ABOVE-CANOPY SNOW TRANSPORT RATE IN THE CENTRAL COLORADO SUBALPINE ZONE

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ABSTRACT

The principles of aerodynamics govern snow transport in open terrain and also the transport of snow within and just above the forest canopy. Only in the last forty years or so, have theories been developed and field tested for wind-driven snow transport above forest canopies. This report presents a seamless transition between the two phenomena. (KEYWORDS: snow transport, forest canopy, subalpine, Colorado)

INTRODUCTION

As with snow transport in open terrain, wind transport of snow in the subalpine zone is also a significant process in differential snow accumulation. The principles of aerodynamics govern snow transport along open terrain and also the transport of snow within and just above the forest canopies. This report highlights the processes of open terrain transport in order to gain a better understanding of similar processes that govern snow transport above the forest canopy.

SNOW COVERED OPEN TERRAIN AND FOREST EFFECTS ON WIND

Forest cover significantly modifies the open terrain wind profile as discussed by Chebotarev (1966), DeWalle and Rango (2008), Geiger (1957), Leaf (2009), and others. In snow covered open terrain, the well-known logarithmic wind profile is defined by the equation (Tabler, 1980):

$$u/u_* = 2.5 \ln (z/z_0) \qquad z \geq z_0 \qquad [1]$$

where u is the mean horizontal fully rough turbulent wind speed at height z above the snow surface, z_0 is the roughness height (z at u=0), u_* is the shear velocity, and 2.5 is the reciprocal of Von Karman's constant, generally assumed as 0.4.

Tabler (1980) published similarity studies of wind profiles in blowing snow over a frozen lake in southeast Wyoming. His studies were made in order to test the hypothesis that roughness height (z_0) varies with the square of shear velocity (u_*^2). Tabler (1980) also developed a relationship for shear velocity (u_*) as a function of wind speed at 10 meters.

SNOW TRANSPORT IN OPEN TERRAIN

From his review of the properties of blowing snow, Schmidt (1982) presented an equation derived by Iversen et al. (1975), for mass flow snow transport rate in open terrain (q_{so}).

Schmidt (1982) calculated envelope curves of q_{so} within 1 meter above the snow surface using Tabler's (1980) results. Schmidt's equations identify a threshold friction velocity (u_{*t}) below which transport does not occur. The threshold friction velocity explains the disparity of results arising from varying snow surface conditions observed by Takeuchi (1980).

SNOW TRANSPORT ABOVE THE FOREST CANOPY

Leaf (2010) found that winds approximately 1 meter above mean canopy level (u_1) in mature lodgepole pine and spruce-fir forest were predominately from the WNW. These winds averaged 4.5 ms^{-1} in 1964-65 and 3.4

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ms^{-1} in 1965-66 across 6 tree height forested and clear-cut strips on Fool Creek, a 714 acre watershed in the Fraser Experimental Forest.

A summary of estimated above canopy snow transport for these years is presented in Table 1. Snow transport rate (q_{sc}) above the forest canopy was determined from theory and supporting field data presented in Leaf (2009), Leaf (2010), and Leaf (2012). In these calculations it was assumed that u_{*t} = 3.44 cms^{-1} and u_1 = 2ms^{-1} for new fallen snow.

Table 1 also presents above canopy transport rate as a ratio of open terrain transport rate (q_{s0}). Note that the ratio decreases exponentially with increasing wind speed.

Snow transport in open terrain was computed from the equations presented by Tabler (1980) and Schmidt (1982), while transport rates above the forest canopy were empirically derived from field observation discussed previously by Leaf (2012) and summarized in Table 1.

As seen in Table 1, the ratio of estimated snow transport above the forest canopy to that in open terrain was 0.353 at a prevailing wind speed of 4.51 ms^{-1} in 1964-65 (high snowpack year) and 0.528 at a prevailing wind speed of 3.42 ms^{-1} in 1965-66, a low snowpack year.

Table 1. Comparison of estimated snow transport above canopy in Block D, 6H on Fool Creek (Leaf, 2012) with open terrain transport

Years	Direction	Canopy Level Wind Speed u_1	Transport Rate (q_{sc})	Open Terrain Transport Rate q_{s0}	Ratio: q_{sc}/q_{s0}
		(ms^{-1})	(g/ms)	(g/ms)	
1964-65	SW	7.00	4.69	61.43	0.076
	S	3.73	3.22	4.77	0.675
	W	3.34	4.24	3.05	1.390
	N	3.17	2.43	2.46	0.984
Season	WNW	4.51	3.64	10.31	0.353
1965-66	N	3.14	0.96	2.37	0.405
	S	2.35	2.19	0.731	2.996
	SW	5.60	3.01	24.83	0.121
	W	3.02	1.42	2.03	0.699
	NW	2.57	1.28	1.05	1.143
Season	WNW	3.42	1.77	3.35	0.528

Above Canopy Effective Shear Velocity

It should be noted that the shear velocity and resultant transport of snow in open terrain greatly increases with increasing wind speed. However, measurement and analysis of differential snow accumulation between the cut and uncut strips on Fool Creek suggest that shear velocities (u_*) above the forest canopy do not increase as rapidly with increasing wind speed when compared with that in open terrain. Troendle et al. (1988), observed only a 10 to 20 percent increase in snow particle flux at and just above canopy level with increasing wind speed.

Apparently, this is largely the result of through fall of airborne and intercepted snow increases with increasing wind speed (Troendle et al., 1988).

It should be noted that Schmidt's (1982) theoretical equation and the empirical equations by Takeuchi (1980) are for fully developed flow and a fetch of sufficient length to ensure saturated wind transport in open terrain.

Above the forest canopy, unsaturated transport takes place at wind speeds (u_1) exceeding approximately 3 ms^{-1}.

DISCUSSION AND CONCLUSIONS

Most above canopy snow transport in mature undisturbed subalpine forests occurs at wind speeds $\leq$ 7 ms^{-1} and during snow storms. At wind speeds $>$ 3 ms^{-1}, the "porous" nature of the forest canopy results in snow transport rates that decrease exponentially compared to saturated wind transport at a given wind speed in open terrain. Apparently, snowfall rate and considerable through fall of snow, which increases with increasing wind, limits the transport rate available for subsequent redistribution into forest clearings.

However, wind redistribution is a significant component of differential snow accumulation. Redistribution amounts to approximately 45 percent of saturated open terrain transport at prevailing above canopy wind speeds observed in the subalpine zone.

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