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# CANOPY ALBEDO AND TRANSMITTANCE IN A BOREAL FOREST

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## ABSTRACT

The shortwave radiation balance of a forest stand of predominately spruce and hemlock in central Maine was investigated. Pyranometer measurements of insolation, reflected solar radiation from the top of the canopy, radiation incident on the forest floor, and radiation reflected from the forest floor were taken under both cloudless sky conditions and overcast cloud conditions. Measurements were made on consecutive days; insuring minimal change in forest canopy characteristics. The canopy albedo computed from half-day radiation totals, thus representative of a daily value, was 10.8% on the clear day and 9.8% on the overcast day. The instantaneous albedo on the clear day ranged from 8.7% at 43° solar zenith angle (solar noon) to 20.1% at 78° solar zenith angle, while on the overcast day the albedo was relatively constant due to the diffuse irradiance condition. Canopy transmittance for the daily period was 2.9% on the clear day and 4.2% on the overcast day. The canopy transmittance was nearly constant throughout the day on the overcast day at about 4.2% while sunfleck penetration on the clear day resulted in a higher transmittance of 4.5% from 43-47° solar zenith angles, that dropped to 1.8% at 68-72° solar zenith angles. Thus over the entire day, for the range of solar zenith angles measured, diffuse radiation on the overcast day penetrated further down into the forest canopy than the predominately direct radiation on the clear day. Keywords: albedo, transmittance, forest, pyranometer.

## INTRODUCTION

Knowledge of the shortwave solar energy balance of vegetation canopies is of interest for ecological, climatological, and remote sensing studies. For studies of forests, the transmission of solar radiation through the canopy is important for analysis of the energy storage in vegetation and soils, photosynthesis of vegetation at the forest floor, snowmelt rates, and the thawing of frozen soil. These factors in conjunction with other influences affect the forest productivity and growth by influencing the cycling of nutrients and the successional stages of vegetation species. Transmission through coniferous forest canopies has been shown to be related to crown closure of the stand and various indices of stand density (Vales and Bunnell, [1]) and to be influenced by cloud cover (Vezina and Pech, [2]).

The albedo of the forest canopy is an important parameter for studies of the local and regional climatological influences of the earth's surface. The foliage of tree canopies is clumped in tree crowns, with organized peaks and depressions in the canopy surface, resulting in much of the incident solar radiation penetrating below the canopy top before its initial reflection (Shuttleworth, [3]). This results in enhanced capture of solar radiation and therefore low albedo. The albedo of forest canopies has been shown to be influenced by sun angle, cloud cover, and season of the year (Stewart [4]), McCaughey [5], Pinker et al. [6]).

In this study we present measurements of the forest canopy albedo and transmittance, and forest floor albedo of a predominately spruce-hemlock forest. These measurements were made in conjunction with simultaneous aircraft overflights of the same site, with the objec-

tive of utilizing these remotely sensed measurements to estimate parameters of the forest canopy, such as the albedo.

## EXPERIMENT SITE AND INSTRUMENTATION

The experiment was conducted at the International Paper Company's Northern Experimental Forest in Howland, Maine. The forest in the vicinity of a meteorological tower (45° 21.21'N, 68° 44.49'W), which was established and is maintained by the University of Maine at Orono, is predominately spruce and hemlock, (92% by stem count) with some white pine and red maple (Nelson, [7]). The average height of all of the trees at a representative site 25m WNW of the tower was 14.5m. The number of trees per hectare, the diameter at breast height, tree height, and basal area for each species are given in Table 1 (Nelson [7]).

Table. 1. Description of site located 25m WNW of Howland, ME meteorological tower.

Species	No. of Trees per Ha.	Spp. by %; Trees per Ha.	Dia. at Breast Ht. (cm.)	Tree Ht. (m)	Basal Area (m <sup>2</sup> /ha)
Spruce	877.5	71.4%	16.2	14.7	20.7
Hem-lock	255.3	20.8%	19.2	12.8	9.2
Wh. Pine	62.1	5.0%	29.7	17.9	4.6
Red Maple	34.3	2.8%	29.2	16.8	2.3
PLOT	1229.2	—	17.9	14.5	36.7

The approximate age of the co-dominant trees in this stand was determined from corings to be 70 years.

Measurements of forest canopy albedo were made with upward and downward viewing Eppley PSP pyranometers mounted on a boom extending 2.4m west from the tower's topmost rail. The measurement of the downwelling solar radiation at the forest floor was made with an Eppley 8-48 black-and-white pyranometer mounted about 1m above the ground. The ground surface was free of undergrowth and was covered with needle litter and moss. A companion Eppley 8-48 pyranometer was mounted facing downward beneath the upward facing unit on a boom which was 2m from the supporting tripod. This pair of pyranometers was used to calculate the forest floor albedo. The site of these undercanopy pyranometers was approximately 40m SSE of the meteorological tower. Both types of the Eppley pyranometers measure global solar radiation in the spectral range 0.3 - 3.0  $\mu$ m. All four pyranometers recorded instantaneous measurements in digital form at one minute intervals on automatic data loggers.

The pyranometers used in this study were inter-calibrated against a reference instrument by exposing all instruments upward facing on a clear, cloudless day. Calibration coefficients were then computed for all instruments so that radiances were equal to the reference instrument values. The instrument that was used as the reference instrument was calibrated at the Eppley Laboratory shortly after the field experiment.

#### WEATHER CONDITIONS

Measurements were taken during both cloudless and completely cloudy overcast sky conditions. These two days were consecutive, September 18-19, 1989, and thus changes in forest canopy characteristics were minimized. The total insolation for both days, as a function of time, is shown in Figure 1. On September 18, 1989 there were three time periods of cloudless conditions (~930-1130 LOCAL STANDARD TIME (LST); 1430-1500 LST; 1530-1630 LST). Cumulus clouds developed and dissipated during the other periods of the day, obscuring the sun at times, resulting in minimum value spikes. On September 19, 1989 there was continuous overcast sky conditions with clouds of varying thickness resulting in variable insolation. The sun was obscured throughout the day, however, thus resulting in completely diffuse or mostly diffuse insolation. The cloud transmission, computed as the ratio of the overcast sky insolation on September 19 to the periods of clear sky insolation on September 18 for the same solar zenith angles, varied from about 0.25 to 0.70. The aerosol optical depth was inferred from sunphotometer measurements on September 18. At 522nm the aerosol optical depth ranged from about 0.19 to 0.13, with the highest values occurring near noon and the lowest values from 1530-1630 LST.

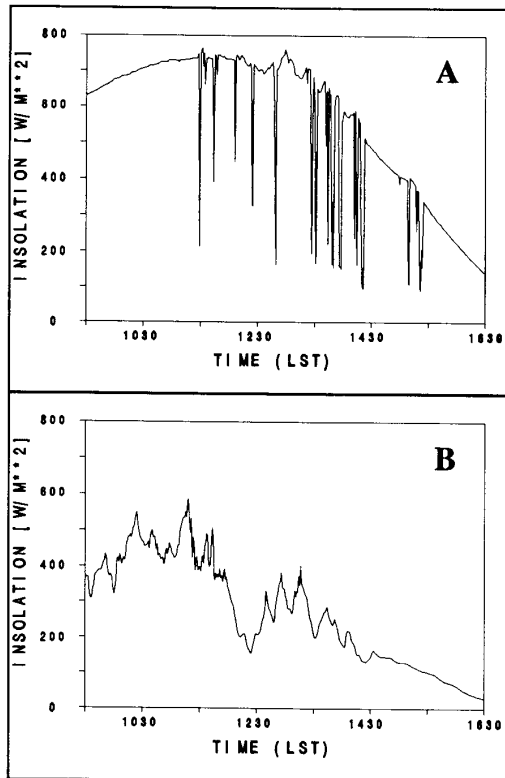


Figure 1. Total insolation measured on (a) September 18 and (b) September 19, 1989 at the Howland, Maine tower site.

#### RESULTS AND DISCUSSION

##### CANOPY ALBEDO

The values of canopy albedo on the clear day (September 18) for periods when the sun was not obscured by clouds is shown in Figure 2a. The albedo during some of the periods when clouds were present, but with the sun unobscured, differs somewhat from cloudless sky albedo but these differences are considered to be insignificant. In Table 2 the canopy albedo values are averaged over solar zenith angle ranges from both the clear and overcast days. The solar zenith angle at solar noon was 43°.

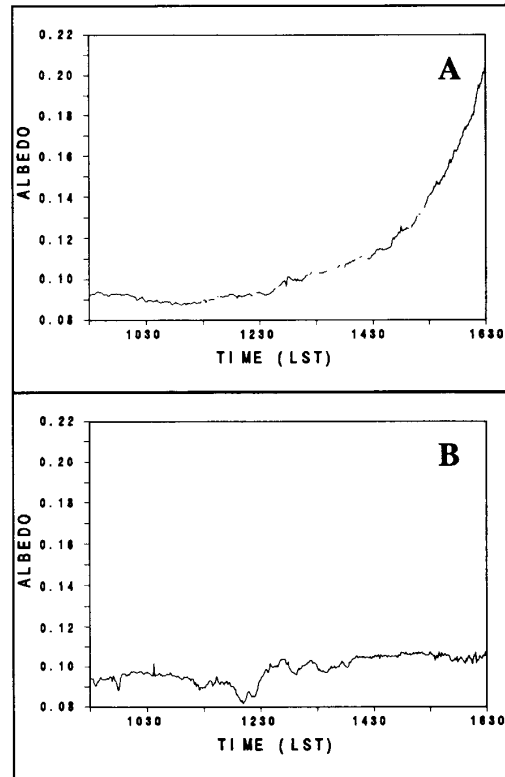


Figure 2. Instantaneous forest canopy albedos on (a) the clear day (September 18) for periods when the sun was unobscured by clouds and (b) the overcast day (September 19).

Table 2. Forest canopy albedo for clear and overcast sky conditions.

Solar Zenith Angle Range	Avg. Albedo CLEAR (%)	Avg. Albedo OVERCAST (%)
43° - 47°	9.2	9.2
53° - 57°	10.8	10.2
63° - 67°	12.6	10.7
73° - 77°	17.6	10.4

The trend of increasing forest canopy albedo with increasing solar zenith angle on a clear day has been observed in pine forests by Stewart [4], tropical evergreen forests by Pinker et al. [6], and

mixed boreal forest of both deciduous and coniferous species by McCaughey [5]. The albedo we measured at the Howland tower spruce-hemlock site ranged from 9.2% at the solar zenith angle range of 43-47° to 17.6% from 73-77° solar zenith angle. Stewart [4] measured albedo ranging from 8.7% to 13.0% for a pine forest for a similar solar zenith angle range on clear days and Pinker [8] measured values ranging from about 11.5% to 18.3% for these sun angles in the tropical rain forest.

The lower albedo at lower solar zenith angles for these forest canopies is due to the further penetration of radiation into the forest canopy resulting in increased absorption and scattering below the canopy top. At the larger solar zenith angles, the incident solar radiation does not penetrate as far down into the gaps in the canopy, thus reducing the probability of absorption from multiple scattering.

The instantaneous albedo values for the same site for the overcast day, September 19, is shown in Figure 2b. Since the sun was obscured by clouds, resulting in diffuse irradiance, there is essentially no trend of the albedo with time or solar zenith angle. There is however a notable decrease in albedo from 1200-1230 LST which corresponds to a decrease in insolation (Figure 1) and low cloud transmittance (~25%). Possibly a spectral change occurred in the insolation due to cloud absorption of near infrared radiation resulted in this decrease in albedo. The constancy of albedo with solar zenith angle under cloudy conditions has also been found for other forest canopies ([4], [5], [6]).

An albedo value representative of the entire day from 43° solar zenith angle (solar noon) to 78° solar zenith angle was computed as the sum of the radiation reflected by the forest canopy divided by the sum of the insolation over this time period. For the clear day this all-day-insolation-weighted value of albedo was 10.8%, while for the overcast days the albedo was 9.8%. Therefore, even though the albedo on the clear day was much higher than the cloudy day at the larger solar zenith angles, the insolation amount is low at these sun angles resulting in only a 1% higher albedo on the clear versus the overcast day.

#### CANOPY TRANSMITTANCE

The transmission of total global solar radiation by the forest canopy was computed from the one minute instantaneous pyranometer measurements as the ratio of the downwelling radiation underneath the canopy (at 1m height; ~40m SSE of the tower) to the downwelling insolation at the top of the tower (above the canopy). The canopy transmittance for the cloudless periods on September 18, 1989 is shown in Figure 3a, and the canopy transmittance for the overcast day (September 19, 1989) is shown in Figure 3b.

For the cloudless periods on the clear day, it is noted that there is some sunfleck transmission at the lower solar zenith angles, 43-47°, with maximum values of about 15%. These sunflecks do not reach 100% transmission since the gaps in the canopy had an apparent angular diameter of less than one-half degree which is the apparent diameter of the solar disk. The diffuse component of the transmitted insolation (at times when there are not sunfleck maximum spikes, Figure 3a) is relatively stable on the clear day, ranging from about 2.5% at 43-47° solar zenith angle to about 1.8% at 68-72° solar zenith angle. This diffuse component results from a combination of penetrating diffuse sky radiance, reflected direct beam, and reflected diffuse sky radiance. It is noted that the transmittance on the cloudy day is higher than on the clear day for all times except for sunfleck occurrence. The penetrating and reflected diffuse sky radiance are the only components of the transmitted radiation on the overcast day since there is no reflected direct beam on the overcast day.

Since some sunflecks move as the solar zenith angle changes, time averaging of transmission at one pyranometer location results in a reduction in the error due to the spatial variability of the radiation transmitted to the forest floor. Gay et al. [9] found for a pine forest that averaging the measurements of a single pyranometer over a one hour period reduced the average deviations of global

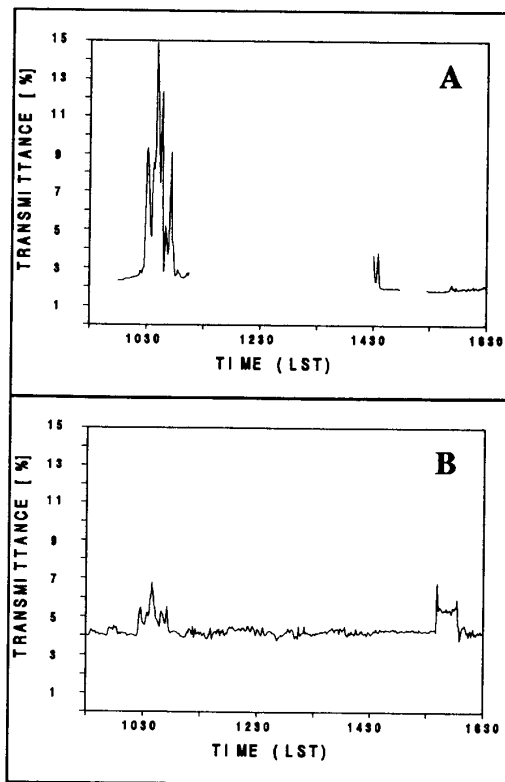


Figure 3. Canopy transmittance for the cloudless periods on September 18 (a) and for the overcast day on September 19 (b).

Table 3. Forest canopy transmittance for clear and overcast sky conditions.

CLEAR (9/18)		OVERCAST (9/19)	
Solar Zen. Ang. Range	Avg. Trans. (%)	Solar Zen. Ang. Range	Avg. Trans. (%)
43° - 47°	4.5	44° - 47°	4.2
59° - 63°	2.2	59° - 63°	4.3
68° - 72°	1.8	68° - 70°	4.3
72° - 76°	1.9	70° - 74°	5.4
		76° - 79°	4.2

radiation on the forest floor by a factor of 2-3. They concluded that mean forest floor radiation was characterized equally well by averaging the simultaneous measurements of five pyranometers or by averaging 5 minute interval measurements by one instrument over an hour period.

We have computed the time averaged transmission for both the clear and overcast days in order to reduce the error due to spatial variability (Table 3). It is observed that the time averaged transmittance near solar noon (43-47°) is only slightly higher for the clear sky condition than for the overcast condition. On the overcast day, the under canopy pyranometer was physically moved from its regular location to an area about 5m north of the tower from 1542-1601 LST

and then moved back again. The time averaged canopy transmittance at this site was measured as 5.4% which is about 1.1% (absolute) higher than the original site due to differences in the canopy geometry and/or density at these two locations.

Canopy transmittance was also computed for the all-day period, encompassing the range of 43-78° solar zenith angles, from the sums of the radiation measured over these time periods. The all-day transmission on the clear day, computed from measurements when the sun was unobscured by clouds, was 2.9%, while the all-day value on the overcast day was 4.2%. Vezina and Pech [2] found the canopy transmittance to be higher on overcast days than clear days for three difference densities of balsam fir stands in Quebec.

The values of transmission which were measured for our spruce-hemlock study site for both clear and overcast conditions fall within the range of  $5 \pm 4\%$  given by Jarvis and Leverenz [10] as typical of temperate forests during summer. Vales and Bunnell [1] measured transmittance ranging from 3-57% for 12 plots of predominantly Douglas fir-western hemlock of varying stand density and structure. Vales and Bunnell [1] computed non-linear regression relationships between global radiation transmission, computed from the average daily sums of radiation on clear days, and different measures of forest stand density. Their regression equation relating global transmittance to the sum of diameters at breast height of plot trees  $\leq 8\text{cm}$  diameter ( $\text{mm}/225\text{m}^2$ ) was applied to our study site using the stand data in Table 1. The Vales and Bunnell [1] regressions yielded a transmittance of 5.5% for our study site (standard error of estimate = 8.7%) using their wet coastal western hemlock relationship. Their regressions were computed from clear sky days with an average solar noon zenith angle of 32° compared to 43° at solar noon for our measurements, which could account for the somewhat higher transmittance predicted by their regressions.

#### FOREST FLOOR ALBEDO

The albedo of the forest floor was measured by the upward and downward viewing pyranometers located 1m above the ground surface. There was a wide variation in forest floor albedo on the clear day ranging from 7% to 36% with the low values occurring during sunfleck penetration. For the periods when the sun was unobscured by clouds, the mean forest floor albedo was 18.5%. On the overcast day the instantaneous forest floor albedo ranged from 4% to 29% with a time averaged value of 19.1%.

#### SHORTWAVE ENERGY ABSORPTION BY CANOPY AND GROUND

The all day values of forest canopy albedo, canopy transmittance, and forest floor albedo are summarized in Table 4 for both clear and overcast conditions. These values are representative of the period from solar zenith

Table 4. Albedo and transmittance values computed from half-day radiation totals, which are used to compute the absorption of solar radiation by the canopy and ground.

	9/18/89	9/19/89
Canopy Albedo	10.8 %	9.8%
Canopy Transmittance	2.9 %	4.2%
Forest Floor Albedo	18.5 %	19.1 %
<u>Absorbed by:</u>		
Canopy and Ground	89.2%	90.2%
Ground Only	2.4 %	3.4%
Canopy Only	86.8%	86.8%

angles of 43° to 78° and are computed from the sums of radiation measured over this time period. The amount of energy absorbed by the canopy and ground have been computed using these parameters and are also given in Table 4.

The absorption of solar radiation by the ground surface, computed from the canopy transmission and forest floor albedo varied from 3.4% on the overcast day to 2.4% on the clear day. This 1% higher ground absorption on the overcast day is due to increased canopy transmission to the forest floor on the overcast day. The higher percentage ground absorption during overcast conditions offsets the 1% higher ground plus canopy absorption, which is due to the lower canopy albedo on the overcast day. The result is that the percentage total energy incident which is absorbed by the canopy (leaves, branches, boles) is the same for the overcast and clear days. These relationships may not hold for smaller solar zenith angles (mid-summer) when direct beam penetration to the forest floor may be greater.

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