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Remote Sensing of Surface Water Temperatures on the Great Lakes and off the Canadian Atlantic Coast

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ABSTRACT

Surface temperatures of lakes and coastal zone waters are extracted from infrared radiances detected by sensors on board NOAA polar-orbiting satellites. The data are transmitted from the satellites in digital form. Selected portions of the data stream are recorded on magnetic tape at the receiving station, and subsequently processed on a mini computer.

Either a direct atmospheric correction method, or a linear algorithm of the relationship between true and indicated brightness temperatures at different wavelengths (multiple-channel method) can be used to correct temperature measurements for atmospheric effects and surface reflection.

The atmospheric correction method requires input of local radiosonde data, and thus, its use is restricted to inland waters and coastal areas. Temperatures derived by the atmospheric correction method are found to have a r.m.s. difference of 0.6°C from buoy temperature measurements. Less reliable results are obtained with the multiple-channel method, due to amplification of instrumental noise in the algorithm and contamination of 3.8 μm channel data by reflected solar radiation.

INTRODUCTION

Surface water temperature is an important parameter in air/water interaction and in the physical and biochemical processes occurring within a water mass. Assessment and monitoring of these processes requires accurate and preferably regular synoptic scale temperature data from water bodies large and small.

During the past three decades intensive environmental research programs of various kinds were carried out on the Laurentian Great Lakes system, with concomitant demand for surface water temperature data. The Hydrometeorology Division of the Atmospheric Environment Service (AES) conducted a program of monthly airborne radiation thermometer (ART) surveys on the Great Lakes bordering on Canada from 1966 to 1980. The surveys were conducted at approximately monthly intervals during the ice-free season (Richards et al., 1969; Irbe, 1972). The ART water temperature data were used by many investigators for diverse applications.

In the early 1970's polar orbiting sun-synchronous satellites, operated by the U.S. National Oceanic and Atmospheric Administration (NOAA), provided the opportunity for acquisition of truly synoptic water temperatures with full spatial resolution over large areas. The feasibility of extracting surface temperatures of the Great Lakes from the NOAA satellite infrared data was first investigated by the National Environmental Satellite Service (NESS) of NOAA (Strong, 1974). In 1975 NOAA-NESS Environmental Products Group started issuing maps of Great Lakes water temperatures derived from satellite data.

The Aerospace Meteorology Division of AES has maintained a satellite data receiving station since the mid-1960's. Recording of digital data from NOAA satellites began in 1974. By 1977 the Hydrometeorology and Aerospace Meteorology Divisions had developed a cooperative program for retrieving water temperatures from digital satellite radiation thermometer (SRT) data.

Analyses of Great Lakes temperatures commenced in 1977. Since 1980 analyses have been done for the Great Lakes and Bay of Fundy/Scotian Shelf at two to three week intervals. In addition, temperatures of other water bodies (e.g. Lake Winnipeg, Hudson Bay) are monitored in support of other programs, or by special request.

SRT temperatures of the Great Lakes have been compared with buoy and ART measurements, using 1977 and 1979-80 data, in order to assess the accuracy of the extraction methods. This report contains the results of these comparisons, as well as a description of: the analysis methods employed, the main structure of the computer program, and the format of the output temperature data.

NOAA SATELLITES

The orbital characteristics, sensor types and data transmission modes of the NOAA satellites are described briefly below. Complete information on the satellite system is provided by NOAA Technical Memoranda: NESS 60, by Fortuna and Hambrick (1974), and NESS 95, by Schwalb (1978).

Orbital Characteristics

The satellites operate in sun-synchronous near-polar orbits at altitudes of 833 $\pm$ 90 km. Orbital inclination is between 98 and 99 degrees, orbital period is about 102 minutes. The satellites orbit the earth 14 times per day, overflying the mid-latitude regions twice in a 24 hour period.

Sensors

The pre-TIROS-N satellites carried one sensor in the visual and one in the thermal infrared spectral region. TIROS-N and NOAA-6 carry four Advanced Very High Resolution Radiometers (AVHRR), operating in the following spectral regions (channels):

Channel No.	Range (μm)
1	0.55 - 0.68
2	0.725 - 1.10
3	3.55 - 3.93
4.	10.5 - 11.5

NOAA-7 carries an additional thermal infrared channel (No. 5), which is centred at 12 μm.

The sensors scan continously at 360 lines per minute while rotating about an axis aligned in the direction of travel of the spacecraft. The field of view of the sensors is 1.3 milliradians. The radiation detected over the earthward portion of a scan is split into 2048 elements (pixels). A pixel comprises the radiation intensity from a km^2 area of the earth's surface at satellite sub-point. Away from the sub-point pixels represent progressively larger rectangular areas.

Data

Data are transmitted in 10 bit digital format. At the AES receiving station selected blocks of data from an orbital pass are recorded on tape. The data are processed in the Hydrometeorology Division on a MODCOMP mini computer.

DATA PROCESSING

Temperature Extraction Methods

Surface water temperatures can be processed from SRT data by two methods. The first method is designated as the Atmospheric Correction Method (ACM), the second as the Two Channel Method (TCM). TCM, which is the simplest variant of the multiple channel method, has been used successfully with NOAA-6 data by McClain (1980). However, at AES rather unsatisfactory results have been obtained with TCM (for reasons that are discussed later), and therefore, practically all routine temperature analyses have been performed using ACM.

The ACM and TCM options are available in the same main data processing program. Use of the ACM option involves a lengthier procedure which requires input of additional information that is generated beforehand by a separate atmospheric correction program.

The MODCOMP System

The MODCOMP system hardware components are:

- 128K memory words floating point hardware
- RAMTEK GX-100B graphics display unit
- 25 megabyte disk drive
- VERSATEC printer/plotter
- magnetic tape drive
- CRT terminals

Data Processing Program

The main program is structured such that the analyst can call up any one of a set of routines. Each routine performs certain operations on the block of SRT scan data that have been read from tape to a disk partition.

The available options include:

1. Display data - displays earth curvature corrected data from a specified channel on the RAMTEK CRT.

2. Colour slicing - allows arbitrary assignment of colours to radiation intensity levels; this helps to discriminate details in the displayed scene.

3. Point location - given the latitude and longitude of a point on earth, calculates its location in terms of pixel and scanline number within the data block, and the zenith angle of the point with respect to orbital track.

4. Calibration - calibrates digital count vs. temperature (ch. 3, 4 or 5), or percent albedo (ch. 1, or 2) from calibration data of a given block of scanlines; atmospheric correction values can be input to obtain digital count vs. corrected temperature for ch. 4 and ch. 5 data.

5. Two channel calibration - given the digital count vs. temperature calibrations of ch. 3 and ch. 4, calculates surface temprature, using the relationship:

$$T_s = a + T_{ch4} + b\ (T_{ch3} - T_{ch4});$$

   multiple channel algorithms may be applied in the future to NOAA-7 data, using ch. 3, 4 and 5.

6. Process data for printing - a block of data is processed and stored for printing; the analyst specifies: size and location of data block, range of temperature or albedo to be output, spatial resolution and map scale of output data, resolution of the temperature or albedo field and digital count cut-off in ch. 1 or ch. 2 data, if either channel is to be used to mask land surfaces in the temperature field.

Print Program

The block of processed data is output in alpha-numeric character code on the appropriate scale. Fig. 1 is a sample output of a 2x2 pixel averaged field on a 1:1,000,000 scale of the Bay of Fundy area. Starting with character "Ø" for the temperature at the warm end of the range, the characters represent stepwise decreases in temperature toward the cold end of the range.

The printout also contains unique symbols that replace certain grouped characters; this is done to facilitate analysis of the temperature field (see Fig. 1 and Table 1).

Data Analysis

The temperature field is hand-analysed and the results are usually transferred to a standard map. Fig. 2 shows the analysed map for the Bay of Fundy printout of Fig. 1.

The alpha-numeric code in Fig. 1 covers a temperature range from 3.9 to 14.2°C. The alpha-numeric code and both the ch. 4 indicated and ACM-corrected temperatures are listed in Table. 1.

Although the data have been rectified for earth curvature and rotation and for map projection, minor distortions of the data field, caused by orbital perturbations, remain in the printed scene. The distortions are adjusted for with the aid of land/water boundaries when the analysed data are transferred to the map.

ATMOSPHERIC CORRECTION METHOD

This method calculates the net atmospheric contribution to radiation measured from aircraft or satellite in the "window regions" of the infrared portion of the spectrum. The windows are located in the vicinity of 900 cm^{-1} (11 μm) and 2650 cm^{-1} (3.8 μm). Attenuation by water vapour and gases is relatively small in these regions amd surface reflection by a water surface is also minimal. Hence, water temperature can be determined by Kirchhoff's Law and the Planck function. Likewise, the atmospheric effect can be expressed in terms of temperature (Fig. 3).

To use ACM, the distribution of several gaseous attenuators and water vapour must be quantified over the atmospheric pass length. Water vapour accounts for most of the attenuation; it is also the most variable component. Other lesser attenuators (carbon dioxide, nitrogen, ozone, etc.) can be assumed to have a relatively slowly changing global distribution. Therefore, the distribution of gaseous attenuators can be reasonably defined by use of standard model atmospheres, but realistic estimates of water vapour distribution through the atmosphere require input of local radiosonde (RAOB) data.

ACM is based on concepts similar to those proposed by Wark et al. (1962). Shaw used a similar approach to develop a method for correcting surface water temperatures measured by an airborne sensor (Shaw and Irbe, 1972). The method was used with good results (r.m.s. error of 0.5°C) in the ART program on the Great Lakes (Irbe, 1972). The ACM now in use was developed by combining the Shaw method with the LOWTRAN (Low Resolution Transmission) model of Selby et al. (1976).

ATMOSPHERIC CORRECTION PROGRAM

The atmospheric correction program calculates correction for surface water temperatures obtained from ch. 4 or ch. 5 SRT data.

Input Data

Pressure, temperature and humidity data from RAOB ascents are input at the beginning of the program. RAOBs from stations nearest to the water body and closest in time to the satellite pass are selected. For large water bodies RAOBs from several stations may be input; the program merges the data to produce an "average" temperature/humidity profile for the atmosphere over the survey area.

Usually the lowest RAOB levels are adjusted prior to input to account for: a) average surface air conditions in the survey area at the time of the satellite pass, as indicated by hourly observations at stations in the area, and b) modification of the air mass by the water body itself. Further adjustments are required if the RAOB ascents penetrate cloudy layers, indicated by spikes in the humidity profile. Since surface temperatures can be evaluated only for cloud-free areas, the cloudy layers are eliminated from the RAOB data by smoothing out the humidity spikes.

Atmospheric Transmittance Model

The program uses the LOWTRAN 3B (updated version) transmittance model developed by Selby et al. (1976). The model is versatile in that atmospheric transmittance can be calculated over a range of 0.25 to 28.5 μm, for vertical, horizontal and slant paths through the atmosphere, and for aircraft as well as satellite heights. The model contains transmittance functions for water vapour, uniformly mixed gases and ozone, and absorption coefficients for the gaseous elements and aerosols. Model atmospheres for water vapour and ozone (six), aerosols (five) and haze (two) are also provided.

Program Functions

The radiation intensity detected by a sensor through a spectral band-pass filter can be expressed as a function of: a) radiation emitted and reflected by the target, b) attenuation and emission by the intervening atmosphere, and c) transmittance efficiency of the filter/optics system.

Starting with a given pressure/temperature/humidity profile (from RAOBs) and a given distribution of gaseous constituents and aerosols (from LOWTRAN model atmospheres), the program uses the radiative transfer equation to calculate the upward intensity of radiation transmitted progressively through 10-millibar layers of the atmosphere, and finally, through the filter/optics systems. Contributions from the different terms are evaluated for small wave-number intervals and then integrated over the filter band-pass range.

In the radiative transfer equation (see below) the net detected radiance is equal to the sum of three terms that correspond to surface emitted radiation, reflected radiation, and radiation emitted by the atmosphere, respectively.

$$N(Z, u) = \frac{1}{\pi} \int_{V_1}^{V_2} \phi(V)\, \varepsilon(V)\, B_V(T_o)\, t_V(o, Z; u)\, dV$$

$$+ \frac{1}{\pi} \int_{V_1}^{V_2} \int_{o}^{Z} \phi(V)\, (1 - \varepsilon(V)) \times$$

$$t_V(o, Z; u)\, B_V[T(z)]\, \frac{\partial t_V(o; z; u)}{\partial z}\, dz\, dV$$

$$+ \frac{1}{\pi} \int_{V_1}^{V_2} \int_{o}^{Z} \phi(V)\, B_V[T(z)]\, \frac{\partial t_V(z, Z; u)}{z}\, dz\, dV$$

where the following notation is used

N	detected radiance
Θ	zenith angle
u	cos Θ
Z	radiometer altitude
V	wave number
$\phi(V)$	filter function so that o(V) = o outside the interval $[V_1, V_2]$
$B_V(T)$	Planck function at absolute temperature T
$\varepsilon(V)$	emissivity of the radiating surface
T_o	surface temperature (K)
$t_V(z_1, z_2; u)$	transmittance of the layer located between altitudes z_1, and z_2 for incidence Θ, and

$$t_V(z_1, z_2; u) = \exp\left[- \frac{1}{u} \int_{z_1}^{z_2} K_V(z)\, dz \right],$$

where K_V is the total absorption coefficient in m^{-1} which is equal to the sum of the aerosol and molecular absorption coefficients.

The atmospheric correction program finds the value of the true temperature for a given indicated temperature and zenith angle by iterative calculation with different target temperatures until the equation is balanced to a specified residual error. Program output is an array of indicated vs. corrected temperatures for zenith angles of 0 to 50 degrees. This array is used later in the calibration routine of the main data analysis program.

TWO CHANNEL METHOD

The two channel (or multiple channel) method for obtaining surface water temperatures is based on the fact that, after some simplification and approximation of the radiative transfer equation, it can be shown that the error introduced in radiometric temperature measurements by the atmosphere is proportional to a wavelength-dependent absorption coefficient. The method has received the attention of several investigators, including Deschamps and Phulpin (1980), who show that surface temperature can be obtained from the linear relationship:

$$T_o = a_o + \sum_{i=1}^{n} a_i T_i$$

where T_o is surface temperature
a_o is a constant term accounting for surface reflection and emission by CO_2
T_i is the radiometric temperature at a wavelength λ_i
a_i is a coefficient dependent on the absorption coefficient at wavelength λ_i

Using a set of diverse RAOB temperature and humidity profiles, McClain (1980) has calculated atmospheric corrections for various combinations of radiometrically derived surface water temperatures from all the AVHRR channels on board NOAA-6. From these calculations McClain has developed a workable algorithm that gives surface temperatures from ch. 3 and ch. 4 data:

$$T_s = 1.28 + T_{11} + 1.42 (T_{3.8} - T_{11})$$

where T_s is surface temperature
T_{11} is ch. 4 radiometric temperature
$T_{3.8}$ is ch. 3 radiometric temperature

The above algorithm is used in the two channel calibration routine of the main data analysis program.

As mentioned before, TCM was found to give unsatisfactory results in most of the cases when it was tried at AES. The main problem is a high noise level in the temperature field. Deschamps and Phulpin (1980) show that the instrumental noise is amplified in a multiple channel algorithm, and they have proposed instrumental noise limits for successful application of the method. In additon, use of ch. 3 data in TCM limits application of the method to nighttime passes, due to contamination by reflected solar radiation and sun glitter in the 3.8 μm window.

It is hoped that the two thermal infrared channels (ch. 4 and ch. 5) carried by NOAA-7 will give better results with TCM and obviate the use of ch. 3.

TEMPERATURE COMPARISONS

When AES decided to undertake systematic monitoring of Great Lakes temperatures from SRT data, it became necessary to assess the accuracy of the temperature measurements. The Great Lakes ART Survey Program was continued on a reduced scale until 1980, in order to compare temperatures obtained by the two radiometric methods. In addition, the SRT temperatures were compared with temperatures measured at meteorological buoys operated by the Canada Centre for Inland Waters.

Certain unavoidable difficulties are encountered when effecting comparisons of SRT temperatures with more conventional temperature measurements. The problems have been discussed fully by Morcrette and Irbe (1978) and Irbe et al. (1979). Briefly, the problems arise due to inaccuracies in matching data points, large differences in data resolution and sensor-related differences in the defintion of "surface water temperature".

Data point location errors are common to SRT and ART measurements. Errors in SRT data registration are caused by orbital perturbation and roll and yaw of the spacecraft. Inaccurate determination of flight tracks introduces errors in ART data point location. Furthermore, SRT and ART data collection times may differ by several hours, in which case diurnal water temperature changes become a factor.

Comparisons have doubtful validity in regions of strong surface temperature gradients, due to disparities in data resolution: 1 km^2 at best for SRT, 10^{-4} km for ART, and point measurement for buoy temperatures.

Significant vertical temperature gradients can occur in the topmost few centimetres of the surface layer of water. Since SRT and ART measure the radiative temperature of the water surface, whereas buoy measurements are taken by an immersed sensor, the differences in measured temperatures can be real.

In view of the several unknown factors, there simply is no standard against which SRT measurements could be assessed. The three data sets can be compared only in a relative sense, i.e. for closeness of agreement, recognizing that each has unique properties and intrinsic errors. Therefore, the term "r.m.s. (root-mean-square) difference" rather than "r.m.s. error" is used in this discussion.

The first comparisons, using NOAA-5 data, were obtained in 1977, and were reported on by Morcrette and Irbe (1978) and Irbe et al. (1979). The results indicated a r.m.s. difference of about 1.5°C between SRT and buoy and 1°C between SRT and ART measurements.

A second set of comparisons was collected in 1979 and 1980. In this case the SRT temperatures were extracted from TIROS-N and NOAA-6 data. Comparisons were attempted also using temperatures produced by the two channel algorithm from ch. 3 and ch. 4 data of NOAA-6, in the few instances where the resultant temperature field appeared to be relatively noise-free.

The results of eight comparisons between SRT (ch. 4) and ART measurements appear in Table 2. In the 14 July 1980 case the SRT data are probably contaminated by very light low-level fog. Excluding this case, the r.m.s. difference is 2.25 °C for indicated (i.e. uncorrected) and 1.2 °C for temperatures corrected by ACM. These differences agree closely with those repoted earlier by Irbe et al. (1979).

No conclusions can be drawn from the three comparisons of the two channel temperatures, except to say that the temperatures appear to be considerably less reliable.

Comparisons between SRT (ch. 4) and buoy temperatures were obtained on Lake Erie for 35 orbits. The buoys were located in deep water, no less than 10 km from shore, so there was no problem with large near-shore temperature gradients that were encountered by Morcrette and Irbe (1978).

Temperature analyses had been done for five orbits when conditions were marginal, i.e. a very hot, humid and hazy air mass occupied the region, and the atmospheric correction was 3.5°C, or greater. Since routine lake temperature analyses are not attempted under such conditions, these cases were excluded from final statistics.

The remaining 30 cases were grouped by zenith angle to investigate the effect of atmospheric path length or reliability of SRT measurements. As can be seen in Table 3, the r.m.s. difference between buoy and corrected SRT temperatures is 0.6°C for zenith angles smaller than 45 degrees. With larger zenith angles the r.m.s. difference increases sharply to 2.1°C.

It appears that, in order to avoid the probability of large errors in SRT measurements, data analyses should be limited to reasonably dry and clear atmospheric conditions and data should be selected from orbits where the zenith angle of the area of interest is smaller than 45 degrees.

APPLICATIONS

As stated in the introduction, there is a continuing demand for surface water temperature data for many diverse applications. Within AES specifically, SRT synoptic water temperatures of coastal zones and large lakes are useful in general meteorological forecasting, as well as in predicting ice conditions on marine shipping routes. Furthermore, it is necessary to accumulate a temperature data base of coastal waters and major lakes for studies of local and regional climatic regimes.

The program of monthly retrieval of surface temperatures from Bay of Fundy and Nova Scotia coastal waters, which was started in 1980, is given as an example of climatological application of a water temperature data base. The SRT temperatures for three selected points in the Bay of Fundy (Fig. 4) are plotted against date (Figs. 5, 6 and 7). The as yet meager data base begins to define the annual temperature regime at the three locations. With input of additional data in the future, the curves will be defined with increasing precision, and other statistics, such as variability and trends in water temperature, will be possible.

CONCLUSIONS

Digital data from infrared sensors on board NOAA polar orbiting sun-synchronous satellites are used for routine retrieval of surface water temperature of lakes and oceans. In areas where radiosonde data are regularly available, temperatures corrected for atmospheric attenuation can be retrieved from single channel thermal infrared (11 μm and 12 μm) data. The corrected temperatures are within $1^{\circ}C$ of buoy temperature measurements (r.m.s. difference of $0.6^{\circ}C$), when the zenith angle of the area in question is less than 45 degrees with respect to satellite track and the atmosphere is relatively dry and clear.

Temperature retrieval by the two channel method is less reliable and has been limited in the past to nighttime orbits, due to contamination of ch. 3 (3.8 μm) data by reflected solar radiation. Furthermore, the two channel method amplifies instrumental noise, necessitating large scale averaging of the temperature field. Therefore, the two channel method is suitable mainly for temperature analyses of large oceanic areas, where degradation of resolution in the temperature field is not a critical factor. It is hoped that improved results will be forthcoming when the two channel method is applied to data of the two thermal infrared channels (ch. 4 and ch. 5) on board NOAA-7 satellite.

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Table 1

ALPHA-NUMERIC CODE AND CORRESPONDING INDICATED AND CORRECTED TEMPERATURE (°C) FOR PRINTOUT IN FIG. 1.

Code Char.	Ch. 4 Ind. Temp.	ACM-Corr. Temp.
□	12.2	14.2
φ	11.8	13.7
1	11.3	13.2
*	10.9	12.7
*	10.4	12.1
4	10.0	11.6
5	9.5	11.1
•	9.1	10.6
•	8.6	10.0
8	8.1	9.5
+	7.7	8.9
+	7.2	8.4
B	6.7	7.8
C	6.3	7.3
–	5.8	6.7
–	5.3	6.2
F	4.9	5.6
G	4.4	5.0
H	3.9	4.4
@	⩽ 3.4	⩽ 3.9

Table 2

COMPARISON OF SURFACE WATER TEMPERATURE MEASURED BY AIRBORNE RADIATION THERMOMETER (A.R.T), SATELLITE CH. 4 (11 μm) and COMBINED CH. 3 (4 μm) and CH. 4

LAKE	ORBIT	SATELLITE		AV. Z.A. DEG.	A.R.T.		TIME DIFF. HRS.	PTS.	CH. 4 R.M.S. DIFFERENCE		CH. 3 + CH. 4 R.M.S. DIFF.
		DATE	TIME G.M.T.		DATE	TIME G.M.T.			IND. TEMP.	CORR. TEMP.	
GEO. BAY	T–N 4230	9 AUG. 79	1000	48	9 AUG. 79	1500	5	91	2.63	0.73	
ONTARIO	N–6 922	31 AUG. 79	1300	40	31 AUG. 79	1430	1.5	94	2.73	1.41	
ERIE	T–N 4786	17 SEP. 79	1930	47	17 SEP. 79	1500	4.5	31	1.31	0.44	
ERIE	N–6 1264	24 SEP. 79	1430	53	24 SEP. 79	1530	1	94	3.67	0.67	
ONTARIO	N–6 3680	12 MAR. 80	1300	31	12 MAR. 79	1600	3	113	1.28	0.42	1.74
ERIE	N–6 4192	17 APR. 80	1300	25	17 APR. 80	1600	3	129	2.00	0.92	
HURON	N–6 4881	5 JUN. 80	0000	53	4 JUN. 80	1600	8	175	1.36	1.89	3.43
ERIE	N–6 5443	14 JUL. 80	1230	60	14 JUL. 80	1600	3.5	131	6.15*	4.74*	1.07
					AVERAGE R.M.S. EXCLUDING LAST COMPARISON				2.25	1.19	

*SUSPECT LIGHT FOG OVER LAKE AT TIME OF SATELLITE PASS

Table 3

COMPARISON OF SURFACE WATER TEMPERATURE
MEASURED BY BUOYS WITH TEMPERATURE
OBTAINED FROM SATELLITE CH. 4 (11 μm) DATA

ZENITH ANGLE	CASES	TEMP. R.M.S. DIFF. UNCORR.	TEMP. R.M.S. DIFF. CORR.	AVERAGE ATM. CORR. °C
0 – 20	6	2.18	0.64	2.3
21 – 40	7	2.58	0.51	2.4
41 – 60	15	3.90	2.03	1.8
⩾61	2	4.26	2.21	2.1
0 – 44	14	2.57	0.60	2.4
⩾45	16	3.93	2.10	1.7
ALL ANGLES	30	3.37	1.59	2.0
ALL CASES	35*	3.38	1.65	2.4

* INCLUDES CASES WITH VERY HUMID ATMOSPHERES, WHERE CORRECTIONS WERE ⩾3.5°C

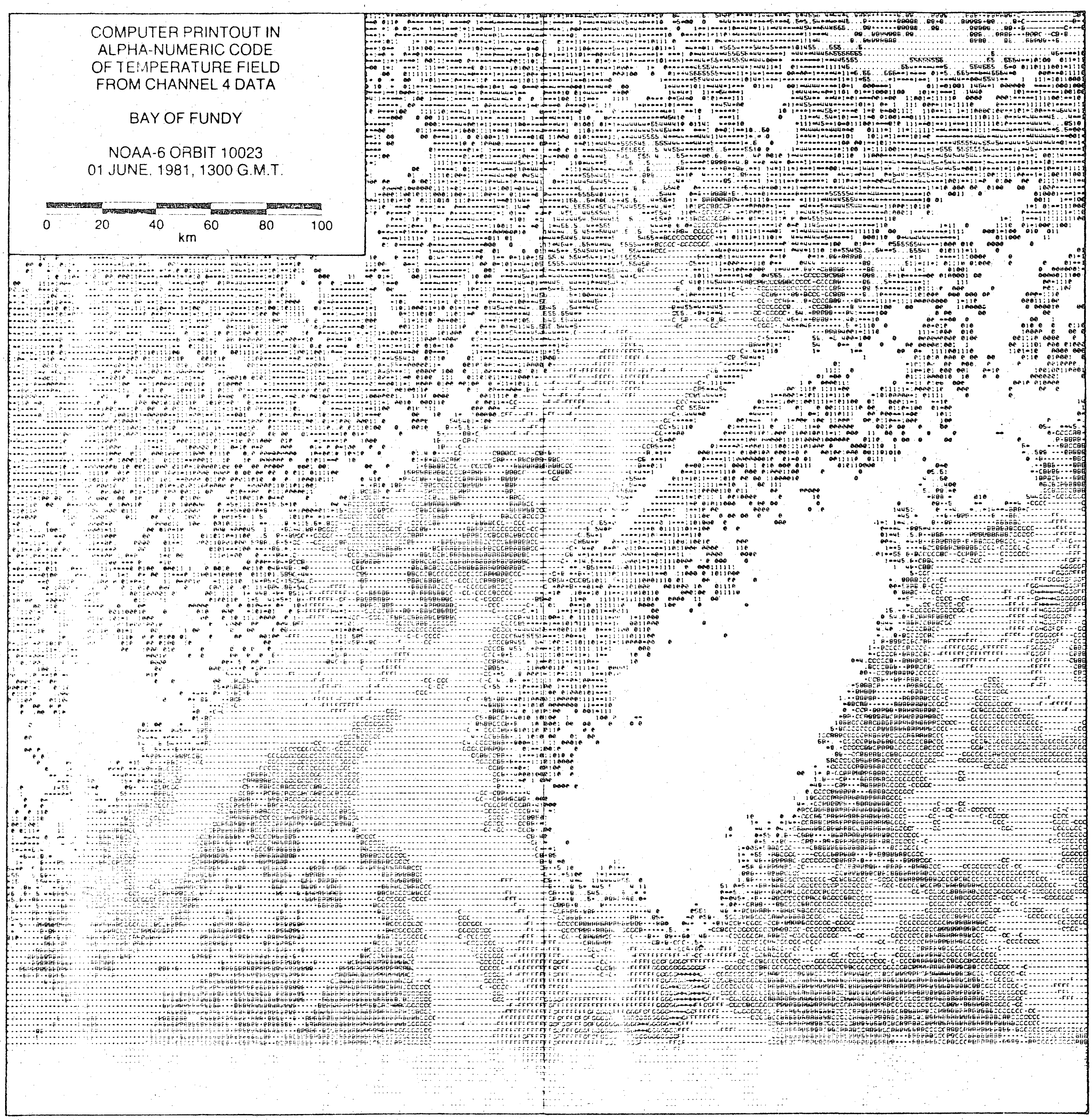

COMPUTER PRINTOUT IN
ALPHA-NUMERIC CODE
OF TEMPERATURE FIELD
FROM CHANNEL 4 DATA
BAY OF FUNDY
NOAA-6 ORBIT 10023
01 JUNE. 1981, 1300 G.M.T.
0 20 40 60 80 100
km

Fig. 1

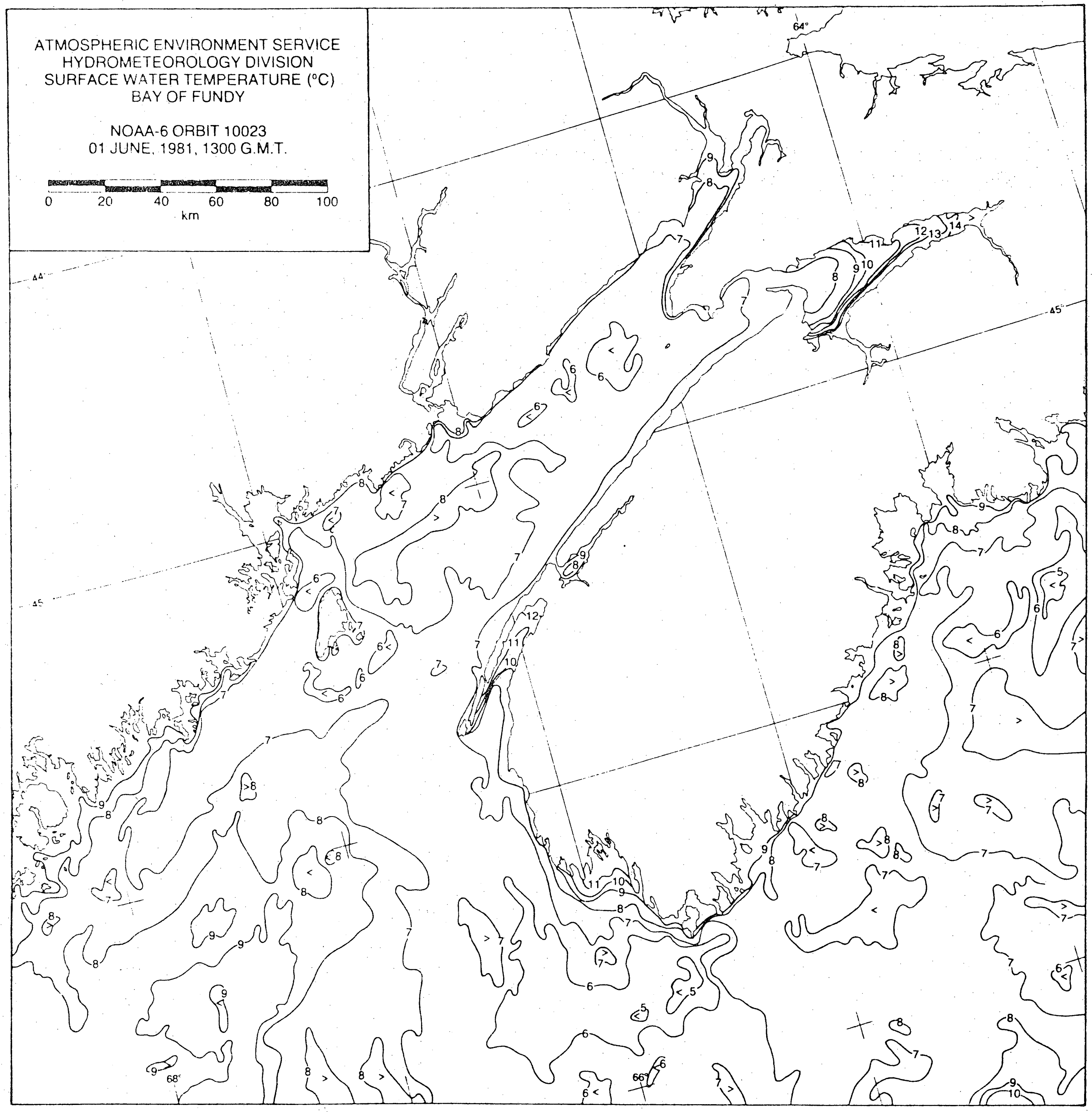
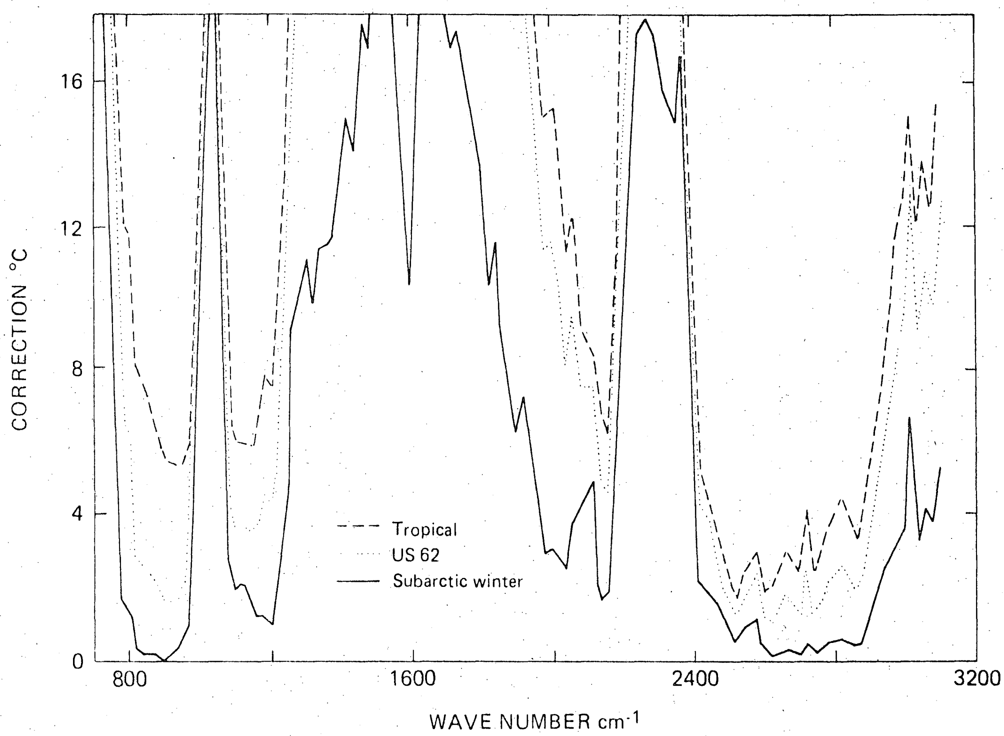

ATMOSPHERIC ENVIRONMENT SERVICE
HYDROMETEOROLOGY DIVISION
SURFACE WATER TEMPERATURE (°C)
BAY OF FUNDY
NOAA-6 ORBIT 10023
01 JUNE, 1981, 1300 G.M.T.
0 20 40 60 80 100
km
64°
45°
68°

Fig. 2



ATMOSPHERIC CORRECTION AS A FUNCTION OF WAVELENGTH BETWEEN 800 AND 3200 CM^{-1}.

Fig. 3

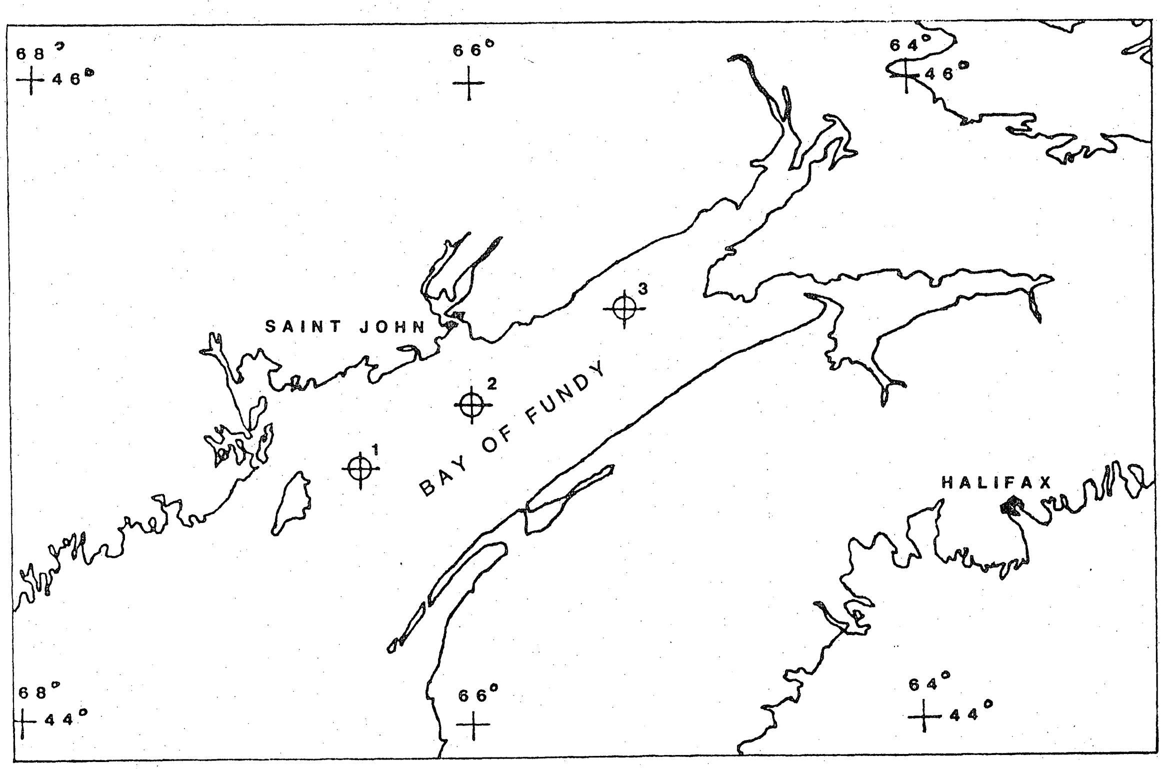


FIG. 4 LOCATION OF SELECTED POINTS

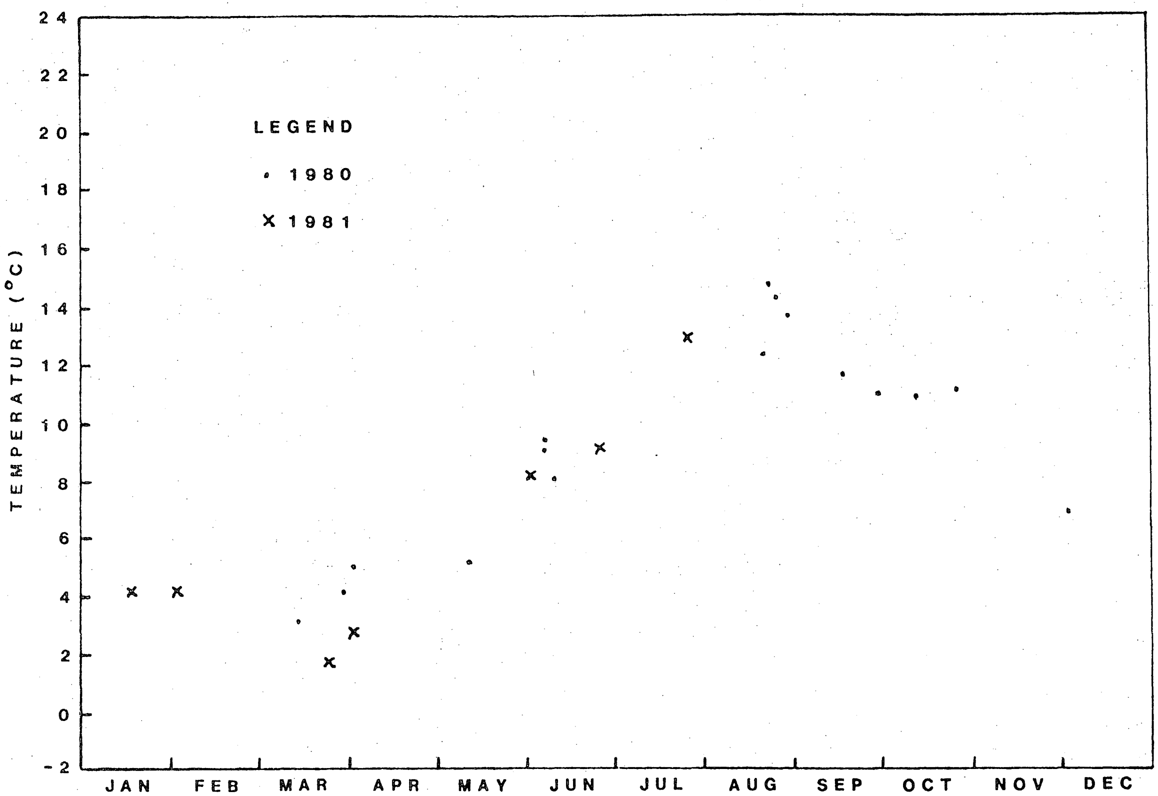


FIG. 5 SURFACE TEMPERATURE AT POINT NO. 1

(44.8°N, 66.5°W, BAY OF FUNDY)

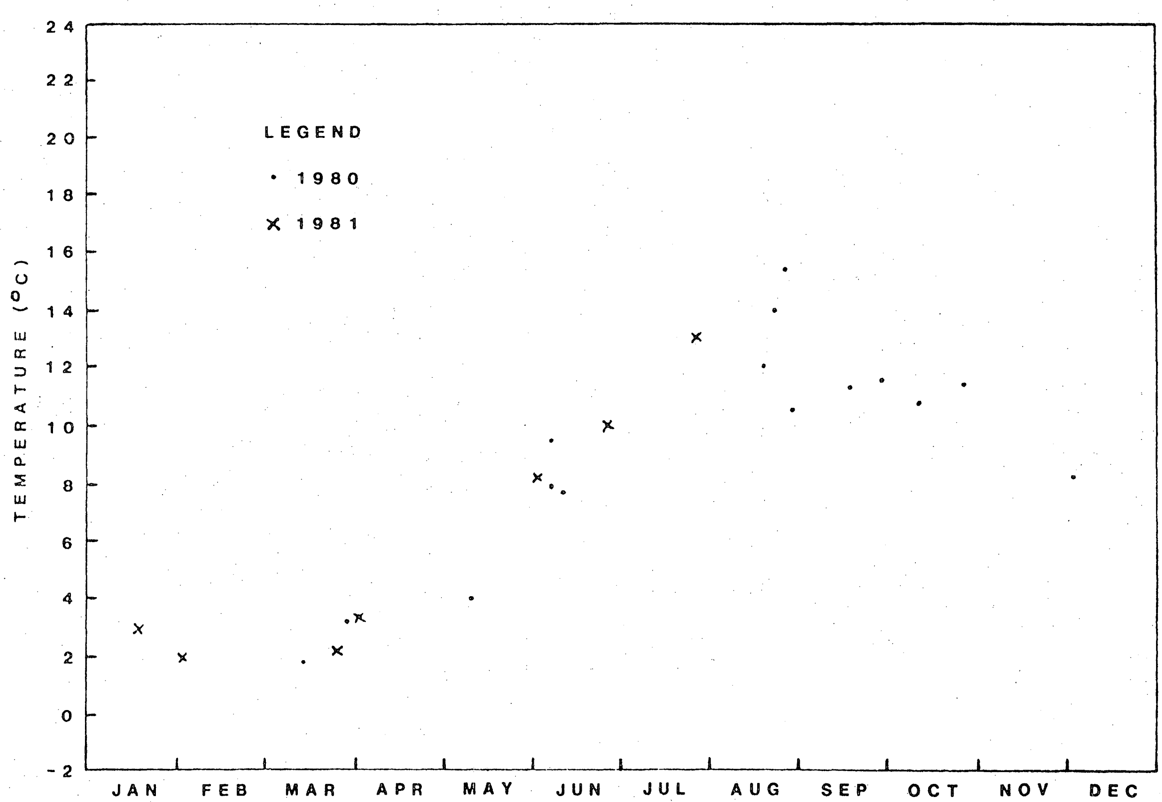


FIG. 6 SURFACE TEMPERATURE AT POINT NO. 2

(45.0°N, 66.0°W, BAY OF FUNDY)

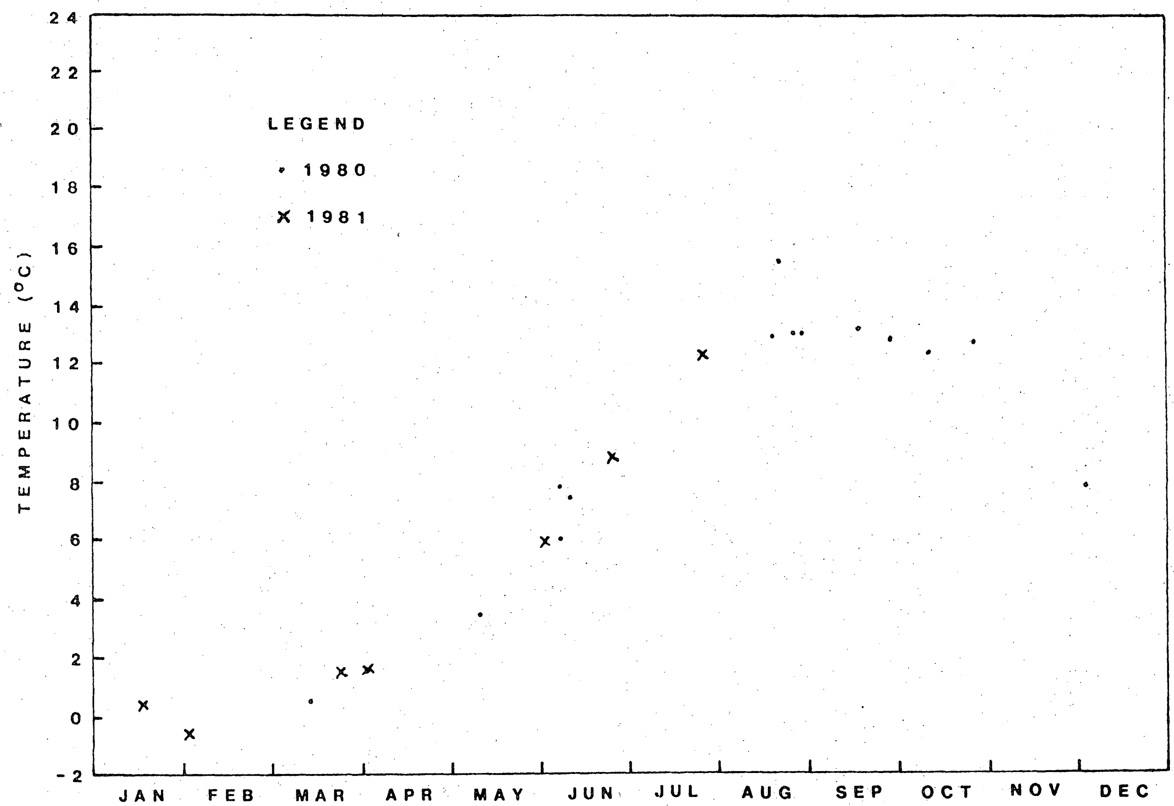


FIG. 7 SURFACE TEMPERATURE AT POINT NO. 3

(45.3°N, 65.3°W, BAY OF FUNDY)