EVAPORATION FROM DRIFTING SNOW

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Erosion of surface snow, its transport by the wind and subsequent deposition are familiar phenomena to residents of the Prairie Provinces. Evaporation from snow during drifting is a less well known phenomenon which can result in major losses from the snowcover of cold, semi-arid and windswept landscapes such as the Canadian Prairies and Arctic. Evaporation occurs in the form of sublimation from the ice surface of blowing snow particles to atmospheric water vapour. The rate of sublimation is controlled by the radiative, latent and sensible energy fluxes to the blowing snow particle. Meteorological factors affecting this energy balance are; solar radiation incident on the particle, windspeed relative to the particle and the ambient atmospheric temperature and water vapour pressure. Where wind directions and weather conditions vary widely from blizzard to blizzard, it is felt that a physically based model of snow transport quantities and sublimation rates is necessary to accurately determine the quantities of surface snow which sublimate before re-deposition. Advantages of a physically based model include its versatility in application to unique environments and problems and the ease of upgrading such a model as the results of research become available.

This presentation discusses: 1) the results of field measurements of vertical gradients of atmospheric snow density, wind speeds, temperature and humidity during blowing snow; 2) the results of a physically based model of sublimation from blowing snow for various meteorological conditions.

Over one winter near Saskatoon and two near Loreburn, Saskatchewan the mean vertical gradients of windspeed, air temperature, dewpoint, snow particle concentration and drift density (mass concentration of blowing snow) were measured at 6 levels, at heights from the snow surface to 3 m. Despite strong mechanical mixing during blowing snow, there is a tendency for stable temperature gradients compared to antecedent conditions. When temperatures at the 2 m level are near freezing, temperature gradients of 2° C per metre can develop. Relative humidity decreases with increasing height during blowing snow from a maximum near the 20 cm level. Differences in relative humidity of 20% can develop between the 2 m level and the surface layer (< 0.2 m) during a strong blizzard in "warm" weather. These measurements indicate strong fluxes of water vapour upwards from and heat downward to the dense lower layers of drifting snow.

A mathematical model has been developed which calculates the sublimation from a column of blowing snow. Flow through the column can be developing horizontally from a boundary or be fully developed as in the centre of a field. Transport rates through the column are calculated using versions of Bagnold's and Einstein's sediment transport theories. The model considers temperature and solar radiation levels and vertical gradients of particle size, drift density, turbulence, water vapour pressure and temperature within the column. For constant conditions, variation of the solar radiation from a flux typical at noon on a clear April day at 3000 m elevation to nighttime values changes the resulting sublimation rate no more that 3%. However, an increase in air temperature from -35° to -1° C results in a 22 fold increase in sublimation rates. At -15° C a decrease in humidity from 90% to 40% RH results in a 6 fold increase in sublimation rates. The drift density and therefore sublimation rate increases approximately as the square of the windspeed. Dramatic losses of moisture can occur in strong blizzards, with surface snow water equivalent losses to sublimation and vertical transport of 10.4 mm/day for a 10 m windspeed of 20 m/s, temperature of -1° C and RH of 70%.

The following table lists horizontal and vertical transport and sublimation rates for a 10 m column of blowing snow. Calculated from these values are the distance over which blowing snow will be completely replaced and the snowcover water equivalent required to replace snow lost by sublimation within the column and by vertical transport out of the column. Constant conditions assumed for these estimates are a meteorological fetch greater than 300 m, windspeed at 10 m of 12 m/s and a fresh, deep snow layer overlying older snow (windspeed at the threshold of blowing u_{10} = 4.5 m/s). It can be seen that sublimation affects the transport distance of blowing snow and overwinter losses of snowcover, however the magnitudes change dramatically with meteorological conditions. The potential errors in assuming a constant blowing snow sublimation rate in any hydrologic design are evident from the variation in D_R.

The calculation procedure used to calculate these estimates is in the final stages of compilation as an operational model by the Division of Hydrology. The model uses standard hourly A.E.S. data available from stations which record the occurrence of "blowing snow". Meteorological conditions measured at A.E.S. stations are transformed to estimate those conditions over particular agricultural snow surface geometries. This allows estimation of the potential effects of land use and engineering structures on the transport and sublimation quantities of blowing snow. It is hoped that accurate estimates of over-winter sublimation losses from and redistribution of the snowpack will permit water and agricultural resource managers to make informed decisions regarding snowcover quantities available for snowmelt in the spring.

RESULTS OF DIVISION OF HYDROLOGY BLOWING SNOW MODEL

T	H	Q^*	Q_{BS}	Q_V	Q_{SB}	D_S	D_R	E
-15	70	120	74.4	8.4	4.8	15.5	5.6	1.14
-15	70	1115	74.4	8.4	4.9	15.2	5.6	1.15
-15	90	120	74.4	8.4	1.6	46.5	7.4	0.86
-15	40	120	74.4	8.4	9.7	7.7	4.1	1.56
-35	70	120	80.6	9.1	0.7	115.1	8.2	0.85
- 1	70	120	70.6	7.9	15.4	4.6	3.0	2.01

Symbols:

T = 2 m air temperature °C
H = 2 m relative humidity %
Q^* = incoming shortwave radiation J/(m² s)
Q_{BS} = horizontal blowing snow flux to 10 m height g/(m s)
Q_V = vertical blowing snow flux at 10 m height mg/(m² s)
Q_{SB} = sublimation rate of blowing snow below 10 m height mg/(m² s)
D_S = distance over which sublimation will require complete replacement of blowing snow below 10 m (km)
D_R = distance over which sublimation & vertical transport will require complete replacement of blowing snow (km)
E = S.W.E. erosion rate for fully developed flow (mm/day).

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