Major avalanches in Eastern Pyrenees and North Atlantic Oscillation

García, C. [1,*], Peña, J.C. [2], Martí, G. [1], Oller, P. [1], Martínez, P [1].
[1] Geological Institute of Catalonia, Barcelona, Spain
[2] Meteorological Survey of Catalonia, Barcelona, Spain

ABSTRACT: The number of major avalanche episodes registered in Eastern Pyrenees (north-east of the Iberian Peninsula) is correlated to the North Atlantic Oscillation (NAO). The NAO is one of the most important and recurrent patterns of atmospheric circulation variability in the Northern Hemisphere and affects the behaviour of surface temperatures and precipitation in Western Europe. The link between NAO and major avalanches activity is done by applying the cumulative NAO index proposed by Keylock in 2003. The link between avalanche activity and fluctuation of NAO index exists in Iceland, but is not detected in the French Alps. This study supposes an essay about what happens in areas further from the centres of the dipole of NAO. Results show a negative correlation between major avalanches activity in Eastern Pyrenees and NAO index (NAOi); it is even higher respect to the cumulative NAOi. The cumulative index NAO reflects the cumulative effect of snow accumulation in the starting zones as precipitation is affected by the fluctuation of NAO. Consequently, the sign of the correlation is negative since it has been demonstrated that increase of precipitation in Eastern Pyrenees is linked to negative values of NAOi. Nevertheless, results from the different avalanche forecasting regions in Eastern Pyrenees suggest a different response of avalanche activity respect to NAO, confirming Pyrenees as a complex snow-climate boundary. Finally, the time evolution of the major avalanche events for this index has been analyzed to observe possible changes in the avalanche activity in future, also taking into account the future NAO evolution suggested by some global warming scenarios.

KEYWORDS: Avalanches, North Atlantic Oscillation, Eastern Pyrenees.

1 INTRODUCTION

Studies dealing with avalanche conditions at the Pyrenees are very scarce, and usually on very specific cases. Recent works have focused on meteorological and snowpack conditions in Eastern Pyrenees to explain extreme avalanche events during the 1996 and 2003 crisis by means of a synoptic approximation (Esteban et al., 2007). Classifications of synoptic patterns producing major avalanches in the Eastern Pyrenees and their relation to the North Atlantic Oscillation (NAO) have been proposed by García et al. (2008), using principal component analysis.

In this work, we put major avalanche episodes in relation to the NAO. The relationship between NAO index (NAOi) and snow avalanche release has been analyzed for different regions in Europe by Keylock (2003) in Iceland and Jomelli et al. (2007) in the French Alps. The NAO, as a low frequency circulation pattern, determines strongly the variability of the temperature, precipitation and winds behaviour in Europe (Hurrell, 1995; Beniston et al., 1996). The interest of connecting major avalanche episodes with this low frequency circulation pattern lies in the fact of NAOi for the next winter seems to be predictable at medium term with a reasonable level of confidence (Jones et al., 1997).

Positive values indicate zonal, westerly atmospheric circulation where low pressures are located over the North Atlantic and high pressures over Azores Islands. In the opposite case, for negative values, low pressures circulate more towards south than usual due to a weakening of the Azores high pressures and vortexes cross the Iberian Peninsula.

It has been demonstrated a positive correlation between monthly precipitation and NAOi in many parts of Western Europe close to the Pyrenees as alpine areas (Quadrelli et al., 2001) and northwestern Iberian Peninsula (García et al. 2005). Nevertheless, the relationship between winter precipitation and NAOi at the Pyrenees shows a negative correlation (Martín-Vide et al., 1999; Esteban et al., 2001) for many regions. The whole major avalanche episodes studied in the Eastern Pyrenees are not directly released by precipitation, but also due to melting processes and wind drift (García et al. 2008). Therefore, linking major avalanches to a large-scale circulation pattern as NAO, would take into

Corresponding author address: Carles García Sellés, Institut Geològic de Catalunya, C/Balmes 209-211, BCN 08006, Spain.
tel: 0034 935538426; fax: 0034 935538436;
email: cgarcia@igc.cat

account meteorological conditions and snowpack evolution besides precipitation.

Over recent decades the NAOi has exhibited an upward trend (Gillet et al. 2003). Some global warning scenarios have suggested that the next decades might show a preferred positive index phase of the NAO (Hurrell et al. 2003). Changes in the atmospheric circulation patterns would seem to imply changes in the meteorological conditions releasing major avalanches. How avalanching can vary in the future due to a rise in the NAOi in the Eastern Pyrenees opens a challenging issue. In this sense Furdada (2006) concludes that possibly major avalanches continues to produce in Pyrenees since extreme precipitation events will not decrease. Anyway, our study tries to know first which the link between major avalanches and NAOi is at present.

2 DATA AND METHODOLOGY

Database consisting of major avalanche episodes (*N* = 26) dated at daily resolution from 1970-71 to 2008-09 winter seasons is used to link with monthly NAO index. A major avalanche episode is defined as the occurrence interval of time (minimum one day is considered) of at least one major avalanche registered. Episodes of exclusively major avalanches triggered by explosives and human released (skiers, surfers, etc) have been rejected. We have considered major avalanches in a wide sense, as defined by Schaerer (1986), avalanches larger than usual, arriving to the bottom of the valley, destroying mature forest or damaging structures. All avalanches travelled further than 1000 m from the starting zone to the run out zone. Data have been collected by the Geological Institute of Catalonia (IGC) in the framework of the avalanche forecasting and cartography project. Major avalanches have been systematically dated at a daily resolution from 1996 until present. In 1996 the Nivometeorological Observers Network (NIVOBS) of the IGC begun a winter surveillance making transects every day to report snow conditions and avalanche events. All the episodes have been dated and mapped by systematic observations in all seven regions from 1996 by means of helicopter flights. Monthly or weekly resolution on avalanche dating exists from 1989 to 1996. Before 1989, avalanche dating is scarce and without continuity and data comes from enquiries to inhabitants; annual and monthly resolution prevails. Finally, 26 episodes have been well dated from 1970.

A monthly NAO index is calculated from the normalized pressure difference between Reykjavik and Gibraltar from December to April. Data was obtained from Jones et al. (1997). Keylock (2003) proposes a new NAO index that cumulates consecutive positive values of NAOi monthly called cumulative NAO index (CNI) since he demonstrates that this new index is a better predictor of avalanching in Iceland than the actual definition of NAOi.

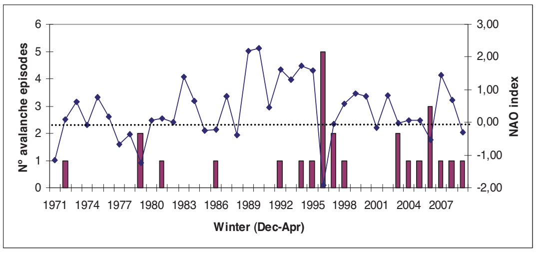

Figure 1. Number of major avalanche episodes (bars) and NAO index (lines) for each winter season comprised from December (*year-1*) to April (*year*). The dashed line corresponds to value 0 of NAOi.

Correlations between the NAOi (December-April) and the number of major avalanche episodes in the Eastern Pyrenees are calculated for the period 1970-71 to 2008-09 and for the period 1988-89 to 2008-09, when data are systematically registered. IGC database includes major avalanche episodes from October to April, but we have treated only data from December to April since this time period gathers the 93% of the population. Furthermore, NAO dictates climate variability mainly during winter season. Major avalanche episodes and avalanche events are correlated to the cumulative NAO index (CNI), both positive CNI and negative, which has been calculated for this purpose. In addition to major avalanche episodes, major avalanche events are also treated in this part of the study to reinforce the relationship between avalanching and NAOi. A major avalanche event is a spontaneous avalanche releasing that has been located and dated, while an avalanche episode gathers the whole avalanche activity occurred in a period of several days. Therefore, we know very probably the real number of major avalanche episodes (26 comprises during 1970-2009), but not the whole avalanche events (at least 254) since they depend of the density of the observation network, which has grown over time. Hence, we must be cautious when dealing with avalanche events.

3 RESULTS AND ANALYSIS.

A comparison between number of major avalanche episodes and NAOi for each winter from 1970-71 to 2008-09 is showed in figure 1. Rank correlation between the NAOi (December-April) and the number of major avalanche episodes in the Eastern Pyrenees is significant at the 5% level with a value of R = -0,44 for the period 1970-71 to 2008-09. Coefficient of correlation improves with a value of R = -0,70 for the period 1988-89 to 2008-09, when avalanche episodes begun to be systematically registered.

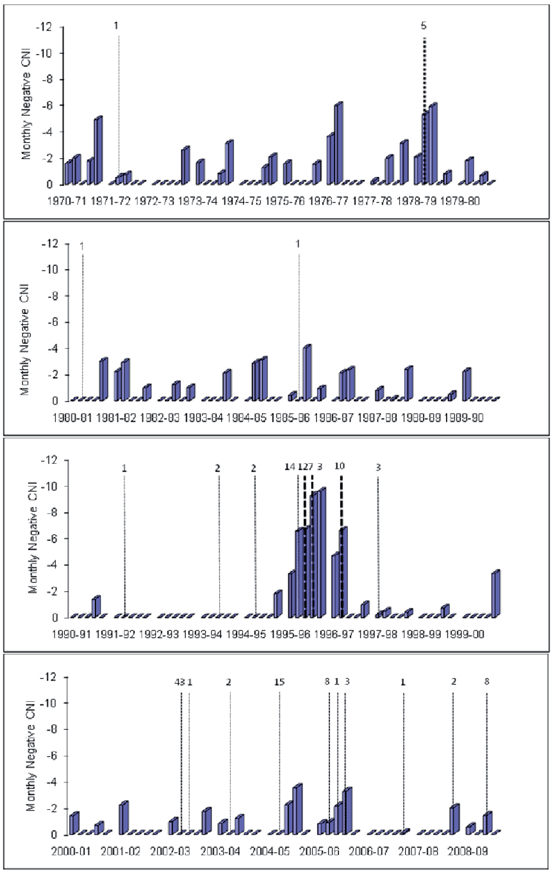

Figure 2. Correspondence between monthly values of negative CNI and avalanche releasing along the period (Dec- Apr). The light line means one major avalanche episode and the wide line more than one episode. At the top of the lines, number of avalanche events is shown.

Delving into this connection, we have applied the cumulative NAOi proposed by Keylock (2002). Since correlation between avalanching and NAOi is negative in Eastern Pyrenees, a cumulative negative of NAOi (CNI) is calculated and applied. Months with positive values of CNI are plotted in the figures as zero value. Of 194 months in the period December-April for the years 1970-71 to 2008-09 positive CNI prevails: 117 months have cumulative positive NAO index and 77 a negative index. An overall of 26 avalanche episodes are registered. Nevertheless, the most part (17 cases, 65%) occurred in monthly negative value of CNI, and only 9 cases (35%) in positive CNI months (figure 2). Hence, the majority of the major avalanche episodes released in months that have negative phase of NAOi. The median value for negative CNI months with avalanche episodes is -2.5. It is worthy to note that the median value of months with positive CNI and avalanche episodes is 1.5 and this value match with the 50% of the observed avalanche episodes in positive CNI months. It means that major avalanche episodes for positive CNI months are concentrated around low positive values, while for negative CNI they match with more extreme negative values (figure 3). Furthermore, a significant part of the episodes (9 of 26) are recorded in months with extremely low values of CNI (below -5.3). It means that the 35% of the episodes occurs in the 96th percentile of the CNI values.

The comparison between avalanche events and CNI values shows a similar relationship than episodes one. From the whole of 254 avalanche events, 186 of them were observed during negative CNI values; 154 of these are registered with a negative maximum CNI value less than -6.6. It means that the 60% of the whole events match to the 98th percentile of the monthly CNI values. Coefficient of correlation between the winter season negative CNI and both avalanche episodes per year (R = -0.69) and avalanche events per year (R = -0.82) are higher than equivalent correlations ranks for the NAOi.

4 DISCUSSION AND CONCLUSIONS

Results show a negative correlation between NAOi and major avalanches releasing in the Eastern Pyrenees, which is higher by applying a cumulative NAO index (CNI). The number of major avalanche episodes and number of events per episode increases in the Eastern Pyrenees when the CNI is negative and the frequency and intensity of the episodes rise when extreme values of negative CNI are observed.

From these preliminary overlook, it seems to be that negative CNI understood as a sequence of negative monthly NAO index could be considered as an indicator of possible extreme avalanche winters. This applies both for avalanche forecasting and for past avalanche climate investigation.

It is worthy to note that the 1995-96 winter season, the maximum in major avalanches activity, both episodes and events (Muntán et al., 2007), broke the record of NAOi negative anomaly (-2.35) at least from 1970 through 2009. Furthermore, it is the only winter that has negative NAOi for the whole months (Dec-Apr) from the last 60 years.

Once argued the relationship between negative NAO and major avalanches, the open issue is which processes of negative NAO govern the avalanche activity in the Eastern Pyrenees. A first step should be to delve into the characterization of the behaviour of the snow and meteorological variables caused by the synoptic patterns typical of atmospheric circulation when negative phase of NAO prevails (García et al., 2007).

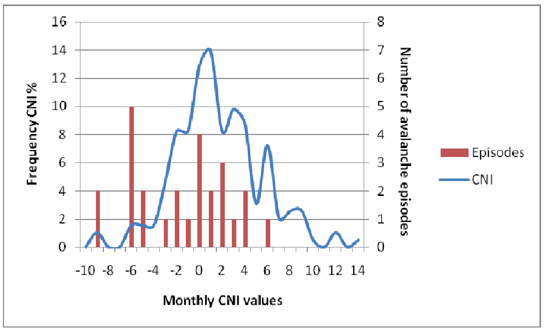

Figure 3. Frequency distribution of the monthly CNI values and number of avalanche episodes observed for each class of CNI values.

While the most part of the episodes occurs in negative NAOi, note also that a significant part of them are observed in months that have positive NAOi (35% of the episodes). The frequency distribution of major avalanche episodes in function of the CNI value suggests a bimodal frequency. The second maximum of observed cases fits with a class close to zero value of CNI (0 to -1) and frequency distribution seems to be skewed to the right to positive CNI values (figure 3). Avalanche activity in positive phase of NAO is probably consistent with spatial differences in the precipitation distribution over the Eastern Pyrenees ruled by positive regime of NAO (Esteban et al., 2001). Future work should focuses on whether the relationship between avalanches and NAO is equally significant throughout the whole regions into the Eastern Pyrenees.

Studies on NAO time evolution published in the recent years describe thoroughly the observed winter upward trend in the NAOi (Hurrell et al., 2003) and the persistence of positive CNI in the 90 decade (Keylock, 2003). According to these works, upward trend is forecasted to maintain by the majority of climate model simulations. Attending to the result of this work, a simple local response over the Eastern Pyrenees might be that avalanche activity would not increase; even it could descend since positive CNI would prevail. Nevertheless, in this work is shown that a surprising spell of negative CNI appears in the middle of the 90s decade characterized by the highest decadal average of winter NAOi. In addition, positive CNI are decreasing from 2000 through 2009 winter seasons.

To conclude, in this work significant findings the relationship between negative phase of NAOi and avalanching in the Eastern Pyrenees are shown, which could be useful for seasonal avalanche forecasting. Furthermore, in the middle of domain of positive phase of NAO, extreme avalanche situations linked to spells of strongly negative CNI has existed. Hence, for future climate scenarios ruled by positive phase of NAO, intense avalanche episodes could be also expected.

5 REFERENCES

Beniston, M. and Rebetez, M., 1996. Regional behaviour of minimum temperatures in Switzerland for the period 1979-1993. Theor. Appl. Climatol., 53, Springer-Verlag: 231-243.

Esteban, P., Soler, X., Prohom, M. and Planchon, O., 2001. La distribución de la precipitación a través del índice NAO. El efecto del relieve a escala local: El Pirineo Oriental. In: J.A. Guijarro Pastor, M. Grimalt Gelabert, M. Laita Ruiz de Asúa y S. Alonso Oroza (Eds.), El Agua y el Clima - L'Aigua i el Clima. Publications of the Spanish association of climatology (AEC), 2002, Serie A, nº 3. Planográfica Balear, Marratxí (Mallorca), pp. xii+594.

Esteban, P., Martí, G., García, C., Aran, M., García, A., Gavaldà, J. and Moner, I., 2007. Heavy snowfalls and avalanche activity over Eastern Pyrenees: a study of two extreme cases. Proceedings of the Alpine&Snow Workshop. Forschungsbericht 53. pp. 44-48.

Furdada, G. 2006. Aludes de nieve. Riesgo actual y riesgo futuro. Cuaternario y Geomorfología, 20 (3-4). pp 74-88.

García, C., Martí, G., García, A., Muntán, E., Oller, P., and Esteban, P., 2007. Weather and snow pack conditions of major avalanches in the Eastern Pyrenees. Proceedings of the Alpine&Snow Workshop, 49-56.

García, C., Martí, G., Oller, P., Moner, I., Gavaldà, J., Martínez, P., Peña, J.C., 2008. Atmospheric patterns leading major avalanche episodes in the Eastern Pyrenees and estimating occurrence. International Snow Science Workshop: pp. 97-105.

García, N.O., Gimeno, L., De la Torre, L., Nieto, R., Añel, J.A. 2005. North Atlantic Oscillation (NAO) and precipitation in Galicia (Spain). Atmósfera, pp. 25-32.

Gillet, N.P., Graf, H.F., Osborn, T.J., 2003. Climate Change and North Atlantic Oscillation. Geophysical Monograph, 134. American Geophysical Union, 10.1229/134GM09, pp. 193-209.

Hurrell, J.W., 1995. Decadal trends in the North Atlantic Oscillation and relationships to regional temperature and precipitation. Science 269, 676-679.

Hurrell, J.W, Kushnir, Y., Ottersen, G., Visbeck, M., 2003. An Overview of the North Atlantic Oscillation. Geophysical Monograph, 134.

American Geophysical Union, 10.1229/134GM01, pp. 1-35.

Jomelli, V., Delval, C., Grancher, D., Escande, S., Brunstein, D., Hetu, B., Filion, L. and Pech, P., 2007. Probabilistic analysis of recent snow avalanche activity and weather in the French Alps. Cold Regions Science and Technology, Vol. 47: pp.180-192.

Jones, P.D., Jonsson, T., and Wheeler, D., 1997. Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. Int. J. Climatol. 17: 1433-1450.

Keylock, C.J.,2003. The North Atlantic Oscillation and snow avalanching in Iceland. Geophys. Res. Lett., Vol.30. Nº5 (58): 1-4

Martín-Vide, J; Barriendos, M.; Peña, J.C.; Llasat, M.C., Rodríguez, R., 1999. Potencialidad del índice NAO en la previsión de episodios de alta pluviometría en España. Análisis, GR 67: 19-29.

Muntán, E., Oller, P., García, C., Gutiérrez, E., Martí, G., 2007. Reconstructing snow avalanches in the Southeastern Pyrenees. Geophysical Research Abstracts, Vol. 9, 07036. Sref-ID: 1607-7962/gra/EGU2007-A-07036. Contributions of the EGU General Assembly *2007*, Wien (Austria), European Geosciences Union. ISSN: 1029-7006.

Quadrelli, R., Lazeri, M., Cacciamani, C., Tibaldi, S., 2001. Observed winter alpine precipitation variability and links with large-escale circulation patterns. Clim. Res., 17, 275-284.

Schaerer, P., 1986. Weather patterns for major avalanches. The avalanche Review, vol. 4, nº 3: 2.