CLIMATOLOGY OF AN EXPERIMENTAL MOUNTAINOUS LOCATION FOR STUDIES ON SNOWDRIFT.

G. Guyomarc'h*[1], Y. Durand[1], L. Mérindol[1], F. Naaim-Bouvet[2]
1 Météo-France CEN (Snow Study Centre)
2 Cemagref Etna (Torrential Erosion,snow and avalanches research unit)

ABSTRACT : Over the last 10 years, 2 French laboratories specialized on snow and avalanche research have joined their resources to investigate snowdrift effects and their consequences on the increasing of avalanche hazard. The experimental site is situated at 2 800 meters high in the French Alps, at a place where the wind is canalized in 2 directions.
The working method was based :

- In a first time, on data measurements separated in automatic measurements (wind velocity, wind direction, snow depth, water equivalent of precipitation, ...) and in a set of field measurements (snow pits, taking of snow samples, vertical profile of snow density, stereo-photogrammetry, ...)
- In a second time, on development of applications for the forecast of blowing snow events and the modeling of snow distribution.
- The current project aims at testing an integrated chain of models which can determine the snow distribution by taking into account the local topography.

This poster will present the results of a climatological study made by using the series of data and the results of the modeling.

KEYWORDS : Climatology, snowdrift, experimental measurements.

1. INTRODUCTION

The purpose of this work is the climatological study of various parameters recorded at an experimental site of high altitude, and the connection with episodes of blowing snow. For 12 years, several research projects have succeeded one another on the site of the "Col du Lac Blanc". All these studies had in common the study of the effects of the snowdrift in the distribution of the snow-pack and in the increasing of avalanches risk. Indeed, the presence of wind during or after snowfalls is often materialized by the constitution of slab. These slabs are often very unstable, and are at the origin of about 80 % of accidents by avalanche in mountain.

These research projects allowed to improve the knowledge on the mechanisms of snow transport, and to determine in particular the thresholds of wind allowing the beginning of the transport, according to the snow type at the surface of the snow-cover. Models were developed and are now operational. For these multi-field searches, different types of sensors were recording parameters connected to the studied phenomenon during the duration of contracts. Recordings were made from October to the end of April from 1988-1989 to 1999-2000 winter seasons. These parameters were used punctually for every study (generally one or two seasons), but had not been the object of an exhaustive study on the set of the 12 years until now. It seemed thus interesting to lead a climatological study to get a tool accessible to all.

* *Corresponding author address* :
Gilbert Guyomarc'h, Météo-France, CEN, 1441 rue de la piscine 38406 St Martin d'Hères Cedex FRANCE
E-mail : gilbert.guyomarch@meteo.fr

2. INTERESTS

The main points justifying the interests of such a study are summarized below:

1 - Constitution of a data base accessible to the partners of the project, notably the Safety and Snow service of "Alpe d'Huez" resort (Sata) and to the scientific community.

This data base will be useful for the future researches and could be completed by results of numerical simulations (Safran – Crocus [Brun and others, 1992]).

2 - Valuation of data recorded on a site which equipment was funded by contracts with "région Rhône-Alpes" and "Pôle Grenoblois" and publication.

3- Synthesis of knowledge on the experimental site, critical exam of data, improvement and validation of already developed or current models.

4 - exhaustive documentation of the periods of blowing snow on the set of twelve winter seasons.

3. DESCRIPTION OF THE EXPERIMENTAL SITE

At this experimental location several research programs have succeeded. The general aim was to study the effect of wind during snowfalls and on the deposited snow. Numbers of sensors have been set up at this location, so we have series of data over a period of twelve winter seasons (in the broad sense! From October to April). This site has been described with details in previous Issw's papers [Guyomarc'h and others, 1992-1996-1998] and in other publications [Guyomarc'h and Merindol, 1997], [Durand and others, 2000], [Michaux and others, 2000]. We can summarize the description as follows :

- Large pass where the wind is channeled according to a northern-southern axis (figure 1).
- The site is situated at an altitude of 2 800m. It assures conditions often favourable to the observation of the snowdrift phenomenon. Several sensors have been set up for the hourly record of data.

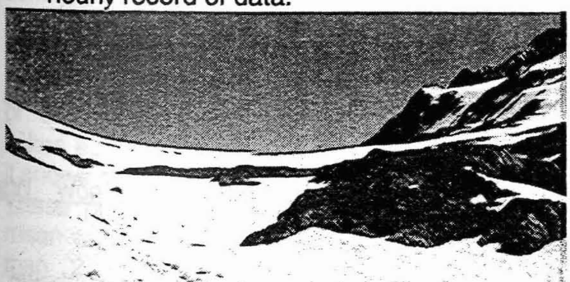


Figure 1 : the "Lac Blanc" pass according to a northern-southern axis.

- Two points of measurements (figure 2 and 3) of wind direction and velocity, precipitation (height of snow and water equivalent) and air temperature. For two years, two other zones were added and were equipped with sensors in order to detect blowing snow events and to measure the erosion and the accumulation of snow.

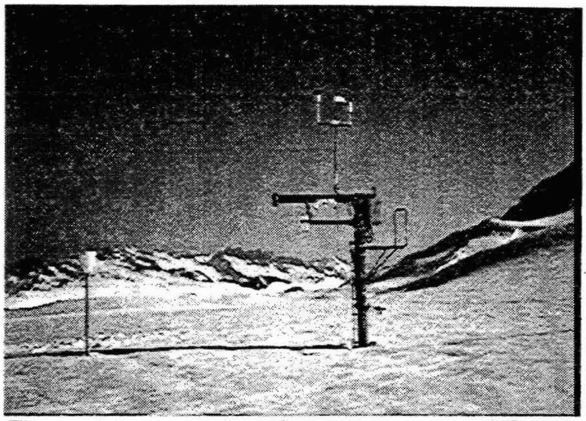


Figure 2 : one point of measurements ("Col du Lac Blanc") (snow depth, snow water equivalent, wind velocity and direction, air temperature). At this site we have 12 seasons of data.

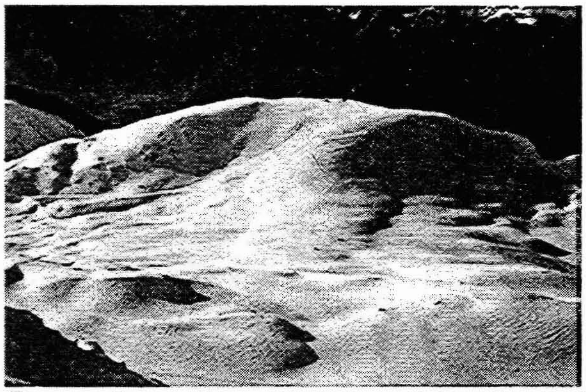


Figure 3 : the second point of wind measurements ("Dôme des Petites Rousses"). At this site we have 8 seasons of data.

4. CLIMATOLOGY

The subject of this study is to describe the different parameters relevant for the snowdrift phenomenon. Thus 5 kinds of graph are shown :

- **Compass card** : The wind velocity thresholds are not standards, but were chosen according to our knowledge on snowdrift.
- **Air temperature histogram and graphs** : We have chosen to visualize the monthly evolution of the air temperature over the season. The chosen thresholds are –10°c, -

5°C and 0°C. We also presented the hourly evolution with the aim of showing the periods when air temperature overtook 0°C.

- **Mean wind velocity** : In order to better visualize strong wind periods, we draw curves of temporal evolution of the wind for which the colour of the line corresponds to a class of direction (only when the wind velocity is greater than 4 m/s – wind threshold for the start of snowdrift).
- **Snow depth and precipitation** : It was interesting to superpose on the same graph the snow depth and the water equivalent of precipitation (most of the time snow at this altitude for considered period). Except during snowfalls, the snow-depth fluctuations are due essentially to the packing down of the snow cover and to the blowing snow periods. This type of graph allows to give prominence to such phenomena.
- **Snow depth differences and wind gusts** : We compared the hourly evolution of snow depth measurements (difference between hourly maxi and mini values – if it is greater than 2 cm) and the wind gust coefficient (ratio between hourly maximum velocity and hourly mean velocity – only when the wind speed is greater than 4 m/s).

5. ANALYSIS OF PARAMETERS

5.1 Air temperature

For this parameter we have 12 seasons at the "Col du Lac Blanc" site from 1988 to 2000. Below (figure 4), as an example, we show the graph for all the seasons. The highest frequency is between 0 °c and –5°C, the positive temperatures are more marginal.

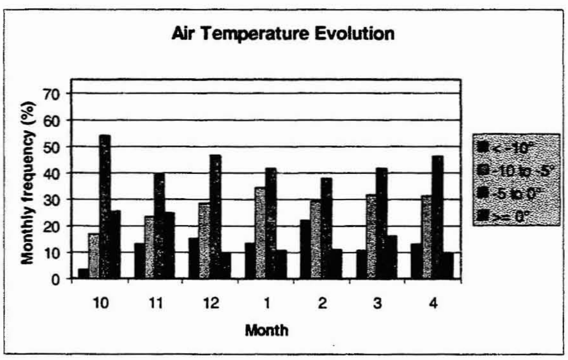


Figure 4 : Frequency of the 4 classes of air temperature for each month of the 12 winter seasons.

5.2 Wind parameters

At the main experimental location ("Col du Lac Blanc") the wind direction are strongly influenced by the topography. Due to this characteristic the northerly winds represent about 50% of cases and the southerly winds 10%. Because of this feature we have zoomed in the compass card on the first 5% of frequency (figure 5). The figure 6 exhibits the detailed frequency for each class of direction and velocity. We can observe the lack of wind from west and about 1% of wind velocity lower than 1 m/s.

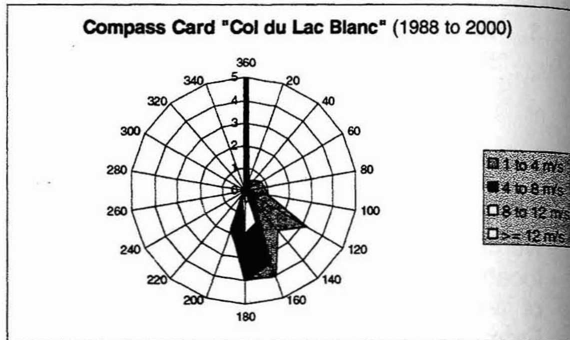


Figure 5 : Zoom on the first 5% (frequency) of the compass card for the 12 seasons at the "Col du Lac Blanc" site.

Direction	1 à 4 m/s	4 à 8 m/s	8 à 12 m/s	>=12 m/s
360	22,8	17,6	8,4	1,9
20	0,5	0,5	0,2	0,1
40	0,6	0,3	0,0	
60	0,8	0,0		
80	0,9	0,1		
100	1,0	0,8	0,1	
120	3,1	0,5	0,0	0,0
140	2,3	0,6	0,2	0,0
160	4,0	3,4	1,5	0,4
180	3,9	4,0	1,9	0,5
200	1,8	1,8	0,3	0,1
220	0,2	0,1	0,0	
240	0,1	0,0	0,0	
260	0,0	0,0		
280	0,0	0,0		
300	0,0	0,0		0,0
320	0,0	0,0		
340	0,1	0,1	0,0	0,0
0 à 1 m/s	12,2			
Nb de données	39143			

Figure 6 : Distribution of the data by class of direction and velocity.

5.3 Snow depth and Snow Water Equivalent

For every seasons, we have drawn on the same graph (figure 7) the snow depth and the snow water equivalent accumulated over the whole period. By comparison with other parameters (wind, snow surface conditions,...), this graph will be able to be used for the identification of the snowdrift periods.

It is very difficult at this altitude to take into account the water equivalent of precipitation, essentially because of the wind conditions. Nevertheless, if we compare the snow depth with the accumulation of precipitation, we can identified some periods of snowdrift.

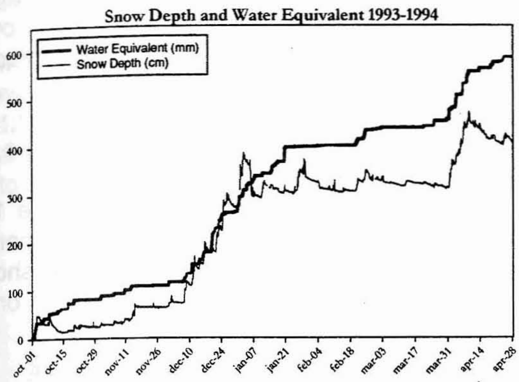


Figure 7 : Example of a graph for the 1993-1994 winter season.

6. STUDY ON THE SNOWDRIFT PERIODS

<u>6.1 Criteria of selection</u>

This experimental site is particularly convenient for the observation of the phenomena of snow transport by the wind.

How to detect these snowdrift periods? For two years, we have been able to use several acoustic sensors [Michaux and others, 2000], but for the previous seasons we only have got the data recorded by the automatic station and in-situ observations. Therefore, we selected the snowdrift periods by using the number of consecutive hours for which difference between hourly maxi and mini values of the snow-depth sensor exceeded a threshold (figure 8). We assume that this difference is big when the wave of ultrasonic sounds is intercepted by snow flakes above the snow surface. It happens when it snows or when the snow is moved by the wind. These periods were only chosen if the hourly mean value of the wind velocity is always greater than 2 m/s. It is possible to discriminate afterwards between events with precipitation or not by using the data from the rain gauge.

By using this method, we have selected, in a first approach, 119 periods for which the snow depth difference is greater or equal to 4 cm (the sensor precision is +/- 1 cm) during a period of at least 5 hours.

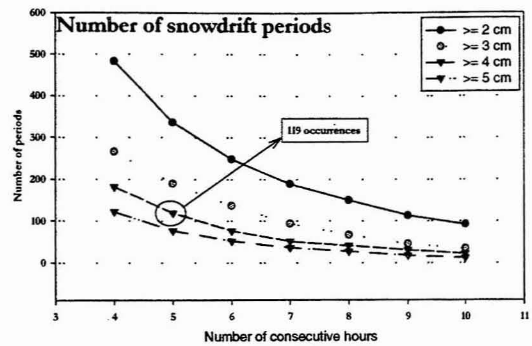
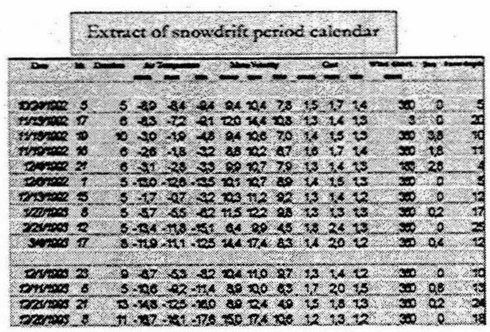


Figure 8 : Snowdrift periods in connection with the hourly difference of the maxi and mini values of snow depth sensor.

<u>6.2 Calendar of snowdrift periods</u>

For every periods recorded parameters allow to describe in detail the weather and snow conditions. It will also be possible to complete these parameters with the results of snow pack simulations (Safran-Crocus [Brun and others, 1992], [Durand and others, 1993]). An extract of this calendar is shown below (figure 9).



Extract of snowdrift period calendar

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	5	5	-8,9	-8,4	-9,4	9,4	10,4	7,8	1,5	1,7	1,4	360	0	5
[illegible]	17	6	-8,3	-7,2	-9,1	12,0	14,4	10,8	1,3	1,4	1,3	3	0	20
[illegible]	10	10	-3,0	-1,9	-4,8	9,4	10,6	7,0	1,4	1,5	1,3	360	3,8	10
[illegible]	16	6	-2,6	-1,8	-3,2	8,8	10,2	8,7	1,6	1,7	1,4	360	1,8	11
[illegible]	21	6	-3,1	-2,8	-3,3	9,9	10,7	7,9	1,3	1,4	1,3	[illegible]	2,8	4
[illegible]	7	5	-13,0	-12,8	-13,5	10,1	10,7	8,9	1,4	1,5	1,3	360	0	5
[illegible]	15	5	-1,7	-0,7	-3,2	10,3	11,2	9,2	1,3	1,4	1,2	360	0	12
[illegible]	8	5	-5,7	-6,5	-6,2	11,5	12,2	9,8	1,3	1,3	1,3	360	0,2	17
[illegible]	12	5	-13,4	-11,8	-15,1	6,4	9,9	4,5	1,8	2,4	1,3	360	0	25
[illegible]	17	8	-11,9	-11,1	-12,5	14,4	17,4	8,3	1,4	2,0	1,2	360	0,4	12
[illegible]	23	9	-6,7	-5,3	-8,2	10,4	11,0	9,7	1,3	1,4	1,2	360	0	10
[illegible]	6	5	-10,6	-9,2	-11,4	8,9	10,0	6,3	1,7	2,0	1,5	360	0,8	13
[illegible]	21	13	-14,8	-12,5	-16,0	8,8	12,4	4,9	1,5	1,8	1,3	360	0,2	24
[illegible]	8	11	-18,7	-16,1	-17,6	15,0	17,4	10,6	1,2	1,3	1,2	360	0	18

Figure 9 : All periods (according to the previous criteria) are described.

<u>6.3 statistical study</u>

Some calculations have been made on the whole sample of snowdrift periods, then on the data without snowdrift periods (figure 10).

	Mean	Median	Stand.-dev.	1st quintile	2nd quintile	3rd quintile	4th quintile
Duration	8.2	6.0	4.2	5.0	6.0	8.0	11.0
Mean Velocity	10.6	10.4	2.8	8.3	9.8	11.1	12.7
Gust coefficient	1.5	1.4	0.3	1.3	1.4	1.5	1.7
Moved Snow Depth	22.2	18.0	18.1	10.0	13.0	21.0	33.0

[illegible]

	Mean	Median	Std-dev	1st quintile	2nd quintile	3rd quintile	4th quintile
Mean Velocity	4.4	3.6	3.4	1.4	2.8	4.6	7.2
Gust coefficient	2.1	1.7	1.7	1.4	1.5	1.8	2.4

[illegible]

Figure 10 : Statistical calculation over the snowdrift or no-snowdrift periods.

It brings us to some conclusions :

- wind speed is on hourly average much stronger when snowdrift is present (10.6 m/s against 4.4 m/s for lack of the phenomenon). We can observe besides an important distance between the average and the median of the wind velocity of no-snowdrift periods because of the distribution of speeds (40 % of wind velocities are in that case lower than 2.8 m/s).
- The coefficient of wind gusts is weak in cases of snowdrift. It is surprising, we could think, on the contrary, that wind gusts allow to extract more easily the snow from the snow surface. Moreover recent studies [Michaux and others, 2000) have shown that by calculating average and the maxi over a shorter period results are appreciably different.

6.5 Examples of snowdrift episodes

We have selected below (figure 11) a graph which represents snowdrift periods. Different types of snowdrift periods are shown : with or without precipitation, with erosion or with accumulation.

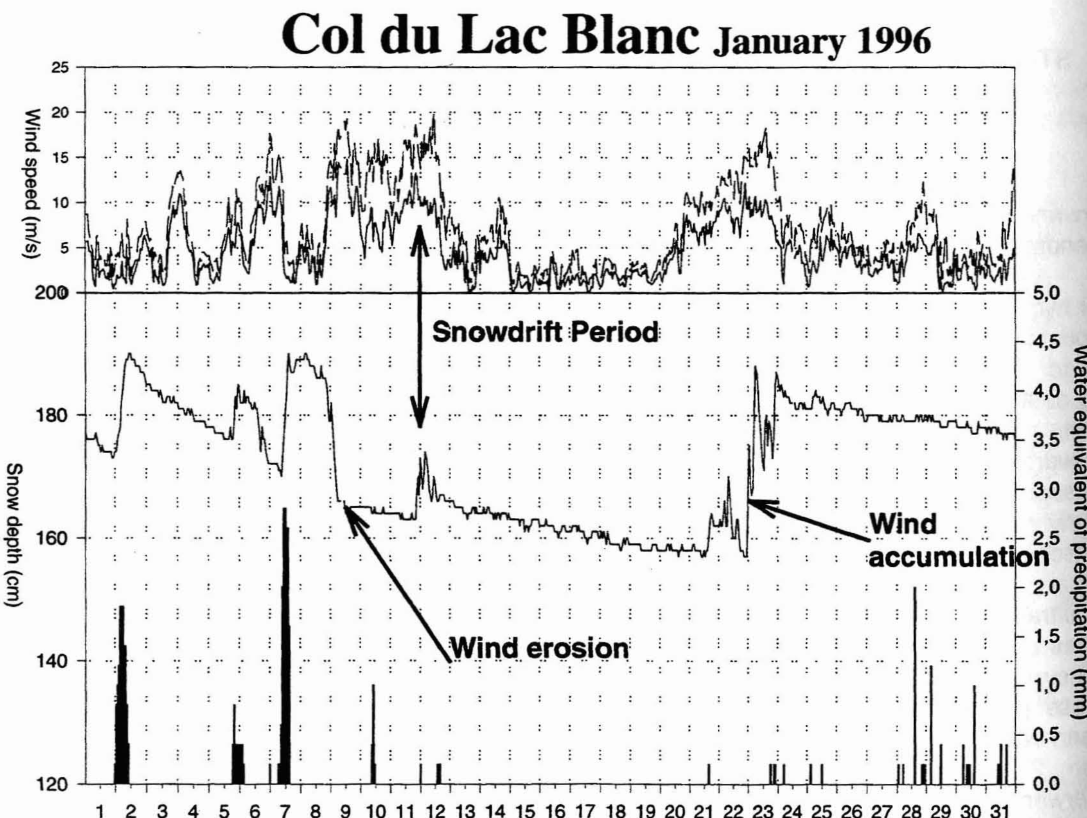


Figure 11 : On this graph several different periods of snowdrift can be observed.

Thus, each selected period can be detailed in terms of weather and snow conditions and we are able to discriminate between periods with or without precipitations. We can also refine the wind velocity thresholds in connection with the snow type at the snow cover surface thanks to the acoustic sensor. These types of snow particles are determined either by ground observations or through the results of snow-pack simulations (Safran-Crocus).

It is also interesting to examine periods with strong wind (over 12 m/s on hourly average) without snowdrift observed (as shown on figure 12). In that case, the quality of the snow grains at the snow surface is the determining element to explain the absence of the phenomenon.

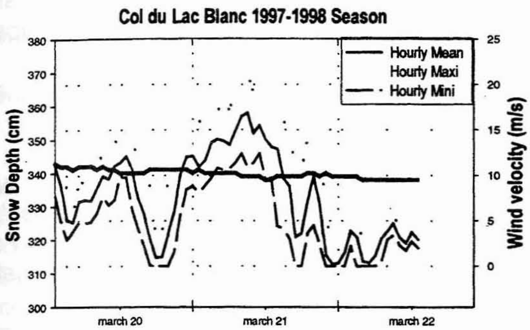


Figure 12 : Strong wind periods without snowdrift observed.

7. DATA SUPPORT

We have chosen to make a model of data server for a later integration in a web site in order to facilitate the data access. In a first time the data are available on a CD-rom.

At the end of the study, the details of the data could be put at the scientific community disposal in the framework of future scientific collaborations.

8. ACKNOWLEDGEMENTS

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