Interpretation of Infrared Nighttime Imagery of a Forested Canopy

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ABSTRACT

The interpretation of an infrared nighttime imagery over a forested valley visualizes cold air drainage with the warmer tops of trees protruding near the center of the valley and whole crowns protruding on higher ridges. This interpretation is supported by detailed measurements of needle and air temperatures. Thermal IR imagery may be used to investigate air circulation patterns in complex terrain.

In early August 1979, the University of Washington, the Army Corps of Engineers Waterways Experiment Station and Colorado State University collaborated in a brief experiment designed to obtain data to support and validate canopy thermal IR signature models at a site within a closed coniferous canopy. One product of this experiment is a set of thermal IR imagery obtained by the Oregon Army National Guard using an Army OV-1C target acquisition system. Because this system is uncalibrated, but very temperature (radiance) sensitive, it is most useful in examining the spacial variation of brightness within a thermal IR scene that contains one highly instrumented ground truth site. Examination of the nighttime images reveals an interesting trend and textural variations of brightness within a scene. Unique ground truth data and familiarity with the area permit interpretation of these features.

An image made over the Cedar River Watershed near Issaquah, WA at 2245 LST about 2100 m above the ground is shown in Fig. 1. The relatively level forested site ranges from black to white (~5°C)[1] with texture contrasts which are visualized as the upper portion of individual trees (Fig. 1). The trees on the site (largely Douglas-fir) regenerated naturally after logging and burning in the mid 1930's. They are ~30 m tall in the middle of Fig. 1 and ~45 m tall on the upper and right edge of the figure. The finer texture on the left one-fourth represents a plantation with 1.8 × 2.4 m spacing. The average tree spacing of the remainder is 5.8 m. The soil at the site is a Barneston gravelly loamy sand originating from glacial outwash and is covered with a deep layer of organic material. Rock outcrops are not visible.

An understanding of mountain-valley circulation, in conjunction with plant and air temperatures, aids interpreting Fig. 1. During the summer when the Pacific high pressure cell is stagnant over the Pacific Northwest, large-scale subsidence prevails and the test site is influenced by mountain-valley and slope winds. Up-valley winds > 1 m s^{-1}, occur between 1200 LST and sunset while down-valley cold air drainage winds < 1 m s^{-1}, occur during the hours of darkness. The drainage winds are laminar and can be visualized as water flowing in a stream or lake. The dense cold air forces the warmer air aloft creating an inversion.

The periods of cold air drainage are characterized by an inversion base in or above the canopy and needle temperatures at or below air temperature depending upon the height of the inversion (0400 and 2400 LST 4 August and 2400 LST 5 August, e.g.,

[1] Black to white saturation represents an apparent temperature difference on the order of 5°C. The OV-1C system is ac-coupled and therefore cannot be calibrated absolutely. The value 5°C should be taken as nominal and is inferred from previous experience with the equipment and the area, and is consistent with measurements. The indium antimonide detector used has peak response from 4.5 to 5.5 μm and minimum detectable temperature differential of 0.1°C. The total field of view was 80° while the instantaneous field of view was 4 mrad.

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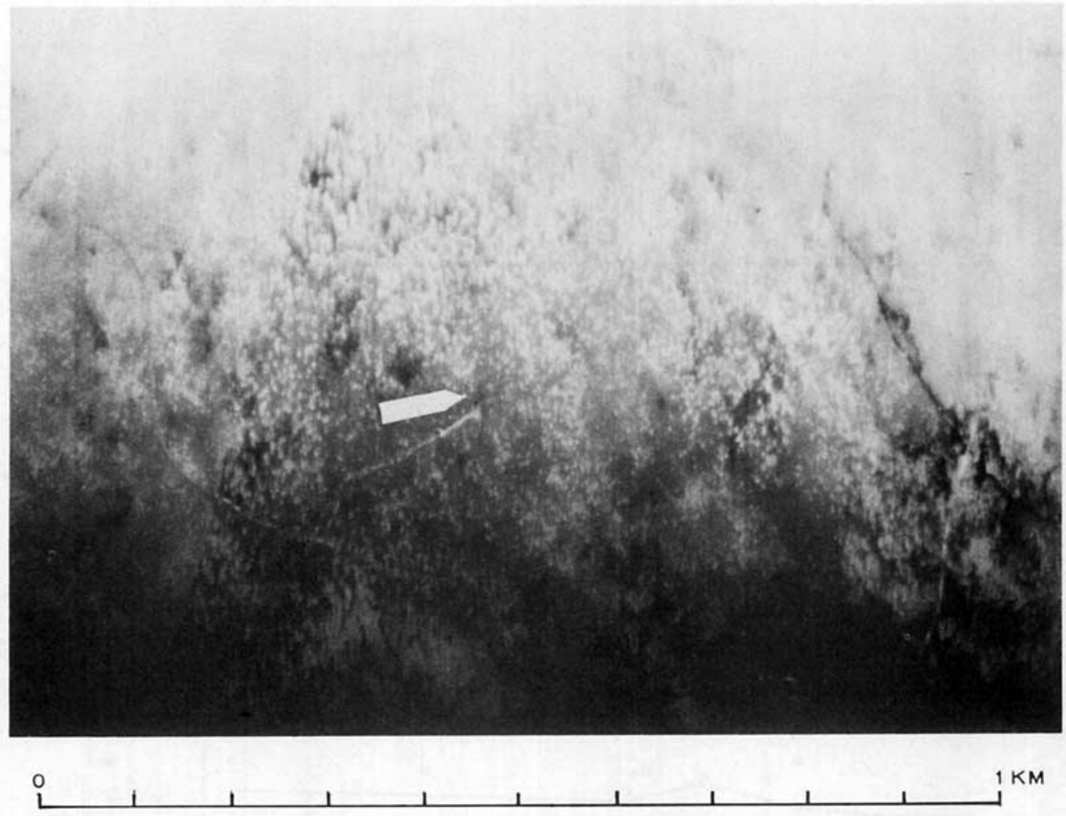

FIG. 1. Aircraft infrared imagery of the lower Cedar River watershed at 2245 LST 4 August 1979. The lysimeter tree is located at the point of the arrow at an elevation of ~274 m above sea level. The aircraft is ~2100 m above ground level. The upper portion of the picture is south.

Figs. 2a and b) and cloudiness. Up-valley wind conditions are characterized by air temperature maxima in the crown and needle temperatures as much as 4.8°C above air temperature (1200 and 1600 LST 4 August). Marine air invasion is characterized by nearly isothermal conditions with warmer temperatures near the ground (0400 and 0800 LST 5 August).

At the test site, a total of 48 needle temperatures were measured every minute on a 29.4 m tree in a weighing lysimeter (Fritschen *et al.*, 1973). Some nearby trees were ~32 m. A 7-level air temperature profile, up to 34.8 m, was monitored adjacent to the tree. In addition, wind speed and direction, and radiation data were collected. Hourly averages of needle and air temperatures for a two-day period are shown in Fig. 2. From the radiation and wind measurements, the meteorological conditions during the two days shown are described as stratus clouds and cold air drainage until 0800 LST 4 August, partly cloudy skies (stratocumulus) and up-valley winds from 1000 to 1800 LST, cold air drainage and clear skies from 2000 to 0200 LST 5 August, marine air invasion and low stratus from 0200 to 1000 LST, partly cloudly skies (stratocumulus) and up-valley winds from 1000 to 2000 LST, and cold air drainage starting at 2130 LST.

The infrared image in Fig. 1 was taken at 2245 LST 4 August, shortly after cold air drainage had commenced. The lower areas were being invaded with cold air (see Fig. 3) forcing the warmer air aloft. On the bottom portion of Fig. 1, the trees were immersed in the cold air. At the lower left center, trees are visible on top of a drumlin[2] (to the left of the test site, Fig. 3). The tops of the taller trees protruded through the cold air in the middle of the picture while most of the crowns in the upper portion of the figure were in the warmer air. Individual tree crowns are visible in the upper center. Since the trees in the upper right of the figure were taller they also protruded into the warmer air. A road is visible from the lower center to the upper left of Fig. 1. The road bed is more exposed to solar radiation in the north-south direction (vertical) and indicates some residual heat. The east-west portion along the bottom of Fig. 1 is detectable only by the absence of tree tops protruding into the warmer air.

It must be noted that if the imagery had been

[2] Oval hill of glacial drift.

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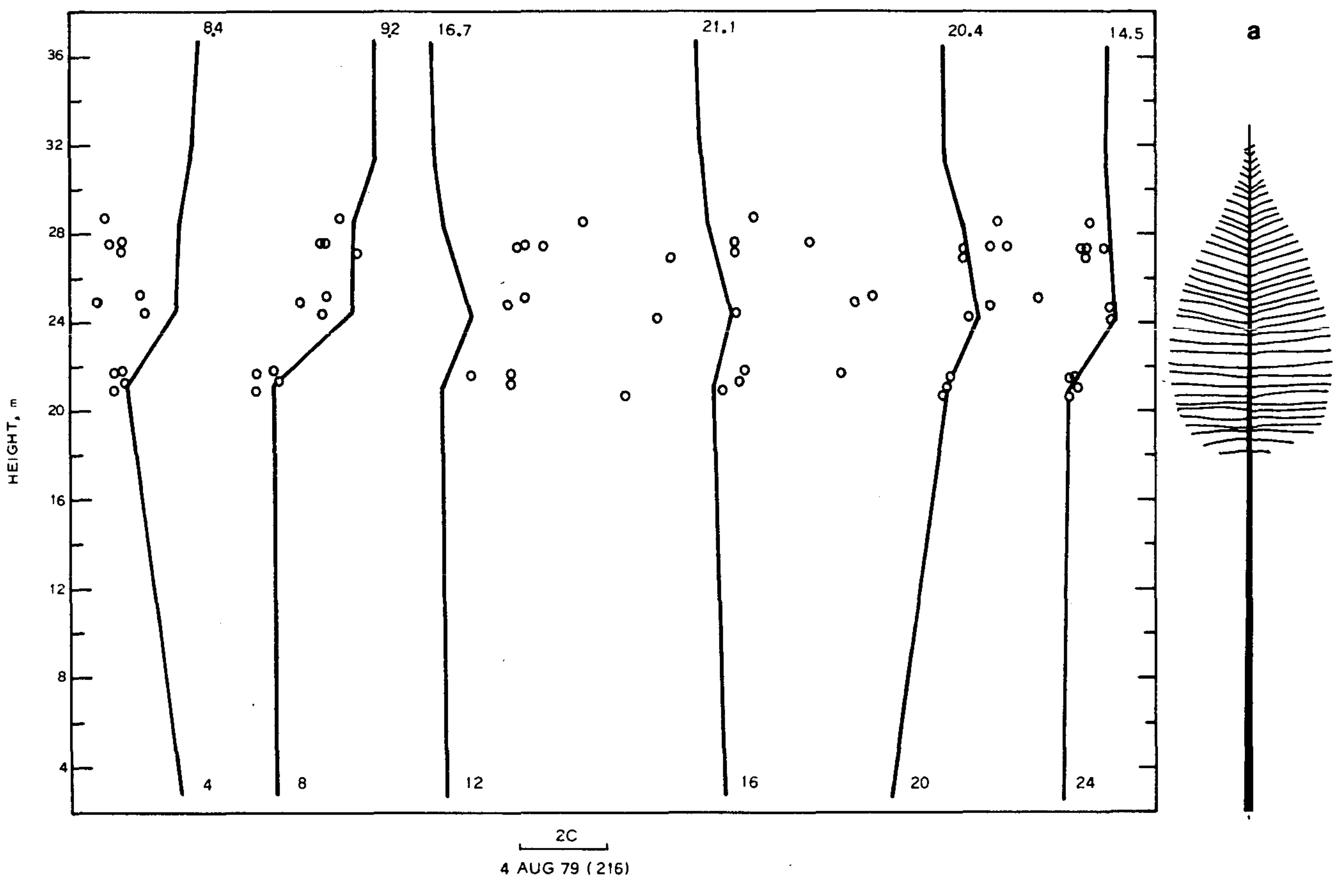

FIG. 2. Air temperature profiles (solid lines) and needle temperatures, average of four temperatures (open circles) on each of the cardinal sides of the crown during 4 and 5 August 1979 [(a) and (b), respectively]. The time of day is indicated by the number at the bottom of the profile, while the number at the top of the profile indicates the temperature at 34.8 m.

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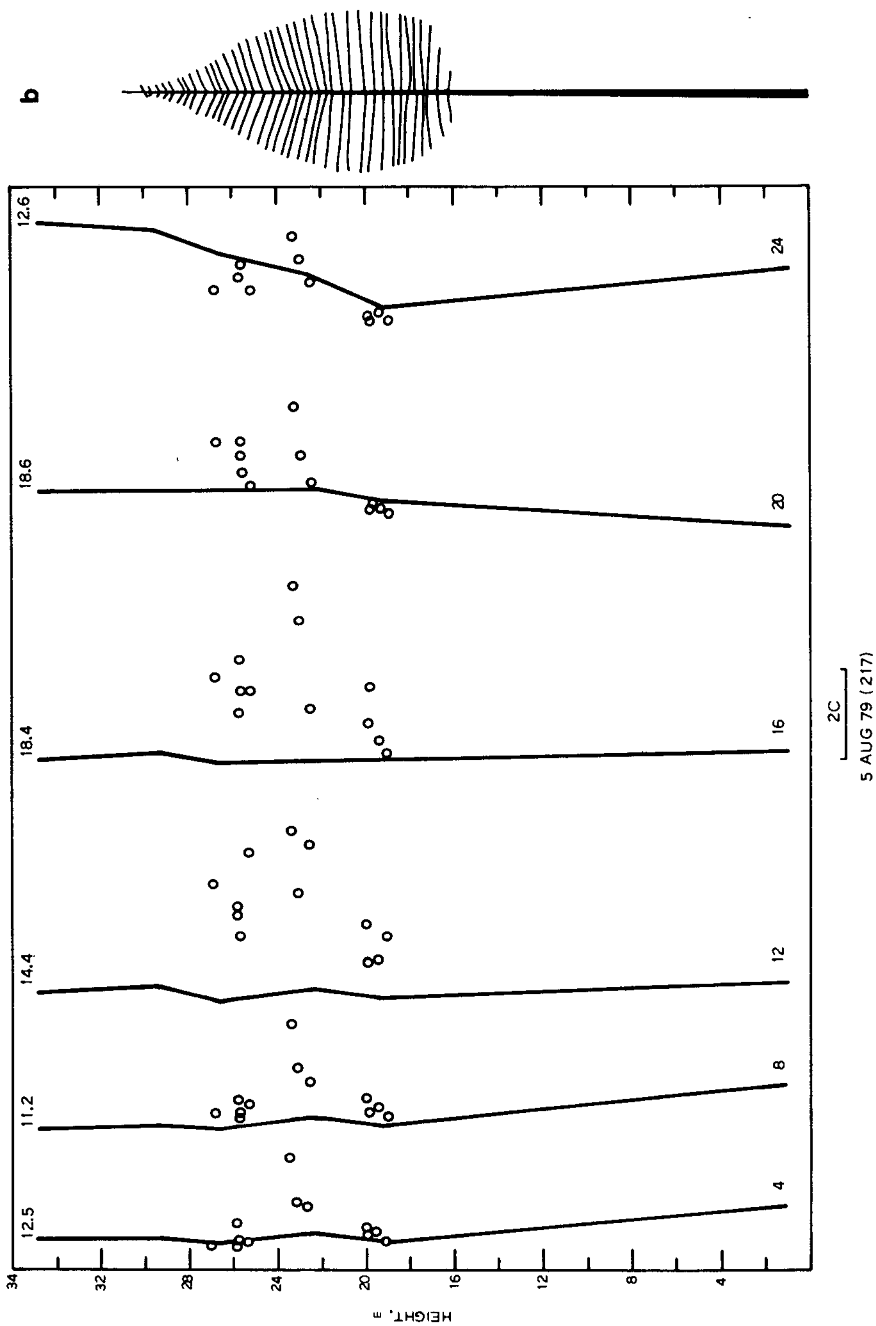

FIG. 2. (*Continued*)

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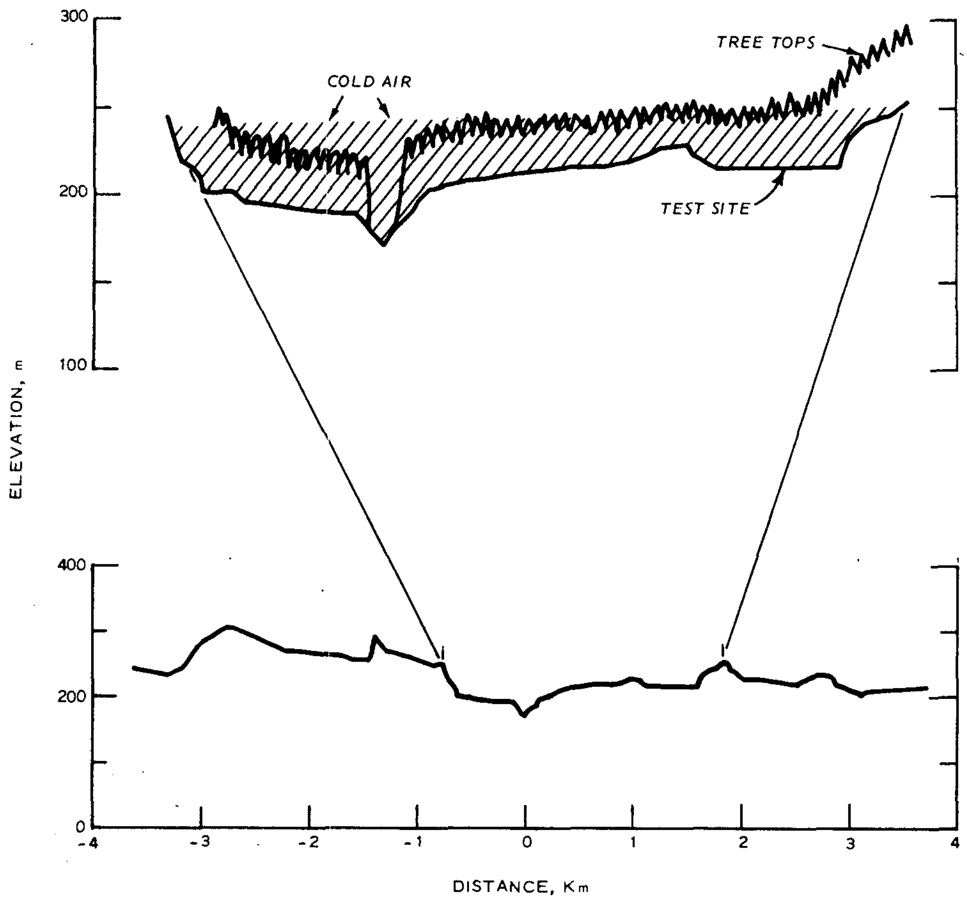

FIG. 3. Topographic cross section of the Cedar River drainage at the test site below the confluence of Taylor Creek and Cedar River. Enlargement shows schematically the position of relatively cold air in the vallley.

obtained 4 h later with marine air invasion the scene would have appeared entirely different.

From the IR imagery and ground truth data, it is concluded that:

1) The overall brightness trend in Fig. 1 results from a local air circulation pattern, which causes crowns to be immersed in air of different temperatures.

2) Brightness texture is related to the canopy top geometry and the vertical profile of air temperature.

3) The brightness trends and textures in Fig. 1 are subject to rapid changes with meteorological conditions.

These conclusions are consistent with those of Balick and Wilson (1980) for a sparse canopy at Los Alamos, NM. Brightness variations of canopies which are responses to micrometeorological conditions must be considered in interpreting nighttime thermal IR imagery. Although these influences may inhibit some applications of thermal IR remote sensing, the potential for using imagery to infer nocturnal air circulation patterns in complex terrain is evident.

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