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THERMAL MAPPING OF THE COLUMBIA RIVER AT HANFORD USING AN INFRARED IMAGING SYSTEM

J. R. Eliason

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USING AN INFRARED IMAGING SYSTEM

J. R. Eliason

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THERMAL MAPPING OF THE COLUMBIA RIVER AT HANFORD
USING AN INFRARED IMAGING SYSTEM

J. R. Eliason

INTRODUCTION

Infrared imagery data used in this study were collected by the U. S. Department of Agriculture Forest Service, Northern Forest Fire Laboratory of Missoula, Montana, for the Geochemical and Geophysical Research Unit of Battelle-Northwest. The information was collected September 13, 1966 from 1010-1013 O'clock, using a mercury-doped germanium detector which was filtered to respond to the 7.5 to 14 μ wave lengths of infrared radiation. The magnetic-tape recorded information was processed with a computer program developed by Systems Analysis and Simulation Unit of Battelle-Northwest, to obtain quantitative evaluations of river temperature variations and to accurately define surface temperature patterns resulting from the discharge of reactor effluents into the river.

SUMMARY AND CONCLUSIONS

The use of infrared scanning equipment in conjunction with a computer program to plot thermal differences over large areas for near real-time evaluations of thermal patterns appears to be an extremely useful tool. The information collected in three minutes of flying time and plotted by the computer in less than one hour has revealed thermal detail that would have otherwise required many field crews working for several weeks. Data collected by the scanning system is also more consistent and useful because it is collected over a short time period.

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The River surface-temperature information collected in the vicinity of the reactor areas was plotted as contours of equal voltage readings which are essentially analogous to isothermal contours. The patterns which developed show clearly: the paths and thermal variations of reactor effluent plumes in the River, points where retention basin subsurface leakage enters the River via the ground water route, and those reaches across from the reactors where the River is recharged by ground water significantly colder (at this time of the year) than the water released from the Priest Rapids Pool.

DISCUSSION

Principles and Scanning System Operation

All materials above absolute zero are radiating electromagnetic energy, and objects near the earth's average ambient temperature (considered to be 300°K) are radiating primarily in the infrared region of the electromagnetic spectrum. Blackbody radiation curves for 373°, 300°, and 273°K are shown in Figure 1; the filtered range of the mercury-doped germanium detector, which includes the maximum of the ambient curve, is indicated.

Remote sensor systems are limited by the transparency of the atmosphere to those wave lengths of electromagnetic radiation which can penetrate significant distances through the atmosphere. The transmission curves for a distance of 1 nautical mile⁽¹⁾ through a vertical atmospheric column are shown in Figure 2. The regions in which significant atmospheric transmission occurs, "atmospheric windows," are evident; the 7.5 to 14 μ region in which the mercury-doped germanium detector is sensitive corresponds to an atmospheric window.

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FIGURE 1
Blackbody Radiation Curves for 373°, 300° and 273° K

FIGURE 2
Atmosphere Transmission Curves for a Distance of 1 Nautical Mile Through a Vertical
Column. (1)

The infrared scanning system collects the incoming radiation and focuses it on a detector which causes a voltage change due to a change in resistance of the detector for different amounts of infrared radiation. The voltage change is used to modulate a sequentially-scanning light beam which exposes a continuous film strip producing an image of the area scanned. The detector voltage output is also recorded on magnetic tape. This information was retrieved and used as input to a computer program recently developed by Battelle-Northwest. The technique allows points of constant infrared radiation level to be contoured and related to temperature levels on homogeneous surfaces; the river is essentially a homogeneous surface.

The infrared imaging system scans an area normal to the aircraft flight path and 60 degrees either side of nadir. The relationship of the infrared scanner to the ground⁽²⁾ is shown in Figure 3 in which h is the altitude of the aircraft, θ is the angle at which the scanner is focused, and D is the scan distance normal to the flight path. The optics of the scanning system limit the instantaneous field of view to a solid angle of approximately 1 milliradian which gives a minimum resolution element of approximately 2 ft^2 at an altitude of 2000 feet.

The surface climatological conditions at the time of the flight were: relative humidity - 54 percent, air temperature - 37.2°C , wind - 6 miles per hour from the northwest and barometric pressure (corrected to sea level) - 29.96 inches. The Columbia River flow at the time of the flight was changing rapidly due to increasing release from Priest Rapids Dam. The approximate flow distribution, ± 1500 cubic feet per second, past the reactor areas is plotted in Figure 4.

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FIGURE 3
Relationship of the Infrared Scanner to the Ground. (2)

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FIGURE 4
Approximate Columbia River Flow Distribution September 13, 1966, 10:10 O'Clock

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Data Evaluation

The photo image of the reactor areas which was produced by the scanning system is shown in Figure 5. This record shows the thermal detail which the scanning system detected in the river. Reactor effluent plumes may be traced from one outfall structure to another, and seepage from the retention basins is evident at several shoreline points near the reactor areas. The photo image of the reactor areas reveals qualitative information on the reactor effluent distribution, and only approximate temperature gradients in the Columbia River can be deduced from this imagery. Quantitative evaluation of the photo imagery is difficult due to the nonlinearities associated with the photo recording system. The dynamic range of the film limits the thermal variation which can be represented by the mid-tones which are proportional to thermal variations.

The magnetic tape recordings made of the detector signal, which comes from the preamplifier of the system, do not contain the nonlinearities associated with further amplification and recording in the imaging system. The amplitude of signals recorded on the magnetic tape is proportional to detector output voltage, and detectors can be selected which have an output voltage that varies linearly with input flux densities over a very wide range. The magnetic tape recordings of the detector output were amplified by a gain of 15, and the detector voltage to temperature relationship was determined (Figure 6). It is necessary to have several temperature measurements of the surface being studied in order to relate detector voltage to the surface temperature.

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7.5-14μ Photo

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FIGURE 5
Aerial View of the Reactor Areas

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FIGURE 6
Detector Voltage and Temperature Relationship

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The computer program produces contours of constant voltage levels which can be related to radiation intensity or surface temperature. The system can generate as many contours as are desired at one time, or only one voltage level may be selected. The latter was found desirable in the case of the recordings collected on the reactor flight due to the scattering of points over areas of near constant temperature. Computer plots of the river data are shown in Figures 7-13 with the corresponding voltage and temperature levels indicated. These plots are not corrected for the nonlinear scanning rate of the detector on the ground which is due to the scanner rotating at a constant angular rate. The relationship of the altitude to the distance from the center line of the scan is $D' = h \tan \phi$, where: D' is the distance from the center line and h is the altitude, Figure 3. The correction was applied to the computer program by using a function generator; the corrected river plot is shown in Figure 14. General thermal patterns are not changed, but the removal of the distortion allows overlays to be made for direct comparison to maps of a study area which would aid in interpretation of the data. This correction, to be applied with precision, will require a refined computer program which is being developed. The detected intensity of infrared radiation from a surface decreases as the observation angle increases, with the intensity being proportional to the cosine of the angle (Lambert's Cosine Law). However, the resolution element of the infrared scanning system increases proportional to the cosine of the observation angle, so this effect compensates for the intensity reduction due to the angle of observation. The size of the resolution element is determined by the solid angle which the detector subtends and the distance to the target; therefore, the radiation collected is nearly independent of the distance provided the resolution element does not exceed the source size.

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The reactor area flight image shown in Figure 5 contains about 36,000 scan lines that were collected in three minutes. The scan lines are closely spaced radiation profiles of the area, and individual lines show the detail which was obtained in one pass of the detector. Selected scan lines, which can be related to ground positions by numbers on the infrared image (Figure 5) are shown in Figures 15-20. The voltage levels indicated by the scan lines may be related to temperatures by referring to the voltage-temperature relationship plotted in Figure 6. Scan line Number 3 in Figure 15 shows voltage overshoot which is caused by the preamplifier in the infrared system. This effect, which caused some problems in evaluating the data and points near large intensity changes, may not be truly representative of temperature.

Points on the scan lines collected over terrain are difficult to relate to temperature because of significant emissivity differences of various earth materials. High-temperature sources near the reactor areas are identified on the individual scan lines. The retention basins are the most predominant heat sources.

The seepage from retention basins is evident in several cases as hot springs near the riverbank. The general temperature gradient from the reactor side of the river to the northwest shore is evident in most scan lines. Reactor effluent plumes are evident and approximate river temperatures are indicated on several scan lines. Low temperatures are indicated on the northwest bank of the river across from 100 K area. The temperature of this area, which appears to be below the ambient river temperature observed above the reactor areas and also below the 17.3°C recorded at Priest Rapids Dam at the time of the flight, may indicate

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that significant ground water is entering the river in this area. The ground water gradient attributable to Priest Rapids Dam may be expected to cause significant quantities of water to enter the Columbia River in this area. The 16.5°C contour in Figure 13 defines the areas which appear to have temperatures below the ambient river temperature. A composite of the river thermal contours (Figure 21) was made from the contour data in Figures 8-13. This composite gives a general indication of the thermal gradients near the reactor areas.

The data evaluated for this report were collected by an extremely sensitive infrared scanning system, but the system was not designed to make detailed thermal evaluations. A system with high resolution which could be flown lower and slower to obtain detail, and filters which would limit the infrared wave length to the center of the 7.5 μ window to reduce the effects of the water absorption bands would greatly improve the thermal resolution of the system. The thermal resolution of the system used in this study theoretically is <0.5°C; the data indicate that an actual thermal resolution of this magnitude (0.5°C) is more realistic.

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FIGURE 7
Points at -22 Volts or 25 °C Plotted by the Computer

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FIGURE 8
Points at -24 Volts or 23 °C Plotted by the Computer

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FIGURE 9
Points at -26 Volts or 21 °C Plotted by the Computer

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FIGURE 10
Points at -28 Volts or 19.5 °C Plotted by the Computer

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FIGURE 11
Points at -30 Volts or 18°C Plotted by the Computer

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FIGURE 12
Points at -33 Volts or 16.5 °C Plotted by the Computer

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FIGURE 13
Points at -23, -14, and -4 Volts or 24 °C, 34.5 °C and 52 °C
Plotted by the Computer

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FIGURE 14
Points at -22 Volts or 25 °C Plotted by the Computer with Sweep
Correction

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FIGURE 15
Response of the Scanner to the Surface Radiation at Selected Scanner Sweeps

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FIGURE 16
Response of the Scanner to the Surface Radiation at Selected Scanner Sweeps

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FIGURE 17
Response of the Scanner to the Surface Radiation at Selected Scanner Sweeps

FIGURE 18
Response of the Scanner to the Surface Radiation at Selected Scanner Sweeps

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FIGURE 19
Response of the Scanner to the Surface Radiation at Selected Scanner Sweeps

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FIGURE 20
Response of the Scanner to the Surface Radiation at Selected Scanner Sweeps

Volts
-50
-40
-30
-20
-10
0
+10

Volts
-50
-40
-30
-20
-10
0
+10

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FIGURE 21
Composite of the River Thermal Levels

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2. Wilson, Ralph A. and Nonan V. Noste, The Evaluation of an Airborne Infrared Mapper as a Tool for Detecting and Measuring Fires, May 1964, (in press, U.S.D.A. Forest Service).

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