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APPLICABILITY OF SATELLITE FREEZE FORECASTING AND COLD CLIMATE MAPPING TO THE OTHER PARTS OF THE UNITED STATES

Subcontract to Michigan State University
Agriculture Experiment Station
Center for Remote Sensing
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ACKNOWLEDGEMENTS

This project has involved a number of MSU faculty, specialists, and students, all of whom have contributed to the process of developing and utilizing satellite imagery for applications in Michigan. The development of the various software and displays required the use of several different computing facilities at MSU including those in the Department of Entomology, the Center for Remote Sensing and the Univeristy mainframe. The project has grown through stimulation from a rather small contract. As more individuals are exposed to the system developed at MSU, additional applications are perceived and suggested. The information and displays provided by the system are currently shown at remote sensing training sessions and the technology transfer process is being extended further through these educational channels.

This report and the results contained herein, are a product of many individuals who have worked on various aspects of this project. Following is an alphabetical listing of those who have made significant contributions to the project.

John Baleja, Programmer Analyst, Center for Remote Sensing
Jon Bartholic, Associate Director, Agricultural Experiment Station
William Corcoran, Student Programmer, Department of Geography
William Enslin, Manager, Center for Remote Sensing
Stuart Gage, Associate Professor, Department of Entomology
Ardeshir Goshtasby, Graduate Research Asst. Center for Remote Sensing
David Lusch, Research Specialist, Center for Remote Sensing
James Pieronek, Systems Analyst, Department of Entomology

We also acknowledge the efforts of Liz Bartels and Rosie Spagnuolo who assisted in preparing the final report.

I. INTRODUCTION

The physiography of Michigan provides a ideal conditions to evaluate the use of GOES thermal imagery for assessing freeze events in the state. Since fruit is among the major commodities grown in Michigan and freezing temperatures can severely limit production, a frost assessment and prediction system can be a definite asset.

For example, 1981 showed that spring frosts can have a major impact on the fruit crop. This year, frosts during April destroyed a major portion of the Michigan cherry crop and were also responsible for diminishing apple production. The cherry crop was reduced by about 75% in the major growing area and apple production was reduced by up to 50%. These events exemplify the need to enhance frost prediction methods and to develop methods to analyze and assess the impact of such events.

This project has addressed some of these aspects and real progress has been made in identifying the value of using GOES thermal imagery in Michigan. The process of technology transfer is a difficult one and we appreciate the efforts of NASA and The University of Florida in this activity.

At MSU we are convinced of the utility of using satellite information to aid in the enhancement of crop production for Michigan. It should be recognized that our growth in this high technology area has been variable. Within the University it has been important to disseminate some of the technology to other units. We have been successful in moving the efforts related to this project to the Center for Remote Sensing from the Entomology Department where the project was first established. Additional state resources were allocated so that we could approach the use of thermal imagery as part of an integrated system. Hardward has been acquired and existing hardware has been used toward these developments.

We now believe that we are on the trajectory of developing an independent and integrated project which will be able to grow on its own accord. This should be truly indicative of the process of technology transfer.

It is the intent of this report to describe the progress we have made and to identify the developments relative to the tasks which were assigned. First, since a great deal of effort was placed on development of a system to process satellite imagery, an overview of the processing system will be presented. Second, GOES thermal images and several surface environmental data bases were prepared to comply with the various tasks which we were able to accomplish. These data bases were developed so that we could begin to assess the physical models developed in Florida. Third, the data bases were then analyzed to identify correlations between satellite apparent temperature patterns, and earth surface factors. Fourth, a discussion of significant freeze events in 1981 and the physical models are presented to provide our perspective on how these models could be applied in the context of the Michigan environment. Next, we felt it necessary to describe some of the difficulties we encountered in obtaining data to develop the system for Michigan.

II. MSU GOES DATA ANALYSIS SYSTEM

New data analysis and display capabilities were developed and implemented around the existing basic software system used at MSU to manage image data obtained from the GOES satellite (Figure 1).

The previous system includes a projection conversion program and several display options. GOES thermal infrared data, stored on nine-track magnetic tape by NESS, are read onto a permanent disk file on the MSU CDC Cyber 170/750 mainframe computer. These data are converted to text and transmitted to a Terak 8510 via a 1200 baud telephone connection and stored on diskette for further processing.

Once the data are available on the Terak microcomputer, they are reconverted into the original format--a 129 by 129 array of integers corresponding to infrared intensities as measured by the GOES/SMS satellite. The projection conversion program converts the satellite's perspective projection centered at 75 degrees west longitude, 0 degrees latitude, to an orthographic projection of Michigan centered at 85 degrees west longitude, 42 degrees north latitude. Although this program corrects the perspective distortion, it does not correct for drift in the satellite's position, which can introduce a registration error of 5 to 30 kilometers in a given data set. Software programs allow an operator to produce several different types of maps interactively

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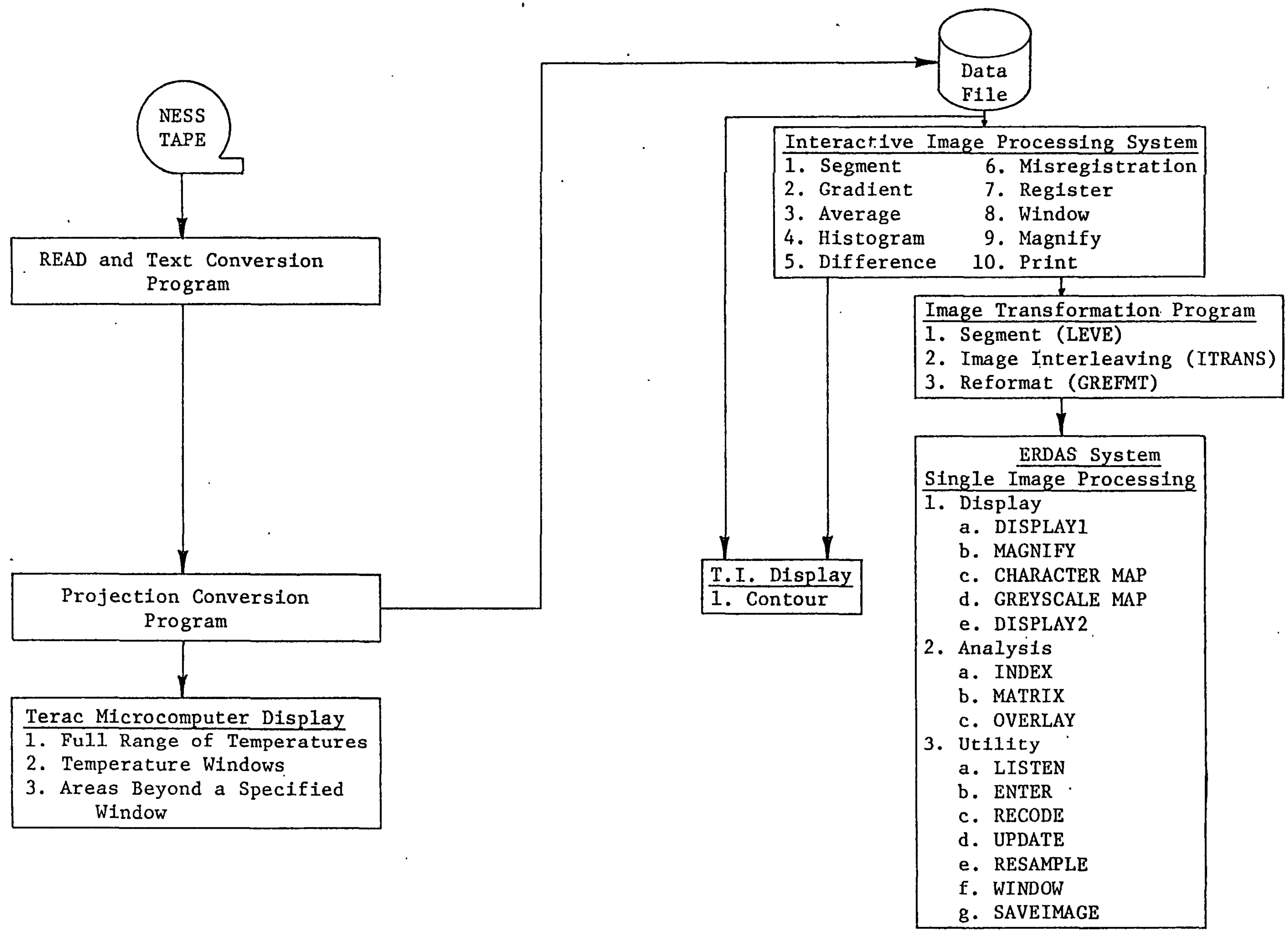

Figure 1. MSU GOES data analysis systems.

using a data value-to-temperature conversion scheme which is basically a two-part linear approximation of an exponential curve (Chen, 1979). The display program produces the following:

a. Map of full range of temperatures across Michigan.

b. Map of areas falling into a specified temperature window.

c. Map of areas with temperatures above or below a specified temperature.

All of the above temperature displays are available in degrees Fahrenheit, Celsius or Kelvin. The program operator selects the desired mapping option and the computer produces an image on either a 12 inch black-and-white video monitor with 320 by 240 on/off pixel resolution or an eight-color video monitor.

A. Interactive Image Processing System

All of the new programs access GOES data that has been transferred back onto a data file on the mainframe computer after being run through the projection conversion program.

An interactive image processing system (IIPS) was developed which contains module subprograms that perform selected operations on image data. The system resides on the Cyber 170/750 mainframe computer and is operated interactively from a terminal. The image operation routines (except for file handling and management) available are:

1) SEGMENT--segments an image into regions of specified gray levels using up to 15 threshold values.

2) GRADIENT--finds the gradient of an image by the maximum difference method. If the input image is a segmented image, the result is a contour image.

3) AVERAGE--finds the average gray level of corresponding pixels of several images.

4) HISTOGRAM--produces a histogram of data values of an image.

5) DIFFERENCE--finds the difference between the data values of pixels in two images.

6) MISREGISTRATION--finds the translational misregistration between images by using a sequential similarity detection method on gradient images of the original data.

7) REGISTER--corrects for translational misregistration through x,y shift.

8) WINDOW--will window out a portion of an image.

9) MAGNIFY--will enlarge an image to a specified magnification factor.

10) PRINT--outputs an image as gray level values on a printer.

B. The Earth Resources Data Analysis System (ERDAS)

Image data generated through the above routines can be transferred via a 1200 baud telephone connection to the ERDAS microcomputer system at the Center for Remote Sensing. One of the following image transformations, accomplished with software which resides on the Cyber 170/750, must be executed prior to data transfer:

1) SEGMENT (LEVE)--groups the Fahrenheit or Celsius temperature value into 2-16 ranges.

2) IMAGE INTERLEAVING (ITRANS)--transforms four GOES images into a band interleaved by line format file.

3) REFORMAT (GREFMT)--processes GOES image data for transfer to the ERDAS system.

A geographic information system, IMGRID2, is available on the ERDAS for the manipulation of grid-based data files. This system will display a data file on a 512 x 480 x 4 bit pixel array capable of a maximum of 16 color-coded categories. The following display, analysis and utility options are available within this GIS:

DISPLAY

1) DISPLAY1--displays a user-specified data file on the color monitor in the 512 x 480 display mode.

2) MAGNIFY--magnifies a user-specified data file on the color monitor in the 512 x 480 display mode.

3) CHARACTER MAP--prints a character overprint grey scale map of a user specified data file on the Anadex printer.

4) GREYSCALE MAP--prints a dot matrix grey scale map of any user-specified data file on the Anadex printer.

5) DISPLAY2--displays a data file that includes user-generated alpha-numeric graphics.

ANALYSIS

1) INDEX--performs a weighted summation on 2-5 variable files and outputs a new variable file.
2) OVERLAY--creates a new file by combining from 2-5 user-specified variables and taking the highest value for any grid cell from the old variables and assigning it as the new data value.
3) MATRIX--compares the occurrences between two variable files and create a new variable file of the coincidences.

UTILITY

1) LISTEN--A system communication package used primarily for mainframe to micro data transfer.
2) ENTER--Allows the user to enter data to create a new variable file.
3) RECODE--Allows the user to change or group specific values in a given variable file.
4) UPDATE--Allows the user to change the value of any data element in a given file.
5) RESAMPLE--Changes the pixel size of any user-specified image.
6) WINDOW--Creates a user-specified subimage from a larger image file.
7) SAVEIMAGE--Stores an image exactly the way it is displayed on

the RGB monitor.

C. Contour Program

The Interactive Image Processing system also transfers GOES data, via a 1200 baud telephone link, to the Texas Instrument minicomputer in the Department of Entomology. The contour program on the T.I. computer is designed to find the boundary between regions of different temperature ranges in a GOES thermal image. After the contours are found, they can be displayed either on the graphics terminal or the plotter.

The program is composed of 3 parts:

1) Thresholding, by which the image is segmented into regions of different temperature ranges which are specified by the user.
2) Contour extractor which produces contours by following the boundary between regions.
3) Plotter program which generates plotting data both for the graphics display and the plotter.

III. DATA BASES

A. Goes Data Base

Computer line printer maps were created from each of the 18 GOES images within the time frame of 3:00 p.m., June 24 to 10:00 a.m., June 25, 1979 which were available for the study. These maps display the Fahrenheit temperature value for each GOES pixel in a given scene. Based on a comparison of all of these line printer maps, the 10:00 a.m. image was selected as having the widest temperature variation for a daytime image (8:00 a.m. - 6:00 p.m.) and the 5:00 a.m. image was selected as having the widest temperature variation of the night images (8:00 p.m. - 7:00 a.m.). The 10:00 a.m. and 5:00 a.m. printer maps were hand-contoured using a 2 degree F contour interval and optimum landmass and water temperature ranges were determined. This process was necessitated by the IMGRID2 graphic information system which is limited to a maximum of 16 color-coded categories. These temperature ranges were used to process all of the GOES data sets using the segment routine on the mainframe computer.

Since the June 24-25, 1979 GOES digital tape did not contain the orbital information necessary for digital geometric correction procedures, a less accurate registration method was employed. Once the 10:00 a.m. data file was contoured and color coded via the IMGRID2 package, it required resampling since the screen pixels on the color monitor are square. Hence, the color-coded image on the monitor could not be used for "fitting" to the base map.

Initial photographic enlargement of color-coded GOES data had suggested that the average pixel size was approximately 9 x 12 km. Using this pixel aspect ratio, a line printer map of contoured (categorized in 16 classes) temperature data was created at a scale of 1:1,000,000. This map was found to be very distorted compared to the 1:1,000,000 U.S.G.S. base map of Michigan indicating that the pixel size was not 9 x 12 km. Several other aspect ratios were tried and the "best fit" was obtained with pixels which were 8 x 11 km. The 8 x 11 km grid cell was adopted for use in data capture in order to match the GOES data.

Figure 2 depicts the thermal patterns in Michigan at six selected times during the interval 3:00 p.m., June 24 to 10:00 a.m., June 25, 1979. The 3:00 p.m. (Figure 3) and 4:00 a.m. (Figure 4) data sets were selected for analysis because they approximate maximum and minimum land-surface temperature conditions, respectively.

The multitemporal analysis of the GOES data mandates that the various data sets be registered relative to one another. Two methods were used to determine and correct translational misregistration between GOES images resulting from satellite drift between acquisition times. The first method involved generating line printer maps of each GOES image, and contouring by hand the shoreline of Michigan (i.e. the maximum thermal gradient contour) on each map. These shoreline contours were used to register map pairs superimposed on a light table. The amount of misregistration between two images was simply the amount of shift (x,y), if any, between the column and row numbers of each map pair. Using the Window program on ERDAS, the GOES data files were properly registered to each other by partitioning out windowed areas specified by appropriate x-y coordinates for each image.

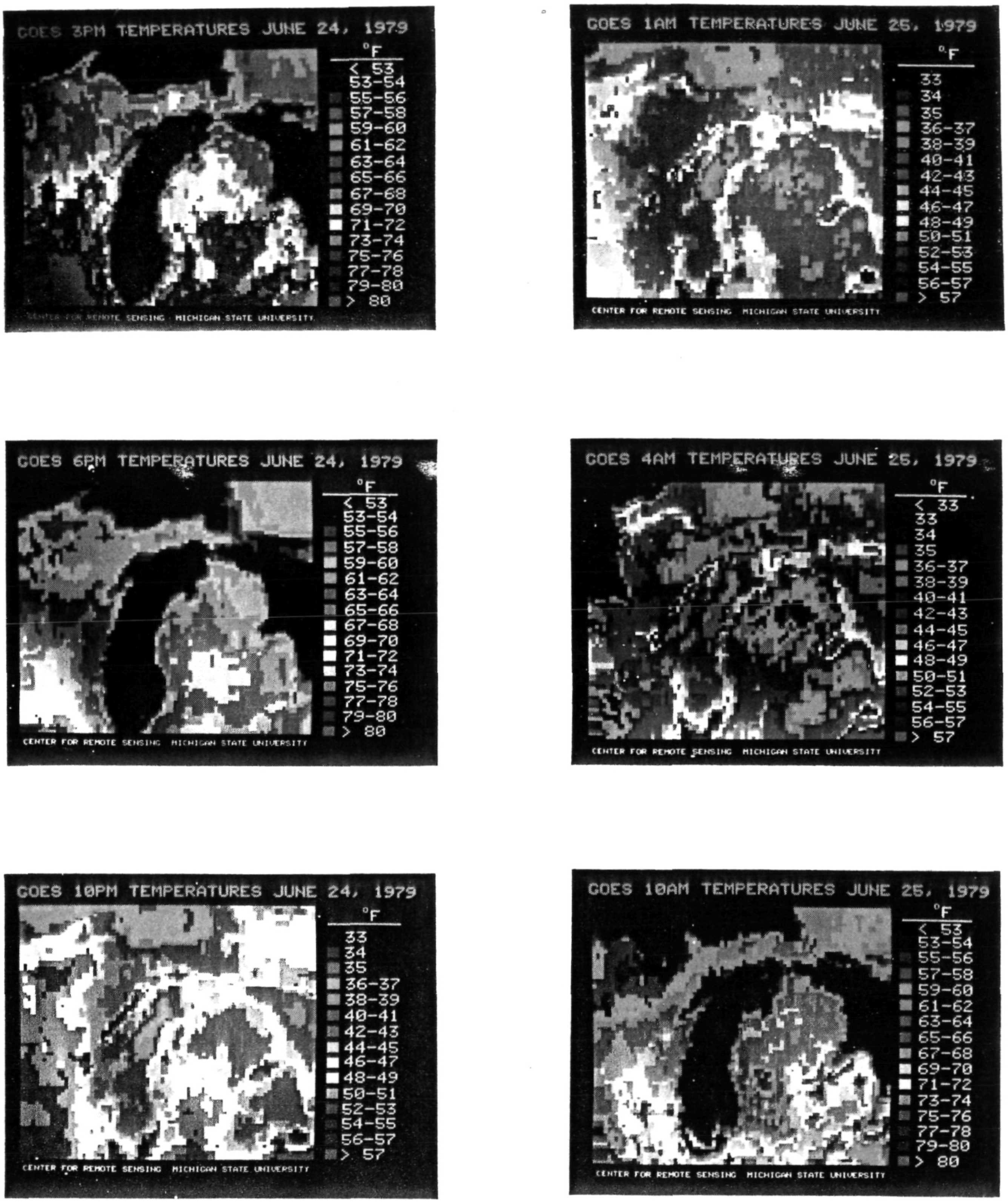

Figure 2. Color display sequence of GOES thermal data of Michigan acquired June 24-25, 1979.

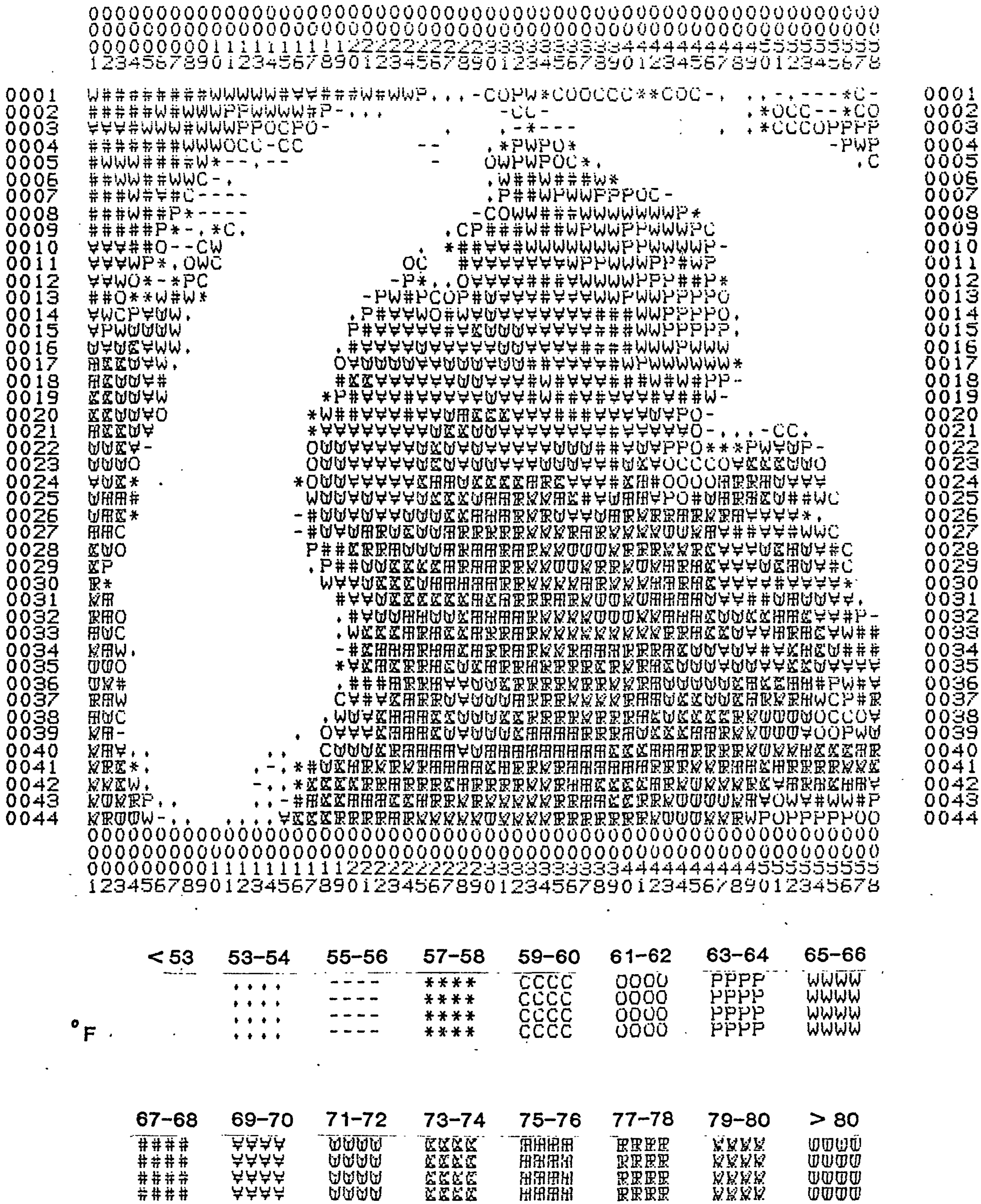

Figure 3. Line printer output of GOES pixel temperatures in Michigan from 3:00 p.m., June 24, 1979.

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A second, digital method was developed which automatically determines the translational misregistration between images. The registration is accomplished using a sequential similarity detection method (Barnea & Silverman, 1972).

This method works as follows:

1) Gradient images of each GOES image are provided.
2) A search area (a subpicture) of one of the two images to be registered is selected.
3) A window area from the other image (which is smaller in size than the search area) is selected which covers (approximately) the same region on the ground as the search area.
4) The window area is shifted exhaustively over the search area and the difference between the search and the window area is computed.
5) The registration is determined by the (x,y) translation which produce the minimum difference value.

The following table shows the amount of translational corrections (x,y shift) needed to register each GOES image to the previous one in the sequence (relative shift) and to the 3:00 p.m. image (absolute shift). The 3:00 p.m. image was selected as the base because it displays the maximum thermal gradient along Michigan's coastline.

IMAGE TIME	RELATIVE SHIFT VALUE (x,y)	ABSOLUTE SHIFT VALUE (x,y)
3:00 p.m.		
4:00 p.m.	(0,0)	(0,0)
5:00 p.m.	(0,1)	(0,1)
6:00 p.m.	(0,0)	(0,1)
8:00 p.m.	(-1,0)	(-1,1)
9:00 p.m.	(0,0)	(-1,1)
10:00 p.m.	(-1,0)	(-2,1)
11:00 p.m.	(1,0)	(-2,1)
12:00 a.m.	(-1,0)	(-3,1)
1:00 a.m.	(0,0)	(-3,1)
2:00 a.m.	(0,0)	(-3,1)
4:00 a.m.	(1,0)	(-2,1)

B. Surface Environmental Data Base

Several environmental factors were selected because of their potential to significantly influence surface temperatures. These included land cover/use, local relief, percent forest land and water holding capacity in the upper three feet of soil. With the exception of statewide land cover/use information, published data were available for each of these variables.

Level I land cover/use data were photo interpreted from 1:1,000,000 scale, diazo-enhanced Landsat imagery. Seven categories were derived: urban, agriculture, deciduous forest, coniferous forest, barren land, water and wetlands. Local relief data were extracted from the very small scale (approximately 1:3 million) map in Pawling (1969). Information on the percent of land in forest was available from a 1:2.5 million map of the state (Michigan Department of Natural Resources, 1970). Data on the water holding capacity of Michigan's soils were obtained from 1:1.8 million maps of the state (Schneider and Erickson, n.d.). Although information was available for several solum depths, data for the upper three feet were selected to take into account the many two-storied soils in Michigan.

All of these maps were brought to a common scale of 1:1 million cartographically. Each factor map was registered to the 1:1 million U.S.G.S. base map of Michigan and overlaid with a computer-generated orthogonal coding grid composed of 8 x 11 km cells. Dominant factor categories were encoded in each cell and, subsequently, placed on diskette storage via direct keyboard entry on the ERDAS microcomputer. These four digital files were output to line printer hardcopy and compared for registration accuracy. Additionally, the percent forest land and land cover/use files were digitally overlaid to assess their compatibility and assist in editing the files for encoding errors. The general patterns of the four surface characteristics are discussed below.

The generalized land cover/use of Michigan's southern peninsula is shown in Figure 5. The large cell size of the encoding grid (determined by the GOES pixel dimensions), is compatable with this Level I categorization of land cover/use. Urban centers large enough to dominate this cell size occur only in the southern half of the peninsula which is dominated by agricultural land use. The two forest categories predominate in the northern half of the Lower Peninsula and water bodies sufficiently large to dominate a coding cell are also restricted to this part of the state.

The forest lands in the southern part of the state are scattered and small in extent compared to the woodlands in the northern half of the Lower Peninsula. With the exception of the Allegan State Game Area in southwestern Michigan, which is 70-95% forested, most of the woodland in southern Michigan is less than 40% forested (Figure 6). The northern Lower Peninsula, on the other hand, has at least 70% forest cover in most places. A notable exception to this generalization is the agricultural area of northwestern Michigan around Grand Traverse Bay which has less than 40% forest cover.

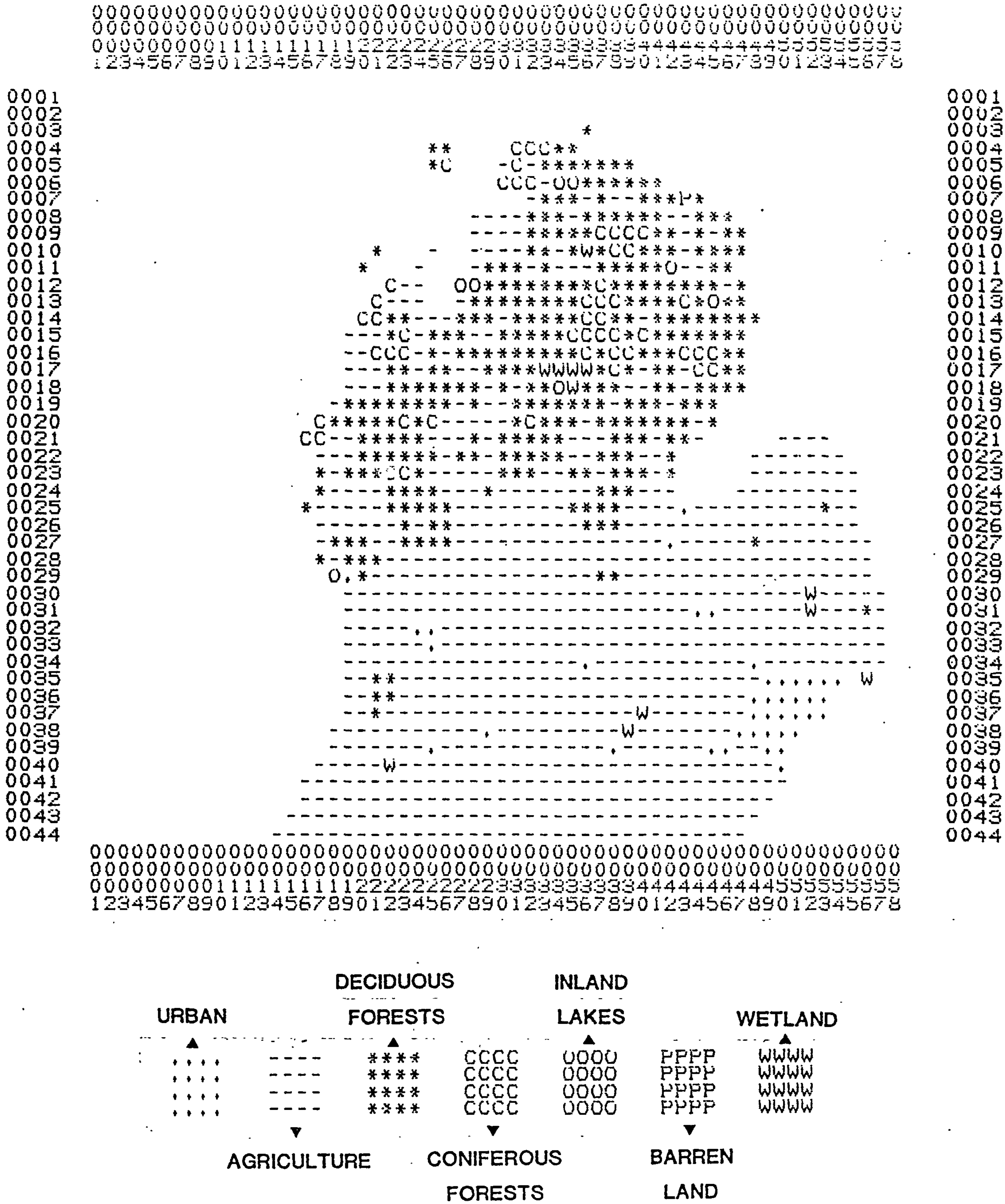
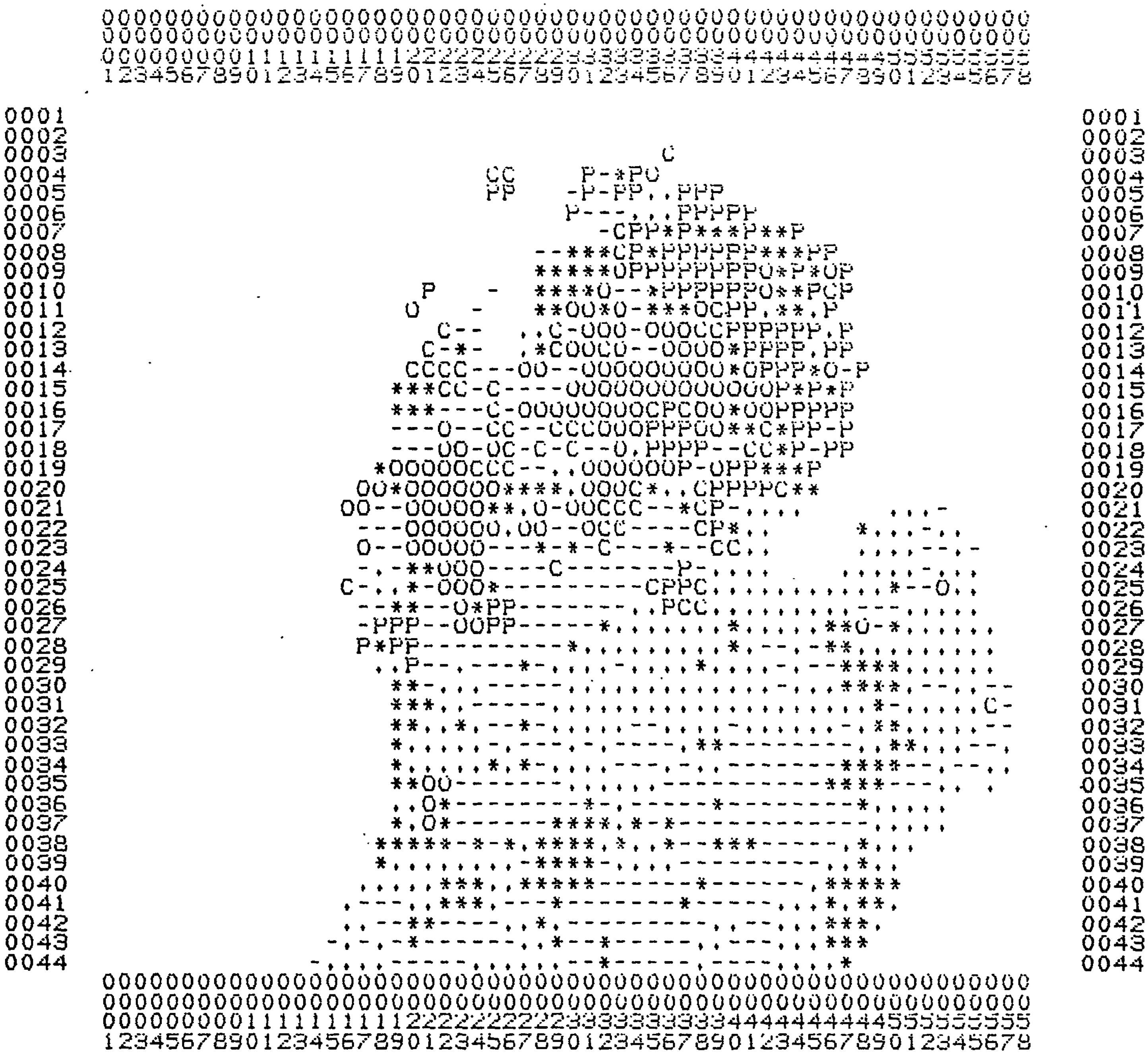


Figure 5. Land cover classification of Michigan.

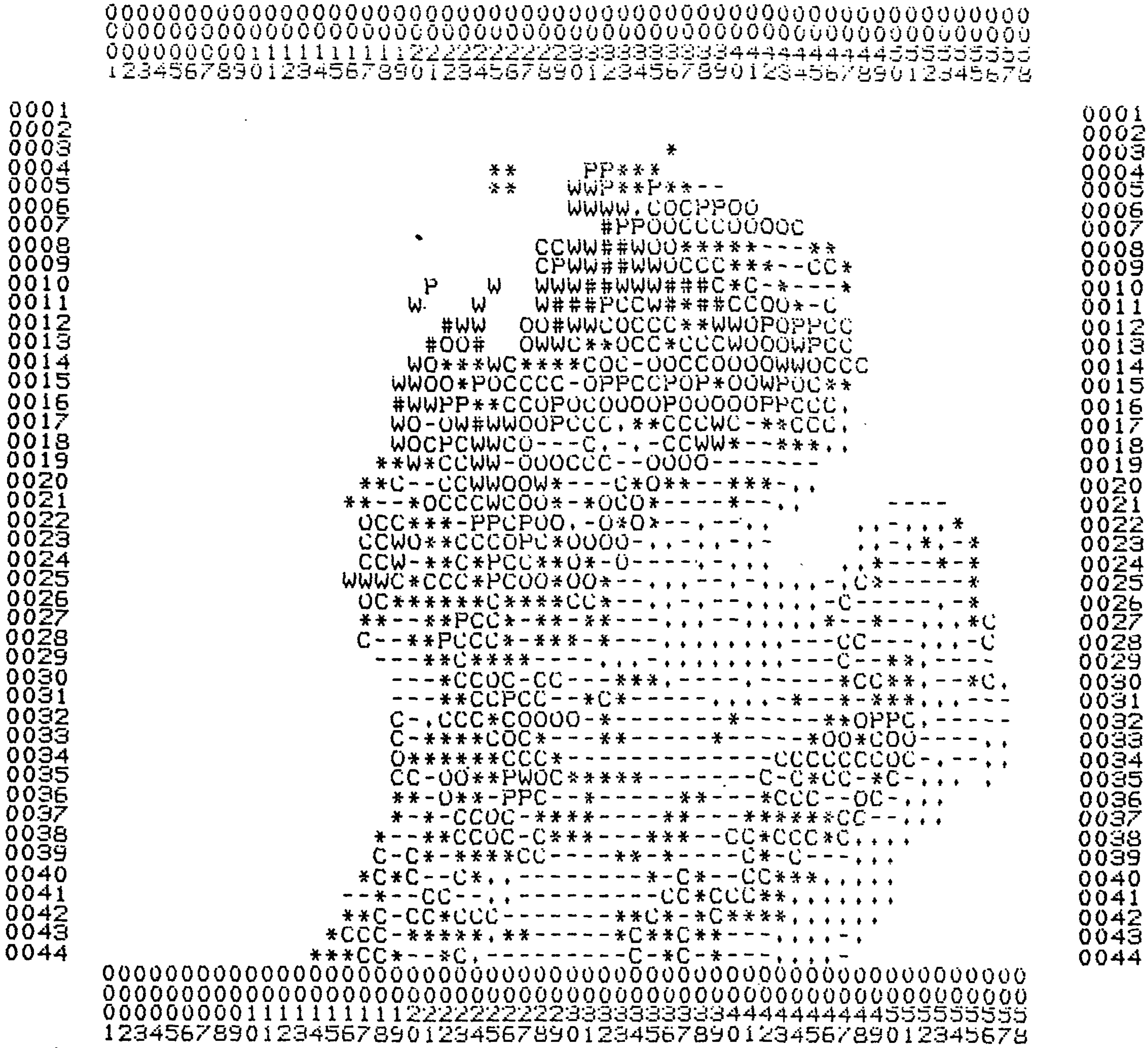


0-5%	5-15%	15-40%	40-70%	70-95%	95-100%
....	----	****	CCCC	OOOO	PPPP
....	----	****	CCCC	OOOO	PPPP
....	----	****	CCCC	OOOO	PPPP
....	----	****	CCCC	OOOO	PPPP

Figure 6. Percent of land in forest for Michigan.

Local relief, a measure of absolute elevation difference per unit area, in the Southern Peninsula ranges from less than 49 feet per cell (GOES pixel) to more than 500 feet per cell (Figure 7). Areas of lowest relief (0-49 feet/cell) correspond to the glacial lacustrine plains around and southwest of Saginaw Bay and along the southeastern coast of the state. The narrow, linear, north-south trending area of low relief on the east side of Michigan's "thumb" correlates with the Black River Valley. A much broader zone of higher relief, up to 249 feet/cell, trends southwestward from the central "thumb" area. This more rugged topography is associated with interlobate ice-contact glacial deposits. A more diffuse zone of high relief relates to other interlobate deposits occurs in southwestern Michigan and trends northwards where it merges with the nearly ubiquitous rugged topography of the northern Lower Peninsula. The very hummocky terrain (greater than 200 ft/cell) of this part of the state results from the abrupt juxtaposition of high coastal dunes or inland morainic masses with broad flat valley-train deposits. A localized area of somewhat subdued local relief (less than 150 ft/cell) occurs in the northeastern-most part of the state.

The distribution of soil types in Michigan at the order level is characterized by the predominance of Spodosols in the northern and west-central parts of the state and Alfisols in the southern and east-central regions of the Lower Peninsula. The gross textural differences between these soil orders results in low water holding capacities for most northern Michigan soils and much higher capacities in the soils of central and southeastern



FEET/PIXEL

0-49	50-99	100-149	150-199	200-249	250-299	300-399	400-599
....	----	****	CCCC	OOOO	PPPP	WWWW	####
....	----	****	CCCC	OOOO	PPPP	WWWW	####
....	----	****	CCCC	OOOO	PPPP	WWWW	####
....	----	****	CCCC	OOOO	PPPP	WWWW	####

Figure 7. Local relief (elevation change per pixel) in Michigan.

Michigan and the "thumb" area (Figure 8). The stratified ice-contact and glaciofluvial drift of the two interlobate zones of southern Michigan produce soils of low water holding capacity as well. Each of the five areas of highest water holding capacity (greater than 20") are associated with areas of Histosols.

IV. ANALYSIS OF GOES THERMAL DATA

A. Comparison of Satellite and Weather Station Temperatures

The recorded ambient air temperatures at selected synoptic weather stations were compared to the 3:00 p.m. and 4:00 a.m. temperatures derived from GOES data as shown in Table 1. Overall, there is a good agreement between GOES pixel temperatures and recorded air temperatures. At 3:00 p.m., 63% of the GOES pixels examined agreed within ± 4 degrees F with corresponding recorded air temperature, while at 4:00 a.m., there was 88% agreement. The majority of 3:00 p.m. GOES temperature values were warmer than the 1.5m air temperatures, but at 4:00 a.m. the positive and negative departures were about equal. The nine pixels which varied by more than 4 degrees F from the synoptic station temperatures at 3:00 p.m. are all located in the southern part of the state and are circled on Figure 9. The three pixels circled on Figure 10 differed by more than 4 degrees F from the 4:00 a.m. station temperatures. The discrepancies between these two data sets are probably due to the inherent differences between thermal radiance values integrated across 88 square kilometers and point sampled ambient air temperatures, as well as the +/- 2 to 4 degrees C accuracy limitation of the VISSR thermal channel (NOAA, 1978:C2).

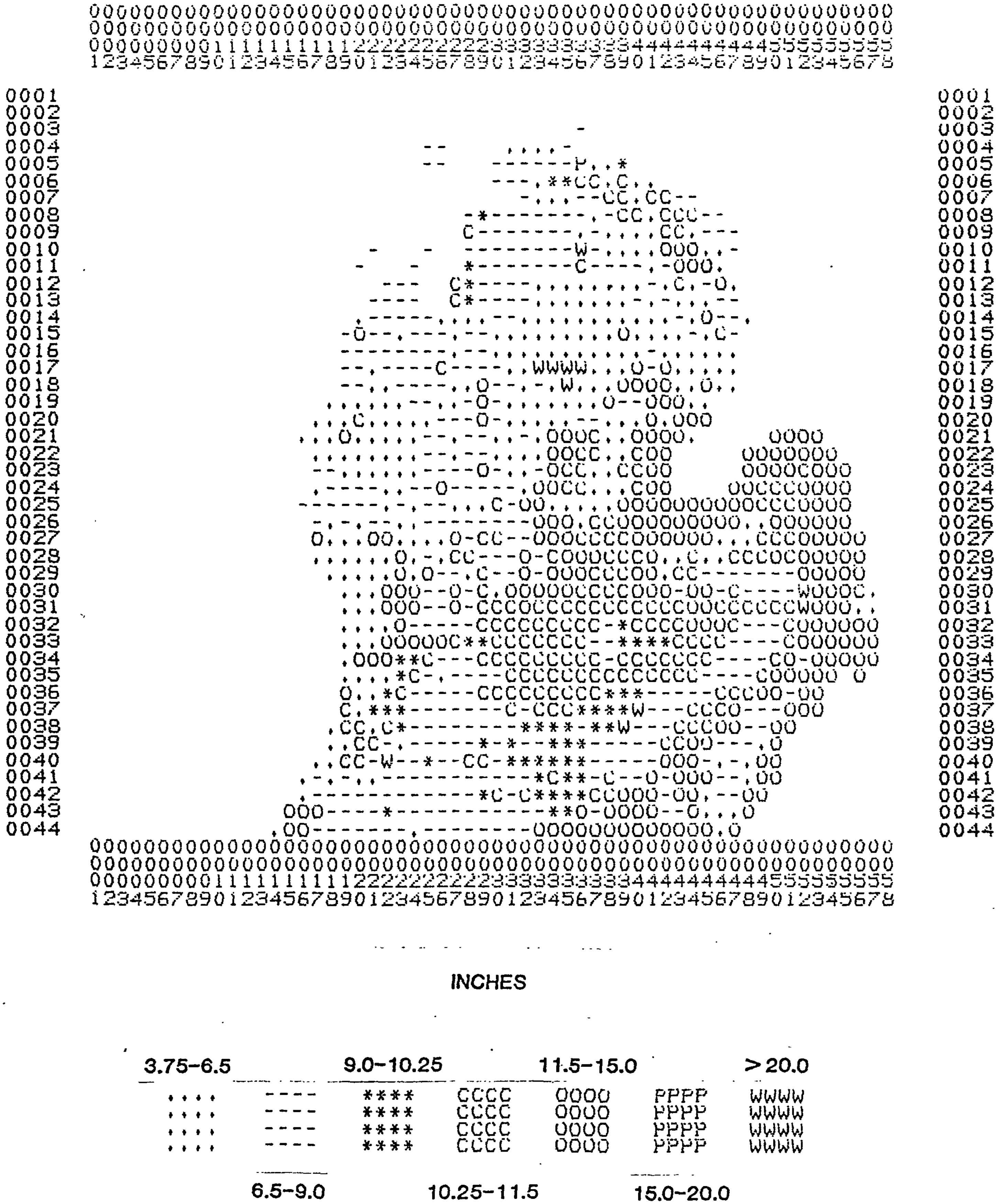


Figure 8. Water holding capacity of the upper 3 feet of soil in Michigan.

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Table 1. Comparison of GOES pixel temperatures with 1.5 m. air temperatures recorded at selected synoptic weather stations.

	4:00 a.m. Temp (F)		3:00 p.m. Temp (F)	
	GOES	STATION	GOES	STATION
Allegan	42-43	41	74-75	66
Alpena City	42-43	40	63-64	61
Alpena WSO	40-41	38	65-66	61
Bad Axe	40-41	38	73-74	60
Benton Harbor	46-47	46	79-80	66
Detroit WSFO	46-47	42	73-74	69
Eau Claire	44-45	42	73-74	66
Flint WSO	40-41	41	75-76	66
Grand Haven	44-45	47	67-68	63
Grand Rapids	42-43	45	74-75	72
Hart	46-47	52	61-62	61
Hesperia	40-41	41	71-72	71
Holland	44-45	41	67-68	61
Houghton Lake WSO	46-47	38	65-66	66
Lake City	38-39	37	71-72	67
Lansing WSO	40-41	39	79-80	66
Lapeer	36-37	36	67-68	65
Ludington	42-43	47	61-62	63
Muskegon WSO	44-45	42	69-70	63
Newaygo	42-43	39	71-72	71
Onaway	38-39	40	63-64	63
Paw Paw	42-43	45	73-74	73
Sandusky	38-39	41	65-66	60
Traverse City	38-39	40	65-66	63

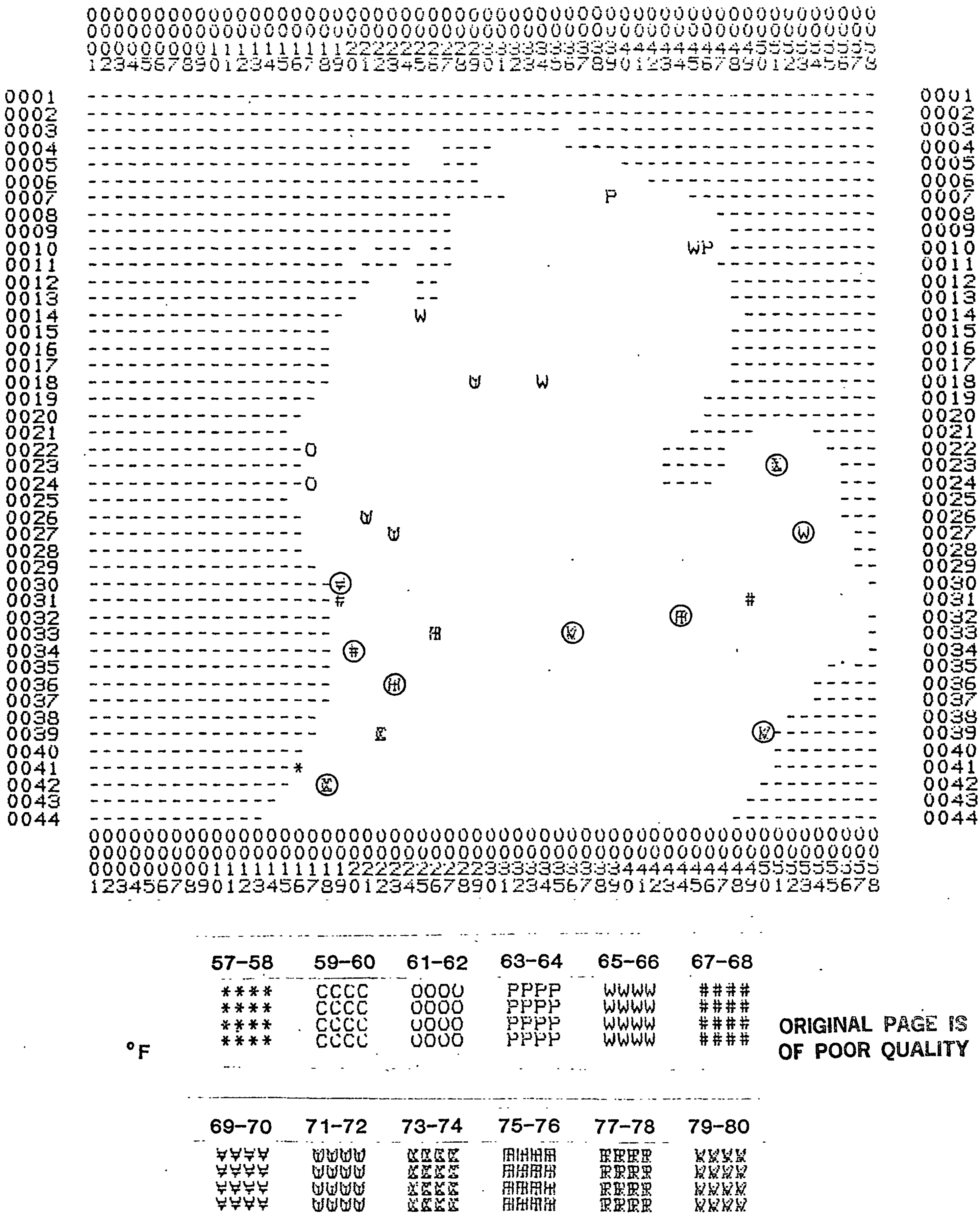


Figure 9. Apparent temperature at selected synoptic weather station sites from GOES 3:00 p.m. data for June 24, 1979 (circled pixel temperatures differed by more than 4° F. from recorded air temperatures).

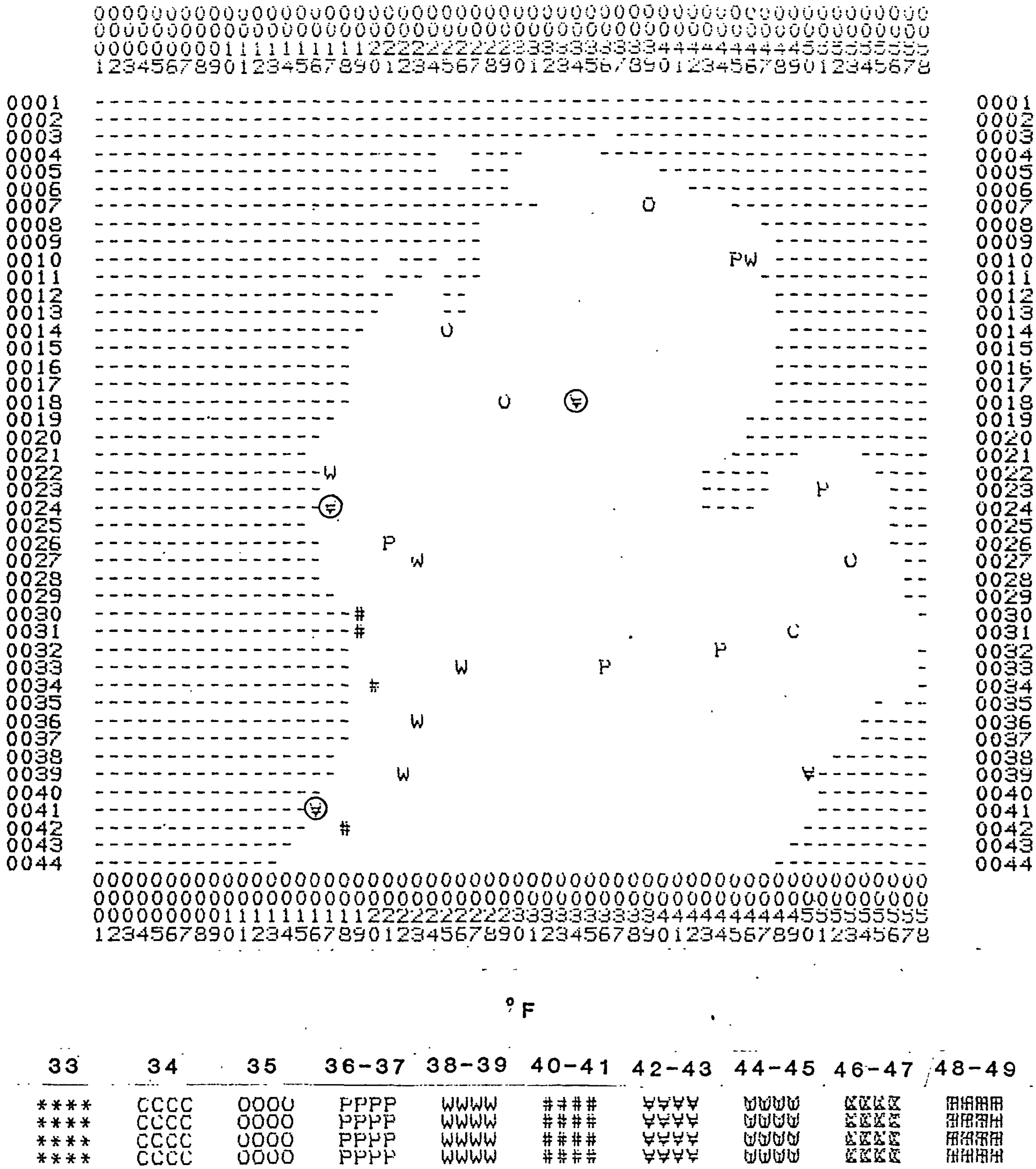


Figure 10. Apparent temperature at selected synoptic weather station sites from GOES 4:00 a.m. data for June 25, 1979 (circled pixel temperatures differed by more than 4° F. from recorded air temperatures).

B. Analysis of Apparent Temperature Patterns

Static temperature patterns at 3:00 p.m. (Figure 3) and 4:00 a.m. (Figure 4), were analyzed as well as patterns of dynamic thermal flux. An average temperature pattern image (Figure 11) was produced from GOES data acquired at 3:00 p.m., 10:00 p.m., 4:00 a.m. and 10:00 a.m., June 24-25, 1979 utilizing the Index routine of the IMGRID2 program. By subtracting 4:00 a.m. radiance values from 3:00 p.m. values using IIPS software, a temperature difference image (Figure 12) was constructed.

The correlation of temperature patterns depicted on these four GOES images with the four surface attributes encoded in the environmental data base was assessed by comparing both printer maps and color images (Figure 13) displayed on a video monitor. A brief description of the major correlations follows.

Land mass temperatures at 3:00 p.m. ranged from 53 degrees to greater than 80 degrees F (Figure 13). The warmest temperatures occurred in the central, south and southeastern parts of the state, whereas the northeast had the coolest temperatures (Figure 14). The hottest pixel temperatures (greater than 80 degrees) were detected in the Detroit metropolitan area, northwest Monroe County, northwest Shiawassee County and the northern boundary between Gratiot and Saginaw Counties (see reference map, Figure 15). These areas are in either urban or agricultural use on lands of low relief (less than 100') and high water holding capacity. Over 75% of these hot areas have relief less than 50'/pixel, a

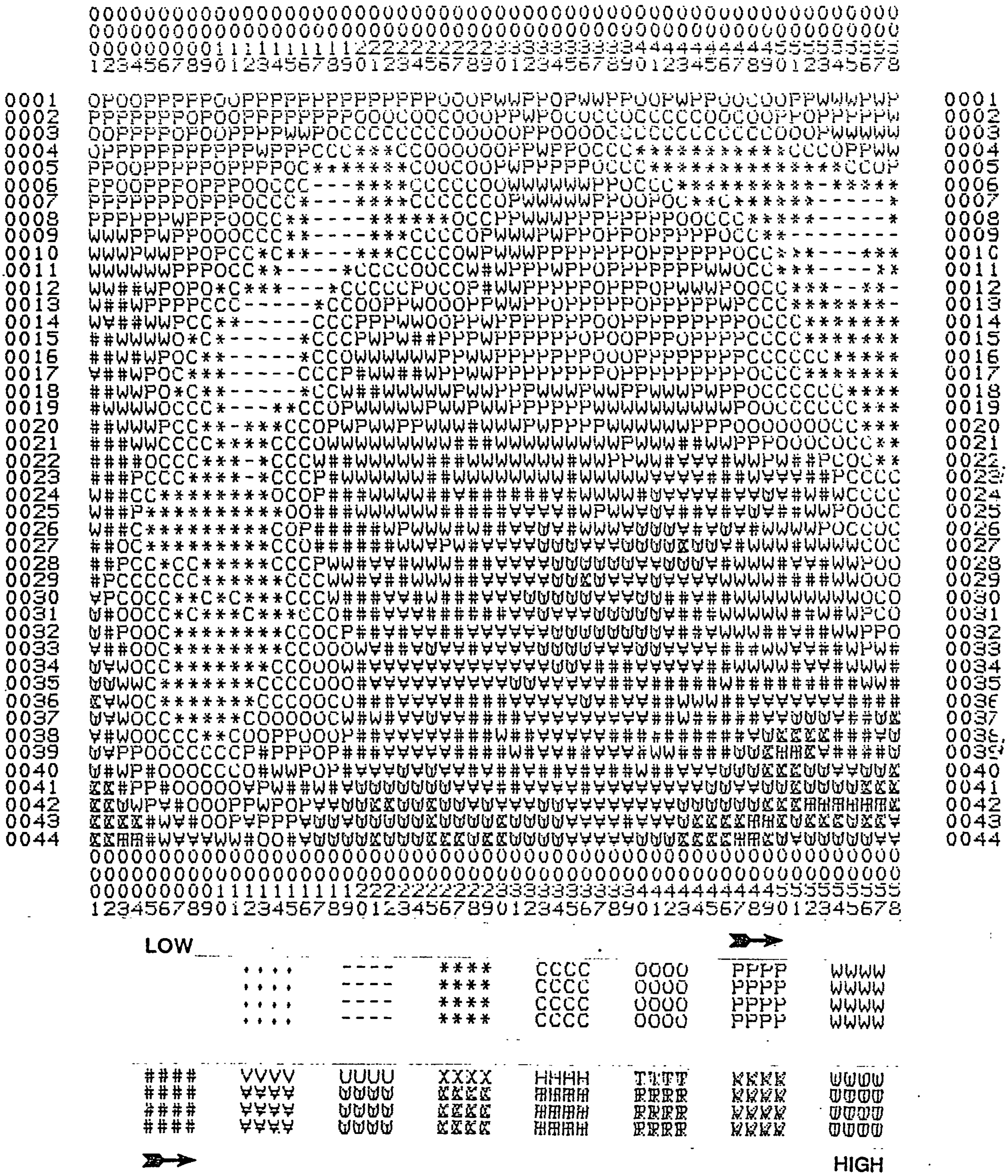
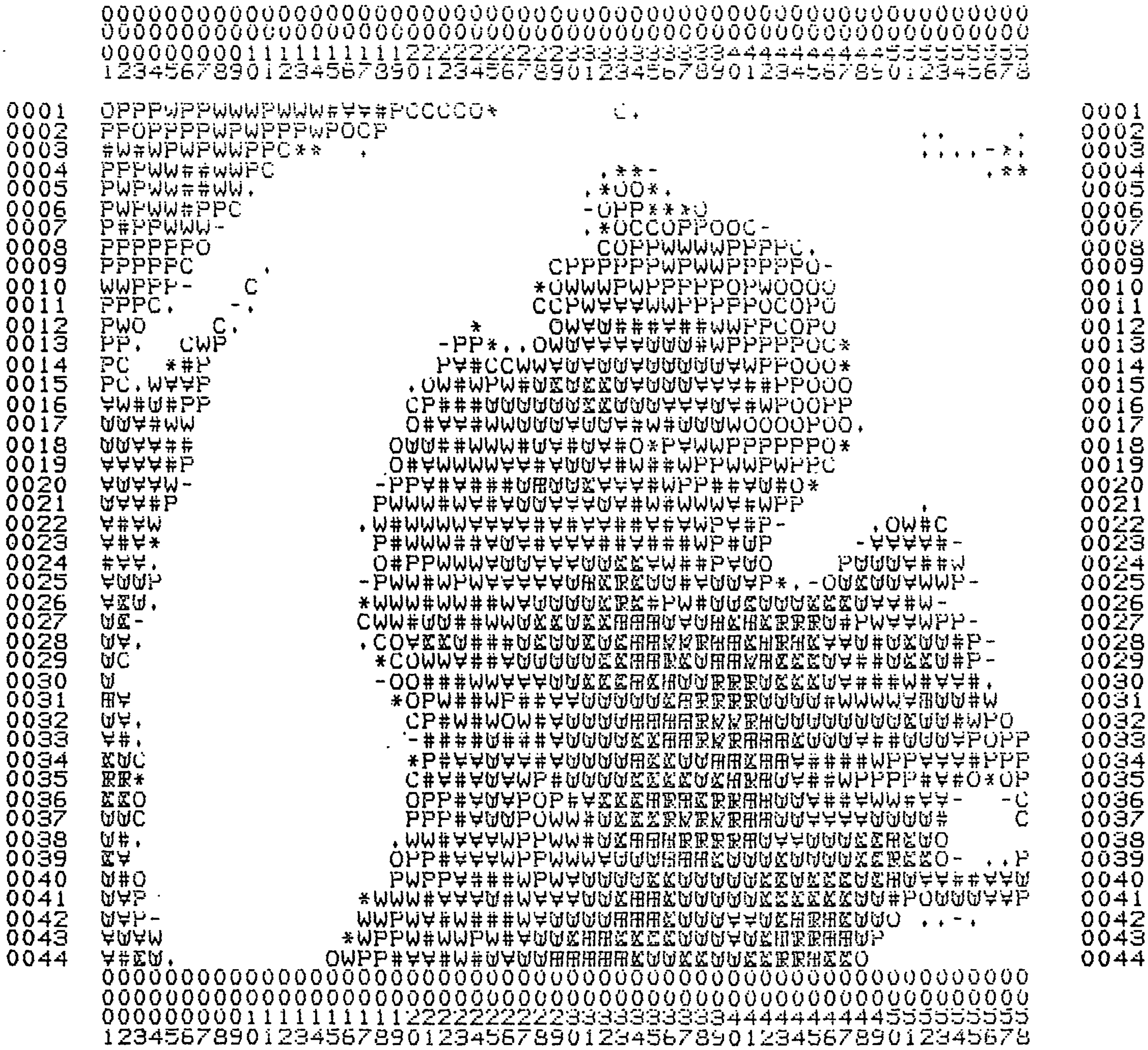


Figure 11. Average pixel temperatures derived from GOES data acquired at 3:00 p.m. and 10:00 p.m., June 24; 4:00 a.m. and 10:00 a.m., June 25, 1979.



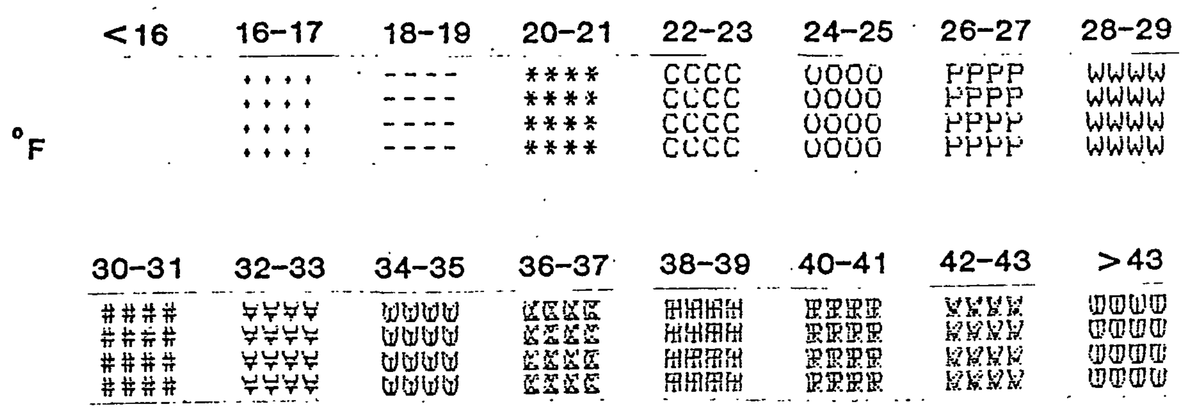


Figure 12. Apparent temperature change from 3:00 p.m., June 24 to 4:00 a.m., June 25, 1979 derived from GOES data.

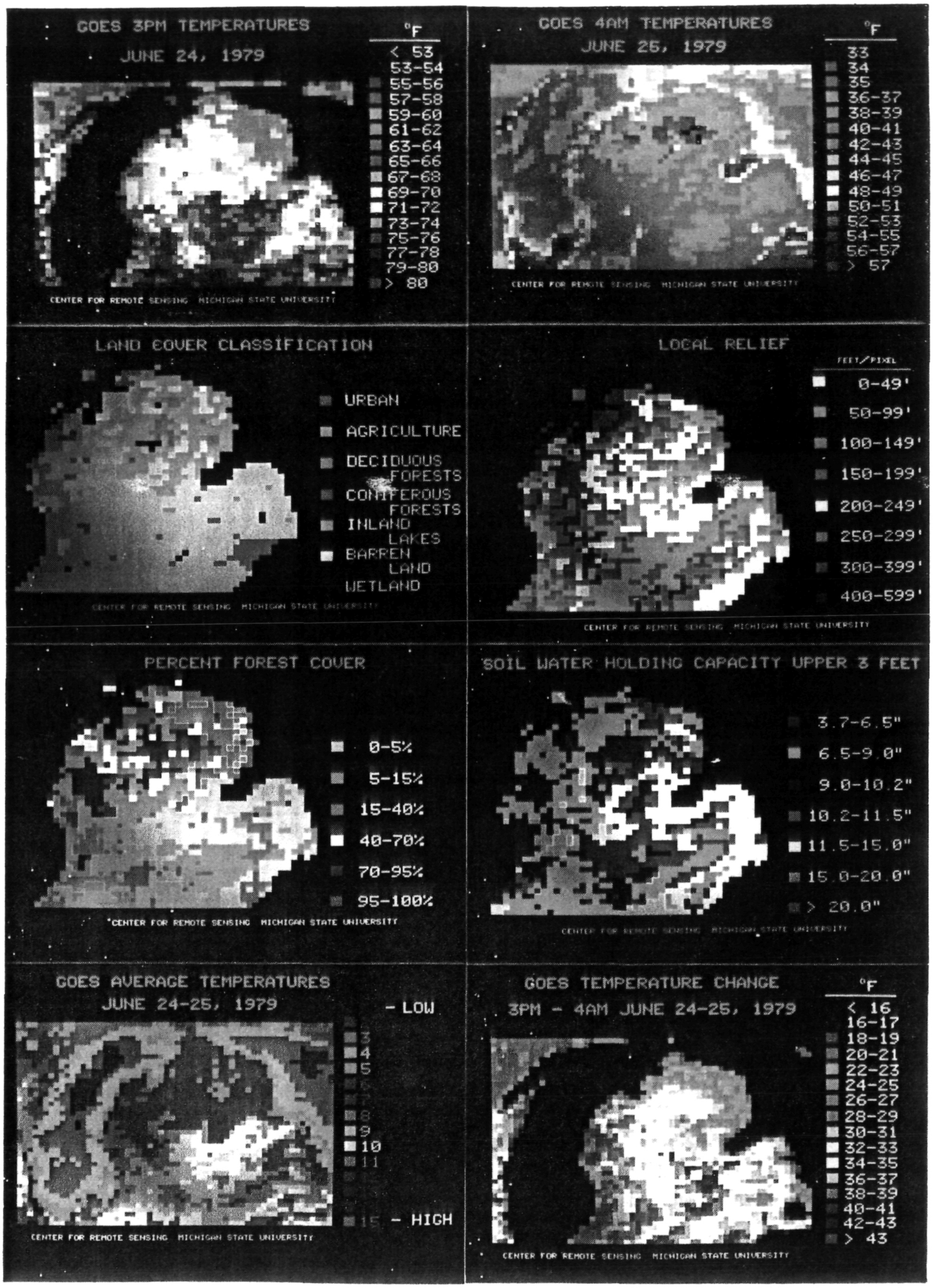


Figure 13. Comparison of GOES thermal patterns with the distributions of selected surface features in Michigan.

CCCC pixel temperatures less than 68°F.

WWWW pixel temperatures greater than 76°F.

Figure 14. Areas of minimum and maximum apparent temperatures at 3:00 p.m., June 24, 1979 from GOES thermal data.

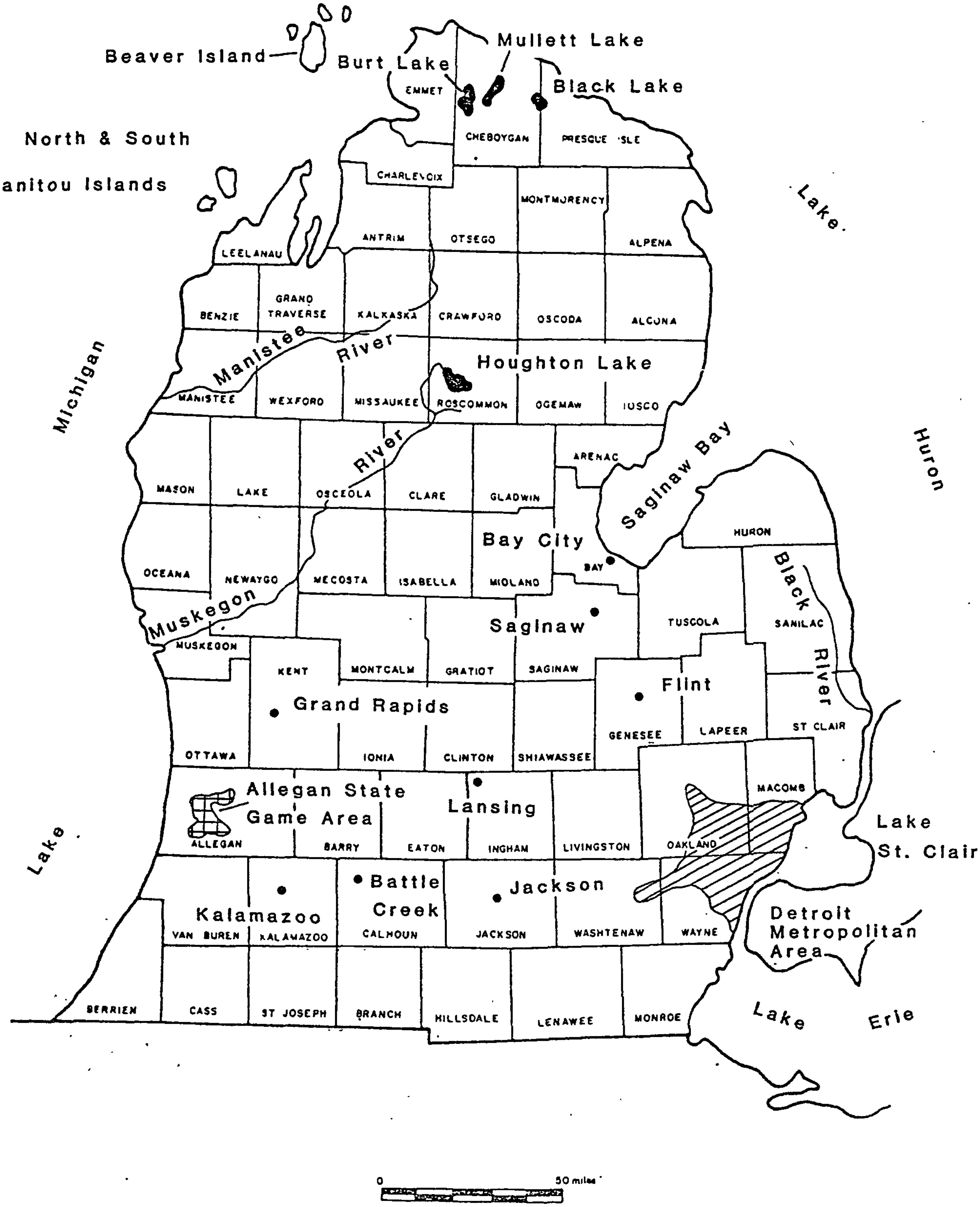


Figure 15. Reference map of Michigan showing county boundaries and selected geographic features.

water holding capacity of greater than 10.25" in the upper three feet of the soil and are less than 5% forested. Pixels with radiant temperatures greater than 76 degrees F at 3:00 p.m. (Figure 14) also correlate with urban and agricultural areas of low relief and high water holding capacity. The majority of the coolest temperatures (less than 68 degrees F) are in the forested areas of the northeastern part of Michigan where the land area is over 95% forested with a soil water holding capacity of less than 9".

The coolest (33 - 35 degrees F) and warmest (44 - 47 degrees F) pixel temperatures at 4:00 a.m. are shown in Figure 16. Cool temperatures were recorded in the north-central part of the state on a heavily forested plateau-like area of well-drained sandy soils with low water holding capacities. Within this cool region, the coldest radiant temperatures were associated with coniferous forests composed primarily of jack pine. Additionally, the effects of latitude and continentality may also contribute to the cold temperatures of this area. The linear series of cool pixels trending southwest from the Houghton Lake area corresponds with the upper Muskegon River valley and may result from cold air drainage. A similar situation in the upper Manistee River valley produced the pocket of cool temperatures south of Grand Traverse Bay in northwestern Michigan.

The warmest pixels over land at 4:00 a.m. are associated with areas of high soil water holding capacity, urban centers such as Detroit and Grand Rapids or inland lakes. Houghton Lake, for

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CCCC pixel temperatures 33° - 35° F.

WWWW pixel temperatures 44° - 47° F.

Figure 16. Areas of minimum and maximum apparent temperatures at 4:00 a.m., June 25, 1979 from GOES thermal data.

example, had an apparent temperature as much as 10 degrees F warmer than its surroundings. The close proximity of Black, Burt, and Mullett Lakes in the northernmost part of the Lower Peninsula contributed to the warmer temperatures of the east-west trending Indian River lowland. The highest temperatures detected at 4:00 a.m. (greater than 57 degrees F) correspond to the shallow waters of Saginaw Bay, Lake St. Clair and Lake Erie (Figure 13).

The lowest average apparent temperatures (based on satellite observations at 3:00 p.m., 10:00 p.m., 4:00 a.m. and 10:00 a.m., June 24-25, 1979) are highly correlated with the deepest parts of Lakes Michigan and Huron indicating the high thermal inertia of these areas. Of the land areas, northeastern Michigan maintained the coolest average temperatures during the observation period probably as a result of its high percentage of forest land, rugged topography and low soil water holding capacities. The highest average apparent temperatures are associated with the city of Detroit and east-central Monroe county. Warm average temperatures are also found in central Michigan's Saginaw lowland which is dominated by agricultural land use, has minimal forest cover and very low local relief.

The greatest diurnal (3:00 p.m. - 4:00 a.m.) apparent temperature changes (greater than 37 degrees F) occurred primarily in the agricultural land of south central Michigan. Temperature changes of less than 28 degrees F were associated with many coastal areas, the rugged, forested northeastern part of the Lower Peninsula, the areas of numerous inland lakes in Barry and Oakland counties, and Houghton Lake and its neighboring wetlands.

C. Contouring Temperature Difference Images

Automatic machine contouring of temperature change digital files provides a valuable analysis technique which is particularly useful for studying thermal patterns and gradients. Temperature difference files record the absolute difference, pixel for pixel, between thermal data files recorded at two separate times. Thermal gradients can be studied using this technique by the repetitive display of multiple contoured images of increasing temperature thresholds. Although a detailed assessment of this technique was not undertaken, a sample data set is included herewith to illustrate this data processing capability.

A temperature difference file was prepared by calculating the absolute thermal flux between the 3:00 p.m. and 11:00 p.m. GOES data sets. This file was then thresholded at various temperature values (e.g. Figures 17-19) to display regions of different temperature change. The contours shown in Figure 17 encompass areas of more than 8 degrees F temperature change (3:00 p.m. to 11:00 p.m.) and depict the land-water interface fairly well. Note especially that Beaver and North and South Manitou Islands in northern Lake Michigan are resolved at this temperature threshold. In Figure 18, areas of more than 20 degrees F temperature difference are bounded by the contour lines. At this threshold, several inland areas are depicted which may be associated with lakes and/or wetlands. Relative to the 8 degree F

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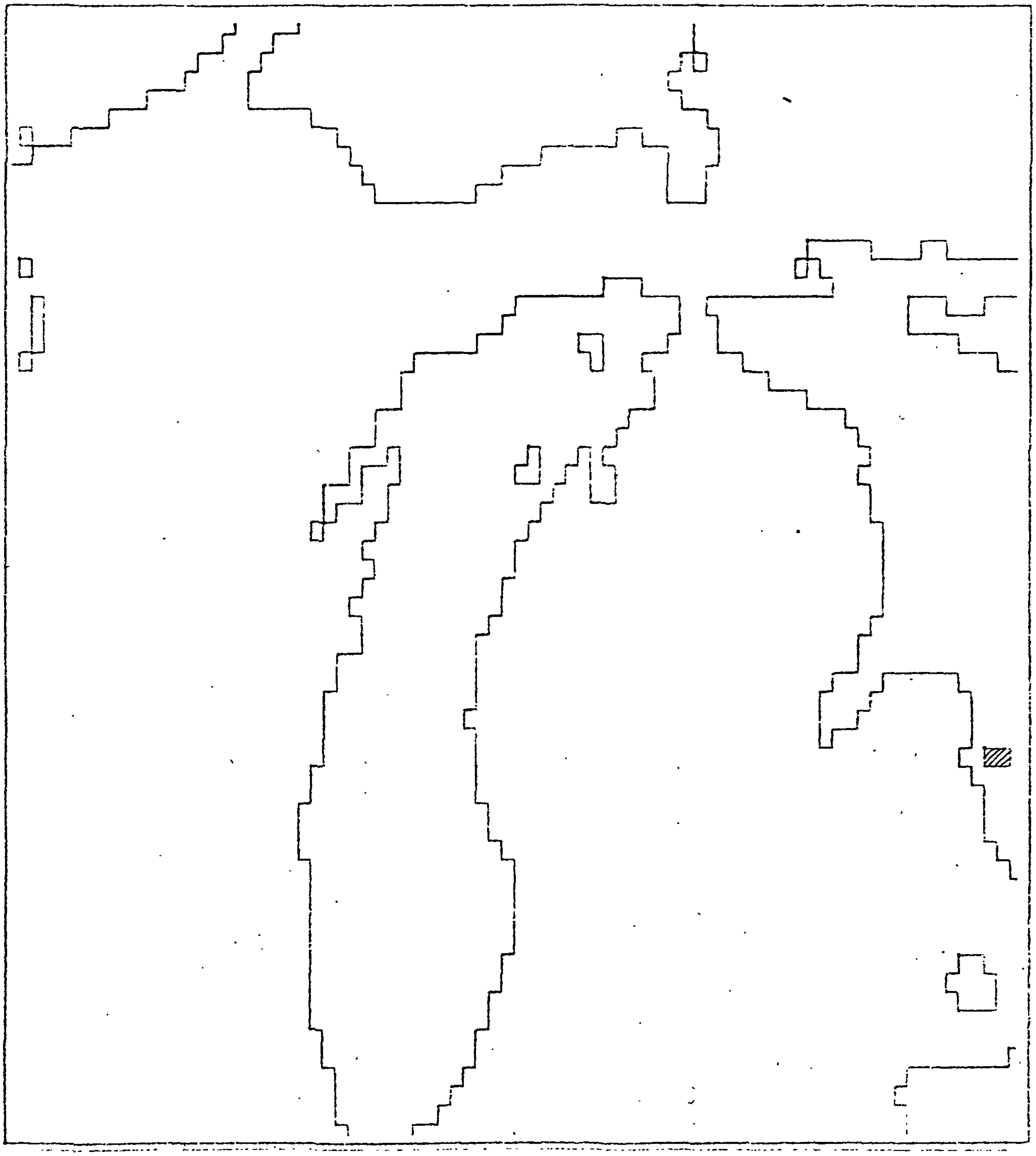

Figure 17. 8° F. temperature difference boundary from GOES thermal data acquired 3:00 p.m. and 11:00 p.m., June 24, 1979.

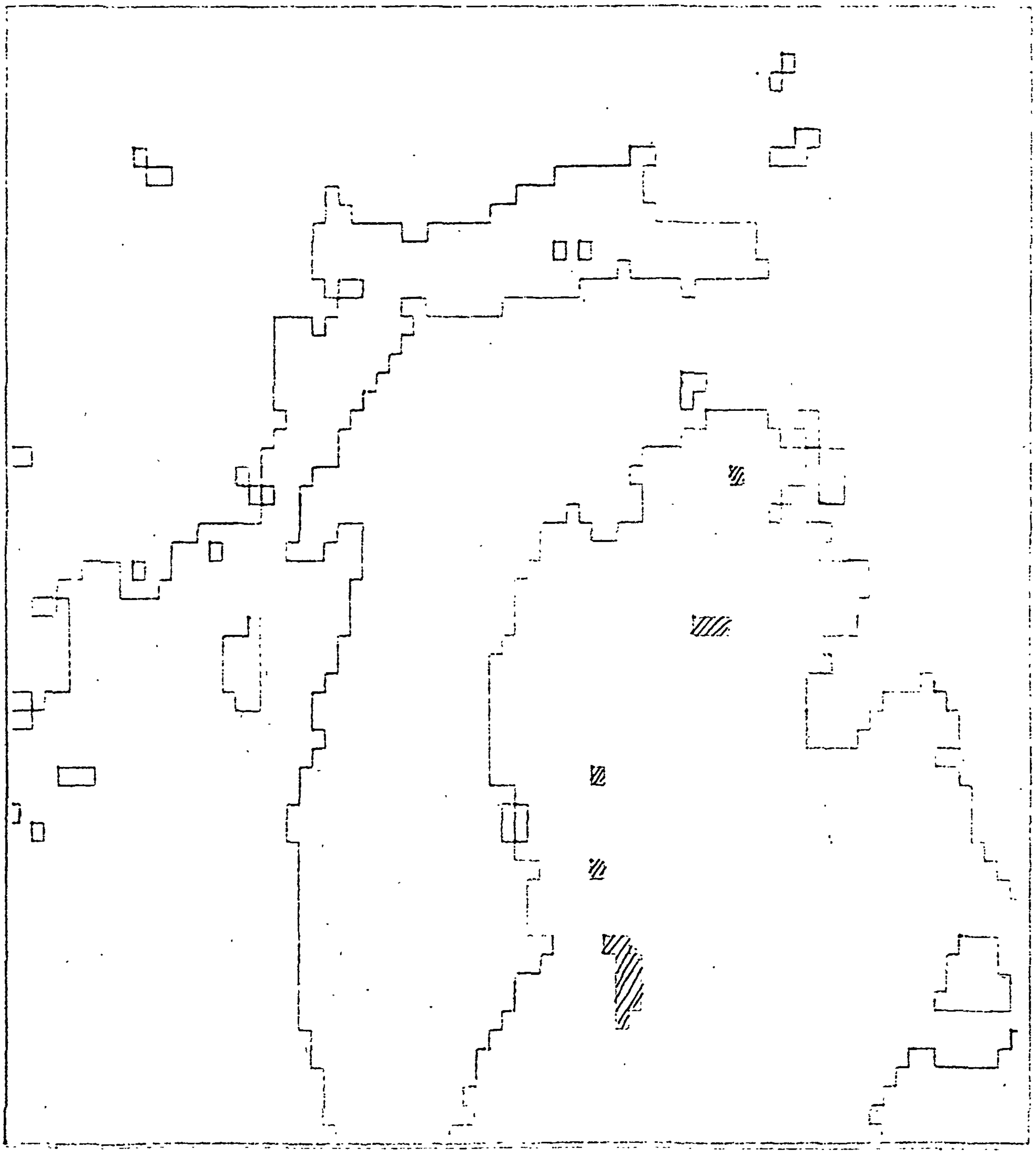

Figure 18. 20° F. temperature difference boundary from GOES thermal data acquired 3:00 p.m. and 11:00 p.m., June 24, 1979.

difference image, the more restricted areal expansion of Saginaw Bay, Lake St. Clair and Lake Erie at this 20 degree F threshold compared to Lakes Michigan and Huron indicates that these shallow water bodies are bounded by steeper thermal gradients. This condition is even more pronounced in the 24 degree F difference image (Figure 19). At this threshold, mesoscale regions of varying thermal flux become apparent within Michigan's land mass. For example, western and southwestern Michigan as a whole seems to have a higher thermal inertia than the central and southeastern parts of the state but also displays more intra-regional variability. This western region of fluctuating thermal differences can also be discriminated in the 3:00 p.m. - 4:00 a.m. temperature change image discussed previously (Figure 13).

V. SIGNIFICANT FREEZE EVENTS IN 1981

In 1981 two significant freeze events occurred during April, the most serious of which occurred on April 21. These freezes seriously affected fruit production in the state. Minimum temperatures which occurred at 61 weather stations during the two freeze events are shown on Table 2. To document the environmental change at one location, hourly data were collected at the MSU weather station.

The variables measured were:

1. Screen temperature (1.5 m)
2. Outside temperature (1.5 m)

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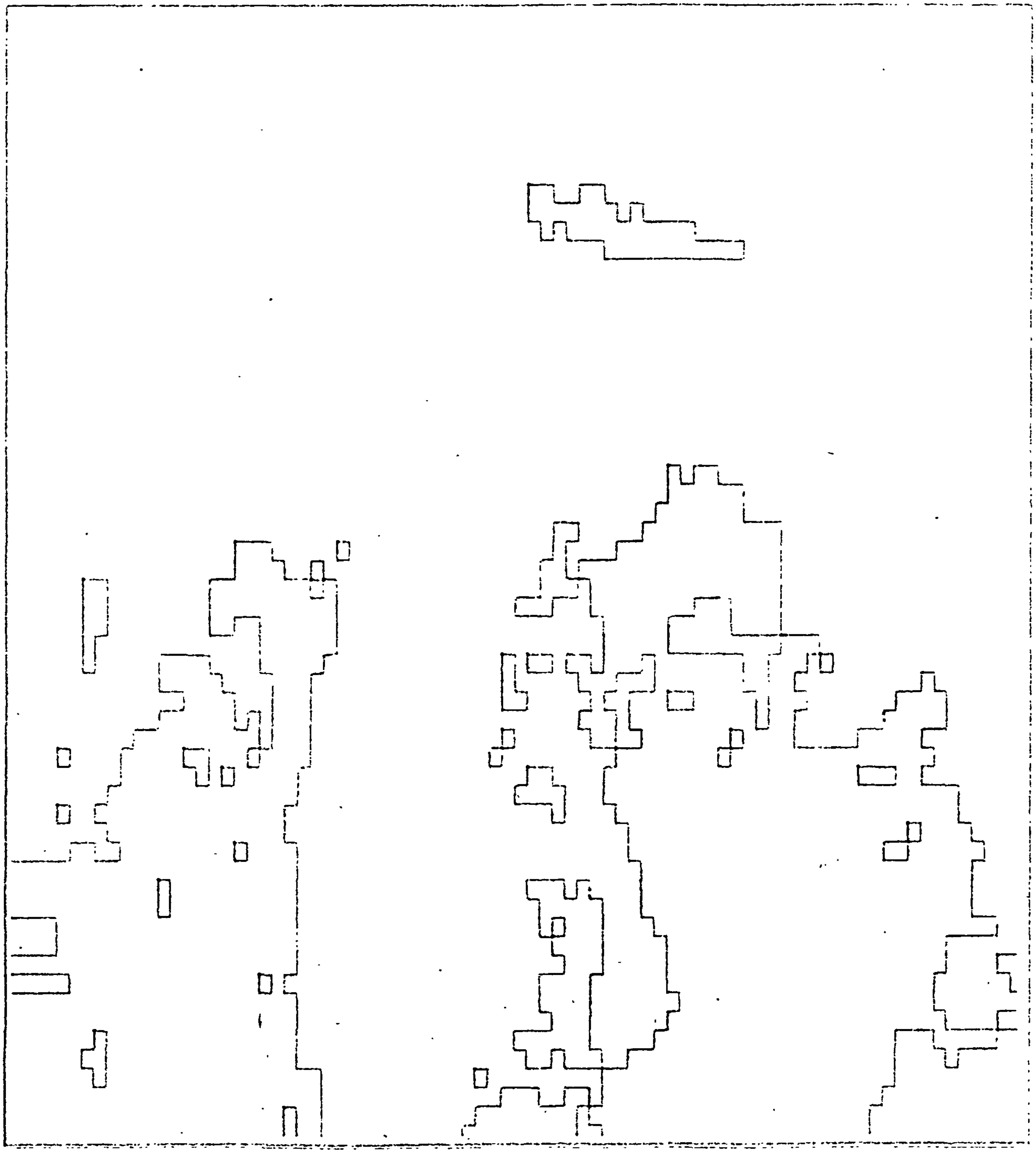

Figure 19. 24° F. temperature difference boundary from GOES thermal data acquired 3:00 p.m. and 11:00 p.m., June 24, 1979.

Table 2. Selected April minimum temperatures in Michigan (1.5m).

STATION	APRIL 15, 1981 MINIMUM	APRIL 21, 1981 MINIMUM
Alpena	23	19
Detroit	29	25
Escanaba	26	26
Flint	26	25
Grand Rapids	26	27
Houghton	22	24
Houghton Lake	23	19
Jackson	30	28
Lansing	26	24
Marquette	17	17
Muskegon	25	27
Pellston	15	16
Saginaw Airport	MM	25
Sault Ste. Marie	18	16
Traverse	21	16
Glendora	28	28
Sodus	30	28
Watervliet	28	24
Paw Paw	28	28
Grand Junction	26	24
Fenville	27	27
Coldwater	29	25
Allendale	26	29
Hudsonville	27	29
Holland	24	28
Nunica	23	25
Mears	25	25
Belding	23	26
Clarksville	25	27
Peach Ridge	25	27
Kent City	25	26
Graham Station	25	29
Edmore	20	24
Grant	23	27
Fremont	23	26
Berrien Springs	Msg.	30
MSU Horticultural Farm	25	24
Bad Axe	25	20
Bear Lake	24	20

Table 2. Con't.

STATION	APRIL 15, 1981 MINIMUM	APRIL 21, 1981 MINIMUM
Beulah	24	22
Empire	20	20
Imlay City	26	21
Kewadin	22	22
Lake City	18	16
Lake Leelanau	22	21
Lexington	26	MM
Ludington	23	22
Montrose	24	19
N.W. Horticultural	22	22
Old Mission	20	22
Ossineke	22	20
Rogers City	21	20
Saginaw Valley	22	21
Saline	26	21
Sandusky	25	23
Standish	22	19
Toledo	27	25
Unionville	26	24
Washington	30	25
Riverside	--	27
Keeler	--	27

3. Soil moisture (5 cm)
4. Relative humidity (%)
5. Light intensity (kj/m)
6. Wind velocity (mph)

An attempt made to measure radiation during this period failed due to technical problems with the device, but radiation was successfully measured during two successive spring freeze events.

Plots of each variable during the April 20-21 freeze event are shown in Figures 20-25. In conjunction with this freeze event, an attempt was made to procure GOES imagery to validate the impact of the freeze and to assist in the interpretation of the physical model and to examine the sequence of thermal events as the freeze approached. Unfortunately we were informed by NESS that we could no longer obtain GOES imagery but could only obtain GOES data from the historical archiving system at Wisconsin (see Data Access Difficulties section). This led to great disappointment and discouragement because the image processing system we developed was based on the GOES format provided by NESS. We are still hopeful that this problem can be resolved as we have spent considerable time and effort developing this component of the system.

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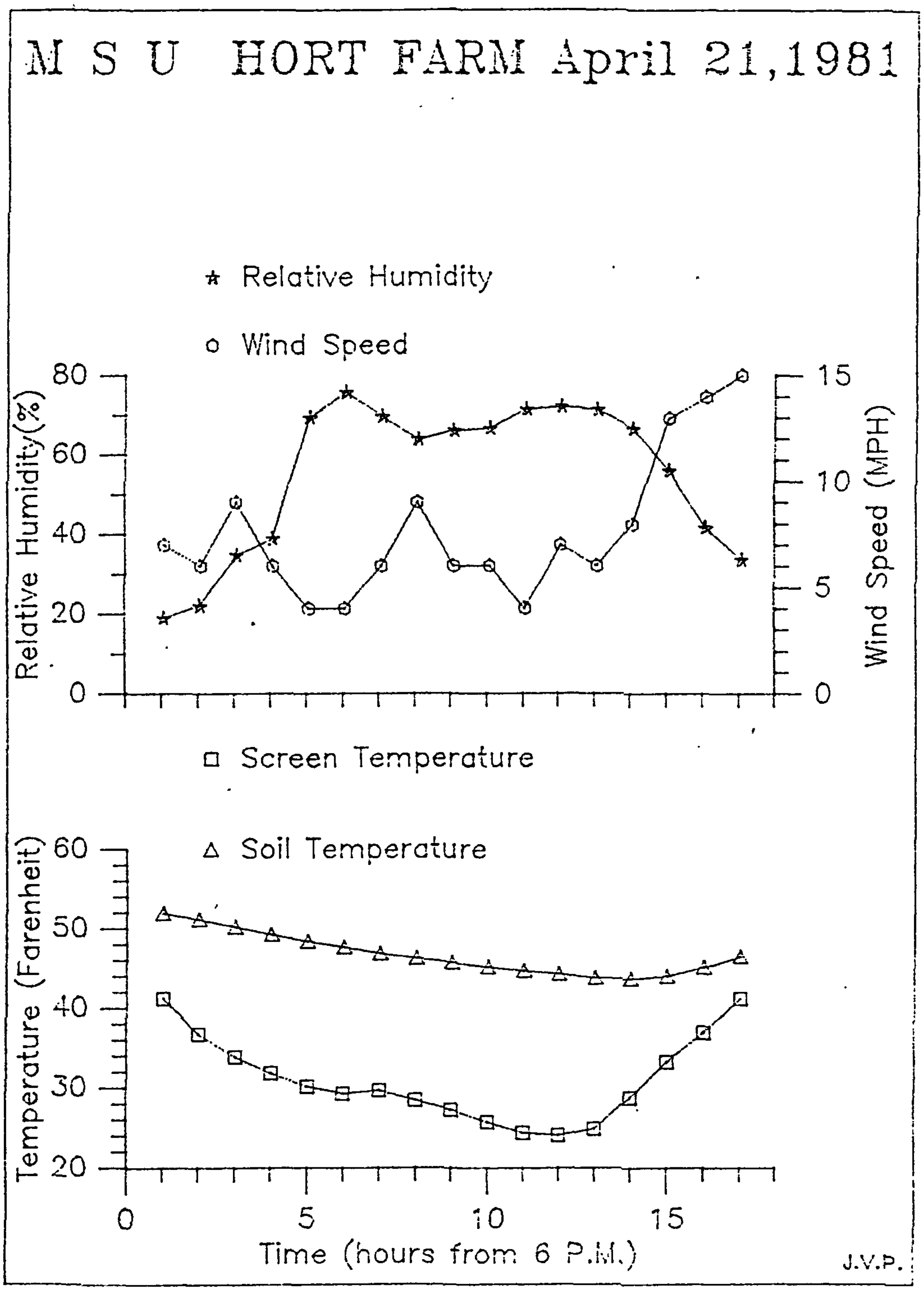

VI. PHYSICAL MODEL AND SPECIFIC TASK DISCUSSION

Task I: From data bases collected, make sample runs of the P-model and/or concept and present observations/conclusions as to results.

Data to characterize the micrometeorological conditions during freezes in Michigan were collected on different spring nights. The measurements included temperature gradient, radiation, wind movement and indication of direction, dew point and soil temperature. This data has been provided to Florida for general analysis.

Our conclusions from the data are the following:

1. The radiation, which is such an important driving force in affecting minimum temperatures, fell in the same range of readings that one might expect over the peninsula of Florida during freeze conditions.

2. The temperature drops observed, although limited in number, have indicated that temperature drops were within the range that might be expected during Florida freezes.

3. Recently, a thesis in Agricultural Engineering (Levitt, 1981) has characterized the statistical types of freeze conditions which tend to verify earlier work by Van Den Brink, (1981), showing approximately 60% of Michigan freezes were radiation, and 24% were advection and 16% were due to both conditions. Again, these general characterizations which show freeze

conditions on a broad scale are similar to the types of general freeze conditions from the statistical standpoint that Florida receives.

4. Persistence of temperature differences between stations seems to exist. MOSS product analysis has been done that indicates there are good correlations between key (weather forecasting sites) locations and agricultural weather measuring locations.

5. Analysis from Phase I of field measurements with an airplane and with temperature instrumentation mounted in moving vehicles provided important data. This information showed that there is clearly cold air drainage with large temperature differences down moderate slopes. Also, the high degree of wind variability and its affect mixing the atmospheric boundary layer were experienced in Michigan as in Florida.

The main difference would be the fact that Michigan's important freezes occur in the spring. Thus, the soil heat flux might be expected to be different from Florida during fall events. Analysis of this effect would show, however, that there has to be warming periods prior to the freeze for nearly all conditions during later spring freeze events. Thus, for many of the most significant freezes, the soil would be considerably warmer than air in a manner similar to that found in Florida. The clear exception would be severe early spring freezes when frozen ground would complicate the physical model.

Task II: Give observations/conclusions as to the applicability of the S-Model and/or concept from the data bases at the two areas.

Before the data bases could even be examined, extensive geometric corrections were required. This was accomplished during Phase I. The whole system for more accurate analysis was transferred over to the ERDAS System in the Center for Remote Sensing during Phase II. The accuracy of the data was again shown to be adequate during Phase I, but during Phase II additional analysis was conducted. Figures 5 and 6 show output of various temperature ranges from the printer on the ERDAS System. Certain patterns, as well as detailed temperature information are clearly portrayed. To enhance analysis, a windowing technique was developed that located the exact GOES element with weather stations for which hourly data was collected. (Figure 8 shows systematically where these airport collecting stations were located). This technique gave us greater capability to locate exact pixels with stations. Figure 9, shows temperature differences observed for those stations at 4:00 a.m. Clearly, the accuracy is shown to be sufficiently good for dependable real time temperature information, as well as for use in developing the S-Model.

Persistence of temperature by location existed throughout the night. With the enhanced capabilities for color display, by smaller temperature increments on the ERDAS system, more detailed persistence patterns were able to be evaluated (Figure 10). This evaluation clearly showed that the coldest temperatures, for example, occurred at specific locations early in the night and continued to be the coldest temperature locations throughout the night. Thus, there was every indication that patterns would persist throughout a night.

Of extreme importance to the statistical model is the persistance of similar patterns from night to night. This would clearly be expected if the temperatures are strongly dependent on permanent surface vegetation and soil characteristics. For this analysis, a variety of data bases were digitized on the same scale as the GOES data. (See Figure 1-4). As a result of an extensive visual analysis, it is clear that the temperature patterns can be specifically related to surface features or combinations of surface features. The conclusion is that one would anticipate the patterns to be a function of surface conditions, and therefore, would persist under similar meteorological conditions.

Task III: Identify and discuss any peculiarities of the Michigan and Pennsylvania sites which might limit conclusions from being applied elsewhere in the United States as a general case.

It has become increasingly clear that there are considerable similarities between Michigan conditions and Florida conditions. The significance of the peninsula and its effect on temperatures inland have been shown to exist for both locations. The advantage in geometrically correcting data and overlaying scenes are clearly easiest when one has a temperature discontinuity as it occurs between water and land for a peninsula.

Also, Michigan has a slightly more rugged terrain, from a meteorological standpoint, than Florida. Thus, there are terrain features that have a significant impact on temperature regimes. However, many of the surface characteristics, such as bare soil, pastures, and forested areas exist in both states.

Task IV: Give recommendations as to whether the concept should be pursued further, and if so, what specific studies should be performed.

Clearly, the conceptual theme of using GOES data to aid in characterizing the thermal regimes in a state both in non-real and real time, need to be further pursued. The data proves to be very accurate, particularly during radiation freeze events and correlations of temperature patterns with general surface conditions which indicates more information could be obtained.

VII. DATA ACCESS DIFFICULTIES

It is appropriate to discuss some of the problems encountered in obtaining satellite data as it relates to the process of technology transfer. One of the objectives of our involvement with the project was to develop capabilities relative to processing GOES thermal imagery.

After considerable difficulty in obtaining the Michigan GOES imagery from NESS, we finally obtained a readable data set. A system of processing the information was developed based on the NESS format and tape characteristics. It required five or six tries to get usable information. In April 1981 a request was made to obtain data for both the freeze events that we had been anticipating. The data for April 15 was requested and sent. It, however, was not Michigan data nor did it conform to the range of data expected. The request for data for the April 21 freeze event was denied due to a change in policy and we were informed that we had to obtain the data from Wisconsin. Since we had previously attempted to obtain archived data from this source we were discouraged.

One of our objectives was to examine GOES thermal imagery over a growing season. We requested and paid for the imagery. After several months a further attempt was made to obtain the information. It finally arrived with no documentation. After many attempts to read the data on our own, we requested assistance again. Some documentation arrived but it still did not seem to help. The format provided was inadequate and the data was provided in 24 bit binary.

Since the project related directly to the access and processing of GOES imagery we were surprised at the difficulty in obtaining this information. We expected that we would be assisted rather than discouraged because we felt this was part of the technology transfer process to involve other areas of the U.S.

After these difficulties we are still convinced that our pursuit of analysis of GOES thermal imagery and its application to Michigan has been and will continue to be rewarding. We trust that NASA and NESS will recognize the problem of data availability and will strive to assist users who want to use the data to benefit a state. We look forward to future assistance in this area.

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