VERTICAL PROFILES OF MASS FLUX FOR DIFFERENT PARTICLE DIAMETERS IN DRIFTING SNOW OVER HARD SNOW SURFACES

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ABSTRACT: The vertical profile of horizontal snow mass flux is a fundamental structure of drifting snow. It is widely recognized that most of drifting snow particles are transported within the saltation layer near the snow surface. However, little is clarified about the dependencies of the vertical mass flux profile in the saltation layer on conditions such as snow particle diameter, snow surface hardness, etc.

In this study, cold wind-tunnel experiments were carried out to measure vertical profiles of mass flux for different particle diameters over hard snow surfaces. Compacted snow was sieved to make a flat snow bed on the floor of the wind-tunnel. The snow bed was left for a night to become hard enough, by sintering, not to be eroded by drifting snow particles. Mass flux measurements in drifting snow by a snow particle counter showed that mass flux at each particle diameter decreased exponentially with increasing height. Previous studies showed that saltation height decreased with increasing particle diameter over loose snow surfaces. On the contrary, present study showed that saltation height increased with increasing particle diameter over hard snow surfaces. This opposite dependence is probably due to differences in particle collision processes on the loose and hard snow surfaces.

KEYWORDS: drifting snow, wind-tunnel experiment, saltation, mass flux, snow cover

1. INTRODUCTION

Drifting snow causes low visibility and often leads people on snow fields to danger. Formation of snow drifts in mountain areas owing to strong wind occasionally result in snow avalanche release.

Many researches have been conducted to clarify the physical features including structures, mechanisms, snow mass transport rate, etc. of drifting snow to prevent from disasters due to drifting snow. The vertical profile of horizontal snow mass flux is a fundamental structure of drifting snow. It is widely recognized that most of drifting snow particles are transported by saltation near the snow surface and that the thickness of the saltation layer is roughly 10 cm. (Kobayashi, 1978; Takeuchi, 1980). Above the saltation layer, snow particles are transported upward by turbulent diffusion in drifting snow and horizontal snow mass flux decreases rapidly with increasing height (Budd et al., 1966; Schmidt, 1986).

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Cold wind-tunnel experiments were carried out to understand the physics of the saltation layer of drifting snow. Maeno et al. (1985) measured some basic physical parameters in the saltation layer, including particle concentration profile, mean saltation lengths, particle diameter distribution, etc. Sugiura et al. (1998) investigated vertical profiles of mass flux for different particle diameters over loose snow surfaces and showed that smaller particles reach higher by saltation. Increment of shear stress due to snow particle saltation was measured by Nemoto and Nishimura (2001). Sato et al. (2004) illustrated increase of total snow transport rate with horizontal distance. The threshold friction wind velocity of snow particle saltation was investigated by Clifton et al. (2006). Although physical characteristics of the saltation layer have been studied as mentioned above, little is know about the effects of snow surface conditions on the structure of the saltation layer. Recently, Sato et al. (2001) and Kosugi et al. (2004) showed that mass flux profile and saltation lengths changed considerably as snow surface hardness changed.

In this study, wind-tunnel experiments of drifting snow were carried out to measure vertical profiles of mass flux in the saltation layer over hard snow surfaces. Mass flux was measured for different particle diameters using an optical device.
The results are compared with those obtained for loose snow surfaces.

2. METHODS

The wind-tunnel is installed in a cold room of the Cryospheric Environment Simulator at the Shinjo Branch, Snow and Ice Research Center. The length and cross-sectional area of the test section of the wind-tunnel are 14 m and 1 m x 1 m, respectively (Figure 1). The walls are composed by glass plates and metallic frames. The wind-tunnel has an air conditioner for fine temperature control. The temperature was maintained at -15 °C in the experiments. Compacted snow was sifted and splayed on the floor of the working section, forming a snow bed 2 cm thick with a flat surface. The snow bed was left for a night before the beginning of snow drifting to become hard by sintering. Thus, a hard snow surface was formed. Its average compression hardness was 65 kPa.

The center wind velocity of the test section was measured with a Pitot tube during the experiments. Vertical profiles of wind velocity measured with a hot-wire anemometer in the test section without snow drifting showed that the thickness of the boundary layer is about 15 cm. Steady snow drifting was produced by seeding snow particles at a constant rate at the upwind end of the test section. A filter is set at the downwind end to remove drifting snow particles away from the air flow. More details of the wind-tunnel are found in Sato et al. (2001) and Kosugi et al. (2004).

Two kinds of experiments were carried out.

Firstly, saltation of snow particles with different diameter was observed. Snow particles of different size, which were prepared by sifting, were supplied from the snow seeder. Snow particles in saltation were illuminated with a vertical sheet of laser and were photographed through the transparent walls of the test section. Secondly, horizontal snow mass flux was measured with a snow particle counter (SPC) mounted on the traverse device. A SPC is an optical instrument that measures the shadow size of each snow particle passing through a sampling area (2 mm x 25 mm). The shadow size is classified into 32 classes between 50 and 500 μm. Snow mass flux for each diameter class is obtained by counting the number of signals for each diameter class every second (Sato et al., 2001).
The SPC was placed at 8 m downwind from the upwind end of the test section and changed automatically the height from 1 to 10 cm above the snow surface every several seconds during the experiments to measure vertical profiles of snow mass flux (Figure 2). No significant erosion of the snow surface was observed during the experiments.

3. RESULTS

3.1 Observation of snow particle saltation

Figure 3 shows examples of photographs of saltating snow particles with different particle diameter over the hard snow surface. As shown in the figure, it is observed that larger snow particles reach higher over the hard snow surface. Similar phenomena were seen for different wind velocities between 6 to 8 m/s.

![Photographs of saltating snow particles with different particle diameters.](image)

Figure 3: Photographs of saltating snow particles with different particle diameters. Wind blowing at 8 m/s to the left. Distance from the upwind end is 8 m. The horizontal thick lines in the photographs are snow surfaces. The vertical thin lines indicate scales of 10 cm. Snow particle diameter ranges are (a) 125 - 250 μm and (b) 250 - 500 μm, respectively.

3.2 Vertical profiles of snow mass flux

The results of mass flux profile measurement for different particle diameters over the hard snow surface are shown in Figure 4. Snow mass flux for each particle diameter decreased exponentially with increasing height. Each of the vertical profiles was fitted by the following equation (lines in the figure):

\[ q_d(z) = A_d \exp\left(-\frac{z}{b_d}\right) \] (1)

where \( q_d \) is the horizontal snow mass flux for the particle diameter \( d \), \( z \) the height, \( A_d \) and \( b_d \) are constants. This equation is similar to that obtained for loose snow surfaces (Sugiura et al., 1998). The constant \( b_d \) is the inverse of the gradient of the mass flux decay with height. \( b_d \) also implies the height where mass flux equals to \( 1/e \) of mass flux at the snow surface. Larger value of \( b_d \) indicates that particle saltation reaches higher. Figure 4 shows slower decay in the mass flux as increase in particle diameter. This result coincides with the observation of saltation for different particle diameter, which is described in section 3.1.
Figure 5 summarizes the relation between the constant $b_d$ over the hard snow surface and the particle diameter for wind velocities of 6 m/s and 8 m/s. $b_d$ measured over loose snow surfaces by Sugiura et al. (1998) are also shown in the figure. $b_d$ increased with wind velocity for either hard snow surface or loose snow surface. This result implies that saltating snow particles reaches higher with increasing wind velocity regardless of the snow surface conditions. Measurements in wide wind velocity range are necessary for systematic investigation of wind velocity dependence of the vertical profile of snow mass flux. $b_d$ over the hard snow surface increased with particle diameter, whereas $b_d$ over loose snow surfaces decreased. The opposite particle diameter dependencies are likely due to the difference in particle impact and splash processes between hard and loose snow surfaces. More precise studies about the effects of snow surface properties and particle diameter on particle saltation are required to improve the estimation and prediction of snow drift transport.

4. CONCLUDING REMARKS

Drifting snow experiments were carried out in a wind-tunnel maintained at -15 °C. Vertical profiles of snow mass flux were measured with a SPC for different particle diameters over hard snow surfaces. The horizontal snow mass flux for each particle diameter decreased exponentially with increasing height above the snow surface. The constant $b_d$, the inverse of the gradient of the mass flux decay with height, increased with wind velocity. $b_d$ also increased with particle diameter. $b_d$ has an opposite particle diameter dependencies between hard and loose snow surfaces.

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REFERENCES


