT E(3)
2 months December THICK E(4)

Case (b)

2 months January MSLP E(1)
2 months October HEIGHT E(3)

Case (a) Number of Years: Dependent	Case (a) Number of Years: Independent	Category Errors	Case (b) Number of Years: Dependent	Case (b) Number of Years: Independent
18	17	0	16	15
10	10	1	12	12
1	2	2	1	2
		Class Errors		
4	7	0	7	4
16	8	1	9	11
6	11	2	10	12
3	2	3	3	2
	1	4		
		5		
		6		
179	220	Mean Absolute Flux Error	205	225
5.6	6.3	Mean Absolute Rank Error	5.9	6.2

increases by 0.7 units. While the absolute skill of case (b) is less than that of case (a), there is a much lesser decrease in skill between dependent and independnet hindcast tests in this second test, than has been described for case (a). Again in this instance there is a very minor shift in the distribution of category errors. The degradation of class errors is, however, similarly slight. While the dependent test accounts for 16 of 29 events with class error ≤ 1, the independent test accounts for a comparable 15 of 29. The mean absolute flux error degrades by 10% from 205 to 225 and the mean absolute rank error shifts by only 0.3 units from 5.9 to 6.2. In spite of these expected and acknowledged degradations, the results of the independent hindcast tests in these two multiple regression cases remain skillful and provide quantitative justification for the use of these predictors in forecasting iceberg abundance.

Consistent with previous discussion (Section 4.4.4.3) the IIP seasonal flux values for 1983, 1984 and 1985 have been reduced by a factor of 3 to approximate compatibility between pre and post-SLAR observation totals. These adjusted values are used in the results for the 1981-1985 interval. Only the latter of the case (a) and case (b) groupings of multiple early season predictors defined immediately above is analyzed.

Results of this independent 1981-1985 test of multiple regression prediction using 2 months January MSLP E(1) and 2 months October HEIGHT E(3) are summarized in Table 4.16. The skill achieved is less than was accomplished previously for these five years by using 2 months January MSLP E(1) above (Table 4.13). In this instance it is only 1984 which returns an accurate class prediction while previously the class forecasts for 1983, 1984 and 1985 were all successful. The predicted 1984 flux value is, however, improved in the present case. The years 1982, 1983 and 1985 are all underpredicted by two classes in this case while 1981 suffers an overprediction by three classes. The overall success of this five year independent verification of one multiple regression model is judged to be very poor.

Table 4.16

Comparison of Observed and Hindcast 1981-1985
Iceberg Fluxes for One Multiple Regression Case

Case (b) 2 months January MSLP E(1)
2 months October HEIGHT E(3)

Flux			Class	
Observed	Hindcast	Year	Observed	Hindcast
68	413	1981	2	5
188	0	1982	3	1
450	191	1983	5	3
735	586	1984	5	5
343	64	1985	4	2

Summary of Class Errors

Error	Number of Years
0	1
1	0
2	3
3	1
4	
5	
6	

5.0 THE FORECAST METHOD

5.1 Review of Objective Methods

The two foregoing chapters have described the complementary statistical analyses undertaken by Sea Ice Consultants Inc. (Chapter 3) and by Seaconsult Limited (Chapter 4) to yield objective formulae by which to forecast the annual flux of icebergs across latitude 48°N. Each investigation yielded two sets of predictors judged to be suitable for incorporation into a multiple regression equation for the prediction of iceberg occurrence. One of the Sea Ice Consultants Inc. sets of predictors is operationally less attractive than the other three options as it requires March input data: operational forecasts are generally required at latest by early February. The four apparently viable sets of predictors are summarized in Table 5.1. The four regression equations labelled as Methods 1 through 4 in Table 5.1 represent the key conclusions of this study. These are objective formulae which have shown apparent skill in the hindcasting of iceberg flux values, and are hence judged to be suitable for use in forecast mode.

5.2 Subjective Considerations

In most instances, the preparation of a forecast of some environmental factor, even if based upon objective schemes as outlined above, will be tempered or tuned on the basis of the experience and judgement of the forecaster and upon any relevant information not explicitly incorporated into the objective scheme. Such is the case with long range iceberg severity predictions.

Three important subjective factors are noteworthy. The first relates to the success or failure of the predictive model (in hindcast mode) in years with analogous atmospheric conditions to those of the year being forecast. The second relates to the early season distribution of icebergs in regions north of the Grand Banks. These two topics are briefly addressed in subsequent sections of this chapter. The third pertinent factor is the effect of pack ice in determining the longevity and mobility of icebergs in transit from the eastern Baffin coast to the Grand Banks. This topic is the subject of a secondary investigation and is reported independently as Chapter 7 of this report.

Table 5.1

Summary of Four Most Successful Forecast Schemes

A. Statistical Correlation Approach

(Sea Ice Consultants Inc. see Chapter 3)

Method 1

6 months March MSLP

40°N	330°W	(P_a)
45°N	340°W	(P_b)
40°N	60°W	(P_c)

Method 2

2 months January 700 mb HEIGHT

50°N	240°W	(H_a)
30°N	70°W	(H_b)
60°N	50°W	(H_c)

Method 1: index = $89.82 - (0.95)P_a - (2.13)P_b - (1.30)P_c$

Method 2: index = $264.74 - (0.94)H_a - (1.69)H_b + (0.27)H_c$

Note that in this instance "index" is rank. The forecast severity is dictated not by the numerical value of the index, but by its rank among all other years.

B. Empirical Orthogonal Function Approach

(Seaconsult Limited see Chapter 4)

Method 3

2 months January MSLP E(1)
2 months October HEIGHT E(3)
2 months December THICK E(4)

Method 4

2 months January MSLP E(1)
2 months October HEIGHT E(3)

where E(i) implies that the coefficient a(i) of the ith eigenvector is input to the regression equation.

Method 3: flux = $294 - (4.26)a(1) - (2.07)a(3) - (2.00)a(4)$

Method 4: flux = $292 - (5.09)a(1) - (2.56)a(3)$

5.2.1 Analogue Years

While it was never the intent of this study to include a thorough investigation of analogue methods of long range forecasting, the analogue approach has obvious application in assessing the credibility of statistically derived forecasts. Adjustments to the empirical forecast may at times be justified on the basis of analogue arguments. The year by year performance of numerous linear predictors has been tabulated in an attempt to isolate years which yield chronic overpredictions or underpredictions. If atmospheric conditions in a given forecast year are found to be analogous to conditions in a year which has yielded poor hindcast results, then subjective adjustment of the empirical forecast may be warranted.

Dependent mode hindcast results for 34 individual predictors, all of which meet the statistical significance criterion $|r| > 0.46$, have been analyzed on a year by year basis. The following definitions have been imposed:

(1) a given predictor yields a severe overprediction if:

- (a) observed flux <150 and predicted flux >300
- (b) 150< observed flux <450 and predicted flux >500

(2) a given predictor yields a severe underprediction if:

- (a) 150< observed flux <450 and predicted flux <100
- (b) observed flux >450 and predicted flux <300

Results of the 34 tests illustrating those years (1952-1980) yielding severe overpredictions are presented in Table 5.2(a) while the companion results for years yielding severe underpredictions appear as Table 5.2(b). Cases are grouped by atmospheric predictor (MSLP, HEIGHT, THICK, SAT) and are sequenced chronologically within predictor. The contents of Tables 5.2(a) and 5.2(b) are summarized in Table 5.3 which quotes the percentage occurrence of severe overprediction and severe underprediction, by atmospheric parameter, by year. Clearly the numerical values of percentage occurrence are conditioned by the number

Table 5.2(a)

Years for Which EOF Hindcasts Yield Severe Overprediction of Grand Banks Iceberg Flux

Hindcast is assumed to yield severe overprediction if:

(a) observed flux <150 and predicted flux >300
(b) 150< observed flux <450 and predicted flux >500

Years: 1952 – 1980

Predictor Param	Predictor # Mon	Mon	a(n)	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
MSLP	2	Oct	6									60	61		63			66			69									78		
MSLP	2	Nov	2					56							63		65	66	67			70	71				75					
MSLP	3	Nov	2		53			56		58					63			66	67			70	71				75					
MSLP	4	Dec	5			54		56		58					63		65				69										79	
MSLP	1	Jan	1		53								61	62			65										75	76		78		
MSLP	1	Jan	2	52		54	55						61				65										75			78		80
MSLP	2	Feb	1		53								61	62		64											75					80
MSLP	3	Mar	1		53	54		56					61			64											75	76				80
MSLP	4	Mar	1		53	54		56					61			64											75	76				80
HEIGHT	2	Oct	3		53			56					61		63		65						71								79	
HEIGHT	1	Nov	3		53			56		58							65				69								77			
HEIGHT	2	Nov	2		53			56		58				62	63		65		67			70	71				75					
HEIGHT	3	Nov	2		53			56		58					63		65	66	67			70					75					
HEIGHT	5	Dec	5					56		58							65															
HEIGHT	1	Jan	1		53								61	62			65						71				75			78		
HEIGHT	2	Feb	1		53								61	62									71				75	76				
HEIGHT	3	Feb	1	52		54							61	62									71				75	76				
HEIGHT	4	Mar	1			54							61														75	76				
HEIGHT	4	Mar	2										61					66									75		77	78		80
THICK	2	Dec	4	52													65	66				70										
THICK	1	Jan	1	52	53	54							61	62								70					75					
THICK	2	Jan	1	52		54							61				65	66					71				75			78		
THICK	2	Jan	2	52	53										63						69	70							77		79	80
THICK	2	Feb	1										61	62			65										75	76				
THICK	4	Mar	1	52									61														75	76		78		
THICK	6	Mar	1	52									61						67								75	76				
THICK	24	Mar	2				55			58								66					71									
SAT	2	Jan	1	52		54							61					66					71				75			78		
SAT	2	Jan	2		53								61		63		65												77			
SAT	2	Feb	1										61	62								70	71				75				79	
SAT	4	Feb	1	52									61	62			65						71				75				79	
SAT	4	Mar	1	52									61										71				75	76		78		
SAT	6	Mar	1	52									61				65		67								75				79	
SAT	9	Mar	1	52									61				65	66					71				75				75	

Table 5.2(b)

Years for Which EOF Hindcasts Yield Severe Underprediction of Grand Banks Iceberg Flux

Hindcast is assumed to yield severe underprediction if:

(a) 150< observed flux <450 and predicted flux <100
(b) observed flux >450 and predicted flux <300

Predictor Param	# Mon	Mon	a(n)	Years (1952–1980)
MSLP	2	Oct	6	57 79
MSLP	2	Nov	2	59 64
MSLP	3	Nov	2	59 64
MSLP	4	Dec	5	60 67 68
MSLP	1	Jan	1	59 60 79
MSLP	1	Jan	2	59 79
MSLP	2	Feb	1	60
MSLP	3	Mar	1	60
MSLP	4	Mar	1	57 60 79
HEIGHT	2	Oct	3	60 64
HEIGHT	1	Nov	3	60 64
HEIGHT	2	Nov	2	60 64
HEIGHT	3	Nov	2	59 64
HEIGHT	5	Dec	5	67 68
HEIGHT	1	Jan	1	59 60 79
HEIGHT	2	Feb	2	60
HEIGHT	3	Feb	1	60 79
HEIGHT	4	Mar	1	57 60 79
HEIGHT	4	Mar	2	68 73 76
THICK	2	Dec	4	73 79
THICK	1	Jan	1	59 79
THICK	2	Jan	1	59 79
THICK	2	Jan	2	59 72 76
THICK	2	Feb	1	60
THICK	4	Mar	1	60 79
THICK	6	Mar	1	57 74
THICK	24	Mar	2	59
SAT	2	Jan	1	59 79
SAT	2	Jan	2	
SAT	2	Feb	1	57 59 60 73
SAT	4	Feb	1	59 60
SAT	4	Mar	1	59 60
SAT	6	Mar	1	60
SAT	9	Mar	1	59 74

Table 5.3

Percentage Occurrence(*) of Severe Overprediction and Severe Underprediction of Grand Banks Iceberg Flux by Atmospheric Parameter by Year

Year (1952–1980)	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
Overprediction																													
Mean Sea Level Pressure	11	55	44	11	55		11		11	66	22	44	33	44	33	22		22	22	22				77	33		3	11	44
700 mb Height	10	60	20		50		40			60	40	30		60	20	20		10	20	50				70	30	20	20	10	10
700-1000 mb Thickness	75	25	25	13			13			63	25	13		38	38	13		13	38	25				63	38	13	25	13	13
Surface Air Temperature	71	14	14							100	29	14		57	29	14			14	71				86	14	14	29	57	
All Parameters	38	41	26	6	29		18		3	71	29	26	9	50	29	18		12	24	41				74	29	12	26	21	18
Underprediction																													
Mean Sea Level Pressure						22		44	55				22			11	11											44	
700 mb Height						10		20	70				40			10	20					10			10			30	
700-1000 mb Thickness						13		50	25												13	13	13		13			50	
Surface Air Temperature						14		71	57													14	14					14	
All Parameters						15		44	53				18			6	9				3	9	6		6			35	

(*) Table entries are percentage of predictors displayed in Tables 5.2(a) and 5.2(b) which yields overpredictions and underpredictions in the indicated years.

of cases tested for each parameter (between 7 and 10) and hence are not significant in absolute terms. It is the relative values of percentage occurrence of overprediction and underprediction from year to year which are of consequence. Composite percentages averaged over all four parameters are also quoted in Table 5.3.

The utility of Table 5.3 is best illustrated by example. It is noted that MSLP and HEIGHT are reasonable predictors for 1952, yielding overprediction in only 11 and 10% of cases respectively. In contrast, THICK and SAT predictors in this same year yield overprediction in 75 and 71% of cases tested. All predictors are consistently bad for 1961 and 1975 as overpredictions result in 63 to 100% of cases tested. This same fact is evident from the large number of entries for years 1961 and 1975 in Table 5.2(a). The years which yield most severe percentage occurrences of underprediction are noted from Table 5.3 to be 1959, 1960 and 1979. This same fact is also clear from Table 5.2(b).

The composite percentage occurrences of overprediction and underprediction for "All Parameters" as quoted in Table 5.3 are displayed in Fig. 5.1. The years 1952, 1953, 1961, 1965, 1971 and 1975 conspicuously yield overpredictions in greater than 35% of cases tested. Correspondingly, the yeras 1959, 1960 and 1979 are underpredicted in greater than 35% of cases tested. It is noteworthy that in only one year (1979) are there measurable percentages of both underprediction and overprediction. This particular year would be most difficult to employ in a subjective forecast adjustment based on analogues.

Coupled with judicious use of the parameter by parameter percentages in Table 5.3, this figure (5.1) is useful in performing subjective forecast adjustments on the basis of atmospheric analogues. Using eigenfunction coefficients as the quantitative indicator, it is readily possible on a parameter by parameter basis to identify those few years which are most similar to a given forecast year. If these analogue years consistently include those years from Fig. 5.1 which are chronic overpredictors or underpredictors, then as a first-order adjustment, the empirical forecast can be subjectively scaled up or down. Any more detailed

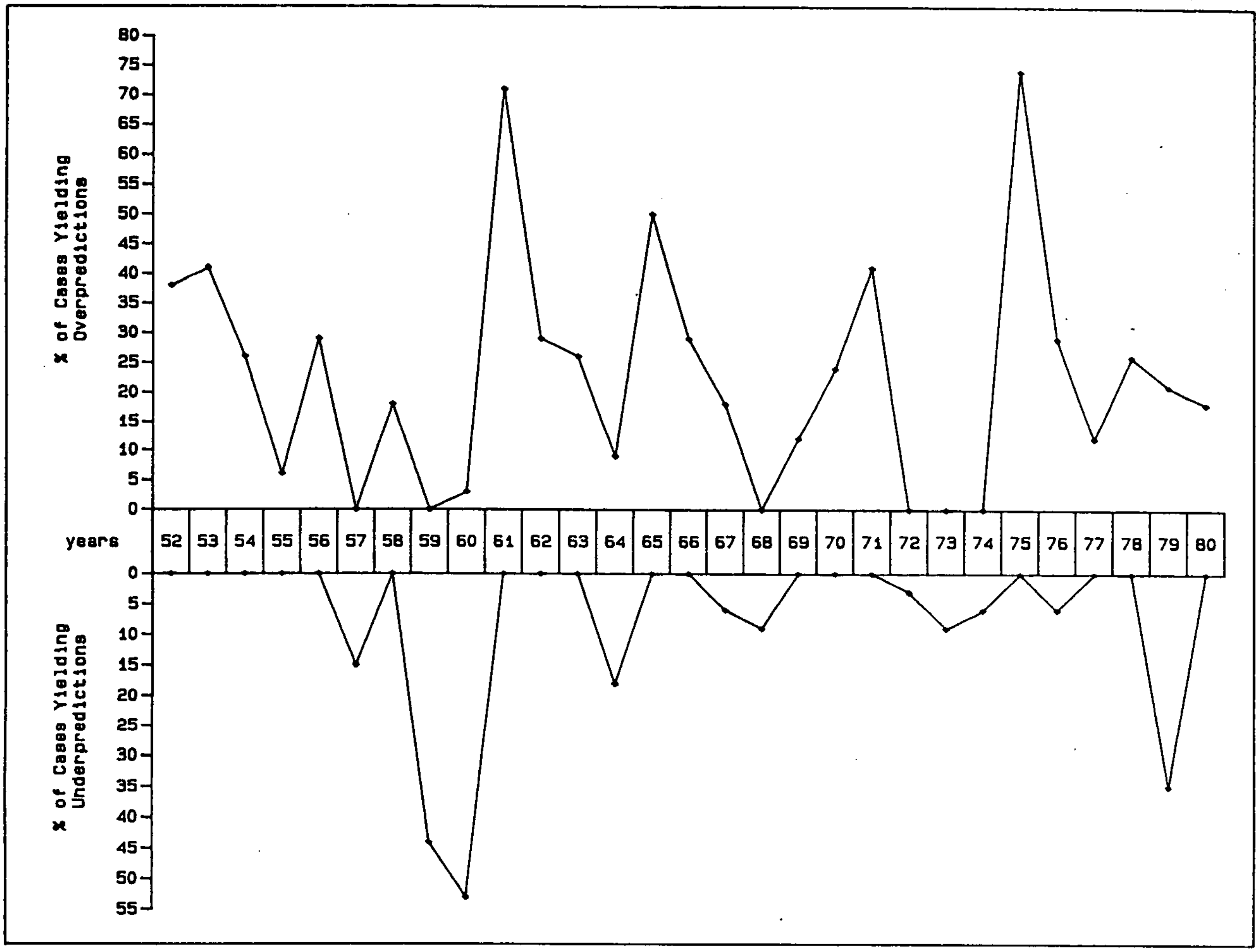


Fig. 5.1 Percentage of Cases Yielding Severe Overprediction or Severe Underprediction of Iceberg Flux by Year.

Plotted Values are Percentage of all Predictors displayed in Tables 5.2(a) and 5.2(b) which yield Overpredictions and Underpredictions in the indicated years.

analogue analysis, requiring the actual comparison of atmospheric fields from selected years, remains as an extension to the present study.

5.2.2 Source Region Iceberg Distributions

The hindcast prediction of the past 30-35 years of annual iceberg flux at 48°N would presumably be a simpler task if an accurate history of the pre-season (October to January) distribution of icebergs in upstream regions were available for these same years. Such records are not generally available, and as noted in Section 1.2, IIP investigators were unsuccessful in the early 1970's in developing accurate forecast methods even at a time when pre-season reconnaissance was available for at least part of the upstream source regions. It must be accepted that historical pre-season surveillance data are too geographically sparse and too temporally irregular to successfully be employed in designing forecast methods.

With the more recent availability of Side Looking Airborne Radar (SLAR) and synthetic aperature radar (SAR) systems, the quality, regularity and geographical extent of pre-season surveillance is (at least potentially) increasing. Suitable resources are presently available to allow accurate documentation of the pre-season numbers and distributions of icebergs along the Labrador and Baffin Island coasts and beyond.

The simple observation to be made in the present context of subjective forecast adjustments, is that these data represent a resource not previously available, and hence not included in the objective forecast methodology. Knowledge of the abundance or absence of icebergs in the source regions, at the time of forecast preparation in coming years, can surely be of subjective value in tuning objective forecasts. Particularly if "class" forecasts are issued for classes in excess of 3, it may be possible to use surveillance data to predict behaviour (low/high) within class. Similarly, based upon the north to south distribution of icebergs in the source regions, it may be possible to add a temporal dimension to the annual flux forecast and to predict early or late season variations in the monthly flux. While application of such ideas exceeds the present project scope it is important to note the availability and potential of this additional subjective tuning factor.

6.0 THE 1986 FORECAST

Development of the forecast methods which have just been summarized (Chapter 5) was essentially completed in January 1986, in sufficient time to allow application of the methods to generate a 1986 forecast. As the available atmospheric data for the fall of 1985 and January 1986 included only 700 mb Height and MSLP, the Method 4 predictors (Table 5.1) were selected to illustrate the operational use of an EOF prediction scheme. While it is obvious that a comparison of forecasts from each of the four primary forecast schemes (Table 5.1) would be instructive, the mandate and budjet of this present study accomodated only this single prediction. Thus the 1986 forecast was prepared in early February 1986 employing:

MSLP E(1) December 1985 and January 1986
HEIGHT E(3) October 1985 and November 1985.

The 1986 forecast, as issued, is reproduced without alteration as Figure 6.1. This figure documents the basic aspects of the 1986 forecast as being:

- predictors are MSLP 2 months January E(1)
  and HEIGHT 2 months October E(3),
- predictand is iceberg class,
- analogue years are 1953, 1963, 1967, 1971. All of these except 1967 yield consistent overpredictions.
- subjective adjustment on the basis of analogue years restricts the forecast to the low end of class 3, or 100-125 icebergs,
- this forecast translates to 200-300 icebergs in the present situation of operational SLAR surveillance.

Fig. 6.1

1986 FORECAST

GRAND BANKS ICEBERG SEASON SEVERITY

This forecast was issued in mid-February 1986 by Seaconsult Limited in compliance with the terms of the modified work statement for ESRF study 8121-16: Long Range Prediction of Iceberg Season Severity.

A statistical prediction method was employed. Multiple linear regression analysis was applied to the time-series of two predictors for the years 1951-1980 to yield a regression equation from which the 1986 forecast was calculated. The method of Empirical Orthogonal Function (EOF) analysis was used to derive the predictors which are eigenfunction coefficients as described in Table 1.

Table 1. Description of Iceberg Severity Predictors

Predictor	Parameter	Time Interval	Eigenfunction
a(1)	Mean Sea Level Pressure	2 months ending January	1
a(3)	700 mb Height	2 months ending October	3

The predictand is iceberg severity class defined on the basis of the annual flux of icebergs across 48°N latitude as per Table 2.

Table 2. Definition of Iceberg Severity Classes

Class	Annual Flux at 48°N
1	0 - 50
2	50 - 100
3	100 - 200
4	200 - 400
5	400 - 800
6	800 - 1200
7	>1200

(over)

Having established the eigenfunction coefficients for 1986, the historical 1951-1980 data series was scrutinized to find years with analogous coefficients. The hindcast performance for these earlier years was used to subjectively adjust or interpret the 1986 forecast. Results of this analogue comparison are tabulated in Table 3.

Table 3. Analogue Years Selected on Basis of Eigenfunction Coefficients

Year	a(1)	a(3)	Multiple Regression Predicted Class	Observed Class	Observed Flux
1986	12.6	-44.9	3		
1953	5.2	-44.8	3	2	56
1963	24.6	-37.8	3	1	25
1967	7.6	-59.6	4	5	441
1971	24.6	-56.0	3	2	73

Tests were performed using 21 different sets of predictors for the years 1951-1980. These particular analogue years (1953, 1963, 1967 and 1971) yielded flux predictions of five to ten times the observed flux in approximately one third of the cases tested. This is in contrast to certain other years which yielded consistently low or consistently good predictions. This analogue behaviour is the basis for subjective adjustment of the 1986 forecast.

Conclusions:

- the 1986 forecast is class 3 which implies a flux of 100-200 icebergs across 48°N
- the analogue years selected on the basis of eigenfunction coefficients frequently were overpredicted; hence the 1986 forecast is subjectively restricted to the low end of class 3 in the range 100-125 icebergs
- the regression model is based on International Ice Patrol flux values in the pre-SLAR years 1951-1980. Given operational differences in present day surveillance, the forecast of 100-125 icebergs should correspond to 1986 IIP flux values which are two to three times larger, or roughly in the range 200-300 icebergs.

7.0 PACK ICE EFFECTS

7.1 Introduction

Does the seasonal occurrence of pack ice in the Davis Strait, Baffin Bay, Labrador Sea region influence the occurrence of icebergs on the Grand Banks? If so, what is the nature of the interaction and can this influence be used in forecasting iceberg occurrence?

There is a pronounced correlation between the appearance of seasonal pack ice in the Labrador Sea and the subsequent appearance of icebergs on the Grand Banks with a phase lag of roughly one month. Pack ice reaches its maximum seasonal extent on the Labrador Shelf and Grand Banks in early April while iceberg occurrence peaks about one month later in May (Markham, 1980).

Icebergs originate from the Greenland ice cap and from several glaciers in the Arctic Archipelago (Robe, 1980). Similarly much of the old ice in the pack originates in Lancaster Sound, Baffin Bay areas (C-Core, 1985). Ocean circulation advects all of this material southward along the Baffin Island and Labrador coasts.

Two separate conjectures are possible. One is that there is no direct coupling between pack ice and icebergs but that the same atmospheric and oceanographic influences cause their more or less simultaneous appearance at low latitudes. The other is that atmospheric and oceanographic influences have different effects on bergs and pack ice but that pack ice can trap icebergs and can carry them southward during its mid-winter drift.

Arguments for this latter case are strong: icebergs persist in the Baffin Bay region throughout the year; winds and ocean circulation advect material southward year round. Icebergs should drift southward continuously throughout the year. If there were no coupling to pack ice, icebergs would appear at low latitudes year round and the strong seasonal correlation between iceberg and pack ice occurrence would not be seen.

The potential thermal and mechanical interactions have been examined in Section 7.2 and are shown to be strong. However, consideration of the circumstances for interaction (Section 7.3) indicates that the actual effect of these interactions is small. The study concludes that although pack ice and iceberg occurrence are correlated, the actual direct influence of pack ice on icebergs is weak.

7.2 Pack Ice/Iceberg Influences

7.2.1 Pack Ice Forces on Bergs

Icebergs have often been observed to plough through pack ice on apparently independent trajectories. How much force can drifting pack exert on an iceberg?

The maximum force exerted on an object by a continuous, consolidated ice sheet can be calculated from one of several formulas on the basis of the measured crushing strength of sea ice (cf Tryde, 1973; Hysing, 1982).

$$F_c = k_f \cdot k_e \cdot k_t \cdot \sigma_c hw$$

where k_f, k_e, k_t are coefficients related to shape, strain rate and multiaxial stress; w is the width of the interface and h is the thickness of the ice. The crushing strength of sea ice σ_c is typically 1 - 5MN/m^2 for a consolidated continuous ice sheet.

The maximum force that consolidated pack could exert on the perpendicular face of an iceberg would be of the order of 1 to 10MN per metre of berg width for a typical range of ice thickness (1 m to 3 m).

Iceberg shape factors, strain rate considerations and the degree of consolidation of the ice will all reduce forces below this maximum level. In addition, as the width of the pack ice - iceberg interface increases to more than a few times the ice thickness (that is as the aspect ratio (w/h) increases), the failure mode of ice changes from crushing to buckling failure resulting in a further reduction in the force of the interaction. For high aspect ratios the maximum interaction forces may be one third to one fifth of the maximum (σ_c) crushing force. (Ralston, 1978).

The forces exerted by unconsolidated pack ice may be much smaller than the estimates above. For the geographic regions of interest consolidated fast ice may be stable throughout the winter in nearshore regions. The pack may also stablize and consolidate to a distance of several hundred kilometres offshore during periods of onshore wind. Onshore winds compress the unconsolidated ice causing immobilization, rafting and thickening of the pack and consolidation into large agglomerated floes. Although floe dimensions in the pack may reach diameters of several tens of kilometres, much of the pack, particularly on the seaward side, is primarily unconsolidated small pans and brash ice. The force exerted by brash ice may be quite variable depending on the confining pressure.

The case of continuous but unconfined brash ice cover would provide a lower bound for ice forces on an iceberg. Mellor (1980) provides estimates of the brash ice resistance to vessels. Fig. 7.1 shows the ice resistance for various thicknesses of continuous but unconfined brash ice. These are in the order of $2kN/m^2$ - $10kN/m^2$, depending on the depth of the brash ice.

Fig. 7.2 shows the magnitudes for various types of ice forces on an object.

The values given in Fig. 7.2 constitute the upper and lower limits for the forces exerted by continuous ice cover on a body such as an iceberg. In discontinuous ice cover, the forces exerted by brash can probably be approximated by calculating the hydrodynamic drag from an equivalent thickness of water. In the case of large floes in an open pack, the force exerted on a berg will be a function of the floe size, atmospheric and oceanic drag on the floe, the contact angle with the berg and the failure strength of the floe. The interaction force may vary from zero to the maximum value indicated for a continuous ice sheet.

7.2.2 Wind and Water Drag

Hydrodynamic drag on a submerged object can be calculated from:

$$F_D = C_d \rho \frac{V^2 A}{2}$$ (Daugherty and Franzini, 1977).

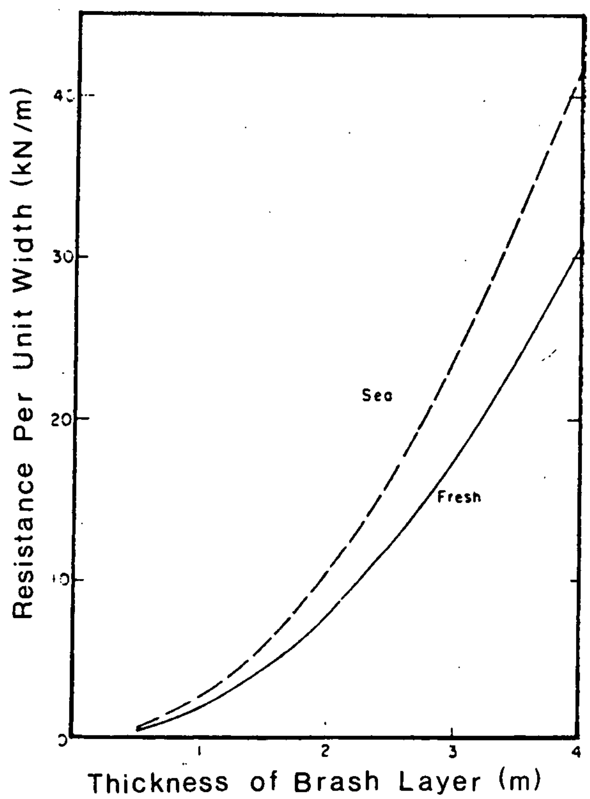


Fig. 7.1 Ice Force As A Function Of Thickness for Unconsolidated and Unconfined Brash Ice. (Adapted from Mellor, 1980)

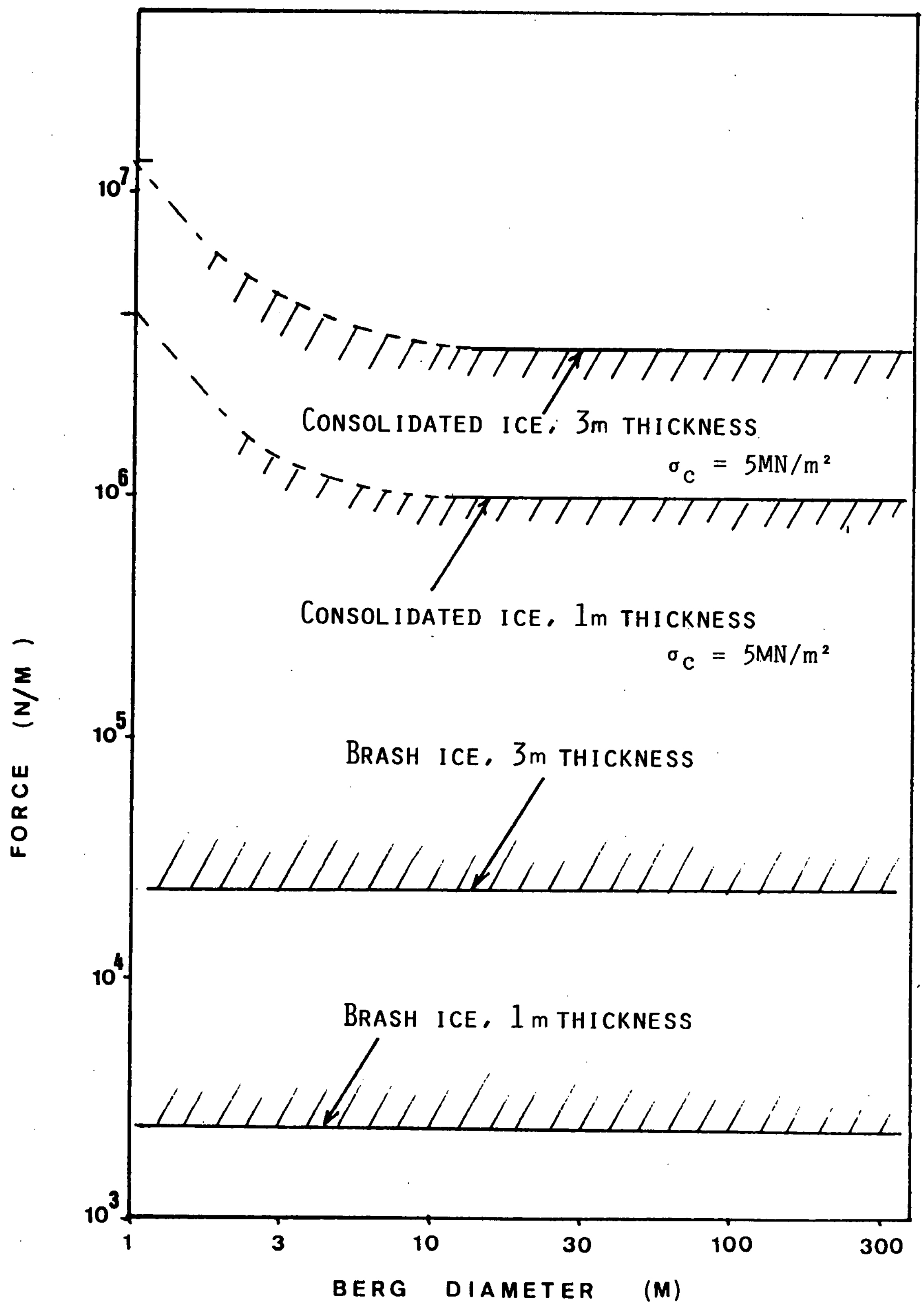


Fig. 7.2 Maximum and Minimum Ice Forces for Continuous Ice Cover 1 Metre and 3 Metres Thick.

where: C_d = drag coefficient
ρ = density kg/m^3
V = velocity m/sec
A = cross-section area m^2

The drag coefficient C_d will depend on the Reynolds number (N_R) and shape of the object:

$$N_R = \frac{D\ V}{\nu}$$

where: ν is the kinematic viscosity of the fluid,
and D is the diameter of the object.

For the range of shapes and sizes of bergs to be considered, the drag coefficient C_D may be between 1 and 0.2. White et al. (1980) measured drag coefficients for ice blocks of between 0.8 and 0.2 for several possible berg shapes. Thus, it is reasonable to use $C_D = 1$ for calculating maximum drag forces. The Reynolds number for both air and water drag will be such that this is a valid assumption for typical icebergs ($10^3 < N_R < 10^6$).

Fig. 7.3 shows the computed relative wind/water drag effects for various berg shapes as reported by White et al. (1980). The calculated magnitude of wind and water drag forces on bergs of various sizes is shown in Fig. 5.4 along with the magnitude of maximum and minimum ice forces on a berg. These values were computed assuming C_D=1 and assuming that the berg is a cube with one face above water. The calculations were not corrected for free fluid boundary effects.

The significant conclusion from Fig. 7.4 is that ice forces in continuous cover are much larger than hydrodynamic and wind drag forces for the drift velocity and wind velocity ranges typically encountered.

7.2.3 Iceberg Deterioration and Melting

The occurrence of icebergs at any given latitude is influenced by both drift rate and deterioration rate. The processes are competitive. The various mechanisms influencing deterioration have been thoroughly

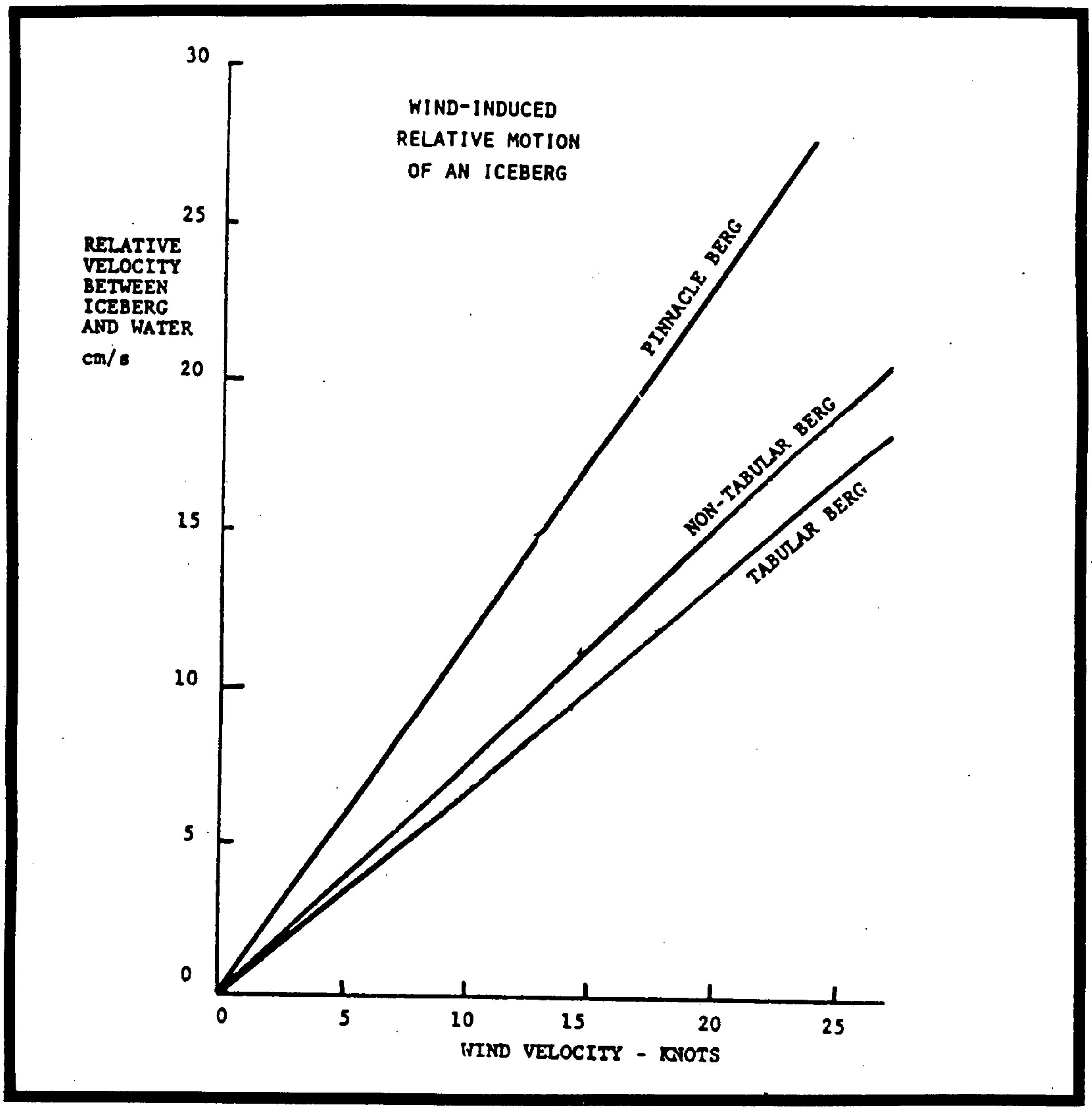


Fig. 7.3 The Relative magnitudes of Wind and Water Drag on Various Iceberg Shapes. (Adapted from White et al, 1980.)

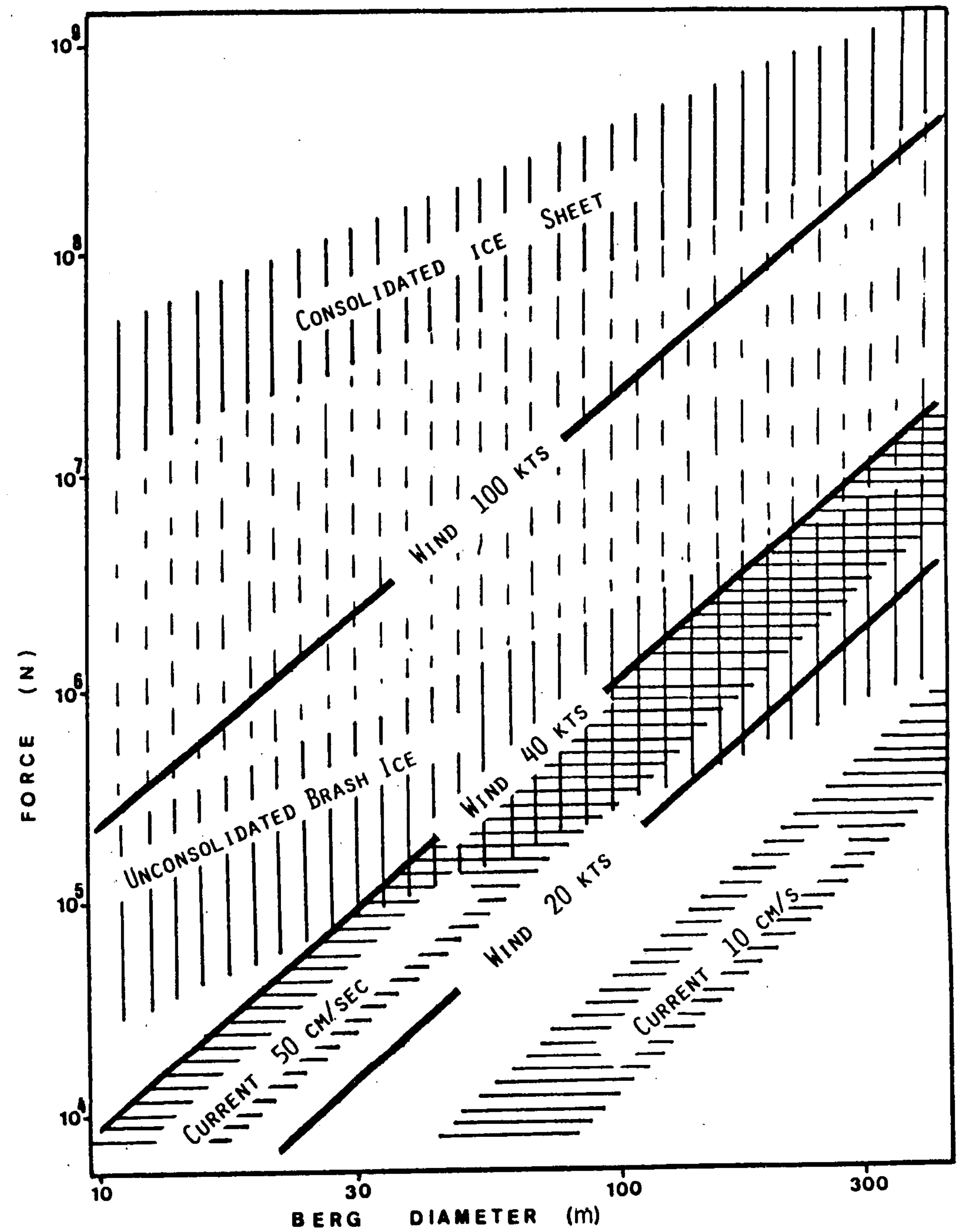


Fig. 7.4 Comparison of Wind, Water and Ice Forces on a Blocky Berg 10m to 300m Wide.

assessed by White et al. (1980). Their observations are succinctly summarized in the following quotation:

> "5. Maximum surface melting due to solar insolation in the Labrador Sea is approximately 7 cm/day on a clear day in June. Average melting, based on measured insolation, varies from 0.5 cm/day in winter to 4 cm/day in summer...."

> "6. Surface melting due to air convection is very small. Average air temperatuers rarely reach more than 8°C. Even a steady wind of 20 knots will cause surface melting of only 8 mm/day/°C."

> "7. Buoyant vertical convection of meltwater on the submerged surface is moderately important with melting rates being approximately 2 cm/day/°C of water/ice temperature difference..."

> "8. Forced convection on the submerged surface is a substantial contribution to iceberg deterioration, because persistent local winds drive icebergs at a relative water/ice velocity of 10-30 cm/s...Resultant melting rates are 5-20 cm/day/°C and decrease moderately with iceberg size..."

> "9. A surface flaw such as a notch enhances the melting rate and may lead to calving or twinning...The present study was not able to develop a realistic statistical analysis of the effect of flaws on iceberg deterioration."

> "10. Wave erosion seems to be the primary cause of iceberg deterioration, due both to high melting rates and subsequent calving of undercut ice slabs. Waterline melting rates can be as high as 150 cm/day/°C of water/ice temperature difference."

> "11. The fracture stress in an overhanging ice slab undercut by wave erosion is computed by elementary plate theory and also by a digital computer finite difference method. The theoretical calving times are plotted in Fig. 7.5."

Apparently wave erosion is by far the most significant factor in deterioration. Fig. 7.6 shows the combined influence of wave period, wave height and water temperature. These influences have been incorporated into a digital model (Fenco, 1983). Using typical Labrador Sea wave data the Fenco algortihm indicated mass losses as shown in Fig. 7.7. The model was compared against observed berg deterioration rates, and gave reasonable estimates for most circumstances. If anything, the mechanisms investigated by White and modelled by Fenco would overestimate the lifetime of smaller ice fragments (<100 m) since the

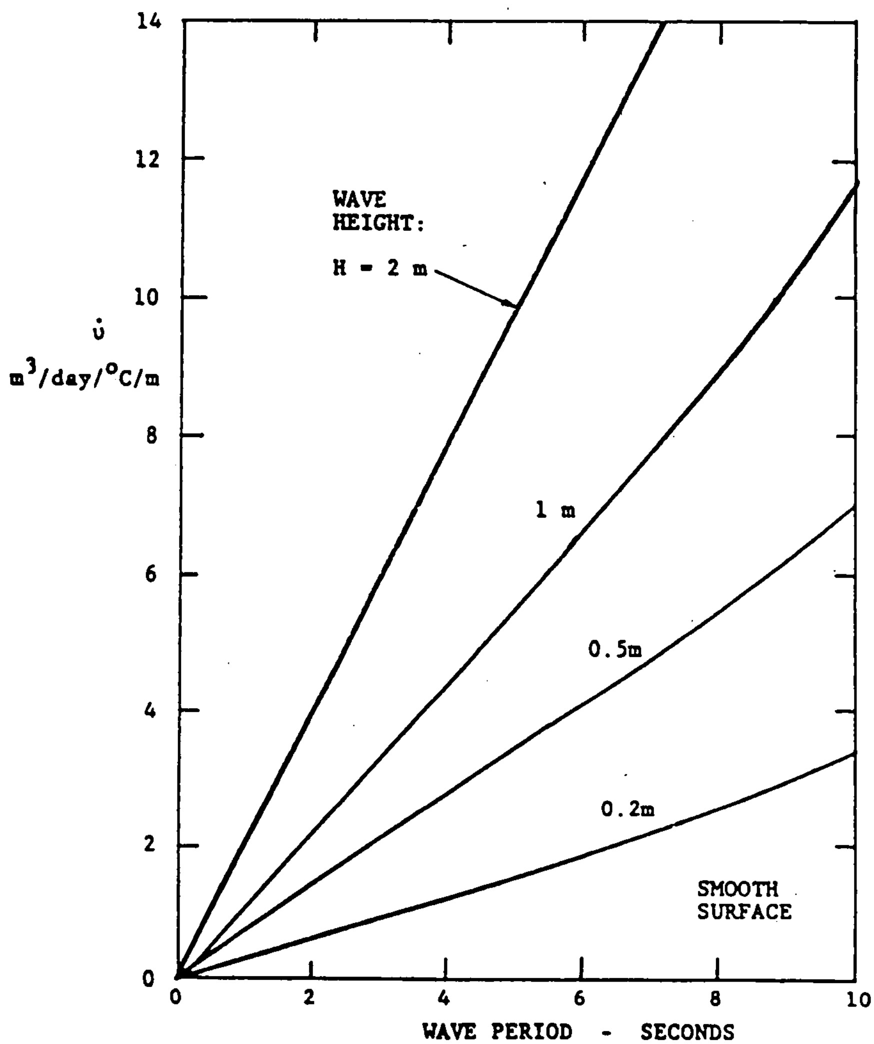


Fig. 7.5 Rate of Erosion of Icebergs by Wave Action at the Waterline. (From White et al, 1980.)

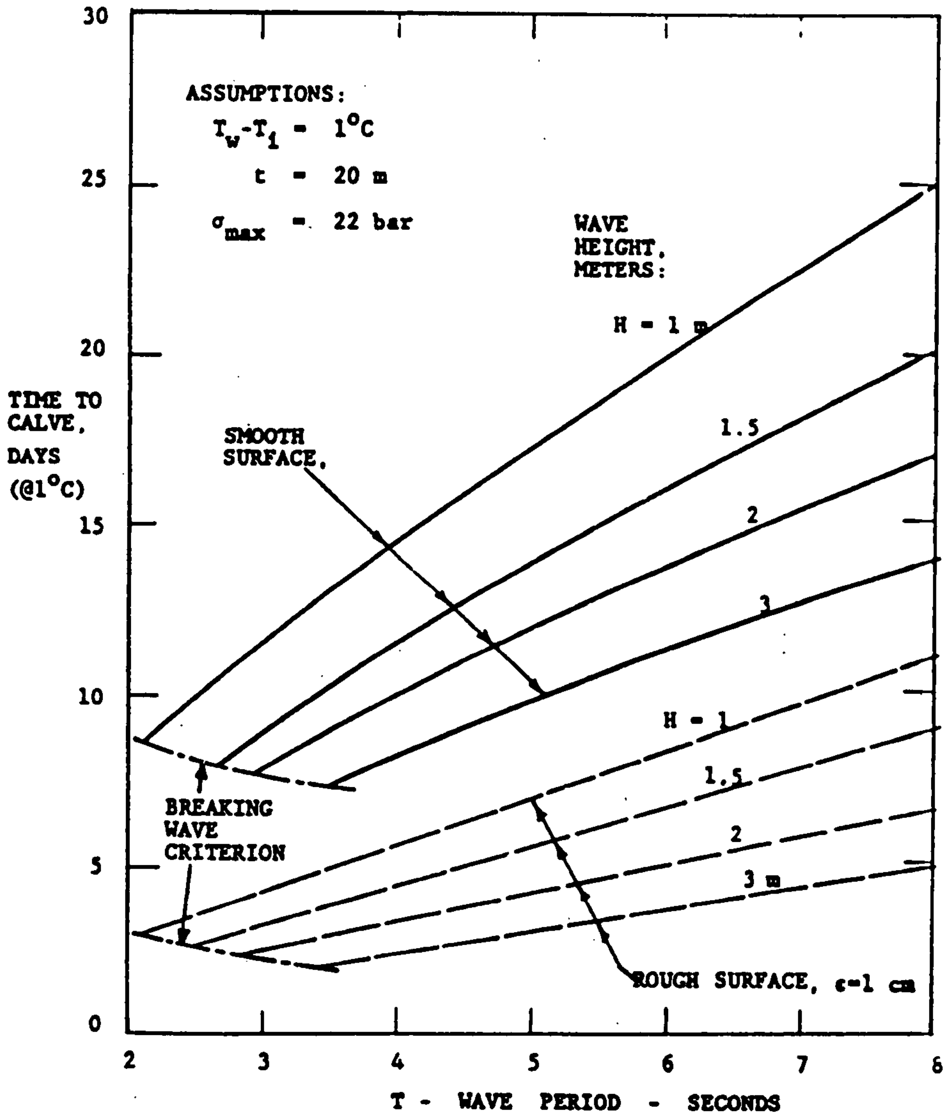


Fig. 7.6 Iceberg Calving Rates as a Function of Wave Erosion. (From White et al, 1980.)

Seasonal variation of volume loss (m^3/day) for a medium non-tabular iceberg (mass = 900,000 tonnes, Volume = 1,000,000 m^3) on the Grand Banks.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Solar	41	72	116	163	193	216	215	171	129	85	44	37
Wind Conv.	0	0	44	117	185	527	545	710	820	700	568	180
Buoyant Conv.	232	232	107	107	372	977	2101	2702	2394	1569	977	372
Forced Conv.	4834	4591	1842	1647	3985	9634	12958	18572	19694	16350	11841	5996
Calving	3410	4546	2378	1382	2324	8768	16503	22320	21120	19067	12735	10884
Wave Erosion	16843	22457	12092	5817	13316	50233	48238	78938	88894	80254	59555	27484
Total	25360	31898	16579	9233	20375	70355	80560	123413	133051	118025	85720	44953
% of original Volume	2.5	3.2	1.7	0.9	2	7.0	8.1	12.3	13.3	11.8	8.6	4.5

Fig. 7.7 Mass Loss Rates for a 900,000 Ton Berg on the Grand Banks as Calculated by FENCO. (1983)

effects of heave and heave resonance are not incorporated into the analytical model.

The significance of the role of waves on pack ice/iceberg interaction is that pack ice tends to damp ocean waves (Wadhams, 1973). The damping effect is strongest in heavy ice cover. It would appear that pack ice, by attenuating ocean waves and swell could remove the primary cause for iceberg deterioration and extend the life expectancy of a berg surrounded by pack ice by at least an order of magnitude.

7.3 Discussion

The foregoing deliberations indicate two types of influence that pack ice may have on iceberg occurrence in southern latitudes.

(a) Drifting ice cover could drive bergs against normal ocean currents or winds.

(b) Ice cover can damp waves and consequently reduce or completely eliminate the dominant mechanism of berg deterioration; i.e., wave erosion.

Although the calculations of the various influences are reasonable and apparently correct, neither mechanism is likely to be a strong influencing factor in the seasonal occurrence of icebergs.

A careful review of wave erosion processes documented by White et al. (1980) shows that they become negligible at water temperature at or below 0°C. (See Fig. 7.5). Surface water temperatures of -1.5°C to 0°C are always associated with the occurrence of pack ice.

Under the circumstances wave erosion effects would be small even if waves were not damped by the pack ice. It is the thermal regime associated with the pack ice that would increase the apparent lifetime of an iceberg. The prevailing ocean surface temperatures are the result of atmospheric influence. Pack ice is an effect rather than a cause.

Pack ice is an influencing factor in ocean-atmosphere heat exchange, in radiative heat exchange and in oceanographic heat transport. It is, however,a mediating phenomenon rather than a thermodynamic driving force.

Pack ice is not a cause and is not a necessary condition for the occurrence of icebergs at low latitudes. However, all of the foregoing considerations suggest that pack ice is an excellent indicator and mediator for the thermal conditions that favour the advection of icebergs to low latitudes.

A similar consideration of the mechanical drift influence of winds, currents, and pack ice shows that the relative effects of wind drag on pack ice and on icebergs are amlost identical. A pinnacled berg will drift at 2.2% of the wind velocity (Fig. 7.3). The typical value applied to the calculation of wind drag on pack ice is 2.5%-3%.

In the absence of wind, surface circulation in the Davis Strait/Labrador Sea is apt to reflect deeper currents. Pack ice and icebergs will have similar trajectories. During periods of strong winds, the influence on both pack and icebergs will be similar. Therefore, although ice could influence berg drift, both are subject to the same atmospheric and oceanic driving forces in approximately the same way.

The argument in favour of any direct mechanical influence of pack ice on icebergs is weak with one exception; namely long range forces in continuous ice cover. It is a consequence of Fig. 7.4 that continuous ice cover can very effectively force or hold a berg against almost any occurring range of wind or current drag forces.

There are two types of situation in which long range forces may have a critical influence on iceberg movement. In one case icebergs imbedded in continuous ice cover may be trapped or immobilized for long periods of time in shore-fast ice. The alternate situation would be one in which bergs could be held offshore by fast ice. The origin of the long range "force" in these situations is the shoreline. The second situation would be one in which bergs could be flushed out of a catchment area (with weak or meandering currents) by long range wind or current forces driving pack ice through the area.

The latter situation could be envisaged for regions such as Lancaster Sound or the Saglek or Hamilton Banks. The former situation may occur in areas such as northern Baffin Bay or nearshore along the Baffin Island and Labrador Coasts.

7.4 Summary and Conclusions

The objective of this study was to determine whether the close correlation between pack ice and iceberg occurrence at low latitudes is due to a direct physical influence of pack ice on icebergs or whether it is a statistical correlation due to parallel influences of atmospheric and oceanographic driving forces. The distinction is important to the development of forecasting methods.

Thermal influences on iceberg deterioration and mechanical influences on deterioration and drift were examined. In both cases there was potential for strong interaction. However, in each case the primary atmospheric and oceanic influence on both pack ice and on icebergs was found to be similar. Therefore the actual interaction between pack ice and icebergs was concluded to be a weak secondary effect.

This finding is tempered with two observations that pack ice can also influence ocean and atmospheric conditions.

In conclusion, pack ice may be a mediator and can be an excellent indicator of conditions favouring iceberg advection but it appears to have little direct physical influence. The one exception is the potential ability of pack ice to exert long range forces to hold bergs in or to flush bergs out of catchment areas. This primary conclusion lends further credance to the selection of statistical correlation techniques for the forecasting of iceberg season severity.

8.0 FUTURE CONSIDERATIONS

Two complementary approaches to predicting the seasonal iceberg flux at 48°N have been developed and presented. The statistical correlation approach designed by Sea Ice Consultants Inc. (Chapter 3) has been subjected to 30 years of dependent mode verification and one year (1985) of independent verification. The empirical orthogonal function approach designed by Seaconsult Limited has been verified in both 30 year dependent and 30 year independent hindcasts, as well as in an independent 1981-1985 hindcast. This method has also been applied to generate a 1986 forecast.

This study stops short of recommending one or the other of the above methods as being most effective because detailed year by year comparisons of dependent, and more importantly of independent hindcasts, have not be undertaken. Certainly all of the necessary data resources are available to allow an evaluation of hindcast performance for these two methods on an individual season by season basis. The relative accuracy of the two prediction schemes for low, moderate and heavy iceberg years could be assessed to yield a rationale for identifying one or the other methods as the primary forecast method to meet immediate operational needs.

Such a practical action as suggested above should not however, be viewed as signalling the end of valuable research into either the statistical or the empirical orthogonal function approach. Both methods merit further individual investigation. Relevant tasks should include:

(a) Statistical Correlation Approach

- a high-latitude domain centred on the Davis Strait - Labrador Sea region could be used (rather than the 65°N - 90°N Arctic subset) in the determination of regional significance. Such an alternative domain would provide an optimal indication of the seasonality and duration of the high-latitude signal. Conceivably, this domain could develop better predictors than those used in Chapter 3.

- an independent verification scheme is necessary to allow the successive exclusion of one year at a time in the 30 year hindcast, analogous to the "one-year-out" approach employed in the EOF analysis.

- a greater reliance on the composite differences in the predictor selection process may enhance the regression -based forecasts of iceberg extremes. There is an inevitable trade-off between the representativeness achieved by the use of the complete sample in the correlative approach and the extreme-year emphasis inherent in the composite difference grids.

(b) Empirical Orthogonal Function Approach

- sea surface temperature data are available on a 4° x 4° geographical grid spanning the same domain employed in the present study of MSLP, HEIGHT, THICK and SAT eigenfunctions. The software modifications necessary to add this fifth parameter to the available data structures are not substantial. Addition of these data would allow the assessment of sea surface temperature influences on iceberg flux.

- no investigation was undertaken to determine how the size of the geographical domain employed in the EOF analysis affects the correlations with iceberg index. It is possible that expansion of the domain could improve the predictive capabilities of the EOF scheme.

Beyond these individual tasks, there are a number of investigations which could enhance both the statistical correlation and the EOF forecast schemes. These include:

- since geostrophic winds are directly proportional to pressure gradients the use of MSLP (or 700 mb height) gradients deserves considerations. While crude measures of large-scale gradient information are implicit in the multi-linear regression formulation, a systematic scan of north-south and east-west gradient correlations might well identify predictors which are more closely related to iceberg fluctuations than are pressure or height points. The framework of the predictive systems would be little changed by use of gradients, except possibly that alternative measures of predictive skill may be required.

- a thorough investigation of differences in the monthly distribution of iceberg occurrence from year to year would prove fruitful in any expanded project. This effectively involves considering the monthly, rather than the annual flux of icebergs at 48°N. A preliminary review of such data for historically severe iceberg years suggests that it is rare for a severe iceberg year to occur when there has not been a substantial influx of bergs by the end of February.

- analogue methods of forecast tuning were briefly addressed in this study but clearly deserve additional attention.

- a better knowledge of iceberg distributions on the source region is required for long-term forecasts. Some degree of initialization is essential for iceberg forecasts of any length, but is especially so for shorter term forecasts. Possibly the perceived source region should be regarded in two respects:

  Primary source region: the actual area where calving from glaciers takes place.

  Secondary source region: the offshore oceanic waters (such as those in Baffin Bay) from which large numbers of icebergs transit into the target area of a forecast.

- there is a need for more basis research into the physics of iceberg behaviour in order to determine the appropriateness of the reliance on atmospheric circulation parameters. The dependence of iceberg break-up on temperatures and/or latitude, the force imbalances responsible for iceberg motion, the factors determining the interannual variability of the source region, and the most meaningful method of iceberg counting are all poorly understood factors relevant to iceberg prediction. A better scientific grasp of these factors will require a combination of year-round observation, modelling studies, and further statistical analysis.

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APPENDIX I

Table I.1 (a)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

Parameter : MEAN SEA LEVEL PRESSURE TIME AVERAGED APPROACH

Number of Months: 2 Correlation Coefficient r: -.49
Ending in : JANUARY

YEAR	a(1)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	36.05	0.	89.	89.	.22	1.	5.	4.
1958	2.63	1.	276.	275.	.67	2.	14.	12.
1952	-19.09	15.	398.	383.	.93	3.	22.	19.
1977	55.99	22.	0.	-22.	-.05	4.	3.	-1.
1980	-13.11	23.	365.	342.	.83	5.	20.	15.
1963	24.57	25.	154.	129.	.31	6.	6.	0.
1953	5.17	56.	262.	206.	.50	7.	13.	6.
1969	63.07	57.	0.	-57.	-.14	8.	2.	-6.
1955	-3.46	61.	310.	249.	.60	9.	16.	7.
1971	24.54	73.	154.	81.	.20	10.	7.	-3.
1978	-5.31	75.	321.	246.	.60	11.	17.	6.
1965	-12.27	76.	360.	284.	.69	12.	18.	6.
1956	23.61	80.	159.	79.	.19	13.	9.	-4.
1970	17.88	85.	191.	106.	.26	14.	10.	-4.
1975	-26.31	101.	439.	338.	.82	15.	24.	9.
1962	.31	112.	289.	177.	.43	16.	15.	-1.
1961	-12.86	114.	363.	249.	.60	17.	19.	2.
1976	-23.82	151.	425.	274.	.66	18.	23.	5.
1979	53.10	182.	0.	-182.	-.44	19.	4.	-15.
1968	24.06	226.	156.	-70.	-.17	20.	8.	-12.
1960	11.74	258.	225.	-33.	-.08	21.	11.	-10.
1954	-47.55	312.	557.	245.	.59	22.	27.	5.
1964	-15.92	369.	380.	11.	.03	23.	21.	-2.
1967	7.55	441.	249.	-192.	-.47	24.	12.	-12.
1959	64.15	689.	0.	-689.	-1.67	25.	1.	-24.
1973	-69.82	850.	682.	-168.	-.41	26.	28.	2.
1957	-70.89	931.	688.	-243.	-.59	27.	29.	2.
1974	-33.91	1386.	481.	-905.	-2.19	28.	25.	-3.
1972	-44.46	1584.	540.	-1044.	-2.53	29.	26.	-3.
MEAN		288.	288.					
STD. DEV.		413.	201.					
MEAN OF ABSOLUTE VALUES				254.0	.62			6.9
STD. DEV. OF ABSOLUTE VALUES				243.1	.59			5.8

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	15
1	12
2	2

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	3
1	12
2	10
3	3
4	1
5	0
6	0

Table I.1(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX CLASS VS PREDICTED ICEBERG FLUX CLASS

Parameter : MEAN SEA LEVEL PRESSURE TIME AVERAGED APPROACH

Number of Months: 2 Correlation Coefficient r: -.49
Ending in : JANUARY

YEAR	a(1)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS CLASS	PRED CLASS	DELTA CLASS
1952	-19.09	1.	4.	3.	N/A	1.	4.	3.
1958	2.63	1.	3.	2.	N/A	1.	3.	2.
1963	24.57	1.	2.	1.	N/A	1.	2.	1.
1966	36.05	1.	2.	1.	N/A	1.	2.	1.
1977	55.99	1.	2.	1.	N/A	1.	2.	1.
1980	-13.11	1.	3.	2.	N/A	1.	3.	2.
1953	5.17	2.	3.	1.	N/A	2.	3.	1.
1955	-3.46	2.	3.	1.	N/A	2.	3.	1.
1956	23.61	2.	2.	0.	N/A	2.	2.	0.
1965	-12.27	2.	3.	1.	N/A	2.	3.	1.
1969	63.07	2.	1.	-1.	N/A	2.	1.	-1.
1970	17.88	2.	3.	1.	N/A	2.	3.	1.
1971	24.54	2.	2.	0.	N/A	2.	2.	0.
1978	-5.31	2.	3.	1.	N/A	2.	3.	1.
1961	-12.86	3.	3.	0.	N/A	3.	3.	0.
1962	.31	3.	3.	0.	N/A	3.	3.	0.
1975	-26.31	3.	4.	1.	N/A	3.	4.	1.
1976	-23.82	3.	4.	1.	N/A	3.	4.	1.
1979	53.10	3.	2.	-1.	N/A	3.	2.	-1.
1954	-47.55	4.	4.	0.	N/A	4.	4.	0.
1960	11.74	4.	3.	-1.	N/A	4.	3.	-1.
1964	-15.92	4.	3.	-1.	N/A	4.	3.	-1.
1968	24.06	4.	2.	-2.	N/A	4.	2.	-2.
1959	64.15	5.	1.	-4.	N/A	5.	1.	-4.
1967	7.55	5.	3.	-2.	N/A	5.	3.	-2.
1957	-70.89	6.	5.	-1.	N/A	6.	5.	-1.
1973	-69.82	6.	5.	-1.	N/A	6.	5.	-1.
1972	-44.46	7.	4.	-3.	N/A	7.	4.	-3.
1974	-33.91	7.	4.	-3.	N/A	7.	4.	-3.
MEAN		N/A	N/A					
STD. DEV.		N/A	N/A					
MEAN OF ABSOLUTE VALUES				1.3	N/A			1.3
STD. DEV. OF ABSOLUTE VALUES				.9	N/A			.9

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED

AND PREDICTED CLASSIFICATION	COUNT
0	5
1	16
2	4
3	3
4	1
5	0
6	0

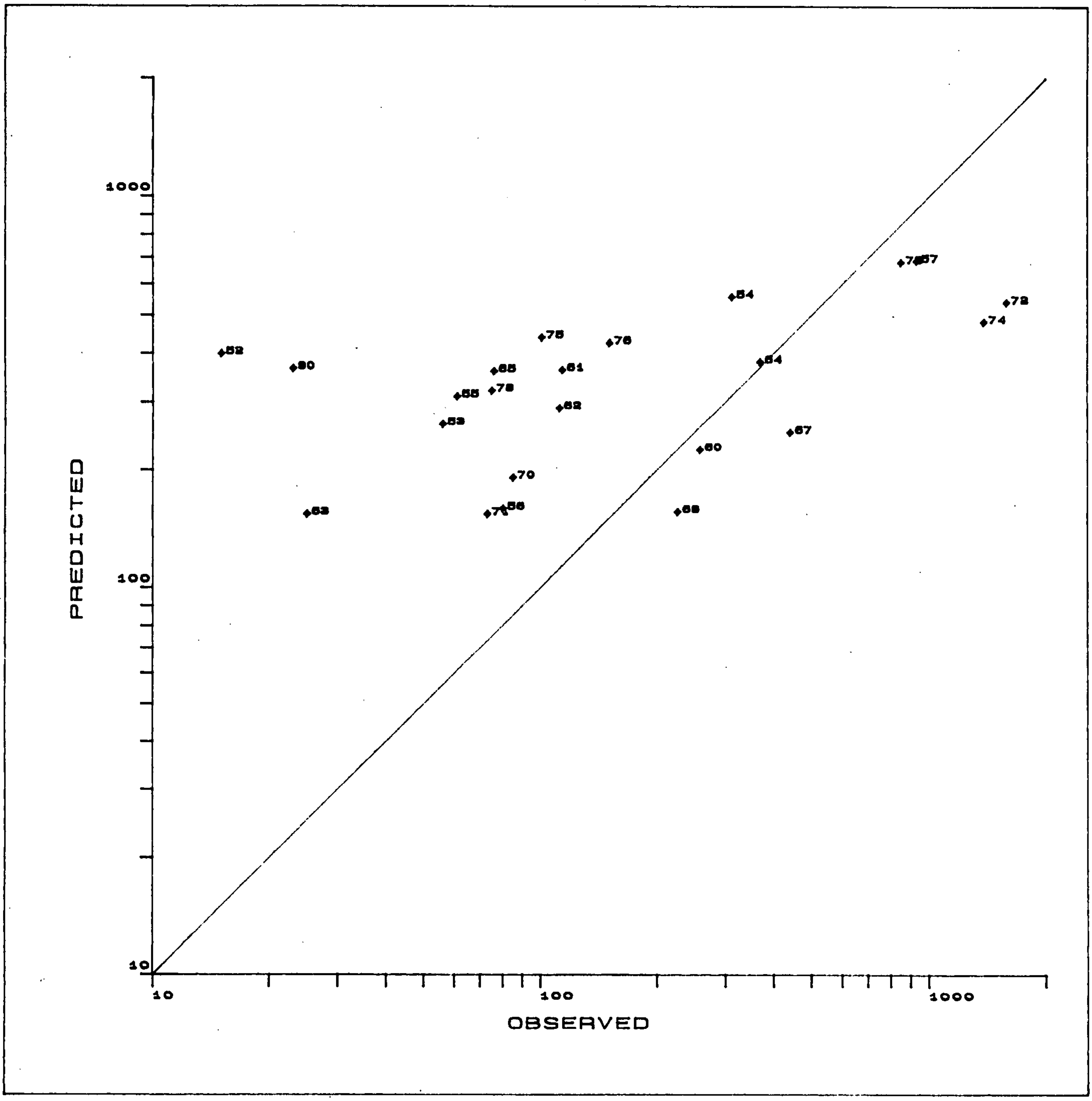

Fig. I.1 Predicted versus Observed Iceberg Flux for mean sea level pressure 2 months ending January, time averaged approach

Table I.2(a)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

Parameter : 700 MB HEIGHTS TIME AVERAGED APPROACH

Number of Months: 2 Correlation Coefficient r: -.57
Ending in : OCTOBER

YEAR	a(3)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	51.04	0.	142.	142.	.35	1.	8.	7.
1958	78.24	1.	68.	67.	.16	2.	7.	5.
1952	80.01	15.	63.	48.	.12	3.	5.	2.
1977	-6.31	22.	298.	276.	.68	4.	14.	10.
1980	181.31	23.	0.	-23.	-.06	5.	1.	-4.
1963	-37.82	25.	383.	358.	.88	6.	20.	14.
1953	-44.81	56.	402.	346.	.85	7.	21.	14.
1969	38.95	57.	175.	118.	.29	8.	11.	3.
1955	150.01	61.	0.	-61.	-.15	9.	3.	-6.
1981	-11.69	63.	312.	249.	.61	10.	15.	5.
1971	-55.98	73.	433.	360.	.88	11.	22.	11.
1978	45.92	75.	156.	81.	.20	12.	10.	-2.
1965	-32.56	76.	369.	293.	.72	13.	19.	6.
1956	-14.77	80.	321.	241.	.59	14.	17.	3.
1970	46.02	85.	155.	70.	.17	15.	9.	-6.
1975	23.80	101.	216.	115.	.28	16.	13.	-3.
1962	155.25	112.	0.	-112.	-.27	17.	2.	-15.
1961	-21.48	114.	339.	225.	.55	18.	18.	0.
1976	-58.88	151.	441.	290.	.71	19.	24.	5.
1979	-121.59	182.	611.	429.	1.05	20.	27.	7.
1968	29.18	226.	201.	-25.	-.06	21.	12.	-9.
1960	86.01	258.	47.	-211.	-.52	22.	4.	-18.
1954	-14.49	312.	320.	8.	.02	23.	16.	-7.
1964	79.12	369.	65.	-304.	-.74	24.	6.	-18.
1967	-59.58	441.	443.	2.	.00	25.	25.	0.
1959	-134.84	689.	647.	-42.	-.10	26.	28.	2.
1973	-135.17	850.	648.	-202.	-.50	27.	29.	2.
1957	-58.54	931.	440.	-491.	-1.21	28.	23.	-5.
1974	-138.92	1386.	658.	-728.	-1.79	29.	30.	1.
1972	-97.41	1584.	545.	-1039.	-2.55	30.	26.	-4.
MEAN		281.	281.					
STD. DEV.		407.	234.					
MEAN OF ABSOLUTE VALUES				231.8	.57			6.5
STD. DEV. OF ABSOLUTE VALUES				225.8	.55			5.1

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	15
1	12
2	3

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	5
1	10
2	10
3	5
4	0
5	0
6	0

Table I.2(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX CLASS VS PREDICTED ICEBERG FLUX CLASS

Parameter : 700 MB HEIGHTS — TIME AVERAGED APPROACH

Number of Months: 2 — Correlation Coefficient r: -.56
Ending in : OCTOBER

YEAR	a(3)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS CLASS	PRED CLASS	DELTA CLASS
1952	80.01	1.	2.	1.	N/A	1.	2.	1.
1958	78.24	1.	2.	1.	N/A	1.	2.	1.
1963	-37.82	1.	3.	2.	N/A	1.	3.	2.
1966	51.04	1.	2.	1.	N/A	1.	2.	1.
1977	-6.31	1.	3.	2.	N/A	1.	3.	2.
1980	181.31	1.	1.	0.	N/A	1.	1.	-0.
1953	-44.81	2.	4.	2.	N/A	2.	4.	2.
1955	150.01	2.	1.	-1.	N/A	2.	1.	-1.
1956	-14.77	2.	3.	1.	N/A	2.	3.	1.
1965	-32.56	2.	3.	1.	N/A	2.	3.	1.
1969	38.95	2.	3.	1.	N/A	2.	3.	1.
1970	46.02	2.	2.	0.	N/A	2.	2.	0.
1971	-55.98	2.	4.	2.	N/A	2.	4.	2.
1978	45.92	2.	2.	0.	N/A	2.	2.	0.
1981	-11.69	2.	3.	1.	N/A	2.	3.	1.
1961	-21.48	3.	3.	0.	N/A	3.	3.	0.
1962	155.25	3.	1.	-2.	N/A	3.	1.	-2.
1975	23.80	3.	3.	-0.	N/A	3.	3.	-0.
1976	-58.88	3.	4.	1.	N/A	3.	4.	1.
1979	-121.59	3.	4.	1.	N/A	3.	4.	1.
1954	-14.49	4.	3.	-1.	N/A	4.	3.	-1.
1960	86.01	4.	2.	-2.	N/A	4.	2.	-2.
1964	79.12	4.	2.	-2.	N/A	4.	2.	-2.
1968	29.18	4.	3.	-1.	N/A	4.	3.	-1.
1959	-134.84	5.	5.	-0.	N/A	5.	5.	-0.
1967	-59.58	5.	4.	-1.	N/A	5.	4.	-1.
1957	-58.54	6.	4.	-2.	N/A	6.	4.	-2.
1973	-135.17	6.	5.	-1.	N/A	6.	5.	-1.
1972	-97.41	7.	4.	-3.	N/A	7.	4.	-3.
1974	-138.92	7.	5.	-2.	N/A	7.	5.	-2.
MEAN		N/A	N/A					
STD. DEV.		N/A	N/A					
MEAN OF ABSOLUTE VALUES				1.3	N/A			1.3
STD. DEV. OF ABSOLUTE VALUES				.7	N/A			.7

CLASS ERRORS:

DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	6
1	14
2	9
3	1
4	0
5	0
6	0

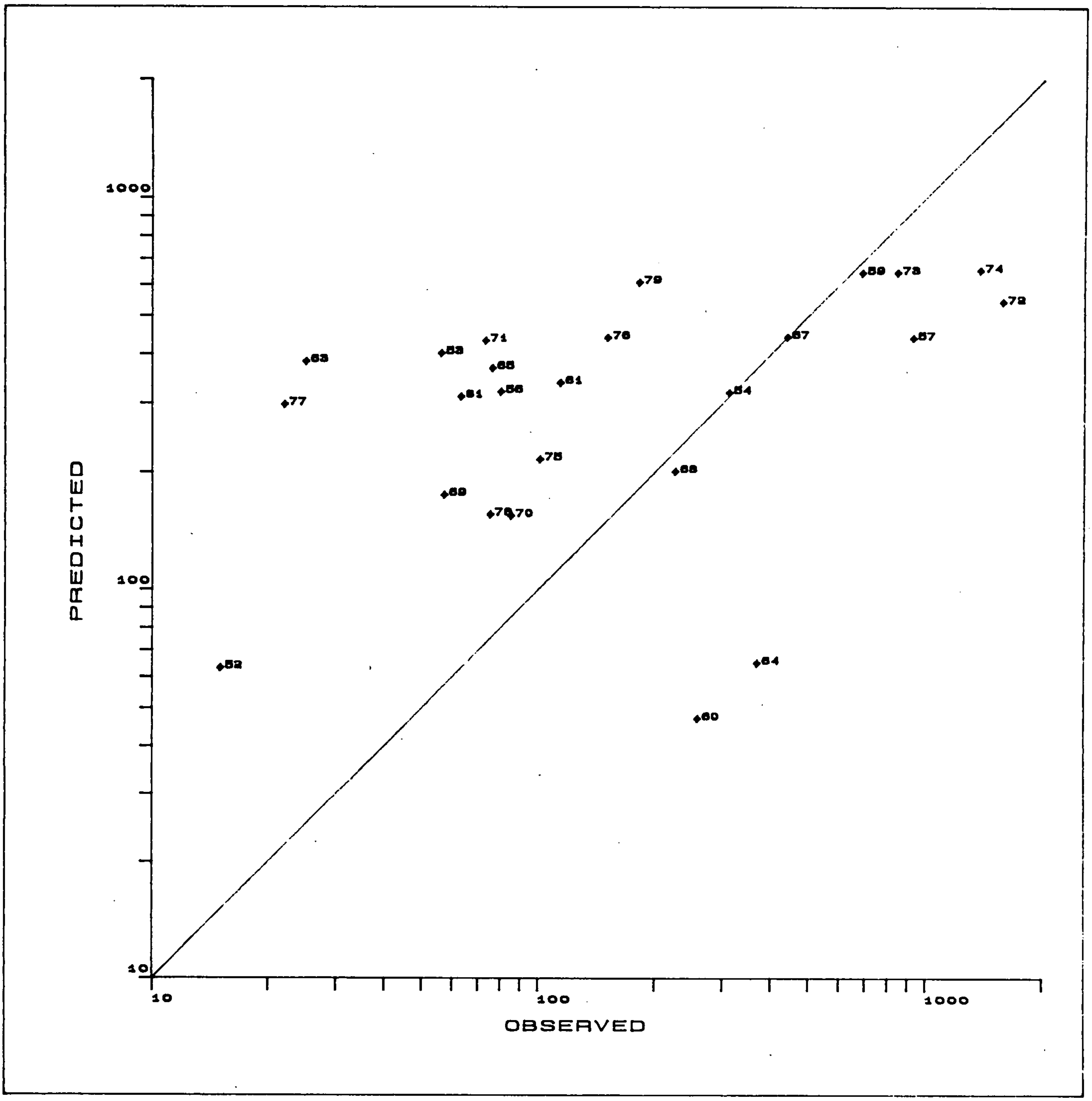

Fig. I.2 Predicted versus Observed Iceberg Flux for 700 mb Heights
2 months ending October, time averaged approach

Table I.3(a)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

Parameter : MEAN SEA LEVEL PRESSURE TIME AVERAGED APPROACH

Number of Months: 4 Correlation Coefficient r: -.49
Ending in : MARCH

YEAR	a(1)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	42.28	0.	11.	11.	.03	1.	3.	2.
1958	35.16	1.	57.	56.	.14	2.	6.	4.
1952	22.02	15.	142.	127.	.31	3.	9.	6.
1977	39.25	22.	30.	8.	.02	4.	4.	0.
1980	-17.09	23.	396.	373.	.91	5.	20.	15.
1963	4.38	25.	257.	232.	.56	6.	14.	8.
1953	-15.37	56.	385.	329.	.80	7.	19.	12.
1969	50.80	57.	0.	-57.	-.14	8.	1.	-7.
1955	23.06	61.	136.	75.	.18	9.	8.	-1.
1971	12.70	73.	203.	130.	.31	10.	11.	1.
1978	6.71	75.	242.	167.	.40	11.	13.	2.
1965	1.76	76.	274.	198.	.48	12.	15.	3.
1956	-3.79	80.	310.	230.	.56	13.	16.	3.
1970	20.62	85.	151.	66.	.16	14.	10.	-4.
1975	-21.05	101.	422.	321.	.78	15.	22.	7.
1962	36.13	112.	51.	-61.	-.15	16.	5.	-11.
1961	-14.03	114.	377.	263.	.64	17.	18.	1.
1976	-64.98	151.	708.	557.	1.35	18.	29.	11.
1979	30.22	182.	89.	-93.	-.23	19.	7.	-12.
1968	8.51	226.	230.	4.	.01	20.	12.	-8.
1960	42.35	258.	10.	-248.	-.60	21.	2.	-19.
1954	-49.06	312.	604.	292.	.71	22.	28.	6.
1964	-34.07	369.	507.	138.	.33	23.	26.	3.
1967	-28.82	441.	473.	32.	.08	24.	23.	-1.
1959	-17.81	689.	401.	-288.	-.70	25.	21.	-4.
1973	-47.72	850.	596.	-254.	-.62	26.	27.	1.
1957	-10.59	931.	354.	-577.	-1.40	27.	17.	-10.
1974	-30.35	1386.	483.	-903.	-2.19	28.	24.	-4.
1972	-33.23	1584.	501.	-1083.	-2.62	29.	25.	-4.
MEAN		288.	288.					
STD. DEV.		413.	203.					
MEAN OF ABSOLUTE VALUES				247.4	.60			5.9
STD. DEV. OF ABSOLUTE VALUES				255.4	.62			4.8

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	18
1	10
2	1

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	5
1	10
2	11
3	3
4	0
5	0
6	0

Table I.3(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX CLASS VS PREDICTED ICEBERG FLUX CLASS

Parameter : MEAN SEA LEVEL PRESSURE TIME AVERAGED APPROACH

Number of Months: 4 Correlation Coefficient r: -.56
Ending in : MARCH

YEAR	a(1)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS CLASS	PRED CLASS	DELTA CLASS
1952	22.02	1.	2.	1.	N/A	1.	2.	1.
1958	35.16	1.	2.	1.	N/A	1.	2.	1.
1963	4.38	1.	3.	2.	N/A	1.	3.	2.
1966	42.28	1.	2.	1.	N/A	1.	2.	1.
1977	39.25	1.	2.	1.	N/A	1.	2.	1.
1980	-17.09	1.	4.	3.	N/A	1.	4.	3.
1953	-15.37	2.	4.	2.	N/A	2.	4.	2.
1955	23.06	2.	2.	0.	N/A	2.	2.	0.
1956	-3.79	2.	3.	1.	N/A	2.	3.	1.
1965	1.76	2.	3.	1.	N/A	2.	3.	1.
1969	50.80	2.	1.	-1.	N/A	2.	1.	-1.
1970	20.62	2.	2.	0.	N/A	2.	2.	0.
1971	12.70	2.	3.	1.	N/A	2.	3.	1.
1978	6.71	2.	3.	1.	N/A	2.	3.	1.
1961	-14.03	3.	4.	1.	N/A	3.	4.	1.
1962	36.13	3.	2.	-1.	N/A	3.	2.	-1.
1975	-21.05	3.	4.	1.	N/A	3.	4.	1.
1976	-64.98	3.	5.	2.	N/A	3.	5.	2.
1979	30.22	3.	2.	-1.	N/A	3.	2.	-1.
1954	-49.06	4.	5.	1.	N/A	4.	5.	1.
1960	42.35	4.	2.	-2.	N/A	4.	2.	-2.
1964	-34.07	4.	4.	0.	N/A	4.	4.	0.
1968	8.51	4.	3.	-1.	N/A	4.	3.	-1.
1959	-17.81	5.	4.	-1.	N/A	5.	4.	-1.
1967	-28.82	5.	4.	-1.	N/A	5.	4.	-1.
1957	-10.59	6.	3.	-3.	N/A	6.	3.	-3.
1973	-47.72	6.	5.	-1.	N/A	6.	5.	-1.
1972	-33.23	7.	4.	-3.	N/A	7.	4.	-3.
1974	-30.35	7.	4.	-3.	N/A	7.	4.	-3.
MEAN		N/A	N/A					
STD. DEV.		N/A	N/A					
MEAN OF ABSOLUTE VALUES				1.3	N/A			1.3
STD. DEV. OF ABSOLUTE VALUES				.8	N/A			.8

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION

DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	3
1	18
2	4
3	4
4	0
5	0
6	0

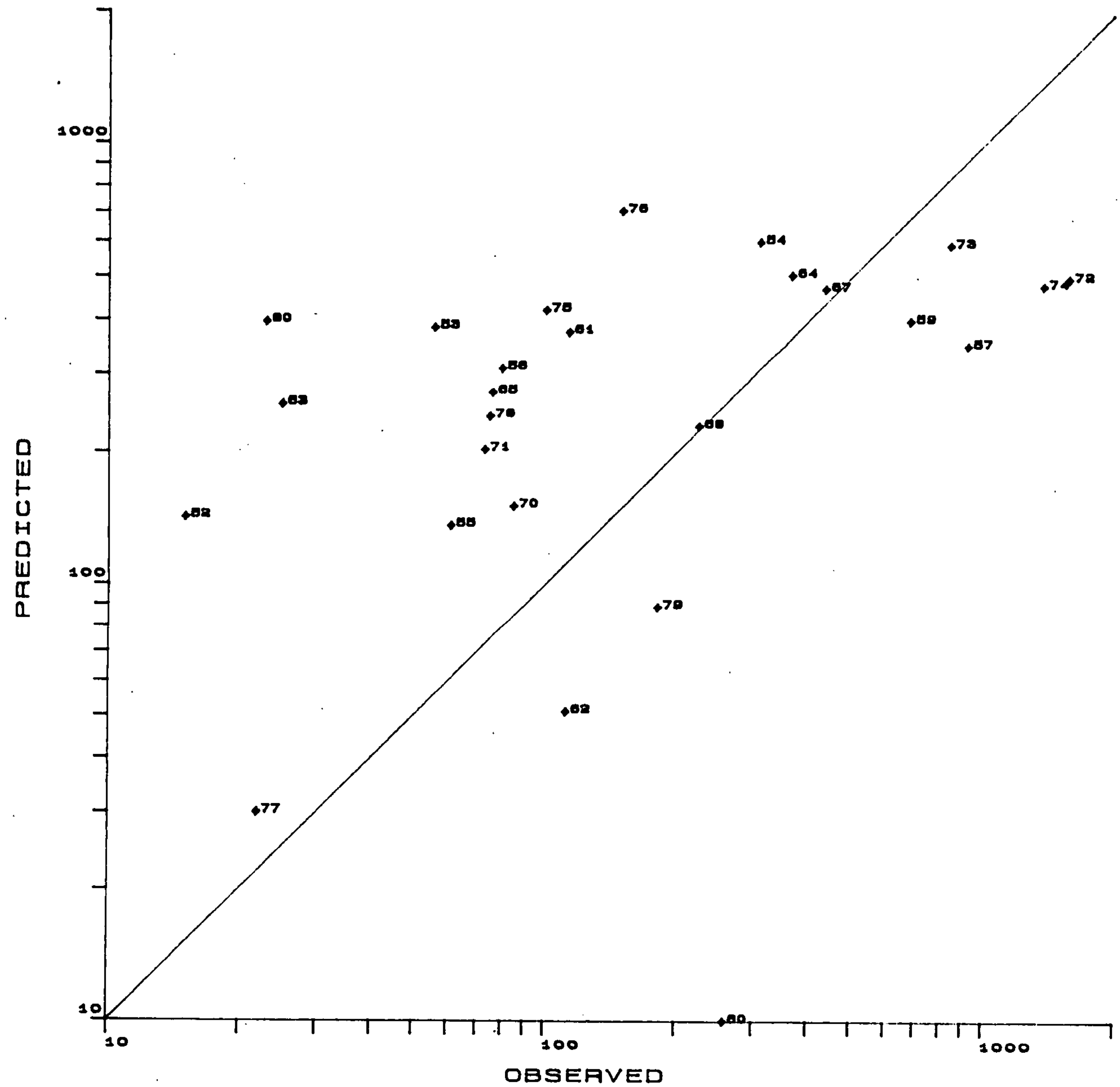

Fig. I.3 Predicted versus Observed Iceberg Flux for mean sea level pressure 4 months ending March, time averaged approach

Table I.4(a)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

Parameter : 700 - 1000 MB THICKNESS TIME AVERAGED APPROACH

Number of Months: 2 Correlation Coefficient r: .61
Ending in : FEBRUARY

YEAR	a(1)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	-94.18	0.	102.	102.	.25	1.	8.	7.
1958	-223.84	1.	0.	-1.	-.00	2.	2.	0.
1951	51.35	9.	375.	366.	.90	3.	20.	17.
1952	11.25	15.	300.	285.	.70	4.	17.	13.
1977	-154.69	22.	0.	-22.	-.05	5.	5.	0.
1980	-167.25	23.	0.	-23.	-.06	6.	4.	-2.
1963	-37.37	25.	209.	184.	.45	7.	11.	4.
1953	-42.26	56.	199.	143.	.35	8.	10.	2.
1969	-296.76	57.	0.	-57.	-.14	9.	1.	-8.
1955	-88.64	61.	112.	51.	.13	10.	9.	-1.
1971	3.24	73.	285.	212.	.52	11.	15.	4.
1978	-99.97	75.	91.	16.	.04	12.	6.	-6.
1965	28.05	76.	331.	255.	.63	13.	19.	6.
1956	-98.88	80.	93.	13.	.03	14.	7.	-7.
1970	-8.17	85.	263.	178.	.44	15.	14.	-1.
1975	113.19	101.	491.	390.	.96	16.	24.	8.
1962	161.84	112.	583.	471.	1.15	17.	28.	11.
1961	98.96	114.	465.	351.	.86	18.	22.	4.
1976	141.44	151.	544.	393.	.96	19.	26.	7.
1979	7.91	182.	294.	112.	.27	20.	16.	-4.
1968	-11.22	226.	258.	32.	.08	21.	13.	-8.
1960	-210.64	258.	0.	-258.	-.63	22.	3.	-19.
1954	89.94	312.	448.	136.	.33	23.	21.	-2.
1964	-16.30	369.	248.	-121.	-.30	24.	12.	-12.
1967	104.63	441.	475.	34.	.08	25.	23.	-2.
1959	13.78	689.	305.	-384.	-.94	26.	18.	-8.
1973	151.02	850.	562.	-288.	-.70	27.	27.	0.
1957	119.41	931.	503.	-428.	-1.05	28.	25.	-3.
1974	169.30	1386.	597.	-789.	-1.93	29.	29.	0.
1972	284.88	1584.	814.	-770.	-1.88	30.	30.	0.
MEAN		279.	279.					
STD. DEV.		409.	250.					
MEAN OF ABSOLUTE VALUES				228.9	.56			5.5
STD. DEV. OF ABSOLUTE VALUES				207.9	.51			5.0

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	17
1	12
2	1

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	8
1	9
2	9
3	4
4	0
5	0
6	0

Table I.4(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX CLASS VS PREDICTED ICEBERG FLUX CLASS

Parameter : 700 - 1000 MB THICKNESS TIME AVERAGED APPROACH

Number of Months: 2 Correlation Coefficient r: .64
Ending in : FEBRUARY

YEAR	a(1)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS CLASS	PRED CLASS	DELTA CLASS
1951	51.35	1.	3.	2.	N/A	1.	3.	2.
1952	11.25	1.	3.	2.	N/A	1.	3.	2.
1958	-223.84	1.	1.	0.	N/A	1.	1.	0.
1963	-37.37	1.	3.	2.	N/A	1.	3.	2.
1966	-94.18	1.	2.	1.	N/A	1.	2.	1.
1977	-154.69	1.	2.	1.	N/A	1.	2.	1.
1980	-167.25	1.	2.	1.	N/A	1.	2.	1.
1953	-42.26	2.	3.	1.	N/A	2.	3.	1.
1955	-88.64	2.	2.	0.	N/A	2.	2.	0.
1956	-98.88	2.	2.	0.	N/A	2.	2.	0.
1965	28.05	2.	3.	1.	N/A	2.	3.	1.
1969	-296.76	2.	1.	-1.	N/A	2.	0.	-2.
1970	-8.17	2.	3.	1.	N/A	2.	3.	1.
1971	3.24	2.	3.	1.	N/A	2.	3.	1.
1978	-99.97	2.	2.	0.	N/A	2.	2.	0.
1961	98.96	3.	4.	1.	N/A	3.	4.	1.
1962	161.84	3.	4.	1.	N/A	3.	4.	1.
1975	113.19	3.	4.	1.	N/A	3.	4.	1.
1976	141.44	3.	4.	1.	N/A	3.	4.	1.
1979	7.91	3.	3.	0.	N/A	3.	3.	0.
1954	89.94	4.	4.	-0.	N/A	4.	4.	-0.
1960	-210.64	4.	1.	-3.	N/A	4.	1.	-3.
1964	-16.30	4.	3.	-1.	N/A	4.	3.	-1.
1968	-11.22	4.	3.	-1.	N/A	4.	3.	-1.
1959	13.78	5.	3.	-2.	N/A	5.	3.	-2.
1967	104.63	5.	4.	-1.	N/A	5.	4.	-1.
1957	119.41	6.	4.	-2.	N/A	6.	4.	-2.
1973	151.02	6.	4.	-2.	N/A	6.	4.	-2.
1972	284.88	7.	6.	-1.	N/A	7.	6.	-1.
1974	169.30	7.	5.	-2.	N/A	7.	5.	-2.
MEAN		N/A	N/A					
STD. DEV.		N/A	N/A					
MEAN OF ABSOLUTE VALUES				1.1	N/A			1.2
STD. DEV. OF ABSOLUTE VALUES				.8	N/A			.8

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION

DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	6
1	15
2	8
3	1
4	0
5	0
6	0

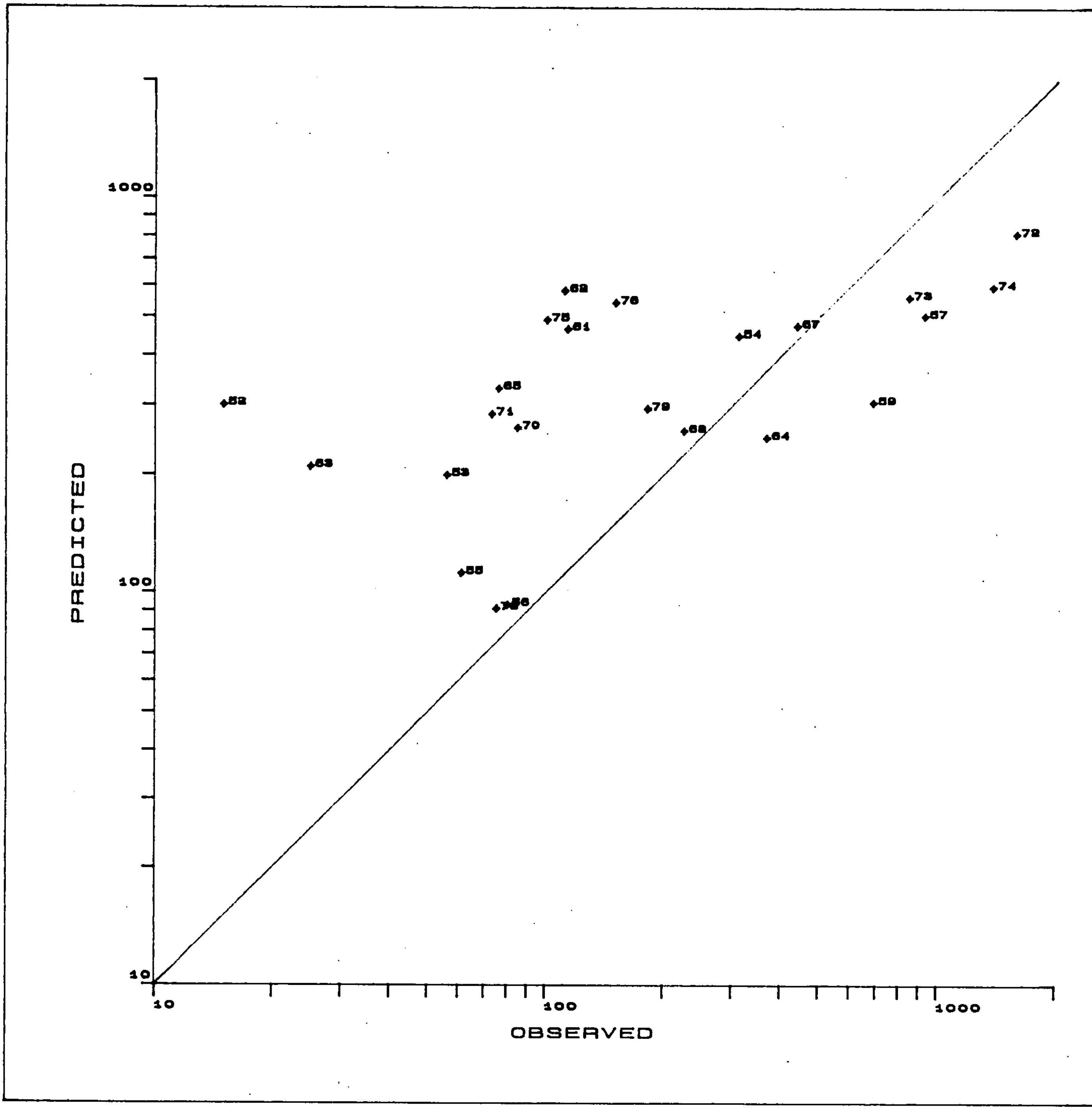

Fig. I.4 Predicted versus Observed Iceberg Flux for 700-1000 mb Thickness 2 months ending February, time averaged approach

Table I.5(a)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

Parameter : SURFACE AIR TEMPERATURE TIME AVERAGED APPROACH

Number of Months: 4 Correlation Coefficient r: -.67
Ending in : MARCH

YEAR	a(1)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	5.12	0.	116.	116.	.29	1.	10.	9.
1958	12.45	1.	0.	-1.	-.00	2.	2.	0.
1952	-1.92	15.	342.	327.	.82	3.	20.	17.
1977	9.09	22.	0.	-22.	-.05	4.	5.	1.
1980	8.03	23.	23.	0.	.00	5.	6.	1.
1963	4.10	25.	149.	124.	.31	6.	12.	6.
1953	10.97	56.	0.	-56.	-.14	7.	4.	-3.
1969	14.54	57.	0.	-57.	-.14	8.	1.	-7.
1955	2.26	61.	208.	147.	.37	9.	14.	5.
1981	11.67	63.	0.	-63.	-.16	10.	3.	-7.
1971	-1.30	73.	322.	249.	.62	11.	18.	7.
1978	-1.33	75.	323.	248.	.62	12.	19.	7.
1965	1.25	76.	240.	164.	.41	13.	16.	3.
1956	5.81	80.	94.	14.	.04	14.	9.	-5.
1970	6.52	85.	72.	-13.	-.03	15.	7.	-8.
1975	-10.72	101.	624.	523.	1.30	16.	29.	13.
1962	5.04	112.	119.	7.	.02	17.	11.	-6.
1961	-9.18	114.	575.	461.	1.15	18.	27.	9.
1976	-9.70	151.	591.	440.	1.10	19.	28.	9.
1979	2.52	182.	200.	18.	.04	20.	13.	-7.
1982	-2.80	188.	370.	182.	.45	21.	21.	0.
1968	1.84	226.	221.	-5.	-.01	22.	15.	-7.
1960	6.24	258.	81.	-177.	-.44	23.	8.	-15.
1954	-5.75	312.	465.	153.	.38	24.	23.	-1.
1964	-5.64	369.	461.	92.	.23	25.	22.	-3.
1967	-5.90	441.	469.	28.	.07	26.	24.	-2.
1959	.20	689.	274.	-415.	-1.04	27.	17.	-10.
1973	-13.25	850.	705.	-145.	-.36	28.	30.	2.
1957	-7.55	931.	522.	-409.	-1.02	29.	25.	-4.
1974	-8.76	1386.	561.	-825.	-2.06	30.	26.	-4.
1972	-21.12	1584.	957.	-627.	-1.56	31.	31.	0.
MEAN		278.	278.					
STD. DEV.		401.	270.					
MEAN OF ABSOLUTE VALUES				197.1	.49			5.7
STD. DEV. OF ABSOLUTE VALUES				210.3	.52			4.3

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	20
1	10
2	1

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	9
1	10
2	11
3	1
4	0
5	0
6	0

Table I.5(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX CLASS VS PREDICTED ICEBERG FLUX CLASS

Parameter : SURFACE AIR TEMPERATURE TIME AVERAGED APPROACH

Number of Months: 4 Correlation Coefficient r: -.71
Ending in : MARCH

YEAR	a(1)	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS CLASS	PRED CLASS	DELTA CLASS
1952	-1.92	1.	3.	2.	N/A	1.	3.	2.
1958	12.45	1.	1.	0.	N/A	1.	1.	0.
1963	4.10	1.	2.	1.	N/A	1.	2.	1.
1966	5.12	1.	2.	1.	N/A	1.	2.	1.
1977	9.09	1.	2.	1.	N/A	1.	2.	1.
1980	8.03	1.	2.	1.	N/A	1.	2.	1.
1953	10.97	2.	1.	-1.	N/A	2.	1.	-1.
1955	2.26	2.	3.	1.	N/A	2.	3.	1.
1956	5.81	2.	2.	0.	N/A	2.	2.	0.
1965	1.25	2.	3.	1.	N/A	2.	3.	1.
1969	14.54	2.	1.	-1.	N/A	2.	1.	-1.
1970	6.52	2.	2.	0.	N/A	2.	2.	0.
1971	-1.30	2.	3.	1.	N/A	2.	3.	1.
1978	-1.33	2.	3.	1.	N/A	2.	3.	1.
1981	11.67	2.	1.	-1.	N/A	2.	1.	-1.
1961	-9.18	3.	4.	1.	N/A	3.	4.	1.
1962	5.04	3.	2.	-1.	N/A	3.	2.	-1.
1975	-10.72	3.	5.	2.	N/A	3.	5.	2.
1976	-9.70	3.	5.	2.	N/A	3.	5.	2.
1979	2.52	3.	3.	-0.	N/A	3.	3.	-0.
1982	-2.80	3.	3.	0.	N/A	3.	3.	0.
1954	-5.75	4.	4.	-0.	N/A	4.	4.	-0.
1960	6.24	4.	2.	-2.	N/A	4.	2.	-2.
1964	-5.64	4.	4.	-0.	N/A	4.	4.	-0.
1968	1.84	4.	3.	-1.	N/A	4.	3.	-1.
1959	.20	5.	3.	-2.	N/A	5.	3.	-2.
1967	-5.90	5.	4.	-1.	N/A	5.	4.	-1.
1957	-7.55	6.	4.	-2.	N/A	6.	4.	-2.
1973	-13.25	6.	5.	-1.	N/A	6.	5.	-1.
1972	-21.12	7.	6.	-1.	N/A	7.	6.	-1.
1974	-8.76	7.	4.	-3.	N/A	7.	4.	-3.
MEAN		N/A	N/A					
STD. DEV.		N/A	N/A					
MEAN OF ABSOLUTE VALUES				1.0	N/A			1.0
STD. DEV. OF ABSOLUTE VALUES				.7	N/A			.7

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	7
1	17
2	6
3	1
4	0
5	0
6	0

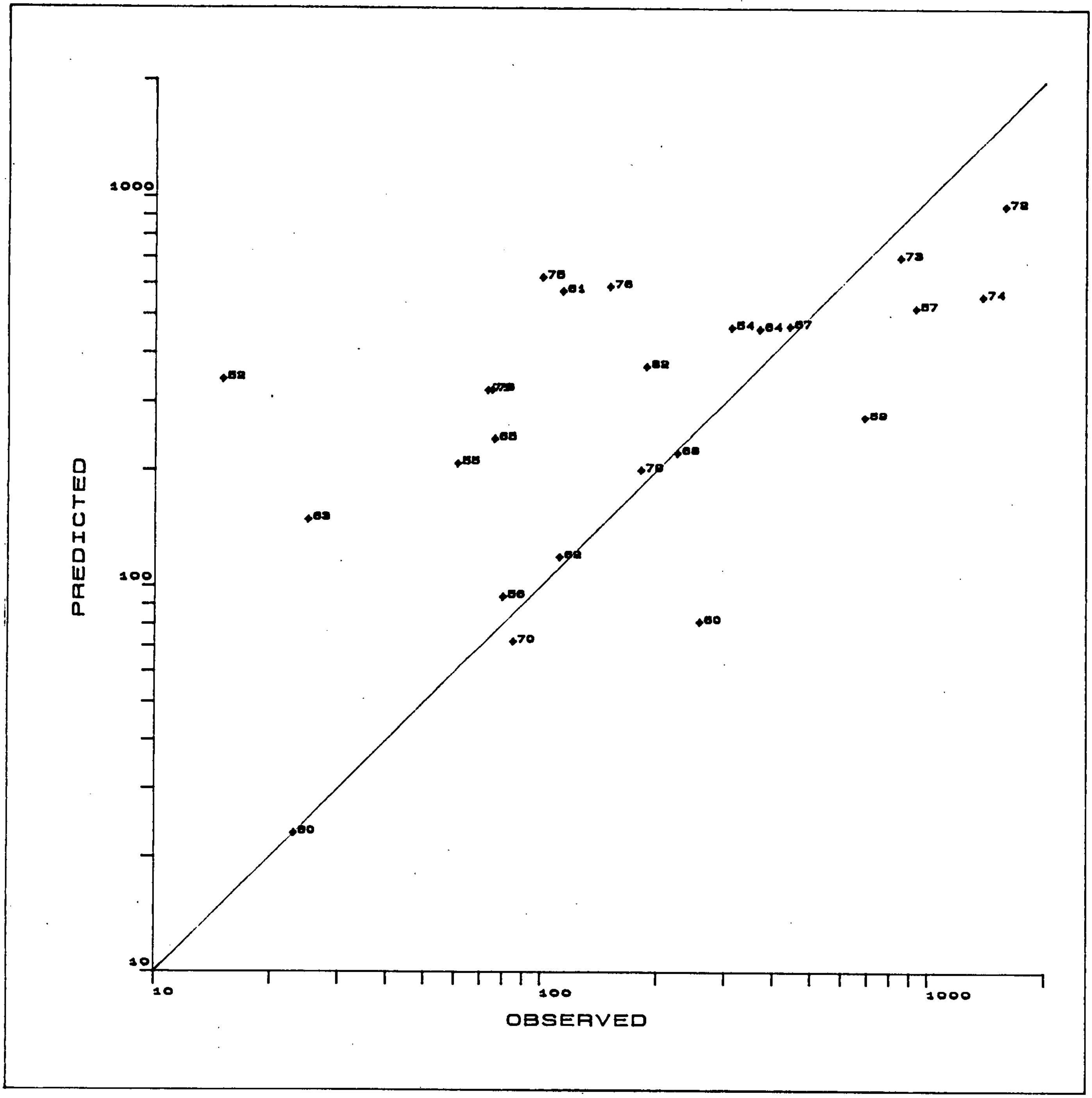

Fig. I.5 Predicted versus Observed Iceberg Flux for Surface Air Temperature 4 months ending March, time averaged approach

Table I.6

COMPARISON OF OBSERVED ICEBERG FLUX
VS PREDICTED ICEBERG FLUX

INDEPENDENT TEST
(ONE-YEAR-OUT)

Parameter: MEAN SEA LEVEL PRESSURE TIME AVERAGED APPROACH

Number of Months: 2
Ending in: JANUARY

YEAR	r	A(1)	OBSERVED	PREDICTED	(P-O)	(P-O/SD)	OBS RANK	PRED RANK	DELTA RANK
1966	-.48	34.39	0	105	105	.25	1	5	4
1958	-.49	2.58	1	287	286	.69	2	14	12
1952	-.50	-18.16	15	410	395	.96	3	23	20
1977	-.48	54.05	22	0	-22	-.05	4	4	0
1980	-.50	-12.98	23	378	355	.86	5	21	16
1963	-.48	22.95	25	170	145	.35	6	9	3
1953	-.49	5.06	56	270	214	.52	7	13	6
1969	-.48	62.38	57	0	-57	-.14	8	2	-6
1955	-.49	-3.35	61	319	258	.63	9	16	7
1971	-.48	24.22	73	160	87	.21	10	7	-3
1978	-.49	-5.28	75	330	255	.62	11	17	6
1965	-.50	-12.18	76	371	295	.71	12	18	6
1956	-.48	23.08	80	166	86	.21	13	8	-5
1970	-.48	17.69	86	197	112	.27	14	10	-4
1975	-.51	-25.67	101	454	353	.86	15	26	11
1962	-.49	.30	112	296	184	.45	16	15	-1
1961	-.49	-12.53	114	371	257	.62	17	19	2
1976	-.50	-21.56	151	426	275	.67	18	24	6
1979	-.50	52.37	182	0	-182	-.44	19	3	-16
1968	-.48	23.09	226	159	-67	-.16	20	6	-14
1960	-.49	11.48	258	225	-33	-.08	21	11	-10
1954	-.50	-46.55	312	580	268	.65	22	27	5
1964	-.49	-15.13	369	376	7	.02	23	20	-3
1967	-.49	7.44	441	242	-199	-.48	24	12	-12
1959	-.60	62.65	689	0	-689	-1.67	25	1	-24
1973	-.43	-68.25	850	633	-217	-.53	26	29	3
1957	-.42	-69.93	931	627	-304	-.74	27	28	1
1974	-.46	-32.73	1386	410	-976	-2.37	28	22	-6
1972	-.44	-44.01	1584	433	-1151	-2.79	29	25	-4
MEAN			288	279					
STD DEV			413	199					
MEAN OF ABSOLUTE VALUES					270	.65			7.4
STD DEV OF ABSOLUTE VALUES					262	.63			5.9

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	14
1	12
2	3

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	3
1	11
2	11
3	2
4	2
5	0
6	0

Table I.7

COMPARISON OF OBSERVED ICEBERG FLUX
VS PREDICTED ICEBERG FLUX

INDEPENDENT TEST
(ONE-YEAR-OUT)

Parameter: 700 MB HEIGHTS

TIME AVERAGED APPROACH

Number of Months: 2
Ending in: OCTOBER

YEAR	r	A(1)	OBSERVED	PREDICTED	(P-O)	(P-O/SD)	OBS RANK	PRED RANK	DELTA RANK
1966	-.56	45.10	0	166	166	.41	1	9	8
1958	-.57	56.84	1	131	130	.32	2	8	6
1952	-.59	74.70	15	74	59	.14	3	5	2
1977	-.58	-4.51	22	302	280	.69	4	14	10
1980	-.55	123.47	23	0	-23	-.06	5	1	-4
1963	-.59	-36.02	25	393	368	.90	6	20	14
1953	-.59	-43.54	56	415	359	.88	7	23	16
1969	-.60	65.76	57	95	38	.09	8	6	-2
1955	-.54	125.77	61	0	-61	-.15	9	2	-7
1981	-.58	-8.42	63	312	249	.61	10	15	5
1971	-.58	-48.31	73	425	352	.87	11	25	14
1978	-.57	41.78	75	171	96	.23	12	10	-2
1965	-.59	-30.66	76	376	300	.74	13	19	6
1956	-.58	-11.07	80	319	239	.59	14	16	2
1970	-.57	28.52	85	207	122	.30	15	11	-4
1975	.56	-26.43	101	214	113	.28	16	12	-4
1962	.52	-87.57	112	56	-56	-.42	17	4	-13
1961	-.58	-19.97	114	343	229	.56	18	18	0
1976	-.29	-54.16	151	443	292	.72	19	26	7
1979	.59	102.29	182	589	407	1.00	20	30	10
1968	-.56	17.08	226	236	10	.02	21	13	-8
1960	-.60	61.88	258	97	-161	-.39	22	7	-15
1954	-.57	-14.62	312	321	9	.02	23	17	-6
1964	-.57	84.20	369	39	-330	-.81	24	3	-21
1967	-.58	-51.59	441	422	-19	-.05	25	24	-1
1959	-.54	-117.92	689	588	-101	-.25	26	29	3
1973	-.51	-122.24	850	571	-279	-.68	27	28	1
1974	-.48	-112.56	1386	478	-908	-2.23	29	27	-2
1972	-.56	-74.93	1584	401	-1183	-2.90	30	22	-8
MEAN			281	282					
STD DEV			407	183					
MEAN OF ABSOLUTE VALUES					249	.61			6.9
STD DEV OF ABSOLUTE VALUES					259	.64			5.2

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	17
1	10
2	3

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	6
1	7
2	12
3	5
4	0
5	0
6	0

Table I.8(a)

CROSS-CORRELATIONS AMONG PARAMETERS TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	A(N)	r
700 MB HEIGHTS	1	JANUARY	1	-.50
MEAN SEA LEVEL PRESSURE	3	MARCH	1	-.52
SURFACE AIR TEMPERATURE	4	MARCH	1	-.67

Value of the correlation coefficient, r, among the parameters.

Horizontal => abscissa, Vertical => ordinate.

Parameter :	H700MB	SLP	SAT
# of months :	1	3	4
ending in :	JANUARY	MARCH	MARCH
An, n= :	1	1	1
H700MB 1 JANUARY 1	1.00	.55	.70
SLP 3 MARCH 1	.55	1.00	.68
SAT 4 MARCH 1	.70	.68	1.00

Table I.8(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	a(n)	r
700 MB HEIGHTS	1	JANUARY	1	-.50
MEAN SEA LEVEL PRESSURE	3	MARCH	1	-.52
SURFACE AIR TEMPERATURE	4	MARCH	1	-.67

Correlation Coefficient (Observed vs Predicted): .68

YEAR	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	0.	70.	70.	.17	1.	8.	7.
1958	1.	0.	-1.	-.00	2.	2.	0.
1952	15.	302.	287.	.70	3.	17.	14.
1977	22.	0.	-22.	-.05	4.	3.	-1.
1980	23.	40.	17.	.04	5.	6.	1.
1963	25.	147.	122.	.30	6.	11.	5.
1953	56.	0.	-56.	-.14	7.	4.	-3.
1969	57.	0.	-57.	-.14	8.	1.	-7.
1955	61.	166.	105.	.26	9.	12.	3.
1971	73.	313.	240.	.58	10.	18.	8.
1978	75.	325.	250.	.61	11.	19.	8.
1965	76.	245.	169.	.41	12.	15.	3.
1956	80.	120.	40.	.10	13.	9.	-4.
1970	85.	63.	-22.	-.05	14.	7.	-7.
1975	101.	633.	532.	1.29	15.	26.	11.
1962	112.	123.	11.	.03	16.	10.	-6.
1961	114.	568.	454.	1.10	17.	24.	7.
1976	151.	640.	489.	1.19	18.	27.	9.
1979	182.	170.	-12.	-.03	19.	13.	-6.
1968	226.	223.	-3.	-.01	20.	14.	-6.
1960	258.	25.	-233.	-.56	21.	5.	-16.
1954	312.	493.	181.	.44	22.	21.	-1.
1964	369.	505.	136.	.33	23.	22.	-1.
1967	441.	484.	43.	.10	24.	20.	-4.
1959	689.	300.	-389.	-.94	25.	16.	-9.
1973	850.	727.	-123.	-.30	26.	28.	2.
1957	931.	523.	-408.	-.99	27.	23.	-4.
1974	1386.	597.	-789.	-1.91	28.	25.	-3.
1972	1584.	957.	-627.	-1.52	29.	29.	0.
MEAN	288.	288.					
STD. DEV.	413.	281.					
MEAN OF ABSOLUTE VALUES			203.	.49			5.4
STD. DEV. OF ABSOLUTE VALUES			212.	.51			4.0

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	16
1	12
2	1

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	8
1	11
2	8
3	2
4	0
5	0
6	0

Table I.9(a)

CROSS-CORRELATIONS AMONG PARAMETERS — TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	A(N)	r
MEAN SEA LEVEL PRESSURE	4	MARCH	1	-.49
MEAN SEA LEVEL PRESSURE	4	MARCH	2	.45

Value of the correlation coefficient, r, among the parameters.

Horizontal => abscissa, Vertical => ordinate.

Parameter :	SLP	SLP
# of months :	4	4
ending in :	MARCH	MARCH
An, n= :	1	2
SLP 4 MARCH 1	1.00	-.00
SLP 4 MARCH 2	-.00	1.00

Table I.9(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	a(n)	r
MEAN SEA LEVEL PRESSURE	4	MARCH	1	-.49
MEAN SEA LEVEL PRESSURE	4	MARCH	2	.45

Correlation Coefficient (Observed vs Predicted): .67

YEAR	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	0.	150.	150.	.36	1.	11.	10.
1958	1.	56.	55.	.13	2.	8.	6.
1952	15.	331.	316.	.76	3.	16.	13.
1977	22.	152.	130.	.31	4.	12.	8.
1980	23.	457.	434.	1.05	5.	20.	15.
1963	25.	83.	58.	.14	6.	10.	4.
1953	56.	74.	18.	.04	7.	9.	2.
1969	57.	0.	-57.	-.14	8.	1.	-7.
1955	61.	9.	-52.	-.13	9.	4.	-5.
1971	73.	49.	-24.	-.06	10.	7.	-3.
1978	75.	392.	317.	.77	11.	18.	7.
1965	76.	0.	-76.	-.18	12.	2.	-10.
1956	80.	181.	101.	.25	13.	14.	1.
1970	85.	19.	-66.	-.16	14.	6.	-8.
1975	101.	641.	540.	1.31	15.	26.	11.
1962	112.	0.	-112.	-.27	16.	3.	-13.
1961	114.	584.	470.	1.14	17.	24.	7.
1976	151.	476.	325.	.79	18.	21.	3.
1979	182.	263.	81.	.20	19.	15.	-4.
1968	226.	17.	-209.	-.51	20.	5.	-15.
1960	258.	163.	-95.	-.23	21.	13.	-8.
1954	312.	510.	198.	.48	22.	23.	1.
1964	369.	333.	-36.	-.09	23.	17.	-6.
1967	441.	506.	65.	.16	24.	22.	-2.
1959	689.	402.	-287.	-.70	25.	19.	-6.
1973	850.	683.	-167.	-.41	26.	27.	1.
1957	931.	638.	-293.	-.71	27.	25.	-2.
1974	1386.	826.	-560.	-1.36	28.	29.	1.
1972	1584.	683.	-901.	-2.18	29.	28.	-1.
MEAN	288.	288.					
STD. DEV.	413.	276.					
MEAN OF ABSOLUTE VALUES			214.	.52			6.2
STD. DEV. OF ABSOLUTE VALUES			207.	.50			4.4

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	15
1	14
2	0

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	4
1	14
2	8
3	2
4	1
5	0
6	0

Table I.10(a)

CROSS-CORRELATIONS AMONG PARAMETERS   TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	A(N)	r
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49
700 MB HEIGHTS	5	DECEMBER	5	-.58
700 MB HEIGHTS	2	OCTOBER	3	-.57
700 - 1000 MB THICKNESS	2	DECEMBER	4	-.54
MEAN SEA LEVEL PRESSURE	4	DECEMBER	5	.55

Value of the correlation coefficient, r, among the parameters.

Horizontal => abscissa, Vertical => ordinate.

Parameter : # of months : ending in : An, n= :	SLP 2 JANUARY 1	H700MB 5 DECEMBER 5	H700MB 2 OCTOBER 3	D700MB 2 DECEMBER 4	SLP 4 DECEMBER 5
SLP 2 JANUARY 1	1.00	.19	.08	.27	-.13
H700MB 5 DECEMBER 5	.19	1.00	.61	.37	-.76
H700MB 2 OCTOBER 3	.08	.61	1.00	.37	-.60
D700MB 2 DECEMBER 4	.27	.37	.37	1.00	-.26
SLP 4 DECEMBER 5	-.13	-.76	-.60	-.26	1.00

Table I.10(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	a(n)	r
700 MB HEIGHTS	5	DECEMBER	5	-.58
700 MB HEIGHTS	2	OCTOBER	3	-.57
700 - 1000 MB THICKNESS	2	DECEMBER	4	-.54
MEAN SEA LEVEL PRESSURE	4	DECEMBER	5	.55
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49

Correlation Coefficient (Observed vs Predicted): .81

	YEAR	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
	1966	0.	84.	84.	.20	1.	10.	9.
	1958	1.	165.	164.	.40	2.	11.	9.
	1952	15.	337.	322.	.78	3.	19.	16.
	1977	22.	0.	-22.	-.05	4.	3.	-1.
	1980	23.	18.	-5.	-.01	5.	6.	1.
	1963	25.	255.	230.	.56	6.	17.	11.
	1953	56.	224.	168.	.41	7.	15.	8.
	1969	57.	0.	-57.	-.14	8.	1.	-7.
	1955	61.	0.	-61.	-.15	9.	4.	-5.
	1971	73.	169.	96.	.23	10.	13.	3.
	1978	75.	0.	-75.	-.18	11.	5.	-6.
	1965	76.	566.	490.	1.19	12.	24.	12.
	1956	80.	306.	226.	.55	13.	18.	5.
	1970	85.	70.	-15.	-.04	14.	8.	-6.
	1975	101.	239.	138.	.33	15.	16.	1.
	1962	112.	0.	-112.	-.27	16.	2.	-14.
	1961	114.	168.	54.	.13	17.	12.	-5.
	1976	151.	551.	400.	.97	18.	23.	5.
	1979	182.	338.	156.	.38	19.	20.	1.
	1968	226.	71.	-155.	-.38	20.	9.	-11.
	1960	258.	28.	-230.	-.56	21.	7.	-14.
	1954	312.	573.	261.	.63	22.	25.	3.
	1964	369.	372.	3.	.01	23.	21.	-2.
	1967	441.	213.	-228.	-.55	24.	14.	-10.
	1959	689.	543.	-146.	-.35	25.	22.	-3.
	1973	850.	718.	-132.	-.32	26.	26.	0.
	1957	931.	805.	-126.	-.30	27.	27.	0.
	1974	1386.	1135.	-251.	-.61	28.	29.	1.
	1972	1584.	992.	-592.	-1.43	29.	28.	-1.
MEAN		288.	288.					
STD. DEV.		413.	336.					
MEAN OF ABSOLUTE VALUES				172.	.42			5.9
STD. DEV. OF ABSOLUTE VALUES				141.	.34			4.7

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	16
1	12
2	1

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	7
1	12
2	6
3	4
4	0
5	0
6	0

Table I.11(a)

CROSS-CORRELATIONS AMONG PARAMETERS — TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	A(N)	r
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49
700 MB HEIGHTS	2	OCTOBER	3	-.57
MEAN SEA LEVEL PRESSURE	4	MARCH	1	-.49
700 - 1000 MB THICKNESS	2	FEBRUARY	1	.63
SURFACE AIR TEMPERATURE	4	MARCH	1	-.67

Value of the correlation coefficient, r, among the parameters.

Horizontal => abscissa, Vertical => ordinate.

Parameter : # of months : ending in : An, n= :	SLP 2 JANUARY 1	H700MB 2 OCTOBER 3	SLP 4 MARCH 1	D700MB 2 FEBRUARY 1	SAT 4 MARCH 1
SLP 2 JANUARY 1	1.00	.08	.64	-.61	.69
H700MB 2 OCTOBER 3	.08	1.00	.47	-.51	.48
SLP 4 MARCH 1	.64	.47	1.00	-.66	.73
D700MB 2 FEBRUARY 1	-.61	-.51	-.66	1.00	-.85
SAT 4 MARCH 1	.69	.48	.73	-.85	1.00

Table I.11(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	a(n)	r
700 MB HEIGHTS	2	OCTOBER	3	-.57
MEAN SEA LEVEL PRESSURE	4	MARCH	1	-.49
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49
700 - 1000 MB THICKNESS	2	FEBRUARY	1	.63
SURFACE AIR TEMPERATURE	4	MARCH	1	-.67

Correlation Coefficient (Observed vs Predicted): .76

	YEAR	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
	1966	0.	65.	65.	.16	1.	9.	8.
	1958	1.	0.	-1.	-.00	2.	3.	1.
	1952	15.	280.	265.	.64	3.	16.	13.
	1977	22.	33.	11.	.03	4.	6.	2.
	1980	23.	0.	-23.	-.06	5.	1.	-4.
	1963	25.	217.	192.	.47	6.	14.	8.
	1953	56.	120.	64.	.16	7.	11.	4.
	1969	57.	0.	-57.	-.14	8.	2.	-6.
	1955	61.	0.	-61.	-.15	9.	5.	-4.
	1971	73.	381.	308.	.75	10.	18.	8.
	1978	75.	242.	167.	.40	11.	15.	4.
	1965	76.	386.	310.	.75	12.	19.	7.
	1956	80.	112.	32.	.08	13.	10.	-3.
	1970	85.	63.	-22.	-.05	14.	8.	-6.
	1975	101.	478.	377.	.91	15.	23.	8.
	1962	112.	0.	-112.	-.27	16.	4.	-12.
	1961	114.	518.	404.	.98	17.	25.	8.
	1976	151.	510.	359.	.87	18.	24.	6.
	1979	182.	401.	219.	.53	19.	20.	1.
	1968	226.	129.	-97.	-.23	20.	12.	-8.
	1960	258.	45.	-213.	-.52	21.	7.	-14.
	1954	312.	465.	153.	.37	22.	22.	0.
	1964	369.	182.	-187.	-.45	23.	13.	-10.
	1967	441.	428.	-13.	-.03	24.	21.	-3.
	1959	689.	301.	-388.	-.94	25.	17.	-8.
	1973	850.	950.	100.	.24	26.	28.	2.
	1957	931.	784.	-147.	-.36	27.	26.	-1.
	1974	1386.	799.	-587.	-1.42	28.	27.	-1.
	1972	1584.	975.	-609.	-1.48	29.	29.	0.
MEAN		288.	288.					
STD. DEV.		413.	315.					
MEAN OF ABSOLUTE VALUES				191.	.46			5.5
STD. DEV. OF ABSOLUTE VALUES				168.	.41			3.9

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	16
1	12
2	1

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	6
1	11
2	9
3	3
4	0
5	0
6	0

Table I.12(a)

CROSS-CORRELATIONS AMONG PARAMETERS — TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	A(N)	r
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49
700 MB HEIGHTS	2	OCTOBER	3	-.57
700 - 1000 MB THICKNESS	2	DECEMBER	4	-.54

Value of the correlation coefficient, r, among the parameters.

Horizontal => abscissa, Vertical => ordinate.

Parameter :	SLP	H700MB	D700MB
# of months :	2	2	2
ending in :	JANUARY	OCTOBER	DECEMBER
An, n= :	1	3	4
SLP 2 JANUARY 1	1.00	.08	.27
H700MB 2 OCTOBER 3	.08	1.00	.37
D700MB 2 DECEMBER 4	.27	.37	1.00

Table I.12(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	a(n)	r
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49
700 MB HEIGHTS	2	OCTOBER	3	-.57
700 - 1000 MB THICKNESS	2	DECEMBER	4	-.54

Correlation Coefficient (Observed vs Predicted): .78

	YEAR	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
	1966	0.	95.	95.	.23	1.	9.	8.
	1958	1.	94.	93.	.23	2.	8.	6.
	1952	15.	358.	343.	.83	3.	20.	17.
	1977	22.	0.	-22.	-.05	4.	4.	0.
	1980	23.	0.	-23.	-.06	5.	3.	-2.
	1963	25.	273.	248.	.60	6.	14.	8.
	1953	56.	328.	272.	.66	7.	19.	12.
	1969	57.	0.	-57.	-.14	8.	1.	-7.
	1955	61.	0.	-61.	-.15	9.	5.	-4.
	1971	73.	284.	211.	.51	10.	16.	6.
	1978	75.	47.	-28.	-.07	11.	6.	-5.
	1965	76.	511.	435.	1.05	12.	24.	12.
	1956	80.	204.	124.	.30	13.	12.	-1.
	1970	85.	198.	113.	.27	14.	10.	-4.
	1975	101.	306.	205.	.50	15.	17.	2.
	1962	112.	0.	-112.	-.27	16.	2.	-14.
	1961	114.	315.	201.	.49	17.	18.	1.
	1976	151.	616.	465.	1.13	18.	25.	7.
	1979	182.	211.	29.	.07	19.	13.	-6.
	1968	226.	199.	-27.	-.06	20.	11.	-9.
	1960	258.	54.	-204.	-.49	21.	7.	-14.
	1954	312.	446.	134.	.33	22.	22.	0.
	1964	369.	283.	-86.	-.21	23.	15.	-8.
	1967	441.	457.	16.	.04	24.	23.	-1.
	1959	689.	391.	-298.	-.72	25.	21.	-4.
	1973	850.	782.	-68.	-.16	26.	27.	1.
	1957	931.	730.	-201.	-.49	27.	26.	-1.
	1974	1386.	1084.	-302.	-.73	28.	29.	1.
	1972	1584.	873.	-711.	-1.72	29.	28.	-1.
MEAN		288.	288.					
STD. DEV.		413.	320.					
MEAN OF ABSOLUTE VALUES				179.	.43			5.6
STD. DEV. OF ABSOLUTE VALUES				161.	.39			4.7

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	18
1	10
2	1

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	4
1	16
2	6
3	3
4	0
5	0
6	0

Table I.12(c)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX CLASS VS PREDICTED ICEBERG FLUX CLASS

TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	a(n)	r
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49
700 MB HEIGHTS	2	OCTOBER	3	-.57
700 - 1000 MB THICKNESS	2	DECEMBER	4	-.54

Correlation Coefficient (Observed vs Predicted): .74

YEAR	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS CLASS	PRED CLASS	DELTA CLASS
1952	1.	3.	2.	N/A	1.	3.	2.
1958	1.	2.	1.	N/A	1.	2.	1.
1963	1.	3.	2.	N/A	1.	3.	2.
1966	1.	2.	1.	N/A	1.	2.	1.
1977	1.	2.	1.	N/A	1.	2.	1.
1980	1.	1.	0.	N/A	1.	1.	0.
1953	2.	3.	1.	N/A	2.	3.	1.
1955	2.	1.	-1.	N/A	2.	1.	-1.
1956	2.	3.	1.	N/A	2.	3.	1.
1965	2.	4.	2.	N/A	2.	4.	2.
1969	2.	1.	-1.	N/A	2.	1.	-1.
1970	2.	2.	0.	N/A	2.	2.	0.
1971	2.	3.	1.	N/A	2.	3.	1.
1978	2.	2.	0.	N/A	2.	2.	0.
1961	3.	3.	0.	N/A	3.	3.	0.
1962	3.	1.	-2.	N/A	3.	1.	-2.
1975	3.	3.	0.	N/A	3.	3.	0.
1976	3.	4.	1.	N/A	3.	4.	1.
1979	3.	3.	-0.	N/A	3.	3.	-0.
1954	4.	4.	0.	N/A	4.	4.	0.
1960	4.	2.	-2.	N/A	4.	2.	-2.
1964	4.	3.	-1.	N/A	4.	3.	-1.
1968	4.	2.	-2.	N/A	4.	2.	-2.
1959	5.	3.	-2.	N/A	5.	3.	-2.
1967	5.	4.	-1.	N/A	5.	4.	-1.
1957	6.	5.	-1.	N/A	6.	5.	-1.
1973	6.	6.	-0.	N/A	6.	6.	-0.
1972	7.	5.	-2.	N/A	7.	5.	-2.
1974	7.	6.	-1.	N/A	7.	6.	-1.
MEAN	N/A	N/A					
STD. DEV.	N/A	N/A					
MEAN OF ABSOLUTE VALUES			1.	N/A			1.0
STD. DEV. OF ABSOLUTE VALUES			1.	N/A			.6

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	8
1	13
2	8
3	0
4	0
5	0
6	0

Table I.13(a)

CROSS-CORRELATIONS AMONG PARAMETERS TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	A(N)	r
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49
700 MB HEIGHTS	2	OCTOBER	3	-.57

Value of the correlation coefficient, r, among the parameters.

Horizontal => abscissa, Vertical => ordinate.

Parameter :	SLP	H700MB
# of months :	2	2
ending in :	JANUARY	OCTOBER
An, n= :	1	3
SLP 2 JANUARY 1	1.00	.08
H700MB 2 OCTOBER 3	.08	1.00

Table I.13(b)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	a(n)	r
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49
700 MB HEIGHTS	2	OCTOBER	3	-.57

Correlation Coefficient (Observed vs Predicted): .73

YEAR	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS RANK	PRED RANK	DELTA RANK
1966	0.	0.	0.	0.00	1.	5.	4.
1958	1.	78.	77.	.19	2.	8.	6.
1952	15.	184.	169.	.41	3.	12.	9.
1977	22.	23.	1.	.00	4.	7.	3.
1980	23.	0.	-23.	-.06	5.	3.	-2.
1963	25.	264.	239.	.58	6.	15.	9.
1953	56.	380.	324.	.79	7.	20.	13.
1969	57.	0.	-57.	-.14	8.	1.	-7.
1955	61.	0.	-61.	-.15	9.	4.	-5.
1971	73.	310.	237.	.58	10.	16.	6.
1978	75.	201.	126.	.31	11.	13.	2.
1965	76.	438.	362.	.88	12.	23.	11.
1956	80.	210.	130.	.31	13.	14.	1.
1970	85.	83.	-2.	-.01	14.	9.	-5.
1975	101.	365.	264.	.64	15.	19.	4.
1962	112.	0.	-112.	-.27	16.	2.	-14.
1961	114.	412.	298.	.72	17.	22.	5.
1976	151.	564.	413.	1.00	18.	24.	6.
1979	182.	333.	151.	.37	19.	18.	-1.
1968	226.	95.	-131.	-.32	20.	10.	-10.
1960	258.	12.	-246.	-.60	21.	6.	-15.
1954	312.	571.	259.	.63	22.	25.	3.
1964	369.	170.	-199.	-.48	23.	11.	-12.
1967	441.	406.	-35.	-.08	24.	21.	-3.
1959	689.	311.	-378.	-.92	25.	17.	-8.
1973	850.	994.	144.	.35	26.	29.	3.
1957	931.	803.	-128.	-.31	27.	27.	0.
1974	1386.	821.	-565.	-1.37	28.	28.	0.
1972	1584.	768.	-816.	-1.98	29.	26.	-3.
MEAN	288.	288.					
STD. DEV.	413.	300.					
MEAN OF ABSOLUTE VALUES			205.	.50			5.9
STD. DEV. OF ABSOLUTE VALUES			181.	.44			4.2

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	16
1	12
2	1

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	7
1	9
2	10
3	3
4	0
5	0
6	0

Table I.13(c)

DEPENDENT COMPARISON OF OBSERVED ICEBERG FLUX CLASS VS PREDICTED ICEBERG FLUX CLASS

TIME AVERAGED APPROACH

PARAMETER	NUMBER OF MONTHS	ENDING IN	a(n)	r
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	-.49
700 MB HEIGHTS	2	OCTOBER	3	-.57

Correlation Coefficient (Observed vs Predicted): .73

YEAR	OBSERVED	PREDICTED	(P-O)	(P-O / SD)	OBS CLASS	PRED CLASS	DELTA CLASS
1952	1.	3.	2.	N/A	1.	3.	2.
1958	1.	2.	1.	N/A	1.	2.	1.
1963	1.	3.	2.	N/A	1.	3.	2.
1966	1.	2.	1.	N/A	1.	2.	1.
1977	1.	2.	1.	N/A	1.	2.	1.
1980	1.	1.	0.	N/A	1.	1.	0.
1953	2.	3.	1.	N/A	2.	3.	1.
1955	2.	1.	-1.	N/A	2.	1.	-1.
1956	2.	3.	1.	N/A	2.	3.	1.
1965	2.	4.	2.	N/A	2.	4.	2.
1969	2.	1.	-1.	N/A	2.	1.	-1.
1970	2.	2.	0.	N/A	2.	2.	0.
1971	2.	3.	1.	N/A	2.	3.	1.
1978	2.	3.	1.	N/A	2.	3.	1.
1961	3.	4.	1.	N/A	3.	4.	1.
1962	3.	1.	-2.	N/A	3.	1.	-2.
1975	3.	3.	0.	N/A	3.	3.	0.
1976	3.	4.	1.	N/A	3.	4.	1.
1979	3.	3.	0.	N/A	3.	3.	0.
1954	4.	4.	0.	N/A	4.	4.	0.
1960	4.	2.	-2.	N/A	4.	2.	-2.
1964	4.	3.	-1.	N/A	4.	3.	-1.
1968	4.	2.	-2.	N/A	4.	2.	-2.
1959	5.	3.	-2.	N/A	5.	3.	-2.
1967	5.	4.	-1.	N/A	5.	4.	-1.
1957	6.	5.	-1.	N/A	6.	5.	-1.
1973	6.	6.	0.	N/A	6.	6.	0.
1972	7.	5.	-2.	N/A	7.	5.	-2.
1974	7.	5.	-2.	N/A	7.	5.	-2.
MEAN	N/A	N/A					
STD. DEV.	N/A	N/A					
MEAN OF ABSOLUTE VALUES			1.	N/A			1.1
STD. DEV. OF ABSOLUTE VALUES			1.	N/A			.6

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	6
1	14
2	9
3	0
4	0
5	0
6	0

Table I.14

COMPARISON OF OBSERVED ICEBERG FLUX VS PREDICTED ICEBERG FLUX

INDEPENDENT TEST (ONE-YEAR-OUT)

PARAMETER	NUMBER OF MONTHS	ENDING IN	A(n)	TIME AVERAGED APPROACH
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	
700 MB HEIGHTS	2	OCTOBER	3	
700 - 1000 MB THICKNESS	2	DECEMBER	4	

YEAR	r	A(n)	OBSERVED	PREDICTED	(P-O)	(P-O/SD)	OBS RANK	PRED RANK	DELTA RANK
1966	.63	N/A	0	134	134	.32	1	8	7
1958	.63	N/A	1	147	146	.35	2	10	8
1952	.63	N/A	15	453	438	1.06	3	23	20
1977	.63	N/A	22	0	-22	-.05	4	3	-1
1980	.63	N/A	23	17	-6	-.01	5	5	0
1963	.63	N/A	25	292	267	.65	6	17	11
1953	.63	N/A	56	325	269	.65	7	18	11
1969	.63	N/A	57	0	-57	-.14	8	1	-7
1955	.63	N/A	61	0	-61	-.15	9	4	-5
1971	.63	N/A	73	282	209	.51	10	16	6
1978	.63	N/A	75	61	-14	-.03	11	6	-5
1965	.63	N/A	76	527	451	1.09	12	24	12
1956	.63	N/A	80	207	127	.31	13	11	-2
1970	.63	N/A	85	280	195	.47	14	15	1
1975	.63	N/A	101	327	226	.55	15	20	5
1962	.63	N/A	112	0	-112	-.27	16	2	-14
1961	.63	N/A	114	327	213	.52	17	19	2
1976	.63	N/A	151	649	498	1.21	18	26	8
1979	.63	N/A	182	143	-39	-.10	19	9	-10
1968	.63	N/A	226	231	5	.01	20	12	-8
1960	.63	N/A	258	85	-173	-.42	21	7	-14
1954	.63	N/A	312	448	136	.33	22	22	0
1964	.63	N/A	369	262	-107	-.26	23	14	-9
1967	.63	N/A	441	430	-11	-.03	24	21	-3
1959	.63	N/A	689	249	-440	-1.07	25	13	-12
1973	.63	N/A	850	611	-239	-.58	26	25	-1
1957	.63	N/A	931	666	-265	-.64	27	27	0
1974	.63	N/A	1386	735	-651	-1.58	28	29	1
1972	.63	N/A	1584	699	-885	-2.15	29	28	-1
MEAN			288	272					
STD DEV			413	271					
MEAN OF ABSOLUTE VALUES					220	.53			6.3
STD DEV OF ABSOLUTE VALUES					209	.51			5.2

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	17
1	10
2	2

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	7
1	8
2	11
3	2
4	1
5	0
6	0
3	2
4	2
5	0
6	0

Table I..15

COMPARISON OF OBSERVED ICEBERG FLUX
VS PREDICTED ICEBERG FLUX

INDEPENDENT TEST
(ONE-YEAR-OUT)

PARAMETER	NUMBER OF MONTHS	ENDING IN	A(n)	TIME AVERAGED APPROACH
MEAN SEA LEVEL PRESSURE	2	JANUARY	1	
700 MB HEIGHTS	2	OCTOBER	3	

YEAR	r	A(n)	OBSERVED	PREDICTED	(P-O)	(P-O/SD)	OBS RANK	PRED RANK	DELTA RANK
1966	.61	N/A	0	0	0	0.00	1	2	1
1958	.61	N/A	1	139	139	.33	2	10	8
1952	.61	N/A	15	199	184	.45	3	13	10
1977	.61	N/A	22	28	6	.01	4	4	0
1980	.61	N/A	23	30	7	.02	5	5	0
1963	.61	N/A	25	283	258	.63	6	16	10
1953	.61	N/A	56	393	337	.82	7	21	14
1969	.61	N/A	57	0	-57	-.14	8	1	-7
1955	.61	N/A	61	0	-61	-.15	9	3	-6
1971	.61	N/A	73	305	232	.56	10	18	8
1978	.61	N/A	75	217	142	.35	11	15	4
1965	.61	N/A	76	447	371	.90	12	23	11
1956	.61	N/A	80	209	129	.31	13	14	1
1970	.61	N/A	85	130	45	.11	14	9	-5
1975	.61	N/A	101	374	273	.66	15	19	4
1962	.61	N/A	112	83	-29	-.07	16	7	-9
1961	.61	N/A	114	419	305	.74	17	22	5
1976	.61	N/A	151	574	423	1.03	18	24	6
1979	.61	N/A	182	299	117	.28	19	17	-2
1968	.61	N/A	226	127	-99	-.24	20	8	-12
1960	.61	N/A	258	52	-206	-.50	21	6	-15
1954	.61	N/A	312	596	284	.69	22	26	4
1964	.61	N/A	369	143	-226	-.55	23	12	-11
1967	.61	N/A	441	384	-57	-.14	24	20	-4
1959	.61	N/A	689	141	-548	-1.33	25	11	-14
1973	.61	N/A	850	923	73	.18	26	29	3
1957	.61	N/A	931	748	-183	-.44	27	28	1
1974	.61	N/A	1386	638	-748	-1.81	28	27	-1
1972	.61	N/A	1584	595	-989	-2.40	29	25	-4
MEAN			288	285					
STD DEV			413	258					
MEAN OF ABSOLUTE VALUES					225	.55			6.2
STD DEV OF ABSOLUTE VALUES					226	.55			4.5

CATEGORY ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CATEGORIES	COUNT
0	15
1	12
2	2

CLASS ERRORS: DISCREPANCY BETWEEN OBSERVED AND PREDICTED CLASSIFICATION	COUNT
0	4
1	11
2	12
3	2
4	0
5	0
6	0