Key parameters for local drifting snow events.

Gilbert Guyomarc’h and Yves Durand
GAME/CNRM – CNRS/Météo-France, Grenoble

ABSTRACT: The transport of snow by the wind is one of the most important processes influencing the accumulation and ablation of the snow in the mountains; this is often the cause of the accidental triggering of avalanches. The Snow Study Centre (specialized research centre of Météo-France) has been working for several years towards upgrading the knowledge on drifting snow and its numerical modelling. In order to obtain this goal, an experimental high altitude site has been set up for the observation of the phenomenon.

After several years of in-situ measurements (automatic and manual), a long series of blown snow periods has been observed. These periods (around 15 for each winter season) are well documented by using the recorded parameters eventually completed with human observations and the results of numerical snow pack simulations.

For the more recent years, we will show a study about the key parameters of drifting snow events. We will also take into consideration some periods of strong wind without observation of transported snow. In this paper, we will detail the characteristics of the weather conditions (wind speed and direction, precipitation, air temperature, …), the type of surface snow, … which are common to these periods.

These key parameters, among others, have been basically used to define the modelling of transported snow used at present time for the forecasting of avalanche hazard into automatic numerical suites.

KEYWORDS : blowing snow modeling, operational avalanche forecasting.

1. INTRODUCTION

The Snow Study Centre of Météo-France is in charge of the development of tools for the operational forecasting of avalanche hazard in France over Alps, Pyrénées and Corsica mountains. In order to improve again the models used for that aim (Safran-Crocus-Mepra), we have to take into account the effects of wind on the snow spatial distribution which is important to assess snow stability, due to both redistribution of load and changes in the shape of snow crystals during transport (Gauer, 2001). Additionally, this redistribution of snow pack has a great influence on the increasing of avalanche risk. (Naaim-Bouvet and others, 2000)

For several years, a dedicated high altitude site has been set up for observations and measurements related to the drifting snow phenomena. Basically, we have started this study with observations and measurements of drifting snow conditions : wind velocity and direction, characteristics of snow surface particles, water equivalent of precipitation, air temperature, …

The first step for developing tools for taking into account drifting snow was to design and equip a high altitude site. The objectives of these studies, among others, are to clarify the threshold wind speed for different types of surface snow and to integrate into forecasting models some laws relating to the movement of snow due to the wind.

At present time, we can detail and document numerous events of drifting snow. This paper presents a study based on data acquired at our experimental site. It describes the key parameters observed during drifting snow events over the last ten years.

2. EXPERIMENTAL SITE

2.1 Description:

The “Col du Lac Blanc” experimental site is situated 2,700 m a.s.l. in the “Grandes Rousses” massif - French Alps. It is a large north-south (figure 1) oriented pass where the wind is generally similarly channeled. This corridor shape produces a tunneling effect on the wind, which is often rather strong during the winter months with evident snow transport.

Figure 1: View to south-west of the experimental site.

---

[*] *Corresponding author address*:
Gilbert Guyomarc'h ;
Météo-France/Centre d'Études de la Neige,
1441 rue de la Piscine, 38400 St-Martin d'Hères, FRANCE.
E-Mail: gilbert.guyomarch@meteo.fr

So, all weather events directly linked with the moving of snow by the wind are observed and measured at this experimental site. We focus especially our attention on:

- wind velocity thresholds according to snow particle types at the snow surface which are at the origin of snow erosion,
- physical parameters of the re-deposited snow (size of snow particles, density, shear strength, etc…)
- snow morphological transformations during the blowing snow events,
- snow distribution on both faces of the pass.

This experimental area allows to investigate the effects of drifting snow in high mountainous regions. These equipments and measurements are expected to provide a link between field observations of snow characteristics and our understanding of the mechanisms of blowing snow conditions.

2.2 Instrumentation and sensors:

The "Col du Lac Blanc" pass is equipped with three automatic weather stations (figure 2). Two of them are situated on either side of the pass and the third is on a surrounding point (Dôme des Petites Rousses – 2800m) and gives information on the synoptic wind (figure 3).

Figure 2: View of one of the weather station situated in the southern side of the "Col du Lac Blanc" pass.

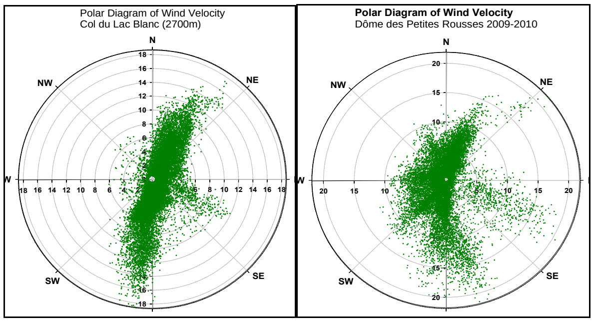

Figure 3: Comparison of the wind direction and velocity for the "Col du Lac Blanc" site where the wind is channeled and the "Dôme des Petites Rousses".

Several sensors measuring specific parameters related to snowdrift events are recorded every 15 min on both sides of the pass:

- Snow depth sensors and air temperature,
- Water equivalent of precipitation measured by a heated rain gauge,
- Direction and velocity of the wind.

The recorded data consist in average, maximum and minimum values recorded every 15 minute steps.

A horizontal profile of snow poles (along 500m) is regularly observed (figure 4). Thus, we can monitor the evolution of snow accumulation or erosion on both sides of the pass.

Figure 4: Partial view of the horizontal profile of snow depth on both sides of the pass.

3. DRIFTING SNOW PERIODS

3.1 Selection method

The selection of periods of snow transport by the wind is not very easy, due to the difficulty to determine, even being on the terrain, what is the precise moment of startup and shutdown of the phenomenon. This is obviously made more difficult when we must work by using only recorded data.

So, our method is based on the following observation. Drifting snow periods are characterized by:

- Erosion or accumulation of snow that we can see on the data of snow depth sensors.
- Differences between minimum and maximum values of the snow depth sensor at each time step which are characteristic of the presence of snow particles between the sensor and the snow pack surface. By using the data of the heated rain gauge, we can make the difference with snow precipitation.
- Wind velocity greater at least than 4 or 5 m/s according to the type of surface snow. The wind velocity threshold is dependent on snow particle bonding and cohesion.

A combination of these observations leads to a selection of drifting snow periods. This observation method (figure 5) used to determine the drifting snow events has been completed by the pictures taken with a web cam that allows to confirm in most cases the presence of the phenomenon.

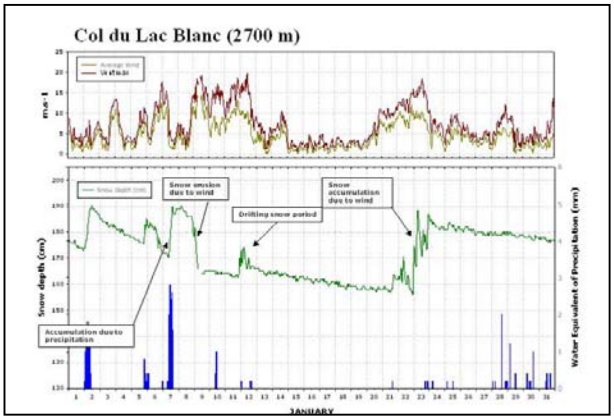

Figure 5: Method of determination of the drifting snow periods for our study.

By applying this method to the 10 years of our study, we determined 145 observation periods of drifting snow and we observe 42 periods of non drifting snow in spite of wind velocity greater than 8 m/s. In order to verify the relevance of this method, we compared afterwards for one winter season (2008-2009) our drifting snow events with the hourly data of a “flowcapt” sensor (Chritin and others, 1999) (Cierco and others, 2007) used by the Cemagref team at the same location.

For every days of the season, we determined whether a drifting snow period is observed either with our method or on the sensor data. For the 2008-2009 season we found 18 days with a period of drifting snow and 5 days of wind velocity greater than 8 m/s without drifting snow. Then, we compared the results, the figure 6 illustrates the results of this comparison and its table shows that in the most cases (95,7 % of well classified drifting snow events) there is a good agreement for the detected periods. Some of the 5 events detected only at the “flowcapt” correspond to high values of wind velocity maybe not properly filtered by the automatic device. Unfortunately, this very useful equipment was not available for the other seasons.

		Flowcapt	
		no DSP	**DSP**
Lac Blanc	**no DSP**	143	5
	DSP	2	14

Figure 6: Comparison of the events detected by the two observation methods over the 2008-2009 season (164 days). DSP: Drifting Snow Periods.

3.2 Noteworthy values:

The table in figure 7 highlights the channeling of winds in a north-south axis (95% of the events) at the experimental site, especially during blowing snow periods. We can also notice that the northerly winds are more than twice frequent as the southerly winds.

Wind direction	**Number of cases**	**Percentage**
North	97	66,90%
East	7	4,83%
South	40	27,59%
West	1	0,69%

Figure 7: Wind direction of all drifting snow events

Over the ten years of this study, 145 periods of drifting snow events were detected. The figures below (8 & 9) shows the maximum durations and the maximum wind velocity during events of snow transport by the wind for each season.

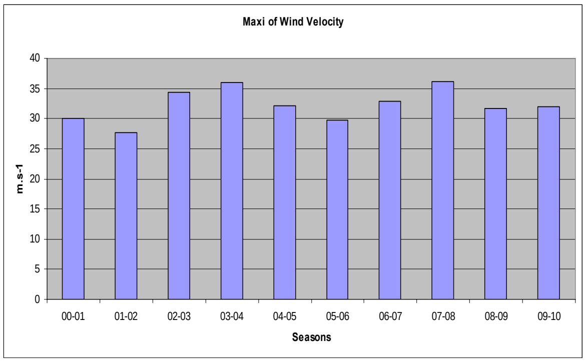

Figure 8: maximum of wind velocity during drifting snow events for each winter season.

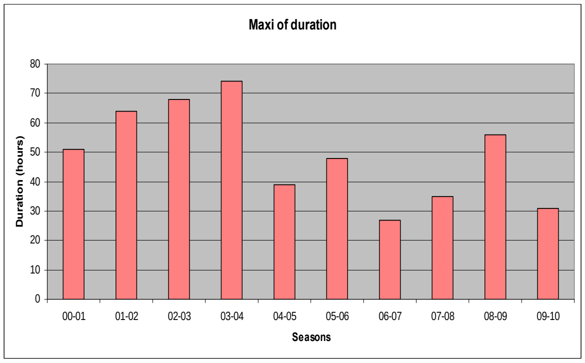

Figure 9: Maximum of duration of drifting snow events for each season.

4. KEY PARAMETERS

4.1 Wind parameters

Increased knowledge of wind conditions observed during drifting snow periods should help to refine the existing models and ongoing developments. This is one of the first necessary steps to model the transport of snow by the wind.

The figure 10 shows the average of mean wind velocity and maxi wind velocity for all periods of each season. The difference between years is not significant.

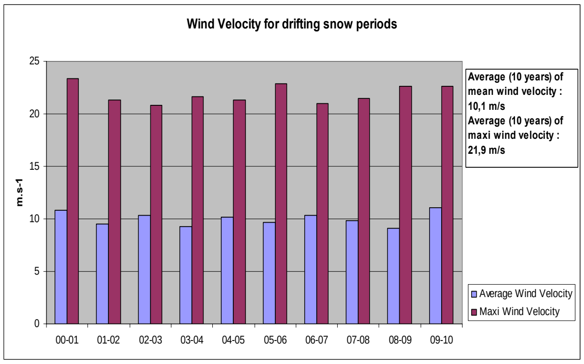

Figure 10: Wind velocities (maxi and average) for each season.

In the figure 11, we investigate the magnitude of the wind gusts (the wind gust coefficient is calculated by dividing the average wind velocity by the maximum wind) during periods with drifting snow or not. The graph shows almost no difference.

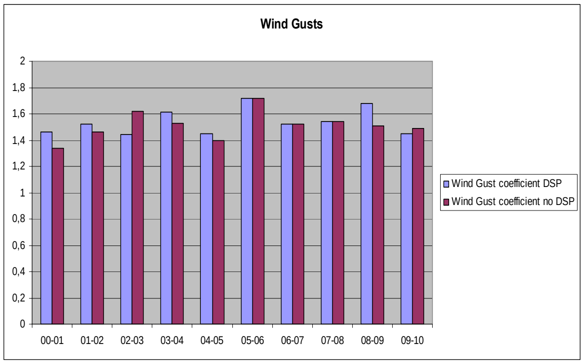

Figure 11: This graph shows a comparison of wind gusts between no DSP (Drifting Snow Periods) and DSP.

4.2 Characteristics of observed drifting snow events

The following graphs present some characteristics of drifting snow events in term of seasonal distribution, number and duration. The annual variability of event duration is almost simple to double (figure 12), the annual averages (figure 13) range from a low of 14 hours to a high of more than 25 hours (average over 10 years : 19 hours). We can notice a similar variability for the distribution of drifting snow events over the ten years of the study (figure 14) and for the frequency (figure 15) when we focus on the percentage of drifting snow time related to the total time of observations each year.

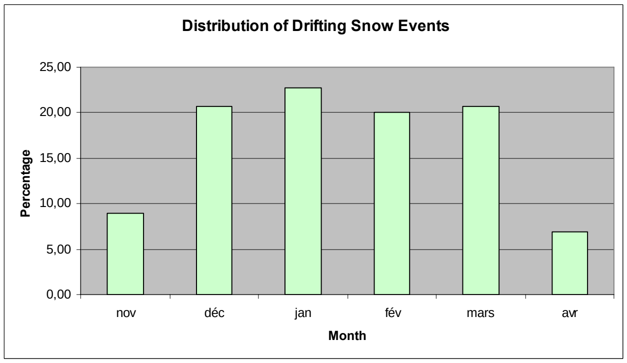

Figure 12: The percentage of observations from each month during 2000-2010 that include drifting snow. Drifting snow is seen significantly more often during winter months (December-March).

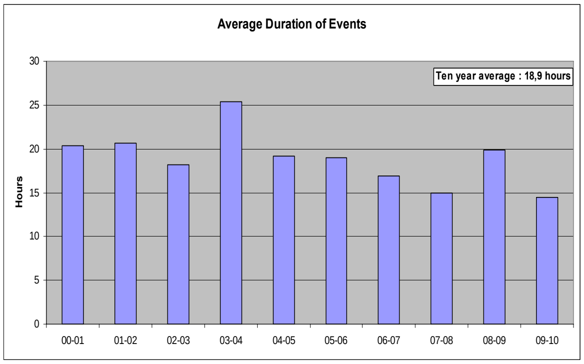

Figure 13: Average duration of drifting snow events for each year.

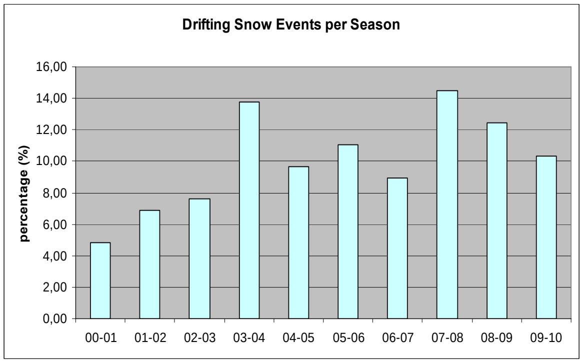

Figure 14: Drifting snow events at the experimental site between 2000 and 2010. We present the percentage of time compared to the total number of observations for all years.

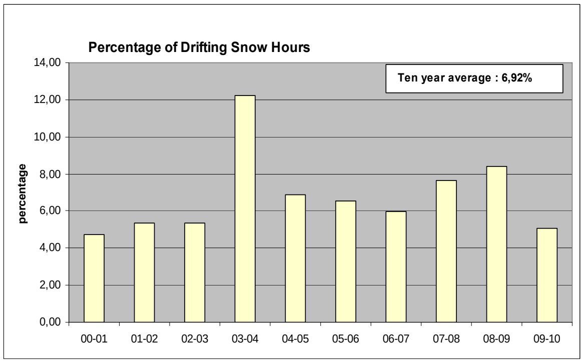

Figure 15: This graph shows the percentage of drifting snow event duration reported to the total duration of observation periods each year.

4.3 Wind velocity thresholds

In order to verify the thresholds of wind velocity according to the type of snow particles at the snow pack surface, we classified the drifting snow events in three classes depending on the age of the fallen snow at the beginning of the event. So, we determined 3 classes :

1. for snow precipitation in the previous 24h,
2. for snow fallen between 24h and 48h before,
3. for snow fall aged of more than 48h.

For the determining of wind velocity thresholds, we calculated a moving average over 6 hours centered on the beginning of the drifting snow event. The figure 16 shows the repartition of the wind velocity thresholds for each class.

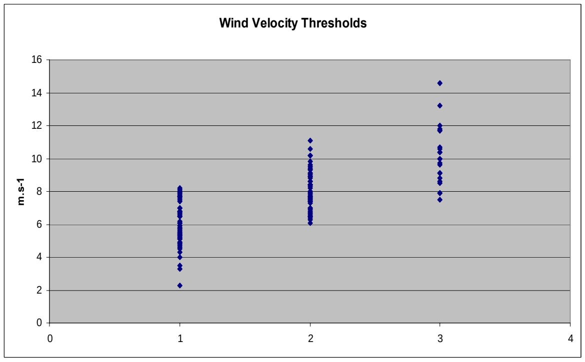

Figure 16: Repartition of the wind velocity thresholds for each class according to the age of snow at snow pack surface.

The figure 17 precise the main characteristics of the various wind velocity thresholds (in m/s) for each class:

Classes	number of drifting snow events	wind velocity average	Standard deviation
1	61	6,13	1,36
2	56	8,04	1,17
3	23	10,13	1,73

Figure 17: Average of wind velocity for each class of drifting snow period as a function of the age of snow fall.

Inversely it is also instructive to study the variability of the wind velocity thresholds (as defined above) of the drifting snow events:

1. for wind velocity threshold < 8m/s (average of wind velocity: 6,6 m/s),
2. for wind velocity >= 8 m/s and < 10 m/s (average of wind velocity: 8,9 m/s),
3. for wind velocity >= 10 m/s (average of wind velocity: 11,4 m/s)

The figure 18 shows the average of wind gust coefficient. We can observe that the average coefficient of gust increases significantly when the wind velocity is greater. This difference between average wind and maximum wind during drifting snow events could play an essential role in the pulling of snow particles at the snow surface when the wind velocity is weak.

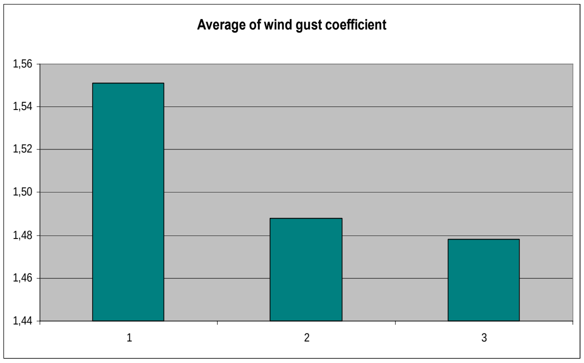

Figure 19: wind gust average for each class.

5. CONCLUSION

This study shows that several drifting snow events can be observed and documented at this experimental site. The database thus created can be usefully completed by integrating the results of snow pack evolution. We can used it to validate existing and under work models for simulating the transport of snow by the wind.

In order to improve the existing operational models (Durand and others, 2004) and to develop new assessments of drifting snow effects on snow pack stability, we have to better understand the mechanisms and the characteristics of snow transport by the wind in mountainous regions. That is why we must always deepen measurements and field observations in combination with the recording of still more parameters related with the studied phenomenon. Some measurements should be performed each time that differences are observed between the numerical simulations with or without the snow transport modeling.

A first step has been made in testing (Guyomarc'h and others, 2009) a first operational application developed and validated from our experimental site. New developments are still ongoing, including the development of 3D simulation versions (Durand and others, 2005). Another development way is an insertion of a snow transport scheme in finer scale meteorological model. This study is currently being developed as part of a PhD thesis, the results of our work will also be used to validate the initial results (Vionnet, 2008).

6. REFERENCES

Chritin, V., R. Bolognesi and H. Gubler. 1999. FlowCapt: a new acoustic sensor to measure snowdrift and wind velocity for avalanche forecasting. *Cold Reg. Sci. Technol.,* **30**(1–3),125–133.

Cierco, F.-X., F. Naaim-Bouvet and H. Bellot. 2007. Acoustic sensors for snowdrift measurements: how should they be used for research purposes? *Cold Reg. Sci. Technol.,* **49**(1), 74–87.

Durand, Y., Guyomarc'h, G., Mérindol, L. and Corripio G., J., 2004: Two-dimensional numerical modeling of surface wind velocity and associated snowdrift effects over complex mountainous topography. Annals of Glaciology, 38, 59-70.

Durand, Y., Guyomarc'h, G., Mérindol, L. and Corripio G., J., 2005: Improvement of a numerical snow drift model and field validation. Cold Region Science and Technology 43, 93-103.

Gauer, P., 2001: Numerical modeling of blowing and drifting snow in Alpine terrain. Journal of Glaciology, 47, 97-110.

Guyomarc'h, G, Durand, Y. and Giraud, G., 2009: Integration of the snowdrift modeling into the French operational chain for avalanche hazard forecasting, proceedings of ISSW 2009. International Snow Science Workshop, 25 sept. – 2 oct 2009, Davos (CH).

Naaim-Bouvet, F., Y. Durand, J.-L. Michaux, G. Guyomarc'h, M. Naaim and L. Merindol. 2000. Numerical experiments of wind transport over a mountainous instrumented site at small, medium and large scales. *In Proceedings of the International Snow Science Workshop 2000, 2–6 October 2000, Big Sky, Montana, USA*. Bozeman, MT, American Avalanche Association, 302–308.

Vionnet, V., 2008: Etudes préliminaires sur l'insertion d'un schéma de transport de neige par le vent dans un modèle météorologique à échelle fine. Rapport de masterII, Université Paul Sabatier.