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PHOTOGRAPHIC MEASUREMENT OF VEGETATION CANOPIES FOR USE IN THE COMPUTATION OF THE RADIATION BALANCE

by

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For many purposes in hydrology, meteorology, and forest ecology, the radiation balance of the forest floor or of some other low-level surface under the canopy must be evaluated. This balance depends upon radiation conditions above the canopy and upon the characteristics of the canopy itself. Radiation in the open can be measured directly, or calculated from empirical relationships. The canopy characteristics vary with the age and species of vegetation, but also from place to place within an assemblage of similar vegetation. It is not possible to sample all the variations with direct measurements of radiation under the canopy. A simple way must therefore be found to measure the canopy characteristics in a fashion that is meaningful for radiation. These characteristics of the vegetation can be related to the measured radiation balance, and it is then quite simple to extend the calculation of the radiation balance by mapping the canopy parameters.

Past Developments

There have been a number of attempts to use photographic equipment to measure the effects of a vegetation canopy on the radiation balance. The amount of radiation reaching the forest floor is a function not only of the vegetation cover but also of the altitude and azimuth of the sun. Thus the technique of measurement must account for variation in the effect of the vegetation canopy over the whole hemisphere.

One commonly used instrument is the pin-hole camera, which produces a projection of the whole hemisphere and may be built quite cheaply. Another device used is a camera which photographs a concave or a convex mirror. They provide good results, and have been used to measure light

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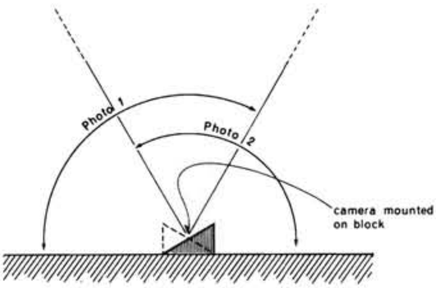
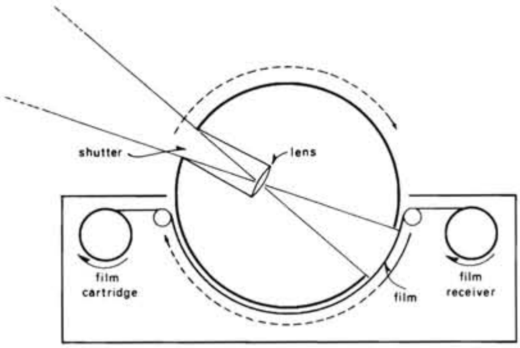
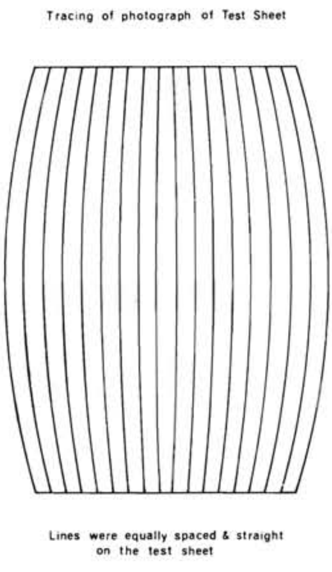


(a)



(c)



(b)

(d)

Fig. 1: Photographic Systems Used:
(a) photographic procedure;
(b) distortion of photograph;
(c) camera mounting;
(d) sample photo of open woodland.

in forests by Monsi and Saeki (1953). Such a camera, however, always appears in the photo, thus obscuring some of the area of the hemisphere. Anderson (1964) describes the use of the Hill camera for taking hemispherical photos of forest canopies of various types. The Hill camera produces a photo of the complete hemisphere as an equal area projection of the hemisphere which is analyzed by using a grid on the photo. Evans and Coombe (1959) have also used the Hill camera for canopy photography. Johnson and Vogel (1968) used a "fish-eye" lens to photograph forest canopies for various purposes. Such a lens only gives a portion of the hemisphere in the view and was used to develop an illumination index.

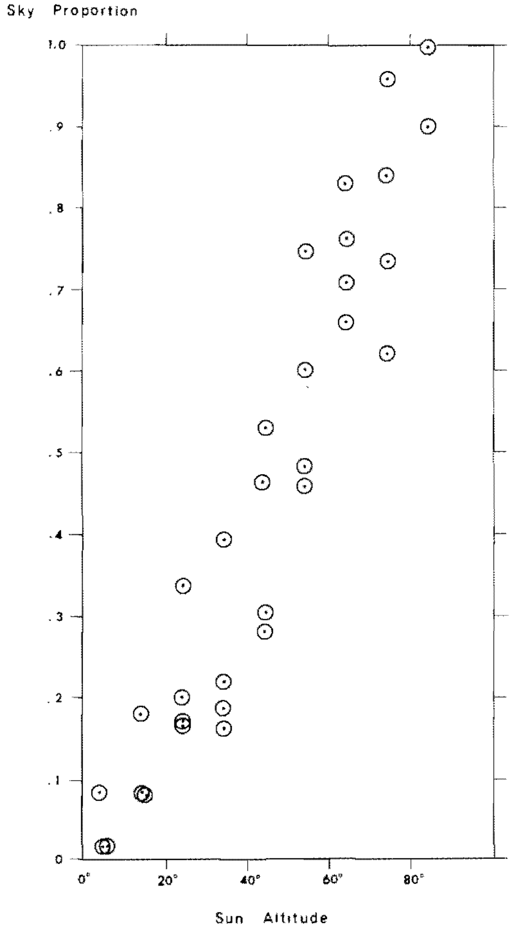
A New Method

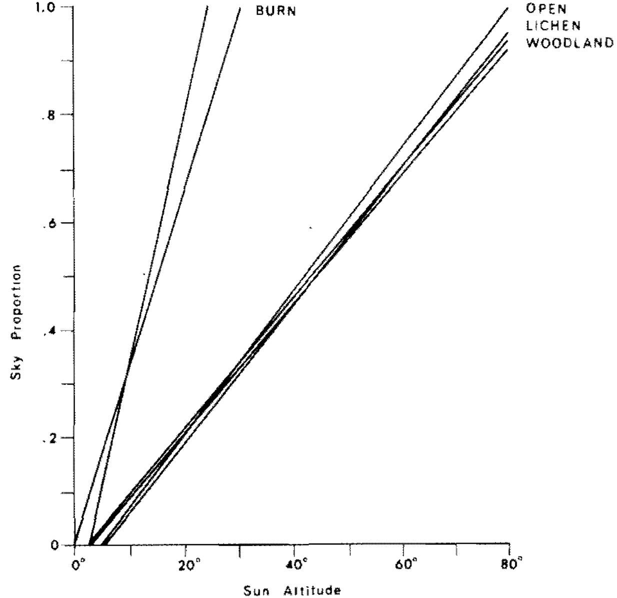
Two major approaches have been taken to the problem of measuring vegetation for the purpose of evaluating the effect of the canopy on the radiation balance. These are measurement by photograph, and measurement of silvicultural parameters of the vegetation (tree height, tree density, breast height trunk girth, percentage of the vertical canopy cover, and others). The method presented below is a photographic technique which gives good estimation of the effect of the vegetation cover on the radiation balance of a surface beneath a canopy.

Measurement may be done with a specialized wide angle camera or with a conventional camera with a wide angle lens. The camera used in the present study is a Russian-made Horizont, panoramic (Zenith) camera, which is capable of photographing an angle of 120 degrees with visible, but acceptably small, distortion.

Figure 1a illustrates the way in which the camera functions. The lens is mounted in a rotation turret which scans 120 degrees. The light beam passing through the lens rotates across the film, which is held tightly against the back plate of the turret. The back plate of the turret has the same radius of curvature as the turret. This scanning provides a near linear image of the portion of the hemisphere seen by the lens. Distortion is at a minimum, as can be seen from Figure 1b. The resulting negative is 6 cm long on 35 mm film.

Since the camera sees only 120 degrees as a maximum, two photos must be taken in order to obtain a complete cross-section of the hemisphere. To achieve this the camera is mounted on a block of wood, which makes an angle of 30 degrees with the horizontal. This inclination allows the camera to see from the ground surface to 120 degrees. The block is then rotated





↑ Fig. 3: Rate of canopy-thinning with altitude under different vegetation.

← Fig. 2: Proportion of sky seen at different angular intervals.

180 degrees, and a second photo is taken from 180 degrees to 60 degrees (Fig. 1c). Several pairs of photographs can be taken in a vegetation unit to obtain an adequate sample from the circumference of the hemisphere. An example of a pair of photographs is shown in Figure 1d.

The procedure described above may be carried out with a camera having a smaller angle of view, but it requires that the block have several angles cut into it so that a cross-section of the hemisphere can be obtained. Alternatively, this could be done by mounting the camera on a short tripod which would allow the camera to be rotated through several angular increments. The prints could then be pieced together.

Analysis of the Photos

Prints of a standard size (in the present case, 12 cm by 7.3 cm) are produced. The print is divided into approximately equal vertical angular intervals representing a small portion of the hemisphere, e.g. 2 degrees, laying a fine grid over the photographs. A point count is taken of the number of points falling on open sky along any one horizontal line of the grid and this number of points is expressed as a decimal fraction of the total number of points on the line. This is the decimal fraction of the sky seen in that angular interval.

In order to characterize the shading properties of the vegetation, the decimal fraction of the sky seen in an interval was plotted against the mean angular distance of the interval from the ground surface. The technique was used in both boreal forest and regenerating burnt areas. For such sites, the proportion of sky on any small portion of the hemisphere is a linear function of angular altitude (Fig. 2) and can be expressed as:

$$s = a + b\gamma \qquad (1)$$

where s = proportion of sky "seen" by the ground in some angular interval;

γ = the mean angular elevation of the interval and ranges from 0 to the angular height of the vegetation;

a,b=emperical constants, characteristic of the vegetation type, especially of its density, height, and shape.

The parameter s indicates the extent to which direct solar radiation can penetrate the canopy when the sun is at a given elevation, γ, less than the angular height of the vegetation. When γ exceeds the angular height of the vegetation, s = 1.00. Alternatively, s may be thought of as the proportion of the time during which the direct solar beam is not intercepted by trees, while it is moving through some small increment of altitude around γ.

The coefficients, a and b, vary with the characteristics of the vegetation. The value of a represents the sun altitude at which the ground is completely shaded from the direct solar beam. It can be thought of as the skyline, or effective horizon for the particular vegetation type. If a is small, for example, the vegetation is open almost down to the ground surface. The value of b represents the rate at which the canopy thins with altitude. In a tall, dense canopy, b is small, whereas in a regenerating burnt area, it is very high (Fig. 3). The sampling characteristics of these a and b values within various boreal forest communities are currently being studied.

It is possible that in other vegetation communities a different relationship between altitude and shading may prevail. For other regions, semilogarithmic or polynomial functions may provide a better fit to field data. In the extreme case, (Reifsnyder and Lull, 1965), in which the vegetation can be described as a solid cylinder, equation (1) would be a step function in which:

$$
\begin{aligned}
s &= 0 \quad \text{for } \gamma < \text{arc tan } 2\ H/D \\
s &= 1.0 \quad \text{for } \gamma > \text{arc tan } 2\ H/D
\end{aligned}
\qquad (2)
$$

where H = average tree height; D = average distance between trees.

The preceding discussion involves the shading effects of the canopy with respect to direct solar radiation. In the energy balance, one must also consider the entry of diffuse solar radiation and the exchanges of longwave radiation between snow surface, trees, and sky. All of these components are non-directional. They occur over the relevant portion of the whole hemisphere.

Diffuse radiation reaches the ground from that portion of the sky not obscured by trees. This sky view factor is obtained by weighting the proportion of sky seen at each angular elevation by the fraction of the total area of hemisphere at that elevation. Thus, the view factor (P) can be defined as:

$$
P = \sum_{\gamma=0}^{80^\circ} s_{\gamma+5^\circ} \int_{\gamma}^{\gamma+10^\circ} \cos\gamma \cdot d\gamma \qquad (3)
$$

which reduces to:

$$P = \sum_{\gamma=0}^{80^\circ} s_{\gamma=5^\circ} \{\sin(\gamma+10^\circ) - \sin(\gamma)\} \qquad (4)$$

for $\gamma = 0^\circ, 10, 20..., 80^\circ$.

When γ is greater than the angular height of the trees, $s_\gamma = 1.0$.

The exchange of longwave radiation between sky and ground surface also takes place over the proportion of the sky represented by P. The exchange of longwave radiation between trees and ground surface occurs over the area (1-P).

A complete radiation balance for a forest floor, therefore, can be expressed as:

$$\{Q(\gamma)s(\gamma) + q(\gamma)P\} \{1 - \alpha(\gamma)\} + L{\downarrow}P + T{\downarrow}(1-P) - S{\uparrow} = N \qquad (5)$$

where $Q(\gamma)$ = direct beam solar radiation, a function of sun altitude;
$S(\gamma)$ = proportion of the sky "seen" by the ground over a small angular interval at the altitude of the sun;
$q(\gamma)$ = diffuse shortwave radiation, a function of sun altitude;
P = view factor;
$\alpha(\gamma)$ = albedo of the snow, a function of sun altitude;
$L{\downarrow}$ = longwave radiation from sky to snow;
$T{\downarrow}$ = longwave radiation from trees to snow;
$S{\uparrow}$ = longwave radiation from snow to atmosphere and trees;
N = net radiation at the forest floor, snow pack surface, or other elevation beneath the canopy.

It is possible to write a similar equation for any other level under the canopy, such as the top of a shrub layer.

The technique described has been used to calculate the energy balance of the snow pack in a boreal forest. There may be other applications, such as calculating the growing season input of radiation to the under storey vegetation on a forest floor. Other uses can be envisaged in forestry. In areas where forest vegetation is being removed, the increased insolation received by streams causes an important increase in the water temperature. To predict this increased temperature, energy balance calculations are used (Brown, 1970). One way of reducing or eliminating the change is to leave buffer zones of vegetation along the stream channel. There is some problem in deciding how wide the buffer zone should be, and which kind of vegetation will shade a stream of a given width and general orientation in a certain latitude. The photographic technique that has been discussed here permits a modification of the energy balance to incorporate the effects of these variables, thus allowing design calculations to be made from some simple photographic measurements.

Acknowledgements

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