AIRFLOW PATTERNS AND SNOW ACCUMULATION IN A FOREST CLEARING [1]

By

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Introduction

Numerous studies in the lodgepole pine type in Colorado and Wyoming have shown that snow accumulation is greater in openings in the forest than beneath the unbroken stand (Berndt 1965, Gary 1974, Hoover and Leaf 1967, Niederhof and Dunford 1942, and Wilm and Collet 1940). In the earliest of these studies, the greater quantity of snow in openings was attributed to eliminating interception of snow by tree crowns and subsequent loss of the intercepted snow by evaporation. The case for snow interception has persisted until recent years mainly because snow quantities in openings and clearings have usually been compared to those under forest cover several to many tree-heights beyond the clearing (Sartz and Trimble 1956, Rothacher 1965).

In 1959, Anderson and Gleason discounted the magnitude of interception effects; they believe the greater amounts of snow in openings and clearings in forests are in effect "stolen" from the forest to the leeward of clearings. It now appears they correctly concluded that snow accumulation in clearings as well as that in the adjacent forest must be taken as a whole when determining the effects of clearings.

In the present study, where the entire zone of influence surrounding the study clearing was surveyed, a clearing 1 tree-height wide by 5 tree-heights long affected the snow accumulation pattern but not the total quantity of snow in the area. The study also demonstrated that increased snow depths in clearings must be weighed against decreased snow depths in the adjacent downwind forest in order to evaluate effects on snow accumulation and melt (Gary 1974). The snow accumulation pattern was most likely the result of airflow. The observations reported in this paper are among the few that allow a relatively good comparison of the airflow pattern and the snow accumulation profile in a forest clearing.

Study Area

The study area, about 1.3 km southeast of Foxpark in southern Wyoming, is about 2,743 meters above sea level and on top of a gently rolling plateau well exposed to prevailing southwesterly winds. Slopes in the immediate area average less than 5 percent. The forest stand is 80-year-old lodgepole pine with an average d.b.h. of 5.4 inches (13.7 cm) and average height of 10.8 m. Tree spacing is about 2.3 m, or about 2,000 stems per ha. The area is usually snow-covered from November to early May; little snow melts under forest cover before April. Snowpack water equivalent has averaged about 7.3 inches (18.5 cm) on April 1 for 32 years of record at Foxpark, Wyoming (Peak and Crook 1967).

Methods

Windspeed and snow accumulation were measured in 1968-70 to establish pretreatment conditions prior to cutting a small clearing. Windspeeds were obtained in a 60 m^2 area of forest using a sampling grid consisting of five points, 6.5 m apart, on each of eight arms radiating from a main tower. Two portable masts equipped with thermistor anemometers (Bergen 1971) were located on opposite sides of the central tower, and after a series of measurements covering various windspeeds, were rotated to other points on the sampling grid. The ascending positions of the anemometers were 1.1, 2.5, 4.0, 5.6, 7.0 and 8.5 m.

A 21.3-m central tower was equipped with a recording cup anemometer and vane at the top, and thermistor anemometers at 11.3 and 16.5 m above the ground. Simultaneous sets of

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anemometer outputs were recorded at intervals of 15 to 40 minutes. An average of 15 profiles was obtained at each sample point. Windspeeds were measured during the late morning and early afternoon, and only during periods when prevailing airflow was within 10 degrees of southwest.

Snow water equivalents were first obtained at established sample points along the radial grid with a Federal sampler and weighed on a sensitive dial-type scale.

In the summer of 1970, a clearing 35 ft (10.7 m) by 160 ft (48.8 m)--1 tree-height (1H) wide and about 5 tree-heights (5H) long--was established (fig. 1). The clearing was oriented with the long axis perpendicular to the direction of the prevailing southwest wind. A total of 100 trees were cut to make the clearing. Ten tree crowns were dissected and weighed to obtain a qualitative description of the canopy. All slash was removed from the clearing and thoroughly lopped and scattered around the clearing.

Windspeed and snow accumulation data were then obtained from seven equally spaced transects established across the long axis of the clearing. The transects were also extended into the forest on either side of the clearing--about 15 m for windspeed and 46 m for snow measurements. Sample points were about 2 m apart within the clearing. Windspeed measurements in the clearing were obtained along one transect at a time using thermistor anemometers on five portable masts and referenced to windspeed measurements on the main tower (fig. 2). Wind measurements were made only during fair weather and when the above-canopy wind direction was within 10 degrees of southwest. Twenty to 40 profile sets were recorded for each transect. Snow measurements were obtained along the same transects, starting at the time of maximum accumulation and continuing periodically through the melt season.

Windspeed distribution under natural forest

Forest canopies are porous media with characteristically rough frictional surfaces that allow airflow to carry snow through, over, and around trees. The numerical description of airflow through canopies is illusive, and we have much to learn about the flow of air masses and interaction with the canopy before we fully understand the "why and how" of snow accumulation within and around clearings.

A qualitative characterization of the undisturbed canopy was determined from needles plus branch weights of 10 trees in order to obtain a relative weight distribution profile (fig. 3a). The greatest concentration of mass was near the midcanopy level. In a later study it was determined that canopy weight distribution was proportional to canopy surface area or the frictional surfaces (Gary 1975). The resulting windspeed profile through the canopy was about as expected.

The shape of the average scaled windspeed profile (speeds at selected heights/friction velocity) indicated the expected reduction on windspeed and an increasing influence due to canopy roughness (fig. 3b). Average windspeed, as reported in greater detail in an earlier study (Bergen 1971b), was minimum where canopy weight or frictional surfaces were maximum. The zone of minimum windspeed in the midcanopy region suggests that speeds above the midcanopy region, on the average, were relatively independent of speeds in the lower canopy. Just below the live canopy region, relative airflow increased to a subcanopy maximum. A maximum subcanopy speed is characteristic of forests that lack tree or shrub understory. The height of the subcanopy maximum speed depends primarily on the relative roughness of the lower canopy, dead branch mass, ground cover, snow depth, and wind velocity.

Information on canopy mass distribution and the shape of the average scaled windspeed profile indicate that snow distribution under the unbroken stand of lodgepole pine was more strongly influenced by subcanopy airflow than by penetration of winds from above the canopy. Openings in the canopy do, however, allow greater penetration of gusty above-canopy winds, and snow accumulation is somewhat greater in such openings.

Patterns of snow accumulation before and after clearing

The pattern of snow accumulation for 2 years before and 2 years after clearing is shown in figure 4. A previous paper describes the snow sampling, accumulation, and melt patterns in greater detail (Gary 1974). The pretreatment measurements under the unbroken

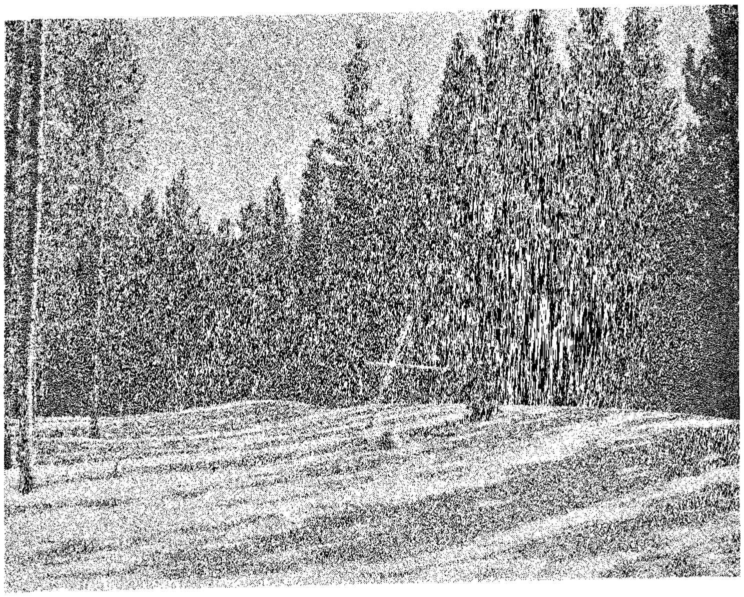

Figure 1.--Windward border of the clearing. The long axis is normal to the prevailing southwest winds. Tree height is about 35 ft (10.7 m).

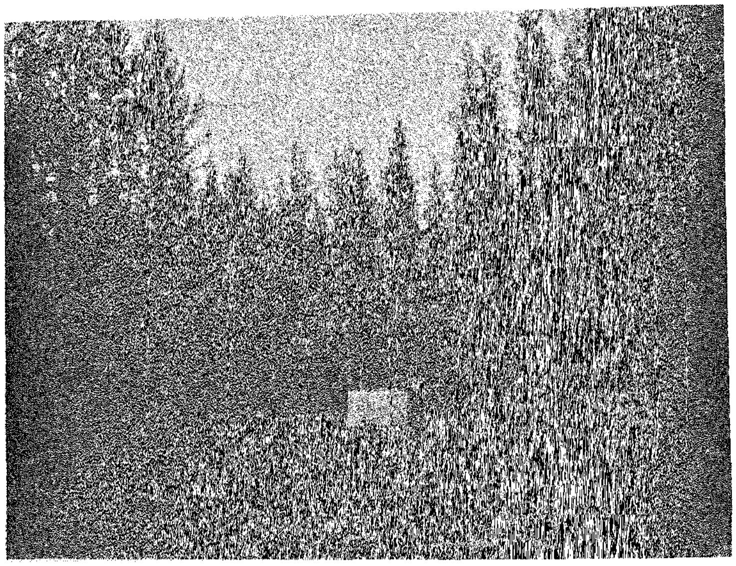

Figure 2.--Portable masts and attached thermistor anemometers along a transect in the clearing.

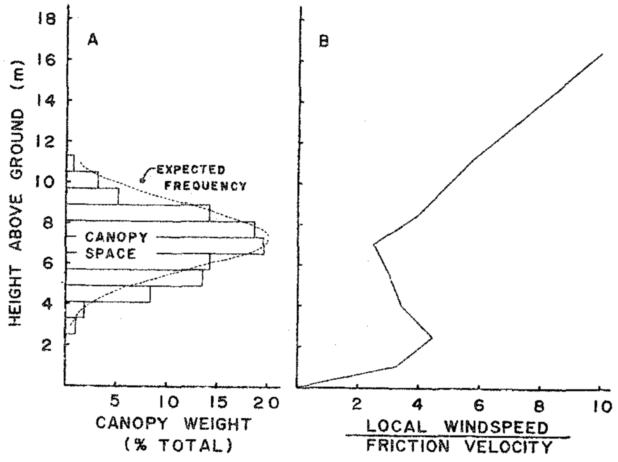

Figure 3.—(A) Relative canopy wieght distribution of the unbroken forest stand and (B) the average windspeed profile (speeds at selected heights/friction velocity)

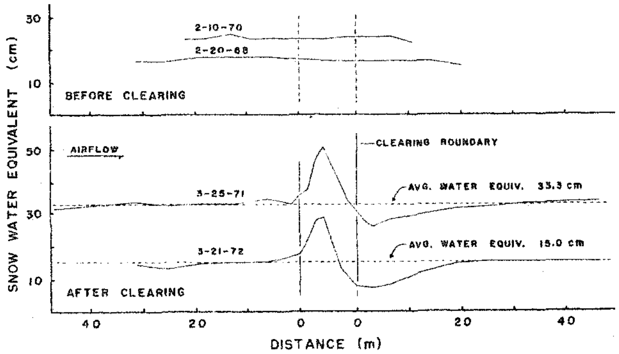

Figure 4.--Patterns of snow accumulation before and after the clearing was cut. Data for 1971 and 1972 were taken near the time of maximum snowpack.

stand for 1968 and 1970 were not taken at the time of maximum snowpack, but illustrate general uniformity in snow water equivalent from point to point. The relatively uniform snow cover was apparently strongly influenced by subcanopy airflow. Blowing snow events have been observed under the unbroken forest, and direction of snow movement is generally east or southeast. The coefficient of variation for snow water equivalent in both pretreatment years was 5.9 percent. After clearing, coefficients of variation for the same upwind sample points were 6.4 percent in 1971 and 11.3 percent under difficult sampling in 1972. The relatively unchanged coefficients of variation indicate no differential pattern of snow accumulation developed upwind of the clearing.

Significantly greater quantities of snow were observed within the clearing, and snow was also greatly reduced along the forest border leeward of the clearing. The general pattern of increased snow within the clearing and decreased snow along the forest border occurred over the full length or long axis of the clearing. Snow volume determined by "average end areas", between seven transects and over both years since clearing, indicated excess and deficit quantities of water were about equivalent. In the high snowfall year, all but 0.04 inch of the increased water was accounted for, and in the low year the net effect was a loss of 0.28 inch of water equivalent. These results were in general accord with the hypothesis set forth by Hoover and Leaf (1967) that total quantity of snow over the study area was not increased due to clearing. The processes that account for the greater relative quantities of snow in the clearing are not fully understood, however.

Visualization of airflow and snow accumulation

When falling snow is observed for any length of time, it becomes obvious that snow particles come from all directions and are carried by various eddies within the airstream. It is difficult to visually determine where the snow will pile up because of widely variable turbulent diffusion, even during light breezes. However, it is logical to assume that the ultimate pattern of snow accumulation will most strongly reflect the average duration and direction of airflow.

Following most winter storms, trees (boles) along the lee side of the study clearing as well as the trees inside the undisturbed forest on either side of the clearing were "plastered" with snow on their west sides. The wind data used in this report were not obtained during the actual period of snow accumulation, but were used in a qualitative way to evaluate the pattern of snow accumulation.

The horizontal and vertical velocity components of windspeed, measured with an array of heated thermistor anemometers and smoke tracers, gave an estimate of the average airflow patterns across the clearing (Bergen 1975a, 1975b). The streamlines for airflow (fig. 5a) represent an average of seven profiles across the long axis of the clearing. Reference velocities are shown as U_* (a quantity about 1/10 of the mean windspeed). The corresponding patterns of excesses and deficits of snow accumulation near the time of maximum snowpack for 2 contrasting years are shown in figure 5b. The snow water equivalent values in figure 5b are the average values (seven transects) at various distances inside and downwind of the clearing less average water equivalent upwind of the clearing (49 samples).

Airflow in the clearing consisted of two regions: one was the recirculation zone, or closed eddy extending from the middle of the clearing to a point about 4 meters (1/3H) downwind of the lee clearing edge; the second was the unseparated upwind flow which met the recirculation zone in a dividing streamline that moved over the lee canopy and reattached to prevailing airflow well behind the lee canopy edge.

Snow accumulation excess was found along the windward side of the clearing and extended for a distance of about three-fourths (3/4H) of the way across the clearing. A deficit snow accumulation pattern apparent all along the downwind forest margin extended 25 to 30 meters (about 3H) into the forest. The patterns and quantities of snow excesses and deficits were much the same during both years, even though snowpack water equivalent varied by a factor of two.

The most obvious relation between airflow and maximum snow accumulation was that maximum accumulation was roughly centered about the windward origin of the closed eddy. The zone of minimum snow accumulation coincided with the downwind terminus of the closed

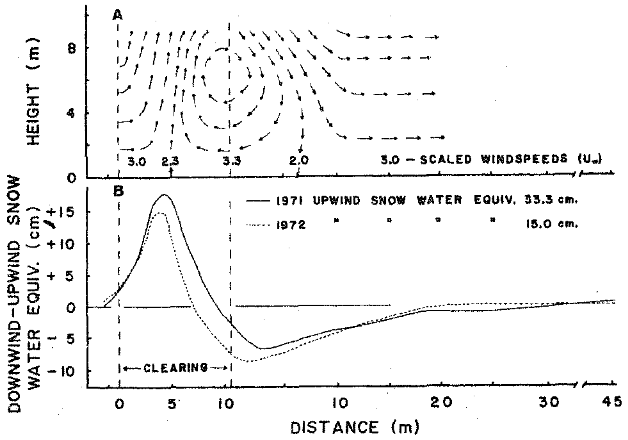

Figure 5.--(A) Measured streamlines of airflow across the clearing showing a well-developed back eddy, and (B) snow water equivalents for various distances inside and downwind of the clearing less average of upwind samples.

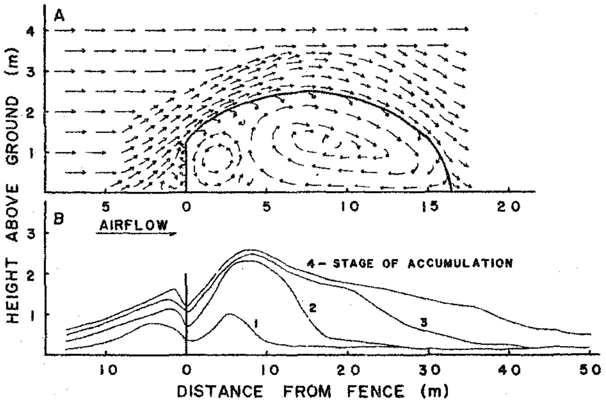

Figure 6.--(A) Turbulent eddies formed behind a long solidly sheeted fence set with no gap beneath, and normal to wind direction (Finney 1934); (B) cumulative snowdrift stages behind a vertically slated 50 percent density snow fence with no gap beneath (Mellor 1965).

eddy. The location of the maximum snow drift was evident after the first snows. Often during each snowstorm, snow was unequally distributed whenever there was a sudden decrease of surface shear stress and/or an enlarged region of stagnant airflow which allowed greater release and redistribution of snow from the upwind canopy flow.

The zone of minimum snow accumulation had relatively low windspeeds and did not appear conducive for accelerated snow loss from wind scour. The zone and its location may therefore be the result of advective processes whereby falling snow is carried to either side of the dividing streamline. Some of the snow trapped by the downwind terminus of the reoccurring eddies may thus be transported back to the clearing, while snow entering the zone of reattachment of airflow was perhaps carried and deposited further downwind of the clearing.

Analogy between the clearing and snowfences

It is not known or implied that forest clearings accumulate snow in the same way as fences, but streamline and snow accumulation patterns previously shown in figure 5 exhibit some of the same qualitative features observed near snowfences. Over open snowfields and/or forests, when airflow encounters abrupt obstacles such as snowfences or a change in canopy surfaces, local separation occurs at the boundary layer and wind energy is dissipated through eddy formation (fig. 6a). Depending on windspeeds and the availability of drifting snow, definite lee drifts are formed (fig. 6b). Whether over fences or in forest openings, snow is deposited and accumulates where windflow is decelerated, and scours in zones of intense eddies and acceleration. Lee drifts behind snowfences continue to build until they reach a shape sufficiently streamlined to inhibit further deposition; at this stage snowfences are termed "saturated" (Mellor 1965).

The primary contrast of airflow in the 1H-wide clearing and that reported behind snowfences is the greatly shortened recirculation zone (about 2H) due to the clearing. Behind high-porosity snowfences, the recirculation and eddy zones extend 10H to 20H downwind of the barrier. There is no minimum zone of snow accumulation, but merely the downwind edge of the zone of accumulation which shifts and is dependent on degree of fence saturation. In the clearing, however, a definite minimum snow accumulation zone was present in the downwind region of flow separation, just beyond the lee border.

Conclusions

During periods of snowfall in small clearings, incoming snow at one time or another comes from all directions. The ultimate pattern of snow accumulation, however, will most strongly reflect the average duration and direction of airflow. In this study, the zone of maximum snow accumulation was near the center of the clearing during both years, and was also centered about the windward origin of dividing airflow where low windspeeds of the back eddy allowed greater release of snow from upwind canopy flow. The minimum snow accumulation zone was along the leeward forest border near the downwind terminus of the dividing airflow--a low windspeed zone. The relatively low windspeeds imply that low snow accuumulation did not result primarily from wind scouring. No doubt, on some occasions, subcanopy airflow may scour snow along the lee borders of the clearing and forest.

It is not known when or if forest openings in low snowfall regions, such as the present clearing, "saturate" and fail to accumulate relatively greater quantities of snow. Snow excesses and deficits due to effects of the clearing were about the same for two contrasting years, however, suggesting that differences between openings and the forest may be reduced during high snowfall years.

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