Summer Circulation Patterns, Northern Smith Sound

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ABSTRACT. The Naval Ocean Research and Development Activity conducted an oceanographic research program in northern Smith Sound during middle July 1977 using USCGC WESTWIND (W-AGB 281) as the data collection platform. One aspect of the program was to investigate the water mass interactions at the narrowest portion of Smith Sound which: (1) represents the boundary between this sound and Kane Basin to the north; and (2) is the area of the most well-known semipermanent open water area — the North Water Polynya.

From an analysis of 2 West-East cross sections and a comparison of these data with data collected by the Coast Guard in 1963, it is suggested that the northern Smith Sound area is a meeting area of two different water masses: (1) a warm (>-1.0°C), dense (>26.8σ_T) mass on the eastern side of Smith Sound which enters the area from the south; and (2) a cold (<-1.0°C), low density (<26.7σ_T) mass on the western side of Smith Sound which originates in the Arctic.

It is further suggested that since the warm, dense water mass was also observed in 1963, this feature in eastern Smith Sound may be a permanent or, more likely, a semipermanent (seasonal) phenomenon and could be highly modified Atlantic Water. This latter conclusion is in contrast to the general belief that Atlantic water does not enter Smith Sound.

RÉSUMÉ. La "Naval Ocean Research and Development Activity" a conduit un programme de recherche océanographique dans la partie Nord du détroit de Smith, à la mi-Juillet 1977, avec l'aide de l'U.S.C.G.C. WESTWIND (comme base pour recueillir les données). Une partie du programme était l'etude des réactions internes à la masse d'eau dans la partie la plus étroite, à la limite du bassin de Kane, au Nord, dans la région la mieux connue, à eau libre, 6 mois par an — "the North Water Polynya".

A partir de l'analyse de deux profils transversaux W-E et de la comparaison de ces données avec celles récoltées par "the Coast Guard" en 1963, on suggère que la partie Nord du détroit de Smith se situe à la rencontre de deux masses d'eau différente — une masse d'eau "chaude (> -1°C), dense (> 26.8) dans la partie Est du détroit de Smith, venant du Sud — une masse d'eau "froide" (< -1°C), de faible densité (< 26.7) dans la partie Ouest du détroit de Smith, venant de l'Arctique.

De plus, on suppose d'aprés les observations de la masse d'eau chaude et dense, depuis 1963, qu'elle se situe dans la partie Est du détroit de Smith, en permanence ou plutôt suivant un phénomène semestriel, saisonier, ayant pu modifier largement l'eau Atlantique. Cette dernière conclusion s'oppose à la croyance génèral que l'eau Atlantique ne pénètre pas dans le détroit de Smith.

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I. BACKGROUND OCEANOGRAPHY OF SMITH SOUND

The Smith Sound area has long been of interest to Arctic oceanographers, mainly because of the presence of the most well-known recurring polynya, the so-called North Water Polynya. This ice-free feature was first observed as far back as 1616 by the British pilot and navigator, Baffin. More recently, the many imaging satellite systems have allowed a more leisurely method of

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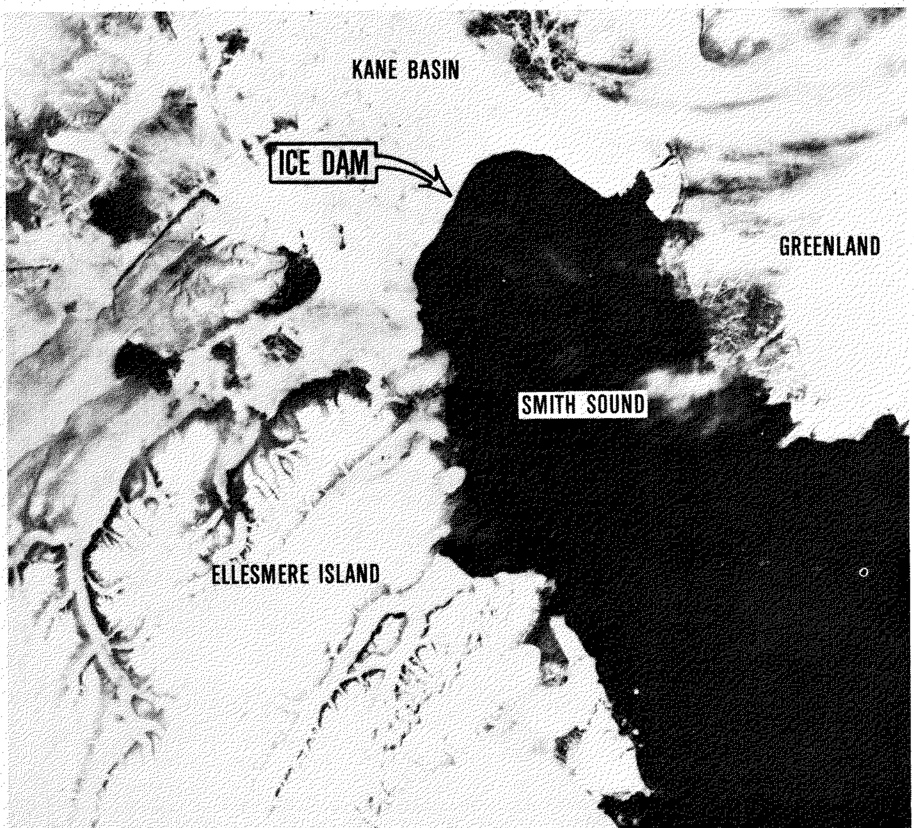

FIG. 1. LANDSAT Image of Smith Sound Area - July 1977

observing this phenomenon and have demonstrated the large yearly variations of its boundaries and yet its remarkable permanence. Figure 1 presents a LANDSAT image of the North Water Polynya/Smith Sound area for 18 July 1977.

Many recent investigations have been conducted in an attempt to determine the mechanisms responsible for the creation and maintenance of this feature; Dunbar (1954), Bailey (1956, 1957), and Collin and Dunbar (1964), just to name a few. However, the most dedicated program designed to study this feature was the international, interdisciplinary research program entitled Baffin Bay-North Water Project sponsored by the Arctic Institute of North America. Several field programs were conducted under this program and several reports were produced; one of which was entitled "The Physical Oceanography of the Northern Baffin Bay Region" (Muench, 1971). In this report, Muench produced a thorough scientific and historical background of the northern Baffin Bay Region. However, despite his use of all available data collected in the north Baffin Bay area, there is still a lack of information on the northern or narrowest part of Smith Sound between Pim Island and Greenland. This area is the region of the northernmost part of the North

Water Polynya and is just south of the ice dam (Fig. 1) a very stable and geographically consistent feature during a majority of the year.

In attempting to determine the mechanisms responsible for the North Water Polynya, studies of the water exchange through Smith Sound have been made by Collin (1965), Muench (1966), and Nutt (1966) among others. These studies were based on dynamic methods, water mass analyses, and studies of glacial ice movements, respectively, rather than on direct water current measurements. Avis and Coachman (1971) reported results from two current meter stations in southern Smith Sound or northern Baffin Bay. They concluded that the harmonic currents observed were of semidiurnal nature. By filtering to remove semidiurnal and diurnal harmonics and other high frequency components, the long term components fluctuated with periods of 3 to 4 days. The only other direct current measurement program to date in Smith Sound was reported by Palfrey and Day (1968). However, because of the extremely short lead time available in preparing for their program, instrumentation failures reduced the data yield considerably. Based on the limited data collected, semidiurnal, tidal circulation was observed which produced a small net transport to the south into Baffin Bay. This conclusion is in almost unanimous agreement with the other investigations cited above, that overall flow is from Kane Basin to Baffin Bay. However, Muench (1971) mentioned that northward pulses into Kane Basin may be common, and Sadler (1976) indicated that Atlantic water may periodically flow into northern Smith Sound when he suggested that Baffin Bay bottom water may be formed in the North Water Polynya by the mixing of water from Nares Strait with Atlantic water from the south.

Water mass analyses (Muench, 1971) have shown that Smith Sound is almost entirely made up of waters originating in the Arctic; i.e., a cold upper Arctic Water layer and a cold Deep Water layer, both defined by temperatures colder than 0°C. Atlantic Water, water warmer than 0°C, has never been observed in Smith Sound (Muench, 1971). However, during the warm summer months, atmospheric warming of the surface waters does occur.

The remainder of this paper will describe the oceanographic conditions observed during the middle portion of July 1977 from the USCGC WESTWIND (W-AGB 281). The discussion will attempt to show that a major influx of warm, dense water (possibly Atlantic Water) occurs from the south along the eastern portion of northern Smith Sound, and that a cold Arctic mass flows south on the western side of the sound. It does appear that the northern Smith Sound area is oceanographically very complex due to the meeting of these water masses.

II. DATA COLLECTION AND REDUCTION

Figure 2 presents the locations of nine oceanographic stations occupied during the 1977 WESTWIND cruise. On these stations, a Bissett-Berman Model 9040 Salinity-Temperature-Depth sensor was originally planned for

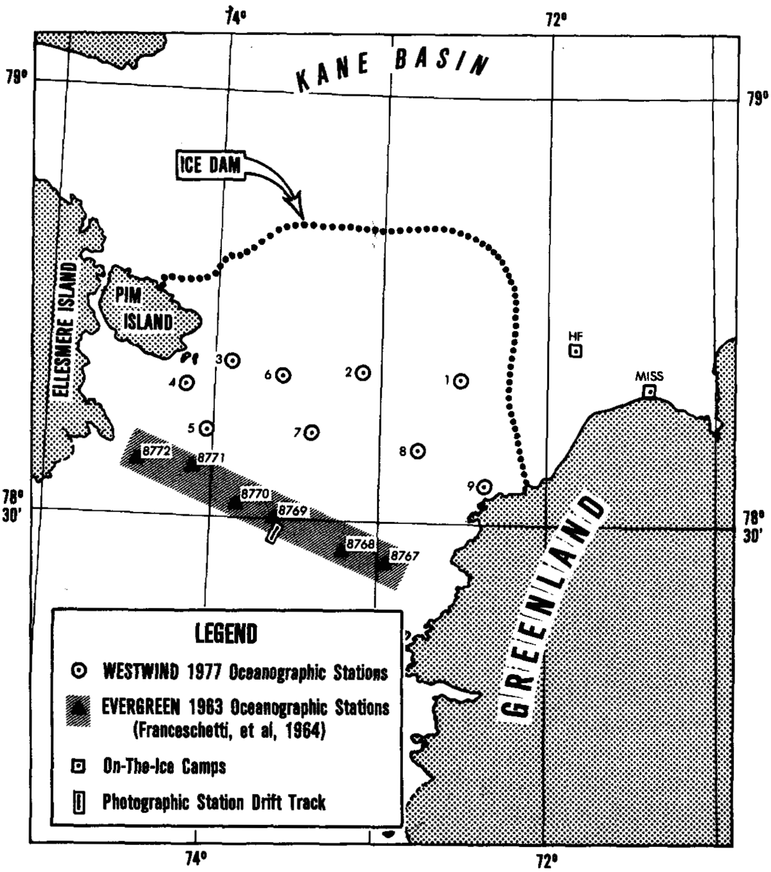

FIG. 2. WESTWIND Oceanographic Station Locations. Coast Guard Stations Occupied in 1963 are Indicated in Shaded Area.

use. This system failed to operate properly. Expendable bathythermographs (XBTs) and a rosette multi-sampler with niskin bottles were used at each of the nine selected stations. Temperature readings and water samples were collected using the XBTs to determine the most desired tripping depths for the niskin bottles. Pairs of standard reversing thermometers were read to 0.01°C, and a Guildline "Autosal" Model 8400 laboratory salinometer was used to determine salinity to $0.001^{\circ}/_{oo}$. The XBT profile values at the tripping depths were compared with the reversing thermometer values. In most cases a reasonably consistent error was determined for each XBT profile. Corrections were then applied to the XBT readings for selected depths to the bottom. Table 1 presents the Station 3 XBT data, reversing thermometer values (rounded to the nearest 0.1°C), temperature differences (T_{xbt} - T_{therm}) at the comparison points, and the corrected XBT values. The corrected XBT profile values were used in developing the vertical profiles and cross sections used in the analysis.

TABLE 1. Corrections for Station 3 XBT Profile

DEPTH (meters)	XBT VALUES (°C)	Reversing Thermometer Values (°C)	Δ T (XBT - Therm)	Correction Applied to XBT	Corrected Temperature (°C)
0	-1.2	-1.1	-0.1	0.1	-1.1
5	-1.2			0	-1.2
10	-1.2			-0.1	-1.1
15	-1.1			-0.2	-1.3
20	-1.1			-0.3	-1.4
25	-1.2			-0.4	-1.6
30	-1.1	-1.6	0.5	-0.5	-1.6
40	-1.0			-0.5	-1.5
50	-1.0	-1.5	0.5	-0.5	-1.5
75	-1.0			-0.5	-1.5
100	-0.6	-1.0	0.4	-0.4	-1.0
125	-0.6			-0.4	-1.0
150	-0.6			-0.4	-1.0
175	-0.5			-0.5	-1.0
200	-0.4	-0.9	0.5	-0.5	-0.9
225	-0.3			-0.5	-0.8
250	-0.2			-0.5	-0.7
300	0			-0.5	-0.5
350	0			-0.5	-0.5
400	0.1	-0.4	0.5	-0.5	-0.4

III. WATER MASS CHARACTERISTICS IN NORTHERN SMITH SOUND

Figure 3 presents the vertical temperature structure observed at Stations 3, 5 and 6. The feature of interest demonstrated by these profiles is the rise in temperature at Station 5 centered at a depth of 40 m and the isothermal areas at Stations 3 and 6 at about 50 and 75 m, respectively. A similar feature was observed in 1963 by Franceschetti *et al.* (1964) at 50 to 75 m depth. The vertical temperature profiles for their stations 8770 and 8771 are presented in

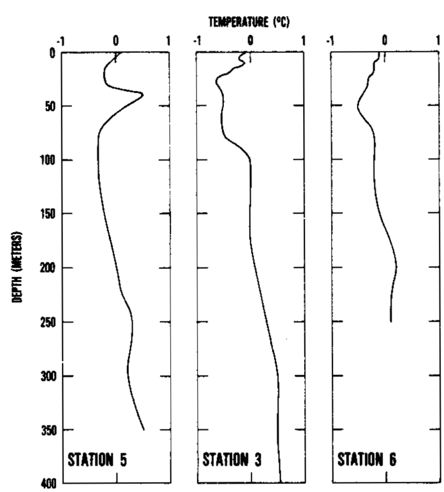

FIG. 3. Vertical Temperature Structures for Stations 3, 5, and 6.

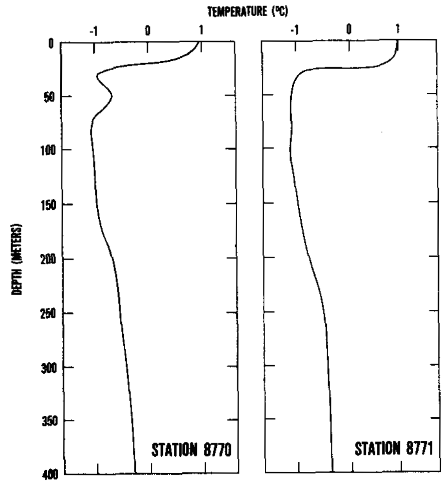

FIG. 4. Vertical Temperature Structure for Coast Guard 1963 Stations 8770 and 8771 (from Franceschetti *et al.* 1964).

Figure 4, and locations of these stations are plotted in Figure 2. To best show what may actually be happening here, vertical cross sections were constructed along the two near West-East lines of WESTWIND stations shown in Figure 2. Figure 5 presents the more southerly of the two sections. Between Stations 7 and 8 there is a mass of warmer water which is limited to the upper 100 m at Station 7 and extends to the bottom at Station 8. On the western side of the sound, a cold mass exists with the coldest part (core) of

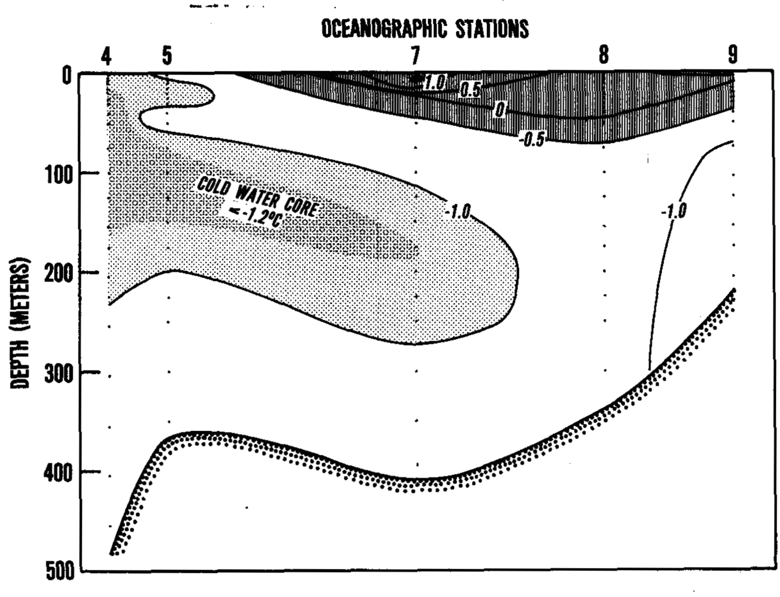

FIG. 5. Southernmost Temperature Cross Section.

this mass around 100 to 125 m. At this latitude, the cold mass is well-defined by the -1.0°C isotherm with its core defined by the -1.2°C isotherm. The influences of the warmer water to the east can be seen at Station 5 with the warm intrusion, extending into the colder water at 40 to 50 m depth creating the rise in temperature shown in Figure 3.

Although the warmest temperatures are observed at Station 7, it is likely that the highest temperatures at the surface are due to atmospheric heating and that the center of the warm water mass is entering northern Smith Sound closer to Station 8. Figure 6 presents the density (σ_T) distributions along the

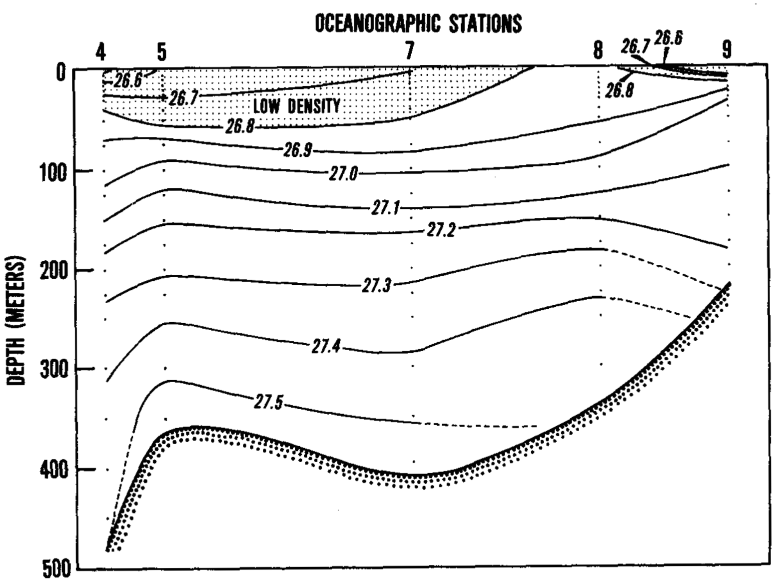

FIG. 6. Density Distributions Along Southernmost Cross Section

same line of stations. The bending of the 26.8 isopleth toward the surface between Stations 7 and 8 and the general higher density water at Stations 8 and 9 between 20 and 150 m indicates that there is an influx into this area of warmer, denser water than that observed to the west. A plan view of the density variations of the study area at a depth of 30 m is presented in Figure 7. This figure delineates both the influx of denser water into the study area between Stations 7 and 8 and the influx of less dense water on the western side of the sound.

The effects of low salinity runoff from the land masses is readily apparent in Figure 6 by the two values observed at the surface at both Stations 4 and 9, the westernmost and easternmost stations, respectively.

A study of the northern line of stations allows a determination of the probable directions of flow of the cold and warm masses. Figure 8 presents the temperature distributions along this line. The two lines of stations are separated by only about 12 km, yet severe modifications to the warm mass

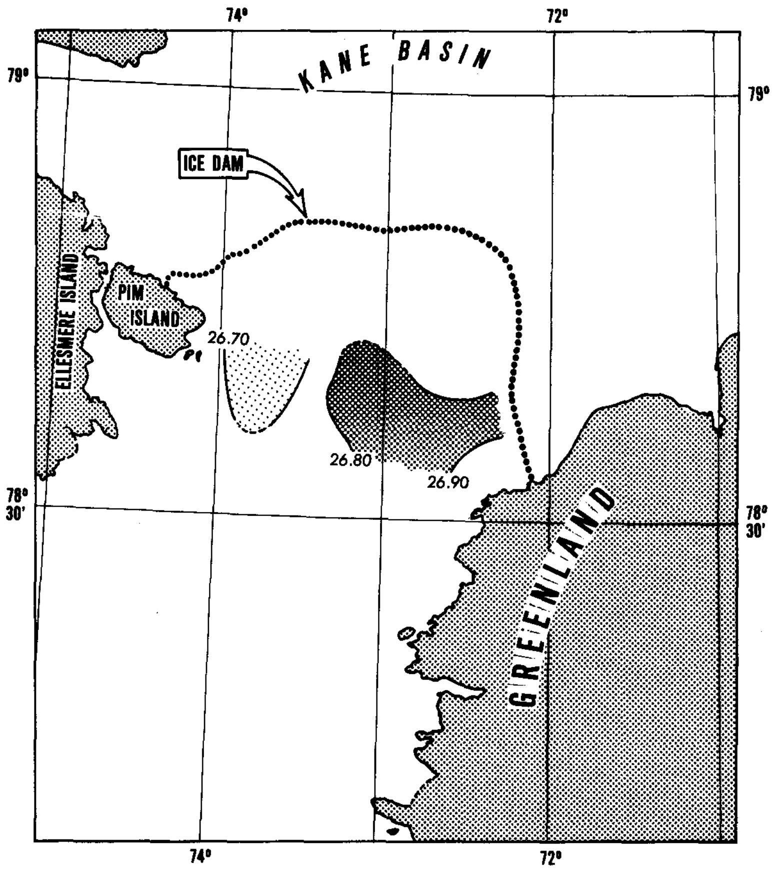

FIG. 7. Plan View of Density Distributions at a Depth of 30 Meters

have already taken place. To the south (Figure 5) the warmer mass was ill-defined by the -0.5°C isotherm and was spread out over a good portion of the sound. At the latitude of the northern line of stations, the warm mass is well-defined by the -1.0°C isotherm and is reasonably compact. The cold water core is better defined by the -1.5°C isotherm rather than the -1.2°C isotherm used in Figure 5. The effect of the warm water on the vertical temperature structure at Stations 3 and 6 is still apparent by the graphic intrusion into the cold mass depicted by the -1.0°C isotherm. Another effect is the forcing of the colder, less dense water to greater depths to the south. In Figure 8, the cold mass is continuous from 10 m to about 100 m (with the exception of the intrusion at about 75 m at Station 6). In Figure 5, the downward slope of the -1.0°C isotherm shows that this water mass is being forced to greater depths. In fact, the deeper -1.0°C isotherm, which usually can represent the boundary between the coldest water in the column, and the gradual rise in temperature to the bottom due to adiabatic heating, has been destroyed at Station 8 by the warm water entering northern Smith Sound from the South.

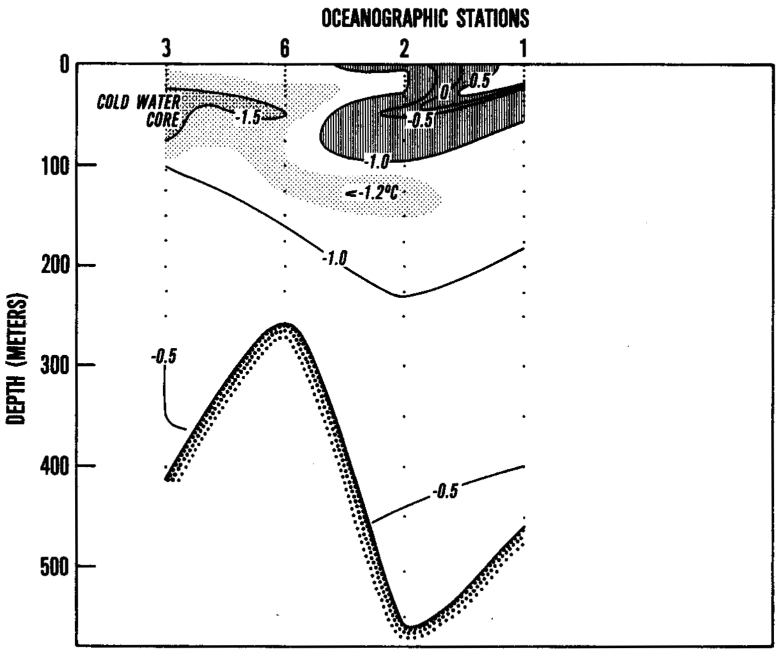

FIG. 8. Northernmost Temperature Cross Section.

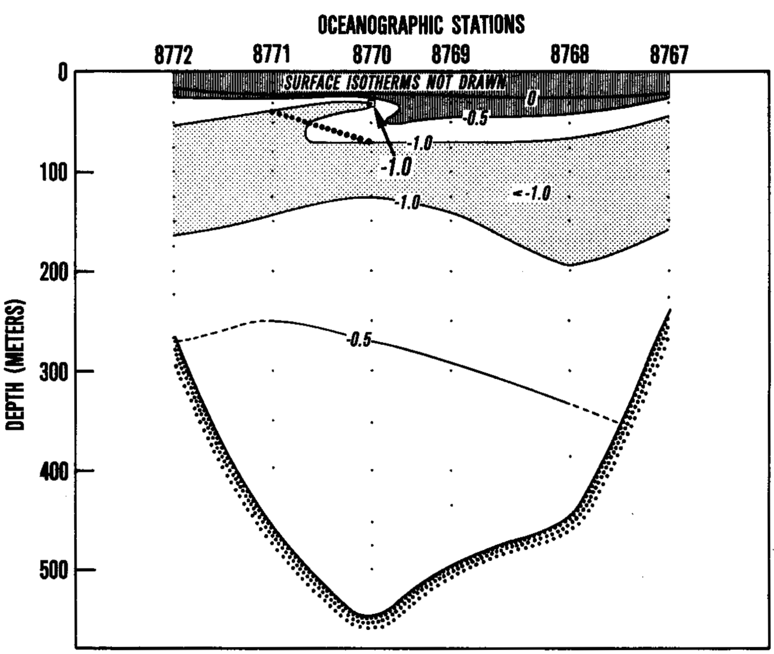

FIG. 9. Temperature Cross Section for Coast Guard Stations Occupied in 1963 (from Franceschetti *et al.* 1964).

Franceschetti *et al.* (1964) presented a temperature cross section located approximately 20 km south of the southernmost WESTWIND line shown in Figure 5. The stations utilized for their cross section were occupied approximately 2 weeks later into the summer season, and the surface values are higher. However, below the upper 30 m, the same warm mass can be observed. Figure 9 is a replot of their data. The dotted line between Stations 8771 and 8770 indicates the original plot of their upper -1.0°C isotherm, and the solid line in this area represents the likely structure based on the 1977 WESTWIND results. In other words, Figure 9 considers the -1.00°C value,

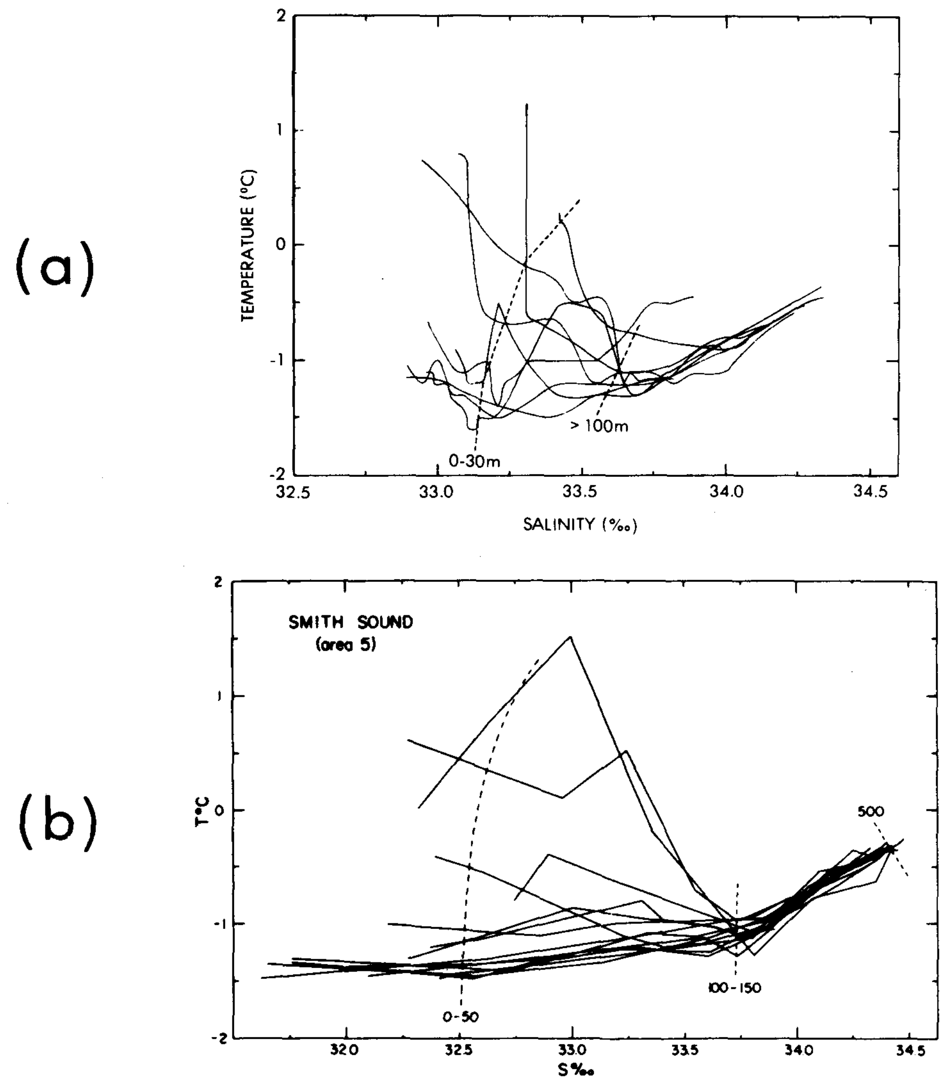

FIG. 10. Composite of Temperature-Salinity Relationships for WESTWIND Smith Sound Stations (Top) and that Presented by Muench (1971) (Bottom).

observed at about 30 m depth at Station 8770, which was reasonably ignored during the original analysis. Again, warm water (>1.0°C) is intruding into the -1.0°C isotherm at Station 8770 creating a situation very similar to that depicted in Figure 5.

Figure 10a presents a composite of the temperature-salinity (T-S) relationships of the 9 oceanographic stations by WESTWIND. Figure 10b presents a T-S composite presented by Muench (1971). Although the majority of the Muench data was collected in the central and southern portions of Smith Sound, there is still a reasonable agreement between the two sets of data, especially below 100 m. A wide variety of values is to be expected in the upper 30 m due to atmospheric heating/cooling and fresh water runoff. The variations between the depths of 30 and 100 m however, are probably due to the sampling within both the warmer and colder water masses discussed above.

Based on the analysis of the cross sections presented here, it appears that during the summer, northern Smith Sound is an oceanographically complex region. This complexity is primarily created by the meeting of significantly different water masses. The eastern side of the sound is dominated by a cold, less dense mass from the Arctic. These water masses are surface features. The warmer mass is limited to the upper 100 m, and the colder mass deepens to the south, extending to about 200 m. Waters shallower than 30 m are highly variable due to atmospheric heating/cooling and fresh water runoff from the nearby land masses.

It is generally agreed that net flow is from Kane Basin through Smith Sound into Baffin Bay. However, it is also felt that pulses into Kane Basin from the south are common (Muench, 1971). The structure as shown here could be one of these pulses and may be short-lived. However, the similarity to the situation observed in 1963 by Franceschetti *et al.* (1964) indicates that these flow patterns may be semipermanent seasonal phenomenon (spring or early summer) rather than short-lived oscillations created by atmospheric mechanisms such as barotropic forcing. If the northerly flow is a seasonal phenomenon, it is possible that the participant warmer, dense water could have originated in the Atlantic. At the latitude of northern Smith Sound, such extreme modification could have taken place as to make this water unrecognizeable as Atlantic Water, when utilizing the normal temperature-salinity definitions for identification. This conclusion is in variance with Muench's (1971) statement that Atlantic water has never been observed in Smith Sound and reinforces Sadler's (1976) suggestion that Baffin Bay Bottom Water may be formed in the North Water Polynya by the mixing of water from Nares Strait with Atlantic waters from the south.

The interest in Smith Sound is attested to by the significant amount of studies conducted in and papers written on this small geographical area. As stated in the Background, Smith Sound is the boundary between Kane Basin to the north and Baffin Bay to the south and is an extremely narrow region within a major egress channel for Arctic ice and water. Further enhancing its importance is the presence of the North Water Polynya. It is, therefore, highly desirable to fully understand the yearly circulation patterns in this region.

To more confidently define the characteristics of these interacting water masses in northern Smith Sound, and to determine the mechanisms responsible for their actions, a series of close-grid oceanographic stations should be occupied throughout the spring-summer season. The grid should cover the extreme southern Kane Basin around 78°50'N down to 78°20' in Smith Sound. Most importantly, several bottom-moored current meter arrays must be implanted within the study area defined above. Measurements must be concentrated in the water column between 30 and 200 m. The measurement period should encompass the entire spring-summer seasons. If possible, the arrays should be replanted for measurements through the fall and winter seasons and recovered the following spring. For these fall-winter measurements, placement of current meters in the upper 60 m may not be feasible because of the danger of deep-drafted transient icebergs through Smith Sound from the north.

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