AERIAL SURVEYS OF HUDSON BAY SURFACE TEMPERATURE-1967

by

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INTRODUCTION

The areal distribution of surface temperature of water bodies is used in studies of the heat budget, thermal and dynamic oceanic/limnologic processes, climatology and airmass modification, to name a few. The time change of the temperature pattern reflects the interaction of the water with the components of the radiation balance, and the airmass above the water surface. Although synoptic information is available for some lakes e.g., Lake Superior (Ragotzkie & Bratnick, 1966; Ragotzkie, 1966), and small portions of the ocean, e.g., the Gulf Stream (Niblock, 1966), and a hurricane wake in the Gulf of Mexico (McFadden, 1967), the day to day changes of most large scale water bodies is, as yet, unknown. Before a full understanding of the interaction of the air and water can be known, a rather complete knowledge of the surface characteristics must be gained.

Mean charts of sea surface temperature (SST) are available. These are composed of ship data gathered over long periods of time, and therefore represent climatological information. Rapid sensing of SST by airborne remote techniques is a recent method, capable of sensing rather large areas in rather short periods of time.

The modification of airmasses which move over Hudson Bay has been studied (Bryson & Kuhn, 1962; Lamont, 1949; Hare & Montgomery, 1949; Burbridge, 1951), but before daily airmass changes can be quantitatively predicted, the temperature characteristics of the Bay must be known.

Early surface temperature data of Hudson Bay is an assemblage of isolated measurements. A review of some of the early work on Hudson Bay can be found in Hachey (1933) and Barber (1967). The first analysis of temperature patterns of the Bay was drawn from data collected by the Loubyrne (about thirteen data points), which surveyed the Bay during August and September of 1930. The result is a necessarily smooth field of isotherms showing the warmest waters to be in the west and south (temperature of about 8C) and coolest water in the northeast (temperature of about 5C near Coats and Mansel Islands)(Davidson, 1930).

The first surface thermal analysis of Hudson Bay using more than just a very few data points, is that by Barber & Glennie (1964). Their report summarizes the Hudson Bay oceanographic survey of the "Theta" and "Calanus" vessels during 1961. Using the data gathered during one week in July (which covered the northern half of the Bay), and during the month of August (which covered most all the Bay), they have compiled two maps of the distribution of SST. Do these charts closely approximate the SST distribution at a given time, or are they a smoothed mean, obscuring changes in space and time?

We hoped to answer this question with two aerial surveys of the Bay planned for the summer of 1965. Due to aircraft problems, only one survey of the Bay was completed. Data was gathered over a three day period, 22-24 September 1965. The results of that survey (Wendland & Bryson, 1966) show some similarities to the surface temperature patterns of August 1961 (Barber & Glennie, 1964). The similarities are found primarily in the western Bay, notably a cold tongue reaching southward just off-shore of the west coast, and a warm tongue reaching northeastward from the Churchill area. In August of 1961, the eastern part of the Bay was warmer than the surroundings, but in September of 1965, the eastern Bay was colder than the environs. It was suggested that this cold pool was the melt water which had remained a surface feature due to its relatively low density. It is also suggested that the cold pool was not found in the eastern Bay in 1961 because, in that year, the ice lingered along the southwestern shores.

A series of flights over Hudson Bay was planned for the summer of 1967 to investigate the change of the surface patterns throughout the ice-free season. Three surveys were completed.

SURVEY TECHNIQUE

The 1967 surveys were similar to those of 1965. Flight tracks were chosen to cover the largest possible area with the flight time available. The infrared airborne radiation thermometer (ART) is a product of the Barnes Engineering Co. of Stamford, Conn., (model 14-320) and was mounted in a U.S. Navy Super Constellation from NAS Patuxent River, Md. The aircraft cruised at about 180 knots at an altitude of 1,000 ft or less. Data was collected only when there was clear air between the aircraft and the water. Aircraft position was monitored by radar when close to land, doppler radar and dead reckoning when on the rather long over-water tracks. Since a single heading was used for the tracks, deviations of perhaps 30 nautical miles (nm) from the planned trajectory are possible when over water. Deviations of this magnitude are not considered significant when one considers the size of the surveyed water body.

INSTRUMENTATION

The ART measures the water skin radiation temperature. This value need not equal the actual surface temperature for two reasons. There may be real differences between the "bucket" temperature and the radiation temperature since the latter is a function of emissivity, evaporation, net radiation, conduction and convection. Second, the emitted surface radiation may be absorbed and reradiated at a different temperature by certain atmospheric gases (water vapor, carbon dioxide and ozone) in the air space between the emitting surface and the bolometer. The possible differences are thoroughly discussed in the literature (Pauls, 1965; Pauls, 1967; Ichive & Plutchak, 1965; Lenschow & Dutton, 1964; Lorenz, 1966; Menon & Ragotzkie, 1967). Differences between the "bucket" temperature and the ART value are smallest when the water surface is well mixed, when the water temperature is close to the dew point temperature (minimum evaporation), and when skies are overcast, or at night (to eliminate strong solar radiation). Weather conditions during the surveys varied from clear to complete obscuration, inferring that at times, the net radiation was strongly positive to the surface. Surface winds, however, were seldom less than fifteen knots (except during the July survey) implying a well mixed surface layer. The ART values were not "corrected" for observed meteorological conditions.

Because of the absorption and reradiation by atmospheric gases, the emitted radiation could be substantially altered when received at the aircraft. However, Lenschow & Dutton (1964) have shown that flight altitudes of less than about 300 meters (984 feet) essentially eliminate the effect of atmospheric absorption and reradiation. Although Pickett (1966) has developed an environmental correction for the model 14-320 which corrects for atmospheric absorption, based on air temperature and flight altitude, it was not used in this study. His correction was developed from 187 comparison points where the ART measured the surface radiation temperature from different altitudes, while a ship measured the surface temperature <u>in situ</u>. Only about twenty percent of the observations were made in air temperatures less than 15C. The remainder were made in tropical airmasses with altitude air temperatures of about 24C. Osborne (1964) claims that Arctic air in summer should not substantially alter the radiation emitted from the water surface due to the temperature and moisture characteristics of Arctic air. Air temperature at flight altitude was within four Celsius degrees of the surface temperature (except during July, when the air temperature at flight altitude was consistantly ten to twelve degrees warmer than the water surface). This suggests that the July data might have been altered by atmospheric reradiation, but probably not to a significant extent.

The model 14-320 bolometer is a rather stable instrument. The calibration made by the U.S. Navy Oceanographic Office staff after the flights differed by only 0.3C from that made before the flights. During the surveys, similar areas on Hudson Bay were measured at two different times, separated by a few hours up to two days. The mean temperature difference of 22 such occurrances was 0.2C. The ART lens temperature was monitored during flight. If this value differed from that observed during instrumental calibration, a correction value was applied to the "raw" ART reading.

The isotherm configuration was independently assessed by soliciting the aid of SST records of freighters and supply ships operating in Hudson Bay during the times of the surveys in August and October. Six ships provided intake temperature records and six reported bucket temperatures, for a total of about 55 data points for the dates of the surveys. While the absolute values of the ship data cannot be used to calibrate the ART in-flight because the times of the two measurements may differ by as much as a few days, and because ship temperature sensing devices may or may not be calibrated themselves (see Saur, 1963), nontheless, the large scale isotherm configuration from the ship data should be representative of the surface patterns. The ship data were used primarily in areas where no ART data was available.

ISOTHERM PATTERN CHARTS

The sum of the ART value plus the lens correction were plotted and analysed, and are presented on Figures 1, 3 and 4. The light, thin lines represent the flight paths where data was collected. No data was recorded when either clouds, fog or precipitation even partly obscured the surface. The small open circles on the charts represent locations of available ship data.

JULY 1967 SURVEY

Figure 1 presents the temperature pattern for 12 and 13 July 1967. About 1650 nm of track were flown. About two-thirds of the Bay was covered with seven to nine-tenths ice (Ice Central, Halifax, N.S.). The radiation temperatures over the ice were about 1.5 to 2.0C and rather steady. The ART measures a weighted area mean radiation temperature. Its field of view from 1000 ft. altitude is a circle with diameter of about 35 ft. Within this area, open water, the ablating ice surface and standing water on top the ice was likely found. The melting ice surface must be between -1.7C (salinity of 30 o/oo) and 0.0C. The open water areas are relatively warm (say, 1 to 2C) even considering the proximity to melting ice. The standing melt water, too, can be at least 1C (Vowinkel & Taylor,

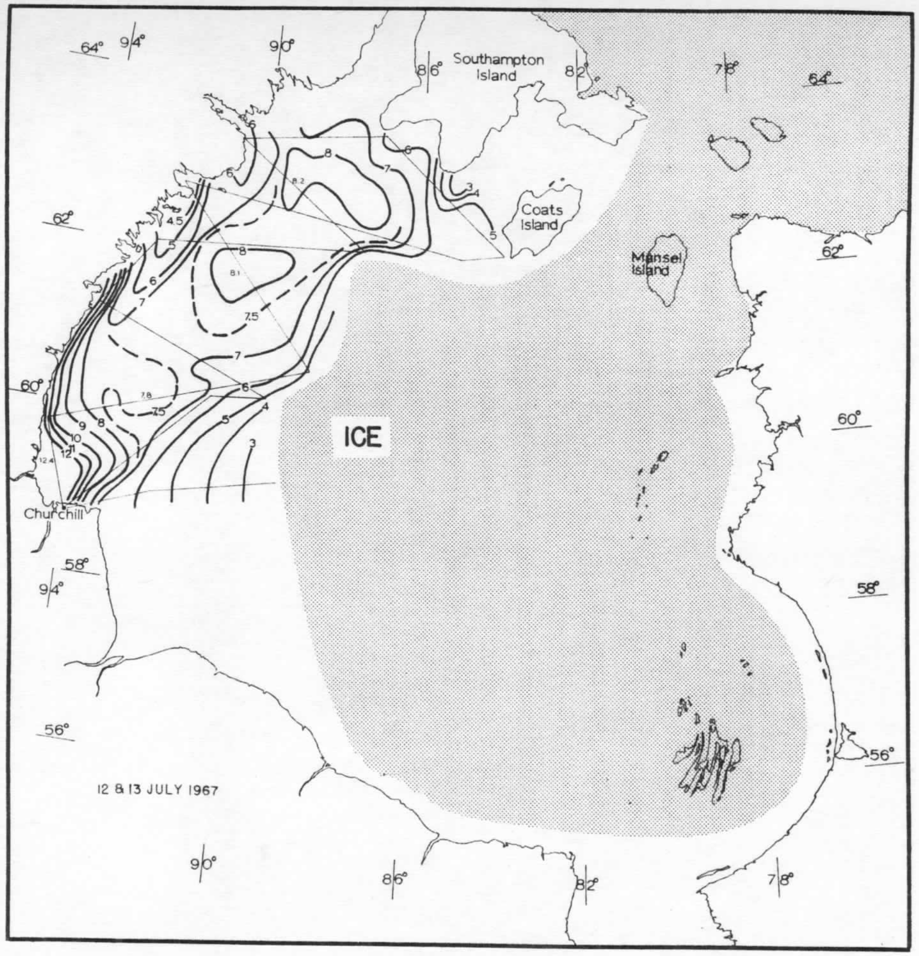

Figure 1. Surface temperature pattern of 12 and 13 July 1967.

1965) and perhaps higher since it is stratified. Evidence is presented later to show that the water rapidly warms after ice-loss, if this occurs during July and August.

The ice-free water which was surveyed exhibited rather warm surface temperatures. Even near the periphery of the ice, the water temperature was well above the melting point. Figure 2 presents the ART plus lens correction traces at the ice-water interface on 28 August 1967. The upper scale on each section represents approximate distance in nautical miles. The lower limit of each trace does not represent the ice surface temperature, but rather, the lowest possible reading with the ART. All three traces were recorded over pack ice just southeast of Leyson Point, Southampton Island. The pack ice covered about 175 square miles. Ice coverage was estimated from four- to seven-tenths. Low, thin stratus was noted over and about this pack ice. The outer ice limit was also the limit of stratus. The water adjacent to the ice edge appears well mixed in "B" presumably due to wind action. In "A" very little horizontal mixing is indicated by the four mile strip of rather cold water adjacent to the ice. The temperature gradient is much sharper in the latter case. The temperature profile in "C" represents an intermediate situation. The temperature change in "C" is not as abrupt as in "A" nor is it as gradual as "B".

Why was the surface temperature of the ice in these three examples apparently lower than over the pack ice in July? Flight altitude was 300 ft. over the ice in August due to the thin stratus. The effect of the stratus on the surface radiation temperature was probably slight since the air temperature at 300 ft. was within one-half degree of zero, i.e., similar to that of melting ice. The surface wind on 28 August was northerly at about 15 knots, and

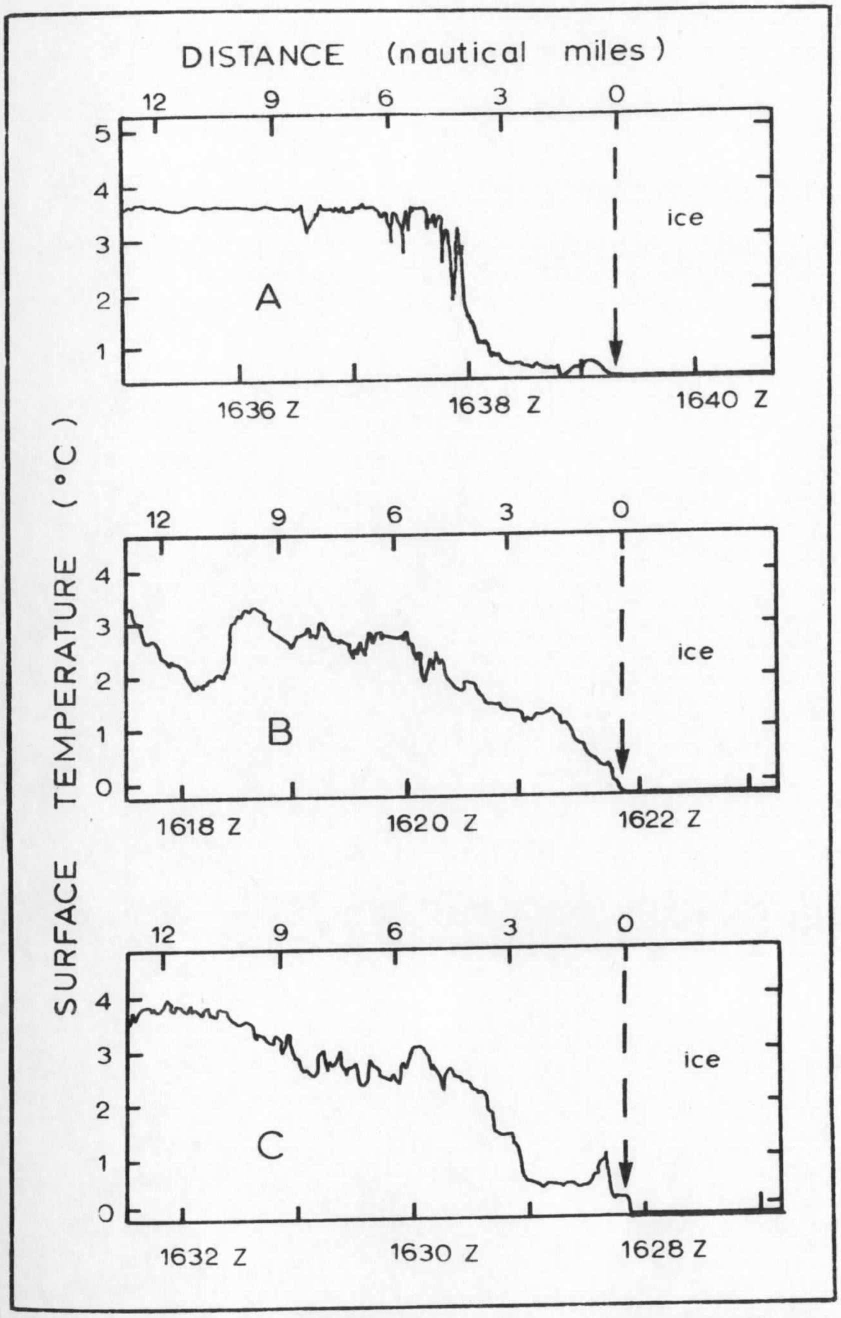

Figure 2. ART temperature profiles over pack ice and adjacent open water from 28 August 1967. Upper scale represents approximate distance in nautical miles. Lower scale is reference time (GMT). Location was about 50 miles southeast of Leyson Point, Southampton Island.

north-northeasterly at about 10 knots on 12 July. It is suggested that the larger, more stable ice pieces in July, under relatively light winds, accumulated standing melt water on the surface. These ponds warmed rather rapidly, being stratified. In August, the ice was much smaller in area, and the pieces were presumably less stable. With the slightly stronger winds, the ice pieces were washed by the surrounding salt water prohibiting the accumulation of standing melt water.

In two cases of Figure 2 ("B" and "C"), the water temperature was relatively stable at 3C (3.5C in "A") within about five nautical miles of the edge of the pack ice.

The warmest water surveyed was just north of Churchill (12.4C), with a warm tongue extending northeastward toward Southampton Island. Note the cold tongue reaching southward just off the west coast of the Bay. These features were noted on the surveys of August 1961 and August 1967.

AUGUST 1967 SURVEY

This survey of about 3900 nm track was made on 26 through 28 August. The only ice seen was in the extreme northeastern part of the Bay just southeast of Southampton Island (see discussion of Figure 2 above). This pack ice no doubt entered the Bay from the Hudson Straits where ships reported considerable ice accumulation. The ice charts prepared by Ice Central, Halifax, N.S., and photo interpretation of the ESSA 3 satellite data indicate that the ice within the Bay disappeared during the week prior to this survey. The last area of ice was in the eastern part of the Bay, centered about 58N latitude, 82W longitude.

In August, the western Bay was warmer than the eastern part (see Figure 3), but the temperatures in the

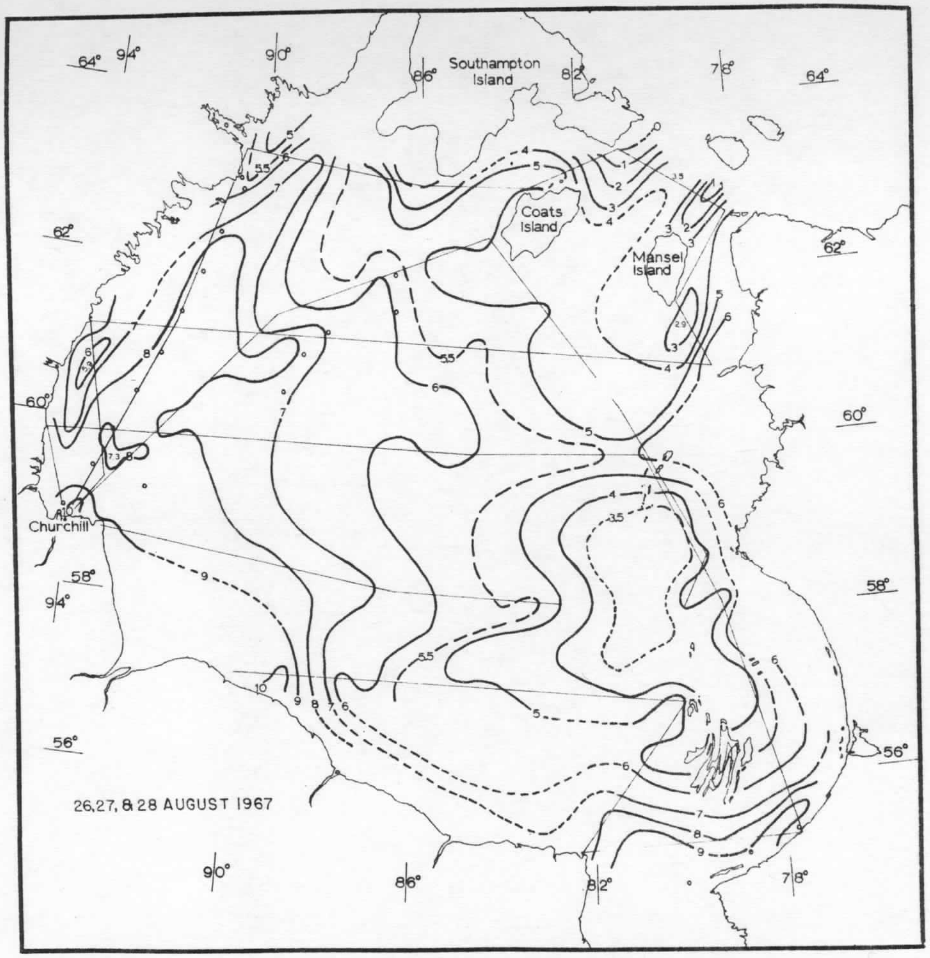

Figure 3. Surface temperature pattern of 26, 27 & 28 August 1967.

west cooled somewhat from the August values, particularly near Churchill. A warm tongue was found again reaching northeastward from Churchill, and the cold tongue was also found along the west coast from near Chesterfield Inlet, southward. The area of last ice was marked with a cold pool with temperatures of 3.5C or less. It was, however, well above the melting temperature. (With salinity of 30 o/oo, the melt temperature is about -1.7C). The coldest area surveyed was near the exit to Hudson Strait. With ice persisting in the straits and pack ice seen in the northeastern Bay, this is not surprising. However, in early August of 1965, the temperature in that area was from 4 to 7C.

OCTOBER 1967 SURVEY

The October pattern is the result of about 3750 nm track, and was decidedly different from those earlier in the season (see Figure 4). The temperature gradient was generally directed to the north, whereas earlier it had been directed to the east or northeast. The area north of Churchill was relatively warm, but much cooler than it was in August or July. The warm tongue again reached northeastward, but it was not as well defined as earlier in the year. The cold tongue was suggested along the west coast, but could be fixed only at one location due to the flight track. The warmest water surveyed was near the Belcher Islands in the southeastern part of the Bay, and temperatures in this area were not substantially changed from those of August.

DISCUSSION

Some features of Hudson Bay can now be described in some detail due to the surveys of 1961, 1965, and 1967. The temperature of the water rises rapidly after ice disappearance, if this occurs during July of August when

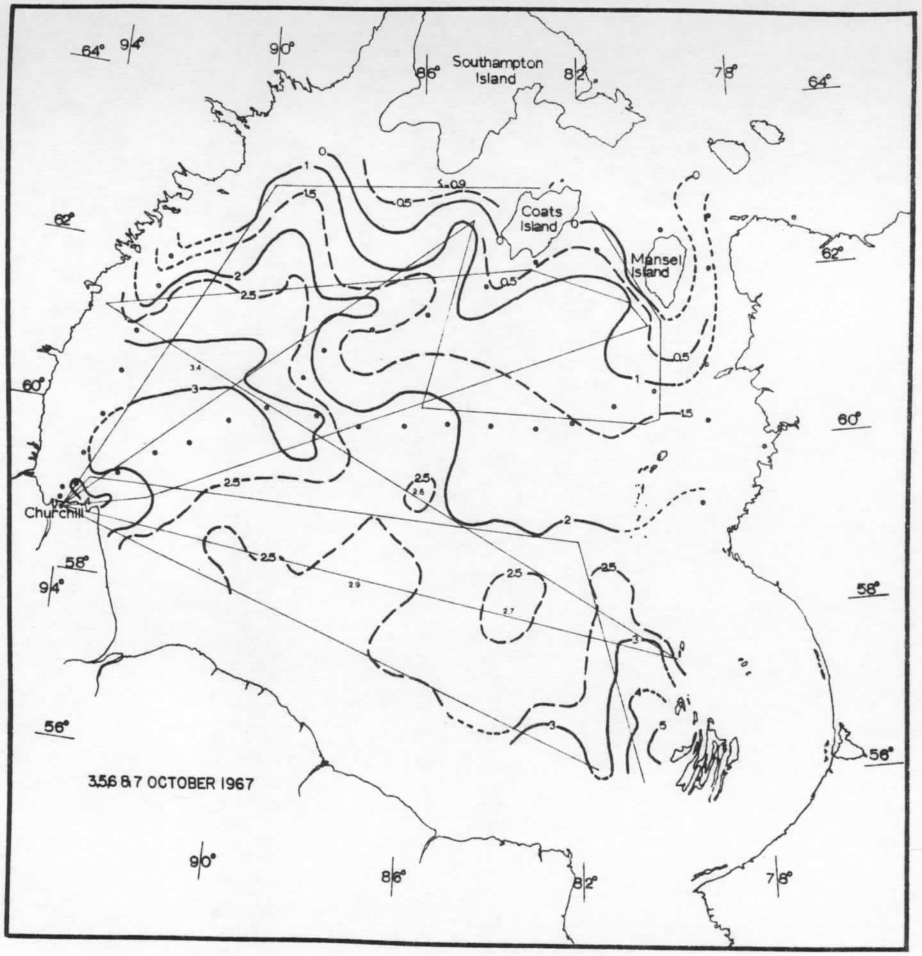

Figure 4. Surface temperature pattern of 3, 5, 6 & 7 October 1967.

strong positive net radiation is available. In September of 1965, a cold pool (temperature less than 0.5C) was found north and east of the area of last ice. It was suggested (Wendland & Bryson, 1966) that this was the melt water of the last Hudson Bay ice. The cold pool found in August of this year substantiates that suggestion. The cold pool in August 1967 was significantly warmer than the pool's temperature in September 1965. This merely shows the large scale heating/cooling cycle of Hudson Bay with the annual maximum value found in August, undoubtedly due to the strong net radiation to the surface. Most probably, the pool in 1965 had warmed after ice loss, but had then cooled by the time of the September survey.

The rather shallow area north of Churchill was warmer than the deeper areas. This warm feature could be found on all charts, extending toward Southampton Island. Similarly, the cold tongue reaching south from Chesterfield Inlet, just off-shore, was a prominent feature. It is unknown, at this time, whether these thermal features represent currents, or semi-permanent features of the surface imposed by the bottom topography. Radar and visual observation of ice movement have indicated a southerly flow near the western shores with speeds of 1 to 1.5 knots (Collin, 1966). Southerly movement along the western shores has also been shown by Collin & Dunbar (1964) and Dunbar (1958), and northerly flow is suggested along the eastern shores by Hachey (1933). These observations tend to confirm the contention of a cyclonic gyre in Hudson Bay. The above studies are at least suggestive that the thermal patterns reflect water movements.

Where Hudson Bay meets the Hudson Straits is probably the coldest area throughout the open season for the entire Bay. The persistent ice in the Straits well into the summer, and the inflow of cold water from the Straits undoubtedly accounts for this feature.

The mean areal temperature of Hudson Bay was calculated from the data of August 1961; September 1965; July, August and October 1967. The results of this calculation are found in Table 1.

Table 1. Trend of mean areal surface temperature of Hudson Bay.

DATE	TEMPERATURE (^{o}C)	
	ICE-FREE AREA	ENTIRE SURFACE AREA OF BAY (ASSUMING TEMPERATURE OF WATER BENEATH ICE -1.7C)
12-13 July 1967	7.00	0.26
3 Aug-3 Sep 1961	5.03	4.23
26-28 Aug 1967	6.11	6.11
22-24 Sep 1965	2.57	2.57
3-7 Oct 1967	2.02	2.02

Ice was observed on the July 1967 and the August 1961 surveys. To determine the areal mean temperature at those times, the water temperature at the water-ice interface was assumed -1.7C (salinity of 30 o/oo). These data are plotted on Figure 5. When ice covered, the mean surface temperature of the water-ice interface is assumed to be -1.7C. The stippled area on Figure 5 represents the upper and lower levels of areal mean surface temperature assuming salinity 20 o/oo (-1.1C) and 30 o/oo (-1.7C). Break-up begins in June and the Bay is usually ice-free by the end of August. Freeze-up begins in October and results in nearly continuous ice cover by late December. The trend curve in Figure 5 indicates that the mean temperature rises rapidly during the season of strong positive net radiation, and cools

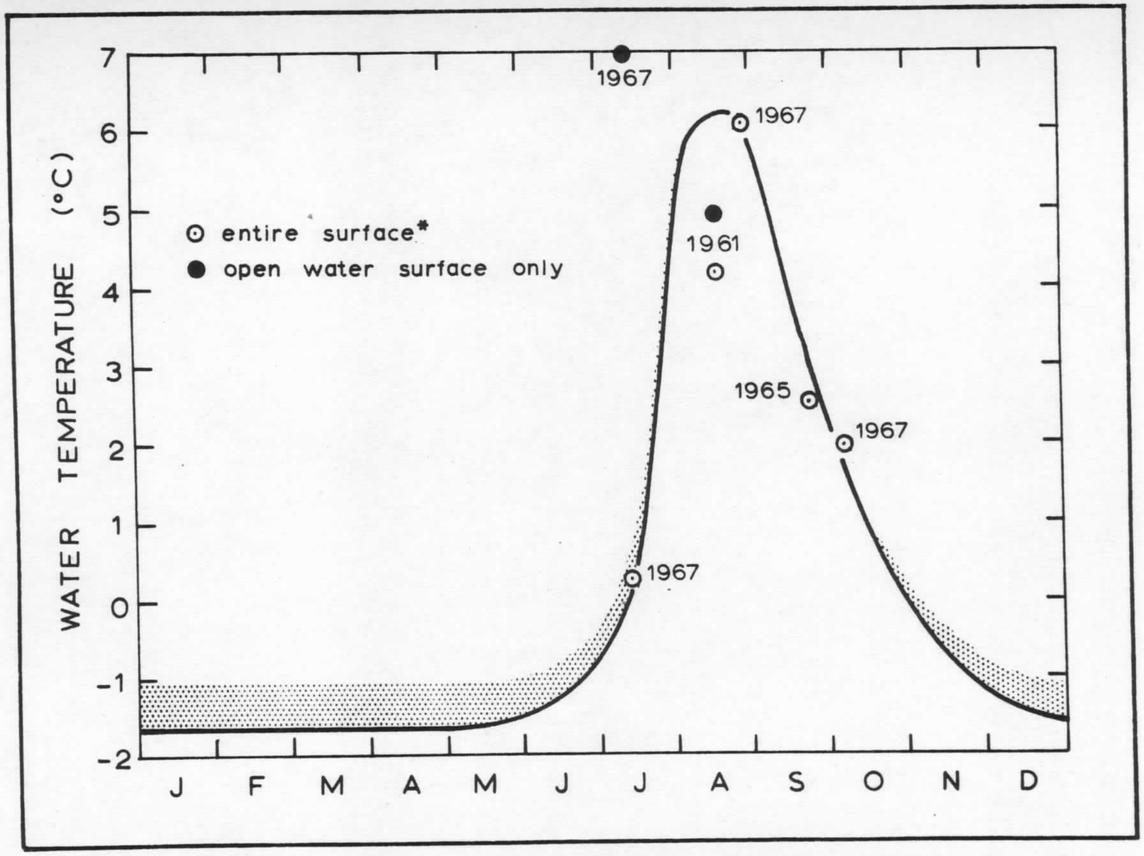

Figure 5. Suggested trend of areal mean surface water temperature of Hudson Bay. See text for discussion.

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*Curve assumes water temperature beneath ice -1.7C. Upper limit of stippling assumes water temperature beneath ice -1.1C.

rather slower thereafter. A mean maximum temperature of about 6.2 C is suggested. Because Hudson Bay is so intensely stratified, at least in the upper 25m in September (Collin, 1966), it is suggested that the curve presented in Figure 5 also represents a near trend curve for the heat content of the Bay during the ice-free season.

The data from August of 1961 does not appear to be representative of the same population. This is probably because the data were gathered over a 31 day period. The ice which was present at the beginning of the sampling period soon melted, the water warmed, and the areal mean temperature would have been seriously altered. Too, the trend curve of Figure 5 can only be considered an estimate, based on so few data. Large water bodies sometimes exhibit anomolous surface temperatures of a few degrees magnitude. For this reason, the curve of any particular year may be shifted horizontally or vertically from that in Figure 5, depending on meteorologic and oceanographic forcing functions. The solid dots of Figure 5 represent the ice-free areal mean surface water temperature. These values must be greater than the areal temperature of the entire Bay if partially ice covered. The July data point does not necessarily represent the time of maximum temperature difference, but early- to mid-July would be the expected time of occurrance, since the open area is relatively small, and the net radiation is near maximum. Of course, as the time of total ice disappearance is approached, the two temperature values (ice-free area and entire Bay area) must converge.

Water surface features were noted again during the flights of 1967 similar to those reported from the 1965 survey. For the most part, these glassy-surfaced streaks were noted at times when the surface wind (estimated from sea state) was about 5 to 10 knots. They were best defined when at least some direct sunlight reached the water surface. Similar features have been reported in the literature (Dietz & Lafond, 1950; Cromwell & Reid, 1956; Ewing, 1950a & 1950b; Uda, 1938, Voorhis & Hersey, 1964). They are known by various terms, e.g., "siome," "current rip" and "ocean front." Streaks are noted primarily in rather shallow water with winds of less than about seven knots. Often debris is aligned along the streaks, suggesting a convergence on the surface of the water. The presence of surface convergence along with the vertical thermal structure through the slicks, has suggested to various authors the presence of internal waves, or near-surface vortices. Voorhis & Hersey (1964) report temperature gradients as large as about 3C/100m across these features. Remote sensing quickly identifies abrupt temperature changes, but the lack of data at depth prohibits any comments being made regarding the processes which accompany such a feature. The forcing function has been attributed to both the wind, and bottom topography. To assess the cause in Hudson Bay, the location of each abrupt temperature change was plotted. These temperature changes were found over all parts of the Bay, and did not favor a particular location. Either the depth of Hudson Bay is below a threshold value, above which slicks/streaks will not form, or they are not necessarily a function of bottom topography. The mean gradient in 39 observed cases was 0.93C/nm

(0.05C/100m). Rather instantaneous changes of as much as 2.8C were noted. Floating weeds and debris were seen along some of the slicks. It is suggested by Dietz & Lafond (1950) and Ewing (1950b) that the slicks are composed of oils secreted from diatoms or perhaps pollutants which accumulate along the surface convergences.

CONCLUSIONS

The temperature surveys of 1961 summarized by Barber & Glennie (1964), and those of 1965 (Wendland & Bryson, 1966) and 1967 showed similar large scale patterns on Hudson Bay, at least throughout August, September and perhaps early October. The patterns found on surveys completed during a few days were very similar to those found on surveys which were compiled from a month's record. Where Hudson Bay joins Hudson Straits is probably the region of coldest water throughout the year. The warmest area is generally found in the south and over the shallow water north of Churchill. This warm water extends northeastward toward Southampton Island. Reaching southward from Chesterfield Inlet, a cold tongue was prominent. The surface thermal patterns may reflect surface water movement.

A signature of the last ice of Hudson Bay apparently can be located throughout the remainder of the ice free season. The melt water, because of its rather low salinity and therefore relatively low density, remains a surface feature. This feature is not destroyed, although it is warmed by the incoming radiation, because of the stratification of the upper layer of the Bay.

The surface water warmed rather rapidly after ice loss. This apparently is the result of absorption of solar radiation. Streaks or slicks were found over most of the Bay, apparently being a function of meteorological and oceanographic conditions rather than bottom topography. Abrupt temperature changes (as large as 2.8C) were found over these features. Such temperature changes were also found when no streaks were visible.

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13. ABSTRACT

Aerial surveys of the surface temperature of Hudson Bay were completed in July, August and October of 1967. An airborne infrared radiation thermometer remotely sensed the surface radiation temperature. The surface temperature patterns are presented for each survey. Certain persistant surface thermal features were found during the first two surveys. In October, the temperature pattern was rather flat, and the large scale features mentioned above, although present, were not as well defined. (U)

Because the ice lingers on Hudson Bay into August, it leaves its "signature" on the surface. A cold pool (presumably low salinity and therefore relatively low density) was found near the area of last ice. Due to the stratification of the upper layer of the Bay, this cold pool persists throughout most of the ice free season. (U)

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