A STUDY OF WIND DRIFT SNOW PHENOMENA ON AN ALPINE SITE

Gilbert Guyomarc'h[1] and Thierry Castelle[2]

ABSTRACT

Over the last three winter seasons four laboratories specialized on snow research have joined their knowhow to better understand the mechanism of wind-transported snow in a project appropriatly named «Snow and Wind». In this project several methods for studying the wind's effect on snow are investigated.
In this paper, we will overview essentially the research conducted on :

-the different wind-speed thresholds allowing drift in connection with snow-grain types and snow cover surface and the characteristics of the blowing snow.

-the spatial snow distribution using photogrammetric techniques.

The group of laboratories have also investigated the : visualization of particles in movement and properties of snow reflectivity.

INTRODUCTION

Wind transported snow plays a prominent role in many problems encountered in mountainous terrain. The wind-drift of snow occurs either with or without snowfall. The principal consequences are :

-increasing hazard of avalanches (more than 40% of avalanches may be related directly to strong winds [Meister, 1989]).

-poor visibility, snow accumulation on roads and engineering structures.

-irregular snow distribution with erosion and formation of excessive snow deposits on several tracks of ski resorts.

-excessive overloading of avalanche defense structures.

In the literature the research concerns essentially the wind-drift snow in plateau regions. Our study differs in that we investigate snow drift phenomena through field observations and measurements on a high altitude Alpine site. Our goals are :

-to measure wind-speed thresholds allowing snow motion in connection with the different grain types of snow cover surface.

-to use photogrammetrical techniques to follow the evolution of the snowcover in the target area.

---

1. Météo-France CNRM-Centre d'Etudes de la Neige(CEN) 1441 rue de la piscine 38406 Saint Martin d'Hères-France © 76 54 34 18

2. Swiss Federal Institute of Technology - GEOLEP 1015 Lausanne-Suisse © 21 69 32 496

EXPERIMENTAL SITE AND INSTRUMENTS

The experimental area chosen for this project is situated at 2710 m a.s.l. in the «Massif des Grandes Rousses» near the ski resort of «Alpe d'Huez». It is a large pass oriented North-South, where the wind is similarly canalysed, excepting cases of east bound catabatic wind (Figure 1).

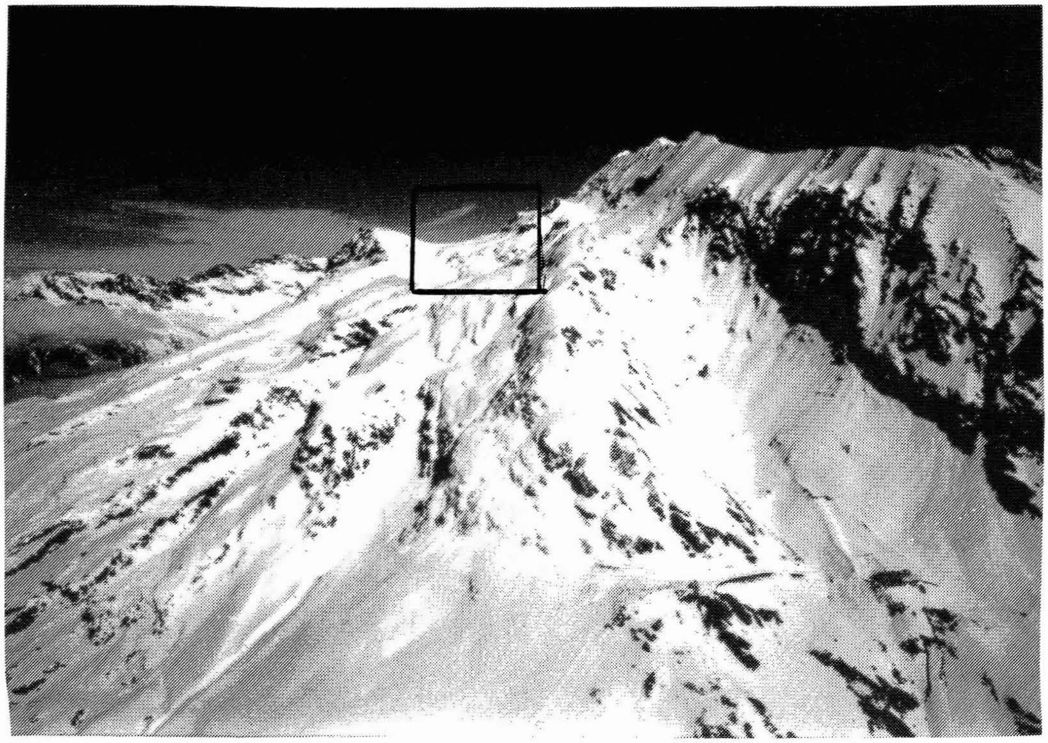


Figure 1 : a view of "Col du Lac Blanc"

Another interest of this site, the «Col du Lac Blanc», is the easy all-weather access which is provided by the Snow Safety Service of «Alpe d'Huez». It seems that this measurement point offers optimal conditions for the monitoring of wind directions and speeds which prevail in this mountainous region.

Over the last two years, several sensors have been set up on this site:

-At first, the instrumentation was installed on the north slope of the pass on a 6 meter mast (wind direction and speed sensors using a heating system; air temperature, snow depth using an ultrasonic sensor; solar radiations, snow surface temperature, heated precipitation gauges).

-We have completed this equipment with a second snow depth sensor on the south side and a snow particle counter (SPC) to detect the presence of snow drift.

All this parameters are collected hourly on a computer sheltered in a nearby mountain chalet and transmitted to the CEN. Each recorded observation includes an hourly average, maxi and mini of measurements taken over a 20 second period.

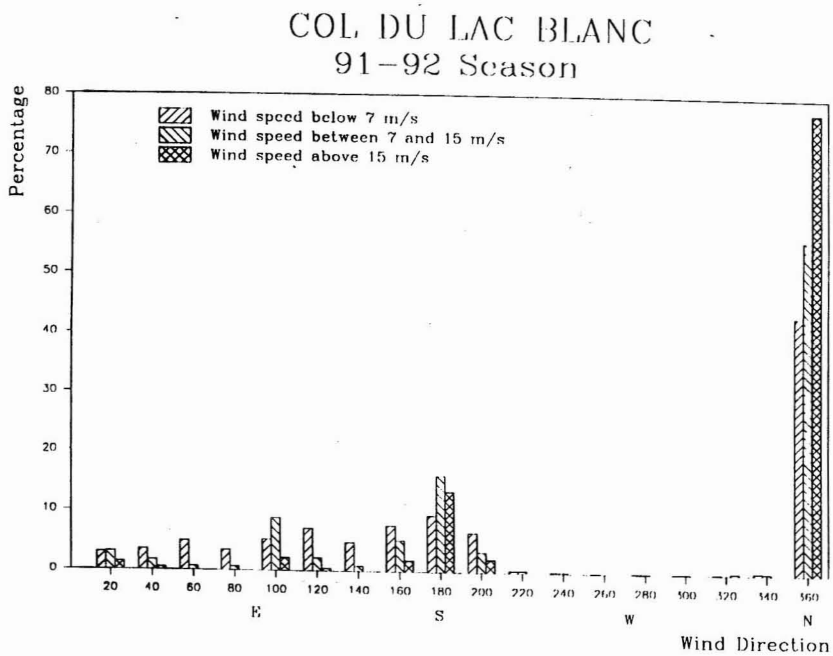


Figure 2 : Wind distribution classed by velocity in each direction.

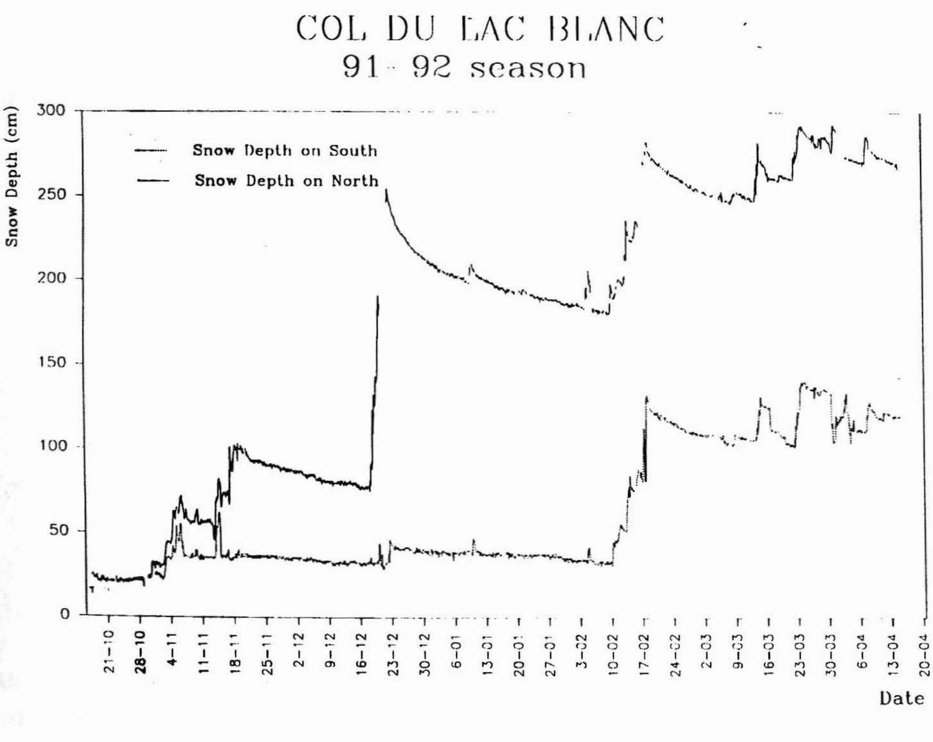


Figure 3 : Snow depth comparison between the north and south side of the "Col du Lac Blanc"

METHODS

Field measurements

In order to complete the automatic measured parameters, we have taken some measurements on the site during strong wind conditions or snow storms :

-Beforehand we made full snowpack observations (snow quality and type, snow mechanics measurements, layering, ...) in the first 50 cm of the snowpack. Stereo-photographs were taken before the snow drift.

-During snow transport periods, detailed snow flux and vertical wind profiles have been made. Airborne snow particles have been collected at different levels in the drift flux

-Afterwards stereo-photographs were taken again, as to follow the storm effects on the snow cover repartition. Snow heigth measurements were made along an horizontal profile going from windward to leeward side.

Study on snow grain morphology

In order to obtain a detailed description of snow particles we have transported wind-drift snow grains from the field to a cold laboratory where they could be analysed under a microscope. During this time, the snow metamorphism are inhibited as long as the sample (liquid iso-octane and snow grains) temperature is below 0°C (for more details on this method see [Brun, Pahaut 1991]).

We have collected snow samples during drift events at different levels above the snow pack surface (between the ground and 100 cm high). We have recorded the pictures of grains on a video-tape and then determined the type and size of wind drift snow particles. These video records were then analyzed using image processing techniques, to calculate the snow's morphological parameters (such as area, perimeter, mean radius of curvature, etc...).

Photogrammetry

The aim of our study is to analyse the wind's effect on snow accumulation on the site of "Col du Lac Blanc". For this, we have used some terrestrial photogrammetric techniques.
We have chosen terrestrial rather than aerial photogrammetric technics for essentially practical reasons.

The "Dôme des Petites Rousses" is situated at 350 m from the "Col du Lac Blanc"(2720 m) and at an altitude of 2820 m a.s.l.. The "Dôme des Petites Rousses" is, therefore, a high point relatively favourable for photographs (figure 4).

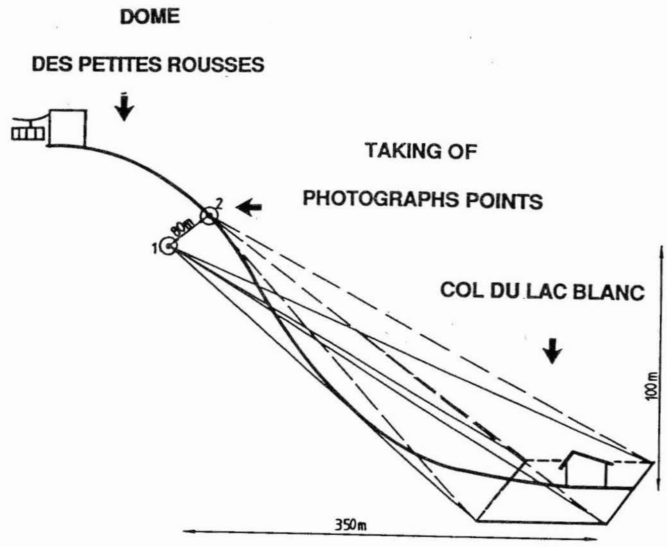


Figure 4 : Schematic representation of the experimental setup used for photogrammetric measurements at "Col du Lac Blanc" site (2700 m).

The cable car of Vaujany offers a comfortable access during the winter. The photogrammetric camera (Leica Wild P31) is kept in a heated shelter nearby. An operator can transport the camera (about 35 kg in two suitcases) and take the photographs which are needed in less than one hour on ski (figure 5).

Figure 5 : The photographic camera P 31 (Leica Wild) in use on the site.

At the Swiss Federal Institute of Technology, the two photographs were analysed with an analytical plotter Wild BC1. For every pair of photographs we selected the same surface (300 m long and 130 m large). The numerical files of the snow cover are visualized with a graphics software using a VAX station.

Each visualization testing cycle consisted of :

-drawing up a map of the contour lines of the ground with snow cover,

-map-making and calculating the distribution of the total snow volume by difference with the ground,

-map-making and calculating the snow volume between two test periods.

RESULTS

Wind drift snow features

In the literature it is assumed that wind drift snow particles are much smaller than the original precipitation crystals, ranging to 0,1 (or less) to 0,5 mm in diameter. It seems that particle size decreases with heigth above the snow surface. If the wind is blowing during snowfall or if the wind starts soon after, the weak structures of the crystals are quickly fragmented as they bounce along the snow surface.

After studies on the first collected samples in snow transport, we can observe some differences in comparison with non wind drift snow :

-the perimeter and area of blowing snow grains are smaller than typical grains (like fragmented precipitation particles or small rounded particles). The rate is about 2.3 : 1 for the perimeter and about 4.2 : 1 for the area.

-the percentage of convex or concave curvature is quite different between wind carried and typical snow (Figure 6)

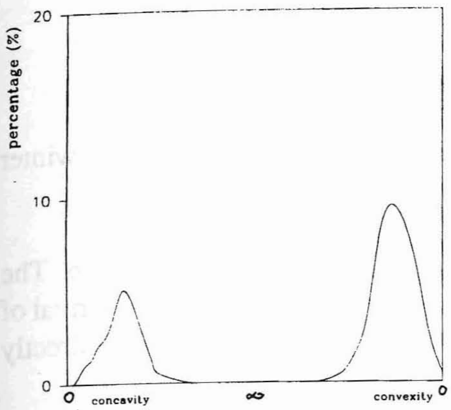
	concave	convex
drift snow	20 %	75 %
other snow	38 %	56 %

Figure 6

This difference can be explained by wind mecanics which tends to break the weaker areas of recent snow crystals. This is done by using the concavity areas as break down points.

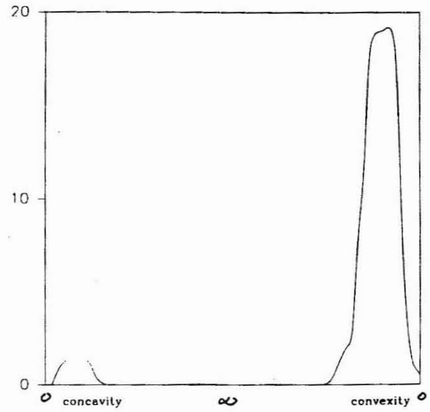
-convexity histogram

On these two tables (Figure 7 and 8), we once again found the low propensity of concave portions and the weak dispersion of the curvature radius of convex parts.



Snow fallen without wind

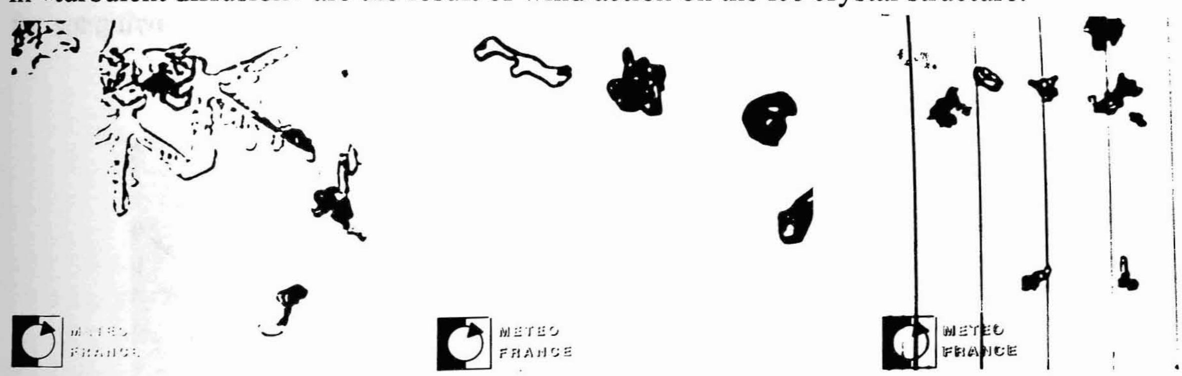
Figure 7



Blowing Snow

Figure 8

We have confirmed that most of snow grains were : decomposing and fragmented precipitation particles (diam. from 1 to 0,5 mm), small rounded particles (diam. below 0,5 mm) and a mixture of rounded and broken particles (diam. below 0,1 mm). These latter grains we found in «saltation» or in «turbulent diffusion» are the result of wind action on the ice crystal structure.



Photographs of snow particles carried by wind

As their size decreases during snow transport, the suspended particles tend to bond in a very short time by a sintering action. This explains the quick formation of cornice and slab avalanche during wind storms. Particularly, when the size is less than 0,1 mm, we can consider that the time to obtain bonds between ice particles is strongly correlated to size and somewhat temperature dependent (for example for an air temperature about -10°C the necessary time is lower than 10 s) [from Hobbs and Mason-1964].

However we must keep in mind that these laws are calculated for spherical particles of ice instead of the irregular fragments that are real particles of blowing snow. Because of these cohesive forces between snow grains, the wind-speed thresholds for snow transport will increase with time since snow deposition.

We have not enough samples to determine with precision the connection between snow-quality and wind-speed thresholds. However, the preliminary results show that wind-speeds between 5 and 8 m/s is a good estimate in the majority of cases.

<u>Snow distribution</u>

We use photogrammetrical techniques to estimate the spatial snow accumulation during the winter period on the site.

During two winter seasons (90/91 and 91/92), about 40 pairs of photographs were taken. The photographs dates correspond as close as possible to the end of a transport period and the arrival of an anticyclonic period. It is therefore possible to assume that the state of the snow cover is directly influenced by the poor weather conditionds prior to the taking of photographs.

The processed data allows us to obtain a large amount of information (qualitative or quantitative) concerning the distribution of snow cover on "Col du Lac Blanc". We present two different analyses below. The first has helped us to measure the mass of displaced snow (erosion or deposition) during a transport period. The second shows the effect of a north-west wind on the snow surface condition.

-1-From the data of December 20 and 28th 1990, we have calculated the contour lines (Figure 9). This allows us to visualize the snow cover terrain topography for these two dates. We have estimated snow depth by substracting the corresponding data.
The AA' cross profile (Figure 10) shows the erosion zones observed at the south slope following a south-west wind.

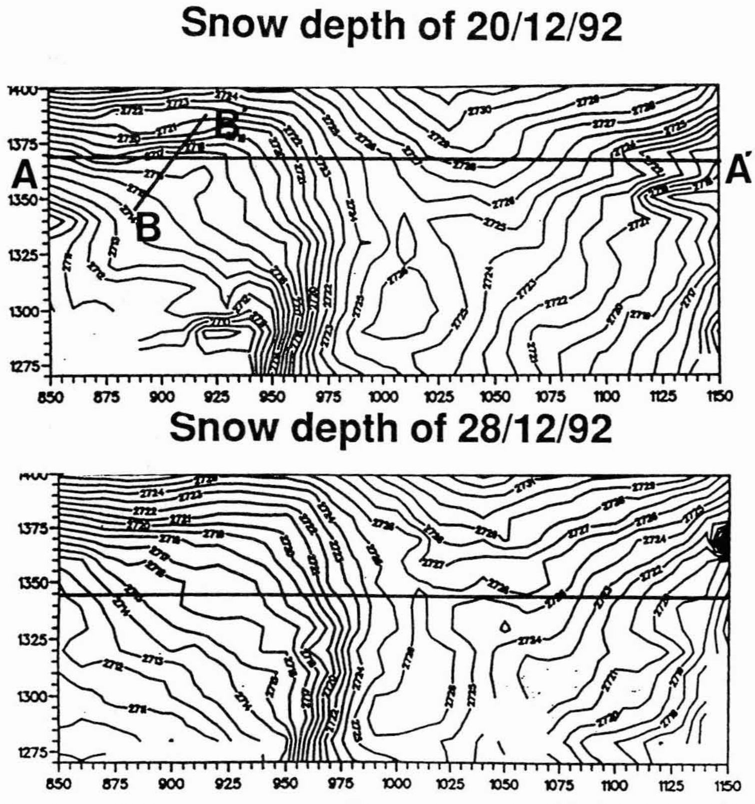


Figure 9 : Visualization of the snow covered terrain on the 12-20-90 and 12-28-90

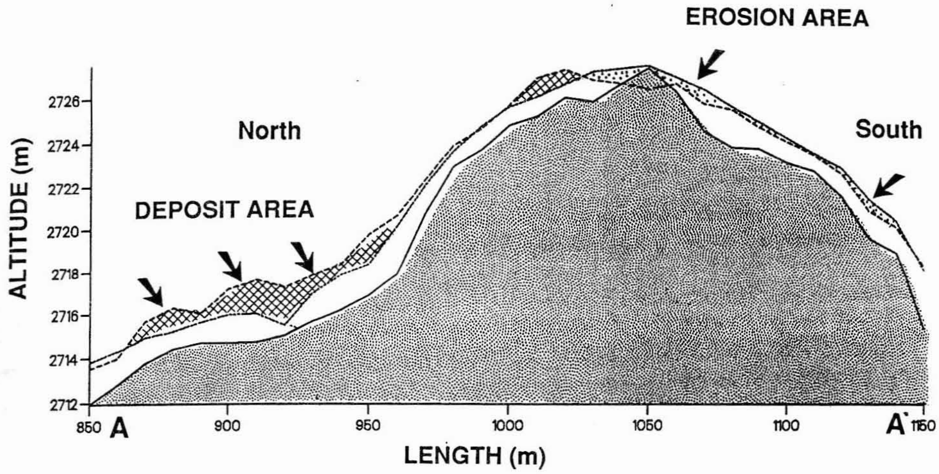


Figure 10 : AA' cross profile . The erosion zone is observed at the south slope of the pass. The accumulation is important on the north slope. Between 12-20-90 and 12-28-90, south-west winds were particularly strong.

-2-The BB' profile measured after north-west winds on fresh snow reveals the formation of regular 0.30 meter high dunes every 4 meters (Figure 11).

For the moment, few periods have been analysed, but we think that terrestrial photographs are useful for specific snow measurements on snow cover.

Figure 11 : BB'. cross profile after an episode with north north-west winds (01-05-91) we have observed the formation of regular "waves" 0.30 m high and approximately 4 m. aparts.

PRACTICAL IMPLICATIONS

Avalanche risk forecasting.

A better understanding of wind transported snow properties is needed to formalize consequences on human activities in mountainous regions. Furthermore we need to take into account its effects on the snowcover stability in avalanche forecast modelling. The results of this research, especially the wind speed threshold correlated to snow grain type will be very useful in the area of forecasting avalanche.

-We are now working on a statistical model for wind drift snow forecasting. The original state of snow cover and the estimated conditions for the day after should permit to forecast the presence of snow-transport (in 3 classes) using statistiscal adaptation methods of meteorological models.

-If we will be able to formalize the results that are obtained at «Col du Lac Blanc», we will introduce, in a snow cover evolution model (**Crocus**), the local erosion or accumulation effects on the snowpack surface.

-Similarly, we can provide more accurate information on spontaneous released avalanches due to transport by employing an expert system for avalanche risk forecasting (**Mepra**).

Developing tools for snow drift diagnostics on an Alpine site

Physical modelisation of snow drift has already been used in order to study the effects of wind transported snow on the environment and to propose development on Alpine areas [Sivardière, 1991].

The wind tunnel of the Swiss Federal Institute of Technology will soon be used to simulate the snow transport on a small scale model (1/500) of "Col du Lac Blanc" site. For one drifting snow period, the simulated snow cover on the model will be compared with the real snow cover measured on the site with the photogrammetric techniques. With the "Col du Lac Blanc" experiments it will be possible to control the validity of the wind tunnel simulation for snow drifting on an Alpine site.

CONCLUSIONS

In high altitude mountainous regions, we have found the wind drift mechanisms similar to there in plateau areas (three modes of transport : creep, saltation and turbulent diffusion). However, our studies suggest that some differences exist (that remain to be quantified) :

-wind action during snowfall is quite different in mountainous regions.

-the quantity of snow moved by wind depends on the quality of the snow at the snowcover surface before a snow drift period and has a great influence on the formation of wind slab.

-topography influences wind direction and snow erosion and deposition zones.

It is clear that more work will be necessary in order to finalyse our study. Particularly :

-use of snow-depth sensors and SPC (Snow Particle Counter) to better determine snow-drift conditions and to complete the spatial repartition.

-integration of our results into snow-drift diagnostic tools and into models used for avanlanche risk forecast.

The next step is a newly funded project called "Snow, Wind and Avalanches". We aim to study the slope behaviour when the wind carries snow particles over a crest and changes the distribution of the snow cover.

PROJECT ORGANIZATIONS

Financial : Pôle Grenoblois - Rhône-Alpes Region - French Government

Technical : Snow Safety Service of Alpe d'Huez (SATA)
Association Nationale pour l'Etude de la Neige et des Avalanches (ANENA)

Scientific : Centre d'Etudes de la Neige - METEO-FRANCE
Division nivologie - CEMAGREF
Geolep - EPFL
Laboratoire de la Montagne Alpine - IGA

REFERENCES

Brun, Pahaut : 1991-An efficient method for a delayed and accurate characterization of snow grains from natural snowpacks. Journal of Glaciology vol. 37 n°127

Castelle et ali. :1991- Utilisation de moyens stereophotogrammétriques pour la saisie de l'évolution des dépôts de neige sur un site. Symposium Cisa/Ikar de Chamonix

Föhn : 1980-Snow transport over mountain crests. Journal of Glaciology vol. 26 n° 94

Guyomarc'h, Mérindol : 1991-Etude du transport de la neige par le vent. Symposium Cisa/Ikar de Chamonix

Meister : 1989-Influence of strong winds on snow distribution and avalanche activity. Annals of Glaciology vol. 13

Schmidt : 1980-Threshold wind-speeds and elastic impact in snow transport. Journal of Glaciology vol. 26 n°94

Sivardière et ali. : 1991-Modélisation en souflerie du transport de neige par le vent en haute montagne. Symposium Cisa/Ikar de Chamonix

Tabler, Pomeroy, Santana : 1990-Drifting snow. Cold Regions Hydrology.