# A French Local Tool for avalanche hazard forecasting : Astral, current state and new developments.

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**Abstract:** In several ski resorts, we have distributed a tool named Astral. Every days, this software calculates an Euclidean distance and correlation with past days, in order to select ten analogous days by a nearest neighbour approach (see Bois 75 and Buser 89) . The input variables are : temperature, daily amount of fresh recent snow and water equivalent, sum of temperature at 13 hour above zero threshold, wind velocity, .... A principal component analysis is done on these raw variables in order to have a data reduction and almost to obtain independent variables before the analogous step. The outputs are the raw variables concerning the ten selected analogous days and the corresponding observed avalanche activity.
A notable insufficiency of this present tool is that no internal variable of snow pack is used to determine analogous days. This is due to the lack of daily observed snow pits. To avoid this default, a new improvement is to use results of the operational snow modelling chain Safran (weather analysis) Crocus (snow analysis) Mepra (stability analysis). We add new variables for a better characterisation of the snow pack and its stability. Our aim is afterwards to use the data from La Plagne resort to validate the result of this approach.

**Keywords:** statistical method, avalanche forecasting, weather and snow pack parameters

## 1. Introduction.

In each daily situation, in a ski resort or in a remote mountainous area, the avalanche forecaster does a difficult task by merging several observations, simulated results, past experience and expert reasoning .

Often, the avalanche forecaster needs a tool to "remember" past similar days and to know what were the meteorological and snow pack conditions and their consequence on avalanche activity. The method to refer to past conditions may be very useful, in order to build up a personal decision scheme.

But it's very difficult to remember with accuracy all the past situations without an objective tool. The central question is : What is the meaning given to the word analogous or similar ?

### 1.1 review of developments

At the beginning of the eighties, a collaboration between the Cen and the La Plagne safety service have permitted to select the daily available parameters which have influenced the avalanche phenomenon. A first software named Prela concluded this period. With the development of the integrated software Geliniv (see Dumas 96), a new module named Astral have been developed and completely integrated in Geliniv environment with some new possibilities, better ergonomic design and scenario possibility. Now, our centre works on integration of results stemming from the operational simulation chain used in French avalanche forecast services in this kind of statistical model.

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## 2. Description of method in Astral.

Astral is a tool developed in order to help the avalanche forecaster at a local scale in a safety service of a ski-resort. In Astral, the selection is only made among the daily observed parameters. The daily observation comes mainly from the snow weather network made at 8h and 13h local time. In particular, daily information from snow-pits are not available. When the raw data are chosen, they are very often correlated ; it is more efficient to avoid variables which are too much correlated each other. Thus, the principal components analysis (see Diday 82) is used to calculate linear independent variables and to minimize the lost of information in term of cumulated variance. In this new space, the principal components vectors space, each day is represented by a point with its new coordinates.
At this step, we can introduce a statistical translation for the "analogous concept" by a calculation of the distance (Euclidian by example) and the correlation coefficient between the day we want to analyse and all other winter days in the past. The strategy, for choosing the analogous days is to combine this two criterions. Finally, we will study how we could validate this approach

**2.1 Search of informative variables**

After previous studies, we chosen :

- air temperature at 8h and 13h local time,
- snow temperature at the same times,
- daily water equivalent of the precipitations,
- daily recent snow amount,
- depth of snow mantle,
- sum on 3 days of the temperatures above 0°C threshold at 13h,
- sum of the water equivalent on two and three days,
- sum of the fresh snow on two and three days,
- penetration depth at 8h,
- wind velocity at 8h and 13h,
- avalanche code at 13h (D) and 8h (D+1).

Fifteen variables are used for the characterization of the day and two (the avalanche code) as illustration parameters.

**2.2 Search of independent variables**

In order to compress the information and mainly to avoid correlated variables, we used a principal component analysis (PCA) on all chosen informative variables excepted the two avalanche codes. The basic idea of this method is the following principle . If X represents a sample of n days, with p variables, therefore X is a n.p matrix, the principal component analysis gives an answer to the question : " How to build a q-space with q-independent vectors in which the projection of X can be made with the minimum lost of information in variance meaning ? ".

In order to avoid scale effects, we normalize raw data, and then we diagonalise the correlation matrix between the raw variables. If we choose the space generated by the q-eigen vectors associated with the highest q-eigen values, the lost of information in the projection of X is minimal. The cumulative explained variance gives an idea of the quality of the projection. In our application Astral, we retain 10 principal components with 15 raw variables, which explains 95% of the cumulative variance. With about 600 days, the percentage explained by each principal component is stable as seen in fig 1. So for any new set up in a safety service, we recommend to have a minimum of 4 winter seasons to avoid statistical instability.

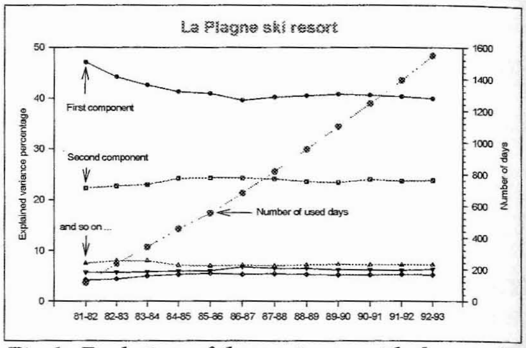


*Fig 1: Evolution of the variance with the number of available days*

**2.3 Search of analogous days**

All the past winter-days are projected in the PCA space and the principal component are calculated. In the PCA vector space, we use an Euclidean distance as a criteria of proximity and also the correlation coefficient. A geometric explanation of this second criteria is the cosine angle between the two vectors. This criteria is very interesting when a day is far away from the density centre of all days. The chosen strategy for the research of the ten neighbours of a selected day is the following :

- calculation of the principal components of the analysed day
- research of the neighbours in a sphere with a radius of the half of the distance between selected day and density centre
- selection among the previous neighbour days of the ten nearest neighbours above a threshold of 0.7 for the correlation coefficient .
- display of raw variables and avalanche activity for the ten selected analogous days and also the raw variables for the analysed day. The Geliniv environment allows an ergonomic access, you can see after on fig 2 and 3 two screen displays.

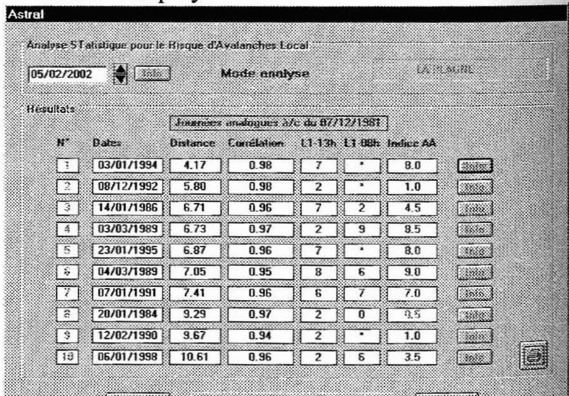


*Fig 2: Astral results screen in Geliniv environment.*

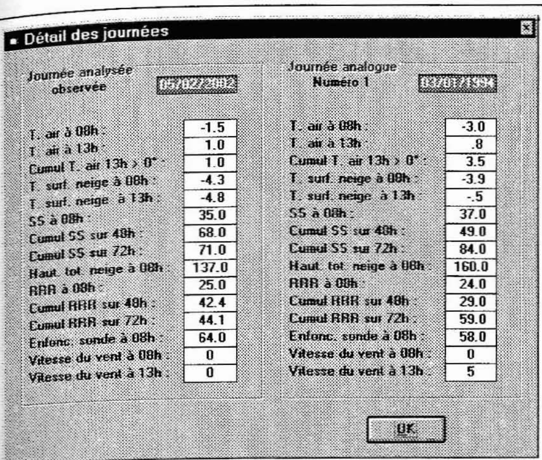


*Fig 3 : Raw variables for analysis day and the first analogous day*

### 2.4 Evaluation and some limitations

With human observations, it is very difficult to observe an area of 100 km2 wide under all weather conditions with the same accuracy and resolution every day of the winter season. Actually, the automatic detection of avalanche activity, like seismic techniques, or acoustic detection are on the research field and not yet available in operational framework. Another problem is that the forecaster works on risk hazard and not on the occurrence of avalanche itself.

So, the contribution of this method can be evaluated by subjective judgement of the local forecaster. The appreciation has been estimated positive and the method used was estimated to facilitate the search of "analogous" days in the past. Now this software is set up in 23 ski-safety-services in the Alps and Pyrénées.

Another way of evaluation is to built a contingency table, for this the avalanche code (J 13h and J+1 8h) is transformed in an index according different weight plotted on table 1 :

| L1 | Weight | Meaning |
|---|---|---|
| 0 | 0 | Nothing to mark |
| 1 | 0 | Accidental releases |
| 2 | 0.5 | Positive artificial releases |
| 3 | 0 | Crack in snow pack |
| 4 | 1 | Superficial snow slides |
| 5 | 2 | One natural avalanche |
| 6 | 3 | Two natural avalanches |
| 7 | 4 | Three to five natural avalanches |
| 8 | 6 | Six to ten natural avalanches |
| 9 | 8 | More than ten avalanches |

*Table 1: Table of weight on avalanche code*

The observed index is the sum of the two weights for the two avalanche code at 13h and at 8h the following day. For the ten neighbours, we use a composite index of the ten indexes weighted by the distance. If the composite index is above a chosen threshold (0.8 in our application), we consider that an avalanche can be occur. So, we can now construct a contingency table with avalanche, non avalanche, observed and forecasted occurrences. For example, on twenty winter seasons with 2695 available days on La Plagne ski resort we obtained, the following table below:

| Obs. \ Forecast | Non Avalanche | Avalanche |
|---|---|---|
| Non Avalanche | 60% | 15% |
| Avalanche | 10% | 15% |

*Table 2: Contingency table*

The lack of internal information from the snow pack explains for a part the non detection rate. The discrepancy between risk hazard and the construction of the index based on observed avalanche can partly explain a part of false alarm rate.

Another function of Astral application is the possibility to try several scenarios. For this purpose, the local forecaster gives an estimation of the future value of raw variables for the following day. Astral computes with this "imaginary" observation, the corresponding analogous days and the forecaster can look at the avalanche activity of the analogous days.

This function is very appreciated by the local forecaster.

## 3 New developments : Anis.

The purpose of the new development is to integrate, some variables to describe the internal structure of the snow pack and also the spatial variability of the weather parameter. Thus, as we have not daily snow-pits and not many observation points, we try to use variables stemming from the Safran Crocus Mepra chain named after SCM (see Brun 88 and 92 and Durand 99). In a first step, we try this method at La Plagne ski-resort, for a test.

### 3.1 Integration of simulated variables

After examination of a map of ski-resort La Plagne, we chosen 17 points in the SCM simulation ( based on aspect, level) on Vanoise massif illustrated in table 3:

| Level\aspect | | | | | |
|---|---|---|---|---|---|
| 1800m | N | SE | S | SW | |
| 2100m | N | SE | S | SW | W |
| 2400m | N | | S | SW | W |
| 2700m | N | | | | W |
| 3000m | N | | | | W |

*Table 3: Table of chosen characteristic points*

We chosen 13 variables in the SCM results (see Table 4) :

| variable | Max on the day | Min of the day |
|---|---|---|
| Air temperature | X | X |
| Wind velocity | X | |
| Infrared and total solar radiation | X | X |
| Height of the snow pack | X | |
| Recent snow depth at snow surface | X | |
| Wet snow depth at surface | X | |
| Angulus snow depth at surface | X | |
| Driftable snow depth at surface* | X | |
| Erodable snow depth at surface* | X | |
| Composite index of natural avalanche from Mepra analysis | X | |
| Composite index of accidental avalanche from Mepra analysis | X | |

* (see Guyomarc'h 98)

*Table 4: Table of new chosen variables*

The learning dataset is the winter since 1993-1994 to 2000-2001, so the number of available days is 1210. In a first analysis, we studied the behaviour of all these variables and also the correlation between them. We have suppressed the wet snow depth at 3000m N because it is always zero value. All the temperature variables are very correlated each other (correlation near .95). Finally, we have a potential of 220 new variables.

### 3.2 Concentration of information

With the same method developed in Astral, we perform a principal component analysis on these new variables, and with a criteria on cumulative explained variance, we retain only 28 principal components. The first one is very correlated with all the temperature variables, the second one with the depth of recent snow...

### 3.3 Analogous days research and evaluation

We built a new file with the ten "observed" principal components stemming from Astral step and the twenty eight "simulated" principal components stemming from the previous step of Anis. We adopt the same method as in Astral to select the ten analogous days. Now, our work is to evaluate the quality of the new analogous days. For this purpose, we plan to compare the climatology of the analogous days stemming from Astral with those stemming from Anis and also with the observed climatology. As the safety service of La Plagne has recorded all avalanche events, we plan to use this file and also the level of avalanche risk forecast to build an index on analogous days. This index could give a synthetic information on the avalanche behaviour of the analysed day. This work is actually in progress.

## 3. Future prospects.

If, as expected, the new variables could better inform on the snow and weather conditions, we plan to try a test application during the winter season 2002-2003 for the ski-safety service of La Plagne. In order to provide this safety service with Anis results, a web site could be developed.

We plan to develop a scenario module in Anis. For this purpose, we use the forecast results from the SCM chain and the local forecaster will give the same "scenario" values as in Astral.

*ACKNOWLEDGEMENTS*

*We are grateful to the management and people of the Safety Service of La Plagne who help us for the observed collected data.*

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