The Role of the Gulf Stream in the Prediction of Iceberg Distribution in the North Atlantic[1]

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(Manuscript received February 1, 1955)

Abstract

A twenty-six year correlation is made between the yearly frequency fluctuations of icebergs south of the 48th parallel and the preseasonal sea surface temperature anomalies at Key West in the Straits of Florida and those of the Labrador Current three years later.

Good agreement among these variables is attributed to (1) the immediate effect of the relative strength of the Gulf Stream in barring the southward flow of bergs, and (2) the effect that varying strength of the Gulf Stream has upon the volume of warm water that escapes to the north, the effect in turn upon the rate of transport of icebergs, and the potential number eventually to be carried into the shipping lanes.

An iceberg prediction table is offered, making possible a prediction for the current year by using the sea temperature anomaly at Key West for March of this year together with the anomaly of three years earlier.

"The opinions and assertions contained herein are the private ones of the author and do not reflect the views of the Navy Department or the Naval Establishment."

The drift of icebergs from their birthplace, the glaciers of Greenland, southward and into the heavily-traveled shipping lanes of the North Atlantic Ocean is a menace to the safety of navigation, long recognized and feared. Only since the "Titanic" sinking in 1912 after collision with an iceberg has any system been in operation for guarding against this danger. The International Ice Patrol was established to warn passing vessels of the limits of danger from day to day throughout each iceberg season. Prescribed steamer tracks were laid out and their use recommended during different parts of each season depending upon the numbers of icebergs and their southward extent. To facilitate a comparison of the seasonal and yearly abundance of bergs in the most critical area, the number of bergs drifting south of latitude 48° N has been compiled to obtain monthly and yearly averages.

The numbers of bergs found south of this latitude have varied markedly, from as few as 0 to 50 per year up to a maximum of 1,351 in 1929. Although the average is a little over 400 for the season, the majority of years have totaled either far above of far below this value. Investigators have concluded that such a phenomenal variation could result from fluctuations in several controlling factors: wind, currents, pack ice, winter temperature, and the production rate of the icebergs themselves, or their rate of calving from the glaciers.

[1] Predictions made for the last three iceberg seasons have been verified:

See — Newsweek Magazine, July 13, 1953,
Science Newsletter, May 1, 1954,
Science Newsletter, April 30, 1955.

However, like all new theory worth serious consideration, many years may be required before complete verification.

It was apparent that if the proper balance between the causative variates and the iceberg distribution could be measured, a means for forecasting the severity of each season well in advance might be obtained.

A great amount of research and many papers have resulted from efforts to determine this balance. The work of Smith and of Soule in this direction is well known. SMITH (1928) developed a formula for iceberg prediction based on the atmospheric pressure distribution over Greenland. He has attributed discrepancies between calculated numbers of bergs and the extreme recorded values to abnormalities, such as "ice jams, variations in precipitation, winter storms, summer calms etc." A similar approach is taken by SCHELL (1952); yet, since it is the extreme rather than the average in iceberg distribution which occurs most frequently, reliable forecasting techniques must prove their ability to correlate well with the extreme as well as with average conditions. Because no one cause has been shown to account for the differences in berg distribution for past and predicted years, the opinion is prevalent that no one cause is predominant.

The writer differs with this opinion and suggests that the reason no better correlations have been found to exist is perhaps a tendency to magnify the complexity of related but secondary causes instead of locating a single cause which alone may be capable of producing at least the greater part of the fluctuation in iceberg distribution. It is the purpose of this paper to provide evidence that fluctuation in the Gulf Stream System is such a single cause and to derive a prediction technique for icebergs south of latitude 48°N from causative variates in this system.

Introduction

Present-day methods for the prediction of the yearly distribution of icebergs in the North Atlantic Ocean from atmospheric variables have proven neither conclusive in theory nor infallible in practice. The present study was begun in the belief that in the deeper, less transitory influence of ocean currents may be found a more reliable means for forecasting iceberg distribution, that is, one that is able singly to effect the extreme periodic fluctuation in this phenomenon.

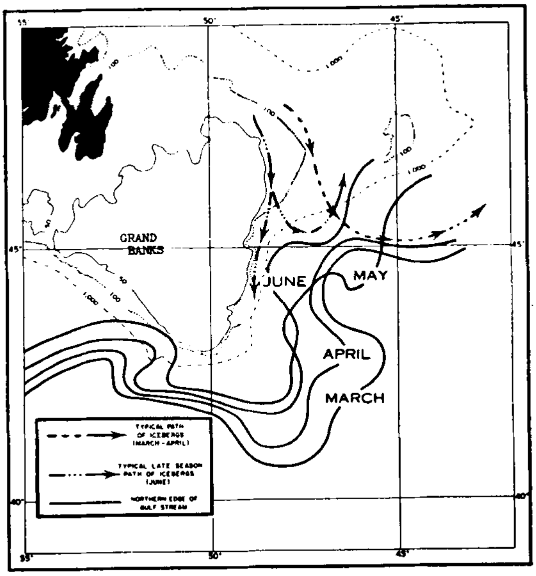

Fig. 1. Shift of the Northern Edge of the Gulf Stream during the iceberg season. Typical monthly limits as derived from Surface Dynamic Current Charts of the International Ice Patrol, from Ice Patrol Bulletins (1932—1950). Northern Edge of Gulf Stream is the typical position of the minimum dynamic anomaly line within the high-speed core in this region. Depths are given in fathoms.

It is further a purpose of this study to demonstrate, and apply to a prediction technique, the relation existing between the ocean's pulse in the Florida Straits where it may be felt most clearly, and its influence, delayed but preserved intact during months and even years until the same pulse will swell in certain measure its spreading arteries and veins.

Because of information made available by the International Ice Patrol in the vicinity of the Grand Banks, and because this region is one in which the conjoining Gulf Stream and Labrador Current display distinguishable characteristics of relative heat and transport, it is a natural location in which to test empirically the above hypothesis and to develop therefrom a method for forecasting the severity of the iceberg season.

Figure 1 illustrates the seasonal shift of the northern edge of the Gulf Stream with change in its "relative" velocity off the Grand Banks. The expression "relative" is used because it is not certain to what extent the Gulf Stream and the Labrador Current are effective in controlling this shift. However, the northward displacement between March and June closely conforms to increasing velocity of the Gulf Stream from monthly drift observations (U. S. NAVY HYDROGRAPHIC OFFICE, 1944). Arrows indicate the typical paths icebergs follow during different parts of the season. It is apparent that increasing "relative" strength of the Gulf Stream acts to reduce the southward progression of bergs, and Ice Patrol records frequently show that when the westward salient in June towards the Banks is well developed or occurs earlier in the season, the supply of bergs is effectively cut off.

Now it would appear that if an entire season or critical month should show this "relative" strength of the Gulf Stream to be above average, a light iceberg season might result; but if it should be below the average, more bergs might be permitted to advance to a more southerly latitude.

The writer selected Key West in the Straits of Florida as a point most suitable from its location and availability of data for the establishment of an empirical correlation between the yearly iceberg concentration south of latitude 48° N and contemporary changes in the strength of the Gulf Stream.

Here, the major portion of the current is closely confined by banks of earth so that its fluctuation in velocity should provide a truly reliable measure of fluctuation in mass transport. Further, the Gulf Stream in this region is far enough "upstream" from the Grand Banks to allow sufficient leeway in preparing forecast information, yet is an integral part, not only of the North Atlantic Eddy, but also of the entire "feedback" circulation systems of the Arctic and of Baffin Bay. It is likely, further, that in this region the Gulf Stream will reflect in definite proportion to their ultimate effects fluctuations of far-reaching influence occurring from causes elsewhere in the system.

Figure 2 displays the general area of the study and the cycle of events which forms the basis for the correlation. The results of this study indicate: (1) An increase in transport of the Gulf Stream measured at (A) produces changes of like sign at (B) in the critical region of iceberg advance. (2) The immediate effect at (B) is a strengthened current and increased

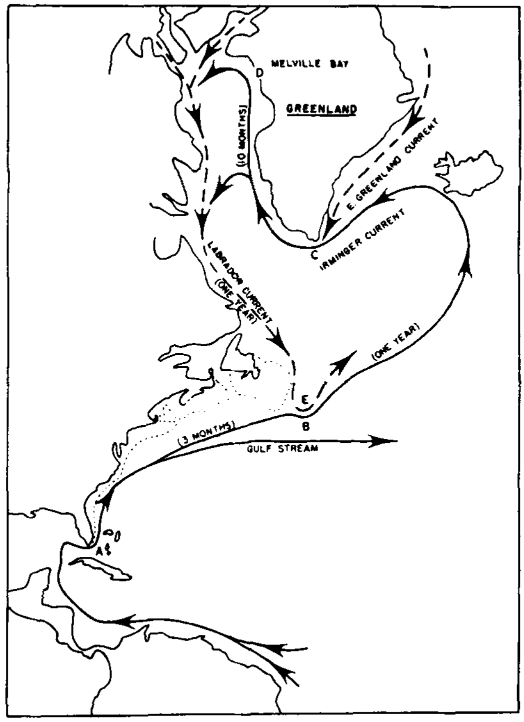

Fig. 2. Area of Study. Arrows with heavy solid line indicate warming current. Arrows with dashed line indicate cooling current. Transport times are estimates based on SCHOTT, 1942, United States Coastguard and U. S. Navy Hydrographic Office, 1944.

resistance to the invasion of icebergs into the shipping lanes to the south, favoring a lighter iceberg count (SOULE, 1949). (3) An increase in volume of the current at (B) after some time increases the volume of warm Irminger Current water meeting the cold East Greenland Current off Kap Farvel at (C). Later an increased volume of warmer than average water reaches (D) in the region of berg formation, favoring reduction in ice cover, greater solar heating of the surface water and of the overlying atmosphere, and calving from the glaciers of a larger than usual number of bergs. (4) The influx of a greater volume of warm water into Baffin Bay must result in a correspondingly greater efflux on the Labrador side, accompanied by a withdrawal from the Bay of greater amounts of icebergs and sea ice stripped away by the current.

While evidence has accumulated (SMITH, 1940) that currents influence both the production and transport of pack ice and icebergs, in the present study the emphasis is placed

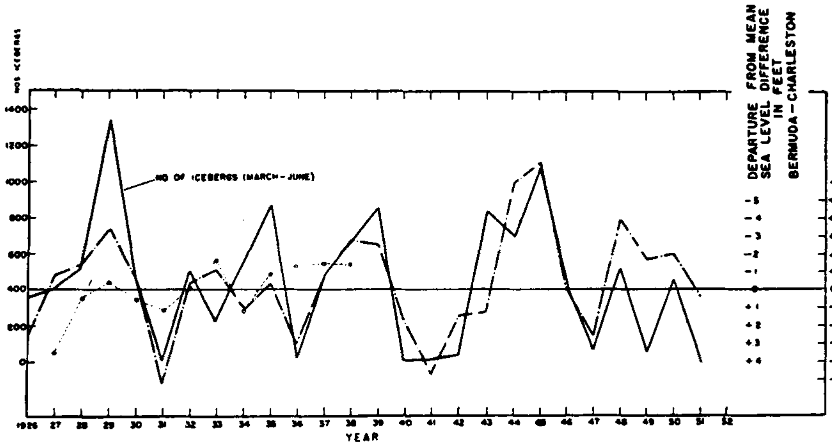

Fig. 3. Number of icebergs south of 48th parallel versus sea temperature anomalies off Key West (1926—1952). Solid line indicates number of icebergs. Broken line indicates mean sea temperature anomalies (March). Anomalies (1941—1946) are from Daytona Beach, Fla. because of absence of data at Key West during these years. Light dotted line indicates the departure from mean sea level difference in feet, Bermuda minus Charleston, SOULE (1940). Sea surface temperature data are from U. S. Coast & Geodetic Survey Pub. TW-I.

on the effect of changes in the transport of currents in the same area in which the berg count is made upon the local distribution of icebergs.

The study of the effect of the Gulf Stream upon iceberg distribution is divided below into two parts: the immediate effect, or the effect of the Gulf Stream in inhibiting the southward drift of bergs in the Grand Banks area; and the delayed effect of changes in the strength of the Gulf Stream through its extension into Baffin Bay upon the eventual strength of the Labrador Current and upon the numbers of icebergs it is able to carry southward.

The Immediate Effect

Figure 3 presents a twenty-six year correlation between the number of icebergs counted south of parallel 48° N during the iceberg season (March—June) and preseasonal sea surface temperature anomalies at Key West in the Straits of Florida. The temperature data are those of the U.S. Coast and Geodetic Survey's monthly averages of daily observations at tidal gauge stations. An anomaly of mean monthly temperature, based on the concepts given below, should therefore reflect proportional change in the strength of the current and provide an extensive record of this change in the absence of any long-period direct measurements of currents. Since three months is the maximum time lag for current between the Straits of Florida and the Grand Banks, fluctuations occurring in the Straits earlier than January (three months prior to the opening of the iceberg season) may be considered ineffective. Actually the March anomalies agreed the best and these have been used after careful comparison with other months has made possible two conclusions: (1) that the changes reflected in the March anomalies persisted at Key West for three to six months, and (2) that the March anomalies fitted the time lag in such a way as to arrive in the Grand Banks area at the most critical part of the iceberg season. The average percentage of bergs by months, based on 50 years of Ice Patrol data (1900—1950), is:

Jan	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Month
1/2	2	11	24	35	17	5	2	1	1	1	1/2	Percent

The time lag required for fluctuations in the Florida Straits to reach the vicinity of Grand Banks and be effective the same season would thus appear to be between 1 and 3 months.

A plausible interpretation of the correlation in figure 3 is that higher than normal temperatures of the water at Key West will be followed by a weaker than normal Gulf Stream off the Grand Banks in order to permit a greater southward extent of icebergs and vice versa. This does not necessarily mean that high temperatures at Key West accompany a weaker current at that point. Two concepts may be advanced to explain the mechanisms involved in effecting the correlation found in figure 3.

The first is that advanced by ISELIN (1938) and (1940) according to which the edge of the current system contracts with increasing speed and expands with decreasing speed.

Under the circumstances prevailing in the Straits of Florida "only a shallow band of coastal water separates the current from the shore"—and "the main thermocline at the western margin of the Florida Current is free to occupy whatever depth is required by the strength of the current". Thus, a stronger current would tend to permit a lesser amount of warm water to invade the coastal water, whereas a weaker current would reverse this tendency (ISELIN, 1940, figures 26-B and B')..

The other concept assumes that the strength is transmitted directly throughout the current system. This would mean that high temperatures at Key West accompany weaker current, and that this weakness, transmitted to the Grand Banks, is reflected in a larger berg count.

Such indirect current measurements as are available tend to support both these concepts. The dotted line in figure 3, representing the sea level difference, Bermuda-Charleston (1926—1938) shows at least a qualitative inverse relationship between current and temperature.

Thus it may be inferred that positive temperature anomalies in the Straits of Florida indicate a weaker current there and vice versa. The immediate effect of Gulf Stream water of higher speeds and lower temperatures (at Key West) in barring the southward flow of bergs via the Labrador Current is apparent.

The Delayed Effect

The immediate effect described above, pronounced over the period of record, appears to establish the responsiveness of the strength

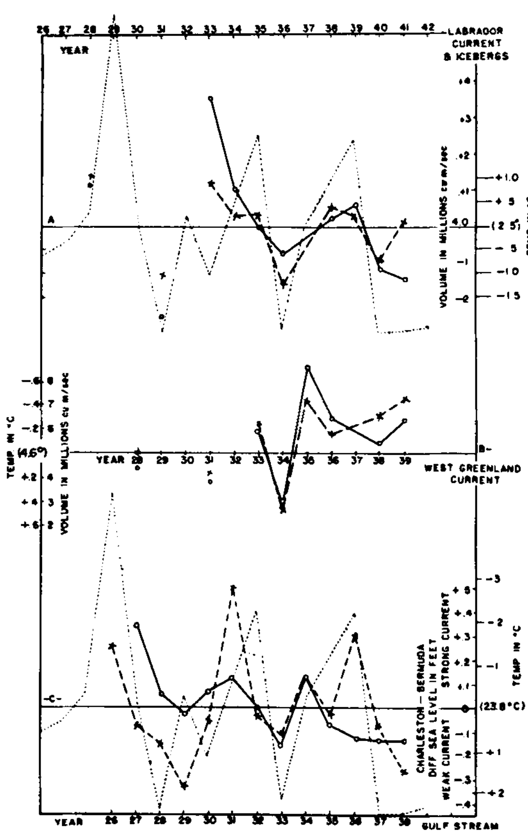

Fig. 4. Time Lag — Labrador Current, West Greenland Current (minus 2 years) and Gulf Stream (minus 3 yars) Solid line: Current Transport. Broken line: Current temperature. Light dashed line: Icebergs. Labrador Current and West Greenland Current are drawn from SOULE and BARNES (1941).

of the Gulf Stream off the Grand Banks to changes one to three months earlier in the Florida Straits. However, as stated previously, this strength is a relative one.

The question remains: can the immediate response, the primary influence of the Gulf Stream upon iceberg distribution, be further traced throughout the branches of the system until ultimately it makes itself felt again as a primary source of variation in the influence of the Labrador Current returning at the Grand Banks to its parent stream?

The estimated time lag of three years between a change in the current in the Straits of Florida and consequent change in the Labrador Current via the Irminger Current and Baffin Bay is only approximate, but it seems likely that changes of several months

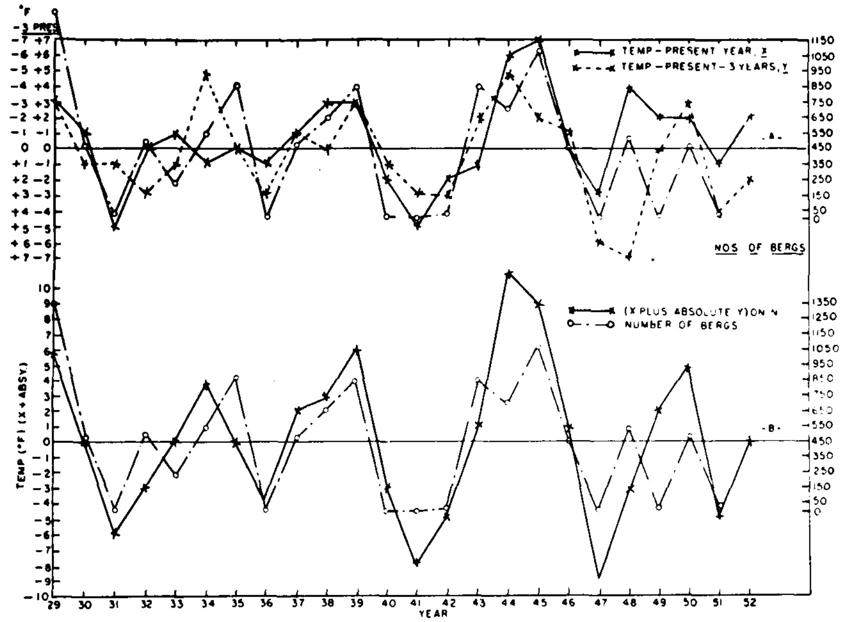

Fig. 5. Correlation—Icebergs south of 48° N versus Gulf Stream Anomalies (°F.) of present year and present year minus 3.

duration in the Florida Straits might be detectable three years later if indeed they continue to be the predominant cause of change in the Labrador Current.

It has been inferred that high temperatures at Key West precede a discharge of weak current to the north and conversely. The effect of a weakened Gulf Stream has been shown in figure 3 to favor a greater number of icebergs; correspondingly, the effect of a weakened Labrador Current would favor a decrease in this number. Therefore, temperatures at Key West must be in inverse relation to the iceberg population approximately three years later if they really reflect Gulf Stream fluctuations which influence the Labrador Current.

Figure 4 supports this hypothesis by demonstrating the agreement between (1) Labrador Current volume and temperature anomalies, measured at South Wolf Island, Labrador, (2) West Greenland Current volume and temperature anomalies at Kap Farvel two years earlier, and (3) Gulf Stream current and Key West temperature anomalies three years earlier, together with the resulting changes in iceberg distribution.

A conclusion previously drawn by SOULE (1940) is that the above "negative correlation between the departure from normal of the mean temperature and volume of flow of the West Greenland Current" implies that these fluctuations "are largely the result of fluctuations in the East Greenland Current rather than the Irminger Current". The fact that figure 4 shows a positive correlation between Labrador Current speed and temperature appears to contradict this conclusion, because only by an increase in the net heat transfer via the Irminger Current could the Labrador Current receive an increase in both volume and temperature. Moreover, it appears extremely unlikely that Gulf Stream fluctuations could have traversed the entire polar basin and reached the vicinity of Kap Farvel in the single year which separates these phenomena.

A more suitable interpretation might be that although an initially stronger and colder Gulf Stream can result in a stronger and colder Irminger Current off Kap Farvel and even in a greater volume of colder than normal West Greenland Current, the total heat transfer into Baffin Bay will be greater thereby, and

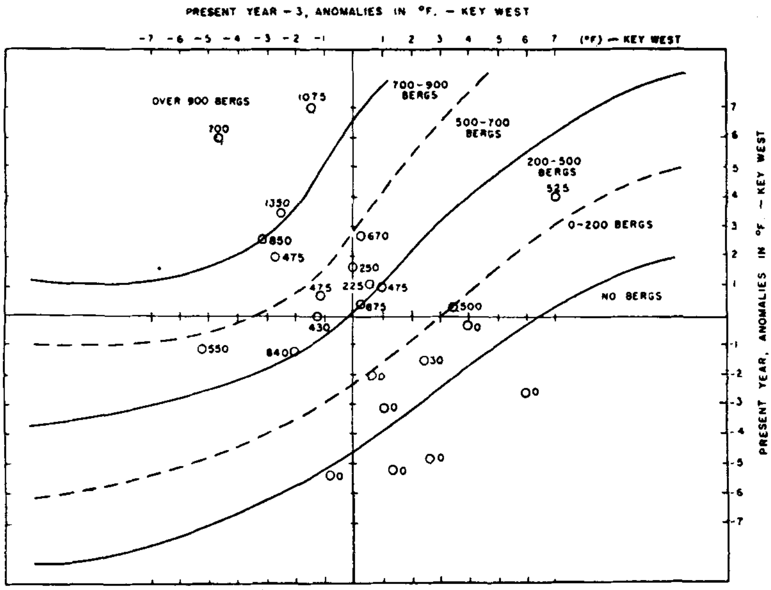

Fig. 6. Relation between number of icebergs south of 48° N and Gulf Stream Temperature anomalies in March of the present year and of three years earlier.

the result will be an increase in both the speed and temperature of the Labrador Current.

The agreement between the observed Labrador Current and that inferred from figure 4-C thus strongly suggests that anomalies of the former reflect, and were induced by, anomalies of the Gulf Stream System and that these are measurable, even three years in advance, in the Straits of Florida. A correlation coefficient of +.72 was obtained between the transport of the Labrador Current and Gulf Stream three years earlier as given in figure 4.

Figure 5 then demonstrates the correlation obtained between iceberg count and Gulf Stream temperature anomalies of the present year and three years earlier. The effect of positive anomalies (weak current) in the present year in influencing larger numbers of bergs in conjunction with negative anomalies (strong current) of three years earlier is apparent in figure 5-A. The summation of the effect of anomalies of the present year and present year minus three upon iceberg distribution is given in figure 5-B. Correlation coefficients listed below show the linear relation between iceberg count and temperature anomalies of the Gulf Stream for the present year alone and in combination with preceding years as indicated.

Correlation Coefficients between iceberg count and Key West temperature anomalies for:

Present Year	Summation of Present Year and Present Year minus:							
	1	2	3	4	5	6	7	8
+.65	+.42	+.55	+.75	+.65	+.46	+.35	+.49	+.54

Present Year	Successive Years without Present Year. Present Year minus:							
	1	2	3	4	5	6	7	8
+.65	+.35	−.51	−.76	−.53	+.43	+.51	−.27	−.37

It is evident that a more reliable correlation than that obtained for the present year alone results only by combining for each year of record the effect upon iceberg distribution of the Gulf Stream anomalies both of the present year and of three years earlier. These values for the years of record are correlated in figure 6, and probable predictable limits in iceberg distribution are indicated. These limits, as drawn, depart slightly from the linear relationship assumed in figure 5 in order to provide for the effect of theoretical extremes in the strength of the Gulf Stream and Labrador Current. Figure 7 correlates the numbers of icebergs observed (1926—1951) with numbers

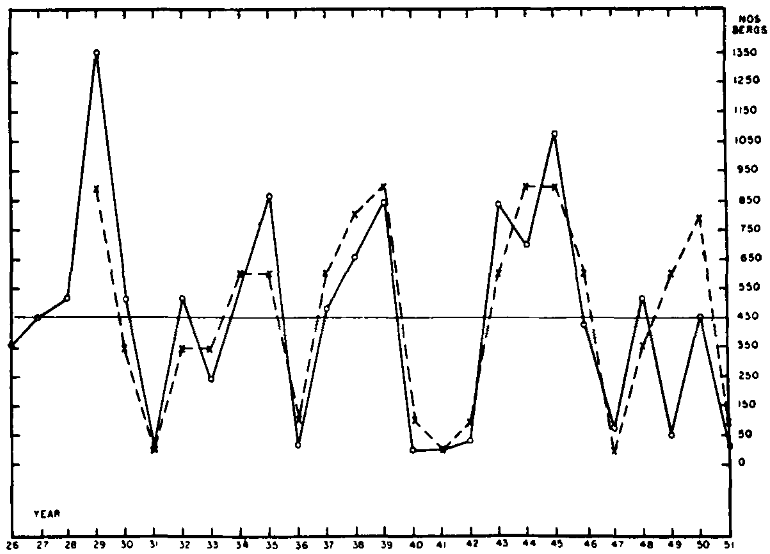

Fig. 7. Comparison between observed (solid) and computed (dashed line) numbers of icebergs appearing south of 48° N, computed from figure 6.

computed from figure 6 by using March temperature anomalies at Key West for the present year and present year minus three. A coefficient of + .94 was obtained between computed and observed numbers grouped as in figure 7 which allows a leeway of ± 100 bergs.

The agreement supports the hypothesis that the Gulf Stream influence is the predominant one. The averages obtained in figure 6 are incorporated into an iceberg prediction table, table I. Monthly temperature means are obtained from "Surface Water Temperatures, Atlantic Coast", U.S.C. & G.S. Pub. No. TW-1. Anomalies during the current year may be obtained directly from the Coast and Geodetic Survey at the end of each month.

Iceberg predictions using table I should be interpreted with caution, despite the satisfactory correlation coefficients. For example, it will be noted that the observed and computed values in figure 7 are in disagreement for the year 1949. The dearth of icebergs that year is attributed (SOULE, 1949) to very abnormal winds that delayed the progress of the bergs until, with the advance of the warm season, they failed to survive the journey to the 48th parallel.

However, the present study has shown that such occurrences have been infrequent over an extended period and that the primary role in controlling the distribution of icebergs south of 48° N is indeed that of the Gulf Stream together with its branches and return-flow tributaries.

Thus, paradoxically, the Gulf Stream plays the role of abettor to the threat of icebergs by its very effort to restrain them. For the greater its volume southward of the Grand Banks, though it impedes the progress of bergs temporarily, the greater must be the volume of water to reach Baffin Bay, and the greater ultimately must be the volume of the Labrador Current three years later.

Summary

1. The drift of icebergs south of latitude 48° N is shown to be controlled seasonally by the relative strengths of the Gulf Stream and the Labrador Current in that vicinity.

2. The Straits of Florida is selected as ideally located for the measurement of anomalies in the strength of the Gulf Stream. Key West temperature anomalies are shown to be related inversely to current speed and to

Table 1. Iceberg prediction table

Number of Icebergs South of 48° N from Temp. (Present Year) and Temp. (Present Year—3) Mean for March

Present Year—Gulf Stream Temperature (°F) Key West Mean

Present Year—3, Gulf Stream Temperature (°F)—Key West Mean

°F	69.8°	70.8°	71.8°	72.8°	73.8°	74.8°	75.8°	76.8°	77.8°	78.8°	79.8°	80.8°
80.8	0	0	0	0	0	100	100	100	350	350	350	600
79.8	0	0	0	0	0	100	100	350	350	350	500	600
78.8	0	0	0	0	100	100	350	350	350	500	600	600
77.8	0	0	0	100	100	200	350	350	450	600	600	600
76.8	0	0	100	100	200	350	350	350	600	600	600	600
75.8	0	100	100	100	350	350	450	600	600	700	800	800
74.8	0	100	100	350	350	450	600	600	700	800	800	800
73.8	100	100	200	350	350	600	600	800	800	800	900	>900
72.8	100	100	350	350	600	600	800	800	800	>900	>900	>900
71.8	100	200	350	500	600	700	800	800	>900	>900	>900	>900
70.8	100	350	350	600	600	800	800	900	>900	>900	>900	>900
69.8	200	350	350	600	600	800	800	>900	>900	>900	>900	>900

For iceberg number = 100 correlation coefficient is +.94 (see figure 7)

be synchronized with current fluctuation at the Grand Banks less than three months later.

3. A curve is drawn relating temperature anomalies at Key West to the iceberg count for a period of twenty-six years. It is found that high temperature and weak current coexist and effect a proportional weakening in the "relative" Gulf Stream strength off Grand Banks together with increase in the southerly drift of icebergs one to three months later.

4. Current fluctuation in the Labrador Current is found to be derived from the Gulf Stream and is shown to be proportional to fluctuations in the West Greenland Current two years earlier and to those of the Gulf Stream at Key West three years earlier.

5. Summation of the temperature anomalies for the present year and three years earlier at Key West results in a closer correlation with iceberg distribution. The numbers of bergs resulting from both anomalies are incorporated in a prediction table.

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