CHANGE IN SNOW PARTICLES' SHAPE DURING BLOWING SNOW EVENT : EFFECTS ON THE SUSPENSION LAYER

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ABSTRACT: Wind-transported snow is a common phenomenon in mountainous and polar regions. Wind erodes snow from high wind speed areas and deposits it in low wind speed areas, thereby forming snowdrifts, cornices and wind slabs which may contribute significantly to avalanche releases. In this context, numerical simulation of drifting snow appears as a potential tool to support avalanche hazard forecasting. Part of the deposited snow is transported in the suspension layer and models simulate the vertical profile of blowing snow density in this layer. Our study focuses on the time evolution of this vertical profile during blowing snow events in order to detect the change in the snow particles shape during blowing snow events.

KEYWORDS: Drifting snow, blowing snow, wind, suspension, snow particle, shape, snow particle counter

1. INTRODUCTION

During a blowing snow event, snow particles are broken down and abraded when they impact the snow surface. Snowflakes are gradually transformed into rounded grains. Only few data are available in the literature about this subject. A drag coefficient modification between dendritic and rounded particles may result in a modification of settling velocity. The vertical profile of the blowing snow concentration in the suspension layer, generally represented by a power law, depends on the settling velocity. Hence we can expect that the study of vertical profile of blowing snow concentration will give us some information about the change in the snow particles' shape during blowing snow events.

This idea is the basis of the preliminary experimental studies carried out at Lac Blanc pass (2700 a.s.l.) in the French Alps and presented in this paper.

2. THEORETICAL BACKGROUND

According to Gordon et al. (2009), the vertical profile of blowing snow density, $C(z,r)$ (kg m^{-3}), for a given particle radius r at height z is governed by a turbulent diffusion equation including upward turbulent diffusion and downward gravitational settling. A power law profile is an analytical solution of this equation under equilibrium conditions and is written:

$$C(z,r) = C(z_{ref},r)\left(\frac{z}{z_{ref}}\right)^{-\frac{\sigma_s U_{F,r}}{\kappa u_*}} = C(z_{ref},r)\left(\frac{z}{z_{ref}}\right)^{-\gamma_{F,r}} \quad (1)$$

where $C(z_{ref},r)$ is a reference blowing snow density for a given particle radius r at height z_{ref}, $U_{F,r}$ is the average particle settling velocity for a given radius, K is the von Karman constant and σ_s is the Schmidt number. The underlying assumption is that a suspended particle travels downstream at a speed approximately equal to the wind velocity (particles horizontal speed = wind horizontal speed U(z)). The Schmidt number is the ratio between eddy viscosity (K_{s0}) and eddy diffusivity (K_s) (Dery et al., 1998).

Equation 1 is sometimes modified to give

$$C(z) = C(z_{ref})\left(\frac{z}{z_{ref}}\right)^{-\frac{\sigma_s U_{F,}}{\kappa u_*}} = C(z_{ref})\left(\frac{z}{z_{ref}}\right)^{-\gamma_C} \quad (2)$$

where $C(z_{ref})$ is the concentration for all particles sizes at the reference level z_{ref}, u_* is the friction velocity, U_F is the mean particle fall speed representing all particles sizes, and σ_s is the Schmidt number. The underlying assumption is that the size distribution does not change significantly with height.

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3. EXPERIMENTAL SITE AND RELATED SENSORS

The experimental site (Guyomarc'h et al., 2014) is located at Lac Blanc pass (2700 a.s.l.) in the French Alps (figure 1). This large north–south-oriented pass has been dedicated to the study of blowing snow in high mountainous regions since 1989 by Irstea – previously Cemagref and Meteo France.

Due to surrounding topography, 90% of observed winds blow from the northeast or the south. Snow transport is observed during 10% of the time in winter and occurs with concurrent falling snow 37% of the time (Vionnet et al., 2013).

Three (or four depending on the winter season) snow particle counters are mounted on a 3 m vertical mast which aims at better investigating drifting snow flux profiles (figure 2). A Jenoptik SHM30 laser snow depth sensor measures the exact position of the SPC above the snow pack and an heated ultrasonic anemometer Snow Particle Sensor supplements these devices. In this paper, we focuses on drifting snow events during which no snow-fall occurred (Naaim-Bouvet et al., 2014).

The Snow Particle Counter (SPC-S7, Niigata Electric) is an optical device (Nishimura and Nemoto, 2005). The diameter and the number of blowing snow particles are detected by their shadows on photodiodes. SPC detects particles between 40 and 500 µm in mean diameter divided into 32 classes and records the particle number every 1 s. Assuming spherical snow particles and a density of the drifting snow particles [kgm^{-3}] equal to 917 kgm^{-3}, the sensor is able to determine the horizontal snow mass flux [$kgm^{-2}s^{-1}$].

Fig. 1: The experimental test site at Lac Blanc Pass

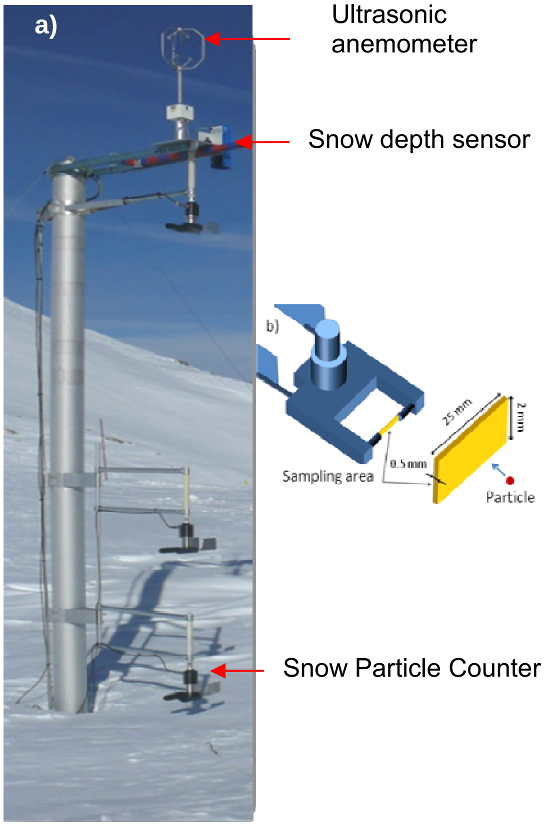

Fig. 2: a) the mast with 3 Snow Particles Counters, one snow depth sensor and an ultrasonic anemometer set up at Lac Blanc Pass
b) Schematic diagram of the SPC7

The joint use of ultrasonic anemometer (U(z), u_*), snow depth sensor (z) and Snow particle Counter profiles (C(z).U(z)) allows determining $\sigma_s U_F$ from equations 1 or 2 presented earlier.

4. RESULTS

4.1 Relation between $\sigma_s U_F$ and the friction velocity

- Reminder of previous results

Equation 2 (Naaim-Bouvet et al. (1996) Mann (1998), Mann et al. (2000), Gordon and Taylor (2009)) is generally used and the Schmidt number is considered equal to 1 (except in Naaim-Bouvet et al., 1996 and Naaim-Bouvet et al., 2013).

It was found that increase in $\sigma_s U_F$ (or U_F if we consider σ_s =1) depends on friction velocity ($\sigma_s U_F = Au_*$) The value of A range from 0.3 to 1 (Naaim-Bouvet et al. (1996 – A=0,4), Mann et al (2000 –

A=0,29), Gordon et al. (2009 – A=0,39), Naaim-Bouvet et al., (2013 – A=1.05)).

In these studies, it was considered that the increase in $\sigma_s U_F$ with friction velocity ($\sigma_s U_F$ =Au_*) is due to the larger particles being carried aloft at higher wind speed

- Results obtained in the present study

We focused on drifting snow events without concurrent solid precipitation but occurring just after a snow fall (Naaim-Bouvet et al., 2014). Besides, we chose to determine $\sigma_s U_F$ for a given particle radius r (equation 1). It was shown that for a given diameter, $\sigma_s U_F$ increases linearly with u_* (figure 3). This result was not expected. This trend was systematically observed in the studied events.

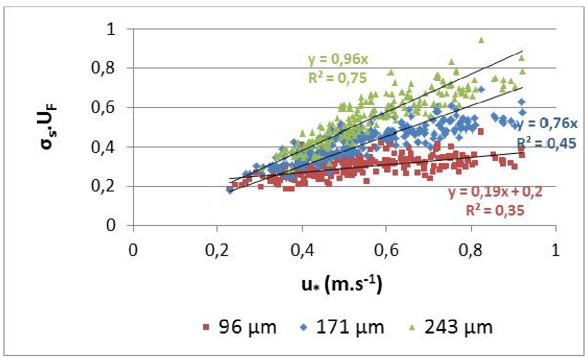

Fig. 3: $\sigma_s U_F$ as function of friction velocity for specific diameters.

It means that the previous explanation, generally accepted, is not sufficient. The increase in $\sigma_s U_F$ with friction velocity (observed when using blowing snow density for all particles size) is not only due to the larger particles being carried aloft at higher wind speed.

Other hypothesis may be suggested :

- σ_s depends on u_* (Rouault et al. (1991), Naaim-Bouvet et al. (2013)).
- Particles horizontal speed differs significantly from wind horizontal speed. (Nishimura et al., 2014)

4.2 Change in the snow particles shape during blowing snow event

Time evolution of the exponent γ_C for a blowing snow event without concurrent snowfall has been studied for a given particle diameter (figure 5). As $\sigma_s U_F$ depends on Au_*, even for a given diameter (paragraph 4.1), it is necessary to select periods with a similar friction velocity (figure 4). The value u_*=0.3 m.s^{-1} (+-0.02 m.s^{-1}) was chosen for the drifting snow event presented in this paper. The Time series of the mean diameter of particles drifted 1.1 m above the snow surface have also been drawn (figure 6).

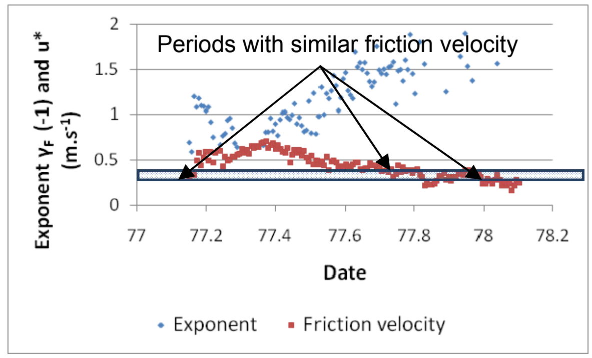

Fig. 4: Selection of periods with similar friction velocity on 18th March 2011 (Seventy-seventh day of the year)

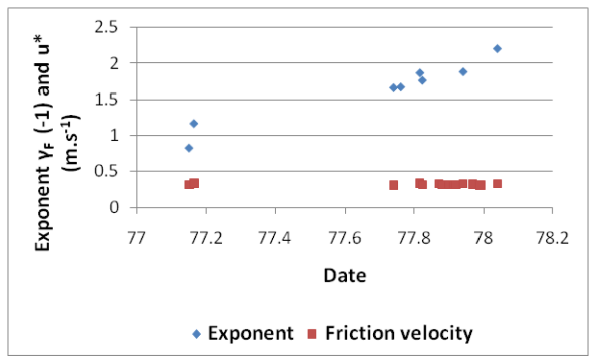

Fig. 5: Time series of the exponent γ_c for particles with a diameter of 171 µm for a blowing snow event without concurrent snowfall

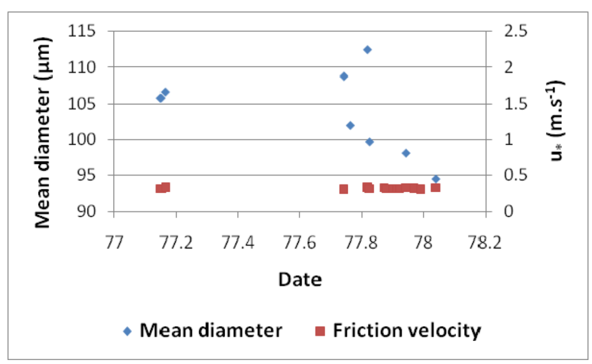

Fig. 6: Time series of the mean diameter of particles drifted 1.1 m above the snow surface

for a blowing snow event without concurrent snowfall

It can be seen that :

- For a given diameter the settling velocity seems to increase (figure 5).
- At a given height above the surface, the mean diameter of drifted particles seems to decrease (figure 6).

These results are consistent with a decrease of aerodynamic drag when mechanical fragmentation causes shape evolution (from angular to more rounded grains).

SPC profiles have been analyzed during two winter seasons (2010-2011 / 2011-2012) but this trend has been observed only for one event ! For the others, no clear trend appears.

It must be noted that the in-situ study of changes in the snow particles shape during blowing snow events based on the vertical profile of blowing snow density requires very specific conditions : a snow fall with dendritic snow flakes and a low wind speed (the dendricity and sphericity of falling snow grains are function of wind speed (Vionnet et al., 2013)) immediately followed by a drifting snow event without concurrent snow fall and with small changes in wind speed.

CONCLUSIONS AND PERSPECTIVES

The time evolution of the vertical profile during blowing snow events was studied at Lac Blanc Pass (2700 a.s.l.) in the French Alps. It aimed at detecting the changes in the snow particles' shape during blowing snow events. A profile of three (or four) Snow Particles Counters was used for the purpose.

It was shown that :

- *For a given diameter, $\sigma_s U_F$ depends on the friction velocity. This trend was consistent throughout the experiments.*
- *For a given diameter, the settling velocity increases over time. This is consistent with a decrease of aerodynamic drag when mechanical fragmentation causes shape evolution. But this result cannot be generalized because this trend was observed only for one event.*

Even if this methodology is interesting, experiments in the field are highly variable and non-reproducible. So they should not lead to definitive conclusions. Experiments in a recirculating wind–tunnel at a constant speed using fresh snow and the same methodology could be more appropriate.

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