Calibration Techniques for Remote Sensing Measurements of Water Temperatures[1]

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Abstract

Remote sensing techniques, involving optical-mechanical scanners mounted in aircraft, offer great potential for meeting some of the needs for more quantitative information on our water (and other) resources. One technique used in remote sensing allows the absolute temperature of water surfaces to be determined from several thousand feet of altitude to within 0.5 degree Centigrade. Two methods for calibration of thermal infrared scanner data were described. The accuracy of these techniques was shown. The limitations of the calibration procedures and use of airborne scanner systems were discussed.

Introduction

One recently-developed remote sensing tool is a "thermal infrared optical-mechanical scanner" or "thermal IR scanner." This instrument can be mounted in an aircraft and flown over an area of interest, thereby allowing one to obtain a temperature map of the area below the aircraft.

Calibration Techniques

To make thermal IR scanner data meaningful, the relative radiance values (as measured by the scanner) must be related to the true temperature of the area being sensed, or target area. Two quite different techniques are possible. These are 1) the correlation method, and 2) the internal calibration techniques.

The correlation method is relatively simple, but does have some serious drawbacks. Variations in tone on the thermal IR imagery correspond to relative differences in the radiant temperatures of the scene imaged. Therefore, if the actual temperature of the various objects on the earth's surface can be determined, it is possible to correlate these measurements with density values of the imagery to those points on the ground. To use this technique for water studies, temperature measurements must be obtained for a number of locations on the river or lake at the time the aircraft passes overhead. Later, these measurement points are located on the thermal IR imagery and the density of the film at these points is measured. In this way, correlation is possible between actual temperature of the water at a few points and the film density at these same points. Intermediate film density values can then be interpolated.

The major drawbacks to this technique are that, 1) it takes only a few minutes to obtain the scanner data via airplane, but it may take

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several hours to obtain surface temperature measurements, during which time the water temperature may have changed significantly, and 2) development of the film on which the data are recorded is subject to many possible variations in chemical processing which can sometimes cause tonal differences to not have a linear relationship.

For several years, the correlation method was the only technique available, due to limitations in the thermal IR scanning equipment. Relatively recent developments in scanning equipment have allowed researchers to devise an "internal calibration" technique, which, with two assumptions, allows the actual water temperature to be determined directly from the scanner data, and no surface observations of temperature are necessary (other than to verify the reliability of the technique). One assumption is that the radiation characteristics of water in the thermal IR region approximate those of a black-body radiator (which is defined as an object that will completely absorb all frequencies of radiation incident upon it). Water departs only 2-3% from being a perfect black-body radiator in these thermal IR wavelengths (1). The second assumption is that atmospheric attenuation has relatively little effect on the amplitude of the signal received at the scanner. This assumption is based on the fact that the 8.0-13.5μm region of the electromagnetic spectrum is in an atmospheric window (where absorption by the various components of the atmosphere is minimal), and also that most of the small amounts of energy absorbed by water vapor or other atmospheric constituents would be reradiated by the water vapor since water acts as a black-body in this portion of the spectrum, thereby allowing only extremely small net losses of radiated energy between the water surface and the aircraft scanner. Previous work has indicated that these assumptions appear to be reasonable (3).

The data used by LARS in this work was obtained by a multispectral scanner, owned and operated by the University of Michigan, and mounted in a C-47 aircraft (4). This scanner has been modified to accommodate two reference black-bodies which are viewed by the scanning mirror during each revolution. These reference sources are referred to as calibration plates, and are temperature controlled, one plate being cooler than the other, in approximately the same range of temperatures of the earth surface features over which the aircraft is flying (2).

Methods

The objective of this study was to determine the reliability of the temperature calibration procedures using data collected over the Wabash River at two different times of the year, and under somewhat different weather conditions. On June 30, 1970, data were collected from an altitude of 3,000 feet at 10:45 AM, with good clear weather conditions, while on August 13, the altitude was 2,000 feet, with somewhat hazy weather conditions and at 3:47 PM.

Using the data logs on the calibration plate temperatures, the data were calibrated for radiant temperature and gray scale maps were produced. The different temperature ranges were depicted by different

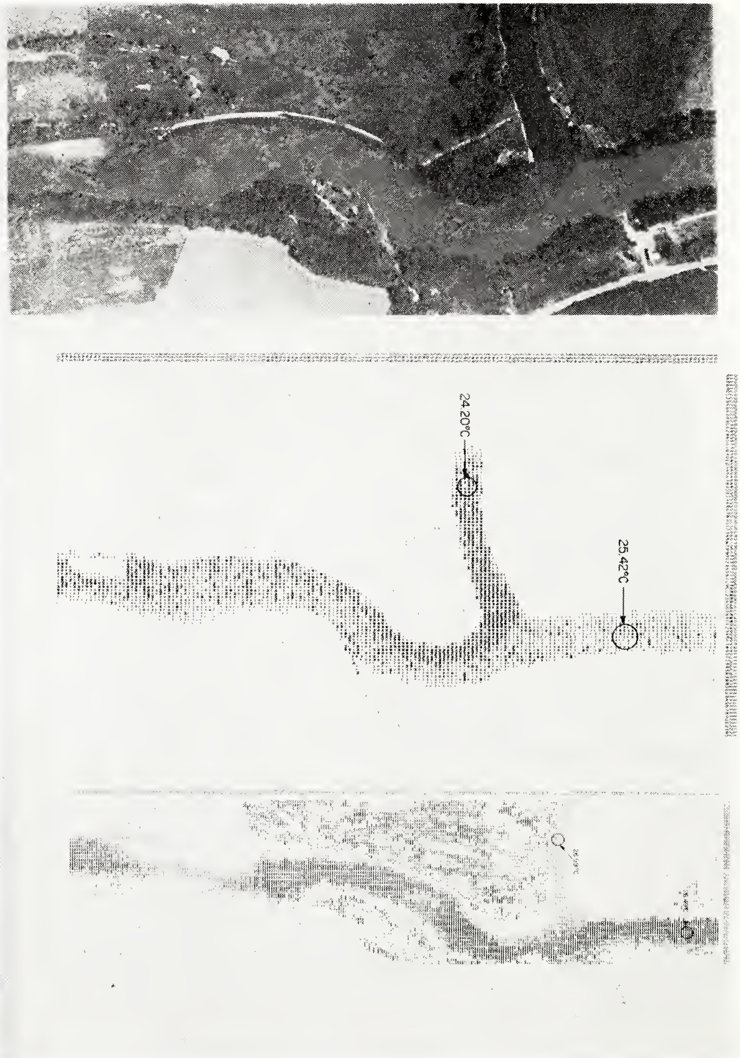

FIGURE 1. *An aerial photograph and computer printouts of calibrated thermal IR scanner data, collected June 30 from 3,000 feet (center) and August 13 from 2,006 feet altitude (bottom). The junction of the Tippecanoe River (from top) and Wabash River (from right) is shown. Note that the June 30 data shows that the water in the Tippecanoe is cooler than the Wabash, while the opposite is true for the August 13 data. The August data also shows much of the land area at the same apparent temperature range as the water.*

Symbol Key. Temperature in °C.

June 30. (blank): 24.0 or lower, (M): 24.0-24.9, (=): 24.9-25.2, (—): 25.2-25.5, (.): 25.5-26.0, (blank): 26.0 or higher.

August 13. (blank): 25.4 or lower, (M): 25.4-25.9, (=): 25-9-26.2, (—): 26.2-26.5, (blank): 26.5 or higher.

computer symbols. Only those temperature ranges that corresponded to the river were displayed. A blank, or no symbol, was used for all other temperatures.

Results

The junction of the Tippecanoe River (from left) with the Wabash river (from top) is illustrated in Figure 1. On June 30, the actual water temperatures, as measured from the boat, showed very good correlation with the temperatures indicated by the calibrated scanner data. Note that the Tippecanoe River was approximately 1.2°C cooler than the Wabash, and that this temperature difference persisted for a considerable distance downstream. On August 13, the Tippecanoe was relatively warmer than the Wabash, but the calibrated scanner data indicates about 0.8°C lower temperatures than were actually measured. Since the August data were obtained under hazy conditions, this could be the cause of the calibration error, and would indicate that additional work is required to obtain a fully reliable calibration technique.

Note that on the June 30 data only the river areas are shown on the printouts, indicating that only the water occupied the temperature ranges indicated, but on August 13, considerable land areas were emitting the same amounts of energy as the water. This indicates that if one is to produce temperature maps showing only the water areas, a layered classification scheme will need to be developed whereby one first identifies all water areas, and then maps the temperature characteristics of the water only.

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