THE ACOUSTIC SNOWDRIFT SENSOR: INTERESTS, CALIBRATION AND RESULTS

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ABSTRACT:

During a drifting snow event, it seems to be important to know the flux of blowing snow. Indeed, the height of the snow accumulation in an avalanche departure zone and also snowdrift on roads depend on this quantity.
In order to estimate this flux, we have developed at Cemagref, in collaboration with Hydroemac, an acoustic snowdrift sensor. It is made of a microphone located in an aluminum pole. The pole is exposed to the snow particle flux and the sound produced by the particle impacts is recorded as an electrical signal. However, this signal depends not only on the particles flux, but also on the type of particles, the presence of a snowfall or not, the wind noise on the sensor, etc. Therefore we have done experiences, both in situ on our experimental site of high altitude called Col du Lac Blanc, and in a climatic wind tunnel (CSTB, France), in order to calibrate our sensor i.e. to establish a relation between the signal on the sensor, and the flux of particles. Moreover, thank to this sensor, we obtained information concerning the threshold velocities of erosion and deposit, and relations between wind and drifting snow. This paper presents our results.

KEYWORDS:

Drifting snow – snowdrift – acoustic sensor – flux – threshold velocities

1. INTRODUCTION

Cemagref's Etna division and Cen of Meteo France have been working together on drifting snow for ten years At the present time, we are developing an acoustic snowdrift sensor, which aims at measuring the flux of drifting snow. Indeed, the flux of drifting snow is an input required by our model of snowdrift (Naaim and others, 1998). We are calibrating this sensor, which is sensitive to the flux, but also to parameters such as the wind or the type of snow particles. Therefore, we need to determine the effect of each parameter, in order to gauge the sensor. To this purpose, we have realized experiments, both in situ, on our experimental site of high altitude, at Lac Blanc Pass, near the ski resort of Alpe d'Huez (France), and in a climatic wind tunnel at CSTB (Nantes, France). This paper presents the first steps of the calibration, which were realized this year, and the present use of this acoustic snowdrift sensor.

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2. CALIBRATION OF THE ACOUSTIC SNOWDRIFT SENSOR

2.1. *Technical aspect of the sensor*

Cemagref's Etna unit has developed an acoustic snowdrift sensor (Fig. 1.), in collaboration with Hydroemac (Font and others, 1998). It is basically a miniature microphone located at the base of a 2 m long aluminum pole. The pole is exposed to the snow particle flux, and during snowdrift, part of the flux impacts on the pole. The sound produced by these impacts is recorded as an electrical signal. The lower-frequency signal produced by the wind and the higher-frequency signal, outside of the audible range, are filtered out. The recorded output voltage indicates when snowdrift occurs.

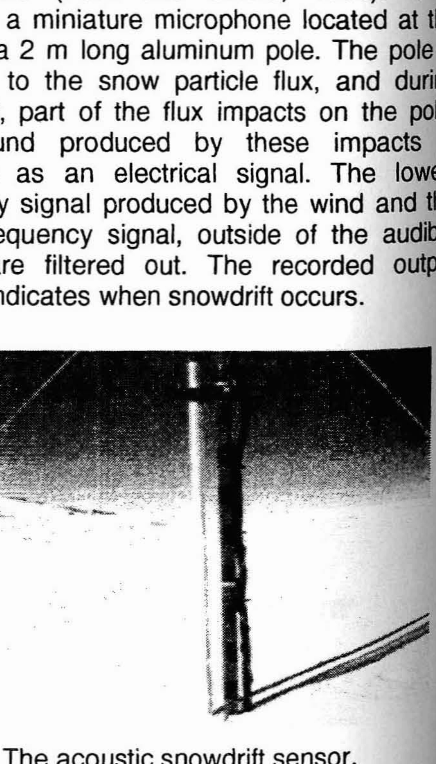

Figure 1: The acoustic snowdrift sensor.

2.2 *Experiments in the climatic wind tunnel of CSTB*

Description of experiments

In order to gauge the acoustic snowdrift sensor, we have realized ten days of experiments in the climatic wind tunnel of CSTB (Nantes, France), on the framework of an European project. This wind tunnel of 26 m length, 10 m width and 7 m high, allows to work with extreme conditions such as temperature of -15°C, regular or gust winds up to 25 m.s-1; and also to produce artificial snow, thanks to snow guns (Fig. 2). The advantage of this wind tunnel is to permit the realization of many experiments in a short time, with well-controlled parameters.

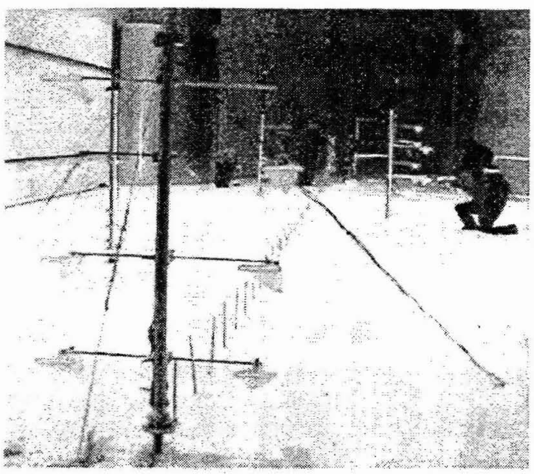

Figure 2 : the wind tunnel of CSTB.

Wind noise on the sensor

A part of experiments realized in the wind tunnel of CSTB was devoted to the determination of the wind signal on the acoustic snowdrift sensor.
To this purpose, we have first realized two types of experiments without snow:
The first one consisted in increasing regularly the wind speed in the wind tunnel, from 3 to 23 m.s-1, and at the same time to record the signal on 6 acoustic snowdrift sensors, fixed in the wind tunnel. The second experiment was similar, except that the wind was blowing by gusts, and not regularly. Gusts had an average wind speed of 10 m.s-1, then 20 m.s-1, and an amplitude of 2.5 m.s-1
The first step of the data processing was the elimination of the wind tunnel noise (fans, vibrations and motors) on the data. To this purpose, we smoothed data, averaging their on 1 minute, whereas the initial recording was every second.
The two experiments produced similar results (Fig. 3):

- A wind lower than 11.4 m.s-1 does not create significant signal on the sensor
- For a wind speed higher than 11.4 m.s-1, the wind signal can be taken as a linear function of the wind speed, in a first approximation:

$$S_{wind} = 15*V_{wind} - 121 \ (R^2=0.7), \qquad (1)$$

- where S_{wind} is the signal produced by the wind and v_{wind} is the wind velocity.

This law is working with errors from 20% to 80% on the signal value due to the wind, depending on the wind speed. These errors seem to be important, however they keep small relatively to the signal during a drifting snow episode.

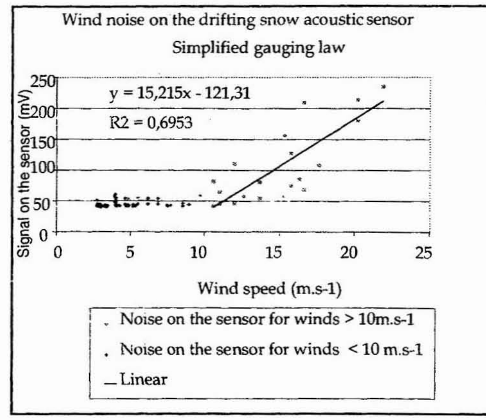

Figure 3: Wind noise on the acoustic snowdrift sensor.

Relation between signal and flux:

The mass flux of drifting snow is one parameter in our numerical model. Up to now, the mass flux has been inferred from the wind speed by means of an empirical law (Pomeroy and Gray, 1990). However, to improve the model, we would like to obtain measurements of the flux, in order to take into account snowfalls. Therefore, we plan to calibrate the acoustic sensor, in order to deduce the flux of drifting snow from the recorded signal. Therefore, we have realised experiments in the CSTB wind tunnel in which we compared the average mass flux during one experiment, and the average recorded signal.
The mass flux was determined using mechanical snow traps. These snow traps, called "butterfly nets", have a rectangular metal frame (15 cm* 2 cm) with an attached nylon bag. The traps, facing the prevailing wind direction, have been fixed at different heights on a pole, next to the acoustic sensor (Fig. 2). We obtain the drifting snow flux by integrating the mass weight at each height.
These values of flux were compared with the average signal on the snowdrift acoustic sensor, for each experiment, with regular winds or gusts.

These firsts results seem to be interesting. The signal on the snowdrift acoustic sensor is proportional to the flux of drifting snow (Fig. 4). This result is a preliminary. It was done with a given type of snow (artificial snow) in the cold wind tunnel of CSTB. Furthermore, studies have shown that the signal depends on the type of snow which hit the pole (see 2.3.) Therefore, for the future, we would like to obtain a gauging which links a given signal with a flux, for a given meteorological event (temperature, snow type, etc.). This sensor will be coupled with the model CROCUS of Météo France (Brun and others, 1992), which simulates the snow type in the snow mantle.

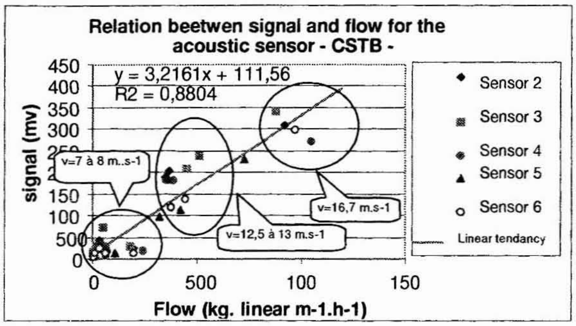

Figure 4: relation between flow and signal on the acoustic snowdrift sensor. Preliminary results for experiments in the wind tunnel of CSTB.

2.3. Experiments in situ, at Col du Lac Blanc

Description of the experimental site

In order to follow the three-dimensional spatial distribution of snow during the winter and to determine where snow accumulates and settles for a given meteorological event, we set up two networks of metallic snow poles at Lac Blanc Pass (Guyomarc'h and others., 2000). The prevailing winds at Col du Lac Blanc are from the North or South. The high wind speeds and the snow cover are favourable to drifting snow. On this site, a square of 20 poles and a 200 m long profile of height poles have been set up (This area is both an erosion zone (near the pass) as well as an accumulation zone (Michaux and others, 2000). We climbed to this experimental site at least once a week, depending on snowdrift event forecasts, in order to measure the snow depth at each snow pole. In addition, a stratigraphic profile of the snowpack and a ram test were carried out to collect data on the time progression of the snowpack and the depth of the snow. Automatically recorded meteorological data complete these measurements. A data logger recorded the following parameters every 15 minutes (with a scan rate of 1 second): average, maximum and minimum wind speed, direction, precipitation, and temperature. Another weather station situated nearby has been equipped with an ultrasonic sensor which measures the snow depth.

Nevertheless, all these meteorological data are not sufficient to test the numerical model; the snow mass flux and the threshold velocity are also necessary for these calculations. For that reason six acoustic sensors were installed along a 200-m profile. These sensors are located in the erosion area, in the transport zone and in the deposition zone.

Variation of the signal with the type of snow

The following graph (Fig.5) illustrates the signal recorded by the acoustic snowdrift sensor (average signal over 15 minutes versus the wind velocity) for various snowdrift episodes at Col du Lac Blanc and thus for different snow types. In order to determine the snow type, we decided to rely on the SAFRAN (Durand and others, 1993)-CROCUS (Brun and others, 1992) model, for two reasons. Firstly, we were not always on our experimental site at the beginning of the drifting snow event and thus we have no other information about the snow type. Secondly we are developing a connected model in which the output of SAFRAN-CROCUS is going to be the input of our numerical drifting snow model NEMO (Naaim-Bouvet and others, 2000).

On March 4, 1998, we observed an episode with both snowfall and wind that appears as widely scattered data points in Figure 5. In this case, the mass flux was correlated both with the wind speed and the snowfall intensity, which was not constant. This scattering of data was always observed in episodes of snowdrift with snowfall during the winter.

The signal induced by rounded grains was higher than the one generated by new snow or faceted grains (Fig. 5) However, we should keep in mind that this difference in signal might be caused by a shift of the signal due to the variation of the snow depth around the sensor during the month of March. Fig. 6. shows the evolution in time oft the snow depth at sensor n° 5; the increase during March is caused by snowfall events without wind. The difference between signals for various types of grains was smaller for another sensor where the snow depth variation was less (Fig. 7). These observations confirm that a snow depth sensor must be added to the acoustic sensor in an operational use. This will allow a correction of the data with regard to the ideal situation on which the sensor was calibrated (erosion area without snow).

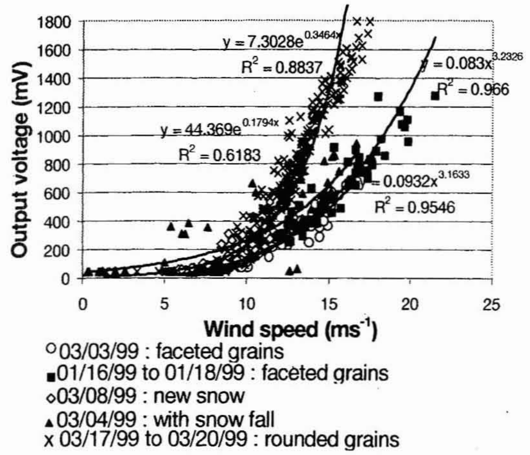

Figure 5: Voltage (mean value over 15 min) from acoustic sensor no. 5 versus wind speed (mean value over 15 min) for different drifting-snow events.

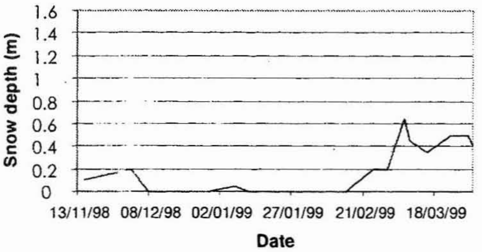

Figure 6: Evolution of snow depth near acoustic sensor no.5 during the winter of 1998-99.

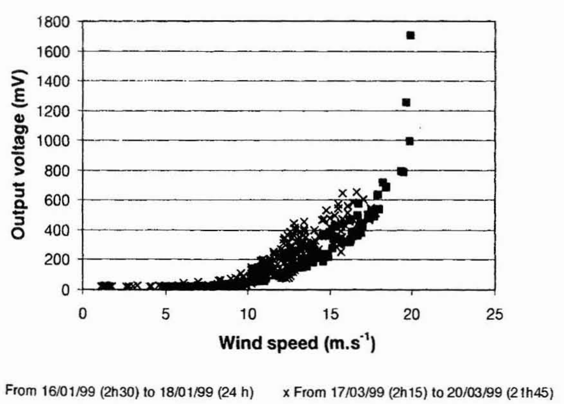

Figure 7: Voltage (mean value over 15 min) from acoustic sensor no. 1 versus wind speed (mean value over 15 min)

3. FIRST RESULTS

3.1. *Determination of drifting snow periods*

This acoustic snowdrift sensor is for the moment operational as a detector of snowdrift episodes. It indicates when snowdrift occurs, and values on the signal give information about the intensity of the drifting snow episode.

In figure 8, we present an example of the signal observed on the sensor, during a drifting snow event.

Figure 9 shows the results of one year of drifting snow on our experimental site of Col du Lac Blanc; the sensor detected these episodes. This use of the acoustic snowdrift sensor permitted us to create a database of snowdrift events on our experimental site, with many parameters (snow depth, wind speed, temperature, etc.) (Guyomarc'h and others, 2000). This data base will be use in order to perform our numerical model of drifting snow.

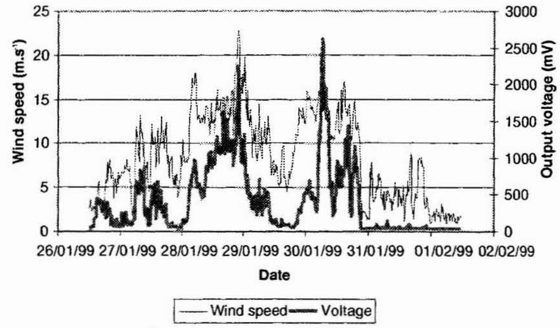

Figure 8: Wind speed and drifting snow from January 26 to February 1.

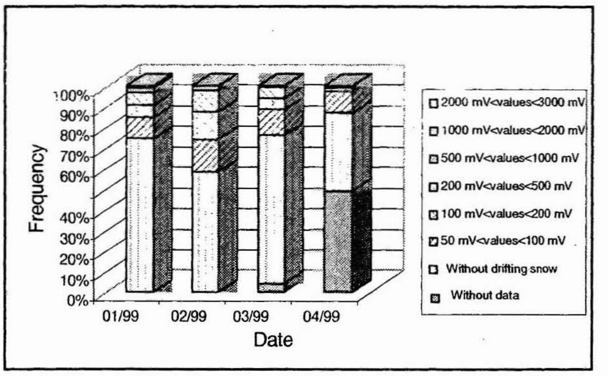

Figure 9: Occurrence of drifting-snow events.

3.2. *Hysteresis phenomenon for threshold velocities*

This sensor is an important tool, not only for engineering and detection of drifting snow episodes, but also for research on drifting snow. For example, it allowed us to highlight the phenomenon of hysteresis of threshold velocities for erosion and deposit. Indeed, we observed during experiments in the climatic wind tunnel of CSTB, that the signal on the sensor for a given wind speed is lower during the increasing phase of the event, than during the decreasing phase. The threshold velocity of erosion (which is the minimum wind speed for which there is erosion of snow) is higher than the threshold velocity of deposit (threshold wind speed below which there is deposit) (Fig.10).

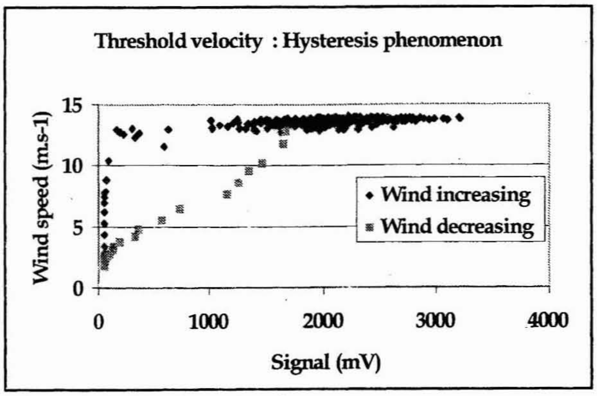

Figure 10: Hysteresis phenomenon.

3.3. _The snowdrift: a non-linear phenomenon_

The gust factor relating to the signal of the acoustic snowdrift sensor, defined as the ratio G_s = maximum signal of the acoustic sensor / average signal, can provide information about the snowdrift. To this purpose, we used an acoustic snowdrift sensor located at our experimental site of Col du Lac Blanc. We first removed the offset of the sensor (50mV). Then, we filtered out the average signal less than 5 mV, because lower values do not correspond to snowdrift. The gust factor was then calculated every 15 minutes for the whole winter (scan rate of 1 second) (Michaux and others, 2000).

We calculated also the wind gust factors. Thanks to these data, we highlighted two types of drifting-snow events:

- A first type of periods of weak snowdrift,
- A second type of periods of heavy snowdrift.

The first scenario (weak snowdrift) corresponds to areas 1 and 3 in Figure 11, and areas A and B in Figure 12. In the first case (area 1 in Figure 11 and A in Figure 12), high wind gust factors were found, indicating highly gusty winds, but very low average snowdrift signals and snowdrift gust factors were observed. Thus, this scenario does not show significant erosion, snowdrift, and deposition. The second case (area 3 in Figure 11 and B in Figure 12) is characterised by gusty snowdrift episodes with sporadic wind gusts generating moderate snowdrift.

The second scenario (heavy snowdrift) corresponds to zone 2 of Figure 11 and part C of Figure 12. Due to the limited output voltage of 5000 mV for the acoustic sensor, the maximum snowdrift gust factor is 50 for average signals greater than 100 mV, causing the cut-off in Figure 12. This type of snowdrift occurs during more regular wind episodes characterised by low wind gust factors.

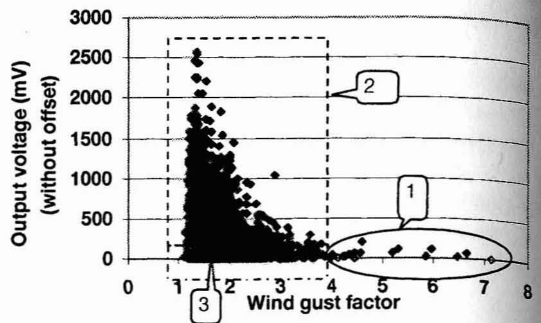

Figure 11: The average snowdrift signal on acoustic sensor no 5 at Col du Lac Blanc.

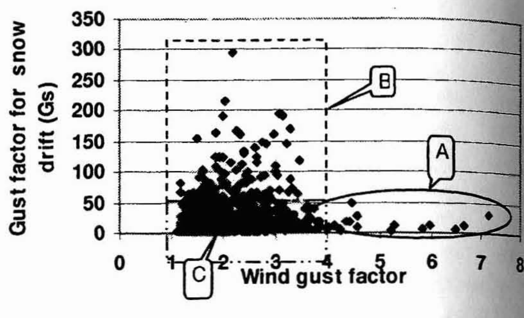

Figure 12: The snowdrift gust factor recorded by acoustic sensor n°5 at Col du Lac Blanc.

This study of the snowdrift gust factor demonstrates that snowdrift is more substantial/voluminous when it is generated by a regular, sufficiently strong wind than when it appears with sporadic wind gusts. This important result will allow us to somewhat simplify the numerical model of drifting snow used at Cemagref.

4. CONCLUSION

The calibration of the acoustic snowdrift sensor is going well. We have realized preliminary validations concerning the wind noise on the sensor and the relation between signal and flux, thanks to experiments, both in situ at Lac Blanc Pass, and in the climatic wind tunnel of CSTB. We highlighted the problems that we need to solve in order to gauge the sensor, in particular the fact that each type of snow might produce a particular signal on the acoustic sensor, and that a snow depth sensor must be added. At the present time, the sensor can be used as a detector of drifting snow periods. We thus created a database concerning snowdrift periods on our experimental site. This data base will be used in order to perform our drifting snow numerical model. Moreover, it has yet allowed us to find interesting results, concerning threshold velocities of erosion and deposit, and also concerning the meteorological conditions which can generate an important event of snowdrift (regular high wind speed is more favorable to snowdrift than high wind gusts). The next step of the calibration will be the determination of the accurate link between signal and flux for each type of snow.

5. ACKNOLEDGMENTS

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