SOME COMPUTER TECHNIQUES FOR PRESENTATION OF THERMAL INFRARED LINE SCAN DATA

by

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Introduction

Thermal infrared imagery line scan data was collected in 1971 over a partially cut area on a forest timber management lease area near Hinton, Alberta. The imagery was assessed for its usefulness for portions of a study of climatic regimes in clearcut forested areas. Its usefulness is limited because the analysis of the grey scales on film becomes quite arbitrary; it is difficult to give quantitative values to the various portions of the grey scale. To make the data more meaningful, a computer technique for presenting thermal infrared line scan data was developed. This paper briefly describes the line scanner used, the computer programs developed, the resulting output and possible application of the technique.

Methods and Materials

Line Scanning Equipment

Infrared (IR) line scan data were taken with a Daedalus Line Scanner System. This radiometric system measures the intensity of electromagnetic radiation (EMR) from preselected wavelength bands or infrared windows. The system features modular design and analog recording of the data, and was specifically designed for an airborne platform. The line scan system consists of three basic units: the scan head with two black body reference sources, the video control console and the magnetic tape recorder (Fig. 1). The scan head fits into a standard 9-inch aerial camera ring mount.

The axe-bladed scan mirror is driven at 3600 RPM by an AC synchronous motor with a bellows shaft and powered by a tuning fork oscillator to insure rotational stability. The scan mirror provides a

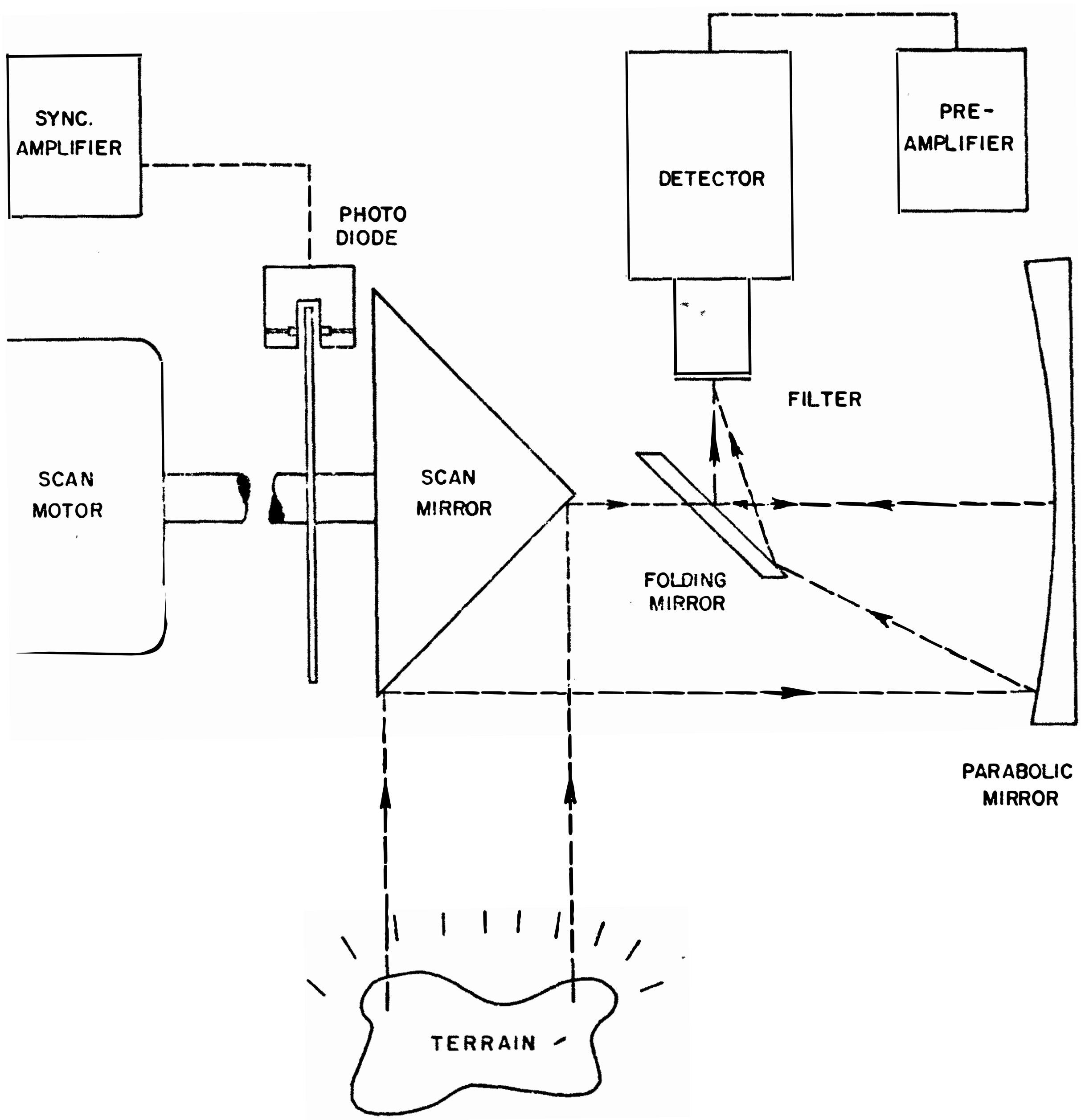

Figure 1. Scanner optical ray diagram (after Daedalus 1971).

scan rate of 60 line scans per second through a solid angle of 77° or swath width of 120°. The forward motion of the plane therefore produces a line of scans leading to a line scan image.

The optical path for the radiation received by the scanner aperture is illustrated in Fig. 1. Radiation from the terrain is reflected by the scan mirror onto the parabolic collector and then brought to focus on the detector by means of the folding mirror. Two detectors were available, a Ge:Cd:Te (Tri-metal) for the 8- to 14-micron IR window and an In Sb (Bi-metal) for the 3.5- to 5.5-micron window. Since the process of emission in the IR range is almost entirely a function of temperature, the choice of detector is based on the response of the detector to specific surface temperature parameters. For this study, the In Sb detector was used; it is more sensitive to warmer spots in the ambient thermal background than the tri-metal (American Geological Institute, 1968). The In Sb detector was filtered with a 4.5 micron filter to increase the desired response and to lower the amount of reflected solar radiation. The temperatures of the two reference sources of the scan head can be adjusted so that one is near the lower end and one near the upper end of the temperature range being investigated. These sources are positioned in the optical system so that they are in the scanner field of view, one being imaged before and one after each scan across the terrain.

The electromagnetic radiation (EMR), which is radiated from the surface, passes through a mirror optical system and is directed onto the sensor chip, which generates a signal that is amplified and taped. The panel, which controls and monitors the signal, consists of an oscilloscope, which monitors the scanner signal or the reproduced signal from the tape recorder, a "sync mixer", which allows adjustments to the signal to obtain optimum contrast in a given set of conditions, and remoted control switches for the scan head and tape recorder operation. The adjusted signal is recorded on ½-inch magnetic instrumentation tape on 7-inch reels.

To convert the data from tape to film, Daedalus supplies a Field Printer. Essentially, the electrical signals on the tape are played through a low retention phosphorous glow tube. A 70-mm camera films these signals; the thermal image of the terrain as seen by the scanner is thus reconstructed. The end result is a black and white picture of EMR, which indicates the temperature patterns on the ground. The size of a resolution element on the ground for a flying height of 1,000 feet with a 2.5 milliradian bi-metal detector is 2.5 feet in diameter. That is, the scanner will pick up objects or areas that are larger than 2.5 feet, but only if the object's temperature differs from its surroundings by an amount greater than the sensitivity of the sensor, or system (ΔT is $\sim 0.1°C$). The field of view at that altitude is 1,000 feet across the ground, perpendicular to the line of flight. At a flying height of 3,000 feet the scanner's resolution is 7.5 feet, and the width of a line scan is 3,000 feet.

Area of Study

An area near Hinton, Alberta, was chosen since ground climatological data were available from a study of clearcut forested areas. Two flight lines were laid down over the North Western Pulp and Power Ltd. timber lease area to the southeast and southwest of Hinton, on legs paralleling the Robb Road and Green Timber Road (Fig. 2). The

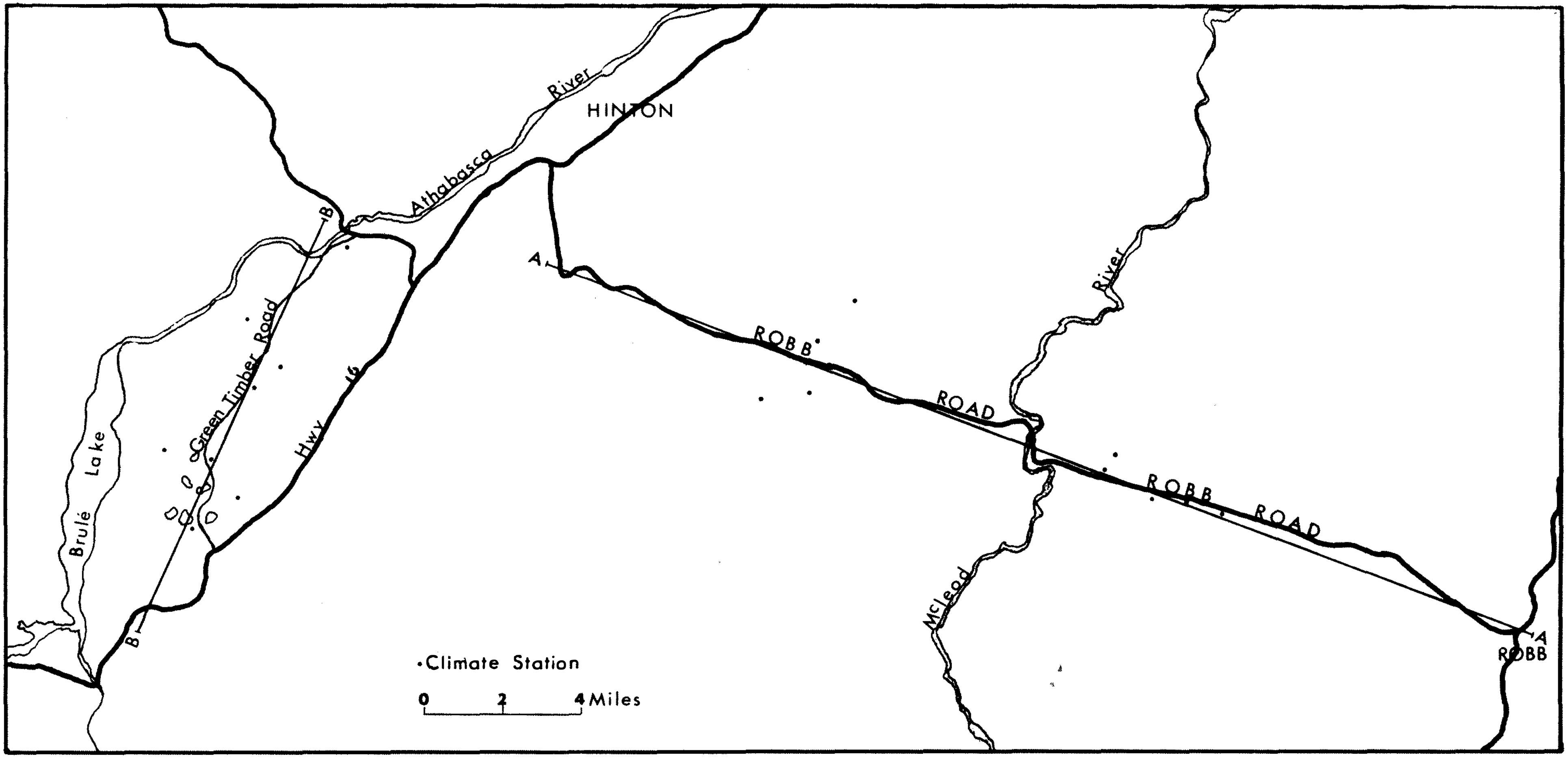

Figure 2. Map of the Hinton area, showing the two flight lines for which thermal infrared line scanning imagery was obtained on August 24 and October 7, 1971.

location of the climatological stations close to the flight lines are shown in Fig. 2. Each station included a hygrothermograph, a maximum and minimum thermometer placed in a Stevenson screen resting on the ground, and a 5 cm soil thermometer; unfortunately no surface temperatures were available. Mobile thermo dew-point traverses were also run along the Robb Road and Green Timber Road during the period of some of the flights, but these data are not included here.

Flying Dates and Heights

The line scanning equipment was mounted in a low-winged, single-engine Piper Cherokee 6 aircraft. On August 24, 1971, both lines were flown around noon MST using the In Sb sensor in the line scanner from 3,000 feet. Three flights, using the In Sb sensor, were flown over both lines on October 7, 1971, at 3,000 feet above mean ground level and at 0645, 1000 and 1200 hours MST.

Computer Programs

The data were originally recorded on analog magnetic instrumentation tape using a Lockheed 417WB tape deck. To make the data compatible with the University of Alberta's IBM 360-67 computer, the analog data were digitized. Digitizing was done on the University of Alberta, Institute of Earth and Planetary Physics' Nova 1200 computer using the following format: each line scan signal was divided into 512 parts or windows, starting at the left temperature body and ending just beyond the right temperature body, which resulted in approximately 207 windows on the 77° ground portion of the scan signal. The voltage level within each window was averaged and a value assigned. This value was then written onto 9-track tape, which stored each line scan as a separate block of data.

Four programs were developed on the IBM 360-67 for presentation of the digitized data. The first (PRINTOBJ) divides the digitized data into 16 levels using ±2.5 volts as the upper and lower limits. The zero voltage portions of the signal between each temperature body is dropped and the ground scan data with a temperature body on each side are printed. Each level is portrayed as a hexidecimal symbol and is printed by a standard IBM line printer at 6 lines to the inch. The second program (SHADEOBJ) is identical to PRINTOBJ except that the line printer output is overstruck eight times to give a 16-level grey scale in place of the hexidecimal symbols. The third program (LEVCON) performs a similar function except that the 16-interval output is placed on magnetic tape as integer half words to the base ten. This is then used as input into WXMAP, the fourth program. WXMAP is a plotting routine employing a Calcomp plotter. The data from LEVCON are loaded into WXMAP where they are smoothed and a bias is added to each level that retains a zero decimal. Smoothing is undertaken to simplify the data field by reducing the number of very small closed contours; this reduces the computation time required for a plot. The bias is added because only an integer value contour can be plotted. If WXMAP finds a field of values exactly the same as the contour being plotted, each value is joined to the others of the same value.

Results and Discussion

Fig. 3 shows two overlapping portions of the thermal IR line scanning imagery taken along the Green Timber Road shortly after dawn at 0645 hours on October 7, 1971. At this time of day the water bodies

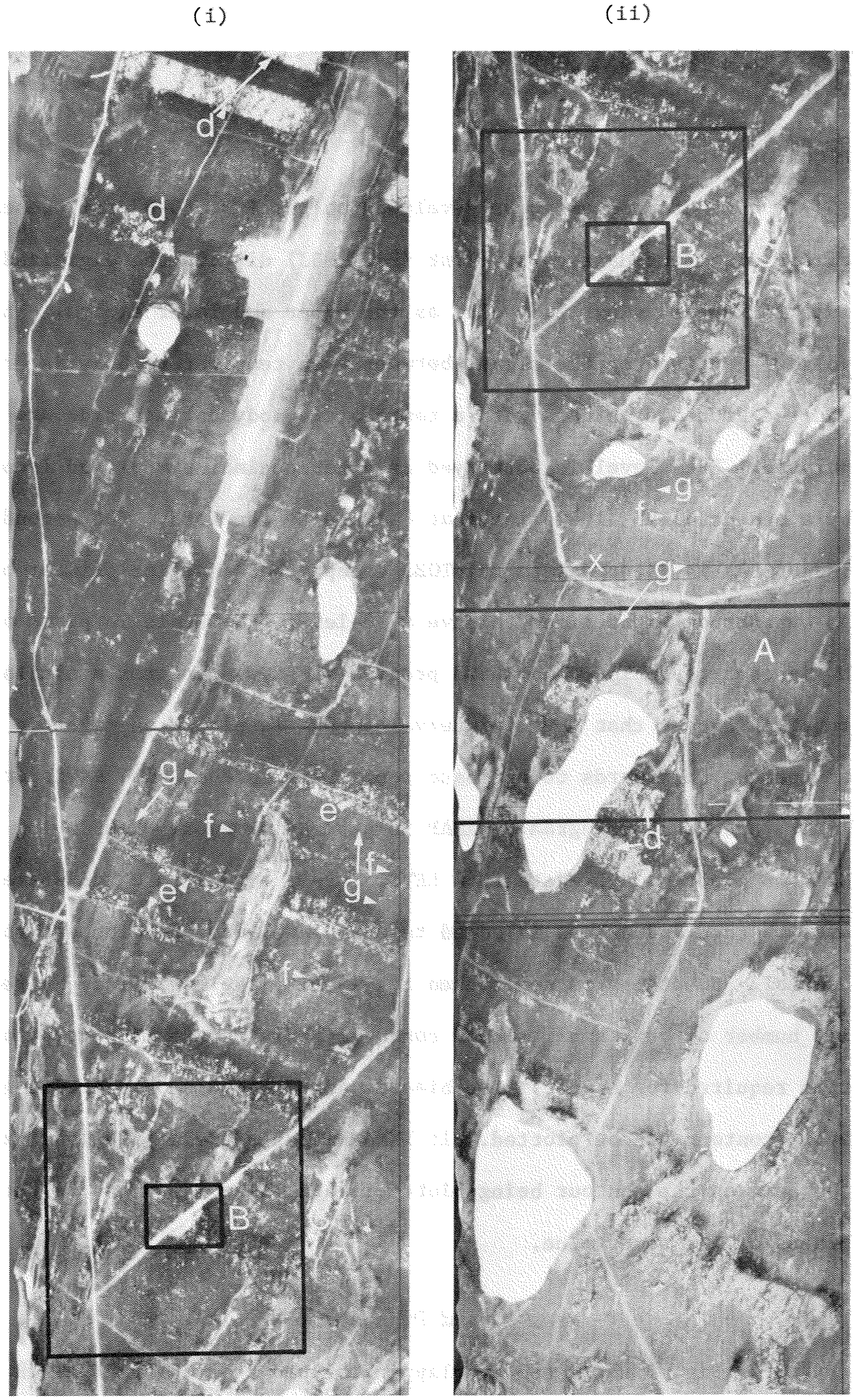

Figure 3. Two overlapping portions (i and ii) of the thermal IR line scanning imagery obtained along the Green Timber Road, near Hinton, October 7, 1971, at 0645 hours. Outlined areas A and B refer to the areas covered by Figs. 4 and 5 respectively. Area C refers to the approximate area covered by Figs. 7 and 8. X indicates the hygrothermograph site; d residual stands of spruce; e 1960 cut, non-scarified strips; f 1960 cut, scarified strips; g 1969 and 1970 cut, scarified strips.

(white), followed by the roads and airstrip are the warmest portions of the imagery. At the top of the (i) strip, some uncut residual stands of spruce can be seen (d) at the end of the airstrip. These conifers are relatively warm, in fact nearly as warm as the roads. The older non-scarified strips (e) (cut in 1960) have numerous warmer bodies scattered over them, which are largely poplar trees and a few uncut spruce. Scarified strips (f), although cut the same year, have fewer warm bodies, while newer cut and scarified strips (g) (1969 and 1970) are more uniform in thermal imagery.

The outlined area A in Fig. 3 refers to that covered in Fig. 4, an example of thermal IR line scan computer output for the SHADEOBJ program. The output from the PRINTOBJ is very similar except that the program uses hexidecimal instead of overstruck symbols. Both programs are limited by the rigid symbol size of the line printer; this produces a linear distortion of a factor of about 10 in the flight path direction. They both require approximately the same amount of computation time, but SHADEOBJ requires eight times the temporary storage to hold the right half of the scan while the left half is being printed, so SHADEOBJ is limited by temporary storage to 1/8 the number of scans per run as PRINTOBJ. It is felt that PRINTOBJ is the more useful of the two programs. The exact range of the data can be determined and the range in values across a very small area can be seen. It also presents the largest number of scan lines per run of any program.

The biggest drawback of the computer presentation is location identification. To do this it is best to resort to the film (Fig. 3), find a prominent feature, estimate the number of scans from the start, and then pinpoint this region with PRINTOBJ. SHADEOBJ could be used as

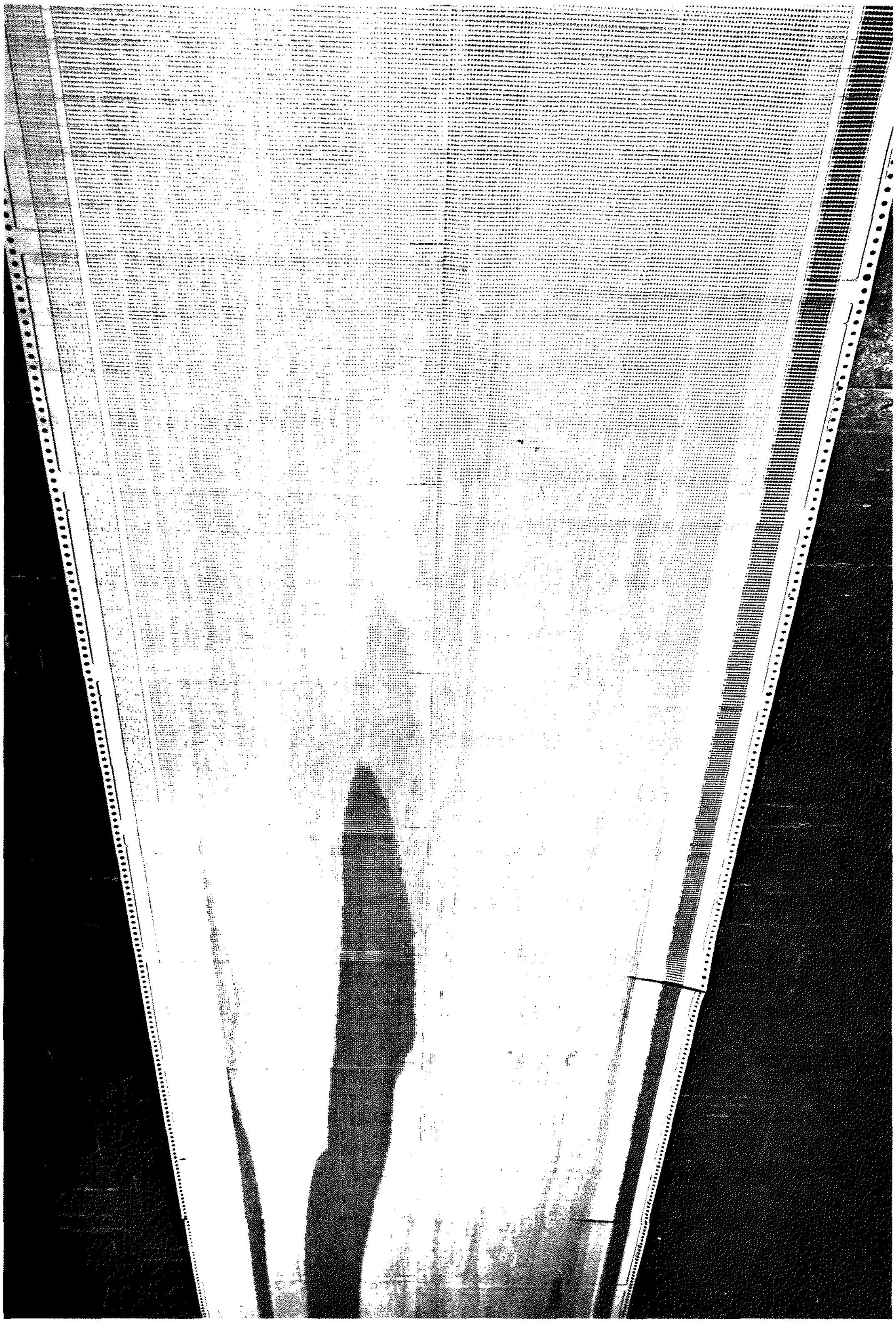

Figure 4. Thermal IR line scan computer output of SHADEOBJ for October 7, 1971, at 0645 hours, for area outlined as A on Fig. 3.

well but tends to be more expensive. After the subroutine program LEVCON has been employed, apparent temperature levels can then be produced with WXMAP.

Outlined area B on Fig. 3 refers to that covered in Fig. 5; an example of the thermal IR line scan computer output for the WXMAP program. Perhaps the most noticeable feature of this contour map is in the sawtooth pattern of the road that cuts through the area. Close inspection of all contour lines reveals a similar pattern. This is the result of WXMAP plotting between data points by linear interpretation. Smoothing of the contour lines is available within WXMAP but was not used due to the already high cost of this program. Careful inspection of Fig. 5, especially in the vicinity of the high values found along the road, reveals the fine decisions that WXMAP can make. However, the cost of this presentation is quite high. To run WXMAP and obtain Fig. 5 it cost $107.00 for the computer printout. This could be greatly reduced if WXMAP were to be rewritten as an operational program.

To make effective use of the output of the computer program, a graph is drawn (Fig. 6) so that each level value can be associated with an apparent temperature. The relationship between temperature and emitted radiation is exponential from 0°K; however, across the very narrow range (<10°C) found within this study a linear relationship may be assumed. To determine the temperature range of each level on the graph, the temperature body values from the computer programs are placed along the sides with the temperature range found on the scanner log sheet along the bottom. The two temperature body values are joined with a straight line and where the temperature value on the bottom of the graph intersects this line, the level that represents it on the

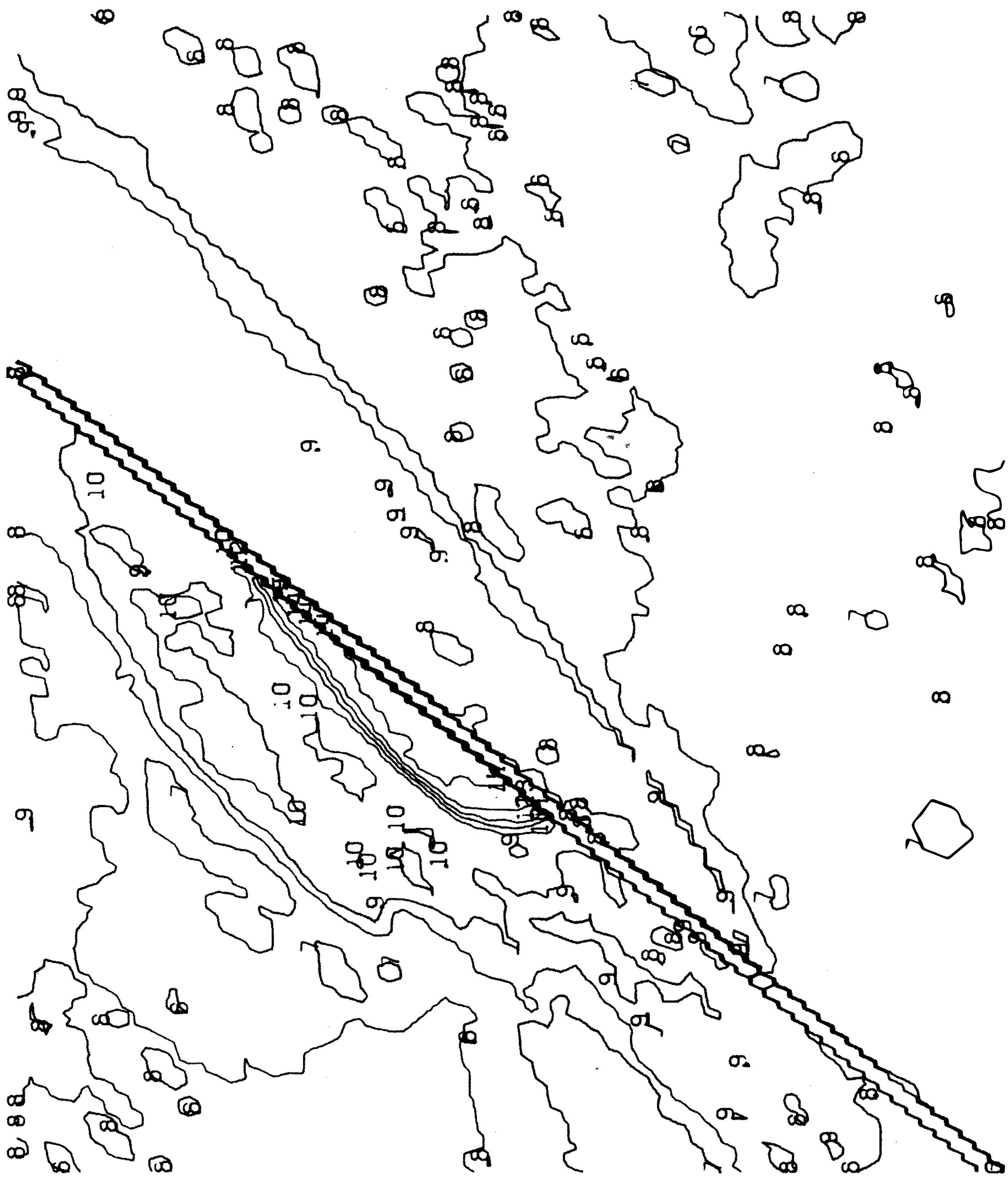

Figure 5. Thermal IR line scan computer output of WXMAP for October 7, 1971, at 0645 hours, for area outlined as B on Fig. 3.

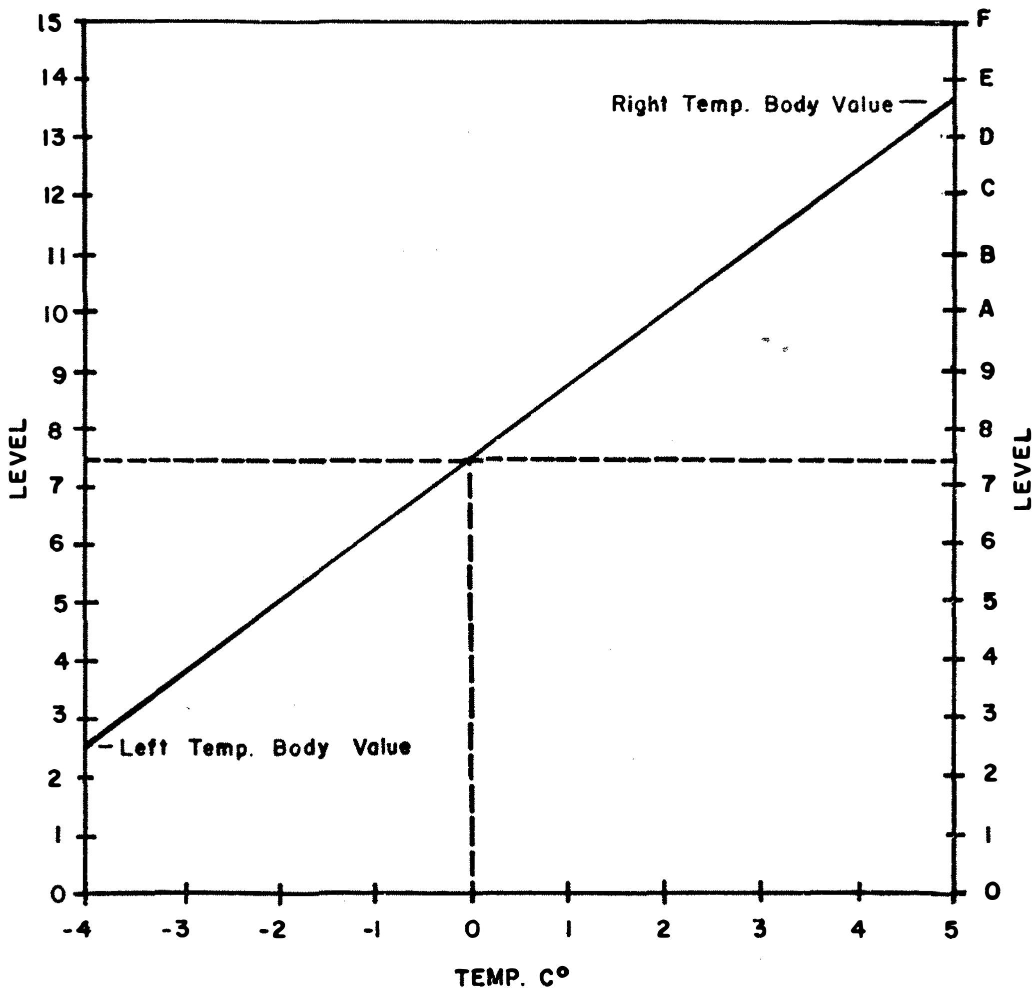

Figure 6. Thermal IR line scan reference calibration chart for converting level values from the computer outputs to an apparent temperature value.

computer output is found. In this case level seven represents approximately -0.5°C.

By using the PRINTOBJ output for the A area of Fig. 3, the lake surface has a hexidecimal value of 'E', the road has a value of '9', and a hygrothermograph located approximately where the X is on the scanner film (Fig. 3) has a value of '7' or '8', depending on the exact location. By consulting Fig. 6, the PRINTOBJ apparent temperature value for the lake 'E' is 5°C; for the road '9' it is 1.2°C; and for the hygrothermograph site it is from -0.2°C to 0.5°C. Above scanner temperatures are single values that represent temperature ranges, for example, level '8' represents the temperature range from approximately 0°C to 1°C; therefore each value given has a range of ±0.5°C. This range can be decreased by increasing the number of levels in PRINTOBJ. The upper limit of this increase is controlled by the digitizing program and is 512 levels.

The number of levels required as output from PRINTOBJ is dependent upon two major considerations: the temperature range of the target and the scanner's ultimate temperature resolution. Since the scanner's resolution of temperature is one one-hundredth of a degree Celsius under ideal laboratory conditions, PRINTOBJ should be able to handle up to the scanner's ideal maximum field temperature resolution. As the target temperature range increases, the value for each level will increase unless the number of levels is increased. Therefore, the major limiting factor of the programs is not hardware or software, but the limits set by the researcher in defining a significant temperature change.

The scanner's signal is derived from the radiation emitted by a series of grey bodies. To obtain a real surface temperature, each grey body must be converted to a standardized emissivity. To do this, Stephan-Boltzman's law is used to derive the power of the grey body emittance. Then the temperature, that a black body with the emissivity of 1.0 would assume when emitting the same power as the grey body, gives the real temperature of the grey body.

$$W = \sigma T^4 \varepsilon$$
$$T^1 = (W/\sigma)^{1/4} \qquad \text{Eq. (1)}$$

where W is the power output of a grey body in watts per cm^{-2}, ε is the emissivity factor, σ is Stephan-Boltzman's constant 5.67×10^{-12} watts per cm^{-2} K^{-4}, T is the grey body temperature in °K, and T^1 is the black body temperature in °K.

To use these normalizing calculations, several assumptions must be made. The emissivities are assumed to be those found in Table 1 and the atmospheric losses are ignored.

TABLE 1. Examples of emissivity values for selected materials (Hudson, 1969).

Material	Emissivity
Lacquer, black	0.97
Soil, dry	0.92
Soil, saturated	0.95
Water	0.96
Wood	0.90

Because the scanner's temperature calibration plates (black lacquer) have an emissivity of 0.97 and their real temperature is obtained from thermocouples within the plate, the scanner sees them as

2.04C° colder (cold body, -4°C) and 2.11C° colder (warm body, 5°C), respectively, than the thermocouple measurements. Thus, for each grey body temperature that we calculate, a value of approximately 2.07C° must be added after calculation of T^1 using Eq. 1. This addition of the correction factor cancels the reading error in the black body temperature reference. The lake returned an apparent temperature of 5°C which was adjusted downward by 0.7C° (calculated from Eq. 1 and corrected to proper black body readings). Similarly, the road, which had a heavy dew deposit, was assumed to be similar to that of a saturated soil surface, and was adjusted downward 1.2C° to read 0°C. The hygrothermograph site which was a 1970 scarified area, partially covered by slash and other timber residue with a fresh growth of grass, had its apparent temperature adjusted downward 5C° to read -5°C. Thus, the ground temperature was about 6C° colder than the hygrothermograph that reported 0°C to 1°C at 6 inches above the ground at the time of the flight.

These corrections were too large because of the assumption that atmospheric losses were negligible. If suitable profiles of atmospheric humidity and temperature were available, the real temperatures could be adjusted upwards to approximate the actual surface temperatures more accurately.

Although the real temperature of a location can be estimated from thermal IR scanner data and could be extracted from the data by the computer if the target emissivity were accurately known, present sensors only indicate radiant power intensity at the entrance to the sensing systems optics. What this means for users is that there is a very long inferential chain between what the sensors measure and what one is interested in. The sensors do not even directly tell us the reflectivity or emissivity.

The computer procedures outlined here for presentation of thermal imagery have little value for general forestry surveys, but could prove useful for detailed analysis in problem areas, such as areas prone to frosts, where a knowledge of the thermal regime at certain times of day or season is required. Murtha (1972) recognized the value of thermal infrared line scan imagery for delineating microclimate patterns and mentioned the possibility of image-slicing by computer programming. Other image-slicing techniques, such as density color slicing, however, may prove more practical than computer techniques for presentation of thermal regimes where relative values are more important than actual values of temperature.

Since the original study was completed an opportunity arose to have the area shown in Fig. 5 processed through a I^2S Digicol Image Enhancement Viewer. Figure 7 shows a black and white photograph taken with this video system of the thermal line scan imagery for an area considerably larger than covered by Fig. 5. (Fig. 5 covers the central portions of Fig. 7 only, where an old log landing is shown). Figure 8 illustrates a composite of 6 density color levels for the Fig. 7 area, with the black areas the warmest, followed by green, yellow, red, brown, blue, and finally, the coolest, purple.

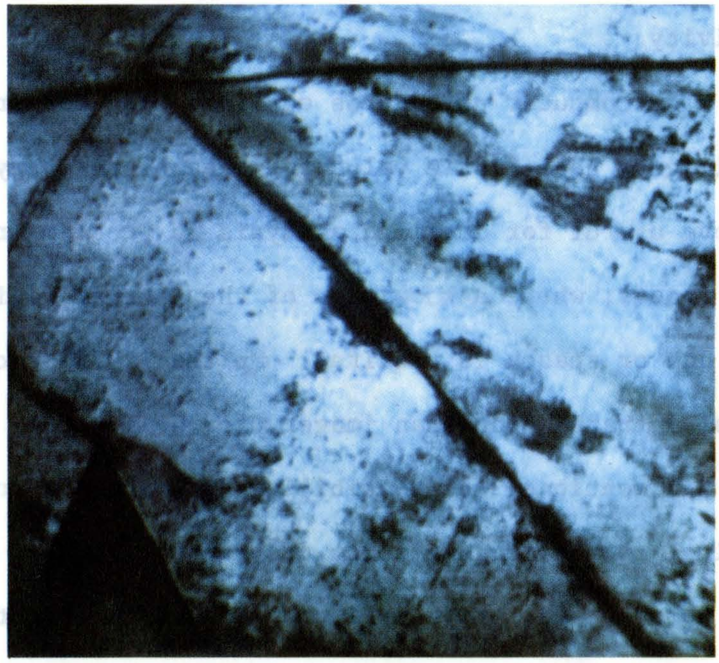

Figure 7. Black and white photograph of the thermal line scan imagery for the area shown as C on Fig. 3.

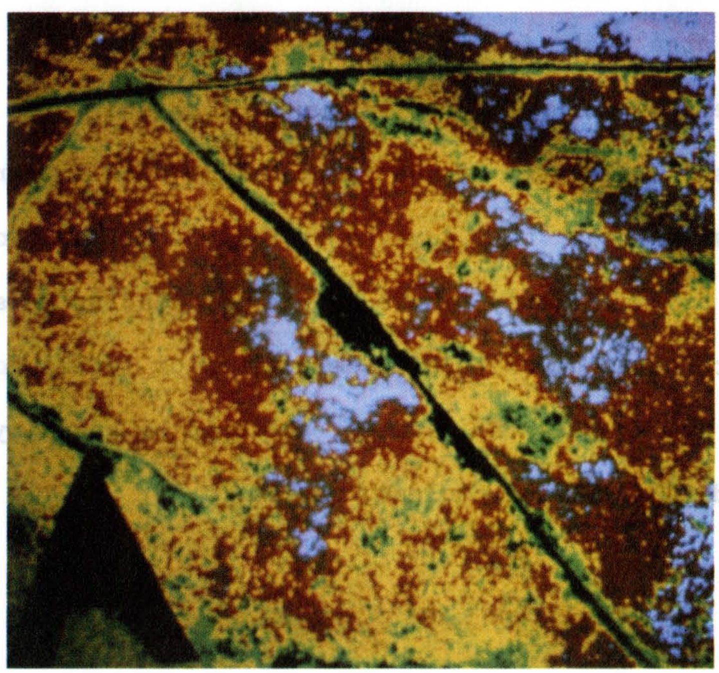

Figure 8. A composite of Digicol image color levels for the same area as Fig. 7. The black areas are the warmest, followed by the green, yellow, red, brown, blue and the coolest, purple.

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Literature Cited

American Geological Institute, 1968. Short course lecture notes on remote sensing. Washington, D.C. 196 pp.

Daedalus, 1971. Daedalus Quantitative Scanning System, Operating Manual. Daedalus Enterprises Ltd., Ann Arbor, Michigan.

Hudson, R. D. 1969. Infrared system engineering. Toronto, Wiley and Sons, 641 pp.

Murtha, P. A. 1972. Thermal infrared line-scan imagery for forestry? Can. Dept. Envir., Can. For. Serv., Forest Management Inst., Ottawa. Info. Rept. FMR-X-45. 46 pp.

Some Computer Techniques for Presentation

of Thermal Infrared Line Scan Data[1]

by

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Abstract

A series of computer programs which increases the ease of interpretation of the thermal infrared line scan data is presented. Each program presents the thermal output in a different format: single hexidecimal symbol, overprint symbols, and isotherms drawn by the Calcomp plotter, for a partially cut-over forested area. The problem of converting from apparent to real temperature is discussed. An example of Digicol image enhancement for a portion of the thermal imagery is also shown.

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