HISTORICAL ANALYSIS OF SNOW COVER AND AVALANCHE EVENTS IN THE BIELLESE ALPS

Massimo Raviglione[1]* e Michela Barberis[2]

[1]*RocK and Snow Engineering, Tollegno – ITALY*
[2]*MountainS WorkinG sas, Tollegno – ITALY*

ABSTRACT: The effects of climate change have largely affected all the nations of the European continent. In Italy, sudden and violent rainfalls have characterized the last summer seasons, while winter seasons have seen long periods without precipitation. Even in the Biellese Alps, located in the north-western part of Italy, in the Piedmont region and in the eastern part of the Pennine Alps mountainous sector, recent climatic variations have characterized the winters and springs of the last 3-4 years in an 'anomalous way' compared to the past. The "large" rainfall "early" snowfall in November/December and the near-absence of precipitation in January and February, the "historically coldest period of winter", have resulted in the scarce presence of snow below an altitude of approximately 1500 m asl and have negatively influenced the formation of a seasonal snow pack. Avalanche events have also undergone changes, particularly in terms of the period of occurrence and type. In fact, in recent seasons, typically 'winter' avalanches involving the mobilization of dry snow have been exceeded in number and size by 'spring' avalanche events involving wet snow, which also occurred in typically winter months.

KEYWORDS: Climate Change, snow cover, avalanche

1. INTRODUCTION

Starting with time series of temperature and snow precipitation data collected from 1920 to 2024, this work analyses the effects of local variations in temperature, type and period of occurrence of cyclonic events, as well as the variation in the altitude of snowfall and the altitude limit of the seasonal snow cover. In connection with the nivo-weather comparison, we will examine how the effects of climatic variations have altered the avalanche events that have characterized the Biellese mountain sector of the Southern Pennine Alps for over 100 years.

2. MOUNTAIN SECTOR UNDER STUDY

The area under study concerns the mountainous range located south of the Western Alps, corresponding to a part of the mountainous sector known as the Southern Pennine Alps. The sector extends from west to east from longitude E 7°90’ to E 8°17’ for a development of approximately 30 km and from south to north from latitude N 45°60’ to N 45°75’ for a development of approximately 12 km. Altimetrically, the mountainous belt includes mountain ranges with altitudes between 1500 m asl and 2600 m asl. The territorial area occupied by the Biellese mountainous sector covers an area of approximately 360 km^2 (Figure 1).

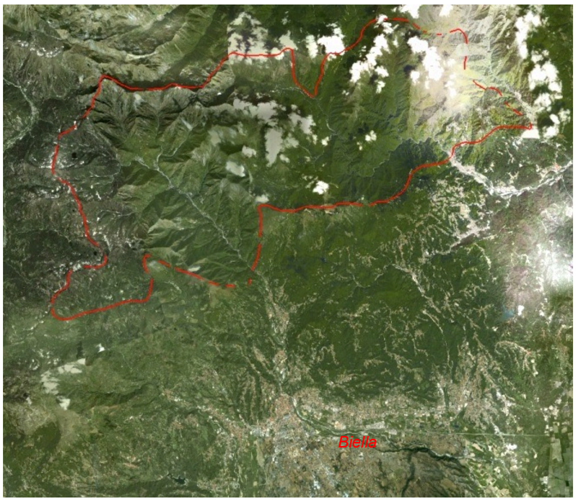

Figure 1: General view of the portion of the Southern Pennine Alps falling under the territorial jurisdiction of the Province of Biella.

3. HISTORICAL CLIMATIC TRENDS

3.1 *Nivo-weather detection system*

The historical climatic trend of the mountainous sector of the Southern Pennine Alps in the Biellese area was studied by analyzing the historical data of the three most representative nivo-weather stations in terms of position and altitude, which are: Oropa Seismic Weather Observatory and the two ARPA Piemonte stations named Bielmonte and Camparient. The

* *Corresponding author address*:
Massimo Raviglione, Studio Tecnico Dott Ing Massimo Raviglione - RocK and SnoW Engineering, via Cesare Battisti 7, 13818 Tollegno (BI) ITALY
tel: ++39 3355289413
e.mail: info@studioraviglione.com

stations are located as shown in the following table and figure 2.

	position[2]		
	est	*nord*	*quota*
Seismic weather observatory of Oropa			
Santuario di Oropa	420668	5053282	1186
ARPA Piemonte – Station Bielmonte			
Bielmonte Poggio Biella	428083	5057024	1480
ARPA Piemonte – Station Camparient			
Alpe Camparient	428882	5064888	1515

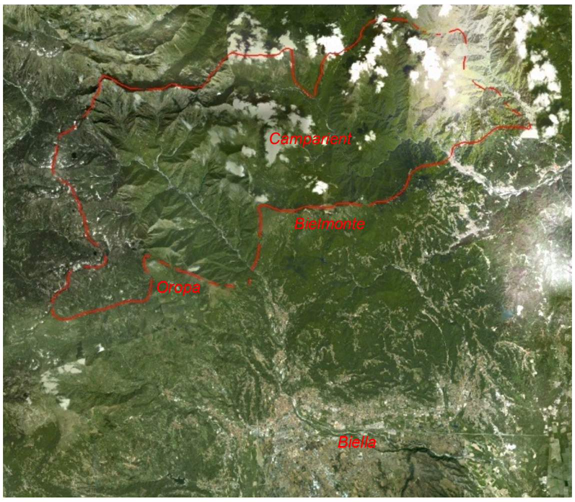

Figure 2: General view of the spatial location of nivo-weather stations.

From the historical yearbooks of the survey stations, data were extrapolated from manual records for the period 1920-2003 and from automatic records for the period 1999- 024.

Seismic weather observatory of Oropa		
T Hs H Neve fusa	manual	1920-2003
	automatic	2004-2024
ARPA Piemonte – Station Bielmonte		
T Hs	automatic	2002-2024
ARPA Piemonte – Station Camparient		
T Hs	automatic	1999-2024

In brief, the manually and automatically measured nivo-weather data cover a measurement period of about 100 seasons for the elevation of about 1200 m asl and a period of about 25 seasons for the elevation range from about 1200 m asl to about 1500 m asl.

3.2 *Summary of historical climate trends*

The analysis of the manual and automatic recordings for the period 1920-2024 of the Oropa Seismic Weather Observatory, ARPA Piedmont Bielmonte and ARPA Piedmont Camparient stations, made it possible to assess the trend over time and the limit values of the main nivo-weather characteristics (T and Hs) that characterize the three survey sites, as the altitude changes.

Regarding the analysis of local precipitation, the following table and figure 4 summarize the analyses performed on the trend of the maximum/ minimum annual snow depth on the ground.

	period	*Z [m]*	*min*	*max*	*med*
Hs [cm]	*Seismic weather observatory of Oropa*				
	1920-2024	1186	19 2005-2006	300 1940-1941	98,1
	Seismic weather observatory of Oropa				
	2003-2024	1186	19 2005-2006	186 2013-2014	81,3
	ARPA Piemonte – Station Bielmonte				
	2002-2024	1480	22 2020-2021	254 2008-2009	93,2
	ARPA Piemonte – Station Bielmonte				
	1999-2024	1515	14 2022-2023	273 2013-2014	111,9

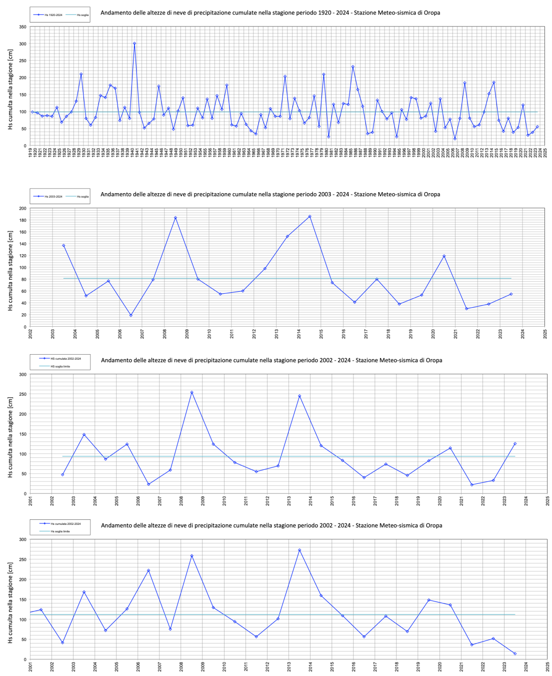

Figure 3: Graph of Hs min, max, annual mean values at Oropa, Bielmonte and Camparient stations.

Using the mean value (Hs med) of the period as the threshold limit for the snow depths on the ground, for the one-hundred-year analysis, starting from the 1987-1988 season, the snow depth on the ground at an altitude of approximately 1200 m asl has decreased, with the annual maximum values fluctuating negatively in relation to the mean value for most of the period.

Also, in the 25-year analysis, for the altitude range 1200-1500 m asl, the snow depth on the

[2] cartographic coordinates expressed in meters and referred to the ED50 system, with UTM projection of fuse 32 and elevation expressed in meters above mean sea level

ground, starting with the 1999-2000 season, has decreased[3] in relation to the mean value.

In addition to the phenomenon of a progressive reduction in the maximum height of snow on the ground, which has been observed since the end of the 20th century, since the 2014-2015 season and below the altitude limit of 1500-1600 m asl, a lower permanence/absence of snow on the ground has been observed, resulting in a lack of seasonal snowpack formation. This anomaly, observed over the last 3 seasons[4] (period 2021 - 2024), is mainly due to the reduction in snowfall in November and December, as well as the simultaneous presence of strong temperature rises and reduced snow depths on the ground. Regarding the analysis of the local thermal regime, the following table and figure 4 summarize the analyses performed on the trend of minimum, maximum and average annual temperatures.

	period	*Z [m]*	*min*	*med*	*max*	*med*
T [°C]	*Seismic weather observatory of Oropa*					
	1920-2024	1186	-17,0 1926	-10,1	+30,4 2019	+25,1
	Seismic weather observatory of Oropa					
	2003-2024	1186	-13,7 2018	-8,2	+30,4 2019	+27,0
	ARPA Piemonte – Station Bielmonte					
	2002-2024	1480	-16,5 2018	-10,8	+30,5 2019	+26,2
	ARPA Piemonte – Station Camparient					
	1999-2024	1515	-17,6 2018	-11,2	+30,6 2019	+25,1

By taking the mean value of the maximum and minimum temperature of the period as the threshold temperature, as shown in Figure 4, for the 100-year analysis at an altitude of approximately 1200 m asl, it can be seen that from the early 1980s onwards, the minimum and maximum temperatures tend to exceed the mean value of the period, a phenomenon that becomes more significant in the period 2000-2024 in which all annual temperature values (Tmax and Tmin) continuously exceed the mean value of the min/max temperatures of the period 1920-2024.

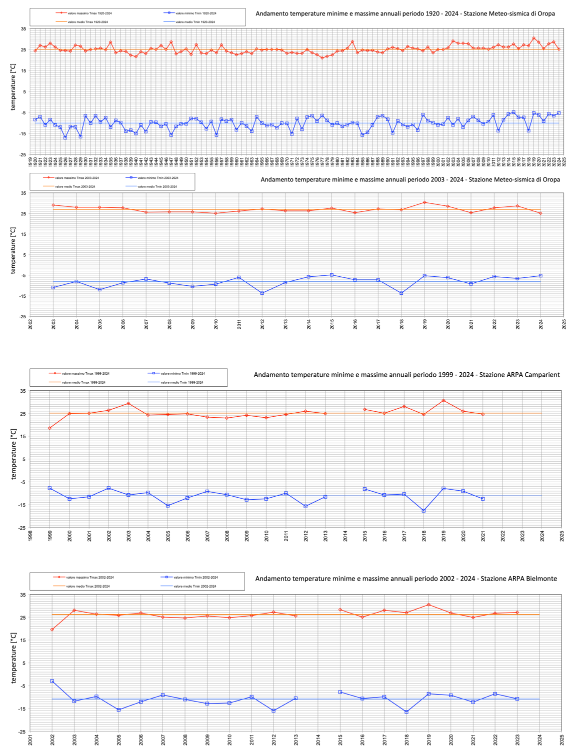

Figure 4: graph of T min max med values of Oropa, Bielmonte and Camparient stations.

Also, in the 25-year analysis, for the altitude range 1200-1500 m asl, it can be seen that the annual minimum and maximum temperatures, starting in 2013, exceed the average values for the period 1999-2024. Increase, which for the year 2019, exceeded the historical limits of the delta between the min/max temperature and the mean value, as shown in the table below.

	min	*med*	Δ	*max*	Δ	*delta*
T [°C]	*Seismic weather observatory of Oropa - 1186 m asl*					
	-5,2 2019	-8,2 2003-2024	+3,0↗	+30,4 2019	+27,0 2003-2024	+3,4↗
	ARPA Piemonte – Station Bielmonte – 1480 m asl					
	-8,5 2019	-10,8 2002-2024	+2,3↗	+30,5 2019	+26,2 2002-2024	+4,3↗
	ARPA Piemonte – Station Camparient – 1515 m asl					
	-7,9 2019	-11,2 1999-2024	+3,3↗	+30,6 2019	+25,1 1999-2024	+5,5↗

The increase in annual temperatures can be further measured by evaluating, for the 100-year series, the deviation between the average temperature value for the period 1920-2024 and the temperature trend approximated with a linear function as shown in Figure 5.

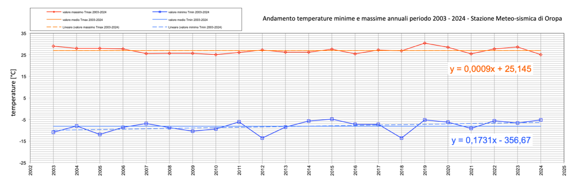

Figure 5: Trend of annual Tmax and Tmin and regression lines Oropa station.

[3] The only exceptions are the 2008-2009 and 2013-2014 seasons in which the snow depth on the ground far exceeded the average value for the period.

[4] The 2023-2024 season is an exception to the lack of seasonal snowpack formation only partially, in fact, thanks to the precipitation in February and March, a snowpack was formed that persisted for the last part of the winter and the first part of the spring (second half of February, March and first half of April).

In fact, from Figure 5, since the end of the 1960s, there has been a positive upward trend in temperatures Tmin and Tmax compared to the average value for the period, which, according to the interpolation method used, results in a temperature increase of approximately +1,7°C for minimum temperatures and approximately +1,0°C for maximum temperatures.

Similarly to the processing of the 100-year data, for the 25-year data, it is also possible to assess the extent of the deviation between the mean temperature value for the period and the temperature trend interpolated with a linear function. The following table and figure 6 provide a summary of the results.

	min	*med*	Δ	*max*	*med*	Δ
T [°C]	*Seismic weather observatory of Oropa - 1186 m asl*					
	-6,3 2024	-8,2 2003-2024	+1,9↗	+27,0 2024	+27,0 2003-2024	0,0⇔
	ARPA Piemonte – Station Bielmonte – 1480 m asl					
	-11,1 2024	-10,8 2002-2024	-0,3↘	+27,7 2024	+26,2 2002-2024	+1,5↗
	ARPA Piemonte – Station Camparient – 1515 m asl					
	-11,8 2024	-11,2 1999-2024	-0,6↘	+27,0 2024	+25,1 1999-2024	+1,9↗

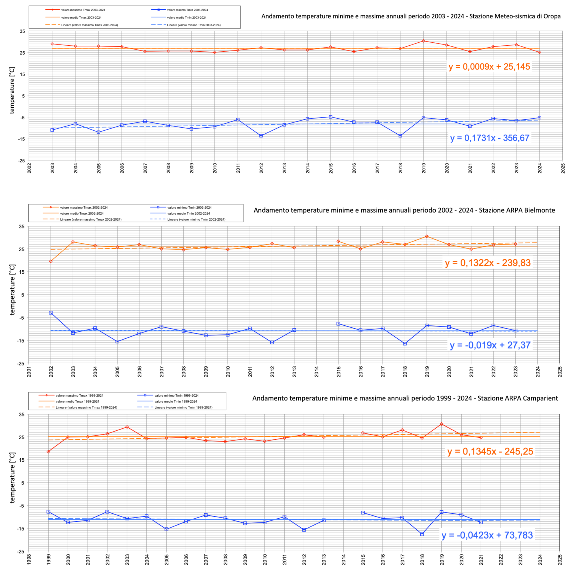

Figure 6: Trend of annual Tmax and Tmin and regression lines, Oropa, Bielmonte and Camparient stations.

As can be seen, in analogy to the centennial analysis, from the end of the 20th century onwards, for maximum temperatures, according to the interpolation method used, an increase in annual maximum temperatures ranging from 0,0°C to +1,9°C is recorded, while for annual minimum temperatures, the increase is only recorded at the station at an altitude of approximately 1200 m asl (Seismic Weather Observatory of Oropa) with a value of +1,9°C. This could support, at first hypothesis, the concept of 'snow elevation', understood as the limit beyond which snowfall occurs or even the limit beyond which the snowpack settles and manages to form a seasonal snowpack.

4. HISTORICAL AVALANCHE EVENTS

The history of avalanches in the Biellese mountainous sector of the Southern Pennine Alps was studied by consulting written historical sources, for avalanches from the 11th century to those at the end of the 19th century, the documentation produced by C. F. Capello and E. Feroggio[5], while for 20th and 21st century avalanches, local press archives[6] and detailed avalanche studies[7] were consulted. The historical analysis made it possible to reconstruct the characteristics, geographical positioning and effects that avalanche events have produced on the Alpine and pre-alpine territory of the Biella area.

Summarizing the results of the historical analyses, it is possible to subdivide the typology of spontaneous avalanche events into two main types: the first concerns recurrent historical avalanches that develop periodically along known routes, when a certain snowfall threshold is reached, triggered mainly by the morphological and forestry characteristics of the site; the second concerns exceptional historical avalanches that occur in correspondence with exceptional snow conditions, along known routes or even along new routes, and are triggered mainly by the morphological and forestry characteristics of the site combined with exceptional snow conditions.

4.1 <u>*Recurring historical avalanches*</u>

Known avalanche events, which occurred in seasons with 'non-exceptional' snowfall along known avalanche routes in the main and secondary valleys of the Biellese area, belong to this category. These events occurred in the recent past (20th century) and in recent seasons (21st century).

Recurrent avalanche events generally have the following main characteristics:

location	generally above forest level from 1400-1500 m asl
type	surface winter avalanches and cross-country spring avalanches

[5] "Studi sulle valanghe (n. 6) – Introduzione allo studio delle valanghe in Italia – Le valanghe della Valsesia e del Biellese"
[6] Articles in local newspapers and periodicals - Editions from 1963 to 2024
[7] Thematic mapping and spatial planning tools

dimension[8] winter avalanches 2 medium, 3 large and 4 very large.

effect generally few or predictable given the knowledge of the avalanche path, its danger and the proper spatial management of areas exposed to danger.

4.2 *Exceptional historical avalanches*

All historical avalanche events associated with particularly significant snowfall seasons (e.g. exceptional snowfalls in the winter of 1887-1888) belong to this category and are remembered for the destructive effects and tragic consequences they produced on the Alpine and pre-alpine territory. The historical yearbooks mention the avalanches of the 11th century (San Bartolomeo avalanche year 1030), those of December 1788 (Ceva or Colle Barma avalanche December 1788) and those of February 1888 (Vittone, Botto, Bulliana and Bocchetta di Valfinale avalanches).

Exceptional avalanche events generally have the following main characteristics:

location depends on the absence of woodland or the presence of sparse woodland, the slope inclination (even slightly inclined ψ=25°-30°) and generally exceptional snow conditions.

type surface and background avalanches based on slope surface roughness and water content.

dimension 3 large, 4 very large and 5 extremely large.

effect unpredictable and unexpected given the lack of knowledge of the location of the avalanche path (absence of historical information or avalanche that never happened), the extent of the danger of the event and the absence of land management related to possible avalanche phenomena interfering with man-made areas.

5. CONSEQUENCES OF CLAMATIC VARIATIONS ON AVALANCHE EVENTS

The climatic variations that have been most evident in recent seasons have led to a significant modification of recurring avalanche events, particularly in type and period of occurrence. Summarizing what has been observed in recent seasons, the nivo-weather conditions that have contributed to modifying the scope of historical avalanche events concern the following areas:

- lack of precipitation in the first part of winter
- increase in rainfall in the late winter period above an altitude of approximately 1500 m asl
- increase in snow depth from 1100 m asl towards 1300-1400 m asl

Regarding the absence of precipitation in the first part of winter, from the observations of the last 3-4 years, the typical snowfall in the first part of the season (November - December) has shifted towards the middle of the winter season (January / February). This 'new' weather condition meant that the slopes had no snow cover until February, resulting in a lack of seasonal snowpack formation.

The reduction or absence of basal snowpack and thermal elevations led to the presence of wet snow bottom avalanche events (particularly on class 4 slopes[9 10]) along many south-facing slopes (ENE-S-WNW) even with moderate precipitation (H_N = 20-40 cm).

This situation is quite anomalous when compared with historical data from the same period (January and February). Figure 7 illustrates a typical situation of the last few seasons in which widespread avalanche activity 'atypical for the period' occurred along the slopes of the 1000-1500 m asl elevation band, exposed to the southern quadrants with meadow cover, with background events of size 1 - small and 2 - medium.

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[8] Dimension:
1 Smal L=10-30 m V<100 m^3 Sp<20 cm
2 Medium → L=50-200 m V<1.000 m^3 Sp ≈ 20 - 50 cm
3 Large L>200 m V<10.000 m^3 Sp ≈ 50 - 100 cm
4 Very large L=1-2 km V<100.000 m^3 Sp>100 cm
5 Extremely large L=3 km V>100.000 m^3 Sp>>100 cm

[9] Reference WSL – UFAM – Costruzione di opere di premunizione contro le valanghe nella zona di distacco – ed 04/07. Tab. 5 / classe 4 – cotica erbosa liscia a stelo lungo, uniforme

[10] Reference EAD 340109-00-0106 – Flexible avalanche protection kit. Table A.3 / class 4 – snooth, long-bladed, compact grass cover

Figure 7: Example of avalanche activity in the first week of February along the slopes exposed to the southern quadrants.

The rise in the level of rain in recent seasons due to various cyclonic events has led to the occurrence of snowfalls with wet snow and wet snow or in borderline cases rain up to an altitude of approximately 2000 m asl in the altitude range between 1500 m asl and 2000 m asl. These situations have led to avalanche events of even great dimensions, both surface (recently deposited wet/wet snow) and ground (snow present on the ground wet by rain up to the ground).

Figure 8: Example of March 2024, in which rain fell up to the limit of about 1600 m asl (melting the snow covering the Saharan sand layer) while above this altitude the precipitation was only snowfall.

The increase in the altitude of snowfall, associated with the absence of winter snowfall in the altitude range between 1000 m asl and 1300-1400 m asl, has led, as far as has been observed in recent seasons, to situations in which at the end of winter - beginning of spring, the slope up to an altitude of about 1500 m asl was completely devoid of snowpack, while beyond this limit there was a continuous snow cover (Hs>100 cm) capable of generating large-sized wet snow avalanches in the spring. Apart from the anomaly related to the absence of a seasonal snowpack below an altitude of 1500 m asl, the situation regarding large spring avalanches observed in recent seasons overlaps perfectly with historical data.

Figure 9: Example of large avalanche activity at the beginning of March, following precipitation where the snow depth was close to 1500 m asl. The additional snowpack in the release zone subsequently generated further avalanche events.

6. CONCLUSION

The evaluations on the local climatic variations and the observations on the changes in avalanche activity have made it possible to ascertain how the nivo-weather conditions and recurring avalanches in the Biella mountainous sector of the Southern Pennine Alps have changed with respect to what has been observed in the recent past. Synthesizing the results of the previously reported assessments, the following summary considerations can be made:

- In the climatic field, compared to the historical period of analysis 1920-2024, the last few seasons have seen the absence of significant cyclonic events in the first part of winter and the 'shift of the first seasonal snowfalls' to the central part of winter, resulting in the absence of continuous snow cover in the first part of winter. The temporal displacement of the first snowfalls combined with the rise in snow depth resulted in a reduced presence of seasonal snow cover in the 1000-1400 m asl range, resulting in a lack of seasonal snowpack formation.

- In the field of avalanches, the reduction of snow cover periods has led to a decrease in avalanche danger periods, at the same time, the rise in snow depth and the rainfall on the snowpack have increased the problems of wet or wet snow avalanches at various scales throughout the snow cover period.

In conclusion, unless there is a reversal in the trend, if the nivo-weather conditions observed in the last 3-4 years were to be repeated in the near future, in the Biellese area of the Southern Pennine Alps, we could see a progressive reduction in the presence of snow at altitudes below the 1300-1400 m asl limit and an increase in wet/wet snow avalanche phenomena in the 1300-2000 m asl range in the period from February to April.

CONFLICT OF INTEREST

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