WIND TRANSPORT SCENARIOS BASED ON THE SLOPE ASPECT FOR AVALANCHE RISK MANAGEMENT PURPOSES

Eloïse Bovet[1]*, Luca Pitet[2], Igor Torlai[3], Valerio Segor[2], Paola Dellavedova[1], and Umberto Pellegrini[3]

[1] *Fondazione Montagna sicura, Courmayeur (AO), Italy*
[2] *Assetto Idrogeologico dei Bacini Montani, Regione Autonoma Valle d'Aosta, Italy*
[3] *Centro Funzionale, Regione Autonoma Valle d'Aosta, Italy*

ABSTRACT: Avalanche risk management assumes an in-depth knowledge of the nivometeorological situation to which tools for the definition of avalanche potential release can be associated. The application of the PRA tool, developed by the SLF, on 600 real cases in Aosta Valley showed the important role played by the wind direction in determining scenarios of avalanche detachment. On those basis a rapid method has been developed, using the 10m wind intensity and direction data provided by the Cosmoi2 predictive model. The wind direction input was calculated by averaging vectorially the wind directions over the 24h, weighted with the cube of the intensity. In order to validate this procedure, the data elaborated with our procedure were compared with 1) the data of 52 automatic stations and 2) the observations contained in the Models 1 A.I.NE.VA. Scenarios of possible snow eroded / loaded areas are realized according to the wind direction at both valley and single-basin scales. Daily, after 40 minutes calculation time, three graphs are forecast: 1) statistical summary of the basins eroded / loaded by the wind on the 26 micro-areas in which the Aosta Valley is divided, 2) wind direction on the 800 cells of the Cosmoi2, 3) probability of erosion / deposit on each individual avalanche basin. Those graphs are displayed in the Avalanche Local Committees (CLV) web platform. The procedure, while giving satisfactory results, has limits due to the simplicity of the model used, to scale issues and to the snowdrift amount neglected in the modelisation.

KEYWORDS: snow-drift, forecast, avalanche risk management, avalanche scenario.

1. INTRODUCTION

In Aosta valley, the management of local avalanche danger is guaranteed by the Local Avalanche Commissions (CLV) that support the mayors in the decision-making (i.e. closure / opening of roads, evacuation of population centers ...), by evaluating snow conditions and snowfall stability.

The CLVs operating in Aosta Valley are 17 and are technically supported by the Avalanche Warning Service of Aosta Valley (UNV) technicians, who make available the material and data in their possession, to improve the evaluations and the forecasting.

Thanks to the implementation of some projects funded by the EC, such as STRADA 2.0 CAPVAL and ART-UP-WEB (Segor et al., 2016), the UNV of Aosta Valley has tried to identify, through a critical analysis, which are the nivometeorological parameters to be monitored and through which tools and methodologies it is more effective to quantify them. The analysis goal is to create event scenarios based on avalanche detachment processes.

* *Corresponding author address:*
Bovet E., Fondazione Montagna sicura,
Courmayeur, AO, Italy;
tel: +39 0165 776851; fax: +39 0165 89133
email: ebovet@fondms.org

2. POTENTIAL RELEASE SCENARIO

Within the CAPVAL project, UNV tested the avalanche tool PRA (@Potential Release Area) (Veitinger et al., 2014) in many real cases occurred in the Aosta valley. The input data needed to PRA simulation are:

<u>DEM</u> (2 meters), that simulates the roughness of the slope.

<u>Hs,</u> that defines the snow depth in the release area.

<u>Wind</u>, that defines the wind direction and the wind tolerance.

600 simulations were carried out and a specific database was created with more event scenario for real cases.

In order to validate these scenarios, a critical analysis of the results obtained was carried out, comparing them with data (photos, shapefiles ...) of the regional Avalanche Cadastre (CRV) (Debernardi and Segor, 2013). This validation has shown that the tool represents adequately and in detail the probable release avalanche areas; however, the representation of very large areas requires very long processing times.

The goal is to have event scenarios in forecast for the entire regional territory in a short time. In order to do this, it was decided to simplify the procedure:

- considering only avalanche events contained within the P.A.V. (Plan Avalanche Activity). The land surface reduction accelerates the data processing, because it reduces the cartographic surface DTM (Digital Terrain Model) on which the data are processed;

- considering only the parameter Wind and omitting the parameter Hs. The analysis of the data processed with the PRA procedure showed that the parameter Wind is much more decisive than the parameter Hs in defining a scenario: when the values of Hs changes, the scenario changes very little. On the contrary, when the values of Wind direction change, scenario significantly changes (Fig. 1) .

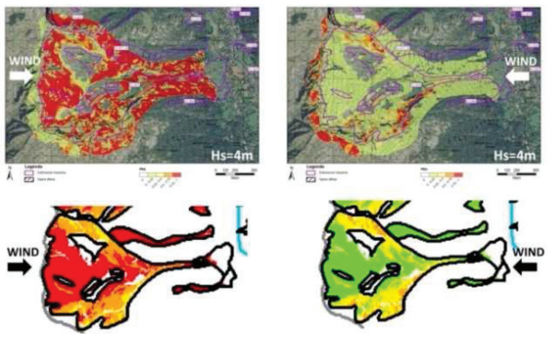

Figure 1: The wind direction influence significantly the event scenario. On the top the PRA procedure, on the bottom our simplified method.

3. METHOD

To associate wind direction to each avalanche site, we decided to use the Cosmoi2 predictive model. Aosta Valley is divided in about 800 cells with 2.7km of edge. In each cell the wind direction and intensity *u* at 10m over the ground are available in forecast with a 3h time step . To take into account the change in direction and intensity of the wind during a day, the wind directions are vectorially averaged over the 24h, weighted with the cube of the intensity. This choice is based on the Föhn (1980) equation:

$$Q=k\cdot u^{3}\text{, with } k=8\cdot 10^{-5}\ s^{3}d^{-1}m^{-2} \qquad (1)$$

At the beginning of our study, we used the Duynin et al. (1980) equation:

$$Q=c\cdot (u-5)^{3}\text{, with } c=7.7\cdot 10^{-5}\ s^{3}d^{-1}m^{-2} \qquad (2)$$

Since in too many situations Eq. 2 gave no snowdrift even when Avalanche Cadastre data recorded snow transport, we decide to not consider the threshold of 5 m/s appearing in Eq.2 and to use Eq.1.

Having obtained the wind direction, we started from the principle that, in relation to a predefined wind direction, the slopes are "loaded" or "eroded" from the snow according to their exposure. The downwind slopes are loaded (and therefore are subject to deposit of snow), those upwind downloaded (and therefore are subject to erosion). According to Fig.2 colors have the following meaning:

RED represents the leeward quadrant whose exposure is opposite to the wind direction and, therefore, subject to probable snow drift deposit;

ORANGE represents the remaining downwind sectors and, therefore, subject to possible snow wind storage;

GREEN represents the upwind quadrant whose exposure is consistent with the wind direction and, therefore, subject to the probable erosion of the snow;

YELLOW represents the remaining windward areas and, therefore, subject to possible snow erosion.

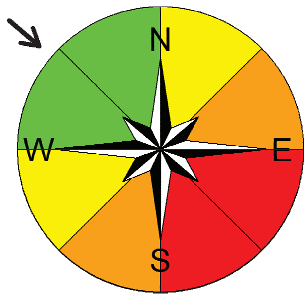

Figure 2: Example of exposures with deposition and erosion of snow, with a NW wind.

Our procedure, written with the open source software R, automatically finds the wind direction for each cell of Aosta Valley by vectorially averaging over 24h, defines which slopes are deposited and which ones eroded, joins the different cells and finally does a statistical analysis at micro-area scale, as explained into details in Sec. 5.2.

4. VALIDATION

The method exposed before is applied to 2011-2016 years and compared with the data recorded by snow weather automatic stations and A.I.NE.VA. Models 1.

In our validation process, we consider valid data where both the Probability Of Detection (POD) and Success Ratio (SR) are greater than 0.5. POD and SR are index based on the contingency table (Fig.3). POD= hits/(hits+misses), answers to the question "What fraction of the observed "yes" events were correctly simulated?" SR=hits/(hits+false alarm) answers to the question: "What fraction of the simulated "yes" events were correctly observed?"

		OBSERVED		
		YES	NO	TOTAL
FORECAST	YES	hits	false alarms	forecast yes
	NO	misses	correct negatives	forecast no
	TOTAL	observed yes	observed no	total

Figure 3: Contingency table.

4.1 A.I.NE.VA. Models 1

A.I.NE.VA. Models 1 are compiled daily in different locations in Aosta Valley and give the information about the snow drift occurrence and, if present, the exposure of the snow deposition. Aosta Valley is divided in the 26 micro-areas used in the Snow and Avalanche Bulletin. Fig.4 shows the 15 sectors (the blue and magenta ones) where there is a good concordance between the A.I.NE.VA. Models 1 data and Cosmoi2 elaborated data..

Figure 4: Validation based on the A.I.NE.VA. Models 1. Yellow: min(SR,POD)≤0.5, blue: 0.5< min(SR,POD) ≤0.75, magenta: min(SR,POD)>0.75, grey: not enough data for the statistics, white: no data.

4.2 Weather automatic station (AWS)

Cosmoi2 data, both with a time step of 3h and vectorially averaged over the 24h, are compared with data of 52 stations located in the Region (Fig. 5). Generally the wind intensities differ less than 4m/s, without a unique pattern (neither AWS nor Cosmoi2 always overestimates values).

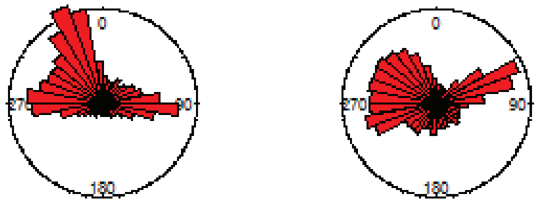

Figure 5: The data in the period 2011-2016 simulated with the Cosmoi2 elaboration (on the left) and recorded by the AWS called Becca-France (on the right).

Fig. 6 shows the sectors where both SR and POD are greater than 0.5. We underline that the introduction of the vectorially average of the wind direction ameliorates the number of sectors where there is concordance of data.

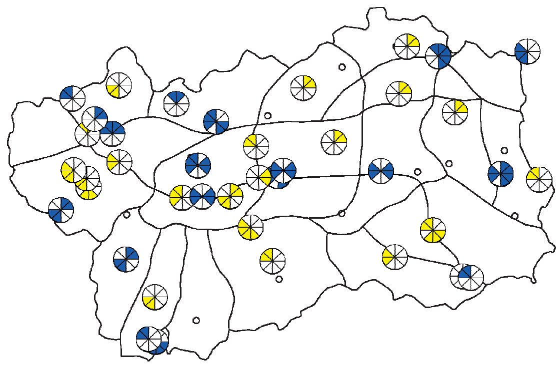

Figure 6: Sectors validated by weather stations data. In blue the sectors of the stations where at least 10% of the intensities are greater than 5 m/s, and hence where the snow drift is significant. In yellow the other ones.

Joining the results of the two validations over described, a mask to hid with the grey color the un-validated sectors is obtained (Fig.10).

5. VISUALISATION

In the Avalanche Local Committees (CLV) web platform, two kinds of scenarios (statics and dynamics) concerning the snow drift are displayed to support the UNV forecasters and the CLV components in their management decisions.

5.1 Static scenarios

The static scenarios are cartographic illustrations that graphically represent the wind transport scenarios, on P.A.V. basins, according to a predefined wind direction and slope exposure. On the Platform these 8 scenarios (N, NE, E, SE, S, SW, W, NW) always remain the same and are viewable every day.

5.2 Dynamic scenarios

As regards the dynamic scenarios, three cartographic representations are proposed daily, after 40 minutes' calculation time. They represent the scenarios, in forecast, of the following day at 6h00, averaging the wind direction on the previous 24h.

The first one (Fig.7) represents the Cosmoi2 wind vectorially averaged directions (through arrows) for each single cell. The blue arrows represent a good degree of reliability with the automatic station data. The cyan arrows represent a concordance (a tolerance of ± 30 ° is allowed) with at least 6 wind directions of the adjacent Cosmoi2 cells (Fig. 8). The red arrows represent the discordance with respect to the wind directions of the 6 adjacent Cosmoi2 cells.

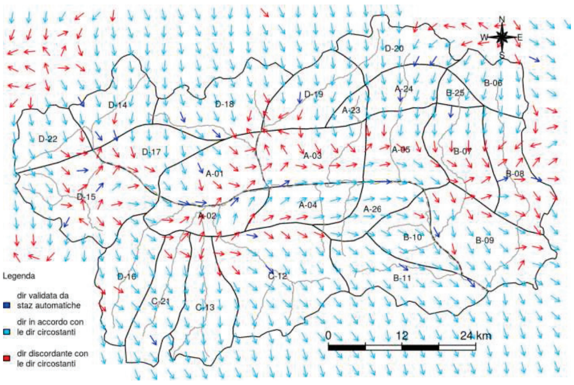

Figure 7: Wind vectorially averaged direction.

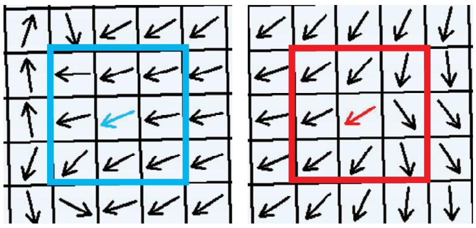

Figure 8: Cases in which the central arrow is validated (on the left), or not (on the right) considering the cells in the box.

The second map (Fig.9) represents the wind transport scenarios, on P.A.V. basins, according to the wind directions of the Cosmoi2 cells (Fig. 7) contained in the avalanche basin and the exposure of the slopes. Unlike static scenarios, these scenarios vary from day to day depending on the different wind direction forecast.

It is important to underline that, even if visible at the basin scale, the information must be considered at the Cosmoi2 scale (grid with side of 2.7km).

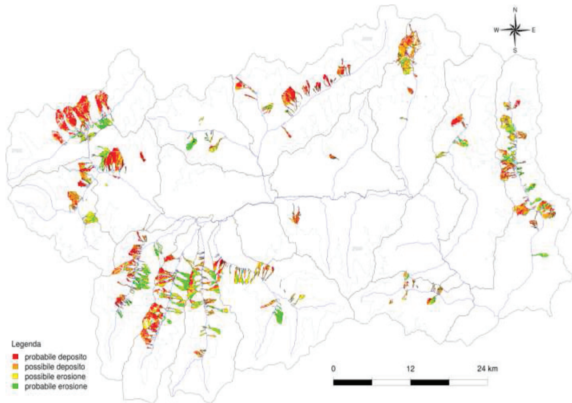

Figure 9: The deposit / erosion area according to the wind direction given by Fig. 7.

The third map (Fig. 10) represents the statistic distribution of wind snow transport for single micro-areas, depending on the exposure of the slopes.

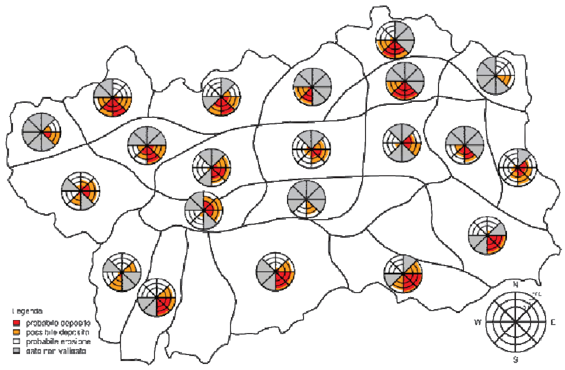

Figure 10: Cartographic representation with pie charts for each micro-areas. In red and orange the deposition, in white the erosion, in gray the sectors whose data could not be validated (Sec. 4), and hence could give an unreliable forecasted situation.

The radii of the segments within the pie chart represent the distribution percentages of red (probable deposit) and orange (possible deposit) for each semi-quadrant for each micro-areas (Fig.11). In particular, the concentric circles represent the achievement of 50%, 75% and 100% of the micro-areas surface.

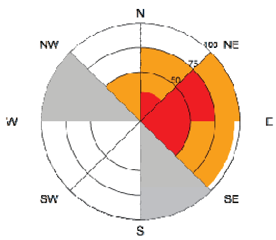

Figure 11: In this case, 75% of the slopes of the micro-area with exposure between NE and E are red (=probable deposition) and 25% are orange (=possible deposition). The slope with exposure between S and W are eroded.

During the winter season 2017-2018 those maps were validated directly on the web platform (Fig.12) by the UNV forecasters and the components of the CLV.

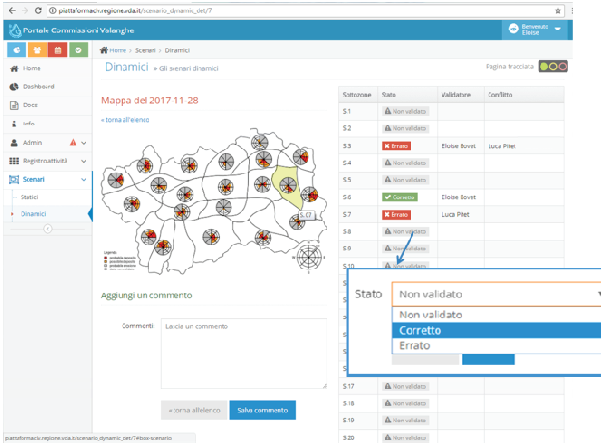

Figure 12: Validation of the map on the web platform.

In particular, they validated 259 scenarios (Fig. 13) on 109 different days giving 97 comments. Unfortunately not all the micro-areas were validated adequately.

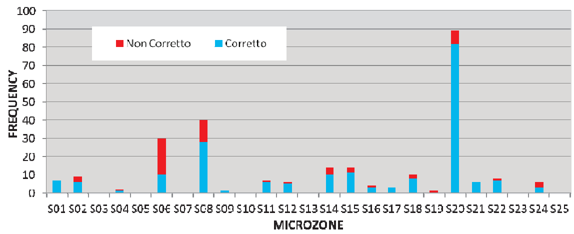

Figure 13: The validation done in the winter 2017-2018.

6. CONCLUSIONS

In conclusion, our procedure gives the information about the slopes loaded and eroded by wind at a scale of 2.7km, for the entire regional territory, in a short time. Since those scenarios, are given in forecast it is possible both to obtain a more accurate Snow and Avalanche bulletin both to focus the attention on the avalanche paths with more problems due to snow drift.

However, this methodology is experimental and has the following limitations:

- wind speed data (direction and intensity) are simulated and forecast, therefore they have the limitations of the model Cosmoi2 (2.7 km wide cells, simulated non real topography, data every 3h…);

- the erosion and deposit phenomena are modeled without taking into account the quality of the snow, the presence or absence of snowfall, the order in which the winds occurred, the proximity or not by ridges and valleys;

- wind transport maps are always provided even when the wind intensity is too low to generate transport.

Finally, in the future we could introduce our procedure in a more complex system for the forecast or, for instance, in a nearest neighbour model.

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