A CORRELATION BETWEEN AVALANCHES AND TELECONNECTION INDICES IN THE ITALIAN ALPS

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Teleconnections, such as the North Atlantic Oscillation (NAO) and the Arctic Oscillation (AO), play significant roles in wintertime weather patterns across wide regions of the Northern Hemisphere, including Western Europe and the Mediterranean basin. In the literature, avalanche activity has been related to major teleconnection indices in various European mountain regions and some Pacific coastal ranges in North and South America. However, no studies have been conducted on the Italian Alps, and this work aims to investigate the possible correlations among teleconnection indices that influence avalanches on the southern portion of the Alps. As the Alpine region sits at a crossroads of Atlantic and Mediterranean influences, this study includes the Western Mediterranean Oscillation (WeMO) alongside the NAO and AO teleconnection indices. Avalanche time series data collected in two Italian Alpine regions and historical data of teleconnection indices were used to investigate possible correlations between the number of avalanche days in each winter season and the values of the seasonal teleconnection indices. The analysis considers avalanche days instead of single events to reduce errors due to non-recorded avalanches, especially during extended periods of bad weather. Spearman correlation coefficient (R) was utilized to assess the relationship between time series data of variables, offering information on the strength and direction of the association. Results reveal different behaviors of the dataset from the western sector of the Alps compared to the eastern one. While the NAO and AO show little correlation with the data in the western Italian Alps, confirming previous findings in the French Alps, they are significantly anticorrelated with the data in the eastern Italian Alps. The WeMO has the most significant influence on avalanches in the western Italian regions. This research could potentially provide avalanche forecasters with meaningful information on seasonal avalanche tendencies, especially as the predictability of atmospheric oscillations continues to improve.

KEYWORDS: Teleconnections, Avalanches, Avalanche Problems, Italian Alps.

1. INTRODUCTION

Teleconnections represent patterns of environmental variables characterized by a very large spatial scale, embracing continents and ocean basins, and a low temporal frequency, ranging from a few months to a few years. Atmospheric and oceanic circulations show recurrent and significant patterns that can be summarized by well-known and widely used indices for the European continent, i.e. NAO (North Atlantic Oscillation) and AO (Arctic Oscillation). These patterns, reflecting variations in general circulation, jet stream, and sea surface temperature, affect meteorological variables, such as temperature and precipitation, over large areas. For this reason, they are often a useful component of seasonal weather forecasting. Nevertheless, their application to avalanche seasonal trends is still limited.

In the literature, there are only a few studies that investigate the link between teleconnections and avalanches. A correlation between NAO and avalanche activity has been identified in Iceland (Keylock, 2003) and in the Pyrenees Range, at the border between France and Spain (García et al., 2009). Similarly, other major oscillations have been deemed relevant elsewhere. For instance, the La Niña phase of the ENSO (El Niño Southern Oscillation) has been linked to an increase in the number and size of avalanches in British Columbia, Canada, while the El Niño phase in the Chilean Andes produces an increase in snowfall and avalanches (McClung, 2013). Since no studies have focused on the Italian Alps, in this work, we aim to provide some indications on the possible correlations between some teleconnection indices influencing the seasonal meteorological evolution in southern Europe and avalanche events in Northern Italy.

Moreover, the Alpine region, due to its geographical position, is located in an area where the influence of the Atlantic Ocean overlaps with that of the Mediterranean Sea. Consequently, we considered, in addition to the better-known NAO and AO teleconnection indices, also the WeMO

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(Western Mediterranean Oscillation) (Martin-Vide and Lopez-Bustins, 2006).

2. DATA AND METHOD

2.1 *Data*

In Italy, avalanches are recorded by the offices of AINEVA, the Interregional Association for Snow and Avalanches, and by METEOMONT, the mountain meteorology service of the Italian Army and of the Carabinieri. To ensure the robustness of the various analyses carried out in this study, we focused only on the Aosta Valley and Veneto regions, whose data are among the most accurate and complete. Furthermore, the temporal extension of these datasets overlaps during the period from 2005 to 2023, thus allowing for a direct comparison.

The Aosta Valley Regional Avalanche Cadastre is an Oracle database that currently contains information on about 2300 sites covering 18% of the region's surface area. The first records date back to 1970, and systematic observations have been available since 2005. The database contains 6539 records of events that occurred between 2005 and 2023, of which 4784 were considered in the present study as corresponding to spontaneous avalanches, i.e., not triggered by human activity. The data are organized according to the general scheme presented in AINEVA's "Modello 7" and are accessible as described in Debernardi and Segor (2013).

The Veneto database is available at, and downloadable from, the WebGis of ARPAV, the regional environmental protection agency of the Veneto region. It contains over 2000 avalanche sites, with events dating back as far as 1979. A total of 830 spontaneous avalanche events from 2005 to 2023 were considered for this study. The data are organized, similarly to the Aosta Valley, according to the "Modello 7" sheets and can also be consulted through a WebGIS interface.

The NAO and AO data were taken from the archives of the National Oceanic and Atmospheric Administration (NOAA). WeMO data are available from the archive of the Climatology group at the University of Barcelona and are limited to 2020. All datasets were appropriately aggregated to consider the winter seasonal anomaly of each oscillation.

2.2 *Method*

Building on the avalanche events surveyed, the number of days with avalanche activity was calculated for each winter season and study area. This choice was aimed at reducing the error present within the data of the avalanche cadastre, which originates when, due to operational difficulties or safety concerns, it was not possible to thoroughly chart all the events that occurred, especially during prolonged periods of bad weather with intense avalanche activity.

The resulting dataset was analyzed together with the relevant teleconnection indices to search possible correlations between the two datasets. Pearson and Spearman correlation coefficients were tested to assess the relationship between the time series data of the variables (days of avalanche activity, NAO, AO, and WeMO). These coefficients evaluate the covariance between two variables, offering insight into the strength and direction of their association. A correlation coefficient R close to +1 or -1 indicates a strong positive or negative relationship, respectively. Conversely, a value between +0.1 and -0.1 indicates no discernible association between the variables. In this study, the Spearman correlation coefficient was preferred as it is more suited to the non-linear distribution of our data.

For each Spearman coefficient R, the significance level p was calculated, i.e., the threshold value below which a given result can be considered statistically significant. In this case, the chosen value is p = 0.10 (Terzago et al., 2013).

Region		*NAO*	*AO*	*WeMO*
Veneto	*R*	-0.48	-0.57	0.03
	p	0.04	0.01	0.92
Aosta Valley	*R*	-0.07	-0.19	0.32
	p	0.78	0.45	0.24

Table 1: Correlation coefficient R and significance level p for each teleconnection index investigated, evaluated for the two study areas with the Spearman method.

3. RESULTS AND COMMENTS

The results presented in Table 1 show a good relationship between the number of days with avalanche activity and the NAO and AO indices in the Veneto region. In fact, during the period from 2005 to 2023, the correlation coefficients are characterized by a good statistical significance, and with R values close to -0.5 with respect to NAO and -0.6 with respect to AO. These values are comparable to those obtained in previous studies on other mountainous areas of southern Europe (e.g., García et al., 2009). Finally, the WeMO index is basically not correlated with the number of avalanche days.

In contrast, in the Aosta Valley region the association fades, and both NAO and AO appear to be not correlated with the number of days with avalanche activity. This result agrees with Jomelli et al. (2007), who ruled out the influence of the NAO index on avalanches in a geographically contiguous area in the French Alps. On the other hand, the WeMO index shows a positive correlation for the Aosta Valley, although not statistically significant.

A hypothesis that could partly explain this behavior is the important orographic and geographical differences within the Alpine chain between the two study areas. Considering that negative NAO values generally reflect a smaller-than-normal pressure difference in the Atlantic dipole, they are associated with weaker zonal winds, together with greater variability in south-central Europe. Similarly, negative AO values represent situations in which the jet stream is more undulating and intrusions of cold air of polar origin towards the mid-latitudes are favored. In these situations, where the Alps are often characterized by disturbances with cold temperatures, it is easy to imagine that snow cover is present continuously at lower altitudes than average, influencing avalanche activity, especially at the average altitudes typical of Veneto mountains.

In addition, in the event of disturbances due to fronts coming from the western quadrants, the central-eastern sectors of the Italian Alps are generally affected by higher accumulations than many sectors of the western Alps, where föhn conditions can also occur locally. The higher average altitude of avalanche sites in the Aosta Valley compared to those in Veneto and consequently a longer avalanche season is also a plausible reason for the higher number of avalanche days normally recorded in the Aosta Valley compared to Veneto (Figure 1, 2).

3.1 *Avalanche problems*

The European Avalanche Warning Services (EAWS) classifies avalanche problems into distinct categories to systematically record and analyze avalanche events in European mountain ranges. The primary categories—new snow, wind slab, wet snow, gliding snow, and old snow—provide a formal structure for documenting the diverse conditions that impact snowpack stability. An additional category, cornices, was added in 2022, but its status is still optional and thus unreliable for our purposes. Each classification accounts for specific meteorological and terrain

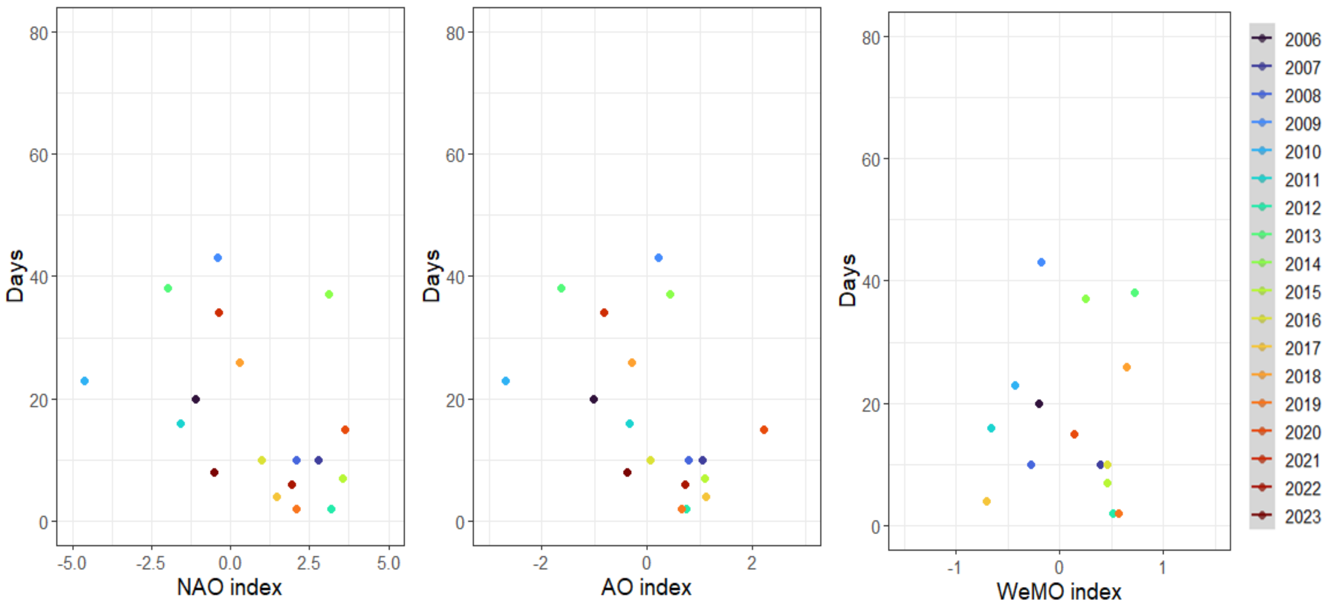

Figure 1: Scatter plot of the days with avalanche activity as the teleconnection index investigated varies for the Veneto Region - left NAO, center AO and right WeMO

factors, ensuring consistent event recording. This standardized approach improves the accuracy and comparability of avalanche data across regions and seasons, offering valuable insights for researchers and professionals studying avalanche dynamics and trends. Moreover, by standardizing these classifications, EAWS provides a clear framework for avalanche forecasting, enabling better hazard communication and management.

The Italian "Modello 7" partially embraces this classification and further expands the wet snow category, which comprises two very different danger patterns: rain on snow and springtime situation (Mair and Nairz, 2012). Unfortunately, gliding avalanches currently are not recorded in a dedicated section and, additionally, no information is provided on which slab events are caused by an old snow problem. Therefore, it is not possible to draw any conclusion on these avalanche problems. In the following list, results are presented subdividing them by avalanche problem.

- New snow conditions occur during and right after intense snowfalls when the new snow overloads the old snowpack. As the new snow is still not bonded with the former surface of the snowpack, the weak layer is localized at this interface. Data from the Veneto region show that the number of avalanche days is anti-correlated with both NAO, and that the association is statistically significant while correlations with WeMO and AO are less significant. No corresponding relationship was found in Aosta Valley, considering NAO, AO, and WeMO.
- Strong wind activity and wind drift, both with and without a snowfall, generally precede wind slab events. Avalanches caused by this problem often occur on the lee side of ridges, close to morphological features, and the weak layer is usually at the interface with old snow, under the slab. Data from the Veneto region show that the number of avalanche days has a negative correlation with both NAO and AO, and that the association is statistically significant. The correlation with WeMO is negligible. In Aosta Valley, considering WeMO, the correlation is positive and strong, with high statistical significance. No correlation exists concerning NAO and AO.
- Wet snow problems have been subdivided into two specific avalanche patterns, better representing radically different meteorological conditions. Rain-on-snow conditions are found when liquid precipitation falls on the snowpack surface. In these conditions, the density of the snowpack increases and consequently increases the overload on existing weak layers as well. Moreover, loose snow avalanches may occur when snow becomes completely saturated and loses its cohesion and strength. The number of days with avalanches caused by rain in Veneto is

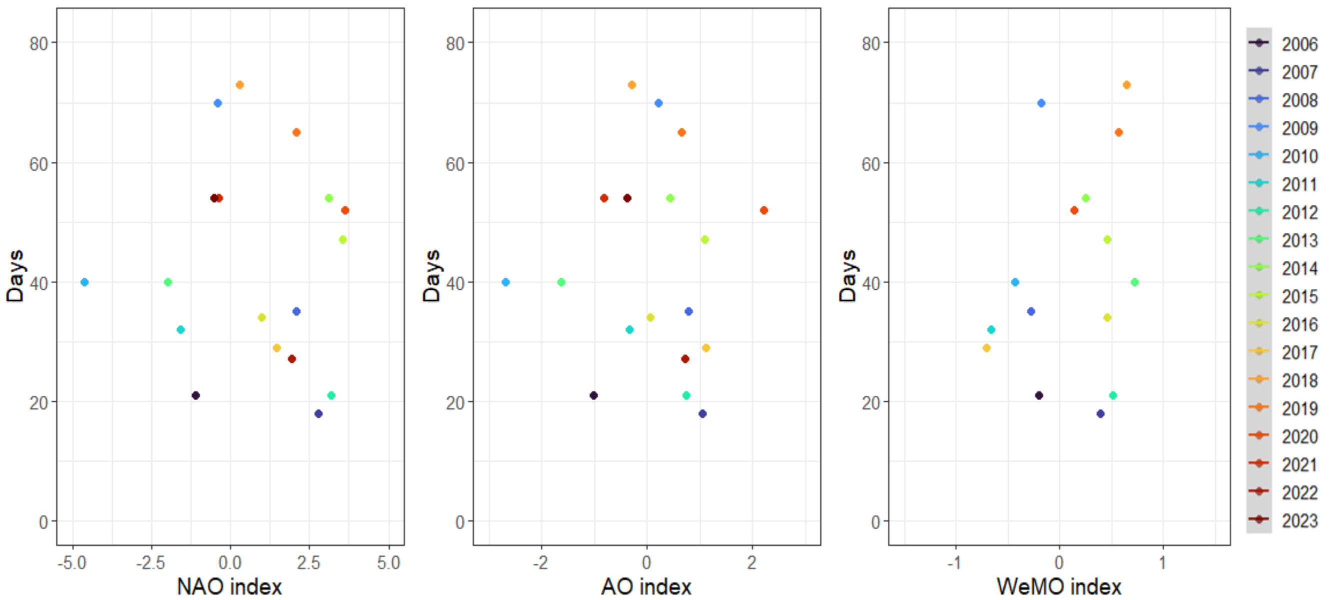

Figure 2: Scatter plot of the days with avalanche activity as the teleconnection index investigated varies for the Aosta Valley - left NAO, center AO and right WeMO

associated with positive WeMO values and is anti-correlated with NAO. No correlation is found with AO. The statistically significant positive correlation with WeMO is also observed in Aosta Valley, but it was not possible to highlight any correlation with NAO or AO.

- The “Springtime condition” as defined by Mair and Nairz (2012) is the typical situation that occurs during the later part of the winter season on south-facing slopes and at increasingly higher altitudes. Snowpack stability fluctuates everyday due to melting and refreezing cycles, as it is particularly influenced by daytime direct solar radiation and night-time heat exchanges by irradiance. Data from the Veneto region shows that this condition is strongly correlated with negative values of NAO and AO, while the correlation with WeMO is weak and not statistically significant. The number of days with avalanches due to springtime situation in Aosta Valley is strongly correlated with WeMO, while the correlation with NAO and AO is almost non-existent.

To provide information as meaningful as possible to forecasters, we present the correlation between the teleconnections previously described and each avalanche problem separately, for the Aosta Valley and Veneto regions. The results are provided in Table 2.

4. SUMMARY AND CONCLUSIONS

In this paper, we applied well-known statistical tools to highlight the effect of seasonal anomalies in three major teleconnective indices on avalanche frequency in a study area, namely two regions of the Italian Alps, that was overlooked by previous literature.

Our analysis of the Veneto dataset reveals a negative correlation between NAO, AO, and the number of avalanche days. The number of avalanche days rises during winter seasons dominated by a negative NAO and AO anomaly. On the other hand, the WeMO index does not show any correlation with the Veneto dataset. In contrast, in the Western Italian Alps, data from the Aosta Valley show a positive correlation with the WeMO, although this relationship is not statistically significant.

By extending the analysis, we revealed that the strength of the association and the level of statistical significance improve when we consider specific subsets of the events, defined by avalanche problems.

The overall relationships are recurrently recognized among different avalanche problems, with the NAO and AO being correlated to the number of avalanche days in the Veneto Region, while the WeMO is correlated to the number of avalanche days in Aosta Valley. However, specific avalanche problems show robust correlations that may be effectively exploited in combination with seasonal forecasts of teleconnection indices to provide meaningful information to avalanche forecasters. It is especially the case for events linked to NAO and AO, whose seasonal forecasts are currently considered rather reliable, such as those caused by wind slabs with a negative anomaly of NAO and “springtime” situation and negative phase of AO in Veneto.

In the future, we plan to further delve into the correlation analysis and look at a single phase of the teleconnections and links to specific snow types, to find even more valuable relationships between teleconnections and avalanches.

Region	*Avalanche problem*	*NAO*	*AO*	*WeMO*
Veneto	New snow	-0.41, 0.14	-0.30, 0.30	-0.16, 0.61
	Wind slab	-0.50, 0.07	-0.48, 0.08	-0.22, 0.48
	Rain on snow	-0.43, 0.22	-0.38, 0.28	-0.40, 0.28
	Springtime	-0.49, 0.04	-0.66, 0.01	0.16, 0.57
Aosta Valley	New snow	-0.31, 0.22	-0.13, 0.62	0.07, 0.82
	Wind slab	-0.08, 0.76	-0.09, 0.73	0.60, 0.02
	Rain on snow	0.05, 0.84	-0.04, 0.89	0.49, 0.08
	Springtime	0.13, 0.61	0.11, 0.67	0.49, 0.07

Table 2: Correlation coefficient and significance level *(R, p)* for each teleconnective index investigated, evaluated for the two study areas with the method Spearman.

Ideally, upon data availability, it would be very beneficial to extend the analysis to other Italian Alpine regions to give a more complete description and understand possible overlapping correlations in the central section (e.g., the Rhaetian Alps) of the Italian Alps.

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