Application of multivariate statistical techniques for the characterization of the surface circulation patterns related to heavy snowfalls in Andorra, Pyrenees

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Abstract: Heavy precipitation in the form of snow over mountain regions can be a direct cause of avalanches. The characterization of the atmospheric situations responsible for these kinds of extreme snowfall events, would be a powerful tool to protect population against the natural risks that can be derived. This fact is of special interest in sectors where the presence of human activities (ski resorts, mountaineering) is important. This is the case with Andorra, a small country located in the Pyrenees, between France and Spain. Our study, using multivariate statistics (Principal Component Analysis and a two-step clustering classification), characterizes the surface circulation patterns, encompassing the region 30°N-60°N to 30°W-15°E for those days, between 1986 and 1999, where an intensity of 30 cm of snow in 24 hours was recorded. This method allows the classification of every day to the circulation patterns obtained, showing what has happened to other meteorological variables and in other atmospheric levels. The results, in the form of weather charts, could lead to a better comparison of the patterns with the products of meteorological models.

Keywords: Heavy snowfall events, Principal Component Analysis and Clustering, Sea Level Pressure, Circulation patterns, Pyrenees, Andorra, Avalanche forecasting.

1. Introduction

In mountain environments, which are covered by snow during the year, avalanches could be an important hazard source depending, obviously, on the use of landscape by population. Ski resorts, outdoor activities, and construction could be affected by this phenomenon in places with frequent contact between population and environment.

Andorra is one of these areas, a small and hilly country (highest altitudes around 2900 m.) located in the middle of the Pyrenees (see figure 1), between France and Spain, where wintertime activities and high-density population could be clearly affected by snow avalanches. The episode that took place near the ski resort of Arinsal in 1996 did not cause casualties, but with an important destruction of buildings by the avalanche, was an example that it would be useful to be able to predict these extreme events (Esteban et al., 2002). One of the most important causes of snow avalanches is heavy precipitation in the form of snow. The threshold at 30 cm in 24 hours (McClung and Schaefer, 1993) is well established. Identifying the circulation patterns that are responsible for such heavy precipitation represents a good way for an accurate prediction of avalanche hazard, combined with snow profile analysis and avalanche hazard cartography. In that way, we selected the days with 30 or more centimetres of fresh snow in 24 hours, and we characterized the map patterns at sea level pressure and 500 hPa level using multivariate techniques, Principal Component Analysis and Clustering, being more
6. Conclusions and Acknowledgements

The automated weather station network of the BC Ministry of Transportation provides the primary source of synoptic weather information relevant to the British Columbia highway system. The data and program as a whole is primarily intended for use by Avalanche forecasters and Road maintenance contractors along with their associated support workers.

The observations also provide a significant component of the forecast verification process performed by agencies that provide highway and community weather forecasting services in BC. When forecasts prove inaccurate, remote stations also provide data on de facto conditions which often support the operational decision making process in lieu of the forecasts.

The record of weather collected is becoming large and at some stations is exceeding 2 decades. It is a potentially valuable tool for managing and planning aspects highways maintenance programs that are directly affected by weather.

The data seems to be somewhat in demand for public purposes also. A properly staffed and funded service to oversee data and associated systems for public dissemination could be of service to the winter traveler especially when planning routes through High Mountain passes. The present unsupervised system of public dissemination provides a service but a potential exists for conflict between station data quality and weather forecast quality.

Automatic weather station design and operations are an evolving combination of Technology, Art and Science. An awareness of sensor operations theory as well as current and past conditions at the station can greatly influence interpretation of data by users. This paper is a small attempt to help bridge the gap between station technology and the resulting datasets which people periodically work with. The importance of station and telemetry system maintenance as a means of ensuring data availability and quality can also not be understressed.

The datasets have also been used for applications ranging from accident litigation to wind power suitability modeling. Modernization of processes for rendering, visualization and model confirmation could span a whole new era of value for this data. That is assuming numerical and computational processes remain at the forefront of applied meteorology.

Many thanks to all BC MoT Snow Avalanche Program staff for supporting MoT Weather Stations. Special thanks to Brant Benum EET Revelstoke (Deicing) and Paul Heikkila EET Nelson (Mounts) mentioned in the paper as well as Ted Weick SAP Victoria, Art McClean SAP Victoria Paul Hadfield EET Terrace, Bill Golley EET Hope, Nic Seaton and Steve Portman SAP Penticton, Doug Tuck SAP Pemberton. All for whom weather station work is a part of daily life in the winter. Final thanks to Jack Bennetto for confidently believing BC MoT’s weather station technology is of a quality that merits an expanded network.

Figure 6. Roadside Weather Station near Barriere BC. Data is used for both Avalanche and Road Temperatwe and condition forecasting.

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Figure 5 to 7 (continuing the previous page): Identified spatial circulation patterns using multivariate techniques for heavy snowfall events over Andorra (1986-1999), a) SLP patterns, b) geopotential height and temperatures at 500 hPa level.
3. Results

Six circulation patterns are identified applying PCA and clustering methods described previously, permitting classification of all the days in this groups. No unclassified days or days classified in more than one pattern are possible. The circulation patterns maps shown in figures 2 to 7, are the mean values of the NCEP/NCAR reanalysis data for SLP (2 to 7 a) and geopotential heights and temperature at 500 hPa (figures 2 to 7 b) corresponding to the days of each group.

The first pair of weather charts (figures 2a and 2b) shows a north-northeast advection, with a low temperature air mass coming from the north of Europe. The Azores high is northward of normal, and a low pressure is located in the Geneva Gulf (due to the orographic effect of the Alps). At 500 hPa height, a trough with the axis crossing central Europe and the western Mediterranean basin draws a strong gradient of isohypses over the area of study, pumping in cold air in high levels.

The second situation (figures 3a and 3b) represents a cold front crossing the Pyrenees related to a low pressure located between Iceland and the British Isles, with the forward area of a trough (increasing instability) over Andorra.

The third group identified (figures 4a and 4b) corresponds to a low pressure over the Pyrenees. The surface winds over the Pyrenees come from the Mediterranean sea (south-southeast), ensuring enough humidity to develop heavy precipitation events. Furthermore, such surface situation is clearly reinforced by the presence of a deep low associated with cold air at 500 hPa to the west side of the Pyrenees.

The fourth situation (figures 5a and 5b) is quite similar to the first one, but with a more clear northwest advection both at the surface and at 500 hPa levels, again with a strong gradient of isobars and isohypses. In figures 6a and 6b we can see an extensive high between Azores area and northern Europe, jointly with a low in the Tyrrenhan sea, giving north-easterly winds over the eastern side of the Pyrenees and Andorra, affected once again by a trough and low temperatures at high levels. These situations, with some Mediterranean air masses, have high precipitable water.

The last one (figures 7a abd 7b) is related to north-northwest entrance of polar winds, with low pressures over central Europe. Aloft, a trough is drawn with the axis over the area of analysis.

4. Conclusions

With multivariate statistics (PCA and clustering), a computer assisted methodology, we have characterized six circulation patterns that explain heavy snow precipitation events in Andorra between 1986 and 1999. These patterns show 5 advective situations (2 with north to east winds and 3 with north to west winds) and 1 with a centred low pressure. In all cases, we observe a high gradient of the isobars, indicating strong winds blowing over the Andorra area. Maps at the 500 hPa level shows troughs with cold air, assisting the instability. Adding the effect of the orography, which supplies enough energy (increasing vertical velocity) for cloud formation, heavy precipitation events are ensured, in the form of snow in wintertime. Such an amount of fresh snow in a few hours (30 or more cm. in 24 hours) could seriously increase the instability of the snowpack, leading to potential avalanche events. As a consequence, these maps, and those obtained for other variables, could be very useful for avalanche forecasters.

Finally, we have demonstrated that the use of multivariate statistical techniques is a powerful tool to identify well-established circulation patterns.

5. References

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6. Acknowledgements
We thank Marc Prohom (Group of Climatology, University of Barcelona) for technical support, and Joan Aymami (Group of Meteorology, University of Barcelona) for helping us with NCEP/NCAR reanalysis data.