FROM FIELD OBSERVATIONS TO ANALYSIS: CHANGING SNOWPACK AND AVALANCHE CONDITIONS IN THE AOSTA VALLEY (NW ITALIAN ALPS)
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ABSTRACT: In recent years, avalanche forecasters in the Aosta Valley have observed significant changes in snowpack characteristics and avalanche dynamics due to climate change. The main observations include a higher rain–snow transition elevation, reduced snow-cover duration at lower elevations, and changes in average snowpack depth, while high-elevation snowfall remains relatively stable but highly variable. Forecasters report increasingly complex and rapidly evolving winter conditions, including prolonged dry periods, extreme snowfall events, high-elevation rainfall, and intense temperature fluctuations. The resulting spatial and temporal variability in avalanche hazard directly affects operational forecasting, increasing uncertainty in hazard assessment and backcountry route selection. To quantify these observations, this study analyzes nivometeorological data and the Regional Avalanche Cadastre using manual measurements together with numerical modelling. The ultimate objective is to improve understanding of these processes, assess their effects on snowpack stability, and evaluate their implications for avalanche forecasting and risk management in a changing climate.

KEYWORDS: snow-cover monitoring, historical database, climate change.

1. INTRODUCTION

The Aosta Valley Region (Fig. 1) is located in north-western Italy, in the heart of the European Alps, bordering Switzerland, France, and Piedmont (Figure 1). More than 60% of its territory lies above 2000 m a.s.l. Several large and very large avalanches occur in the region, including events in areas with no previously documented activity. Eighteen percent of the regional territory is



Figure 2: Map of the Aosta Valley – Italy.

affected by avalanches, as documented in the Regional Avalanche Cadastre (https://valangheweb.partout.it/).

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Global warming is particularly pronounced in high-mountain environments: the European Alpine arc is warming at approximately twice the global average rate (Dumont et al., 2025). Since the end of the nineteenth century, mean Alpine temperatures have increased by approximately 2.0±0.3 °C, with a winter increase of 0.3–0.4 °C per decade over the 1968–2017 period (Monteiro et al., 2023). The signal is also evident in the Aosta Valley, where temperatures have increased by approximately 1.7 °C relative to the 1974–1995 reference period and could rise by a further +1.0–1.2 °C by 2035 and by approximately +4.1 °C by the end of the century under the RCP8.5 scenario (Cremonese et al., 2021). At the synoptic scale, variations in temperature and precipitation are closely linked to changes in atmospheric circulation over the North Atlantic. The NAO (North Atlantic Oscillation) and AO (Arctic Oscillation) indices influence the persistence and trajectories of winter storm systems reaching Europe (Bozzoli et al., 2024). In recent decades, the winter NAO index has tended toward predominantly positive phases, associated with higher temperatures, reduced persistence of cold conditions, and a greater frequency of warm anomalies (Spanjers et al., 2025). Analyses of atmospheric dynamics indicate an increase in circulation patterns associated with heat waves and winter storms and a decrease in patterns responsible for cool and wet conditions (Faranda et al., 2023). Thermodynamic warming directly affects the type and amount of precipitation and Alpine snow resources (Bozzoli et al., 2024), leading to reductions in snow depth and snow-cover duration that

are particularly pronounced at low and mid elevations (Monteiro et al., 2023; Matiu et al., 2021; Carrer et al., 2023). In the south-western Alps, analysis of the 1920–2020 period indicates a 4.9% per decade decrease in snowfall (HN) below 2000 m a.s.l. Rising winter temperatures have made temperature the main limiting factor for snow since the 1980s. Increasingly mild air masses favour rain rather than snow at low and mid elevations (Bozzoli et al., 2024). Accordingly, the rain–snow limit has risen by approximately 240 m in January and by more than 420 m in February over the last thirty years in the southern Alps, with a consequent increase in rain-on-snow (ROS) events at the expense of snowfall days (Valt, 2025). In this context, the regional Functional centres and the regional and provincial Snow and Avalanche Offices belonging to AINEVA preserve a valuable archive of nivological data collected since the 1970s–1980s, and in some cases even longer historical series.

This study analyzes the last 20 winters in the Aosta Valley using data from the Snow and Avalanche Office, with the aim of characterizing at the local scale the response of the Italian western Alpine sector to the climate-related changes highlighted in the literature. The study assesses the nivological effects of climate change, focusing on changes in precipitation regime, the increase in rain-on-snow events and meteorological variability, and the resulting changes in snowpack characteristics.

2. DATA SOURCES

Our study was based on three main data sources: one derived from manual data collection through direct observations and two obtained from model-based processing using interpolation of data available across the region. Data processing was performed using R, a software environment and programming language for statistics and computational graphics. The data sources are:
- The freezing level is the altitude, expressed in metres above sea level, at which the air temperature reaches 0 °C and above which it remains below zero. It is a key parameter in mountainous environments, influencing both the precipitation regime, determining the transition between rain and snow, and the presence and persistence of snow on the ground. The freezing level therefore remains an essential parameter for assessing the development and moisture content of the snowpack. In the Aosta Valley, for monitoring purposes, the freezing level is reported relative to the ground rather than the free atmosphere. It is derived using a procedure in which weather stations are grouped into altitude bands; for each group, a linear regression line is then calculated, resulting in a broken line that describes the temperature trend as a function of altitude. The freezing level, in this case, corresponds to the point where this broken line intersects the zero value. The data is available both in aggregated form for the whole of the Aosta Valley and in detail at the macro-area level.
- AINEVA Model 1 forms are standardized forms used by the Italian Avalanche Services for the daily collection of nivometeorological data. Observations are carried out at fixed snow plots distributed across different elevations. Sites are generally selected in flat areas sheltered from the wind, thereby providing point measurements that are representative of local snow conditions (Figure 2). The observations include snowpack and meteorological characteristics. These data are essential for two reasons: they provide one of the main sources for analyzing snowpack evolution and preparing avalanche bulletins, and they ensure uniform assessments throughout the area of responsibility (AINEVA, 1997).

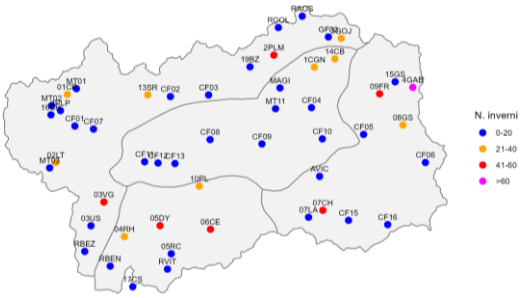


Figure 2: Subdivision of the Aosta Valley into macro-areas and number of winters available for AINEVA Model 1 observations

For this study, stations were selected that are evenly distributed across the regional territory and have the most robust and complete historical series. Over the years, any station relocations have been minimal, maintaining broadly comparable elevation, exposure, and local microclimatic conditions.
- Snow-depth (HS) maps from the S3M model. These products, available daily at https://bollettinovalanghe.regione.vda.it/mappe-neve#, show spatially distributed data obtained from the S3M (Snow Multidata Mapping and Modeling) model developed by Fondazione CIMA. S3M is a dynamic model that provides a simplified description of snowpack evolution using snow-depth observations from automatic stations and MODIS satellite imagery to distinguish snow-free from snow-covered areas. Manual observations from AINEVA Model 1 forms are also assimilated into S3M. Over the Aosta Valley, S3M runs on a grid of approximately 200 m × 286 m with an hourly time step. The model has been operational at the Regional Functional and Planning Centre since 2003 under an agreement with Fondazione CIMA

(Avanzi et al.,2022).
- The Regional Avalanche Cadastre (CRV) of the Aosta Valley is the official historical and cartographic archive that collects and maps avalanche phenomena recorded in the region from the early 1970s to the present. It keeps a record of all inventoried avalanches, assigning each event a unique code and documenting its characteristics. The Cadastre is accessible through a WebGIS portal that displays the mapped extent and location of release and deposition areas (Debernardi et al., 2013).

3. METHOD OF ANALYSIS

3.1 Statistical analyses

The presence of temporal trends in all data sources was assessed using the non-parametric Mann–Kendall test, which determines whether values show an increasing or decreasing trend over time. The test also establishes whether the observed trend is statistically significant, i.e. sufficiently pronounced that it is unlikely to be attributable solely to data variability. A significance threshold of $p < 0.05$ was therefore adopted, and trends with p-values below this threshold were considered statistically significant.
The magnitude of change over time was quantified using Sen's slope. This estimator is obtained by calculating slopes between the different pairs of observations in the time series and using their median, providing a robust estimate that is relatively insensitive to outliers. Positive slope values indicate an increasing trend, whereas negative values indicate a decreasing trend; the magnitude of the slope quantifies the rate of change. The two methods are therefore complementary: the Mann–Kendall test determines whether a statistically significant trend is present, whereas Sen's slope indicates its direction and quantifies its magnitude.

3.1.1 Freezing level

For each season (winter–spring), geographic area, and variable analyzed, the temporal trend from 2000 to the present was assessed. The analysis was conducted for 500-m elevation bands and at different temporal scales: the entire season (TS, December to April), the winter months separately (WI: December, January, and February), the spring months (SP: March and April), and finally each individual month. The Mann–Kendall test and Sen's slope were then applied to assess temporal trends. To provide a concise description of freezing-level elevation, three indicators were calculated as the mean of the daily minimum, mean, and maximum freezing-level values, respectively. These indicators therefore represent the elevations at which the freezing level is typically located at its lowest, average, and highest daily levels.

3.1.2 Model 1 data

As for the freezing level, the analyses were conducted using different temporal aggregations. November and May were not considered because of the limited number of Model 1 observations collected over the years. Before statistical analysis, data completeness was checked: only periods with at least 90% of the expected observations and stations with at least 80% valid years over the analyzed period were considered valid. Consequently, the number of stations included in the analysis is not constant but varies according to the variable, time period, and temporal aggregation considered. Therefore, for each combination of variable and analysis period, trends were calculated only for stations meeting the defined completeness criteria.
In addition, stations were classified by elevation in order to assess possible altitude-dependent differences in trends. For the Model 1 analyses, the following elevation bands were considered: valley floor (< 1250 m a.s.l.), low mountain (1250–1749 m a.s.l.), mid mountain (1750–2249 m a.s.l.), and high mountain (≥ 2250 m a.s.l.). Trends were assessed using the Mann–Kendall test and Sen's slope.

3.1.3 S3M maps

The spatial representation of snow depth (HS) provides an intuitive view of snowpack distribution, highlighting its evolution from season to season and allowing possible trends to be analyzed as a function of elevation bands and the different geographic sectors of the Aosta Valley. The 2003/04–2022/23 period was used as the reference. Seasonal HS anomalies were calculated for each pixel relative to its mean value; positive values indicate greater snow accumulation and negative values lower snow accumulation. Changes in HS with elevation were also analyzed by dividing the territory into 500-m elevation bands. For each band, the mean, median, and selected percentiles of the HS distribution (P10, P25, P75, P90, and P95) were considered in order to describe not only average conditions but also the lower and upper parts of the snow-depth distribution.
In addition to the Mann–Kendall test and Sen's slope, the Benjamini–Hochberg FDR correction was applied to account for the large number of comparisons among elevation bands, maintaining a significance threshold of 0.05. This made it possible to identify the most robust trends and assess whether HS changes differed with elevation and among different parts of the distribution. The

analysis of these data is particularly valuable because, although based on a different definition, it extends the analysis performed in this study to months for which Model 1 data are not collected.

3.1.4 Regional Avalanche Cadastre analysis

In this study, attention was focused on two key parameters from the avalanche cadastre: snow type at release (dry vs wet) and avalanche dynamics (powder-snow vs dense-flow); data were organized by hydrological year (Roveyaz et al., 2025). The Mann–Kendall test and Sen's slope were applied to assess possible temporal trends.

4. RESULTS

4.1 Freezing level

The Mann–Kendall/Sen's slope analysis shows a statistically significant increase in the freezing level, particularly during winter (December, January, and February). Mean freezing-level values increase, as does the number of days and hours during which the freezing level remains above 1500 and 3000 m a.s.l. The signal is weaker or not significant in spring, whereas analysis of the full season partially confirms the increase observed in winter. At the highest elevations, particularly 4000–4500 m a.s.l., many series are constant or nearly constant, making the trend less significant.

4.1.1 Month-by-month analysis

November shows an increasing signal in freezing-level elevation, with increases in the mean/minimum values and in the number of hours during which the freezing level rises above 2000–3000 m a.s.l.
December shows the strongest signal of increasing freezing-level elevation and therefore the clearest warming tendency. In recent years, excluding the latest 2025–26 season, this month has recorded higher rain–snow limits than in the past, with rain-on-snow and freezing-rain events across a large part of the region.In the central sector of the Aosta Valley, which has a continental climate, no rise in freezing-level elevation is observed because of the numerous temperature-inversion days that characterize the area.
January shows a weaker increasing signal than December and February and is more localized both spatially and in terms of the elevations affected, mainly between 1000 and 1500 m a.s.l.
February shows more widespread increasing trends, particularly in the number of hours with the freezing level above the analyzed elevation bands, from 1000 to 3000 m a.s.l., as well as in mean and minimum freezing-level values. Sunshine increases markedly in February compared with December and January; this factor, together with the global increase in temperatures, may explain the rising trends in mean and minimum freezing levels.
March shows an opposite tendency compared with December–February, particularly at high elevations. This behaviour may be related to the transitional nature of March, marking the shift from winter to spring and generally characterized by an increase in storm passages.

April shows a weak and mixed signal. The mean minimum freezing-level elevation increases. In May, in contrast to the winter months, a relatively localized decreasing signal emerges. In particular, the mean of the maximum freezing-level values decreases, as does the number of days with the freezing level above 3500 and 4000 m.
Over the December–April period, the freezing level tends to increase mainly in its minimum and mean values. Depending on the area considered, minimum values increase by approximately 11–32 m yr^{-1} and mean values by approximately 12–26 m yr^{-1}. For maximum values, a statistically significant increase is observed only when the analysis is restricted to December–February. This suggests a rise in the baseline freezing level during the cold season rather than a generalized increase in the highest extremes (Figure 3).

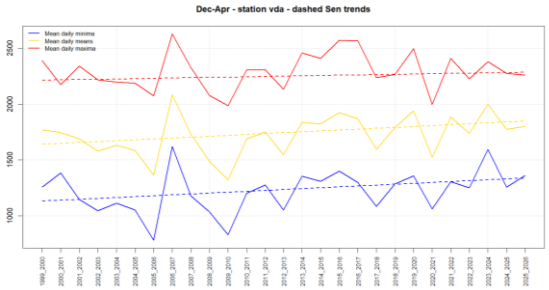


Figure 3: Seasonal freezing-level trend for the entire Aosta Valley.

It should be emphasized that part of December, together with January and February, represents the period in which thermal changes relative to past climatic conditions (e.g. the 1961–1990 reference period; WMO, 1996), characterized by typically lower temperatures, are most clearly perceived.

4.2 Model 1 data

Analysis of the AINEVA Model 1 database revealed several noteworthy trends indicating changes in the behaviour of the different parameters measured by the manual monitoring network over the 2007–2026 period.

4.2.1 New-snow indicators and snowfall frequency

Indicators related to new snow (HN – new snow fallen between two consecutive observations and measured on a nivometric tablet at 07:00/09:00) describe both the frequency of snowfall events and the amount of snow that falls. The number of new-snow days corresponds to the number of distinct days on which new-snow depth HN is greater than zero. Over the analyzed period, this indicator shows a decreasing trend for the full season (TS), with a particularly clear signal during winter (WI) and especially at valley-floor stations. Cumulative new snow represents the sum of valid HN values over the period considered. This indicator also decreases over the full season, particularly during the winter months (WI), with an annual percentage reduction ranging from 6 to 11%, and the largest values at valley-floor stations. Overall, the simultaneous decrease in the number of snowfall days and in cumulative new snow suggests a reduction in both snowfall frequency and total snowfall amount (Figure 4). These results are consistent with the predominantly positive behaviour of the winter NAO index (Spanjers et al., 2025) since the late 1970s–early 1980s, with an acceleration since the early 2000s, associated with increasing temperatures, fewer cold spells, and more frequent warm anomalies (Faranda et al., 2023).

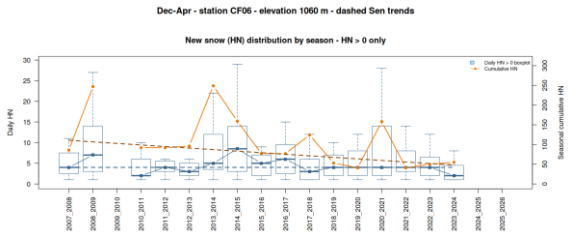


Figure 4: Distribution of HN and cumulative HN during December–April at station CF06 (Gaby).

These conditions are associated with reduced snowfall and a progressively rising rain–snow limit, closely linked to the freezing-level parameter examined above. The median cumulative 24-h new-snow amount is calculated as the median HN on snowfall days, considering only days with HN > 0. This indicator shows no significant trend for the aggregated TT, IN, and PR periods. This suggests that, when snowfall occurs, the amount of new snow associated with the individual event does not show a systematic change as clear as that observed in event frequency. The relative frequency of new-snow days is defined as the ratio between the number of days with HN > 0 and the number of days for which HN data are available. The indicator shows a decreasing trend over the full season of between 4 and 5%, particularly evident in winter and especially at valley-floor stations, with maximum decreases of 8% in January at valley-floor elevations. Overall, the new-snow indicators point to a decrease in snowfall frequency and seasonal cumulative snowfall rather than a decrease in the mean intensity of individual snowfall events.

4.2.2 Snow-cover persistence and snow-depth indicators

The number of days with snow on the ground represents the days on which snow depth (HS – snow depth measured on a graduated snow stake at 07:00/09:00) is greater than zero. This indicator therefore provides a direct measure of seasonal snow-cover duration. Median snow depth is calculated including values when no snow is present on the ground. Over the period considered, a decreasing trend emerges for the full season in both snow-cover duration and snowpack depth, with a particularly clear signal during winter, when decreasing depth trends range from −2.7 to −6.5% across the different elevation bands (Figure 5).

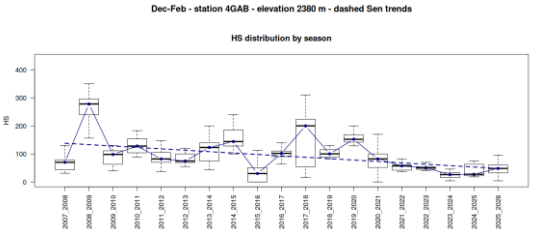


Figure 5: Distribution of HS during December–February at station 4GAB (Gabiet).

4.2.3 Temperature-trend indicators

The parameters considered were the mean minimum and maximum air temperatures (Tmin/Tmax) recorded over the previous 24 h and read from minimum/maximum thermometers, and mean air temperature (Ta) measured at 07:00/09:00. Summarizing the overall pattern by elevation, valley-floor stations clearly emerge as the centre of this increasing trend, particularly in the eastern sectors of the Aosta Valley. In these areas, winter warming, especially in January and February, exceeds +0.30 degrees per year for some indices, causing the progressive reduction in snow cover described in the previous section. At medium- and high-altitude stations, this trend is particularly evident between March and April due to the early rise in temperatures, which accelerates the melting of snow on the ground (Figure 6).

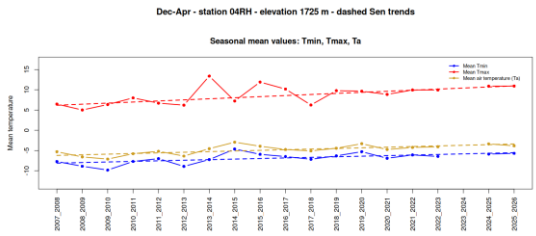


Figure 6: Distribution of Tmin, Tmax, and Ta during December–April at station 04RH (Rhêmes-Notre-Dame).

4.2.4 Rain-on-snow (ROS) events and new-snow density (PS)

The number of rain-on-snow events (HN_R) corresponds to the number of observations in which this phenomenon was recorded during the period considered. This indicator shows an increasing trend over the full season, with values between 6 and 7%, particularly evident during winter and at low elevations (Valt, 2025). The median density of new snow measured between two consecutive observations (PS) is calculated for snowfall events with thickness greater than 6 cm. No significant trends emerge for this indicator in the aggregated TS, WI, and SP periods (Figure 7). The reliability of this variable is strongly limited by data quality and by the relatively small number of measurements available over the period considered.

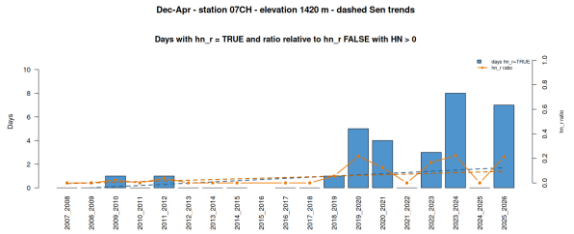


Figure 7: Number of rain-on-snow events (histogram) and ratio of rain-on-snow days to precipitation days (orange line) during December–April at station 07CH (Champorcher).

4.2.5 Snow temperature at 10 and 30 cm below the surface

The indicators developed from TH10 and TH30 (snow temperature at 10 and 30 cm below the surface) are intended to investigate how frequently snow temperature is close to 0 °C, considering conditions with at least 10 cm and at least 30 cm of snow on the ground, respectively. High values of these indicators therefore represent a greater frequency of conditions in which the snow is close to melting. Trend analysis shows that increases in the values measured at depths of 10 and 30 cm occur mainly in mid-winter, particularly between January and February. During the spring part of the season, the signal is less widespread and more localized (Figure 8).

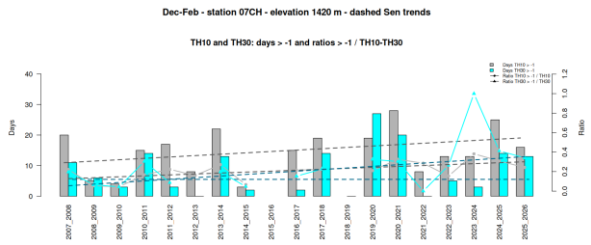


Figure 8: TH10 and TH30 parameters during December–February at station 07CH (Champorcher).

4.2.6 Snow-surface characteristics: surface hoar (SH) and snow-surface penetrability (PF)

These indices, recorded daily in Model 1 observations, provide useful information on the characteristics of the surface layer in contact with the atmosphere and directly influenced by interactions with atmospheric parameters. The frequency of surface hoar on the snowpack (SH – observation of surface-hoar presence) expresses how often surface hoar is observed. The pattern is heterogeneous, with both increasing and decreasing trends. Although limited, the decreasing signal mainly affects lower elevations and emerges during winter, the season typically most favourable for surface-hoar formation. The relative frequency of melt-freeze crusts (PF – snow-surface penetrability, which distinguishes dry from wet snow and records the presence of refrozen or wind crusts) expresses how often these crusts are observed. The indicator shows an increasing trend, particularly during the winter months. During this season, the signal affects both low and high elevations, with percentage increases ranging from 4 to 10%, and is especially evident in winter at low, mid, and high elevations.

4.3 S3M

Analysis of the spatial extent of HS anomalies, performed for the October–September hydrological year, shows marked interannual variability, with seasons characterized by extremely positive or negative conditions over large portions of the region. To distinguish the largest departures, values were compared with extremely low or high conditions relative to local climatology by introducing P10 and P90, corresponding to the 10th and 90th percentiles, respectively. The seasons with the largest positive departures are 2008/09 and 2017/18, with 86% and 67% of the territory, respectively, showing extreme HS values (above P90), whereas the most negative conditions occur in 2021/22 and 2004/05, with 62% and 53% of the territory showing very low values (below P10). Recent seasons show more heterogeneous conditions: positive anomalies predominate in 2023/24, whereas in 2024/25 approximately

68% of the territory has values below the climatological mean and 17% falls below P10. During TS (December–April) and the winter period WI (December–February), a reduction in the upper part of the HS distribution emerges at low and mid elevations, particularly between approximately 500 and 1500 m. At the monthly scale, the clearest decreases occur mainly in February between 500 and 1000 m and in April between 1000 and 2000 m. Percentile analysis also shows that at low elevations the largest snow-depth values decrease most strongly, whereas at very high elevations the values representing relatively less snowy conditions increase most strongly. The observed change therefore does not appear to be a simple uniform shift in HS, but rather a change in the snow-depth distribution whose characteristics vary with elevation. Analysis of the duration of snow presence on the ground (HS > 0 cm) shows a widespread and statistically robust negative signal across several elevation bands (Figure 9).

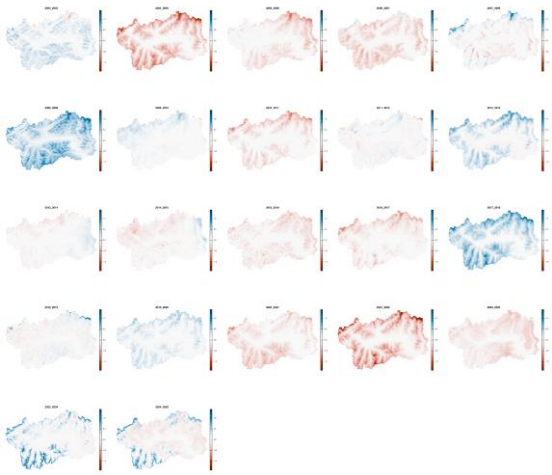


Figure 9: Regional spatial distribution of snow-depth anomalies relative to the mean S3M value. Seasons with greater snow depth are shown in blue and those with lower snow depth in red.

The reduction in snow-cover duration is strongest at low elevations: approximately −10 days per decade below 500 m, −19 days per decade between 500–1000 m, and −21 days per decade between 1000–1500 m. The decline becomes significant again at higher elevations, with approximately −13 days per decade between 2500–3000 m and −12 days per decade between 3000–3500 m. The overall pattern therefore suggests a general shortening of snow persistence, particularly evident at low elevations but also present in some high-mountain bands. Percentile analysis provides especially useful information because it shows that seasons characterized by the longest snow persistence are losing more days than seasons that are already relatively short.

4.4 Regional Avalanche Cadastre

Considering the results obtained from the analyzed parameters, the data suggest a possible tendency toward an increase in avalanches characterized by moist or wet snow at release and predominantly dense-flow dynamics (Eckert et al., 2024; Segor et al., 2013) (Figure 10). This tendency is strongly interannual and linked to the characteristics of individual intense snowfall events that are followed by major avalanche cycles. However, despite the large number of events contained in the Regional Avalanche Cadastre, the available information does not currently allow statistically robust trends to be defined. This is due both to the fact that not all variables are systematically observed or recorded for many avalanche events and to the fact that the Cadastre cannot include every avalanche occurring in the region, but tends to record especially those events that produce greater impacts, damage, or critical conditions. This introduces a potential observation bias that limits the statistical representativeness of the sample.

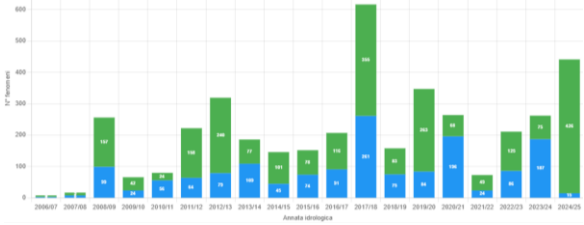


Figure 30: Avalanche release type by hydrological year. Blue dry snow; green wet snow.

5. CONCLUSIONS

Integrated analysis of nivometeorological data and physical models over the last two decades shows a transformation of snow regimes in the Aosta Valley consistent with the amplification of global warming in the Alps. Integrating the three monitoring sources provides a quantifiable picture of climate-change effects on the cryosphere and on regional avalanche dynamics. Model 1 data were also analyzed over longer historical series, although using less stringent statistical criteria than those adopted in this study. Despite the resulting lower statistical reliability, these analyses likewise showed the increasing temperature and decreasing snow resource trends described in this paper. Warming is not homogeneous but is concentrated mainly in winter (December–February), with a systematic increase in minimum and mean freezing-level values (+11/+32 m yr^{-1}).

The S3M maps show a widespread and statistically robust reduction in the duration of snow cover across various altitude bands, albeit with different patterns depending on altitude. The spatial analysis therefore highlights a non-uniform change, which alters the distribution of snow

depths differently depending on altitude. Temperature is thus the main limiting factor at low and mid elevations, whereas at high elevations there remains a marked sensitivity to synoptic and interannual variability. The reduction in snow-cover duration and in the number of snowfall days does not imply a decrease in the intensity of individual precipitation events. Extreme events, enhanced Mediterranean moisture flows, and prolonged anticyclonic periods without precipitation are still observed. Manual observations indicate that the decline in snow at low elevations is mainly related to an increase in rainfall events and a decrease in snowfall frequency (−4/−5% in snowfall days), rather than to a decrease in event intensity. At the same time, rain-on-snow events (ROS, +6/+7% over the season) and melt-freeze crusts (+4/+10% in winter at all elevations) increase, indicating earlier snowpack wetting. Alternating melt, refreezing, and liquid-water inputs often generate more stratigraphic discontinuities, favouring the formation and persistence of complex weak layers that destabilize the snowpack even when HS is reduced. Increasing uncertainty and variability therefore require an evolution of avalanche forecasting, management, and risk-assessment approaches. In this context, it is essential to continue integrating consolidated historical series that are updated and validated by specialized technicians, such as AINEVA Model 1 observations, itinerant snow surveys, and the Regional Avalanche Cadastre. Machine-learning techniques and snowpack modelling also represent a promising avenue for supporting forecasters' operational decisions, adapting safety strategies, and further investigating the future evolution of the observed trends.

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