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A decision support tool for dry persistent deep slab avalanches for the transitional snow climate of western Canada

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ABSTRACT

A decision support tool to aid in forecasting the likelihood of dry persistent deep slab avalanches was created from three separate data sources in western Canada. Data were obtained from an expert opinion survey of avalanche professionals, a dataset of avalanched starting zones that were field-investigated, and a dataset of avalanches from the Canadian information sharing system. The survey and the tool consisted of three sections: snowpack conditions, weather conditions, and avalanche observations. Parameters in the tool were assigned importance values derived from the survey responses. A classification tree was used to determine the threshold tool sum for increasing the likelihood of observing natural persistent deep slab avalanches. Based on some of the data used to create the tool, the tool correctly explained 75% of days with natural avalanches (16 out of 18) and non-avalanche days (61 out of 85), but the false alarm ratio was high (60%). The tool also indicates if triggered avalanches from localized dynamic loads are possible, depending on responses in the snowpack conditions section of the tool. Avalanche forecasters must apply the tool to certain terrain characteristics, at a local to regional scale. The tool may benefit from location-based calibration. The tool only indicates the likelihood of persistent deep slab avalanches based on the datasets used and it cannot determine when or where they will occur.

1. Introduction

Of all the types of snow avalanches, persistent deep slab avalanches are among the most hazardous and difficult to predict. The slab releases from the failure of an underlying persistent weak layer, which subsequently propagates across a starting zone and releases the overlying thick slab of cohesive snow (Schweizer et al., 2003). With high destructive potential from the large release of snow, humans and infrastructure within the avalanche path are often at great risk. Persistent deep slab avalanches are more difficult to forecast than thinner, softer slabs (Jamieson et al., 2001; Föhn et al., 2002). The difficulty of predicting deep slab avalanches creates uncertainty in the avalanche forecast.

There are two fundamentally different trigger types for slab avalanches: natural releases and artificial releases from localized dynamic loads (triggered avalanches). Natural releases (also called spontaneous releases) are those that occur because of the weather (Schweizer, 1999). The most common forms of natural releases are due to increased stresses and increased strain rates from loading (e.g. snowfall, wind-transported snow, and rain). In such situations, failure initiation is caused by localized strain softening of the weak layer (Schweizer et al., 2003), which may lead to crack formation (Schweizer, 1999; McClung and Schweizer, 2006). This crack may then propagate over a much larger area until the crack energy (work of fracture) is higher than the energy release rate. A less common release mechanism for natural avalanches is from increased strain rates in the upper snowpack from warming (e.g. solar radiation, convection). Higher strain rates can lead to ductile failure and strain softening of a persistent weak layer or interface, which may lead to crack propagation and the release of a slab avalanche (Schweizer, 1999). This release mechanism is particularly rare for persistent deep slab avalanches, as the effects of warming on the snowpack are often subtle (Reuter and Schweizer, 2012) and may only contribute to slab release in areas of shallow snowpack (Conlan and Jamieson, 2014).

The mechanics behind triggered avalanches that release due to additional stresses from a localized dynamic load differ from natural release. Under localized dynamic loads (e.g. skiers, snowmobilers, cornice falls, and explosives), the failure initiates at high strain rates directly below the dynamic load. Forecasting for these two trigger mechanisms is different. Weather patterns may not be favourable for natural avalanches but stresses induced by a localized dynamic load may still cause a crack of critical length in a buried weak layer and subsequent propagation of the crack may release a slab avalanche.

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Many days of a winter season are categorized under stormy or warm weather patterns, yet deep slab avalanches only release on a few days over a winter season. The snowpack in an avalanche starting zone must also have certain characteristics to be influenced by the weather; a persistent weak layer must be present, crack initiation must be possible within the layer, and the weak layer must be spatially continuous and have high propagation potential (Schweizer et al., 2003). With the combination of snowpack and weather conditions required for persistent deep slab avalanches, a decision support tool holds promise for aiding forecasters in assessing the likelihood of the release.

Avalanches triggered from localized dynamic loads may not require short-term contributing weather effects on the snowpack. However, the average depth to the persistent weak layer, which is typically > 80 cm (Conlan et al., 2014; Conlan and Jamieson, 2016a), makes triggered persistent deep slab avalanches difficult to forecast. The average slab thickness is often larger than the depth that substantial stresses applied from a human on the snow surface reach (Thumlert et al., 2013). A spatially variable snowpack is likely required, where failure initiation occurs in a relatively thin area of the snowpack (Conlan et al., 2014).

A decision is the outcome of a thought process with at least two different possible results (Kangas et al., 2008); decision making is the process of selecting the outcome. If the decision-making process is complex, properly-used decision support tools can improve the reliability of the decision. Such tools are often developed by analyzing past events and historical knowledge and are widely used in avalanche risk management (CAA, 2016).

Decision support tools have been developed for travel in avalanche terrain, such the Avaluator (Haegeli et al., 2006) and Avaluator 2.0 (Haegeli, 2010). They were developed from historical accident records, social science, and from expert opinion. The Avaluator uses the threshold sum approach, where questions are answered and summed to determine the level of hazard for backcountry skiers. This and other decision aids for traveling in avalanche terrain were evaluated by McCammon and Haegeli (2007).

Schweizer and Föhn (1996) developed decision support systems for avalanche forecasting in Switzerland, using weather, snow, and snowpack information. The systems were accurate for 60 to 70% of data from nine winters, similar to the performance of an expert forecaster using conventional methods. The nearest neighbor decision support approach has also been applied to avalanche forecasting (Buser, 1983), including the development of local and regional forecasting models (e.g. Brabec and Meister, 2001; Gassner and Brabec, 2002; Purves et al., 2003).

With a focus on persistent deep slab avalanches in southwest Montana, Marienthal et al. (2015) created classification trees to identify important meteorological variables during winters of high avalanche activity. They identified that days with deep slab avalanches often had more precipitation over the preceding week and warmer minimum 24-hour air temperatures than days without deep slab avalanches.

A decision support tool used to assess snowpack structure is the yellow flags, or lemons approach (McCammon and Schweizer, 2002; Jamieson and Schweizer, 2005; Schweizer and Jamieson, 2007). The lemons approach was developed by looking at five key parameters individually within a snow profile and evaluating their values with respect to avalanching on nearby slopes (McCammon and Schweizer, 2002). Thresholds for each parameter were identified based on statistical significance, discussion with professionals, and ease of use within the field. This technique is currently in use by some avalanche forecasters and partially in some snowpack models (e.g. SNOWPACK, Bartelt and Lehning, 2002; Schweizer et al., 2006; Monti et al., 2012).

Decision support tools have also been created for the field of avalanche hazard mapping (e.g. Rapin et al., 2006; Tacnet, 2009), and the forestry industry (Stitzinger, 2001), which were developed for risk-based planning. These tools require particular inputs to assess the risk for a given location.

Although decision support tools can help recreationists and professionals in certain situations, expert judgment is crucial for reducing risk (Vick, 2002; Escande and Létang, 2010).

Hitherto, decision support tools have not been developed for any specific avalanche type. Avalanche professionals generally avoid areas where deep slab avalanches have recently released, leading to few snowpack observations in the release zones. This is part of the motivation for this research, where avalanche professionals were surveyed, snow properties were measured at deep slab avalanches (Conlan et al., 2014; Conlan and Jamieson, 2013), and historical events were analyzed (Conlan and Jamieson, 2016a; Conlan and Jamieson, 2016b) to develop a decision support tool.

2. Methods

A decision support tool for dry persistent deep slab avalanches was created, to be applied at a local to regional scale in transitional snow climates of western Canada. To create the tool, data from three primary sources were used: an expert opinion survey, a dataset of avalanched starting zones that were field-investigated, and a dataset of avalanches from the Canadian information sharing system (InfoEx).

2.1. Expert opinion survey

The expert opinion survey (Table 1) was completed by avalanche professionals working as ski patrollers, mountain guides, avalanche researchers, and in highway operations. The survey consisted of three sections: snowpack observations, weather preceding the release of avalanches, and preceding avalanche observations. The questions were derived from parameters that were found to be important from previous studies (e.g. Bradley, 1970; Jamieson et al., 2001; Savage, 2006; Tracz, 2012; Conlan and Jamieson, 2013; Conlan et al., 2014) and from discussions with avalanche professionals. Most questions required the professional to fill in blanked portions of statements with numbers or ordinal levels. Furthermore, the respondent indicated their confidence in their value for each respective question as Poor, Fair, or Good. They also indicated whether they thought the observation in each respective statement had Low, Medium, or High importance for the release of natural persistent deep slab avalanches.

The survey was completed by 31 avalanche professionals. They were not required to complete the entirety of the survey, solely the questions for which their experience was relevant. Weighted averages of each response were calculated based on their confidence in the answers. A weight of 1 to 3 was assigned for confidences rated as Poor, Fair, and Good, respectively. The importance values were also assigned a value of 1 to 3 for Low, Medium, and High, respectively, and averaged for each question. For some questions, responses were grouped based on the mountain range in western Canada where the professional worked (i.e. Coast Mountains, Columbia Mountains, or Rocky Mountains). If the professional indicated that the responses were for more than one mountain range, they were placed in a fourth group called Multiple.

2.2. Dataset of avalanches investigated by field teams

A portion of the data for this research comes from previous studies. Conlan et al. (2014) summarized measurements from 41 investigated persistent deep slab avalanches from 1993 to 2012 in western Canada. The dataset was expanded with more field-investigated avalanches between 2012 and 2014, for a total of 63 avalanches. This dataset included 18 natural avalanches from differing primary causes-of-release (e.g. precipitation loading, loading from wind-transported snow, solar warming, air temperature warming). A second group of avalanches triggered from light loads (e.g. skier, snowboarder, snowmobile) included 25 avalanches. A third group of avalanches triggered by heavy loads (e.g. explosive, helicopter, cornice fall, step-down) included 20 avalanches.

The dataset included snowpack properties (grain size, type, and