ALBEDO OF SIMULATED SNOW SURFACES RELATED TO ROUGHNESS

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ABSTRACT

A 12-foot square model forest was constructed of inverted conical paper cups and pipe cleaners inserted into styrofoam. Artificial snow was sprayed onto the model to simulate intercepted snow on a forest canopy. Reflected solar radiation measurements were taken over the model as "crown closure" was reduced in a random block pattern from 100% to 10%. Albedo was found to increase from about 0.66 to 0.88 as the density of the model forest was decreased.

INTRODUCTION

Over most of the Province of New Brunswick and the Saint John River basin one-quarter to one-third of the total precipitation occurs as snow, and spring snowmelt accounts for well over one-half of the annual streamflow. The winter snowpack lies partly in open fields, partly beneath forest stands, and partly retained in forest canopies. The latter portion is never large in a relative sense, but is of some consequence in this region which is more than 85% forested.

Solar radiation is the prime source of energy for snowmelt and evaporation. Measurement of effective solar radiation at the canopy surface should help determine melt rates as well as the magnitude of water losses from snow interception. One of the major factors needed in these determinations is the surface albedo, that proportion of incoming solar radiation reflected back to space, which is unavailable for use in the melting and evaporation processes.

Snow is one of the most efficient surfaces for reflecting solar radiation. Values of reflectivity (albedo) for newly-fallen snow range as high as 0.95 (Geiger, 1965). Miller (1955) found that the albedo of one-day-old snow varied little, averaging 0.84 with a standard deviation of only 0.03. Leonard and Eschner (1968), by contrast, obtained strikingly different results when they measured albedoes for intercepted snow in a conifer canopy. In these instances the values were nearly all below 0.15 (Figure 1). They attributed this anomaly to the "porosity, depth and opportunity for repeated absorption of the reflected radiation."

Replication of Leonard and Eschner's investigation over natural stands, particularly if a range of crown closures were to be explored, would be a costly undertaking. The investigation reported in this paper used a small scale physical model of a forest, thereby enabling "crown closure", or model density, to be varied with reasonable ease in order to evaluate the effect of its variation on albedo.

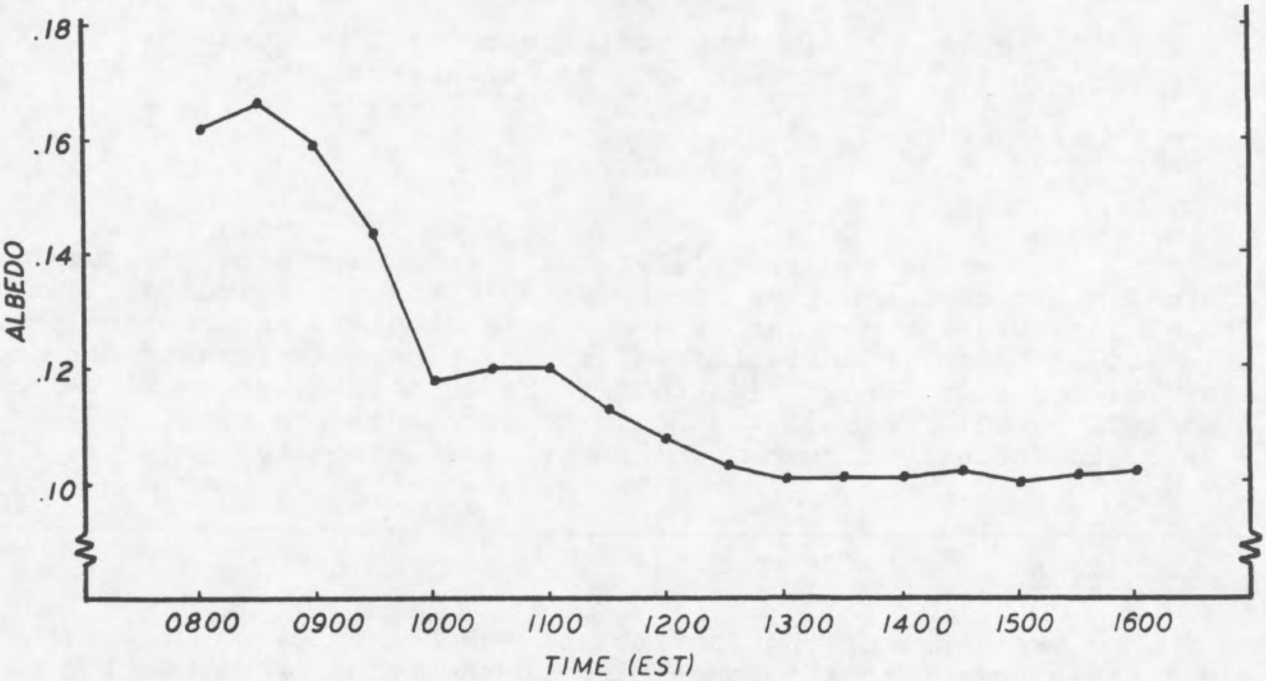

Figure 1. Diurnal changes in albedo of a snow-covered canopy on a clear day. February 27, 1966. (Leonard and Eschner, 1968)

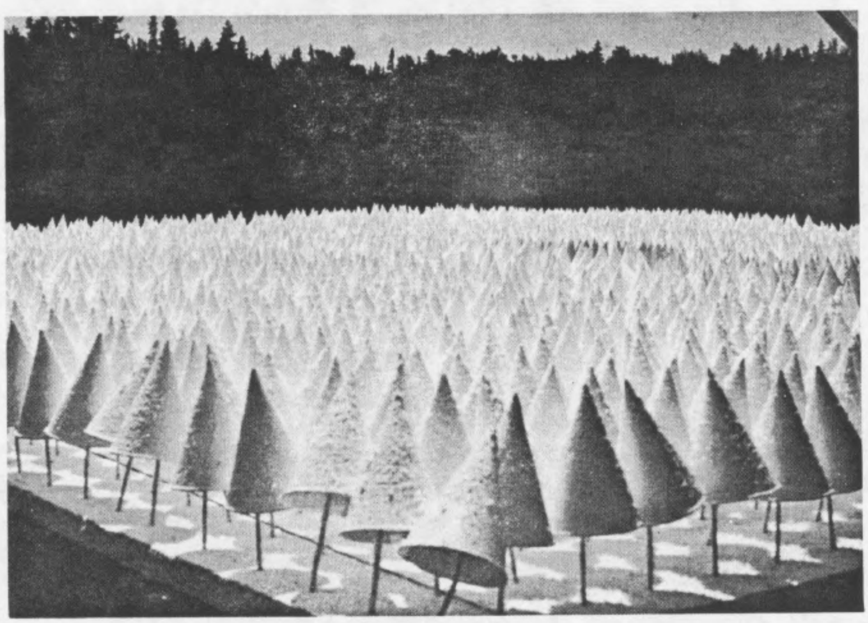

Figure 2. Photograph of snow-covered model forest

METHODS AND PROCEDURES

The model consisted of nine four-foot square sections of one-inch styrofoam, implanted with 3000 "trees" constructed of conical paper cups and pipe cleaners (Figure 2). The sections were arranged into a 12-foot square "forest" on a wooden frame at four feet above ground, thus providing a working space beneath the model. The framework was sheathed with plastic sheeting and served as a storage area for the model sections between observation days. Artificial decorating snow was sprayed onto the model to simulate a snow surface.

Reflected solar radiation was measured by an inverted Moll-Gorzynski solarimeter mounted about one foot above the canopy surface, giving a view factor of about 0.9. Measurements of incoming radiation were taken with a similar instrument located about 50 yards away.

Measurements were taken over the period late July 1970 to late September 1970, on days when weather conditions were suitable. Insofar as possible sunny days were selected, and measurements taken only between 1000 AST and 1400 AST. Difficulties due to rainfall, which was double normal during August 1970, and the problems of handling the light styrofoam sections during windy periods, extended the measurement period considerably.

Measurements were taken over 100% model density for three days with various ages of snow cover. Thereafter the density was reduced randomly within each block and measurements taken at 90%, 80% etc. closures. The 10% level was reached on September 20th. Reflected radiation was measured continuously for about 10 minutes each hour, and comparative readings of incoming radiation noted every few minutes from a separate continuous record.

There was some concern that the albedo of the model stand would be affected by the coverage and freshness of the artificial snow. Observations were made prior to and following coverage, and for fresh and four-day-old snow. The results, as demonstrated by Table 1, showed no significant effects of snow condition, which was not surprising since the styrofoam base and paper cups were also white.

Table 1. Comparative albedoes of full model density for various coverages and ages of artificial snow

Coverage (%)	0	0	60	100	100	100
Age of coverage (days)	N/A	N/A	0	1	4	0
No. of readings	24	13	21	31	30	19
Average albedo	.647	.656	.663	.645	.670	.667

The quality of the coverage was therefore dismissed as a source of error. Throughout the remainder of the measurement period artificial snow was added only to replenish that lost by wind and handling, principally to maintain a degree of realism.

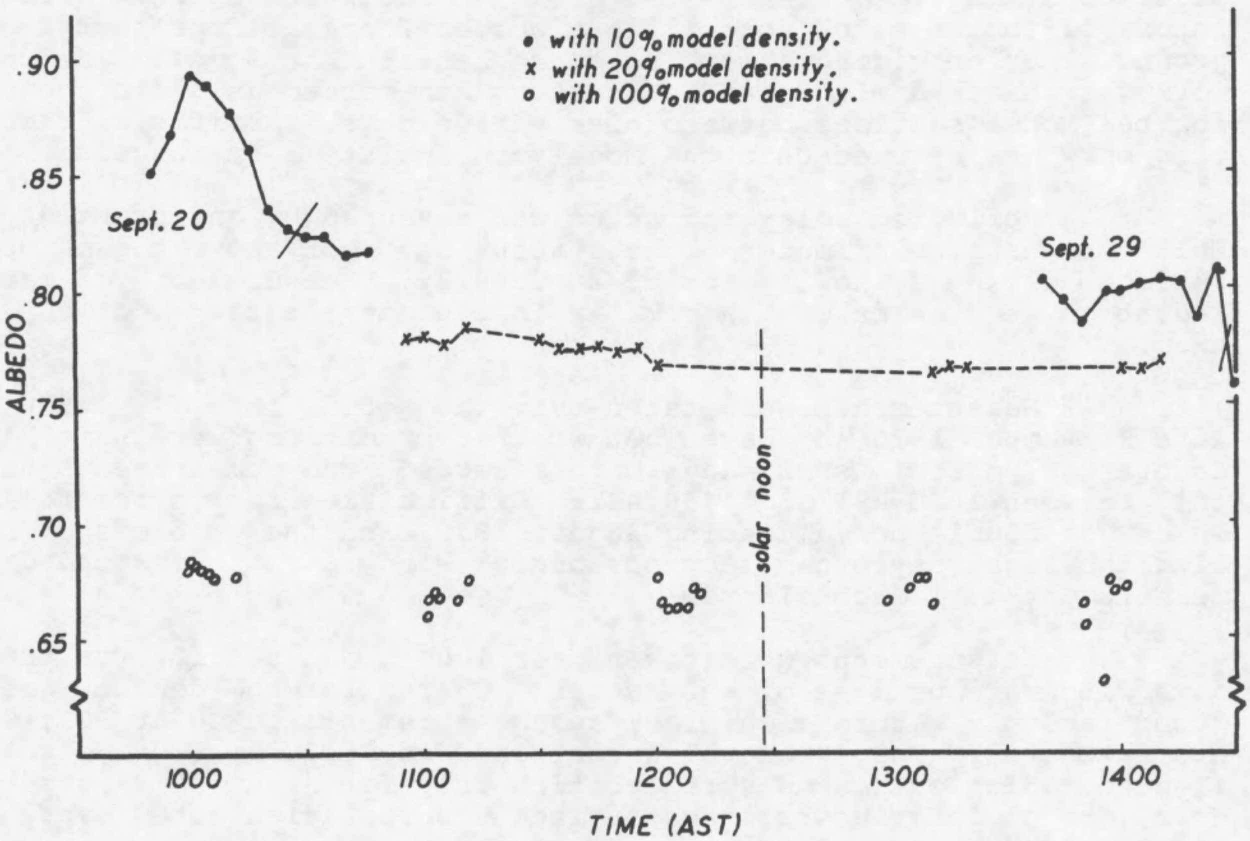

Figure 3. Variation of albedo with time of day

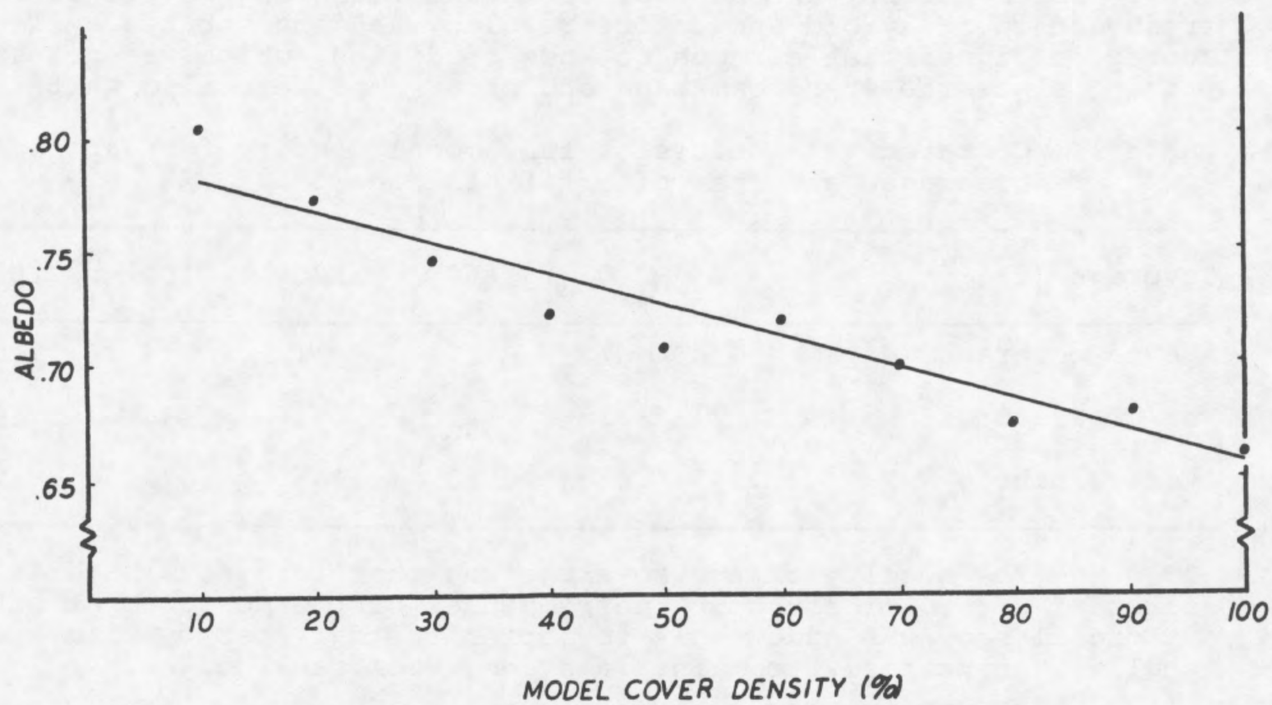

Figure 4. Variation of albedo with model density

RESULTS AND DISCUSSION

Measurements had been confined to mid-day periods in order to avoid low solar angles, which were found by Leonard and Eschner (1968) to produce higher albedoes. The period selected resulted in no apparent difference due to time of day, except late in the season. Measurements taken on September 20th showed evidence of unrepresentatively high values at the beginning of the measurement period (Figure 3). Readings within two hours of solar noon appeared stable, therefore only those were used in the remainder of the analysis.

Average albedoes from the data thus selected were then calculated for each model density level. These are shown in Table 2.

Table 2. Average albedoes at various model density levels

Density (%)	Number of observations	Average albedo
100	80	.660
90	26	.679
80	29	.676
70	9	.699
60	15	.718
50	10	.707
40	16	.721
30	9	.747
20	17	.773
10	14	.804

Analysis of the relationship between albedo and model density by linear regression (Figure 4) resulted in the following equation.

$$\text{Albedo} = 0.7968 - 0.001433\, D$$

where D is the model density in percent.

The results of this experiment demonstrate rather convincingly that albedo is not only a feature of a material but also a function of the roughness of its surface. Albedo at maximum "crown closure" remained well above the values obtained by Leonard and Eschner (1968), but this is not interpreted as a conflict in results. The paper cups provided only "primary" roughness, since each cup has a smooth surface -- unlike a forest which has several orders of roughness.

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