HOW TO IMPROVE SNOW AVALANCHE OBSERVATION QUALITY?

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ABSTRACT: Snow avalanches are a major natural hazard concerning mountainous areas around the world. Each winter in many countries, human life and land-use planning depend on enduring risk management and avalanche forecasting. At present, it’s difficult to accurately predict a single avalanche event in terms of both location and time of event (Schweizer, 2003). It is also challenging to take into account the impact of climate change (Robinet, 2013). Methods employed for avalanche zoning and warning strongly depend on the reliability of input data (Bonnefoy, 2010). There are several avalanche databases that exist in France as well as in other countries worldwide. Avalanche records are more or less realistic, sometimes based on observations or from measurements or statistical or numerical models. There is no international standard established for avalanche event recording and mapping. A practical analysis has been realized in order to know state-of-the-art and to ask appropriate questions. We propose an overview of means to collect, validate and centralize avalanche knowledge with heterogeneous sources and for various uses.

KEYWORDS: snow avalanche, acquiring knowledge, database, mapping, data quality

1. INTRODUCTION

Snow avalanche observations represent an important tool for natural hazard management and avalanche forecasting in mountainous regions. Since 1971, avalanche records have been documented and used in France for the Localization Map of Avalanche Phenomena (Carte de Localisation des Phénomènes d’Avalanche, CLPA). The CLPA records and plots the greatest limits of past snow avalanches.

Many detailed studies have been compiled in order to implement operational tools with old and new data; classification, digitization, data modeling, and archiving. Observation data processing uses recently improved mapping tools and web-based information systems. At present, more than 25 000 avalanche paths are recorded, corresponding to an 8 600 square kilometer map coverage. It represents only 1.5% of France, but comprises

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17% of the French Alps and Pyrenees territories. Almost 15 000 CLPA sheets are stored in order to describe avalanche observations. The CLPA database is continuously updated. Since 2003, between 40 and 50 new avalanches or avalanches having exceeded previously known limits have been reported each year.

All this information is available on the website www.avalanches.fr. Both the public and professionals can download this avalanche data and use the web mapping and digital files library facilities. It shows the result of efforts for decades and expresses the need of maintaining such a wealth of information about avalanches.

This data is increasing in detail and quality (eye witness accounts, written information, photographs, and measurements) and could also be more and more complex (satellite pictures, dendrogeomorphological analysis, specific field instrumentation, photogrammetry and remote sensing). Moreover, the quality of data can sometimes be affected by a subjective interpretation of the avalanche event or its visible landmarks. The avalanche records might also be rare and more focused on damages than on a complete description of the phenomenon.

At the same time, tools and technologies available to collect and disseminate large amounts of information and data from -and to- a huge amount of
people are becoming more and more powerful and commonly used.

This review focuses on avalanche characteristics and recording methods commonly used for public information throughout the world. The purpose is to draw up a classification of the existing information about snow avalanches in order to exchange knowledge, to transfer our 40 years practical experience and to innovate and improve the French avalanche information system.

This paper proposes an international inventory of avalanche data collecting methodologies. The list is probably non-exhaustive. Despite careful drafting, errors or omissions may appear. Everyone concerned is invited to contact the authors with comments.

Threshold issues are listed at the end of the presentation. The purpose is to open the discussion and to provide some responses to the question: “How to collect more avalanche data without affecting data quality?” Of course data quality must be considered with reference to the expected use of the data.

Our analysis focused on readily available information through previous publications, internet search skills and contact mailing.

2. AVALANCHE EVENTS RECORDING

After the exceptional winter of 1887/88, Coaz organized the first detailed survey of avalanche damage in Switzerland. A few years later (1899), Mougin implemented in France the Avalanche Permanent Survey (Enquête Permanente sur les Avalanches, EPA) with the forestry services. It initiated the compilation of avalanche data over many decades.

Today, a lot of avalanche event databases exist throughout the world. Their needs and uses are numerous and varied. For example, an International Avalanche Association, based in France, has developed www.dataavalanche.org for everyone who has seen an avalanche and who wants to post information about it. Other databases are also used for more specific users and applications.

2.1 Avalanche damage survey

Avalanche events recording began with the avalanche damage survey. The aim was already to develop a scientific knowledge of avalanche activity mechanisms and to record all known damage events in order to protect human and economic interests (forests, houses, roads...), from avalanche dangers. The extensive long-term snow and avalanche observations were also used for deriving statistical avalanche forecasting rules and for climatological surveys and are extremely valuable input for modern avalanche warning models (Laternser, 2002).

Such observations mostly involve a formalized network of observers. Since the 1950s in Switzerland, avalanche data has been systematically collected by the Swiss Federal Institute for Snow and Avalanche Research (SLF) thanks to the AO (Avalanche Observations) observers. Each winter in France, avalanche paths have been surveyed on a continuous or intermittent period by forest officers (National Forest Office) and stored in a shared database managed by Irstea. In the same way, observations could also be done in expeditions of Federal Service for Hydrometeorology and Environmental Monitoring of Russia or from helicopters in Uzbekistan (Semakova, 2009). The Destructive Avalanches Database (Laternser, 2002) and the Localization Map of Avalanche Phenomena (Irstea) also compile information from archives data of individual avalanches causing property damage or affecting people.

Required information is parameters characterizing avalanche mechanisms and damages and the danger area extent. The following items are usually recorded: affected territory (country, municipality, watershed and mountain range), dates of event, snow and weather conditions, snow quality and quantity, triggering mechanisms, avalanche type and size, elevation of the release zone / of the deposit zone, and impacts and damages.

Data is more or less spatially referenced. An avalanche event can be localized with the flow path (Avalanche Cadastre of USSR) or the watershed shape (EPA, France). Data might be more precisely referenced. Accurate boundaries of events are transferred on the Localization Map of Avalanche Phenomena (Irstea, www.avalanches.fr), on the Avalanche paths map (ICGC, 2014, http://www.igc.cat/web/en/allaus.php) and also on Avalanche Atlas Maps of Avalanchemapping.org (2010, http://avalanchemapping.org). It is not known if it is exactly the same with the AvalEdit tool (WSL, 2013, http://www.wsl.ch/fe/warnung/warn_informationssysteme/informationssysteme/avaledit/index_EN) which gives observers the chance to record avalanche observations and damage caused by avalanches efficiently and link them up with geographic data. The Avalanche cadaster of the Valle d’Aosta Region presents on its website...

Data is increasingly published on the internet. Users can find snow observations data, written archives, photographs, measures, avalanche description reports and scanned or interactive maps depending on the country. Thanks to the internet users can gain access to an international extensive avalanche register including chronological lists of events and mapped avalanche paths.

2.2 Avalanche accident reporting

While avalanche accidents mainly affected people living and working in mountainous areas in the past, in most cases today these occur in the context of recreational activities in the mountains. The democratization of snow sports has led to a collective awareness on the need for training and information for practitioners of winter sports (Avalanche Centre Haute-Gaspésie Québec). Several avalanche databases motivate users of winter mountains to report avalanche accidents. There are several objectives: to complete the avalanche bulletin and to inform users of mountain snow conditions, to participate in avalanche education and accident prevention, to exchange about means of search and rescue and to increase the number of statistical data used for research.

In France, rescue professionals are invited to report avalanche accidents (ANENA, 2014) in which individuals have been involved in their leisure activity. The following are the main parameters required and are published in a summary table: date and place of the accident, type of leisure activity, number of people caught, number of people buried, number of people dead, number of people injured, number of people unharmed. Avalanche accidents are published in the same way in Italy (AINEVA, 2014) but also include accident in public road traffic and in places of residence. In Switzerland, parameters as slope angle and index of the avalanche bulletin are presented from the summary table of fatal avalanche accidents (SLF, 1999-2014). In USA, we can know the type of the weak layer (Utah avalanche Center) and visualize the snowpit profile graph (Sierra Avalanche Center).

Several other data is also recorded and concern source of information, characteristics of the release zone, the run-out zone and the deposit zone, weather conditions, avalanche characteristics and size, accident factors, rescue operations, behavior, level of awareness and safety equipment of the involved people, type of injuries and death cases (ANENA, 2014). Those details and sometimes photographs are available from the summary table of avalanche accidents in Canada (Canadian Avalanche Centre, 2014) and in USA (Avalanche.org, 2014; Utah avalanche Center; Sierra Avalanche Center; Colorado Avalanche Information Center, 2008-2014) and also from a webmapping tool in USA (Sierra Avalanche Center; Colorado Avalanche Information Center, 2008-2014) and in Japan (Izumi, 2003).

Publications of details with photographs and localization map are sometimes available as in USA (Chugach National Forest Avalanche Information Center, 2014). Complete expert reports can be consulted in Japan (Japan Avalanche Network).

2.3 Avalanche parameters observation

Due to economic reasons and because of difficulties in accessing the avalanche field observation site, human observation has sometimes been substituted with a sensor and weather stations system. Field observation may also be focused on some operating parameters according to the study objective.

For example, although the avalanche observation program was initially launched only for the short-term use for the operational avalanche warning in Switzerland, the data is now also used for other purposes, such as for the improvement of forecasting models and for climatological evaluations (Laternser, 2002).

Daily records of the avalanche activity are available through the AO observations (WSL, 2013) and 84 stations with electronically accessible records (Laternser, 2002). Five avalanche parameters are observed; triggering mechanism (natural/human release, artificial by skier/firing/snow cat, etc.), avalanche type (slab/loose snow, dry/wet, surface-layer/full-depth avalanche, etc.), slope direction of starting zone (N, E, S, W, sunny/shady, lee/windward slopes, etc.), elevation of starting zone (below/above certain elevation zones) and number, size and impact (Laternser, 2002). The purpose was to select reliable observations and to compare the predicted and the effective avalanche activity. Number, size and impact of avalanches are of primary interest for that (Laternser, 2002) and a plausibility check has been developed in order to control observation
quality of these parameters. This algorithm is based on the annual number of observed avalanche days, the annual frequency distribution and the longest, annual sequence of missing data and determines a quality estimate for every station and every winter (Laternser, 2002). Quality breaks appear often after an exchange of the observer, which shows the subjectivity of observations that cannot be measured with a standard instrument (Laternser, 2002).

3. AERIAL PHOTOGRAPHS ANALYSIS

In France for the Localization Map of Avalanche Phenomena (Bonnefoy, 2010) and in Catalonia for the Avalanche paths map (Cartographic and Geological Institute of Catalonia, 2014) the photographs analysis is based on the observation of the referred summer vertical aerial photographs. Without snow cover the observation of slopes morphology, roughness of ground and vegetation affected by avalanches is easier. The photographs analysis is done using the human stereoscopic vision helped by a stereoscope and the overlay of two aerial photographs. Nowadays in France this stereoscope has been adapted to be used on a computer screen. This allows for a faster switch between each campaign without causing the localization to move. In Catalonia each Avalanche paths map shows the route of flights followed for taking photographs.

In France Irstea use numerous aerial campaigns in order to get reliable avalanche paths boundaries and validate the results with a field visit. In Catalonia “slopes map” obtained with an altimetry database help to control avalanche routes boundaries. At the end boundaries of zones affected by avalanches are defined, mapped and set as a layer in a GIS tool.

In Japan scientists (Akiyama, 2013) used winter aerial photographs allowing to see snow avalanches. 2 300 avalanches have been studied and mapped with aerial photographs. The aim was to define following characteristics of each avalanche: geometry of avalanches (release, run-out and deposit zones), slope angle and altitude of those zones, type of avalanche (surface layer avalanche or full-depth avalanche). Relationships between avalanche horizontal run-out distance and vertical drop on the one hand and avalanche release altitude and excessive travel distance on the other hand were researched.

4. AVALANCHE DANGER MODELING

In Switzerland the AVAL-2D model is used in order to map snow avalanche risks. The SilvaProtect project (OFEV, 2006) considered a 10 meters DTM (Digital Terrain Model), areas of protective forest, a 2 000 m altitude regional snowcover model and a 3 days snowcover increasement model for a 300 years return period. Analysis results were compared with historical archives and views of local experts. Indeed avalanche risk features are bigger than observed or historical avalanche events one because the model considers a tricentenial return period. Moreover the model did not include effects of avalanche protection structures.

In Uzbekistan Semakova and al. (2009) used modeling with Digital Elevation Model (DEM) and input data as snowy parameters, avalanche basin characteristics and avalanche observations (Avalanche Cadastre of USSR database and expeditions observations) and considered the avalanche danger by mapping avalanche widest boundaries and correlating data with human land uses.

5. AVALANCHE EXPOSURE MAPPING

Rules have been defined in order to map presence or absence of houses avalanche exposure (Izumi, 2003; Niigata Prefectural Government, 2014). Collected data from newspapers from 1867 to 1999 representing 7468 avalanches with 6053 casualties in Japan revealed those following rules: a vertical drop higher than 10 m and a slope angle (release zone and deposit zone) greater than 15 degrees, more than 5 houses (or only one for public office, school, hospital, emergency shelter, railway station, hotel, etc.) facing the slope, houses situated below the slope with more than 18 degrees of angle between the top of the slope and the location of the house.

The Canadian Avalanche Centre has developed the Avalanche Terrain Exposure Scale tool (ATES). The aim was to classify avalanche exposure of backcountry recreational routes (Campbell, 2010, 2012, 2013). The scale considers parameters like slope angle, terrain roughness, forest density, glacial features, exposure time and available route issues. Avalanche exposed areas and exposure level are determined with a field analysis, local experts knowledge and a GIS analysis. ATES started to emerge as a classification system for zoning avalanche terrain (Campbell, 2013) and 8 000 km² were zoned with the ATES method for workplace or recreational safety purpose in Western Canada.
6. ANALYSIS OF AVALANCHE DATA
COLLECTING METHODS AND RESULTS

Avalanche mapping and databases around the world have been identified and analyzed. We made a brief description in preceding paragraphs and tried to categorize this. To compare avalanche recording methods more easily and accurately, we have arranged them into a table. Five main parameters have been selected:

- Main information of the publication,
- Source data,
- Published data,
- Source of funding,
- Additional information (data quality concept, notion of context, multiple language translation, links to other sites).

Each parameter is subdivided into several sub criteria. Main information of the publication concerns particularly the main objective of published information (observation, education, accident, forecast …) (Fig. 1) and the importance given to avalanche mapping. Source data is described through the current unit of study (event, hazard, risk, vulnerable exposed element, descriptive inventory or prospective analysis), the data source (professional observations, volunteer observations, written archives, expert reports, photointerpretation, measurements, numerical models…), the data producer, data control processing, spatial coverage of the data (country, region…), spatial referencing of the data (point, line, shape, precise boundaries…). Published data is identified with intended audience, uses, decision framework, publication processing, data accessibility, and type of data published.

Fig. 1: The main objective of published information on websites or publications

![Main information of the publication](image)

Fig. 2 shows that 72% of data are spatially referenced. 28% are referenced with their accurate boundaries (including 8% with only the deposit zone boundaries) and 24% with only a point location (including 8% with a Google Map® point). 16% are referenced with theoretical boundaries or exposed areas using so a perspective approach.

![Spatial referencing of the data](image)

As shown in Fig. 3 most of avalanche information is collected with an empirical approach. 24% comes from professional observers. 43% originated from volunteer observers, avalanche reports and historical archives for which we can’t estimate easily the quality level of data. The prospective approach based on terrain parameters concerns 25% of avalanche published information. Only 7% of data come from avalanche modeling. It is interesting to note that most studies combined those various data sources (Fig. 3 (b)).

![Data source](image)

Various avalanche data sources graph (a)
Types of avalanche data published on websites or publications are presented in Fig. 4. We can see that avalanche information is mostly available as event description. Only 29% of published data concern maps including a minority of vector files only accessible with a restricted-access.

Last but not least, it is difficult to know if a data control processing is used for all studies. In most cases avalanche data producers and data quality managers seems to be the same. If an avalanche observation (e.g. online report) control is done by qualified people, we don’t know clearly how it is managed. However, a lot of photographs are publicly accessible (Fig. 5) and data users have nowadays the opportunity to compare the published information with the original source.

For prospective analysis the problem remains. Source data comes mostly from an empirical approach especially event observations (Fig. 3), while published data are analysis results according to the initial objective. Intermediate reflection steps allowing the shift from first ones to last ones are not precisely recorded. For example, it is generally labour intensive to trace an observed avalanche among predicted avalanches with representation used for avalanche risk maps.
7. DISCUSSION AND PROSPECTS

Laternser (2002) studied the best ways to obtain information about the avalanche activity for the operational avalanche warning and for the verification of the avalanche bulletin in retrospect, and concluded that consideration of only destructive avalanches could be problematic. Destructive avalanches may not be recorded for various reasons (by chance no damage caused, objects removed by antecedent avalanches, effect of protective measures, land use changes). In this case study, avalanche observations are a more objective measure of natural avalanche activity than only destructive avalanches.

To answer the question “How to improve snow avalanche observation quality?” needs to know which data reliability is required, for which type of analysis and for which uses. Organizing the best avalanche data collecting process would thus be possible.

In France, most data observations are centralized and analysed by data control managers in order to ensure the consistency and reliability of these observations. Therefore a strong effort has been undertaken for training observers and control managers (accurate observation guidelines, sufficient observer training, reliable observers, regular quality control) (Robinet, 2013). It is a considerable investment in time and money to guarantee the quality and continuity of the data. It was decided to involve and awareness volunteers observers with disseminating information on the internet, education meetings, and appropriate process tools. Concerns regarding the data interpretation still remain. Are avalanche knowledge and training of observers sufficient to believe in the value and the usability of avalanche observations? How classify the reliability of observations? How classify the reliability of observations? How organize a traceability system reliable?

Same questions could also be raised for other avalanche data collecting method; which avalanche parameter is recorded and by whom? Which aerial photographs are analyzed and by whom? Which modeling tool is used and by whom? Which criteria allow upgrading or downgrading the avalanche exposure of an area?

Answers to these and other many questions may already exist. Discussion and sharing will help us and others find these.

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