AREAL DETERMINATION OF THE INFLUENCE OF A FOREST CANOPY ON THE SURFACE RADIANT ENERGY EXCHANGE

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By

Barbara Marks [1] and Danny Marks [2]

Introduction

To accurately model radiation exchange at a snow surface over a large area, the influence of a vegetation canopy must be considered. A vegetation canopy modifies the amount of beam and diffuse radiation reaching a surface. Price and Dunne (1976) found that for the same amount of solar radiation, net radiation was greater at a partially forested site than at an open site. This increase was due, in part, to the addition of thermal radiation emitted by the canopy. Reifsnyder and Lull (1965) demonstrated that the density and distribution of canopy foliage influences the net radiation reaching the surface. A dense stand of trees absorbs virtually all the incident beam solar radiation it receives. The radiation reaching the surface is primarily diffuse solar radiation and thermal radiation emitted by the canopy. As canopy cover decreases more solar radiation reaches the surface and the combined energy input to a snow surface is increased.

The increase in radiant energy within a partially forested site is magnified by a decrease in turbulent exchange. Trees reduce the surface wind velocity and increase the roughness length reducing heat loss by sensible and latent exchanges. Varying snow depth must also be considered as it controls the amount of vegetation exposed at the surface. As a snowpack thins, more vegetation protrudes and the absorption of solar radiation by the ground and protruding vegetation provides extra energy to the snowpack by conduction and longwave radiation (Price and Dunne, 1976).

To accurately model beam and diffuse radiation reaching the snow surface at a point in a forested area, an estimate of the canopy density is needed. For diffuse radiation studies, a general estimate of the percent of the hemisphere obscured by canopy can be used. However, to calculate beam radiation reaching a surface, a measure of the variation of canopy density with zenith angle is required. Thus, two methods of describing canopy density are under development: one for beam radiation and one fo diffuse radiation. A general factor was developed for use in diffuse solar and thermal radiation models (see Marks and Dozier, 1979) which describes that part of a hemisphere surrounding a point obscured by canopy. Diffuse solar and thermal radiation were treated in the same manner although the effect of canopy is opposite for these two parameters. A dense stand of trees increases diffuse thermal radiation but reduces diffuse solar radiation reaching the surface. Thus, the effect of a canopy cover is to increase thermal radiation transfer and to decrease diffuse solar radiation transfer. A method was developed to express canopy density at various zenith angles for use in beam solar radiation models such as that by Dozier (in press). The effect of snow depth was simulated by obtaining canopy density measurements at selected heights within a forested area.

Extensive point measurements of canopy density over a remote area of highly variable canpy cover are costly in terms of time and money. This study is a preliminary effort to determine the number and type of measurements necessary for an areal estimate of canopy density in a diverse alpine region. After delineating areas of apparent homogeneous canopy cover on aerial photographs, a limited set of point measurements of canopy density have been made with the intent of expanding this procedure to satellite imagery once it is fully developed and tested.

The Study Area

The study area for this research was in the southern Sierra Nevada. This area is of special interest to water resource managers because it provides most of the domestic and agricultural water for central and southern California (Brown and Hannaford, 1979).

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[1] Department of Geography, University of California, Santa Barbara

[2] Computer Systems Laboratory, University of California, Santa Barbara

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The Sierra Nevada are an area of high topographic relief where all possible exposures can be found. Much of the precipitation is orographic in nature as the range acts as a barrier to winter storms coming off the Pacific. The major snow catchment areas are at high elevation with only moderate to sparse forest cover. For this reason the study was limited to areas above 2500 m. The data were collected during summer 1979 in the Mammoth Lakes Basin on the eastern side of the Sierra Nevada. This area was selected because of the ease of access and because of the diversity of forest types and densities within this basin.

Table 1

Tree Species Found in the Study Area

Species	Average Height	Location
Whitebark Pine (Pinus albicaulis)	0.3 to 1.5 m (windswept areas) 6 to 12 m (protected areas)	2400-3700 m dry rocky areas
Limber Pine (Pinus flexilis)	7.5 to 15 m	2300-3500 m eastern slopes
Foxtail Pine (Pinus balfouriana)	6 to 14 m	1800-3500 m dry slopes
Mountain Hemlock (Tsuga mertensiana)	18 to 38 m	1800-3350 m
Western White Pine (Pinus monticola)	up to 46 m	1800-3000 m scattered
Lodgepole Pine (Pinus contorta var. murrayana)	15 to 30 m	1500-3300 m
Red Fir (Abies magnifica)	18 to 55 m	1500-2750 m
White Fir (Abies concolor)	18 to 61 m	1000-2500 m
Jeffery Pine (Pinus jeffreyi)	18 to 55 m	1000-2600 m

(From: Peterson, et al., 1975)

Forest canopies in the study area consist primarily of seven pine and fir species (see Table #1). At lower elevations where snowfall is limited (1500-2000 m) tree cover consists of Ponderosa Pine (Pinus ponderosa) on the more xeric sites and White Fir (Abies concolor) on the more mesic sites. At higher elevations (2000-3000 m) where major snow catchment occurs and tree cover is more sparse, Red Fir (Abies magnificia), Jeffrey Pine (Pinus jeffreyi) and Lodgepole Pine (Pinus contorta spp. murrayana) are found. Several geographically restricted types are found above 2700 m, dominated by Mountain Hemlock (Tsuga mertensiana), and Western White Pine (Pinus monticola). At elevations above 3000 m very sparse stands of Whitebark Pine (Pinus albicaulis), Limber Pine (Pinus flexilis), and Foxtail Pine (Pinus balfouriana) are found. Tree densities are highest in White Fir and Ponderosa Pine forests in the lower areas. In the higher alpine region, tree densities are highest in Red Fir forests. Canopy cover density decreases with elevation becoming very sparse in Foxtail Pine communities (Barbour and Major, 1977).

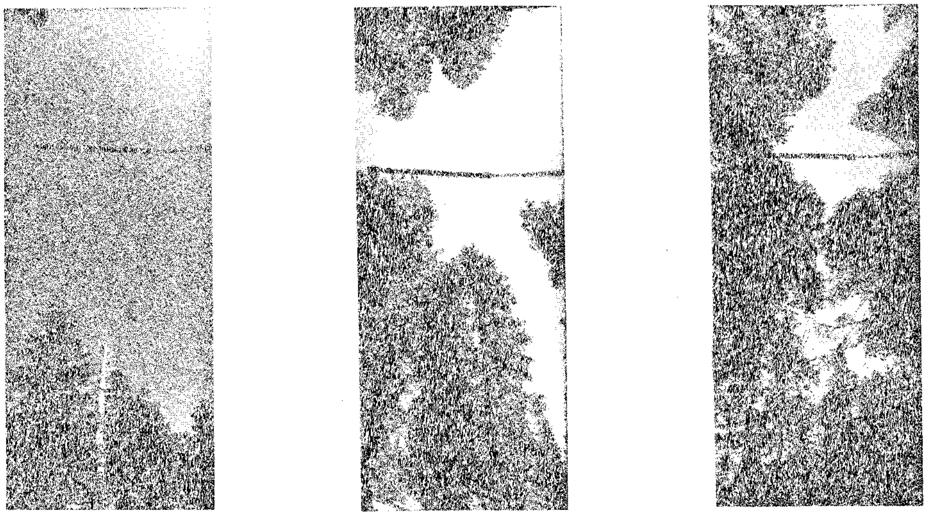
Understory vegetation varies with elevation, light, temperature, moisture, and fire history within the coniferous forests. Generally, understories are denser in lower areas and decrease to virtually no ground cover in the higher alpine region. Understories are virtually non-existent in the greatest snow acculuation zones, and would effect radiation transfer only for very shallow snow covers.

Data Collection

Data requirements for this project consisted of measurements of canopy cover density at selected heights within a canopy. To obtain this measurement, representation of an entire hemisphere surrounding a point was needed. Two photographic systems appeared suitable for this objective: a Widelux F-7 camera or a fish eye lens. The Widelux was chosen over the fish eye lens because the Widelux is a panoramic camera (rotating lens) with a scan of 140 degrees and minimal distortion. Because the film plane is curved, a constant focal length is maintained. Although two photographs are necessary in order to obtain a complete 180 swath, it is easy to ensure horizon to zenith coverage in a single photo. Location of both horizon and zenith is very difficult with a fish eye lens.

To obtain a density measurement, the Widelux was pointed at the sky such that the scan began at the horizon and traveled to fifty degrees past the zenith (see Figure #2). Only the horizon to zenith portion of the image was used in the analysis. Photos were taken in four directions (N, S, E, W) to represent the entire hemisphere.

Aerial photographs of the Mammoth Lakes Basin and vicinity were used to select field sites. Several apparently homogeneous areas of differing densities of forest cover were designated form the aerial photos. Seventeen homogeneous sites were sampled by selecting four points in each and taking a set of widelux photos at these points. The sample points were determined by locating a starting point and drawing two random numbers, one for the direction (N, NE, E, SE, S, SW, W, NW) and one for the number of meters to walk from the starting point (between 50 and 350 meters).



SPARSE MEDIUM DENSE

Figure 1. Three Widelux negatives, from areas of differing canopy densities. Sixteen of these were taken at every sample point.

At each of the four sample sites, Widelux photographs were taken in four directions (N, S, E, and W). This was done to represent the entire hemisphere and so that in later analysis it could be determined if there was any significant canopy density difference between the four directions. When a sample site fell on a slope, photographs were taken upslope, downslope, and across the slope. In this case, the camera was kept horizontally leveled, not perpendicular with the slope, in order to keep a constant zenith angle.

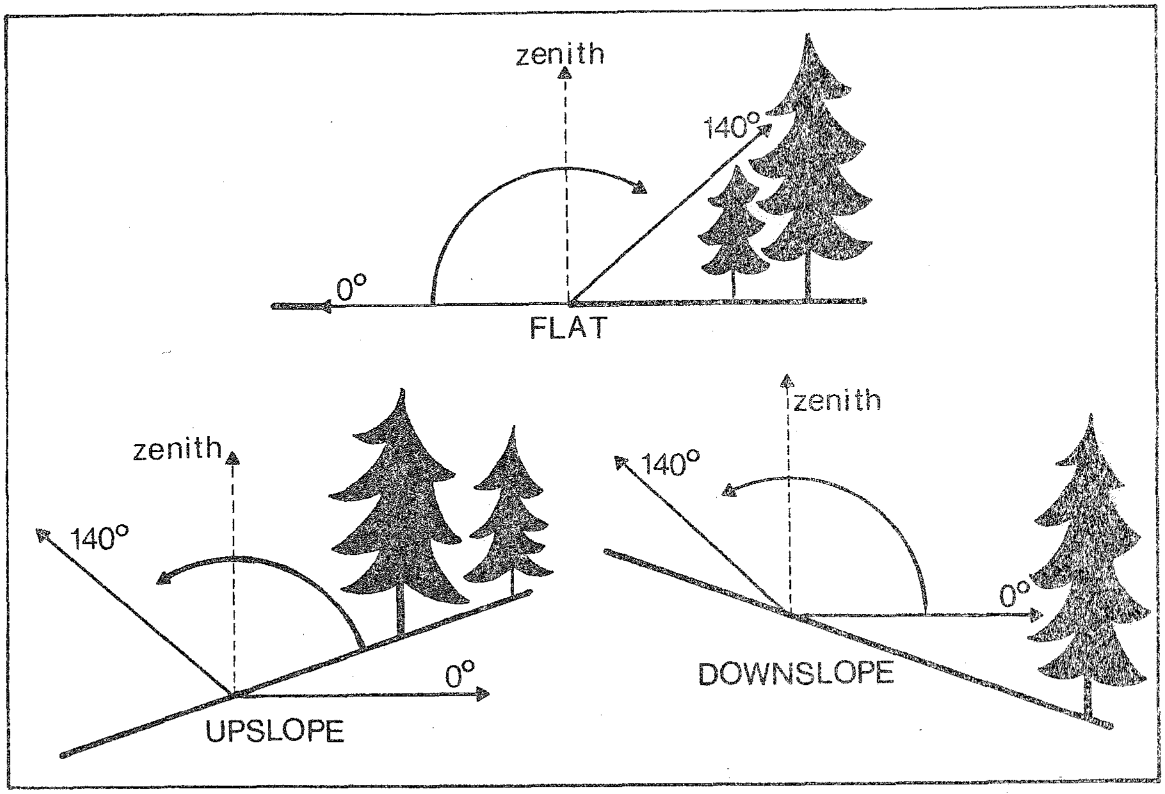
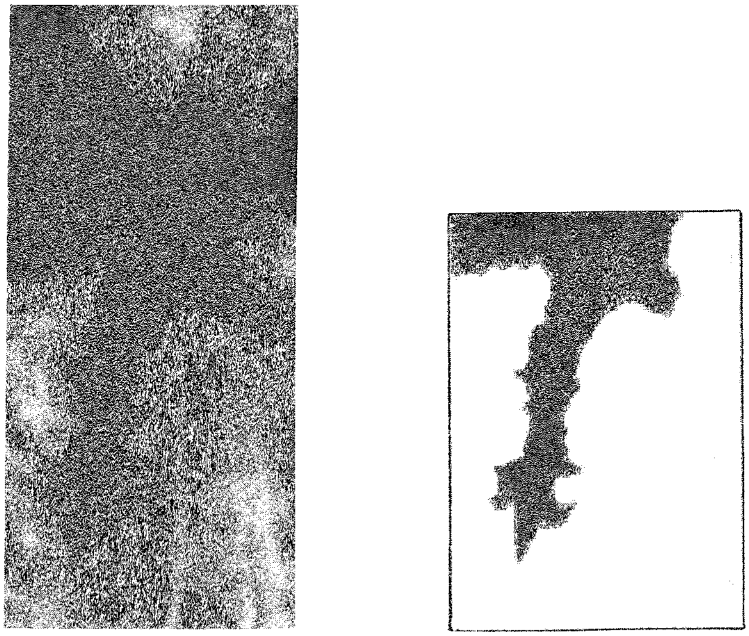


Figure 2. Camera orientation for flat and sloping sample sites.

In addition, photographs were obtained at four heights above the ground (ground, 1 m, 2 m, and 3 m) to simulate the effect of varying snow depth on the density of the vegetative canopy.

Data Analysis

Black and white negatives were prepared for each of the sample points. Each negative was digitized using a Spatial Data Systems Computer Eye. This system's scanner views the negative, samples brightness values, and produces a computer compatible digital image. The digital image was next displayed via a Grinnell Systems Digital Refresh Memory on a Video monitor. Software was devised which enabled the raw Widelux negative to be "digitally trimmed" to a ninety degree portion (from the horizon to the zenith). As images were collected in four directions, four "digitally trimmed" images were produced for each level at a sample site. From this "corrected" image, pixels containing trees and sky were separated based on their radiance, or brightness value. This was done by displaying the "corrected" image on the video monitor and masking out the pixels associated with trees. The radiance value which most closely separated trees from sky was recorded and used in the determination of canopy cover density.



UNCORRECTED WIDELUX IMAGE (full 140°)

CORRECTED AND TRIMMED WIDELUX IMAGE (90° portion)

Figure 3. Raw and corrected digital images of Widelux photos. Note bar in the raw image indicating the zenith.

Overall canopy cover density was expressed at a percentage of the toal number of pixels classified as trees divided by the total number of pixels in the image. This was to indicate the density for that hemisphere. To obtain a measure of canopy cover density by zenith angle, the percentage of pixels in a one degree portion of the image was computed. This was also averaged over the four directions. Rather than store this large data set, a third order equation was derived which describes the relationship of the cosine of the zenith angle and the percent canopy cover. The cosine of the zenith angle is used to linearize the projection of the shading function from a flat plane onto a curved hemisphere.

$$\% \text{ canopy} = 1 + A\cos(z) + B\cos^2(z) + C\cos^3(z) \qquad (1)$$

where:

z = angle from zenith (radians)
A, B, & C = coefficients constrained by:

$(A+B+C) <= -1$ and

if $(A+B) < 0$, then $C = 0$, else $C = -(A+B)$

This equation gives a result which is between 0 and 1, and was found to be the smoothest approximation to data plotted as percent canopy cover vs. cosine of zenith angle. Two restrictions were placed on the equation when a smaple fell on level ground: shading must be 100% at the horizon and zero at the zenith (one pixel). The first restriction was removed when a sample fell on a slope thus allowing the density measure to be less than 100% in the downslope direction. (See Figure #2).

Canopy density was computed at all four heights for each sample point by averaging the density measurements obtained in each direction. Four density measurements were computed for each sample point within a homogeneous site. In addition, canopy density was computed for each of the four directions at each level (16 density measurements for each sample point). This was done so that it could later be statistically determined if there was any significant difference between canopy density and aspect, between density measurements from different heights, and between sample points within a homogeneous area.

An analysis of variance (ANOVA) was performed on the data to determine which factors were most important in explaining the variance in the model. Specific hypotheses about the independent variables were also tested. The dependent variables were the three coefficients produced when canopy cover by zenith angle was computed. The independent variables were: (1) the homogeneous site, (2) the samples taken within the site, (3) the height above the ground the photo was taken, and (4) the direction in which the photo was taken.

Results of the analysis of variance test showed that there was a significant difference between homogeneous areas, between samples taken within each homogeneous area, and with aspect for each sample. In general, there was no significant difference between density measurements obtained at different heights within the canopy. The standard ANOVA F-test was used to reach these conclusions.

Conclusions

The ANOVA results are somewhat surprising. First, they indicate that snow depth is relatively unimportant in deriving measurements of canopy density, except in areas of very sparse tree cover. In these areas canopy density was usually less than 20% and tree heights were under 10 m. This suggests that, for most forested areas, measurements need only be collected at one level within a vegetation canopy. Second, although there was a significant difference found between density measurements and aspect, no one direction proved to be more significant than the others. Therefore, an averaged density measurement over the four directions gives the best estimate of overall canopy density. Thirdly, the significant difference between samples within a homogeneous area indicates that either the chosen areas were not as homogeneous as they appeared on the aerial photos, or that more than four samples per area are required.

It is clear from these results that additional measurements of canopy cover densities are needed to make an areal estimate of canopy density. The delineation of areas of homogeneous canopy needs to be accomplished over large area in a more automated fashion and a larger number of samples must be collected from each area. An approach is being developed which will use LANDSAT imagery to map canopy density over snow in the study area. The canopy density mapping will be done using a "pixel-splitting" algorithm which computes the proportion of trees, rocks and snow for each pixel in a LANDSAT image of an alpine area (Woodcock, Smith, Strahler, 1979). The technique employs a look up table of four dimensions, one for each LANDSAT channel. For each location in the table, a maximum likelihood value will be computed corresponding to each possible combination of the proportion of snow, rocks, and trees in a LANDSAT pixel. The required input data are the means and covariances of the three classes in each of the four LANDSAT channels. Based on its radiance value, a pixel will be assigned to a location in the table which best estimates the amount of trees, rocks, and snow in that pixel. This technique will be tested from satellite data from spring of 1980 when it is available, and data for field verification will be collected during summer of 1980.

In addition to a larger scale sampling of scheme, a detailed set of radiation measurements under canopies of divergent densities will be made to determine the sensitivity of surface radiant transfer to variations in canopy cover. From these data the accuracy necessary in an areal estimate of canopy density can be determined.

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