# Test of a Multiplex Snow-depth Sensor along a Down Slope

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## ABSTRACT

For 2 years, the CEN (Centre d'Etudes de la Neige - Snow Study Centre) has been making snow depth measurements on a location of avalanche starting zone which undergoes snow transport by wind. The goal of this work is a refined study of the temporal evolution of a snow profile.

The experimental site, already used for studies on blowing snow periods characteristics, is located in the French Alps near Grenoble, at an altitude of 2800 meters. A slope has been instrumented with a set of 7 snow-depth sensors using ultrasonic waves. These sensors have been set up between two pylons. The device delivers measurements every 15 minutes. Concurrently, monitoring of meteorological conditions is achieved on a nearby site. The first snow-depth records show that, in most cases, this equipment does not suffer from heavy snowfalls, hoar frost and strong wind velocity. However, statistical post-processing is needed to eliminate bad values.

This experimental equipment is expected to provide a link between field observations of snow characteristics and our theoretical understanding of the necessary time to erode or accumulate snow quantity according to snow-grain morphological features.

This paper describes the development and experimental testing of the installation, then the observations used to correlate weather conditions, snow particles features with evolution of snow pack are presented.

## INTRODUCTION

### Study framework

The effect of wind on snow grains begins during precipitation. The weak structures of crystals are quickly fragmented and their size decreases. Immediately after a snowfall, snow flakes begin to move as soon as wind velocity reaches a threshold characteristic of each snow particle. The threshold usually increases with time, depending on air temperature, crystal characteristics and the quality of the cohesion between snow particles [Guyomarc'h and et al., 1994]. So, these snow grains produce accumulations with more or less high cohesion and hardness. Redistribution of the snow by the wind is essential for snow-slab formation. Snow particles are picked up in windward zones where the wind near the snow cover surface is efficient and deposited in leeward zones. This deposit is often at the origin of an overload that can lead to slab avalanche release.

### Research directions

After much research works on blowing snow, snowdrift accumulations and, more generally, on wind effect on the snow distribution in high mountainous regions [Castelle, 1994], it appears that understanding the evolution of a snow pack which undergoes wind effect should also result in taking into account more effectively of the erosion or accumulation rate of an amount of snow thickness at the starting zone of avalanches.

In order to improve our current understanding, at the present time, based on empirical knowledge, visual observations of calibrated wooden snow poles (apart from about 5 meters) have been first acquired. However under bad weather conditions, it was impossible to have access to the location and to obtain data regularly. In other respects, for our studies on snow transport by wind, we need to focus on real time snow depth evolution data. These data need to be compared to real time weather information. Such a correlation would provide a much more accurate picture of snow evolution due to wind effect at the snow surface.

Unfortunately, it seems that such a set-up does not exist, especially to follow the evolution of the snow pack surface. For these reasons 2 years ago, the CEN has started to develop and experiment a new device based on a set of snow depth sensors. These sensors have been set up on two cables stretched between two pylons on a east-faced slope. A first test of this apparatus, named "Profileur", was carried out during the last 35 days of 1994-95 winter season. Over the winter season of 1995-96 3 sensors were added and data of the whole season recorded.

## PRESENTATION OF THE DEVICE

### What difficulties must be resolved?

The most important point was to be able to have good working order whatever the weather conditions. Secondly, our installation has to deliver regular information in real time and if possible, be easily transmitted to Grenoble. Interaction between the installation and the environment must not occur and its access must not be too difficult during winter season. Last but not least, the cost of the installation has not to be too high.

### What kind of sensor can be used?

For several years the CEN has attempted to elaborate a sensor based on ultrasonic wave to measure the snow depth at high mountainous locations. The basic principle is the following : the travel time of ultrasonic pulses emitted by a transducer fixed about 6 meters above the ground and reflected by snow surface back to the transducer is measured. This transducer works successively as a transmitter and then as a receiver. The microprocessor calculates the snow thickness according to three parameters: travel time, height of the sensor above ground level and air sound velocity. As the last parameter is temperature dependent, the air temperature is measured in a ventilated shelter and taken into account in the calculation. This sensor is the result of many improvements over the years and now gives an accuracy of ±1 cm, whatever the characteristic of the snow surface. The reliability of this kind of sensor has been proven, even during snowfalls (figure 1) and allows us to precisely mark accumulations, packing down and melting periods [Lecorps and Sudul, 1989].

The idea of designing a set of several acoustic sensors to follow the evolution of the snow surface, led to the device as shown in the figure 2 and photo 1.

Some hardware and software adaptations to the initial device were needed. A multiplex system has been developed to achieve the monitoring of all sensors, one after the other (figure 3), a sampling rate of 15 min. used, and the data are recorded on a computer placed in a shelter on the mast. It is possible to use the telephone network in order to consult the system and to collect the most recent data.

### Where can the sensor device be installed?

The "Dôme des Petites Rousses", located close to the ski resort of Alpe d'Huez (south-east of Grenoble-France), was chosen as the best study area because of:

- the relatively complete record of meteorological data (wind velocity and direction, air temperature, water equivalent of precipitation). These data are available on an hourly basis from the start of November to the end of April for 5 years.
- the proximity of our experimental site on snow transport by wind (Col du Lac Blanc - 2700 meters a.s.l.).
- the easy access by the Vaujany cable car whatever the weather conditions.
- the complete observation of avalanche activity (natural or artificial) made by the ski patrollers of Alpe d'Huez ski resort.

Moreover, the slope is perpendicular to prevailing wind, subject to high altitude weather conditions (as high wind speed, hoar frost formation, strong precipitation,...) and is relatively steep (gradient of about 35°).

### Processing and Graphs

Unfortunately with data that are collected in such an environment, input is not always consistent. The main problems to be resolved can be summarized as follow:

- strong average winds (> 25 m/s) can shake cables and deviate ultrasonic pulses. Then, the pulses which are sent back by the snow surface are unable to reach the receiver.
- heavy snowfalls can induce interferences leading to wrong measurements.
- the frost (photo 2) can stiffen and overload the whole framework of the system. It can obstruct the sensor opening and can be at the origin of mechanical vibrations.

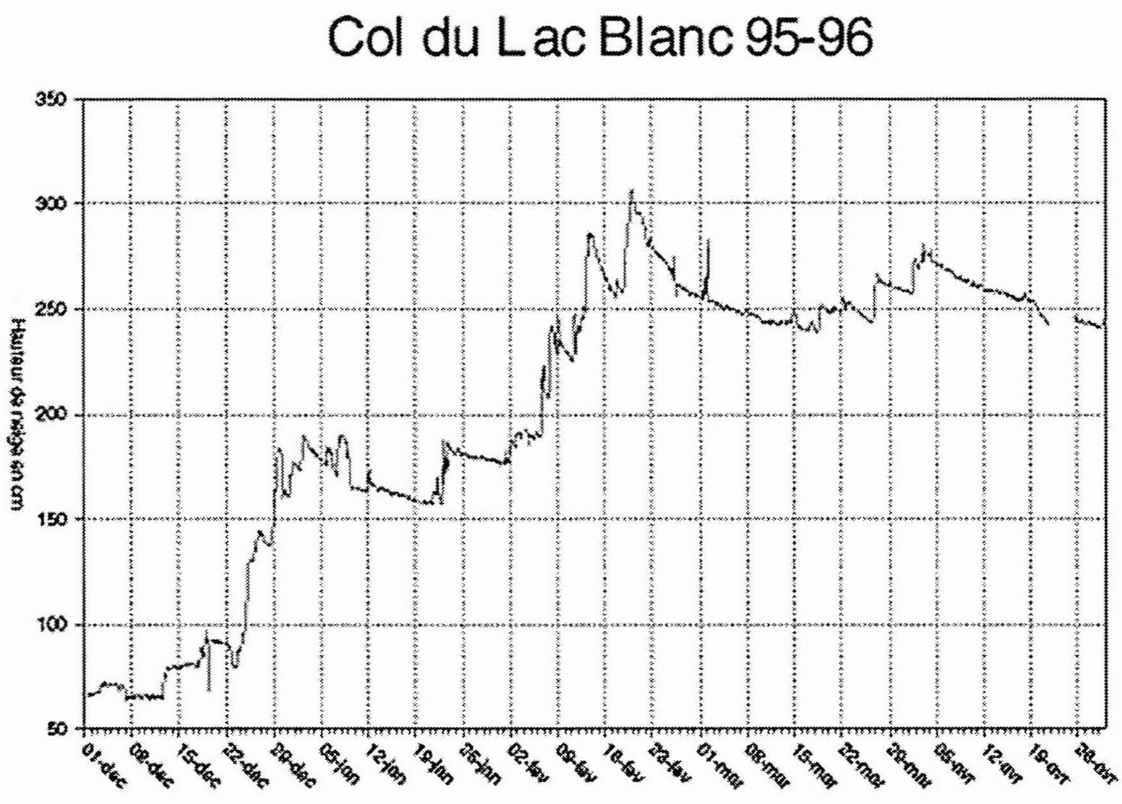


Figure 1 : graph of snow thickness at the "Col du Lac Blanc" (2700m) using a snow depth sensor.

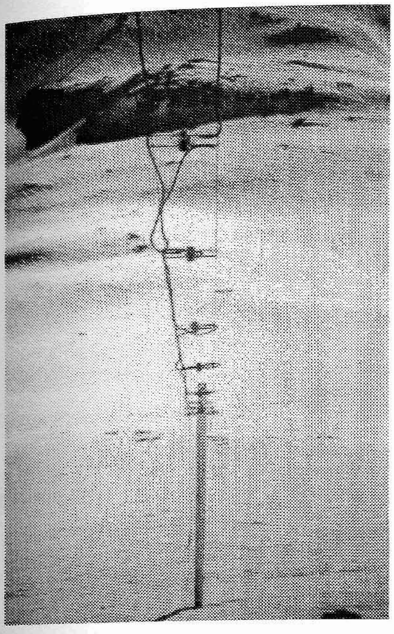

Photo 1: View of a part of the apparatus above the "Col du Lac Blanc" location.

Photo 2: Photograph of a heavy frost period.

Wrong values can be eliminated through a statistical post-processing. This last one is able to restore the missing data in certain conditions. The snow pack thickness is represented by the 7 sensor measurements in order to obtain consistent data and a general view of the snow profile along the slope. This processing follows four steps: a first smoothing of extreme data, checking of real presence of at least 4 sensor's data, missing values are replaced by a moving average method (only if no more than one value is missing after another) and a final smoothing by the previous method for the whole period (figure 4).

In addition to this processing, some statistical parameters can be analysed. For example, it is interesting to compare each sensor data with the smoothing average in order to display their particularity. On the other hand, the standard-deviation of the snow-depth profile can be calculated at each time interval. It appears that when the standard deviation is high, the behaviour of the sensors is obviously different. The snow surface does not undergo the same modifications all along the slope.

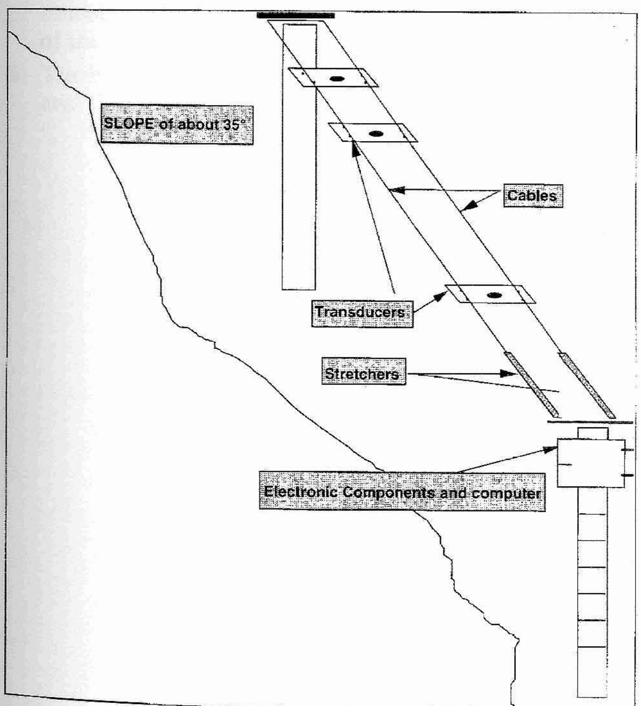


Figure. 2: scheme of our "profileur" installation.

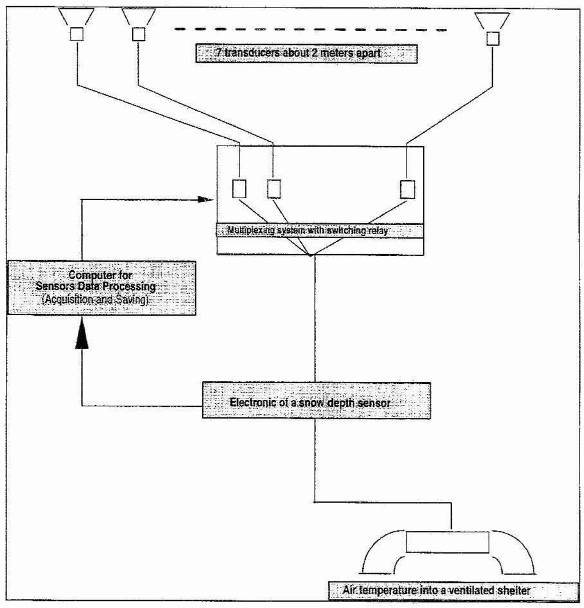


figure 3

Figure3 : synoptic diagram of the apparatus.

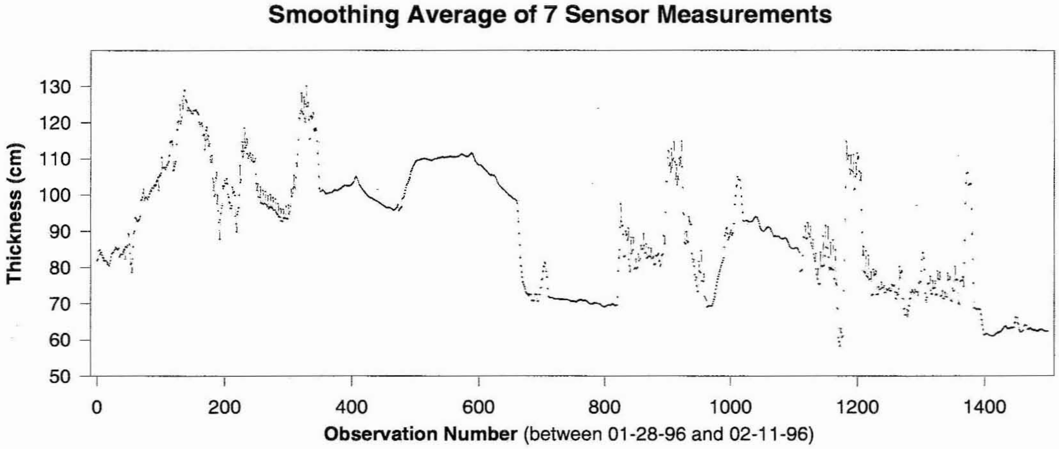


Figure 4: graph of a 95-96 season period (between January 28th and February 11th 1996). The wrong values have been replaced by the moving average method and then the data have been smoothed.

## FIRST OBSERVATIONS ON THE CORRELATION WITH SNOW TRANSPORT BY WIND

### Focus on a blowing snow period

The major aim of this test is to get information on the correlation between the duration of snow erosion (or accumulation) and the weather parameters (essentially wind speed and direction). As an example, the following graphs represent a ten-day period, a typical accumulation due to snowfall and a period of erosion due to wind transport of the snow. The curves of the 4 snow depth sensors are displayed on the figure 5. Concurrently, on figure 6, the strengthening of wind velocity and the shift of wind direction can be observed. The latter is strongly correlated with the slope aspect to determine the wind velocity efficiency on the snow pack.

During this period (between the middle of April 19th and the end of April 22nd), here are 5 main phases, 1, 2 & 3 for accumulation of snow and 4 & 5 for erosion. These phases are characterized by:

1. The strengthening of wind speed (blowing from South Southwest) during the day of April 19th and the beginning of a snowfall.
2. During the night between April 19th and 20th, the temporary weakening of wind speed while a weak snowfall persists.

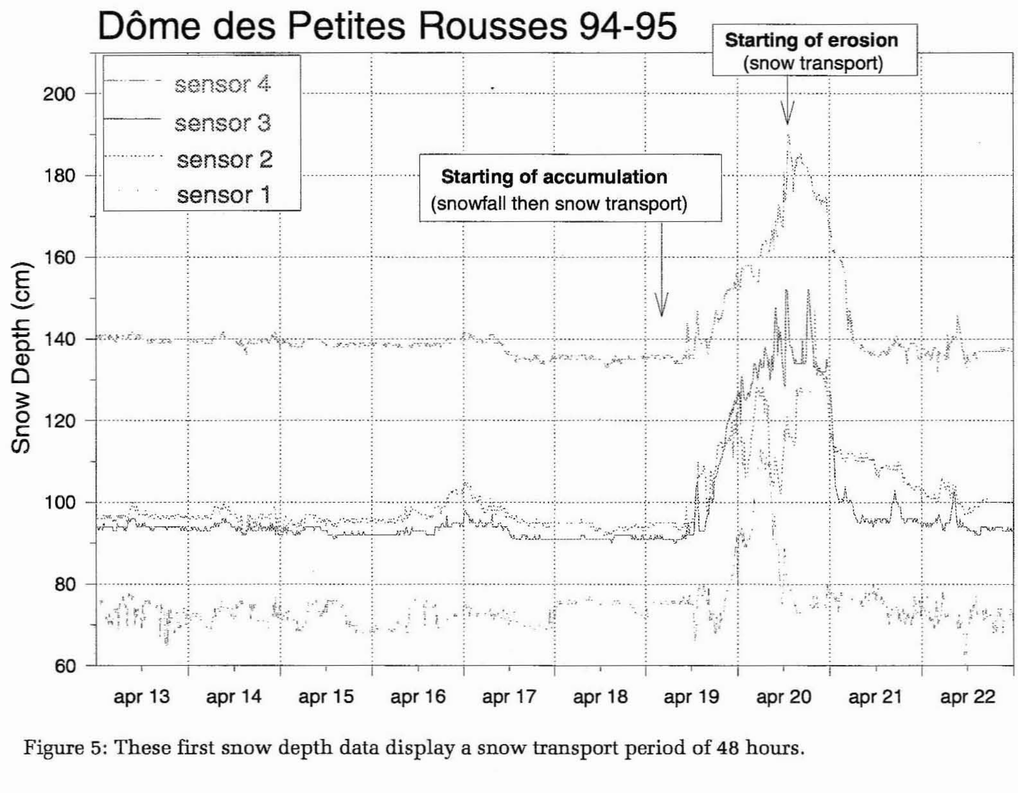


Figure 5: These first snow depth data display a snow transport period of 48 hours.

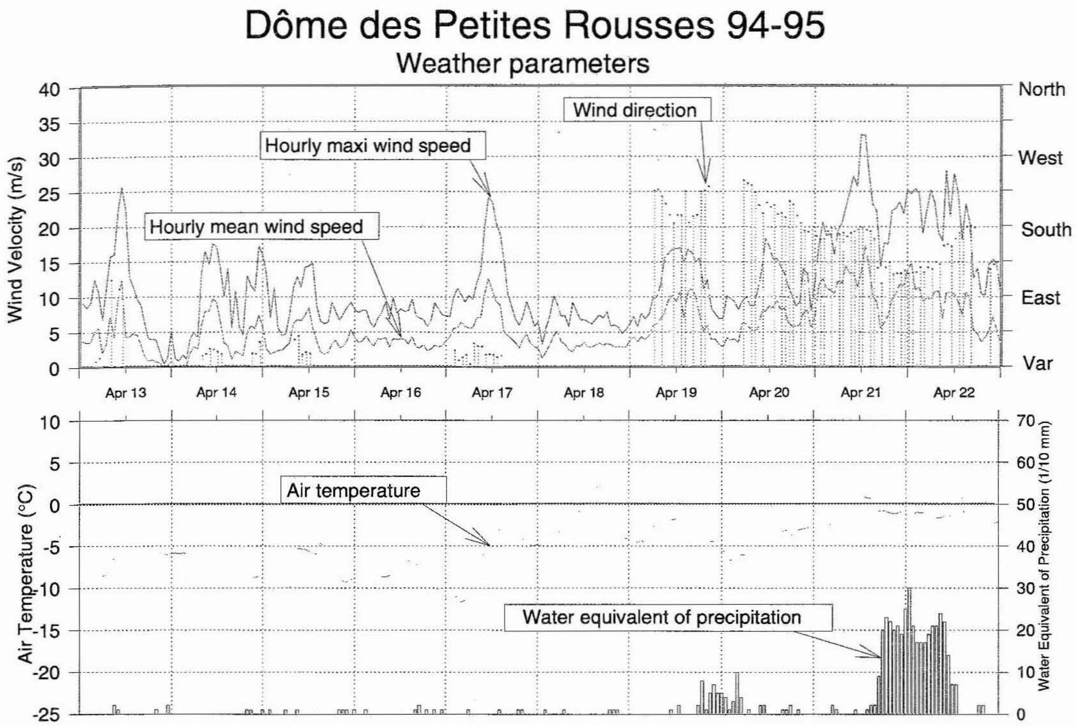


Figure 6: On this graph, the weather parameters can be followed in connection with the snow transport period.

3. On the morning of April 20th the wind speed increases (between 5 and 10 m/s) while the wind direction turns to South and the snowfall stops.
4. Then, the wind velocity continues to increase to 15 m/s (hourly mean value) and 32 m/s (maxi hourly value), the wind direction shifts slowly to Southeast then East. The snow erosion of the snow surface observed simultaneously on the 4 sensors becomes accentuated in spite of the new heavy snowfall.
5. The hourly mean wind speed stabilises around 10 m/s and the heavy snowfall has no accumulation effect on the snow pack. The wind direction is now perpendicular to the slope aspect. At this moment (end of April 22nd), it can be considered that the thickness of the snow pack has come back to its initial value. In that case it can be observed that the snow pack is very sensitive to a slight difference in wind direction during a snowfall and strong wind period.

During this blowing-snow period the time needed to erode 50 cm of recent snow can be calculated. After about 17 hours and half, all recent snow which was added by precipitation and wind has been eroded at our location. This corresponds to an average erosion rate of

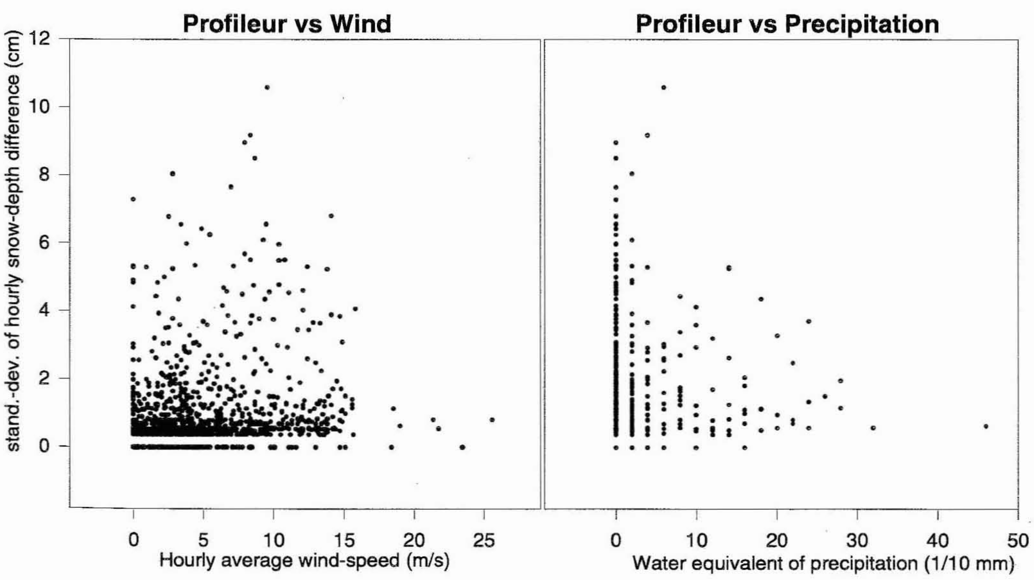


Figure 7: Correlation of precipitation and wind speed with standard-deviation of the 7 hourly snow-depth differences (on a 46 day period 12-28-96 & 02-11-96).

2.8 cm/h with a mean wind velocity of 10 m/s. On the graph (figure 5), the behaviour of each sensor is different, depending of its position along the slope. For example, the sensor 1 seems to measure a smaller thickness of snow accumulation than the others. However, the snow rate of erosion is approximately the same in the 4 cases, except for the sensor 2 which display alternately erosion and accumulation phases.

### Correlation with weather parameters

During the same period, if the standard-deviation of the 4 hourly differences of profileur data is compared separately with precipitation or wind speed, it appears that the snow surface evolution cannot be explained by a single parameter (figure 7).

In order to understand the mechanism of snow transport by wind other parameters are needed: snow particle characteristics and grain cohesion.

After an additional winter season of data, we expect to have interesting snow transport records (it was not really the case of last winter because of the prevailing nice weather!). So, Proteon (Guyomarc'h and Mérindol, 1995) will be used to analyse a snow pack simulated by Crocus. The correlation between the snow transport index calculated by Proteon and the hourly evolution of the snow "profileur" could be interesting.

## CONCLUSIONS

The purpose of this paper was to show the feasibility of automatic snow-depth measurements along a slope and to get a better idea of the correlation with meteorological parameters on the one hand and with snow grain features on the other hand.

The field measurements are made under conditions which are sometimes very bad. Nevertheless, these preliminary observations allow us to make some concluding remarks : this device seems, in a first approximation, to work regularly even under heavy snowfalls and strong wind, this equipment should permit us to precisely describe the evolution of a snow pack which undergoes wind effect. For this reason, we want to have one more season of field measurement records.

The final aim is to take into account the behaviour of snow under wind effect and to improve snow transport by wind and snow pack evolution modelling software.

## ACKNOWLEDGEMENTS

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