The Driftometer

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ABSTRACT

Wind can create even greater unstable accumulations of snow in mountainous areas than heavy snowfalls. But knowing wind conditions is not sufficient to predict these accumulations because their formation also depends on the snow quality of the snowpack surface all around the measurement station. In consequence, the assessment of snowdrift is required to improve avalanche forecasting. According to this assumption, a very simple (and cheap) instrument has been designed to take snowdrift measurements, and tested in a wind-tunnel. This instrument is called 'driftometer'. The driftometer can catch snow particles blown by the wind, which makes a daily evaluation of the direction and intensity of the snowdrift possible. Driftometers have been used by several safety services at European ski resorts during three winter seasons. Snowdrift data has been recorded as well as avalanche activity. This experiment has shown that there is a strong correlation between snowdrift and avalanche occurrence. The experiment also demonstrates that the driftometer is a useful tool for avalanche forecasting.

INTRODUCTION

Everyone agrees that snowdrift is responsible for plenty of avalanches. As a matter of fact, winds can create huge accumulations (fig.1) which are quite often very unstable.

As already mentioned, wind measurements do not give very reliable information about snowdrift intensity which also depends on the quality of the snow cover. Let us remember that snowdrift can only occur when the snow is mobile; there may be not at all, even during strong wind situations (fig.2)!

Instead of using wind data for snowdrift assessment and resulting avalanche risks, a direct measurement of snowdrift would be better!

This idea of measuring snowdrift is not new and a lot of scientists and technicians have been working on this subject during the last 35 years. They built many sensors, but, as far as we know, none can record snowdrift direction during 24 hours without energy: an instrument had to be designed for such a purpose.

We called this instrument a 'driftometer'.

1. DESIGN

The design of the driftometer was based on 2 basic constraints imposed by practice:

- the instrument should record snowdrift direction as well as snowdrift intensity.
- the instrument must be cheap and work without energy

In 1990 two prototypes were built at CEMAGREF (R.Bolognesi, F.Naaim, F.Ousset) and one of them was tested in field conditions during winter 1990-91. This first trial was not successful: the prototype was not able to indicate the snowdrift direction with sufficient reliability. After this experiment, the development of the instrument continued at SFISAR (R.Bolognesi, O.Buser) in cooperation with CEMAGREF.

Two problems had still to be solved: separation air / snow particles and determination of snowdrift direction.

1.1. SEPARATION AIR / SNOW PARTICLES

Learning from various experiments (Mellor, Foehn, Meister, Castelle), we decided to catch snow particles blown into a tube by the combined effects of filter and pressure fall.

Then we built some new simple prototypes in order to check in the field that the tube sections and the volume of

Fig.1: An example of wind effect on snow deposition. Similar effects are observed on mountain slopes.

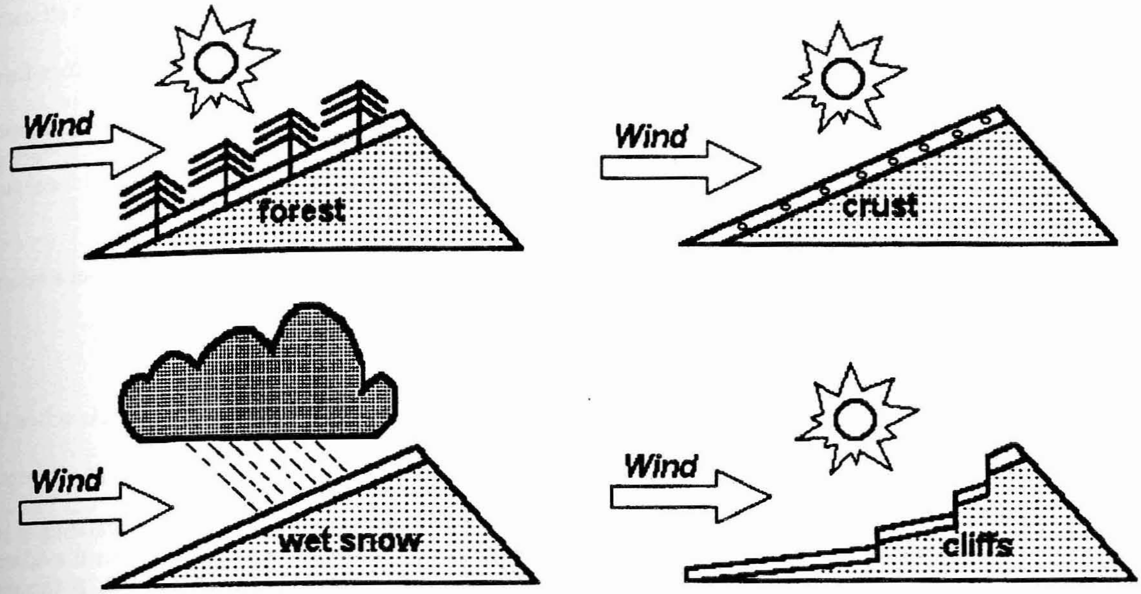

Fig.2: Some typical wind situations without significant snowdrift.

the particles collector given by calculations were convenient for daily measurements (fig.3). The experiment site was located in a high mountain area (Weissfluhjoch, Switzerland). An automatic wind measurement station was available on the same site as well. So it was possible to evaluate snow concentrations from mass flux to be sure that experimental conditions were correct. These tests have shown that this principle of separation is efficient. The user has simply to weigh the caught snow to get an *index* (not an actual value!) of the snowdrift intensity.

1.2. DETERMINATION OF SNOWDRIFT DIRECTION

The local avalanche forecasters need to know the snowdrift direction because the location of snow accumulations directly depends on it. But it makes no sense to want to know whether the snowdrift direction is 180 or 181 degrees. So it was decided that the snowdrift direction indicated by the driftometer should be a sector of 45 degrees: N or NW or W or SW or S or SE or E or NE.

The most simple solution for knowing the snowdrift sector is to put one snow particle collector in each of the 8 sectors: if the North collector catches snow particles, it means that the snowdrift direction is more or less North. Unfortunately, if the snowdrift direction is North then the collectors North-East and North-West will also catch snow particles! So we designed a system of deflectors (fig.4) and tested it in the wind-tunnel at CEMAGREF with laser visualization. With this system, only one collector catches a significant mass of snow if the wind direction is constant: so it is possible to know snowdrift direction for 24 hours without any automatic recording instrumentation.

Following the validation of the principle in the wind-tunnel, the last prototype was built and installed in a high mountain ski resort (Alpe d'Huez, France) to be tested in actual conditions by practitioners. According to their suggestions, some last technical improvements were made and the plans of the definitive instrument were drawn up.

The driftometer (fig.5) is now manufactured and sold by a small French company called ISER'OUTIL (price approximately $200), and used daily by the numerous ski resorts which work with the avalanche forecasting system NxLog (Bolognesi, 1994). The driftometer is also used for some scientific studies about snow slabs formation (Duclos, 1995).

2. VALIDATION

Every snowfall is more or less responsible for avalanche occurrence: forecasters usually consider the height of new snow as a predictive variable for avalanche activity. So it seems reasonable to think that the snowdrift, which is simply a 'horizontal snowfall', may also be a predictive variable for avalanche activity.

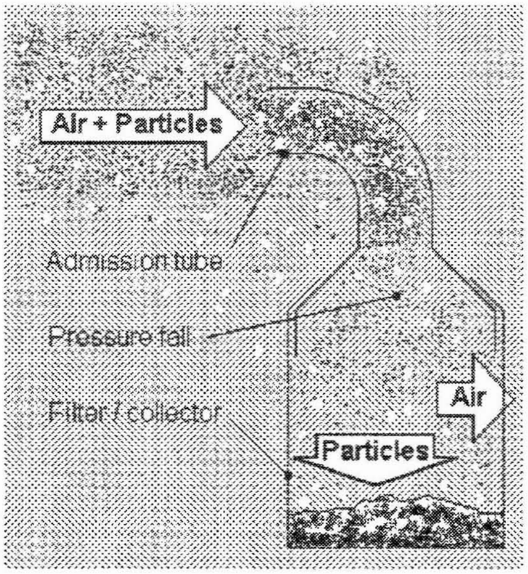

Fig.3: Principle of the separation air / snow particles.

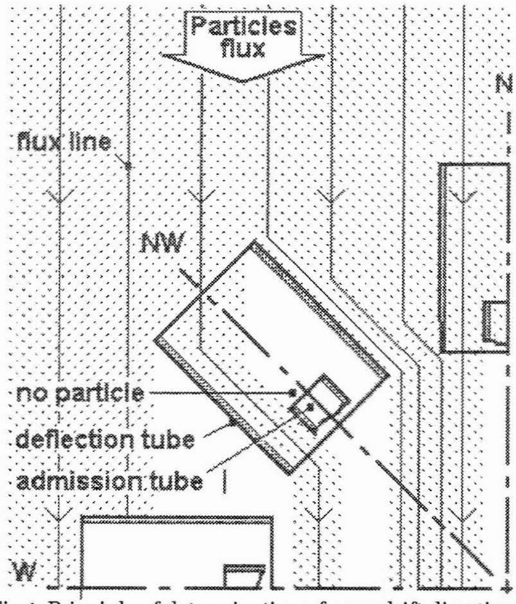

Fig.4: Principle of determination of snowdrift direction.

Fig.5: The driftometer: a tool designed for practice.

The question is now: *how much does knowing snowdrift improve our ability to predict avalanches?* In order to give an answer we studied the relationship between snowdrift and avalanche activity.

2.1. TEST SAMPLE

We used data collected during a whole winter season (1995-96) at Alpe d'Huez ski resort. This ski resort is our 'outdoor laboratory' for the development of the forecasting system NxLog and provides very accurate and reliable data: ski patrol men daily attempt to trigger avalanches in some defined paths whatever the snowpack conditions are. For our experiments, the same slopes are tested every day, irrespectively of their expected stability state. This means that we actually know, day by day, whether the snowpack was stable or not in these paths.

At the same time weather data are collected at a measurement station which is very close to the paths. Wind-(instantaneous values) and snowdrift measurements are taken twice a day (9:00 am and 1:00 pm) as well as various other measurements.

So we can perform quite significant tests from this information.

Our sample consists of 123 days with 140 avalanches for 1111 release attempts. Obviously, we selected days without significant snowfall to eliminate statistical noise.

2.2. PROCEDURE

We calculated, for each day from the sample, an avalanche activity index as following:

Acti = nAval / nEvent

where

nAval is the number of observed avalanches (artificially released or not),

nEvent is the sum: (number of release attempts) + (number of natural avalanches).

For example, during March 7th 1995, 7 avalanches were observed for 9 release attempts and no natural avalanche occurred: the avalanche activity index was 0.78; the snowdrift index was 30 g, the wind speed was nil, and the wind speed the day before was 15 knots.

We completed charts to visualise the statistical distributions of avalanche activity according to wind speed and snowdrift (fig.6).

The charts confirms that avalanche activity strongly depends on snowdrift which seems to be more informative than wind. Now let us quantify this intuitive deduction and let us turn to an index of association in the predictive sense.

Let us assume that our sample is large enough to consider that frequencies and probabilities of events are equal and let us describe the distributions by the mean of joint probability distribution tables (fig.7).

Let us now characterise the relationship between snowdrift and avalanche activity. The index of predictive association developed by Goodman and Kruskal is:

$$\lambda AS = [P(e) - P(e|S)] / P(e) \qquad [1]$$

where

.S is the snowdrift index given by the driftometer,

.P(e) is the lowest probability of an error in avalanche activity classification when S is unknown;

$$P(e)=1-\max \sum P_{ij}$$

(Pij : probability from cell [Si, Aj]) [2]

.P(e | S) is the lowest probability of an error in avalanche activity classification when S is known;

$$P(e | S)=[P(e | S_o).P(S_o)+P(e | S_1).P(S_1)]/[P(S_o)+P(S_1)]$$

$$P(e | S) =1-\sum_i \max_j P_{ij} \qquad [3]$$

The index λAS shows the proportional reduction in the probability of error afforded by specifying snowdrift data: if the knowledge of snowdrift does not reduce the probability of error, the index is 0. On the other hand, if the index is 1, no error is made given the snowdrift classification: there is complete predictive association.

Now let us calculate λAS. It comes from [1], [2] and [3]:

$$\lambda AS=(\sum_i \max_j P_{ij} - \max_j \sum_i P_{ij})/(1-\max_j \sum_i Pij) \qquad [4]$$

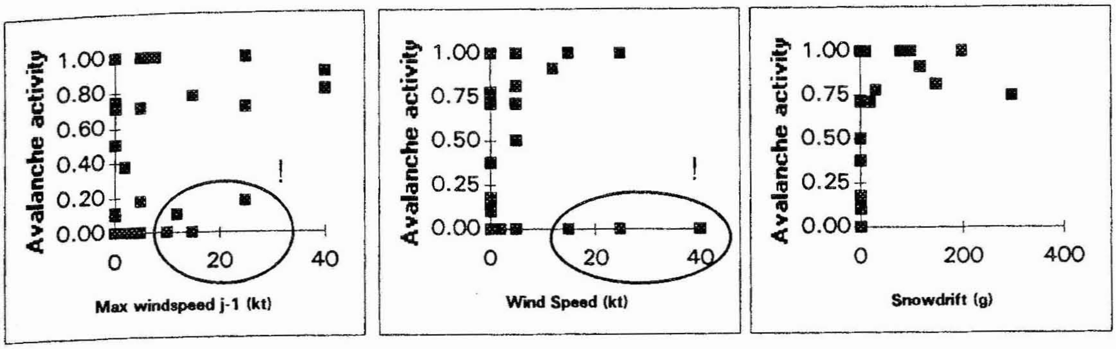

Fig. 6: Statistical distributions of avalanche activity according to windspeed and snowdrift.

	S0	S1	
A0	0.77	0.00	0.77
A1	0.13	0.10	0.23
	0.90	0.10	1.00

	W0	W1	
A0	0.70	0.07	0.77
A1	0.20	0.03	0.23
	0.90	0.10	1.00

Fig. 7: Joint probability distribution tables (rounded values) derived from data collected at Alpe d'Huez.
A0: probability that avalanche activity index = 0, A1: probability that avalanche activity index > 0;
S0: probability that snowdrift index = 0, S1: probability that snowdrift index > 0;
W0: probability that windspeed < 10 knots (snowdrift threshold), W1: probability that windspeed > 10 knots.

By applying [4], we find $\lambda AS \approx 0.44$ so that knowing whether or not snowdrift occurred reduces the probability of error in predicting avalanche activity by 44 percent on average.

What about wind?

Using the same sample, we find $\lambda AW = 0$. If we calculate $\lambda AW(j\text{-}1)$, using the higher wind speed values measured the day before avalanches occur, we find $\lambda AW(j\text{-}1) = 0.04$. This means that we expect an improvement of avalanche activity prediction by using snowdrift data instead of wind data. This also means that wind speed and snowdrift intensity are not strongly correlated. Field measurements confirm this deduction (fig. 8).

2.3. DISCUSSION

It must be emphasized that these conclusions only concern situations without snowfall, and that this experiment shows that snowdrift measurements are more predictive than non-continuous wind measurements when no other information is available. Wind measurements are probably more predictive when they are used in combination with other data. Of course, comparing the performances of forecasting systems using snowdrift data or not would be very interesting. But let us advance step by step. The experience shows that avalanches are due to unstable snow accumulations and that snowdrift is more related to snow

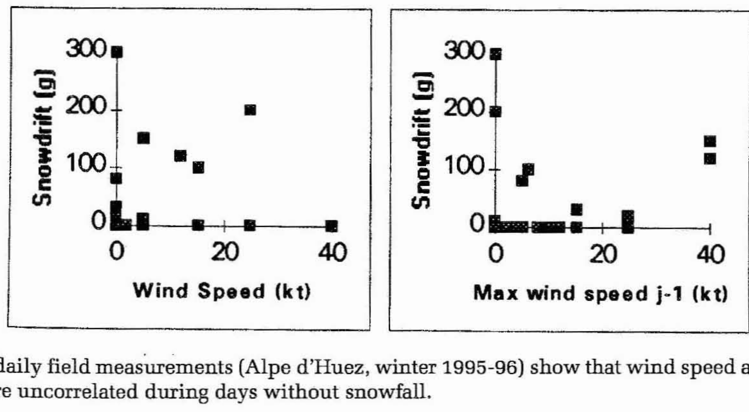

Fig.8: daily field measurements (Alpe d'Huez, winter 1995-96) show that wind speed and snowdrift are uncorrelated during days without snowfall.

accumulation than wind. The experiment shows that snowdrift index and avalanche activity are correlated, and that P(A1 | S1)=1. Therefore we believe that snowdrift data are useful for local avalanche forecasting.

In future, snowdrift characteristics may be calculated from real-time multiple snowpack simulations and wind fields computations. Snowdrift may also be automatically measured. This will require high-tech equipments. At present, using a driftometer is already effective and... cheaper!

CONCLUSION

The main results of this study are:

- the driftometer is a simple instrument which makes quantitative snowdrift assessments without energy possible,
- the driftometer index is more predictive of avalanche activity during days without snowfall than wind data.

Thus, the driftometer helps to achieve reliable local avalanche forecasting.

This is the reason why we included the driftometer index in the input data set of the decision support system NxLog.

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