Intermittent drifting snow – combining experimental and model studies

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ABSTRACT:. A study combining field observations and wind tunnel measurements of drifting snow is presented. In field measurements we found fluctuations of the snow mass flux on short time scales. From observations by eye and model results these may be ascribed to mass transport in coherent flow structures. The wind tunnel measurements do not show this type of flow structures, due to the restriction of the dimensions of the flow. However, we found increased fluctuations of mass flux of drifting snow with progressing erosion, which could be explained by the creation of surfaces ripples, which can break and release a large amount of snow particles in a short time.

KEYWORDS: Drifting snow, Large eddy simulation, wind tunnel.

1 INTRODUCTION

Snow transport due to wind has a large influence on the variability of mountain snow-covers and avalanches. Resulting from intense studies both in wind tunnels (e.g. Clifton et al., 2006), for example on the threshold wind speeds for drifting snow and in the field, our current knowledge enables simplified descriptions of drifting snow and estimates of the snow distribution on mountains over long time scales.

However, these studies also show that our process understanding is limited. Strong fluctuations in the snow mass flux on short time scales are poorly understood. Even though some factors can be excluded in wind tunnel studies, measurements taken with a high speed imaging system demonstrate the intermittency and complexity of the process. The intermittent behavior of drifting snow may have important consequences for the modeling of total snow mass flux, since the momentum coupling between wind and particles is highly non-linear. In this study we compare measurements of drifting snow obtained in the SLF wind tunnel and at the Weissfluhjoch Versuchsfeld.

Knowledge gained in these wind tunnel and field measurements is used in the development of a Lagrangian stochastic model based on wind fields from large eddy simulations (Groot Zwaaftink et al., submitted). First results showed that the model is able to describe intermittent drifting snow and may even capture the development of features similar to streamers. Moreover, a variable snow cover or a changing wind can be isolated to describe their effect on the drifting snow mass flux.

The insights gained from our measurements and model results will in future improve the prediction of snow mass flux in operational snowcover models like SNOWPACK.

2 FIELD MEASUREMENTS

At the Weissfluhjoch Versuchsfeld (2540 m above sea level, near Davos, Switzerland) drifting snow has been observed over a relatively smooth, gently sloped field (see Figure 1) in winters 2011 and 2012. Previous measurements of drifting snow at this location were reported by Doorschot et al. (2004). The current measurement setup included vertical profiles of the snow mass flux, temperature, humidity and wind over approximately 2.5 m which were continually recorded. Additionally, snow properties such as snow density were observed during several snow fall or drifting snow periods. The snow mass flux measurements presented in the results section were obtained at approximately 1 cm above the snow surface with a Snow Particle Counter (SPC, e.g. Sugiara et al., 1998) on a resolution of 1 s.

Figure 1. Sensors deployed at Weissfluhjoch during winter 2012/13. The particle streaks most likely due to the coherent vortex structures can be seen on the image.

3 WIND TUNNEL MEASUREMENTS

An open circuit wind tunnel situated outside Davos in the Flüela valley in a former Swiss ammunition bunker at 1650 m above sea level was used to study wind blown fresh snow. The wind tunnel comprises a contraction through which air from outside is entrained and led through a 6 m flow conditioning section (for details see for example Clifton et al., 2006). For the measurements in winter 2011/12 the floor in this section was flat wood, while for the measurements during winter 2012/13 the flow was conditioned by 4 regularly spaced spires of height 50 cm of triangular shape and base length 5 cm. Additional roughness elements of width 3 cm, height 1 cm and length 1.5 cm with a density of 190 per m^2 were mounted on the floor. The flow conditioning section was followed by a 8 m long section with a floor that can be adjusted in height to obtain a smooth transition to the snow surface and takes the snow trays. Before the experiment, these trays were exposed to natural precipitation of snow outside of the wind tunnel. The wind tunnel ends with the fan that sucks the flow through it to be able to generate low inflow turbulence.

The ceiling of the wind tunnel was adjusted in height so that the pressure gradient along the test section was below 5 Pa at 10 m/s. The mean air flow of the free stream was measured approximately 70 cm above the snow cover by a mini Air fan anemometer together with the temperature. The relative humidity was measured on the ceiling of the tunnel approximately 3 m upstream of the position where the images of the drifting snow particles were obtained.

A high speed camera (HighSpeedStar 5.1) with resolution 1024 times 1024 pixel was used to record the shadow images of the snow particles, which were illuminated from the opposite site of the wind tunnel by a 1 kW lamp. To smooth the light intensity a translucent paper was placed in front of the lamp.

4 RESULTS

An example of time series of the wind speed and snow mass flux obtained from field measurements briefly after snowfall are shown in figures 2 and 3. Fluctuations of the snow mass flux are up to two orders of magnitude over this period and can be split in time scales of minutes and seconds. We find different mechanisms behind the fluctuations on these two time scales. On time scales of minutes (figure 2), the snow mass flux signal correlates with the measured wind speed. However, on smaller time scales (figure 3) we see more random like fluctuations. While several explanations are possible, such as spatially inhomogeneous snow properties, we suggest that these can be related to streamwise coherent vortex structures leading to aeolian streamers, see for instance fig. 1, Baas (2008) and Baas and Sherman (2005). Our recent model simulations of drifting snow on short time scales support this. Groot Zwaaftink et al. (submitted) have simulated drifting snow by using Large Eddy Simulations (LES) and a Lagrangian stochastic model to describe particle trajectories. The results showed that aerodynamic entrainment of snow driven by the spatially varying surface shear stress (obtained from the LES) induced a spatially varying snow mass flux and streamer-like formations appeared to be formed, even though the snow properties were homogeneous.

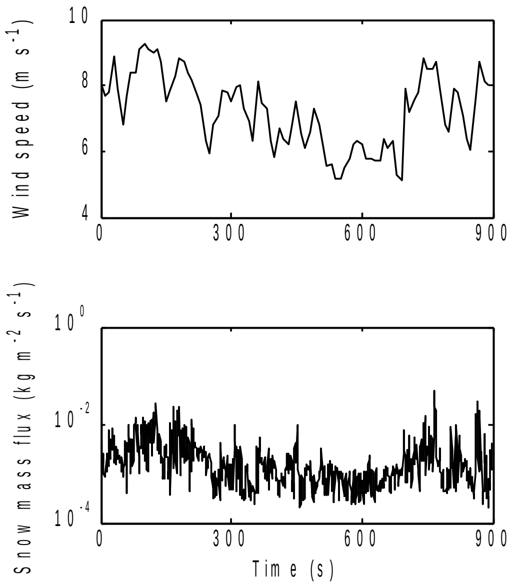

Figure 2. Wind speed at about 2 m above the snow surface (top panel) and the observed snow mass flux (bottom panel) over a period of 15 minutes as observed at Weissfluhjoch Versuchsfeld on 8 February 2012.

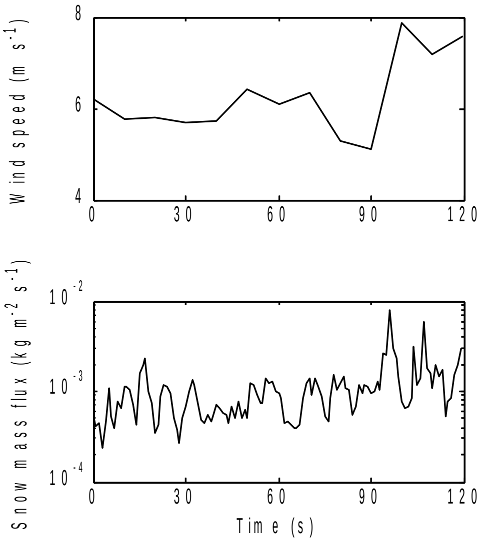

Figure 3. Wind speed at about 2 m above the snow surface (top panel) and the observed snow mass flux (bottom panel) over a period of 2 minutes (selection from the period shown in Figure 2). Note that snow mass flux measurements were obtained at 1s-resolution and wind speed measurements are 10s-averaged values.

In the wind tunnel, on the contrary, such coherent vortices are much smaller due to the smaller Reynolds number and the maximum possible flow length scales. Therefore, snow particles cannot form streamers. Our measurements, however, show that fluctuations of the snow mass flux on short time scales appear nonetheless. Figure 4 presents such a series of measurements in the SLF wind tunnel. As for the field experiment, measurements were done for a fresh, undisturbed snow surface. Comparing with Figure 2 it is clear that the variability drifting snow was smaller than for the field measurements, since the wind was kept level and the coherent structures could not form. However, for longer erosion times we found increased fluctuations of drifting snow in the wind tunnel. Figure 4 shows the time series for fresh snow which became gradually eroded. For the first 200 s the signal shows random fluctuations and for larger time becomes spikier, with larger maxima and deeper minima compared to the beginning. We attributed the maxima to the creation of surface ripples, which could be named mini-zastrugi, see fig. 5. In case these break off, a large amount of particles is released in a short time. The minima, which are close to zero, meaning that drift ceases for short periods might be related to the fact that loose snow on the surface has been removed. The underlying snow that is now exposed may have bonded and can therefore not be entrained by the flow. The fact that the drifting snow period is merely interrupted and not finished, may indicate that once the bonds between the snow particles are sublimated the snow particles are entrained.

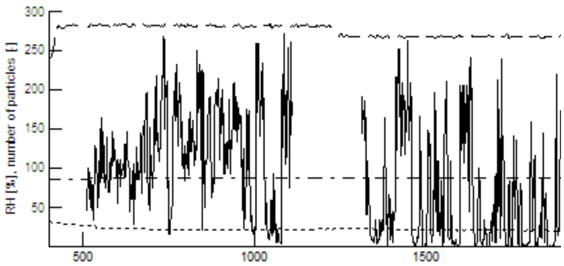

Figure 4. Time series (units x-axis: s) of detected particles number in the wind tunnel.

This comparison of wind tunnel and field measurements reveals some relevant differences on short time scales that need to be accounted for when for instance using wind tunnel data to validate model simulations. Moreover, they show that the influence of different factors, such as the variability of snow properties and turbulent structures, on the intermittency of drifting snow are hard to quantitatively distinguish as they act on different scales. This may be possible with model simulations such as presented in Groot Zwaaftink et al. (submitted).

5 SUMMARY AND CONCLUSIONS

In this study we qualitatively compared measurements of the fluctuations of the mass flux of drifting snow from a wind tunnel and a field experiment. We conclude that in the field measurements the coherent vortices are contributing short time scale fluctuations of drift. The wind tunnel measurements do not show this type of flow structures, due to the restriction of the dimensions of the flow. However, we found increased fluctuations of mass flux of drifting snow with progressing erosion, which could be explained by the creation of surfaces ripples, which can break and release a large amount of snow particles in a short time. This mechanism will also be present in the field, although it could not be observed directly in this study.

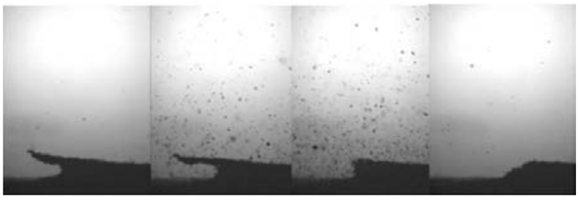

Figure 5. Break down of surface structure during set 1, from left to right: 400 s after start-up, 800 s after start-up, immediately before breakdown, just after break down. Flow was from left to right.

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