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NORMAL WATER TEMPERATURE AND ICE COVER OF THE LAURENTIAN GREAT LAKES: A COMPUTER ANIMATION, DATA BASE, AND ANALYSIS

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NORMAL WATER TEMPERATURE AND ICE COVER OF THE LAURENTIAN GREAT LAKES
A Computer Animation, Data Base, and Analysis Tool

Karl Schneider, Raymond A. Assel, and Thomas E. Croley II

ASTRACT. A long-term temperature and ice cover data base was created together with a computer program to display and analyze different aspects of normal temperature and ice cover in the Great Lakes. "Normal" refers to long-term averages over the annual cycle. The daily normal surface temperature of each of the Great Lakes was derived from remotely sensed data acquired by the Canadian Atmospheric Environment Service (AES) and by NOAA. Normal ice cover maps, from the NOAA Great Lakes Ice Atlas, were interpolated to yield daily patterns and converted to a Mercator projection with a 2.5 km grid resolution used for the satellite-derived surface temperature maps.

The two-dimensional surface temperature and ice data, bathymetry maps, and normal daily vertical temperature profiles (interpolated from thermodynamic models) were combined into a data base for an analysis and animation program. This interactive, menu-driven computer program, for an IBM-compatible PC with color VGA graphics, has four main modules for data presentation: a) normal daily surface temperature and ice patterns, b) horizontal surface temperature profiles, c) normal daily vertical temperature depth profiles, and d) surface temperature and ice cover versus bathymetry. All modules display daily normal values in animated sequences. Online documentation of the program and the dataset is provided. The two-dimensional data (module a) are presented in color-coded maps, and modules b, c, and d provide line drawings. The animations can be manipulated interactively and temperature and ice values, along with geographical location or depth, can be accessed and displayed numerically with a mouse-driven cursor. The dependence of temperature and ice cover on bathymetry can be investigated in two ways: (1) by toggling between the spatial temperature pattern and bathymetry, and (2) by viewing plots of temperature or ice versus depth. The two-dimensional surface temperature data for each lake are stored in a documented data base with 0.1°C resolution. Ice cover data are stored in 10% ice cover concentration steps. Modeled normal vertical temperature profiles are stored in 0.0 1°C steps.

1. INTRODUCTION

Lake surface temperature is a critical factor in many physical, biological, and chemical studies. It also has a great impact on human activities on the lake and its environs; many social, economic, and cultural activities are determined by the temperature of the lake. Knowledge of the lake surface temperature is critical for research (primary production, hydrological and meteorological studies, water quality), economic decisions, and investments (sewage or power plant management, transportation, recreation, fishing).

Lake surface temperature is an integrated expression of past meteorology, heat storage, and lake dynamics. The parameters that determine lake surface temperature are not horizontally homogeneous. Thus, lake surface temperatures show horizontal patterns, which result from the complex interaction of energy fluxes, heat storage, and limnokinetics. Especially with regard to climate change studies, lake surface temperature and heat storage are very important indicators for long-term changes of environmental conditions. Due to their large energy storage capability, lakes integrate energy fluxes over longtime-periods and are therefore especially sensitive to changes of the magnitude and temporal course of energy fluxes which occur as a result of changing climatic conditions.

Deriving two-dimensional temperature and ice patterns from synoptic measurements is practically impossible with conventional methods, especially for large lakes such as the Great Lakes. The development of remote-sensing technology for environmental research during 1960-1980 made monitoring synoptic surface temperature and ice distribution patterns in lakes feasible. In 1983, a 20-winter normal of the spatial and seasonal pattern of ice cover concentration for the Great Lakes was published from historical ice charts produced during the 1960s and 1970s (Assel et al., 1983). More recently, a 23-year (1966-1988) Great Lakes surface water temperature climatology was published (Irbe, 1992). These two publications contain maps which provide very useful information about ice cover and lake surface temperature seasonal and spatial patterns.

However, the printed maps have two major shortcomings which limit their utility: (1) the information access for further research is difficult, and (2) maps do not provide an understanding of the dynamics and temporal development of the changes in two dimensional patterns from one map to the next. The accessibility of personal computers today offers new ways to present two-dimensional data, thus solving some of the shortcomings of printed maps. Computer animations and films of water surface temperature and ice cover have proved to be a very useful tool to understand lake dynamics (Leshkevich, 1982; Assel and Ratkos, 1991; Schneider, 1992).

This report presents an update of the temperature and ice cover patterns presented in previous publications. A computer program to display and analyze various aspects of Great Lakes temperature and ice cover patterns is described. The interactive, menu-driven computer program was written for an IBM-compatible PC running under DOS, with a color VGA graphics adapter. It displays two-dimensional patterns of temperature and ice cover in animated sequences. To visualize the dependence of temperature and ice cover patterns on the depth of the lake, two-dimensional temperature and ice cover patterns can be directly compared with the lake bathymetry. To further investigate the relationship of temperature/ice cover and bathymetry, plots of temperature versus bathymetry and ice cover versus bathymetry can be displayed. Furthermore, horizontal temperature profiles along user-defined trajectories can be selected and presented in line drawings. Patterns of surface temperature and ice cover depend on the temperature and heat storage of the underlying water column. To investigate this dependence, normal temperature profiles for each Great Lake are presented. The format of the two-dimensional normal surface temperature and ice cover data base and of the vertical temperature profile data base is described in appendix A. The datasets build, along with bathymetric data, a data base for a variety of further research.

2. DATA SOURCES, PROCESSING, ANALYSIS

Figure 1 gives a schematic overview of the processing of the normal temperature and ice cover data base. The processing steps include generating a satellite image data base from which the normal temperature patterns are defined, creating a normal ice cover data base from multi-year ice cover observations, and developing bathymetry maps from a bathymetry data base. These data bases are extrapolated to a common grid and combined to a normal temperature and ice cover data base. Data sources, processing, and analysis of the data to generate the data base are discussed in detail in the following paragraphs.

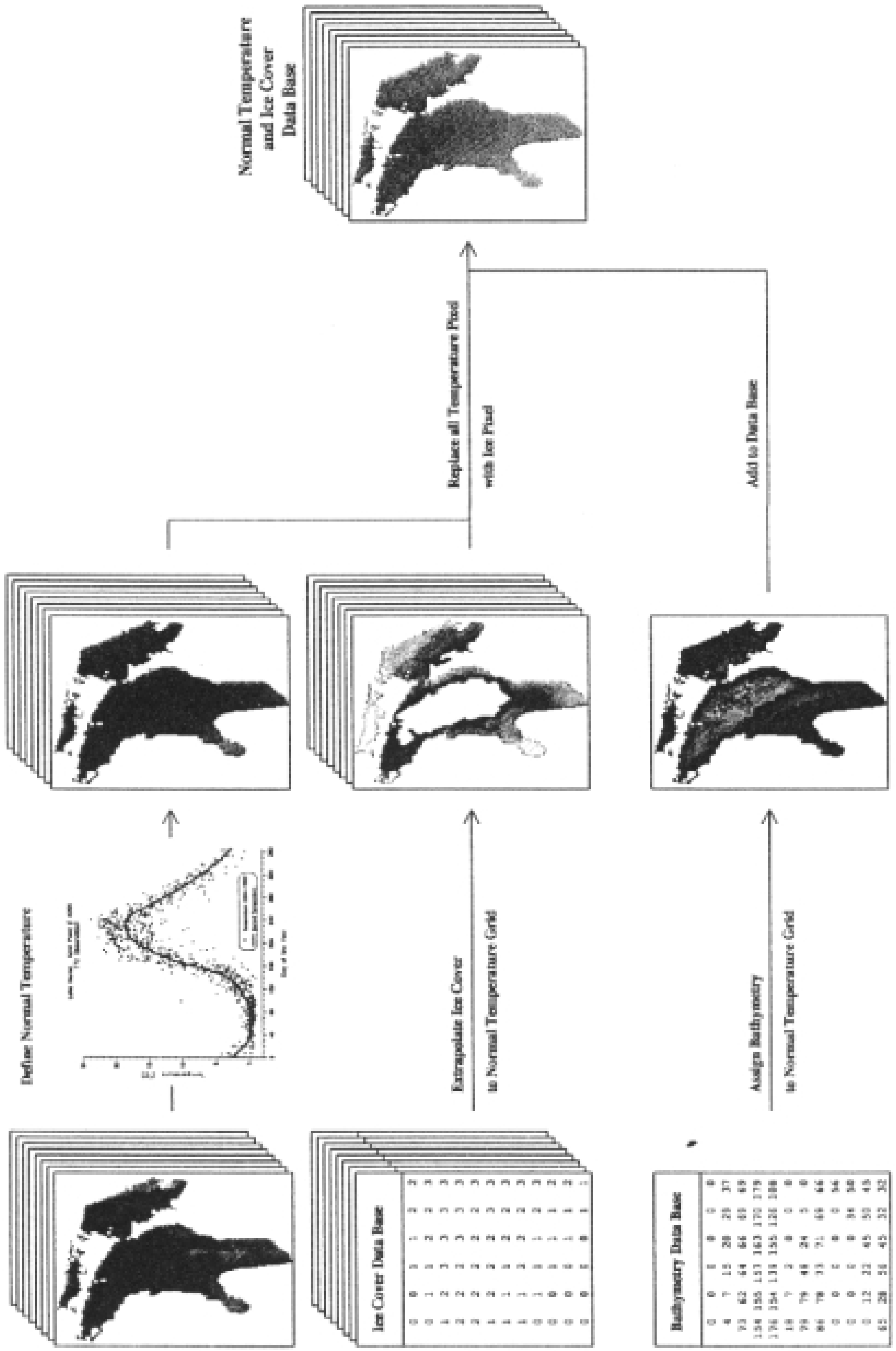


Figure 1.--Schematic overview of the generation of the normal temperature and ice cover data base.

2.1 Ice Cover Data

2.1.1 The GLERL Ice Concentration Data Base and Climatology

Ice concentration, the percent of a unit of surface area covered by ice, was digitized for more than 2800 ice charts spanning 1960 to 1979 to 5-by-5-km Cartesian coordinate grid cells (Assel, 1983) for each Great Lake. Table 1 shows the number of ice charts used to generate the normal ice cover database and the number of grid cells per ice chart for each Great Lake. The center of each grid cell was cross referenced by its latitude and longitude coordinates, enabling georeferencing of these data. The original ice chart observations were quite heterogenous in spatial and temporal coverage, making it untenable to perform analysis below a half-month time period. The gridded data were divided into 9 half-monthly periods (HMP), starting 16-31 December and ending 16-31 April. The maximum, minimum, average, mode, and median ice concentrations were calculated for each HMP for each grid cell for each of the five Great Lakes. The median (instead of mode or average) ice concentration was used to define the normal spatial and seasonal progression of ice cover on each Great Lake (Assel et al., 1983) because it provides the most coherent spatial and seasonal pattern of ice formation and loss. The ice cover data base and climatology is available to the public through World Data Center A for Glaciology (Snow and Ice), CIRES, Campus Box 449, University of Colorado, Boulder, Colorado 80309.

Table 1.— The GLERL Ice Cover Data Base

Lake	Number of Ice Charts	Number of Grid Cells	Total number of observations
Superior	618	3,195	1,974,510
Michigan	489	2,224	1,087,536
Huron	845	2,308	1,950,260
St.Clair-Erie	565	1,041	588,165
Ontario	307	739	226,873
Total	2,824	9,507	5,872,344

2.1.2 Derivation of the Normal Daily Ice Charts

Normal daily charts of ice cover concentration were derived by linear interpolation between each grid cell of each of the nine HMP normal (median) ice charts given in the NOAA Great Lakes Ice Atlas for each Great Lake. This resulted in 121 normal daily ice charts for each Great Lake starting 22 December, the midpoint of the first HMP and ending 22 April, the midpoint of the ninth HMP. The linear interpolation was made in a straightforward manner, defining the starting date of the interpolation period as the midpoint of each HMP and an ending date as the midpoint of the next HMP and assuming a linear change in ice concentration, at a given grid cell, between these two dates. These normal daily ice charts represent the transition from the normal ice concentration distribution patterns of one HMP to the normal ice concentration distribution patterns of the next HMP. Thus, the normal daily ice charts are not a true daily normal for any given date, but they nevertheless are useful in illustrating the spatial and temporal change in the normal ice cover given in the NOAA Great Lakes Ice Atlas. The interpolated ice concentrations were rounded to the nearest 10% increment; for example, 12% ice concentration was recorded as lo%, and 16% was recorded as 20%. This rounding was done to be consistent with the accuracy of original data. A detailed description of the interpolation procedure and methodology is available elsewhere (Assel and Ratkos, 1991).

2.2 Lake Surface Temperature Data

By averaging across all years of record, the "normal" annual cycle of the water surface temperature was derived from remotely sensed data acquired by the Canadian Atmospheric Environment Service (AES) and by NOAA's Great Lakes Environmental Research Laboratory (GLERL). Images from 1966 to 1993 were used to process the normal lake surface temperature patterns. Table 2 shows the total number of images available to this study. Since the number of images acquired by GLERL for all lakes exceeds the number of images available through AES, the normal surface temperature is biased by the higher abundancy of images since 1990. But, comparing the normal temperature patterns displayed here with the climatological temperature patterns published in the Great Lakes Surface Water Climatology (Irbe, 1992) reveals the same major temperature patterns, and thus the bias can be considered small. An image consists of digital surface temperature data. The number of grid points per image in the original datasets is listed in Table 2.

Table 2.—Number of images for normal temperature calculation.

	AES			GLERL			Total
Lake	Period	Images	Gridpts	Period	Images	Gridpts	Images
Superior	1966-1990	236	150	1990-1993	536	12970	772
Michigan	1966-1990	77	164	1990-1993	627	8031	704
Huron	1966-1990	327	188	1990-1993	553	8234	880
St.Clair	1966-1990	0	0	1990-1993	544	126	572
Erie	1966-1990	417	81	1990-1993	544	3292	961
Ontario	1966-1990	509	64	1990-1993	565	2514	1074

Lake St. Clair, North Channel, Black Bay, and Nipigon Bay were not represented on the AES grid. Lake Michigan surface temperatures were only available from AES starting in 1988. Lake Ontario, Lake Erie, Lake Huron with Georgian Bay, and Lake Superior surface temperatures are available since 1966, but the data base for the above-mentioned lakes and bays is considerably shorter.

Remotely sensed surface temperature measurements result from the application of Plank's Law to derive surface temperatures from radiation measured in the thermal infrared spectral region. Unlike conventional temperature measurements, which are conducted within the turbulent mixed layer of the lake, remotely sensed temperature measurements represent the uppermost fraction of a millimeter of the lake. Due to skin effects at the surface, the surface skin is usually some tenths of a degree Celsius cooler than the temperature of the directly underlying, well-mixed water layer (Ewing and McAlister, 1960; McAlister and McLeish, 1969; Paulson and Parker, 1972; Grassl, 1976; Schneider and Mauser, 1991; Schneider, 1992). The surface skin is cooler because of energy losses from longwave radiation, and convection and evaporation. These energy fluxes occur within the surface skin, whereas energy gain due to shortwave radiation penetrates into the water body. Clouds significantly restrict the applicability of remotely sensed surface temperatures; they do not transmit infrared radiation. A closed cloud cover can easily be detected in thermal infrared images, and especially in images of the visible spectrum, but fractional cloud cover, and transparent, light fog cause problems in distinguishing cloud contaminated from cloud free surface temperatures (Simpson and Humphrey, 1990). Thus, one major step in deriving surface temperatures from remote measurements is to eliminate all cloud-contaminated pixels. Even a fractional cloud cover covering only 1% of a pixel can lead to a temperature error of 0.2°C or more (Saunders, 1986). This shows the importance of cloud detection and elimination.

Even a cloud-free atmosphere affects radiative surface temperature measurements because the atmosphere absorbs radiation emitted by a lake surface and emits thermal radiation according to its own temperature and emissivity (Schneider et al., 1990). The atmospheric effect on remote temperature measurements is largely dependent on the water vapor content in the atmosphere (Bernstein, 1982) and usually reduces the satellite-measured absolute temperature and decreases the temperature range. The atmospheric effect is corrected by applying a split window correction algorithm which uses the wavelength dependency of the radiation absorbed by the atmosphere, or by modeling the atmospheric attenuation with an atmospheric radiation and transmittance model (McClain et al., 1985; Bymes and Schott, 1986; Wilson and Anderson, 1986; Walton, 1988; Schneider, 1992).

The influence of cloud cover on the availability of remotely sensed surface temperature images is obvious in Table 3. High cloud probability from November to April (Eichenlaub et al., 1990) significantly decreases the number of available images. The frequency of cloud cover from December to February is for most parts of the lakes greater than 75%. The summer months, June to August, usually have less than 50% cloud cover (Saulesleja, 1986). These 3 months hold more than 40% of Lake Superior, Lake Michigan, Lake Huron, and Lake St. Clair images. The frequency of surface temperature images in September and May is also high. The eastern lakes, Lake Erie and Lake Ontario, have many images in September.

Table 3.— Number of images available for each month.

Lake	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Superior	18	24	59	50	78	105	113	132	85	57	35	16
Michigan	31	35	49	36	64	96	98	107	75	44	31	38
Huron	27	23	56	69	97	129	118	134	93	55	46	33
Erie	29	37	69	81	81	124	111	141	111	78	42	57
St. Clair	12	20	25	35	45	79	67	89	75	35	23	39
Ontario	44	63	92	83	93	122	125	127	123	86	54	62

Since 1990, GLERL has received satellite images from NOAA satellites on an operational basis (Leshkevich et al., 1993) in its CoastWatch program. The data are calibrated, quality controlled, earth located, and atmospherically corrected by NOAA's National Environmental Satellite, Data, and Information Service (NESDIS), mapped to a Mercator projection, and resampled to a 5 12x5 12 pixel grid (Maturi and Taggert, 1993). To be compatible with this dataset, the grid used to process the normal surface temperature and ice cover was adapted from the full region, Mercator projection grid of the CoastWatch dataset. The grid spacing is 2.56 km at mid latitude.

Due to their different origin and processing level, the AES and GLERL surface temperature datasets were processed differently and then combined.

2.2.1 AES Dataset

The AES dataset consists of airborne and satellite-borne radiometric surface temperature measurements. Airborne surface temperature measurements were taken between 1966 and 1979. Starting in 1980, surface temperature maps were derived from satellite images of the NOAA Advanced Very High Resolution Radiometer (AVHRR). Lake Michigan surface temperature maps have been processed since 1987. As stated earlier, Black Bay and Nipigon Bay in Lake Superior, Lake St. Clair, and North Channel were not represented in the AES grid. The dataset provided by AES is sampled to a grid with a 5-15 minute latitude/longitude spacing and tailored to suit the size and shape of each lake.

AES surface temperature data are atmospherically and geometrically corrected. A comparison of 452 satellite-based temperature measurements with buoy measurements at 1-m depth yielded an average difference of 0.3°C and a standard deviation of 0.9°C. Fifty-one intercomparisons for airborne measurements with submerged thermistors and ship buckets revealed a 0oC difference and a standard deviation of 0.6°C (Irbe, 1992). Given that radiometric temperature measurements take place within the viscous boundary layer and that conventional measurements are taken within the turbulent mixed zone below this boundary layer, this difference is negligible from a climatological viewpoint.

To combine the AES surface temperature measurements with GLERL satellite images, we extrapolated the surface temperatures for each observed day with more then 33% observed grid points to the 2.56 km grid using an inverse square distance weighting method. Table 2 lists the number of grid points in the AES and GLERL grids for each processed Great Lake.

2.2.2 GLERL Dataset

GLERL surface temperature data are based solely on images from the NOAA/Am. In the first phase of NOAA's Coastal Ocean Program (CoastWatch) only mostly cloud-free images were processed by NESDIS and available to GLERL. Since May 1991, all images of NOAA AVHRR-11 are processed regardless of cloud cover, yielding one daytime and one nighttime image of the Great Lakes area per day. Several improvements were made to the processing procedure used to create and map Great Lakes surface temperature images from AVHRR data. Since 1990, three procedures have been used: SSTMAP (April 1990-June 1991), IMGMAP (June 1991-October 1992), and OCNMAP (since June 1992). The major distinctions between OCNMAP, SSTMAP, and IMGMAP algorithms are different atmospheric correction equations (Leshkevich et al., 1993). The images received by GLERL are calibrated, corrected for atmospheric effects, mapped, and resampled to a 2.56-km grid.

Only fully atmospheric corrected images of AVHRR-11 were used in this study. AVHRR-11 is equipped with three spectral bands in the thermal infrared region, and therefore enables correction of atmospheric attenuation using a multiple window algorithm. These multichannel equations are based on the observation that atmospheric attenuation depends on wavelength, whereas atmospheric radiation is largely independent of wavelength (Viehoff, 1983). Therefore, the atmospheric effect can be calculated from two or more independent spectral measurements in the thermal infrared. As mentioned above, the atmospheric correction equations used in the SSTMAP, IMGMAP, and OCNMAP procedure are different. A comparison of buoy measurements at 0.5-m depth with AVHRR-11 temperature measurements yielded, for SSTMAP images, a mean offset of buoy minus satellite measurement of 1.13°C for daytime images and 1.72°C for nighttime. Using the IMGMAP procedure, the mean difference was -0.11% for daytime images and -0.03°C for nighttime images. A similar comparison between AVHRR images and buoy measurements will be done for the OCNMAP procedure when sufficient data are available. However, a comparison of temperatures, produced by OCNMAP and IMGMAP atmospheric correction equations with buoy measurements, revealed that OCNMAP-derived temperatures were in most cases closer to the buoy measurements and generally showed a lower bias than IMGMAP temperatures (Leshkevich et al., 1993). Table 4 lists the number of SSTMAP, IMGMAP, and OCNMAP images used to derive the normal temperature patterns.

Table 4.— Number of CoastWatch images used for normal temperature calculation.

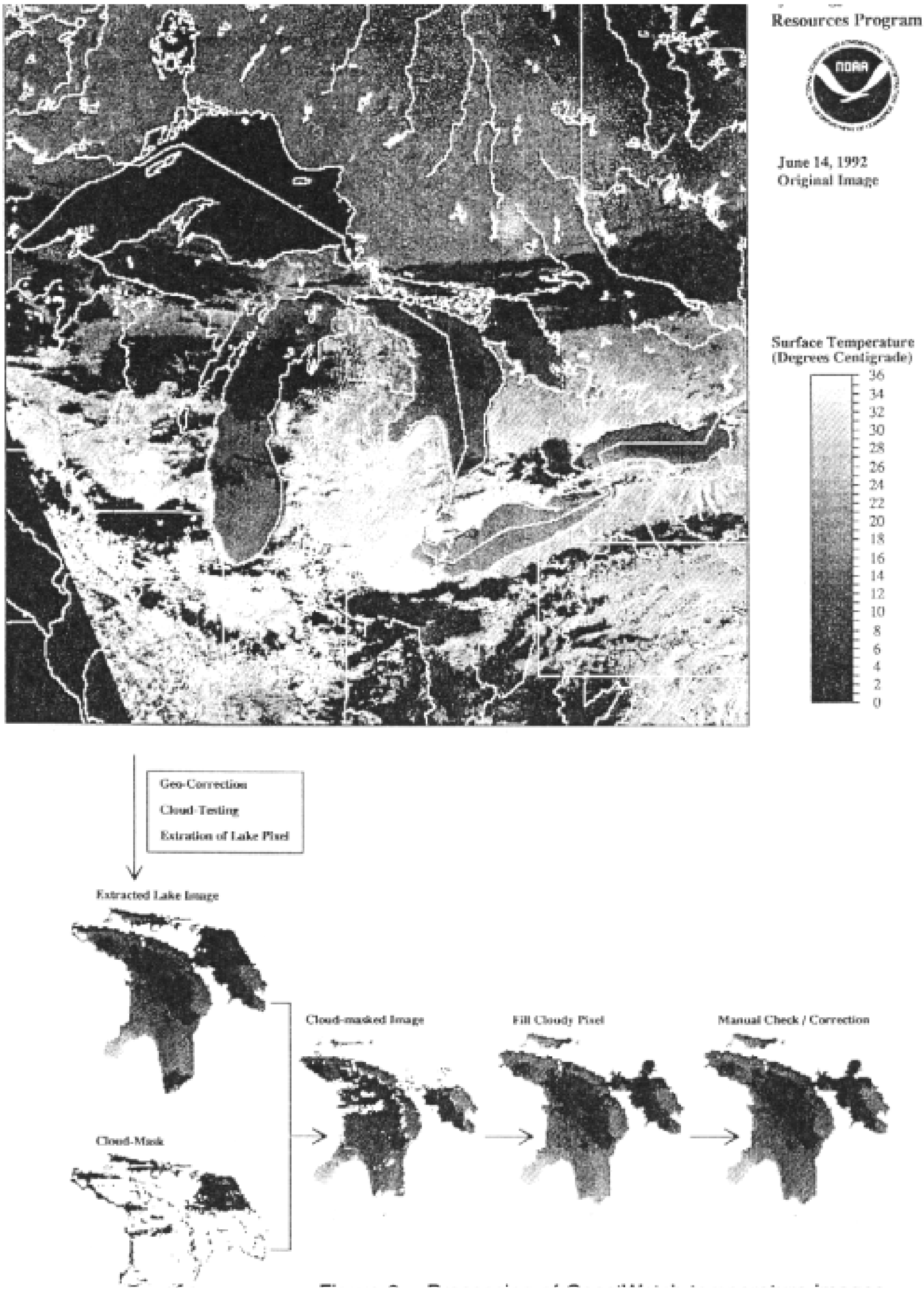
Lake	SSTMAP Period	SSTMAP Images	IMGMAP Period	IMGMAP Images	OCNMAP Period	OCNMAP Images	Total
Superior	1990-1991	65	1991-1992	443	since 1992	28	536
Michigan	1990-1991	81	1991-1992	491	since 1992	55	627
Huron	1990-1991	71	1991-1992	457	since 1992	25	553
Erie/St. Clair	1990-1991	68	1991-1992	433	since 1992	43	544
Ontario	1990-1991	61	1991-1992	445	since 1992	59	565

GLERL's basic satellite dataset consists of AVHRR lake surface temperature maps. Albedo measurements of bands 1 and 2 are frequently available. The mapping of the satellite data to a Mercator projection is based on satellite orbital data. Errors in the orbital parameters can lead to mapping inaccuracies, usually of 5-10 km (Leshkevich et al., 1993). These errors are corrected with an automatic correction algorithm (Schwab et al., 1992). Figure 2 gives an overview of the processing steps performed to derive cloud-free water surface temperature data from CoastWatch satellite images. The data received by GLERL have not been tested for cloud contamination. To extract meaningful lake surface temperature data from these satellite measurements, the data are tested for cloud cover and cloud contamination in a four-step automatic cloud-testing procedure. Cloud-free lake surface temperature for each lake is extracted from the original satellite images and used in further image processing steps if at least 33% of the lake surface tested cloud free. Small cloud-contaminated areas are filled using an inverse square distance weighting method and averaging cloud-free pixels within seven pixels from the cloud-contaminated grid point. The results of these automatic processing steps are visually checked and corrections are performed manually.

2.3 Processing Normal Temperature Patterns

The total number of images used to calculate the normal surface temperature pattern is shown in Table 2. Since AVHRR data are available to GLERL on an operational basis, the frequency of surface temperature images has increased considerably since 1990. Due to spatially and temporally changing cloud cover, the surface temperature dataset is not homogeneous. The typical long-term temperature, defined here as normal temperature, of each grid point and day of the year cannot be calculated as the arithmetic mean over all such days of all years, since each grid point and day has a different observational base. Especially in the late fall and winter, the high probability of cloud cover decreases the frequency of satellite-derived surface temperature images considerably (Table 3).

Following a method described by Irbe (1992), the normal lake surface temperature was derived using a regression method. A day number was assigned to each image according to its day of the year (Julian Calculation of normal temperature-day). A linear least squares regression of temperature and Julian day number was calculated on segments of the dataset. The normal temperature of each grid point and day of the year was calculated from a linear regression of all observations within a 1 May period (Julian days) before and after the currently processed day of the year. A minimum of five observations before the day of interest and five observations after was required to calculate the regression. If this requirement was not met, which was sometimes the case in late fall and winter for North Channel, Green Bay, Grand


Resources Program
June 14, 1992
Original Image
Surface Temperature
(Degrees Centigrade)
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Geo-Correction
Cloud-Testing
Extration of Lake Pixel
Extracted Lake Image
Cloud-Mask
Cloud-masked Image
Fill Cloudy Pixel
Manual Check / Correction

Traverse Bay, Black Bay, and Nipigon Bay, the time range was extended accordingly. For instance, to calculate the normal temperature for Julian day number 2 15 (August 3), all images with Julian day numbers 200 (July 19) through 230 (August 18) were used for the linear regression analysis. Figure 3 shows an example of the course of the normal temperature calculated for gridpoint number 4000 of Lake Huron: 772 temperature observations of the AES and GLERL satellite measurements were available for this gridpoint.

2.4 Combining Normal Ice Cover and Temperature Data

The determination of ice cover from remotely sensed surface temperatures is ambiguous for several reasons:

(a) A remote instrument measures the average temperature in its field of view. Frequently the surface is broken ice cover. Thus, the remotely sensed temperature consists of a mixed signal from ice surface temperature, which can be considerably lower than O°C, and the water surface temperature, at or above 0°C. The percentage of ice cover cannot be clearly defined from the temperature of the mixed signal if the ambient temperature of the ice surface is not known.

b) Remote surface temperature measurements are limited to cloud-free weather: thus, the frequency of satellite images decreases considerably in late fall and winter.

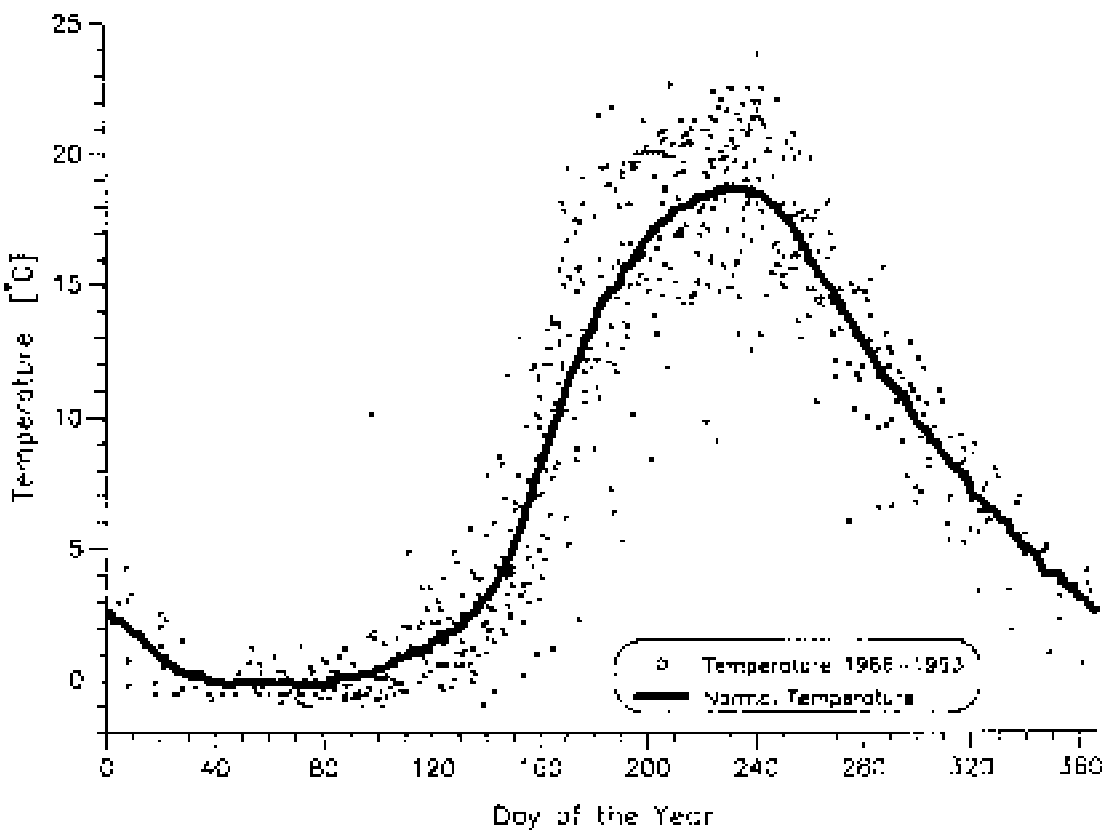


Figure 3.--Calculation of normal temperature.

c) The cloud-masking technique used here is optimized to reject all nonwater pixels. Ice-covered pixels are, therefore, frequently masked as cloudy. Pixels with a temperature under -1°C are always considered cloudy.

Due to these problems, the normal ice cover documented in the Great Lakes Ice Atlas (Assel et al., 1983) was used to display the ice cover and ice extent of the Great Lakes.

The two datasets, normal ice cover and normal temperature, are derived from different observational bases and with different techniques. Simply replacing all temperature data for each ice-covered grid point yields inconsistencies and unrealistically large temperature gradients, especially during the freezing and melting period.

Normal ice maps from the normal ice cover data base were available between 23 December and 22 April. In some lake parts, especially in shallow bay areas, parts of the lake already had considerable ice cover. To smooth the ice buildup before 23 December and the ice decay after 22 April, the ice cover data base was extended by allowing an ice buildup of 10% per day before 23 December and an equally dimensioned ice decay after 22 April. Looking at the ice cover data base, this ice cover buildup and decay rate seemed reasonable.

This adjusted normal ice cover data base was merged with the normal temperature data maps. Water temperature in ice-covered areas was assumed to be 0°C. For each day with ice cover, the temperature of the normal temperature dataset was changed so that the area at or below 0°C matched the ice-covered area of the normal ice cover dataset. On the average of the ice-cover period, Lake Superior temperatures had to be decreased by 0.95°C, Lake Michigan by 1.3 8°C, Lake Huron by l.O6°C, Lake Erie/St.Clair by 1.48%, and Lake Ontario by 1.15°C. The positive offset of temperature versus ice cover maps is because remote temperature measurements have a good-weather bias due to their limitation to cloud-free weather situations and, therefore, tend to overestimate the normal surface temperature.

Since the locations of subzero degree pixels (ice covered) in the normal temperature dataset and ice covered grid points in the normal ice cover data base do not match in all cases, the combined ice-temperature map is smoothed using a 3x3 mean filter.

As described above, the temperatures in the normal ice cover dataset were adjusted to match those of ice-covered areas and subzero degree areas. This leads to unrealistically large temperature changes between the last ice-free day and the first ice day and between the last day with ice cover and the first ice-free day. Before the first ice day and after the last ice day, temperature offset values were applied to the normal temperature maps to smoothly build up and decay the temperature adjustment necessary for the first and the last ice day, respectively, using the rate of 0.2°C per day.

2.5 Vertical Temperature Profiles

Surface temperature is closely linked to the temperature of the underlying water column. Temperature patterns and the structure of the surface temperature field depend to some extent on the temperature gradient near the surface. Vertical mixing in the presence of a strong temperature gradient near the surface will change the surface temperature, whereas vertical mixing of a homogeneous epilimnion does not change the surface temperature. Thus, the strongest horizontal temperature gradients can be expected during the warmup period when the shallow inshore regions have already built a stable stratification, whereas the deep lake parts are still at or close to 4°C. Small-scale temperature patches can be observed when a weak stratification has established. A horizontally inhomogeneous wind field mixes waters of different depth and temperature, resulting in small-scale temperature patterns. The presence of the deep, homogeneous, upper water zone promotes the development of homogeneous temperature fields (Schneider, 1992).

Horizontal patterns of the surface temperature persist to some extent into the water body. The thermal structure of a lake is three dimensional. It cannot be measured directly because temperature profile measurements are rare and limited to specific measuring sites. In rare cases, well-equipped small lakes offer the possibility of interpolating the three-dimensional thermal structure of a lake from a network of profile measurements. This is rarely the case for any of the Great Lakes.

The patterns of lake surface temperature and ice cover depend mainly on energy fluxes at the water surface, heat storage, and lake dynamics. The latter processes include horizontal and vertical mixing.

The depth of vertical mixing, along with the heat stored in a lake, can be displayed with vertical temperature profiles. Although the three-dimensional temperature structure cannot be shown here, the normal daily temperature profiles are very important to understand the lake surface temperature and its patterns.

Lakewide mean daily temperature profiles have been calculated using GLERL's thermodynamic and heat storage model (Croley, 1989; 1992). These temperature profiles were designed to describe the mean lakewide heat storage in the lakes.

2.5.1 Current Thermodynamic Model

GLERL's thermodynamic and heat storage model uses areal-average daily air temperature, wind speed, humidity, precipitation, and cloud cover. Over-land data are adjusted for over-water or over-ice conditions. The surface energy balance is calculated from shortwave radiation and reflection, net longwave radiation, advection, and latent and sensible heat flux. Atmospheric stability effects on the bulk transfer coefficient are formulated and used with the aerodynamic equation for sensible and latent heat flux.

Energy conservation and superposition mixing are used to account for heat storage in the lake. The effects of past heat additions or losses are superimposed to determine temperatures at all depths. Each past addition or loss is parameterized by its age and allowed to mix throughout the volume accordingly. Mass and energy conservation are used to account for ice formation and icepack decay in the lake.

These relations are solved simultaneously through iterative determination and use of water surface temperature and ice cover. GLERL's thermodynamic and heat storage model was calibrated to give the smallest sum of squared errors between model and actual daily water surface temperatures observed by satellite during the calibration period of 1979- 1988. Statistics compiled over independent verification periods agree well with the calibrations.

The model was also partially assessed by comparing model evaporation with water balance derivations for 1951-1988, and low annual residuals resulted.

Turnovers (mixing of deep waters with surface waters as surface temperature passes through that at maximum density), which are a fundamental behavior of dimictic lakes, are well represented by GLERL's thermodynamic and heat storage model. Hysteresis between heat in storage and surface temperature, observed during the heating and cooling cycle on the lakes, is preserved. The model also correctly depicts lake-wide seasonal heating and cooling cycles, vertical temperature distributions, and other mixed-layer developments.

Comparisons with actual data include 23 years of daily aerial and satellite observations of water surface temperature on all lakes, 8 years of bathythermograph observations of depth-temperature profiles on Lake Superior, and 1 year of independently derived weekly or monthly surface flux estimates on Lake Superior, Erie, and Ontario (two estimates). GLERL's lumped evaporation and heat storage model is described in detail elsewhere (Croley, 1989; 1992).

The shallow main channel connecting Lake Huron and Georgian Bay does not allow the waters to mix. Thus, both bodies of water develop different temperature profiles, which are displayed separately.

Since the day of the turnover changes from year to year, simply averaging vertical temperature profiles for each day over a long period yields nonsense profiles when preturnover profiles are averaged with post-turnover profiles.

To calculate normal vertical temperature profiles, the following processing technique has been used:

> For each lake, a mean turnover day (spring and autumn turnover) was calculated from modeled daily lakewide temperature profiles for 1956-1985 (Table 5). All temperature profiles with the same relative distance from the two annual turnover days were averaged.

2.6 Bathymetry Data

For each grid point, a bathymetry value was extracted from a bathymetry data base published by Schwab and Sellers (1980). The depth value of the nearest data point reported in the data base was assigned to each grid point.

Bathymetry data are stored in 1-m depth intervals. Both mean and maximum depths, displayed in the animation program, are calculated using extrapolated gridded data. Because of the extrapolation method

Table 5.— Mean turnover days from 1956 to 1985.

	Spring			Autumn		
Lake	Earliest	Mean	Latest	Earliest	Mean	Latest
Superior	06/16	07/02	07/22	12/09	12/21	01/04
Michigan	05/13	05/28	06/22	12/18	12/31	01/13
Huron	05/12	05/26	06/09	12l30	01/12	01/24
Georgian Bay	05/16	05/31	06/08	12/14	12l29	01/12
Erie	04/10	05/01	05/11	12/04	12/23	01/12
Ontario	05/04	05/30	06/19	12l22	01/11	01/27

of the bathymetry data and the land-water mask used, shallow inshore areas are under represented. This leads to higher average depth values than reported elsewhere.

3 . THE ANIMATION PROGRAM

The normal temperature and ice cover animation shows daily patterns of ice cover and temperature, daily vertical temperature profiles, temperature and ice cover versus bathymetry, and horizontal temperature profiles for each of the Great Lakes. Several aspects of the thermal characteristics of the Great Lakes can be displayed and analyzed.

Horizontal temperature data are stored with a resolution of 0.1oC. The ice concentration is in 10% steps. Normal vertical profiles are stored with 0.01oC resolution. The program runs under DOS.

To run the program, the following system requirements have to be met:

- IBM compatible PC
- 533 Kb accessible RAM
- VGA graphics adapter
- 14.5 Mb hard disk space
- Mouse (highly recommended)

3.1 Installation

To install program and data base under DOS, insert floppy disk #1 in the appropriate disk drive. Make this floppy disk drive the default drive and enter INSTALL destination-drive:\destination-path. This command uncompresses and installs all necessary files to your hard disk. You are prompted to insert the last backup disk. This is floppy disk #3. Then insert disks as requested by the installation program. Finally you are prompted to insert disk with batch program. This is disk #1.

Example:

B:
INSTALL D:\GLTMPICE
defaults to floppy disk drive B, creates directory GLTMPICE (if this directory does not exist already) on drive D and installs all files.

Data and program are stored in compressed files. After the installation is complete, you should find the following files on your disk:

a) DISP.EXE	: Animation program
b) DISPlNLDAT	: Initialization file for animation program
c) VERTPROEINI	: Initialization tile for vertical profiles
d) GLTMPICE.xxx	: Normal temperature and ice cover data base
e) NORMPROExxx	: Normal temperature profiles
The extension xxx is:	SUP = Superior
	MIC = Michigan
	THUR = Huron with Georgian Bay and North Channel
	ERI = Erie with St. Clair

	ONT = Ontario
f) BACKGRND.BIN	: Binary graphics background for menus and documentation
g) GLTEMPSD.BIN	: Binary documentation file
h) LIST.DAT	: List of all files
i) RESET.BAT	: Batch file to reset screen text mode if program was aborted.

To execute the program make sure that the following graphics font files are accessible: HELVB.FON and TMSRB.FON supplied with MICROSOFT FORTRAN, or COURF.FON and SMALLE.FON supplied with MICROSOFT WINDOWS. If MICROSOFT FORTRAN is available on your PC, use the font files HELVB.FON and TMSRB.FON. These two files must exist in directory C:\FORTRANUIB or in your animation program directory. If you do not have MICROSOFT FORTRAN, the MICROSOFT WINDOWS fonts COURF.FON and SMALLE.FON must be present in directory C:\WINDOWS\SYSTEM or in your animation program directory. If you do not have either the MICROSOFT FORTRAN fonts or the MICROSOFT WINDOWS fonts, you cannot run the animation program.

To run the animation program, make the directory containing the program and data files your current directory and enter DISP. A title screen (in Appendix B) will be displayed. Two selection buttons in the lower left and right comer of the screen allow you to exit the program or to enter the selection menu

3.2 Selection Menu

To select a submenu, move the cursor to the command button and click on the left mouse button. A shortcut to using the mouse is to hit the key displayed on the selection button. After entering the main menu by clicking the right button or hitting M, you are prompted to choose between the following submenus (Fig. B-2):

0) Return to Main Program
1) 2-D Animation
2) Horizontal Profile
3) Vertical Profile
4) Variable vs. Bathymetry
5) Documentation.

Select a submenu by hitting the appropriate number, or moving the pointer to the button and clicking the left mouse button.

The 2-D animation displays two-dimensional maps of normal temperature and ice cover in animated sequences. The horizontal profile allows you to define a transect across the lake and displays the surface temperature along this profile line in an x-y graph. The vertical profile shows normal temperature profiles of each lake. The submenu variable vs. bathymetry lets you investigate the dependency of temperature and ice cover on the lake depth. The documentation submenu explains briefly the data base and the program.

After selecting a submenu, you are prompted to select the lake(s) to be displayed (Fig B-3). The vertical temperature profile and variable vs. bathymetry submenus let you display multiple lakes at the same time and allow direct comparisons of the thermal characteristics of the lakes. All menus let you dump the graphics screen to an ASCII file. The graphics pixels are read from the upper left to the lower left comer and written as hexadecimal values in (3222) FORTRAN format. This graphics file can be used as part of a postscript file to print the graph or can be converted to various image formats for further processing.

3.3 2-D Animation

Figure B-4 through Figure B-8 show examples of the two-dimensional patterns for each lake. The title of the animation, the lake name, and the date of the temperature and ice cover pattern are shown in the central upper frame. To the left and right of the title is the temperature statistics, the left frame shows mean temperature and standard deviation, the right rectangle displays minimum and maximum temperature. These statistical parameters were calculated for each image. For ice covered pixel a water surface temperature of 0°C was assumed.

A command bar is shown at the left side of the screen. To manipulate the display, 10 options can be chosen. A legend showing the ice cover and temperature color bar occupies the lower portion of the screen.

Moving the mouse, or hitting a key, halts the animation and a cursor is displayed. If the cursor is moved inside the image, temperature, ice cover, and geographical location of this grid point is displayed in a text area above the temperature color bar. If the cursor is located on a command button, a brief explanation of this button appears. In some cases, the execution of a command will also be reported in the text area.

If the program was halted by mouse movement or key, the program will resume execution after a brief waiting period if the display mode is set to automatic forward (default).

The default display mode of the animation is:

- automatic forward
- day increment = 1
- temperature scale 0°C 24.5°C
- write buffer is empty.

Changes to the default display mode can be made either by moving the cursor to a button and clicking the left mouse button or by hitting the key displayed on the button.

The following options can be chosen:

S : Change the delay value for each image. This option lets you slow down or speed up the animation. After selecting this option, buttons 3 and 4 will change from I < to + and -, respectively. A message in the text area appears. To increase the speed select +, to decrease select -. The delay value is shown in the text area. Hit C, or left and right mouse buttons to continue.

L : Change the scale of the temperature color bar. After selecting this option, buttons 3 and 4 will change to F and J. F stands for first (lower) value of the temperature color bar, and J stands for temperature steps. By default, the temperature steps are set to 0.5”C. After selecting F or J you are prompted to enter the appropriate value. Continue with C or left/right mouse button.

I : Change the day increment.
By default the day increment is 1. Increasing the day increment results in a faster animation. A day increment of 0 stops the animation, and a negative day increment displays the animation backwards.

G : Go to selected day number.
You will be prompted to enter the image number to be displayed. In the case of the normal temperature and ice cover data base, the image number is equal to the day of the year.

M : Manual forward on/off switch.
By default, the program forwards automatically to the next image. To disable the automatic forward, select M. If the current forward mode is manual forward, this mode is displayed in the text area.

Q : Quit the animation and return to the lake selection menu.

B : Switch bathymetry display on/off.
If the bathymetry is displayed, buttons 1 and 2 change to D and S. D allows you to change the base depth, which is by default 0, and S allows you to change the depth steps, which is by default 1 m. Changing these parameters lets you investigate details of the bathymetry. To disable the bathymetry display, select B again.

T : Toggle between the image stored in the buffer and the currently displayed image. To change the toggle speed, hit S and + or -. To disable the toggle mode, select T or Q.

W : Capture an image to an internal buffer. This command is useful in combination with the toggle command. If you want to investigate the relationship between bathymetry and temperature pattern, or the development from one temperature pattern to another, capture the current screen, forward to the next image, and select toggle (T).

P : Dump graphic screen to file in hexadecimal format (3222). You will be prompted to enter a file name (12 character maximum). To prevent overwriting of existing tiles, the image will not be saved if a file with this filename already exists.

A : Automatic scaling of temperature axis. This command is useful to investigate details of the temperature pattern. The temperature color bar will be automatically scaled using minimum and maximum temperature of the image.

3.4 Horizontal Profile

User-defined horizontal surface temperature profiles can be plotted as graphs. To define the profile line:

1. Move the cursor to the desired starting point.
2. Hit S or left mouse button to select this profile boundary point.
3. Move the cursor to the next profile point.
4. Repeat steps 2 and 3 until the profile line is complete.
5. End profile point definition with Q or right mouse button.

The form of the profile line is arbitrary. Loops and crossing lines are possible. However, the maximum number of grid points on the profile line is 500. If the selected profile line crosses more grid points, all data points beyond this limit are ignored. The program defines for each grid point the geographical location, stores the selected grid points and their order, and displays the selected profile line. You are asked to confirm the displayed profile line. Hit Y to accept the profile line, otherwise hit N. If the profile line is not satisfactory, you can redefine the profile. After successfully defining a profile line, the program displays the lake mask along with the selected profile line in high-resolution mode on the screen and sets up a graph (Fig. B-9). Only lake grid points are displayed. The temperature plot is discontinued if the profile line crosses a land pixel.

If the cursor is moved inside the plot area, the temperature value and the location of the grid point are displayed in the text window at the lower right hand side of the screen. This feature allows accurate readings of the displayed data. To find the location of the grid points in the lake image area, move the cursor inside the lake image. The geographic location of the grid point is displayed.

By default the display mode is:

- automatic forward
- fixed y-axis with a temperature range from 0 to 25°C

The following options can be chosen in the horizontal temperature profile display:F

F : Increase the animation speed. Each time you hit F, the delay value is decreased by a factor of 2.

S : Decrease the animation speed. Each time you hit S, the delay value is increased by a factor of 2.

> : Forward by 2 days.

M : Manual forward on/off switch.
To disable the automatic forward, select M. If the current forward mode is manual forward, this mode is displayed in the text area.

G : Go to day. Enter the day of the year to be displayed.

Q : Quit horizontal profile display.

L : Define lower value for y-axis.

H : Define upper value for y-axis.

A : Automatic scaling of y-axis (on/off).

P : Dump graphic screen to file in hexadecimal format (3222).

3.5 Vertical Temperature Profile

To analyze the relationship of horizontal temperature and ice cover patterns with the heat storage in the lake, normal lakewide vertical temperature profiles for each lake can be displayed. The profiles are derived from modeled temperature profiles.

To directly compare the vertical temperature profiles for different lakes, multiple profiles can be displayed simultaneously. Select the desired lakes from the selection menu and choose Quit to end selection.

An x-y graph is displayed with temperature on the x-axis and depth on the y-axis (Fig. B-10).

To accurately read the plot, depth and temperature of the cursor position are displayed, if the cursor is placed in the plot area.

By default, the display settings are:

- automatic forward
- fixed temperature axis from 0 to 25°C
- day increment 1

The following options can be chosen:

F : Increase the animation speed. Each time you hit F, the delay value is decreased by a factor of 2.

S : Decrease the animation speed. Each time you hit S, the delay value is increased by a factor of 2.

> : Forward by 2 days.

M : Manual forward on/off switch.
To disable the automatic forward, select M. If the current forward mode is manual forward, this mode is displayed in the text area.

G : Go to day. Enter the day of the year to be displayed.

Q : Quit horizontal profile display.

C : Continue.

L : Define lower value for y-axis.

H : Define upper value for y-axis.

A : Automatic scaling of y-axis (on/off).

D : Change maximum depth.

I : Change day increment.

P : Dump graphic screen to tile in hexadecimal format (3222).

3.6 Temperature and Ice Cover versus Bathymetry

Surface temperature and ice cover depend on the energy stored in the underlying water column. The energy storage capability at a given location is directly proportional to the depth. The submenu “Variable vs. Bathymetry” lets you investigate the dependency of surface temperature and ice cover on the depth of the lake. This module calculates the mean temperature and ice cover for each 1-m depth step and displays graphs of temperature and ice cover versus bathymetry. The graphs can be smoothed by selecting one of three smoothing algorithms. The program allows direct comparisons of different lakes by displaying multiple lakes simultaneously. Select the desired lake(s) from the selection menu and quit selection.

A plot is displayed with the depth on the abscissa, the temperature on the left ordinate, and the ice cover on the right ordinate (Figs. B-11 to B-13). If the cursor is moved inside the plot area, depth, temperature, and ice cover values at the cursor location are displayed in a text window. Several smoothing methods are implemented (compare Figs. B-11 to B-1 3). A text window in the lower screen area shows the currently active setting of the smoothing algorithm.

The default settings are:

- automatic forward
- average temperature and ice cover values over 5-m depth steps
- futed temperature axis 0-25^{o}C
- display temperature and ice axes
- set maximum depth according to deepest lake displayed.

You can choose from these options:

F : Increase the animation speed. Each time you hit F, the delay value is decreased by a factor of 2.

S : Decrease the animation speed. Each time you hit S, the delay value is increased by a factor of 2.

> : Forward by 2 days.

M : Manual forward on/off switch.
To disable the automatic forward, select M. If the current forward mode is manual forward, this mode is displayed in the text area.

G : Go to day. Enter the day of the year to be displayed.

Q : Quit horizontal profile display.

C : Continue.

I : Change day increment.

X : Change maximum depth.

U : Define upper value for left y-axis.

L : Define lower value for left y-axis.

A : Automatic scaling of left y-axis (on/off).

1 : Smooth plot by averaging over classes. Each class has a user supplied percentage of elements.

2 : Smooth plot by averaging over depth steps defined by user.

3 : Use moving average over user supplied depth steps.

Y : on/off switch for left y-axis.

R : on/off switch for right y-axis.

D : Change maximum depth.

P : Dump graphic screen to file in hexadecimal format (32z2).

3.7 Documentation

Documentation of the program and the data base is available on line. The documentation explains the data base, data processing, and analysis as well as program usage and commands. Chapter 1 gives an introduction and an overview of the data base and data processing. Chapter 2 explains the 2-D animation, chapter 3 documents the horizontal profile submenu, chapter 4 discusses the vertical profile submenu, and chapter 5 reviews the submenu variable vs. bathymetry. To page through the documentation, hit N or space, or click on the N button. To read a specific chapter, select the appropriate number. Quit the documentation with Q.

4. DISCUSSION

A normal temperature and ice cover data base for the Great Lakes of North America was produced from remote sensing data. To display and analyze the data, a computer program for IBM-compatible PCs was developed. This memorandum describes the data base, its generation, and the animation program.

Temperature and ice cover patterns were developed from long-term observations and are designed to describe the normal temperature and ice cover of the Great Lakes. Since actual temperature and ice cover patterns for a specific day are determined by the current meteorological and limnological situation, they are likely to be different from the normal patterns. Interpretations of the normal patterns for a specific location and time must be very cautious and could yield large errors.

The normal temperature and ice cover are derived with different observational base and different methods. Thus, merging them into one data base resulted at some locations and in some cases in discrepancies between surface temperature and ice cover.

The surface temperature measurements are based solely on remote sensing data. This technique is limited to cloud-free weather. Thus, the normal surface temperature patterns are biased toward good weather. Although, under cloud-free skies, the surface temperature at night is usually lower due to increased longwave radiation. This effect is not likely to compensate for the warmer surface temperature during the day. The temperature decrease at night is limited by the fact that large energy losses at the surface lead to increasing convection. A larger water body participates in the cooling process, then in the heating, thus limiting the temperature decrease at the water surface at night. The heating of the water leads (especially under calm wind conditions) to a strongly stratified upper water zone, where most of the incoming solar radiation is absorbed. The stronger the short-wave radiation and the smaller the vertical mixing, the higher the surface temperature.

Another problem with the measuring technique of the surface temperature is that cloud-free conditions are frequently associated with specific wind situations. The likelihood of cloud-free skies is higher with northwesterly winds than with southern and southeasterly winds which often bring humid air to the Great Lakes region. This wind bias probably has an effect on the temperature patterns. However, since westerly winds prevail in the Great Lakes region, and since this wind direction often allows remote surface temperature measurements, the effect of wind bias on the temperature patterns is most likely small.

A comparison of the temperature patterns discussed in the Great Lakes Surface Water Temperature Climatology with the patterns shown here reveals their similarity though both data bases were derived from different observational base. This indicates that the major surface temperature patterns are quite stable.

5. DATA AVAILABILITY

Both the normal temperature and ice cover data base and the animation program for IBM-compatible PCs are available on diskettes.

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APPENDIX A - Description of the Data Format

A.1 Surface Temperature and Ice Cover Data Format

The surface temperature and ice cover data are stored in direct access fries with 1 header record, 2 pixel location records, 2 bathymetry records, and 365 image records. The record length is different for all data bases and is stored in the header record. To open the data base file, open the file with a record length of 2 bytes. Read the record length from record 1 to an I*2 variable, close the data base, and open it again with the correct record length.

The header record contains the following information:

Bytes Type	Variable
1- 21*2	Record length of data base in byte
3- 4 1*2	Number of data points
5- 6 I*2	Number of image rows
7- 8 I*2	Number of image columns
9- 10 1*2	Data type of image data where:
1' = imsigned byte	2 = unsigned integer*2
3 = not used	4 = signed integer *4
5=Real*4	6 = signed byte
7 = signed integer *2	
ll- 12 1*2	Number of images in data base (here: 365)
13- 14 1*2	Number of bathymetry records (here: 2)
15- 16 I*2	Number of bytes reserved for 2nd (Ice) data base (here: 10)
17- 18 I*2	Start row of image in CoastWatch synoptical scene
19- 20 1*2	Start column of image in CoastWatch synoptical scene
21-22 1*2	End row of image in CoastWatch synoptical scene
23- 24 I*2	End column of image in CoastWatch synoptical scene
25- 28 R*4	Lower default value for main y-axis (temperature-axis)
29- 32 R*4	Upper default value for main y-axis (temperature-axis)
33- 33 1*1	Number of character in title string (max.:50)
34- 83 A50	Title
84- 84 I*1	Number of character in subtitle string (max.:30)
85-114 A30	Subtitle
115-1151*1	Number of character in legend text string (max.:20)
116-135	A20 Legend text string

Records 2 and 3 contain the location of the lake grid points in a two-dimensional array with n rows and m columns as defined in the header, where the location is defined as the grid point number and all grid points are sequentially numbered from the upper left to the lower right comer. To maintain the record length defined by the shortest possible data type (I*1), the location and bathymetry data are split into two records.

To read the location data, use the following program sequence:

```
integer* 1 locbuf(26000)
integer*2 location( 13000)
equivalence (locbuf,location)
.
.
read (unit=inputunit,rec=2) (locbuf(i),i= 1 ,recordlenght)
```

```
read (uni~inputunit,rec=3) (locbuf(i),i=recordlenght+l,2*record lenght)
```

Records 4 and 5 contain statistics of the bathymetry and the bathymetry data as I*2 data in 1 -m steps. To read the bathymetry data, use the following program sequence:

```
integer* 1 bthbfl26000),lineheader(48)
integer*2 bathymetry( 13000)
equivalence (bthbuf,bathymetry)
.
.
read (unit-inputunit,rec=4) (lineheader(i),i=1,48),
& (bthbuf(i),i=l ,recordlenght-lineheader)
pos=recordlenght-lineheader
read (unit=inputunit,rec=5) (bthbuf(i+pos),i=l,recordlenght)
```

The line header contains statistical information of the bathymetry and the image:

Bytes Type	Variable
l-1 1*1	Day of the image (not used for bathymetry)
2-2 1*1	Month of the image (not used for bathymetry)
3-4 1*2	Year of the image (not used)
5- 6 I*2	Tie as HHMM (not used)
7- 8 I*2	Number of Observations (not used)
9-12 R*4	Mean
13-16R*4	Standard deviation
17-20R*4	Minimum
21-24R*4	Maximum
25-28R*4	Scaling factor
28-32R*4	Scaling summand
3348	not used

Records 6 through 370 contain the image records. The image data are stored in I* 1; bytes l-10 (see byte 15 and 16 in header record) contain ice information and byte 1 l-255 contain surface temperature information.

To unpack the ice values, use the following lookup table:

Byte Value	Ice Cover
1	100%
2	90 %
3	80 %
. . . . .	
. . . . .	
9	20 %
10	10%

To unpack the water surface temperature (all byte values must be > lo), use the following scaling formula:

Temperature = (Unsigned Byte Value - Scaling Sumrnand) / Scaling Factor

A.2 Vertical Temperature Profiles

The vertical temperature profiles are stored on direct access files with a variable record length. To store the header information, the minimum record length is 128 bytes. The first record is a header record containing the following information:

Bytes Type	Variable	
l- 2 1*2	Record length	
3- 4 1*2	Data Type where:	
	1 = unsigned byte	2 = unsigned integer*2
	3 = not used	4 = signed integer *4
	5=Real*4	6 = signed byte
	7 = signed integer *2	
5- 6 I*2	Number of profile data points	
7- 8 I*2	Number of profile lines stored	
9- 10 1*2	Depth intervals of profile data points in tenths of meters	
ll- 11 1*1	First day of profile data	
12- 1 2 1*1	First month of profile data	
13- 1 4 1*2	First year of profile data	
15- 1 5 I*1	Last day of profile data	
16- 1 6 I*1	Last month of profile data	
17- 2 0 I*2	Last year of profile data	
21-24 R*4	Factor to convert data to units	
25- 2 8 R*4	Summand to convert data to units	
29- 2 9 I*1	Number of character in title	
30- 79 A50	Title	
79- 8 0 I*1	Number of character in subtitle	
81-110 A30	Subtitle	
111-128	not used	

Records 2 through number of profile lines +1 hold the profiles lines. The temperature profile is stored as Integer*2 values. To convert the stored values to units, use the following conversion:

SI-Value = (InputValue-Summand)/‘Factor

Each profile is lead by a line header containing the following information:

Bytes Type	Variable
1- 1 1*1	Day I
2-2 I*1	Month
3- 4 1*2	Year (not used here)
5- 6 I*2	Time as HI-IMM where HH is Hour and MM is Minutes (not used here)

To read the temperature profile and convert the input data use the following statement:

```
      Integer* 1 DayMonth
      Integer*2 Year,Tiie,prftmp(500)
      Real*4 temperature(500),Summand,Factor c
      n=NrOfPrftmpData
      read (inputunifreqxftmprec) day,mon&year,time,(prfbp(i),i=l,n)
c factor and summand are defined in file header
      do i=l,n
      Temperature(i)=(prfhnp(i)-summand)/factor
      enddo
```

APPENDIX B - Example Screens

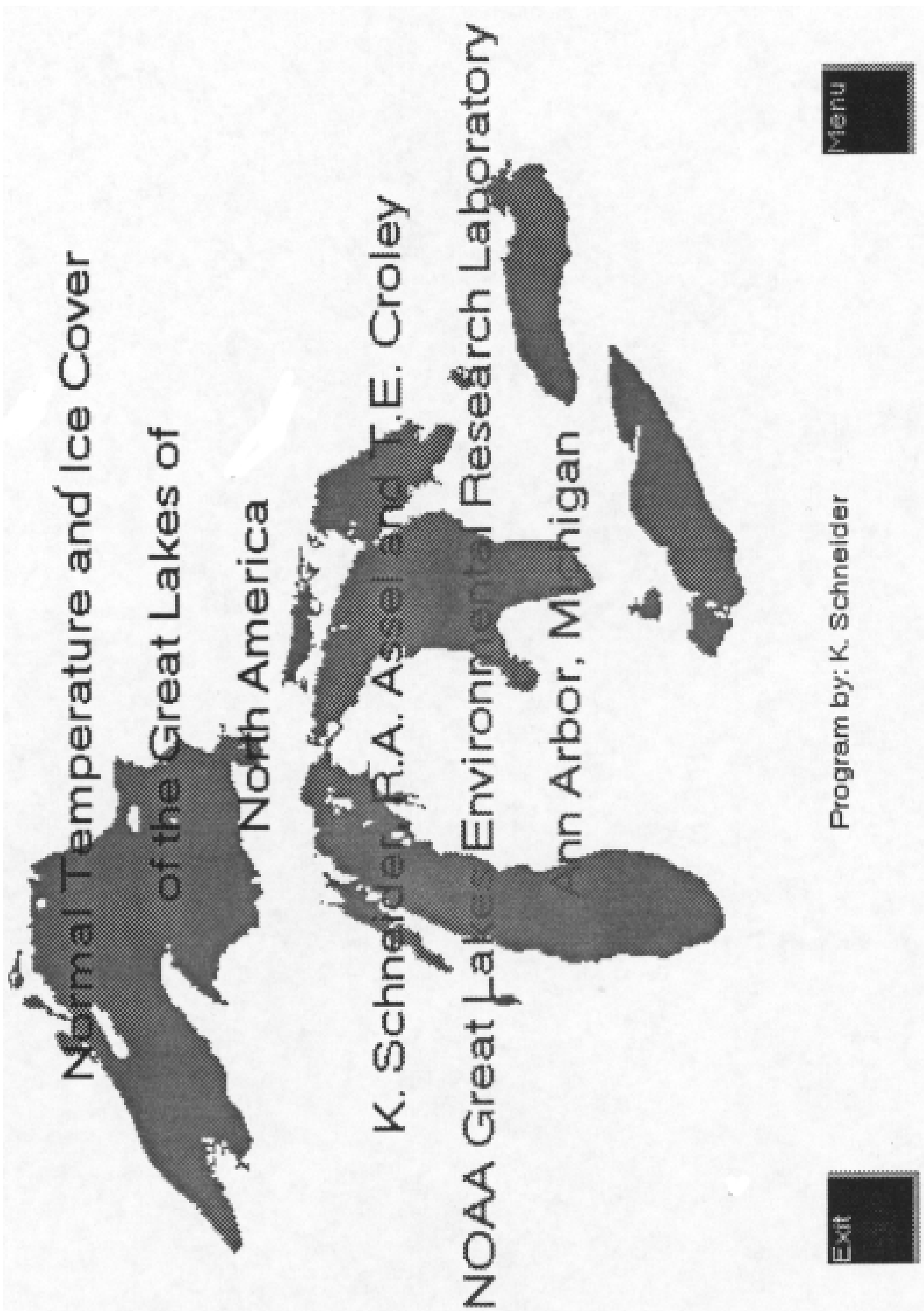

Figure B-1.--Menu Selection Screen

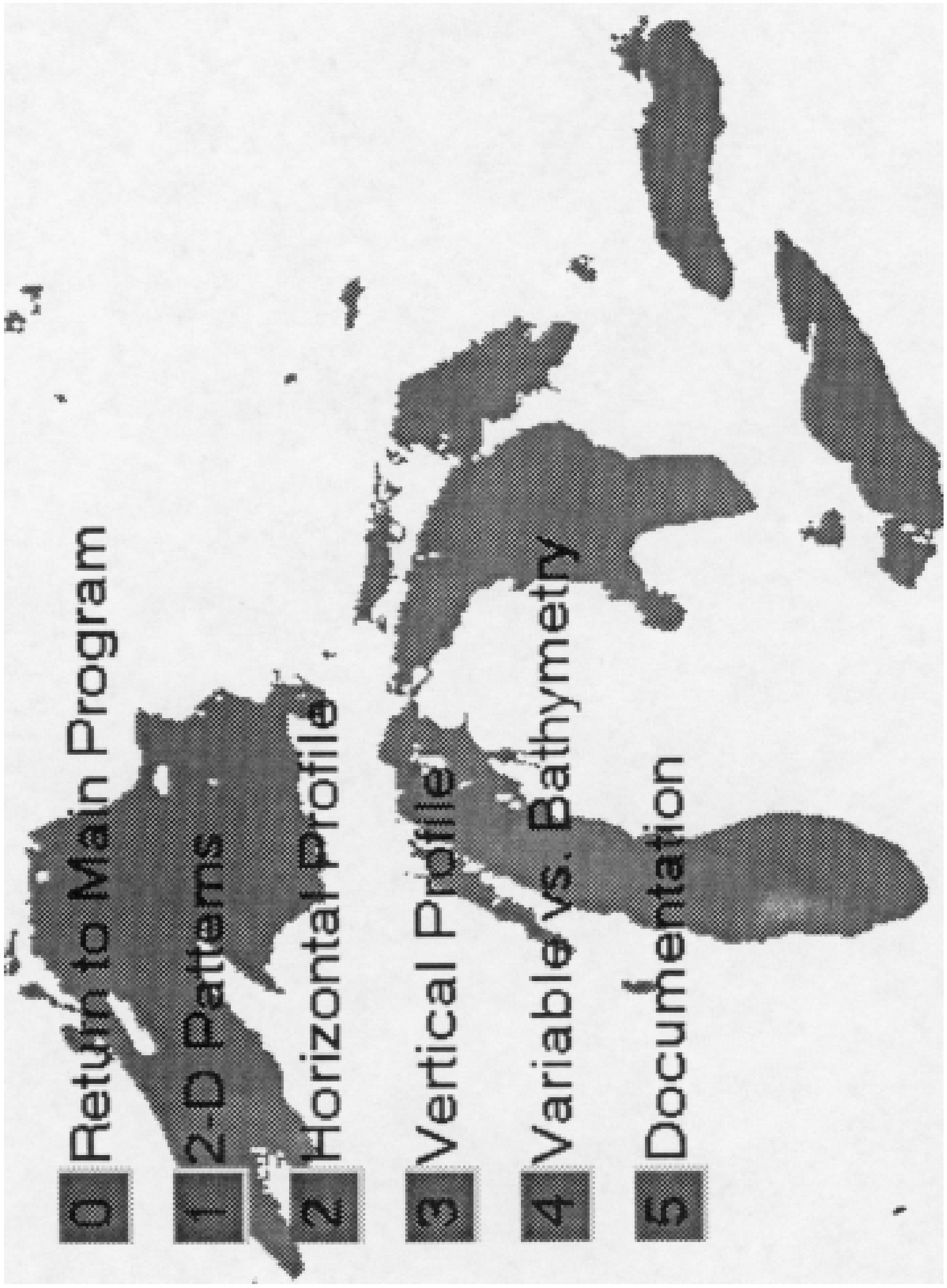

Figure B-2.--Menu Selection Screen

Figure B-3.--Lakes Selection Screen

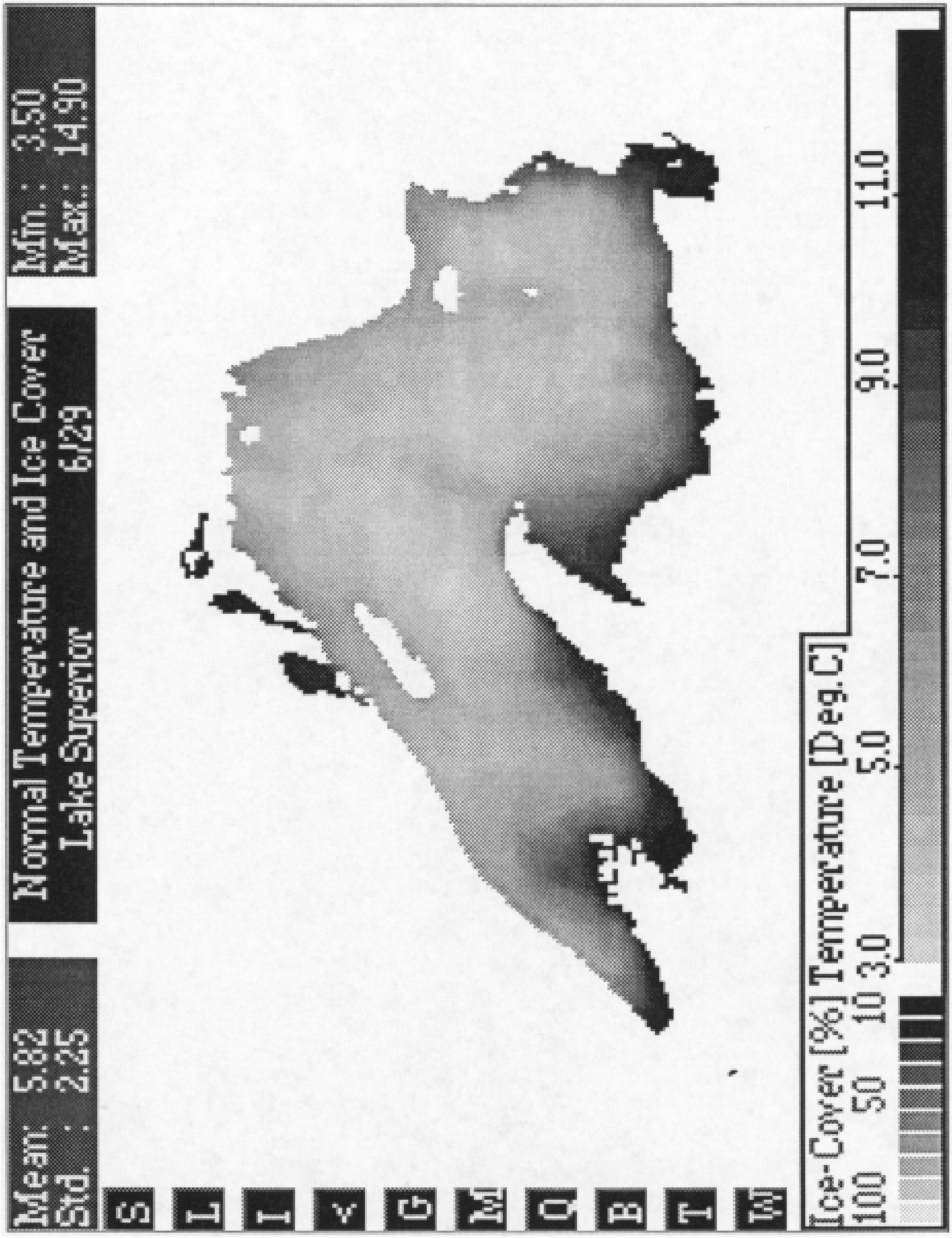

Figure B-4.--2-D Animation for Lake Superior

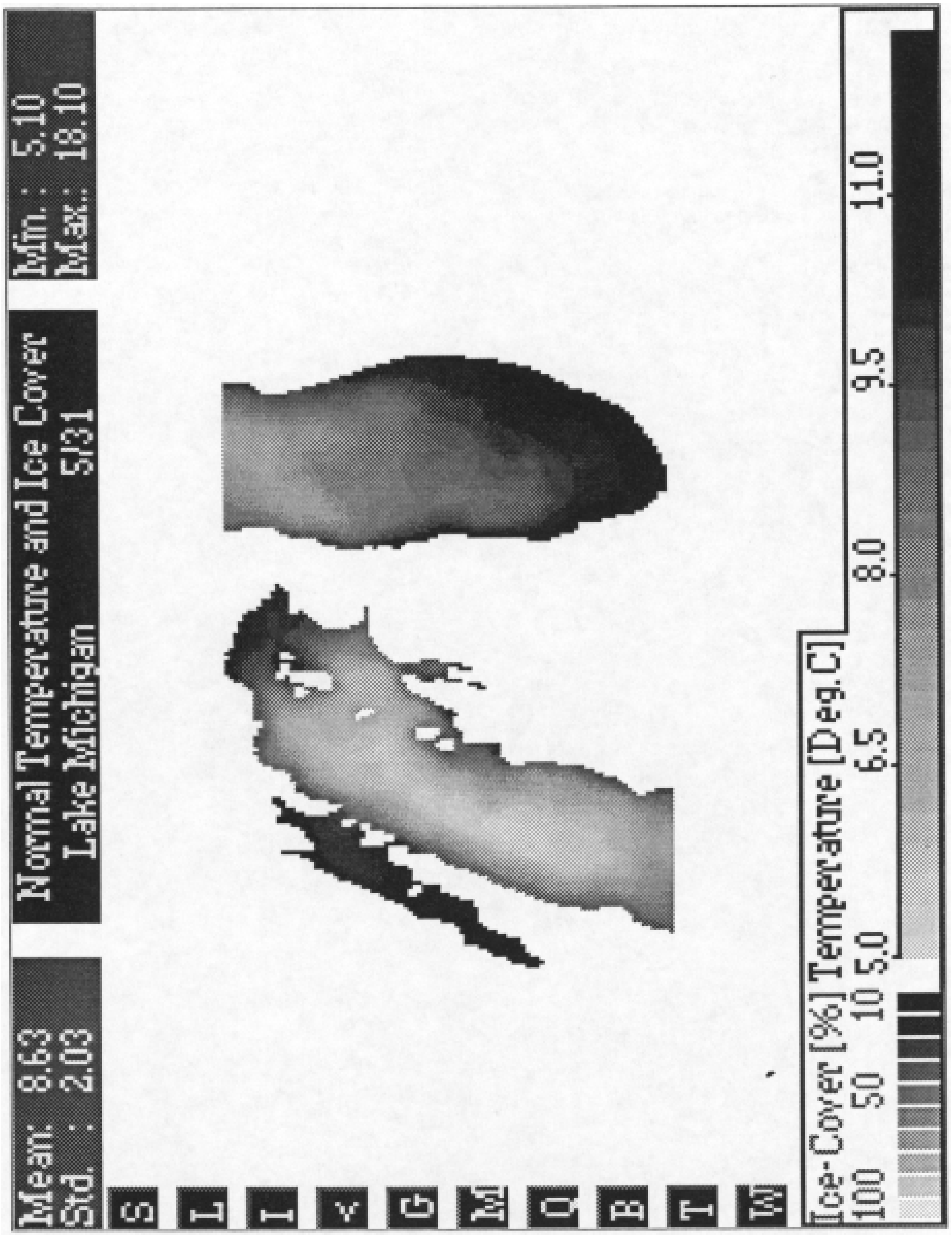

Figure B-5.--2-D Animation for Lake Michigan

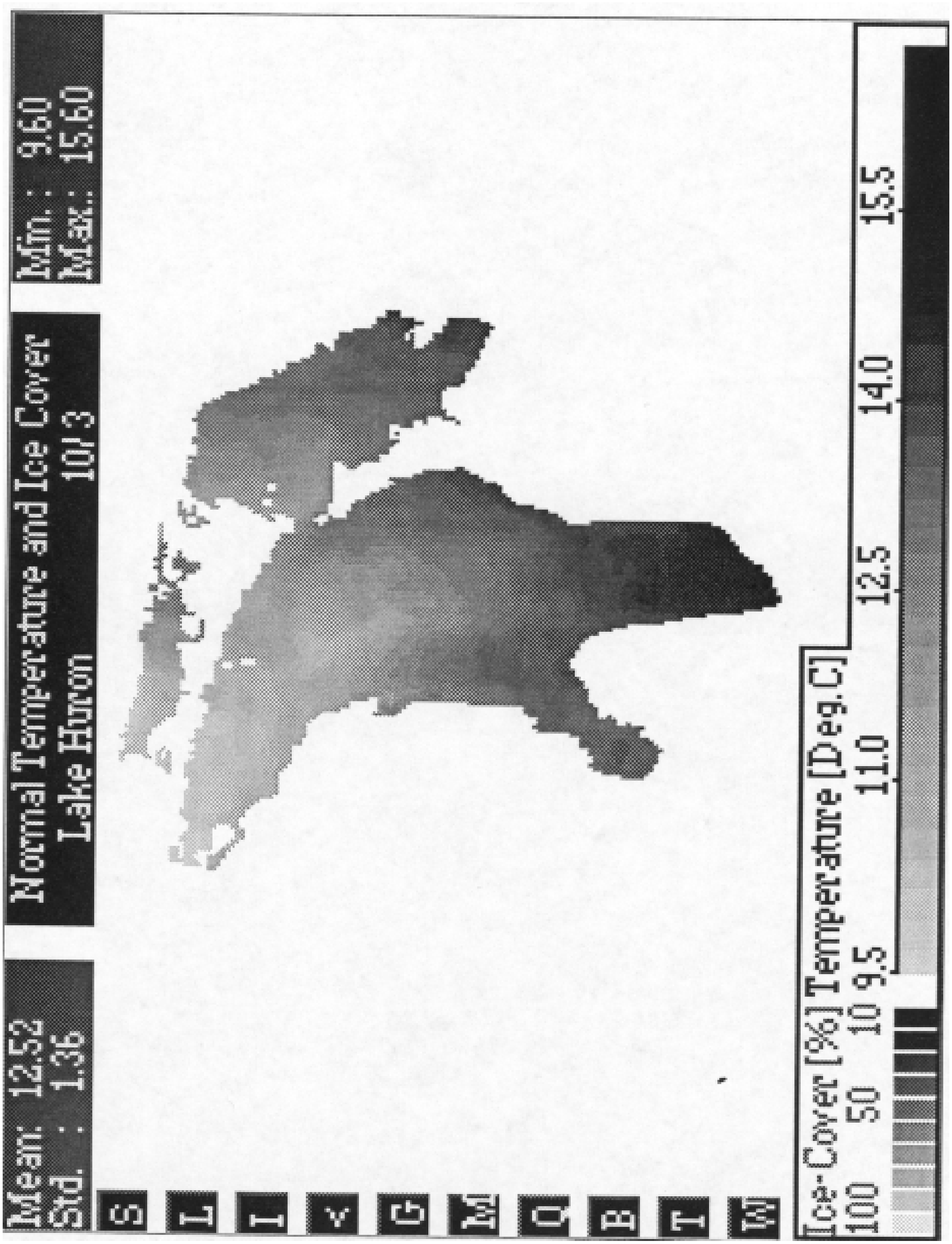

Figure B-6.--2-D Animation for Lake Huron

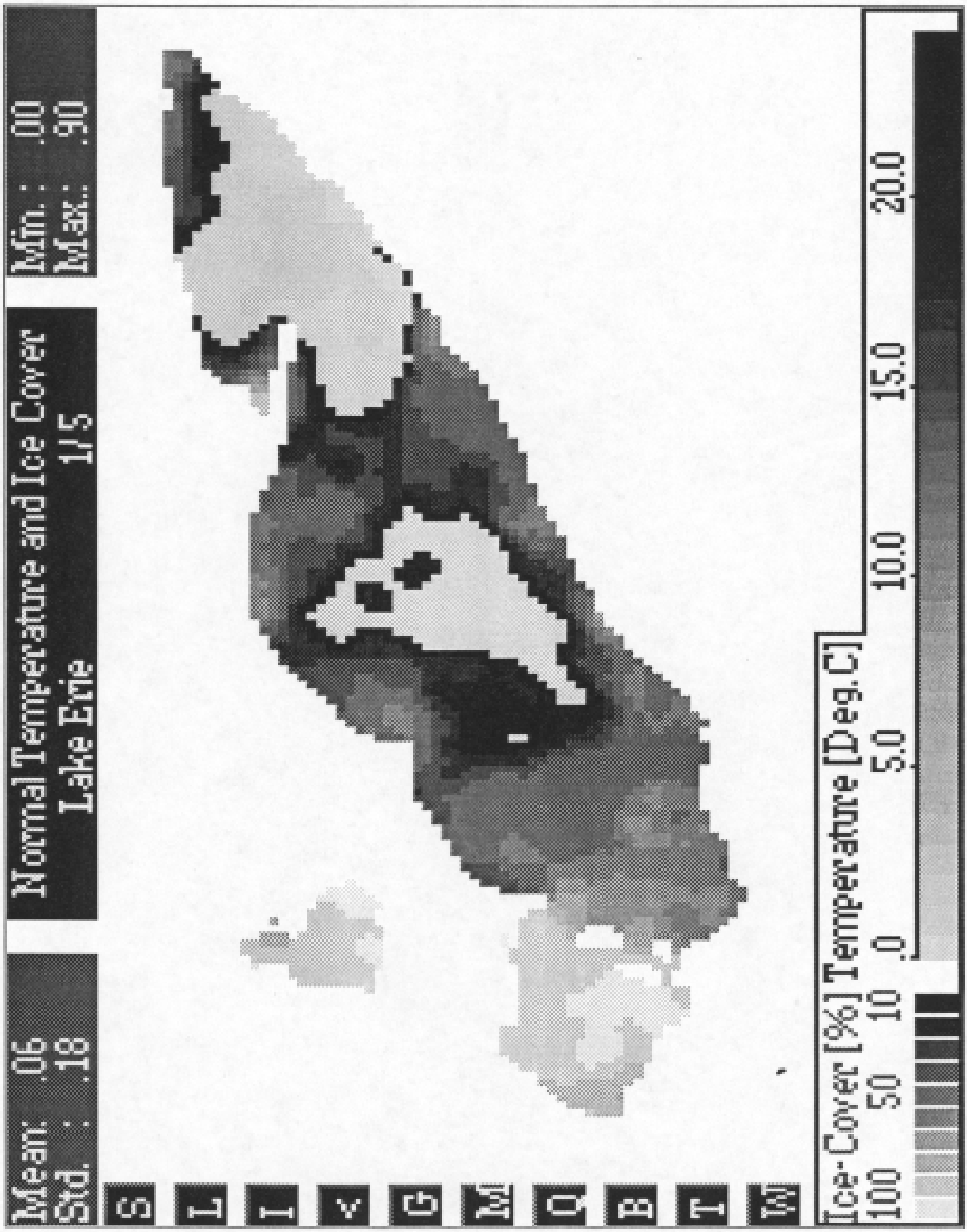

Figure B-7.--2-D Animation for Lake ErieFigure B-4.--2-D Animation for Lake Superior

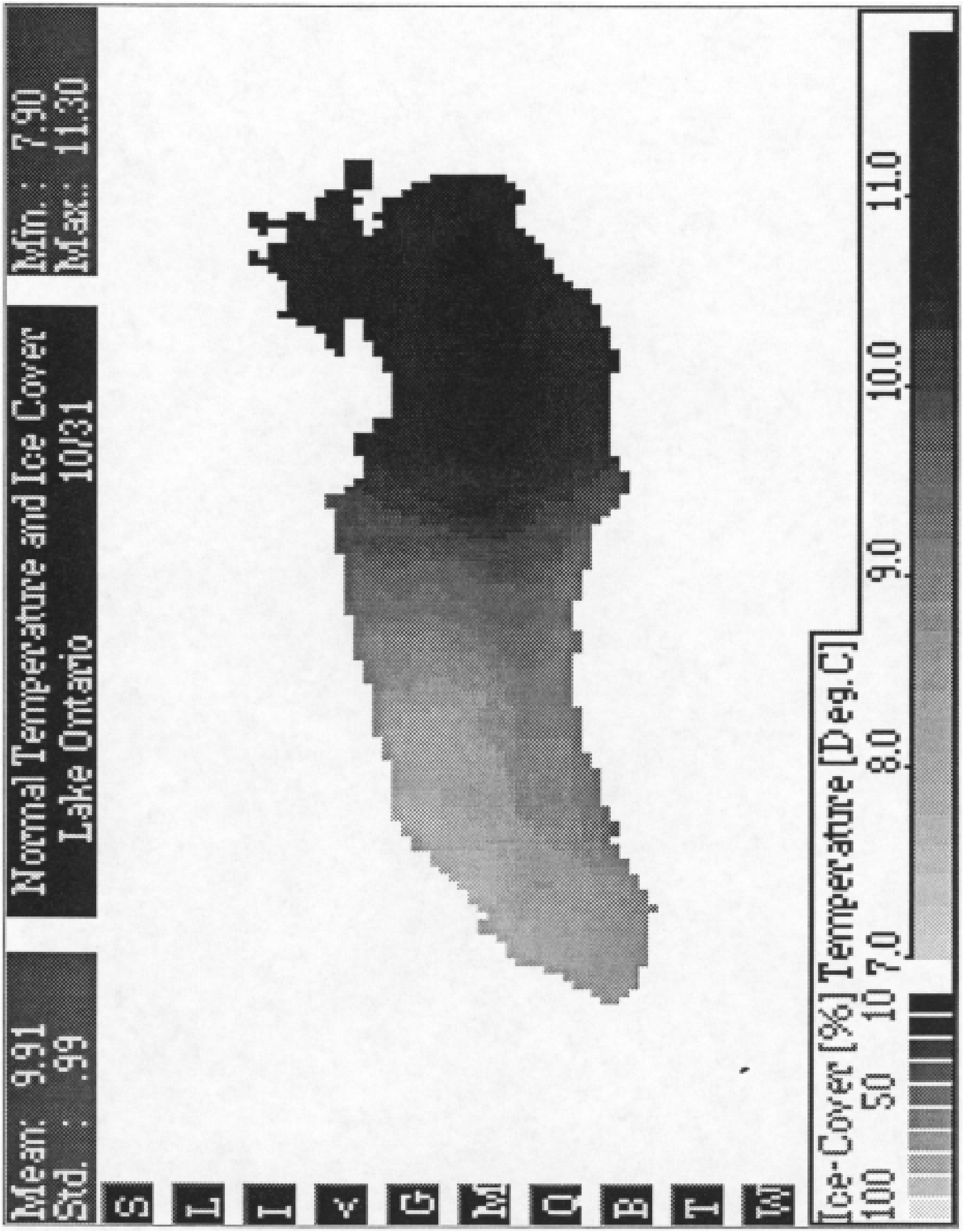

Figure B-8.--2-D Animation for Lake Ontario

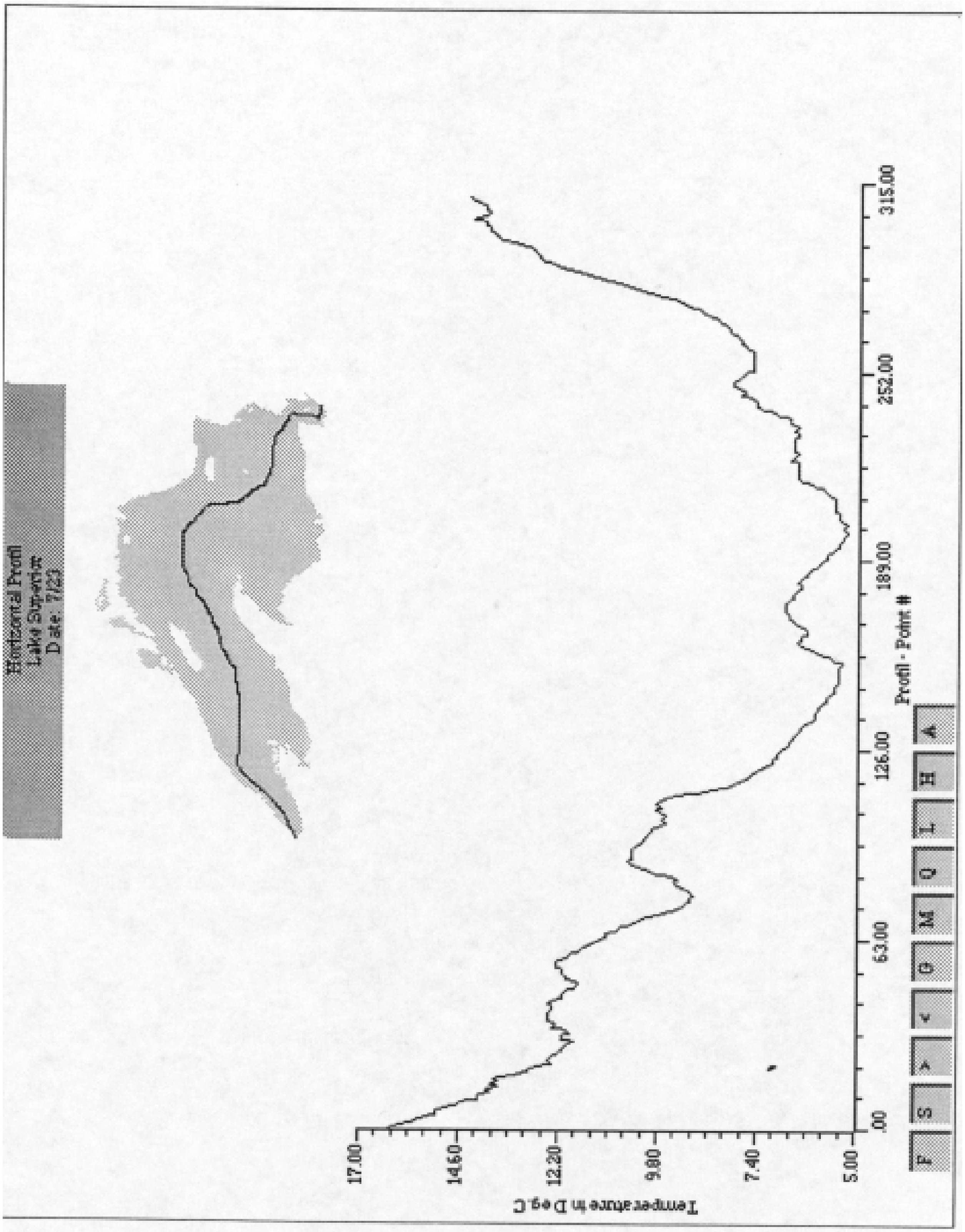

Figure B-9.--Horizontal Temperature Profile

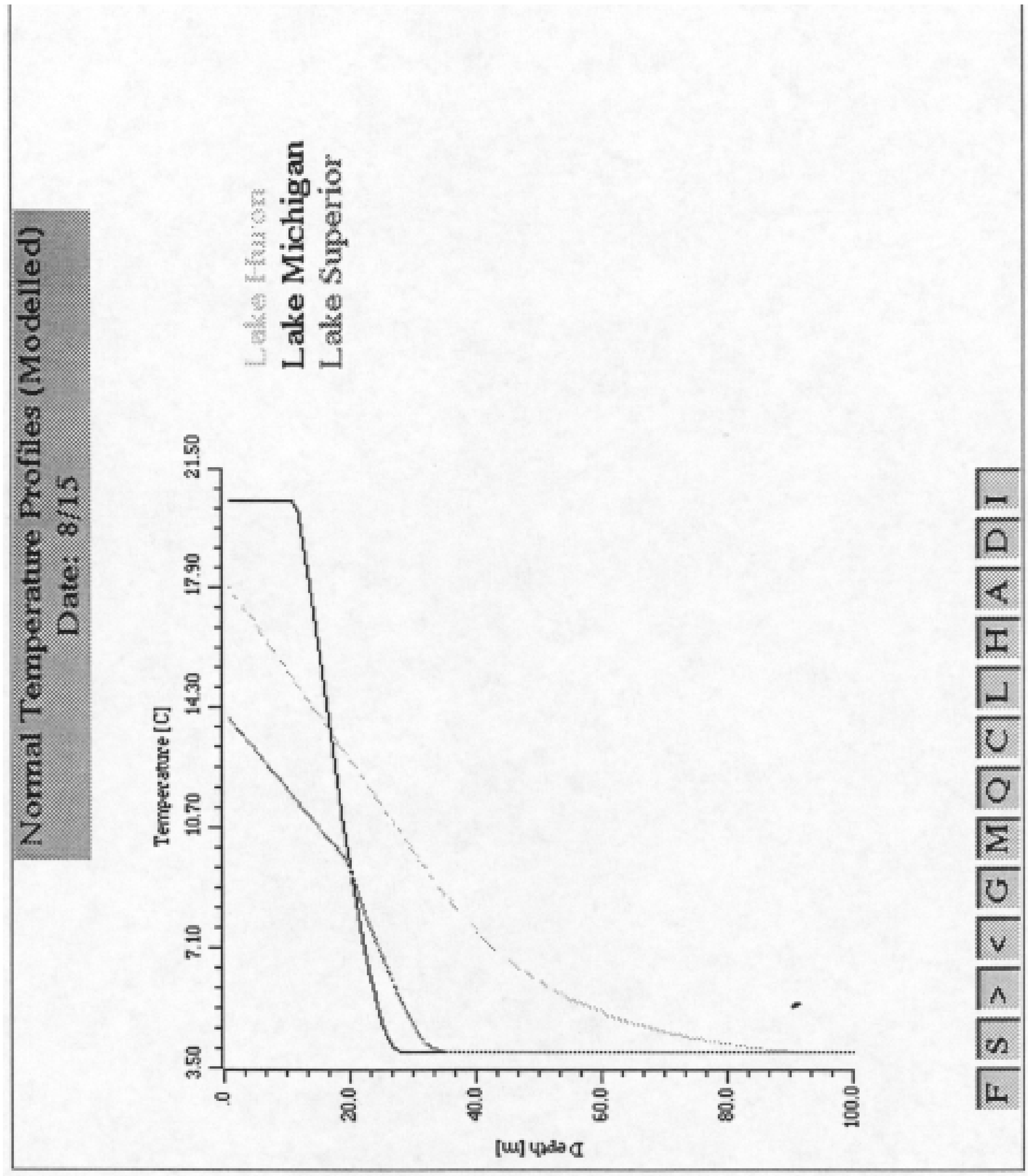

Figure B-10.--Vertical Temperature Profile

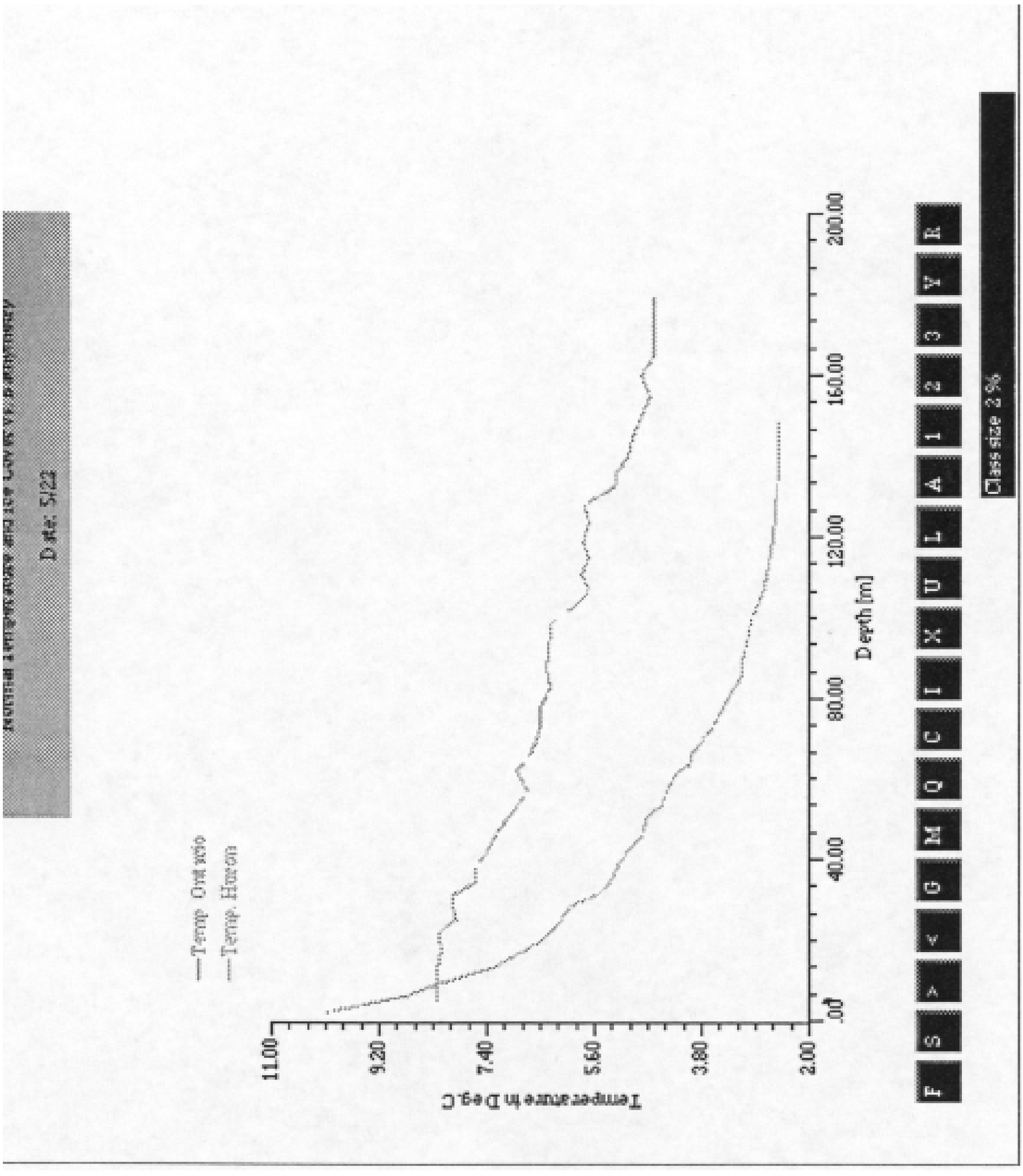

Figure B-11.--Temperature versus Bathymetry

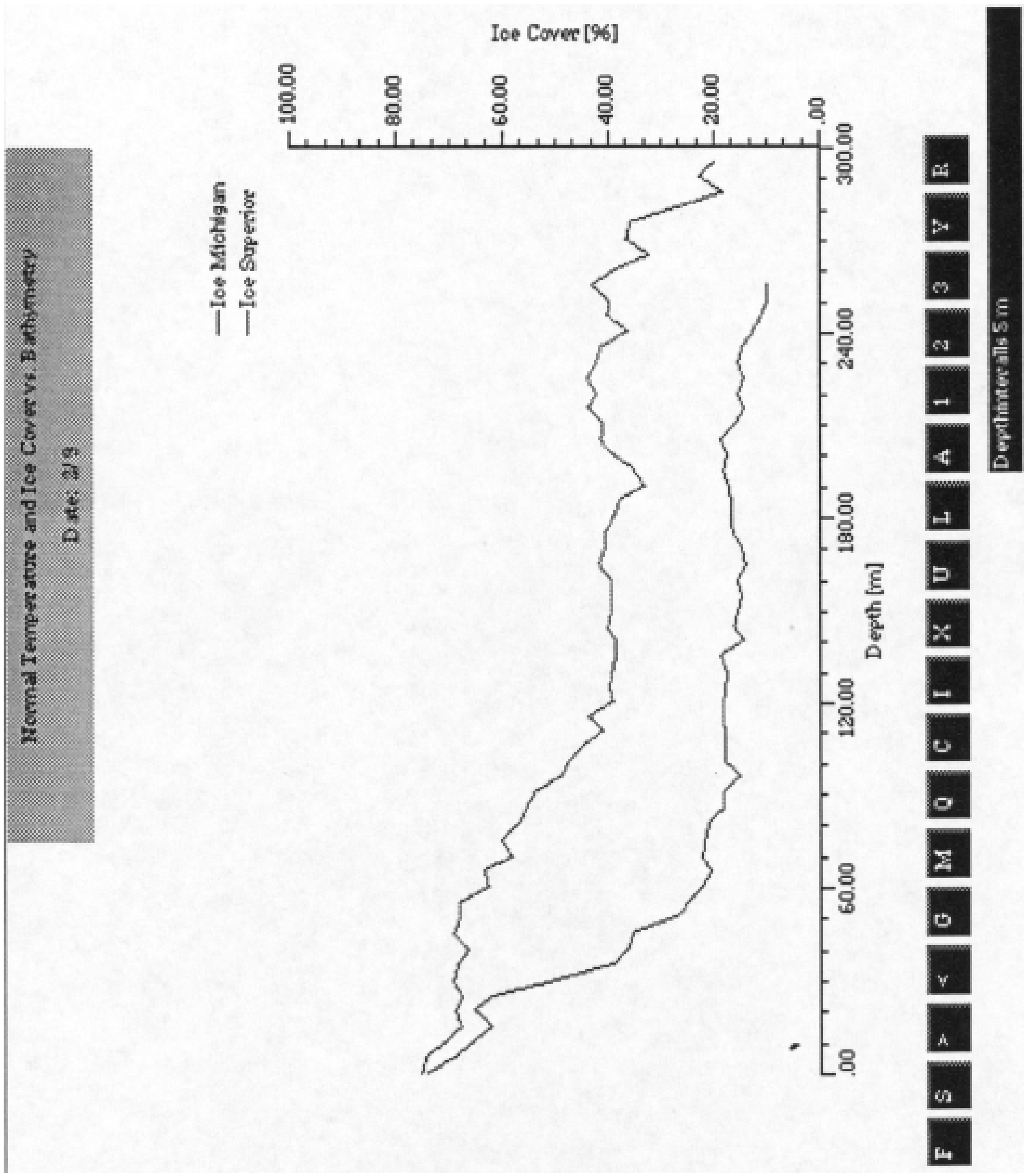

Figure B-12.--Ice Cover versus Bathymetry

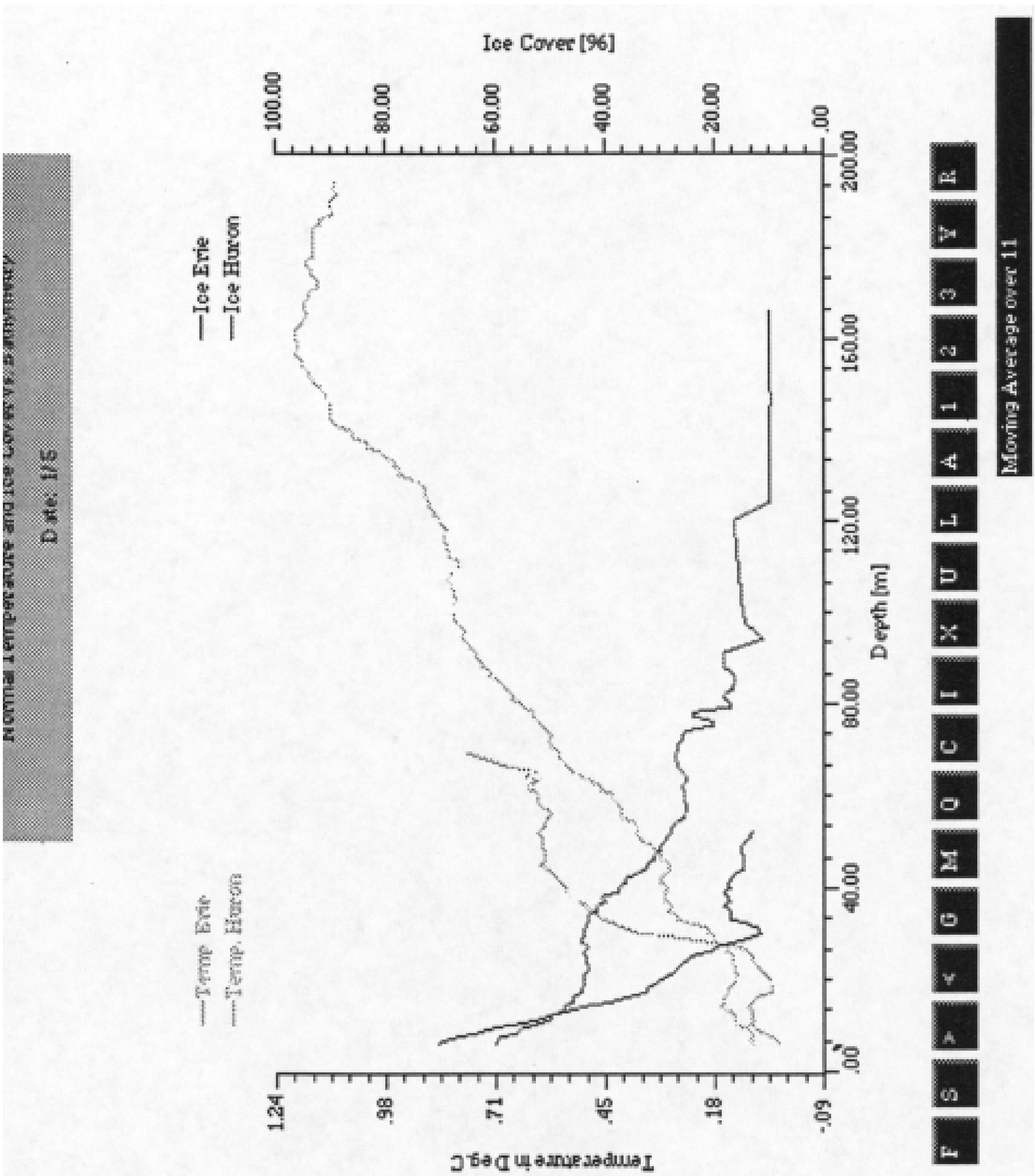

Figure B-13.--Temperature and Ice Cover versus Bathymetry

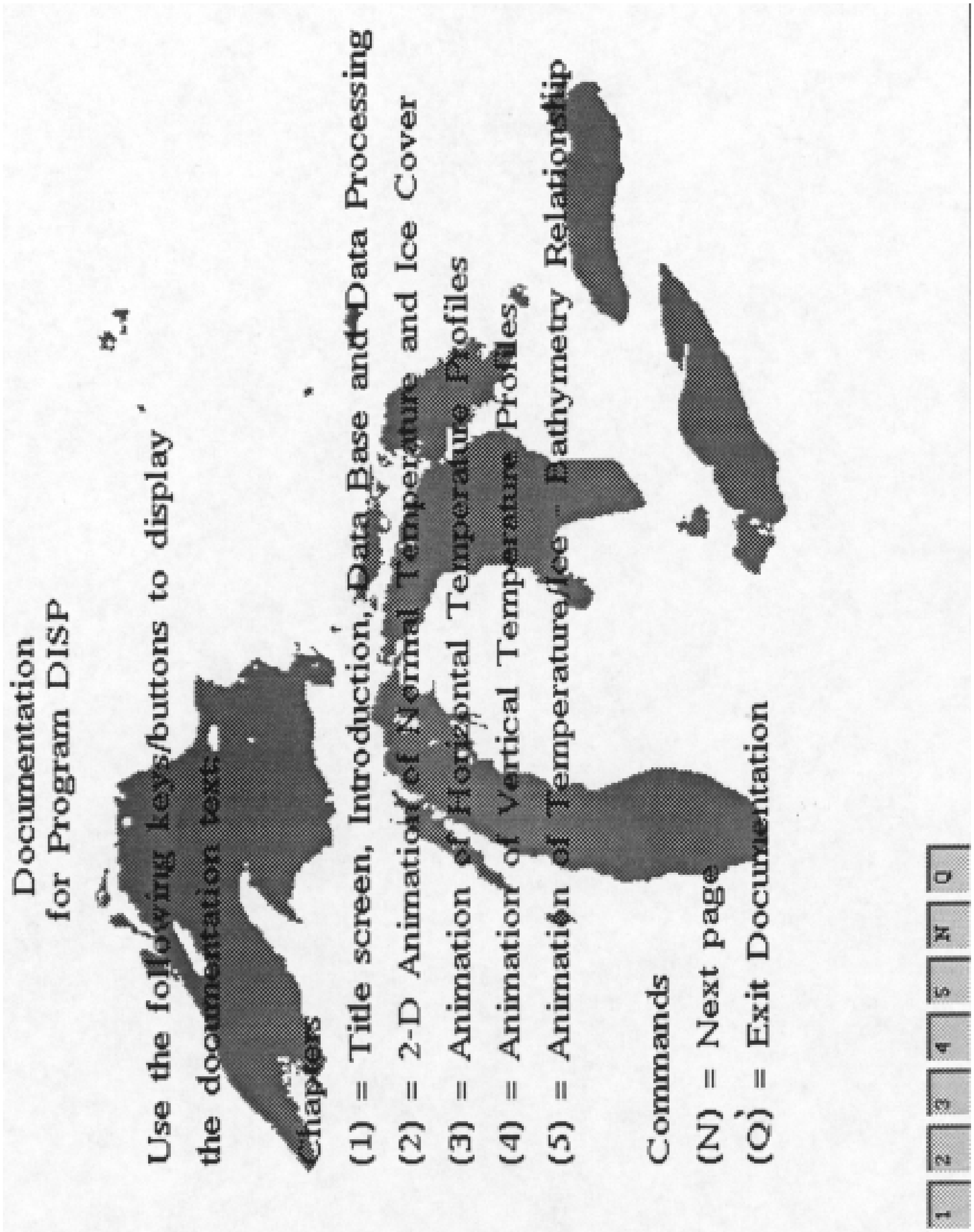

Figure B-14.--Documentation Screen