

SNOW DEPOSITION PROCESSES IN A FOREST

STAND WITH A CLEARING

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INTRODUCTION

Watershed experiments dating back to the early 1900's have demonstrated that timber harvest increases water yield. Plot studies in the 1940's indicated that snowpack increased in direct proportion to the amount of a stand harvested (Wilm and Dunford, 1948). This snowpack increase is strongly correlated with the observed changes in flow, in the cold subalpine environment (Troendle 1987). However, questions exist concerning the cause of the increase in snowpack and the nature of the deposition processes altered by harvesting.

From the strong correlation between harvest intensity and increase in peak water equivalent, Wilm and Dunford (1948) inferred that cutting reduced evaporation of snow previously intercepted by the tree crowns. Measurements by Goodell (1959) supported this conclusion. However, when snowpack measurements on the Fool Creek watershed failed to demonstrate a net increase in peak water equivalent after partial clearcutting, Hoover and Leaf (1967) suggested that the intercepted snow was redistributed into the clearing by wind, with little loss to evaporation.

A longer term of record on Fool Creek allowed Troendle and King (1985) to detect and overall net increase in snowpack on Fool Creek of 9% (significant at the 1% level) or the equivalent of 22% more snow in the openings. This finding supports reduced interception loss as a factor in manipulating water yield by timber harvest.

Wheeler (1987) compared deposition in a clearing and surrounding forest by frequent snowboard measurements. Most of the increase in accumulation in the open occurred during storms (supporting results of Troendle and Meiman, 1984, 1986), while little snow was added to the clearing by wind between storms. Curiously, the magnitude of the difference in accumulation between forest and clearing was inversely related to wind speed during storms. Meiman (1987) presents a summary of research on snowpack deposition processes.

We began experiments in 1987 using electronic sensors to compare the flux of snow into the same forest and clearcut block studied by Wheeler. Towers in the center of the cut and in the upwind forest supported snow particle counters--devices that sense snow crystals passing through a light beam (Schmidt and Jairell, 1987). Reasoning from the photographs of Hoover and Leaf (1967) that redistribution by the wind should produce a flux concentration near the top of the canopy, we positioned sensors to detect this snow plume as it spread into the clearing. Such a concentration was detected during several storms in February-March, 1987 (Schmidt and Troendle, in preparation).

The objective of this paper is to report results of January-March, 1988 experiments at the same site, using the same techniques to compare flux differences between forest and clearing for periods with and without snowfall. The results support the hypothesis that redistribution of intercepted snow by wind is negligible when snowfall has ceased.

THE STUDY SITE AND INSTRUMENTATION

A rectangular block 80 m wide along the direction of prevailing wind and 100 m long up a 40% slope of 20° aspect, was clearcut in a stand of spruce, fir and scattered mature lodgepole pine. Average tree height is approximately 20 m with individual trees reaching to 30 m.

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Table 1 represents the summary of the peak water equivalent in the forest and open, before and after harvest. The sampling scheme, described earlier by Troendle and Meiman (1984, 1986) compares 15 grid points in the clearing with similar grids in up- and downwind forest. Since 1982, the opening accumulated an average of 52 percent more water than the surrounding forest by April 1 of each year.

Table 1. Peak Water Equivalent (cm) on April 1 on Study Site

<u>Year</u>	<u>Upwind Forest</u>	<u>Clearing</u>	<u>Downward Forest</u>
1981	15.5	15.8	15.5
1982	31.0	31.8	31.8
	----- Clearing Harvested -----		
1983	30.2	43.7	31.2
1984	37.6	54.1	36.6
1985	30.0	44.5	29.7
1986	23.1	41.4	23.6
1987	17.1	27.0	16.2
1988	29.3	44.5	26.9
	----- Average after Harvest -----		
'83-'88	27.8	42.5	27.4

Towers erected in the clearing and forest (Fig. 1) were of triangular cross-section, 30cm on a side. The 27-m mast (#2) centered in the clearing is 40 m from the west forest edge, and the 34-m forest mast (#1) is 45 m upwind of that edge, at an azimuth of 287° from the clearing tower. Towers #1 and #2 were wired for a 3-cup anemometer and a snow particle counter (SPC) at each 3 m interval from the top. In addition, an anemometer and direction vane was positioned at 21 m on tower #2 (open) to measure wind speed and direction.

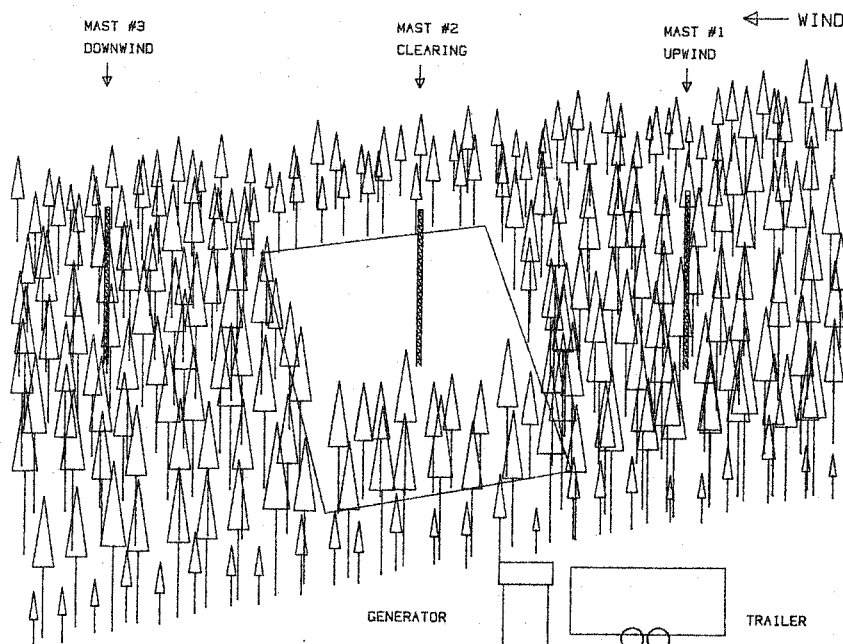


Figure 1. Schematic of study site show the location of the 3 instrument masts, the generator shed, and instrument trailer (from Schmidt and Jairell 1987).

On the road below the north edge of the cut block, a small trailer provided shelter for observers, and electronic equipment that was powered by a 6-kilowatt, propane-driven generator. Schmidt and Jairell (1987) described more details of the site and instrumentation.

The SPC's detect the shadows of individual snow crystals passing between a small lamp and a phototransistor (Schmidt, 1977, 1986, Schmidt *et al.*, 1984). Particle flux is measured through an area of 1 cm^2 , in a vertical plane. Amplifiers in the sensor produce signals of sufficient strength for cable transmission to the recording equipment in the trailer (Fig. 1). The count from each SPC or anemometer cup is accumulated in a corresponding 16-bit binary counter at the trailer. This accumulation is controlled by a microprocessor that sends each result to a computer (COMPAQ* or IBM PC-XT*) when the computer signals the end of the measurement period.

An analog-to-digital converter in the computer sampled output from the wind speed and direction sensor on the clearing tower as well as from a thermistor monitoring temperature at the base of the tower. During each sampling interval (usually 5-min), air temperature, and average windspeed and direction in the clearing were sampled at approximately 1-s rates.

RESULTS

For six distinct storms in the first three months of 1988, sensors provided flux measurements at three positions on each tower. The highest position, 33.5 m on the forest tower, is 13 m above average canopy height, and 3.5 m above the tallest tree on the slope. Assuming this position provided our best measure of incoming precipitation flux, we divided each sensor count by this reference count, to allow comparison of flux ratios between runs. Nominal sensor heights on the forest tower were 33.5, 21.1 and 15.2 m, and on the clearing tower, 27.4, 18.3 and 9.1 m. The snowpack made actual heights 1 to 2 m less.

Since the towers are 85 m apart, a short period at the beginning and end of each run sampled wind and flux that did not pass both towers. We felt 5 min was the shortest period that gave an adequate sample of the regime passing both forest and clearing towers (Schmidt and Troendle, in preparation).

Measurements continued after each storm's snowfall until one of the following conditions was met: (a) 4-6 hours after all snow transport ceased, (b) intercepted snow was gone, or (c) another storm began. Data from these periods comprise the non-storm records.

STORM PERIODS

Approximately 950 five-min intervals sampled the 6 storms. The smallest storm deposited 3 cm of snow while the largest dropped a total of 22 cm, of which 19.5 fell during the measurement period. Particle counts reached 10,000 for a 5-min sampling interval. However, 0 to 3000 counts (0 to 10 particles s^{-1}) was the normal range. Particle count and the variability at the reference elevation increased with average wind speed (Fig. 2). When wind speed averaged 3 to 5 m s^{-1} for the interval, we commonly observed instantaneous wind speeds from 11 to 18 m s^{-1} .

The ratio of counts to reference counts increased near the canopy top. At low wind speeds (0-1 m s^{-1} in Fig. 3) the flux at the top of the canopy is about the same as that at the reference location (ratio ~ 1.0). As wind speed increased, so did the relative flux at the canopy level. At 4-5 m s^{-1} average wind speed, 10-20 percent more particles passed the forest tower at the average canopy height than at the 33.5 m reference location (Fig. 3). Regression lines plotted on Figures 3-7 represent a least squares fit of a linear relationship to the 954 points. Because of the large variance, error terms and regression coefficients are not given. However all slopes are significant at $p = 0.05$.

*The use of trade and company names is for the benefit of the reader; such use does not constitute an official endorsement or approval of any service or product by the U. S. Department of Agriculture to the exclusion of others that may be suitable.

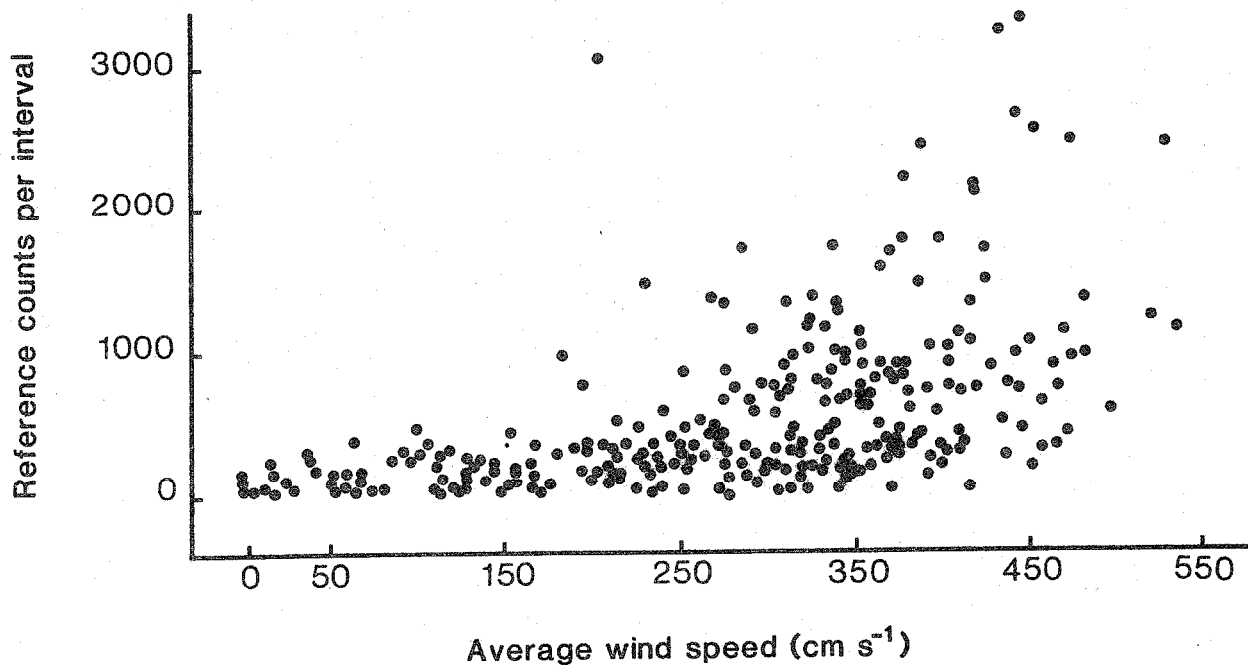


Figure 2. Reference counts during storm period at 33.5 m in forest tower.

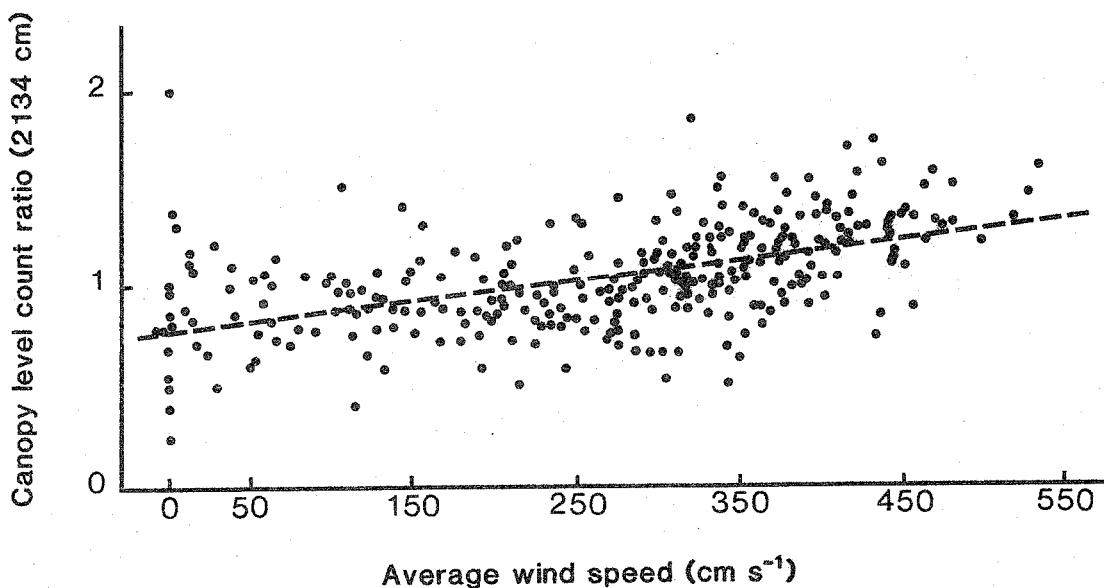


Figure 3. Ratio of particle counts at the forest canopy to reference counts as a function of wind speed.

Particle flux decreased significantly and was more variable within the canopy. At 15.2 m in the canopy, count ratio was approximately 0.5 at low wind speeds (Fig. 4). The count ratio increased with wind speed, suggesting that with greater wind speed, a greater percentage of the particles entering the canopy make it to lower levels. At 12.2 m in the forest canopy (not shown), the ratio dropped to 0.4 at low wind speed. Figure 5 shows the relationship between count ratio at 15.2 m in the forest and the particle count at that location.

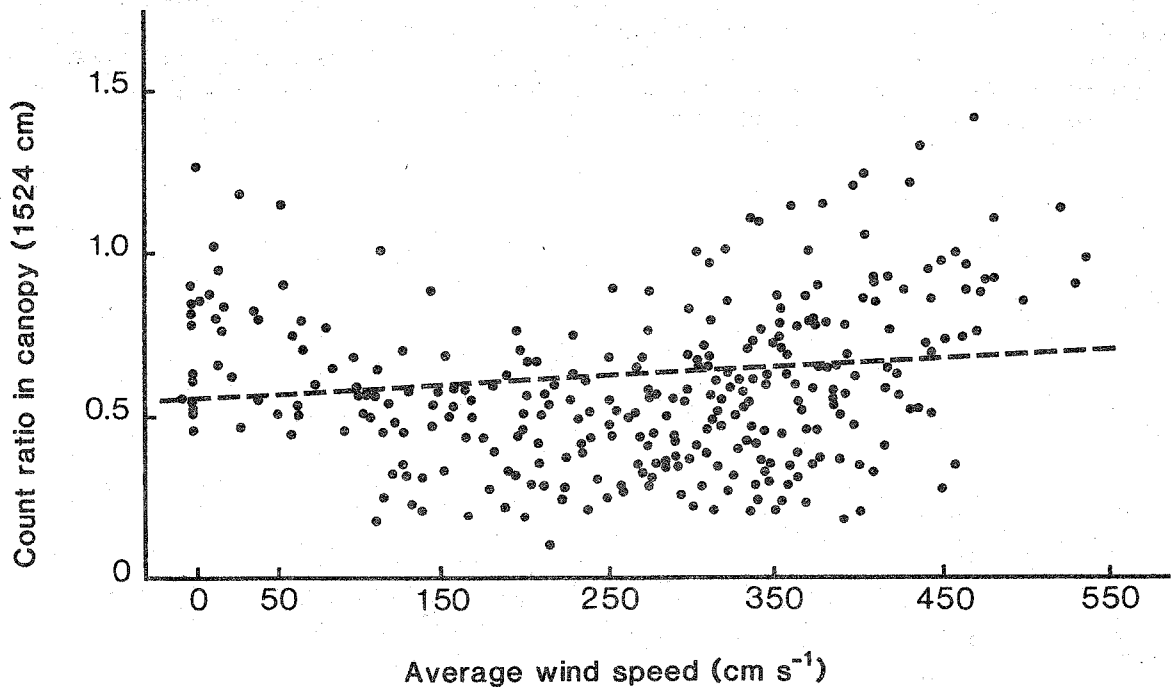


Figure 4. Ratio of particle counts in the forest canopy (15.2 m) to reference counts as a function of wind speed.

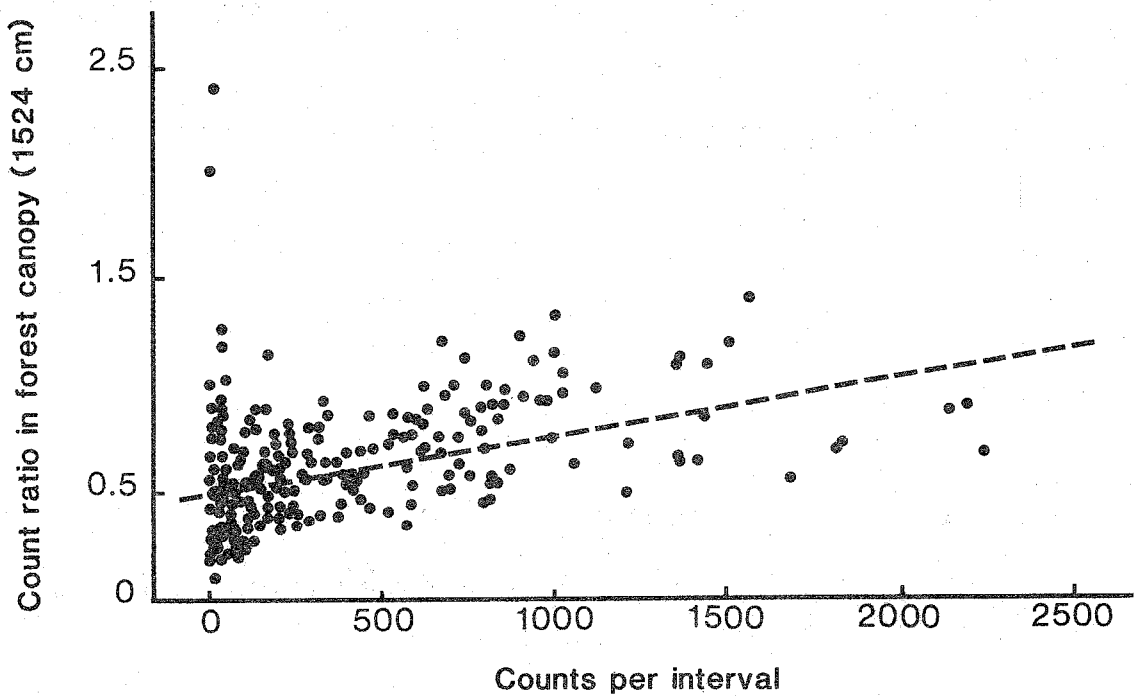


Figure 5. Relation of count ratio at 15.2 m and total counts at 15.2 m for the measurement interval.

The count ratio at 27.4 m on the clearing tower (Fig. 6) and at 9.1 m (Fig. 7) were greater than ratios at equivalent heights in the forest. On average, flux was 7% greater at the top of the tower in the open than at the reference location (Fig. 6). The ratio did

not increase with wind speed as it did for the forest locations. In some storms the flux was greater in the open, other times it was much less. For the data represented here, the average flux ($N = 954$) into the forest was 485 counts, while it was 477 in the open -- no difference in the mean values. The flux passing the 9.1 m elevation in the open (Fig. 7) was reduced to 70% of the reference value. However, at the corresponding elevation in the forest, flux was 40-45% of the reference value.

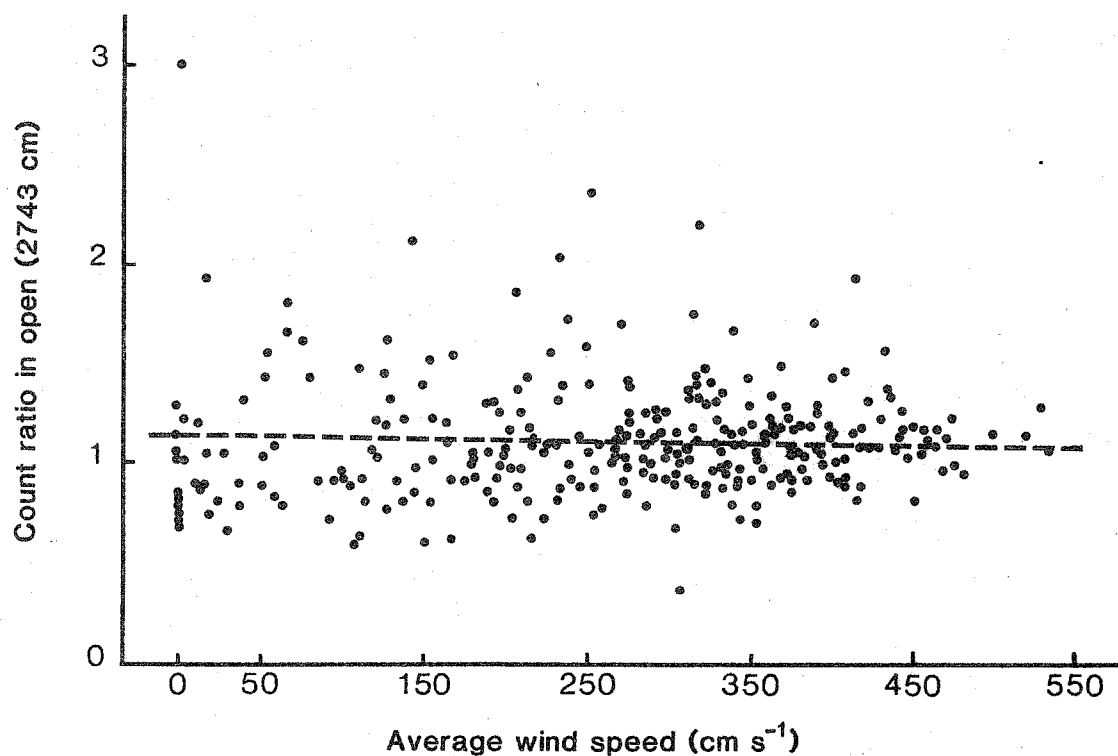


Figure 6. Relation of count ratio at 27.4 m in the open and wind speed.

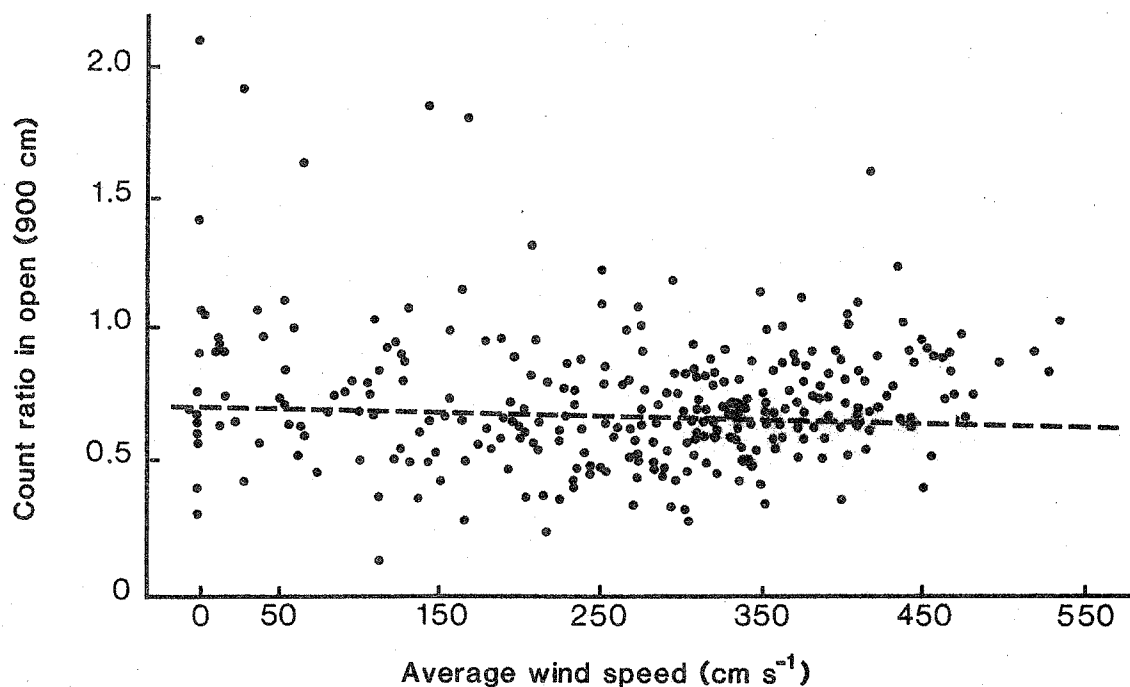


Figure 7. Relation of count ratio at 9.1 m in open and wind speed.

NON-STORM PERIODS

Once snowfall subsided, measurements continued as non-storm observations until activity ceased or the next storm occurred. The post-storm data showed very little transport at night. As the temperature rose during daylight hours, a threshold appeared to be reached for release of intercepted snow (See Schmidt *et al.* 1988). Released snow either fell to the surface or was carried with the wind. Releases were sudden, localized, and not repetitive. As the temperature receded in the afternoon, releases usually ceased even in the presence of wind.

For non-storm periods, low counts dictated a 15-minute sampling interval. Fifty percent of all samples collected had 2 or less counts in 15 minutes. In total 795 intervals were sampled to represent the unloading periods after the six storms. For the 795 runs, counts averaged of 12.05 in the forest and 12.04 in the open. Visual observation indicated spacially discrete releases resulted in spectacular plumes if wind existed. However, duration of the plume was short, and our measurements show the flux was negligible compared to storm flux.

Figures 8 and 9 present the non-storm counts at the top of the canopy and at the most comparable elevation in the open, plotted over average wind speed. Very little correlation exists between particle count and wind speed (lines not plotted, slope = 0). The flux is very low relative to the flux which occurred during storm conditions (See Fig. 2).

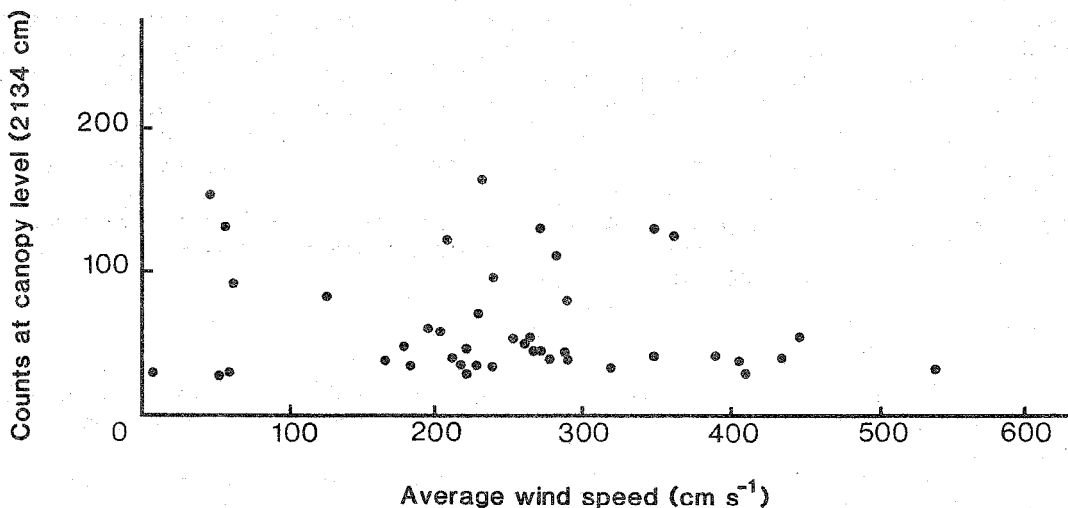


Figure 8. Particle counts above the forest canopy during non-storm measurement intervals as a function of wind speed (all counts less than 25 deleted).

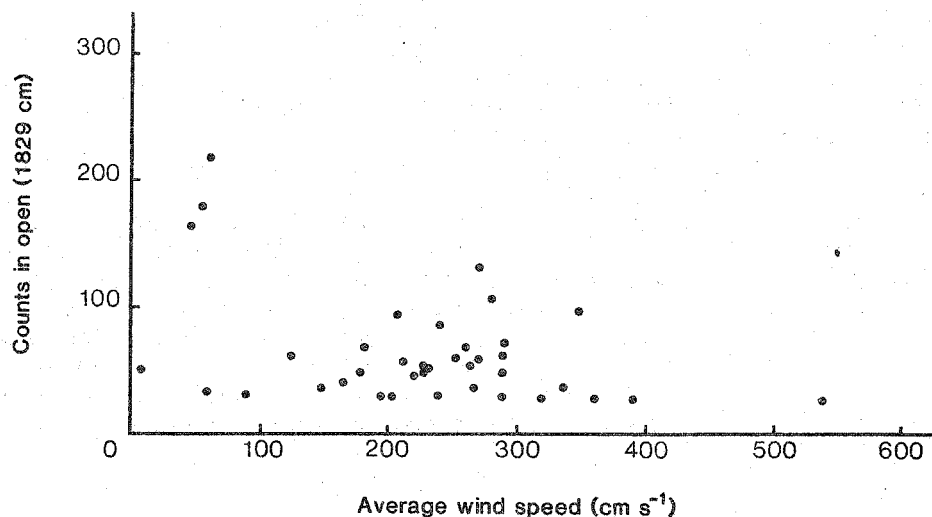


Figure 9. Particle counts in the forest opening during non-storm periods as a function of wind speed (all counts less than 25 deleted).

Troendle and Meiman (1984, 1986) and Wheeler (1987) concluded non-storm periods contribute little to the observed snowpack differences between forest and clearing at this site. Two facts might explain their observations. Either intercepted snow redistributed by wind after a storm does not reach the surface in the clearing, or such redistribution is not significant. Our experiments support the latter explanation.

SUMMARY

Observations from the 1988 experiments include:

1. Snow particle flux measured by electronic counters displays a persistent maximum near the top of the forest canopy (Fig. 3).
2. When expressed as a ratio of the reference flux at the top of the forest tower, the canopy-top maximum increases with wind speed (Fig. 3).
3. As this layer or sheet of concentrated flux moves from canopy-top out over the opening, turbulence diffuses the flux, reducing the maximum and increasing the thickness of the layer, as measured at the center of the clearing (Figs. 6 and 7).
4. However, the trajectory of the flux concentration crosses the center of the clearing near the top of the tower, suggesting that this snow may not add to the clearing snowpack (Figs. 6 and 7).
5. Canopy-top fluxes attenuate rapidly with decreasing height in the canopy, reflecting interception (Figs. 4 and 5).
6. With greater snowfall intensity, the percentage intercepted by the canopy decreases, as demonstrated by the increase in count:reference ratio with increasing count (Fig. 5).
7. The tops of dominant trees (20-30 m) accumulated less snow than the tops of trees of average height (20 m). Visual observations during storms suggest that redistribution from these dominant tops is one source of snow for the canopy-top flux maximum.
8. By far the largest difference in the vertical profile of snow flux between forest and clearing was created by canopy interception.
9. These experiments gave a definitive test of our hypothesis concerning non-storm transport. Compared to the flux during storms, redistribution of intercepted snow by wind after snowfall produced negligible flux.

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