

CHARACTERISTICS OF OLD-DEEP-SLAB AVALANCHES

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ABSTRACT: Deep and old slab avalanches (ODS) are often hard-to-forecast. The size and destructive potential of ODS avalanches can be disturbing. As a starting point for a study of hard-to-forecast avalanches we define ODS avalanches based on a large dataset spanning the three main mountain ranges of western Canada: Coast, Columbia and Rocky Mountains. The definition is based on extreme slab depth and extreme age of the snowpack weakness that failed. Our data did not reveal a difference in slope angle or aspect between the ODS and “Other” avalanches. However, compared to Other avalanches, ODS avalanches were typically of greater size, involved less human triggering, released more often on crusts and weak layers of facets and tended to occur more often in early winter.

1. INTRODUCTION

Deep slab avalanches present a unique hazard. The depth at which the snowpack weakness is buried suggests that they are less prone to triggering (Föhn, 1987; Schweizer, 1997). Often the length of time and amount of overburden pressure acting on the snowpack weakness would suggest that the layer should be gaining strength (Jordan et al., 2008; Shapiro et al., 1997). However, recent research and seasoned practitioners say that slab properties such as stiffness and thickness are positively correlated with weak layer fracture propagation (van Herwijnen and Jamieson, 2007). These factors

add together to make deep slab avalanches the quintessential “Scary Moderate” hazard, a seemingly difficult to initiate slab avalanche, but when they go, they go big (Tremper, 2009).

Previous studies, each with their own definition of ‘deep slab’, have attempted to explain this phenomenon. Bradley and Bowles (1967) and Bradley (1970) define deep slab avalanches as being natural ground avalanches. To perform case studies of particularly destructive avalanche winters, Jamieson et al. (2001) and Greene and Johnson (2002) focussed on deep slab avalanches that released on an early season crust with faceted crystals above or below; Comey and McCollister (2008) define deep slab avalanches based solely on crown depth; Savage (2006) defines deep slab avalanches by crown depth and slab hardness. The Canadian Avalanche Centre (e.g. Klassen et al., 2010) define a “persistent deep slab avalanche” as a deeply buried hard slab avalanche that often fails on or near the ground

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and commonly will lay dormant for several weeks or months. For all the differences that exist between these definitions, the goals are similar. All aim to understand a thick, persistent and difficult to forecast avalanche hazard that has a high risk both to infrastructure and human life.

2. METHODS

‘Rare events that are truly extreme are generally found at the tails of distributions’ (Bier et al., 2004). Familiar to many is the idea of the 1:300 year avalanche or 1:100 year rainfall event which are based on similar principles. The selection of a non-exceedance probability is arbitrary and done so to best suit the particular study (Zhu and Toth, 2001). A common non-exceedance probability in meteorological studies is 90% and it is often necessary to define extreme cut-off values by geographic areas (IPPC, 2007), i.e. 1000 mm of seasonal precipitation may be extreme in a continental climate but not for a coastal climate.

A common industry practice is to report the average and maximum, or maximum and minimum, crown heights observed for individual slab avalanches. For this study, we define the slab depth as the average or midpoint value of maximum and minimum crown height. Another common industry practice is to assign the date when a weakness is buried as an identifier to track the weakness over time. Age is defined as the number of days between the snowpack weakness burial date and the avalanche occurrence.

For the analysis of a large data set this paper defines ODS avalanches as being equal to or rarer than the 80th percentile of depth and of age when compared to all other slab avalanches recorded within their respective region. The Rocky Mountain region is an exception. Extreme age is defined as equal to or rarer than the 70th percentile. This exception is made because of data availability.

Several avalanches in the Rocky Mountain region were reported to have released on the ground but no associated burial date was recorded. Because the Rocky Mountain region is typically classified as having a continental climate which is prone to cold temperatures, shallow snow cover and depth hoar formation (Haegeli and McClung, 2004; LaChapelle, 1966), it is assumed that the ground release avalanches are associated with a layer of depth hoar crystals. However, 'depth hoar layers cannot easily be associated to specific burial dates' (Haegeli and McClung, 2004). For these cases we assigned an arbitrary burial date of November 10th.

Box plots and other distribution independent statistics are used to make comparisons of ODS and Other avalanches. An "Other" avalanche is defined as a slab avalanche possessing both a snowpack weakness burial date and a recorded depth but is not a ODS avalanche.

Table 1: *Parameters distinguishing old deep slab (ODS) avalanches, the ratio of ODS and Other avalanche occurrences and the ratio of ODS and Other avalanche observations. C: Coast; NC: North Columbia; SC: South Columbia; R: Rocky.*

	Depth	Age	Ava. Ratio	Obs. Ratio
	80th %	80th %	ODS: Other	ODS: Other
C	80	23	13:163	3:53
N.C	85	20	296:2050	181:629
S.C	100	19	103:843	70:279
R	100	39*	13:97	4:35

* 70th percentile

3. DATA

The data used in this study are based on the information exchange (InfoEx) service of the CAA. The data were originally assembled by Gruber et al. (2004) and include the winter seasons of 1991/92 to 2001/2002. We present a short description of the data set and refer the reader to the original source for a more detailed description.

3.1. Data description

For their study of large scale snow instability patterns in western Canada, Gruber et al. (2004) devised a parsing code based on flex/bison technology. This enabled comprehensive text avalanche InfoEx records from the 1991/92 to 2001/2002 winter seasons to be structured into tables. Daily avalanche records generally include the number of avalanches, associated size, trigger, location, dimensions and weak layer/bed surface characteristics. Data have been separated

into four regions: Coast, North Columbia, South Columbia and Rocky. The resulting data set is comprehensive and covers 'vast spatial areas and a mix of snow and avalanche climates' (Gruber et al., 2004).

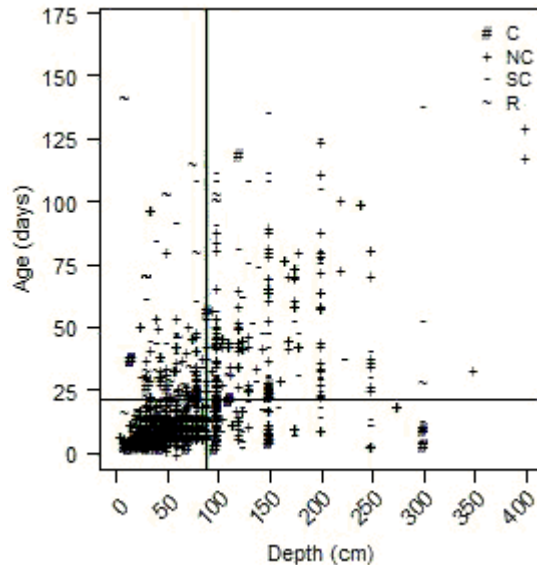


Figure 1: *Age vs. Depth for all avalanches. Vertical line plotted at the 80th percentile of depth calculated using all recorded avalanches. Horizontal line plotted at the 80th percentile of age calculated using all recorded avalanches. C: Coast; NC: North Columbia; SC: South Columbia; R: Rocky.*

Of the original 45 718 avalanche records, each of which may describe multiple avalanches, only records representing slab avalanches with either a snowpack weakness burial date or depth have been selected. The result is a data set of 4 606 avalanche records, representing 13 775 slab avalanches.

Using the selection process outlined in section 2 approximately 10% of avalanches from each region are defined as ODS avalanches (see Table 1). A scatter plot of age vs. depth is shown in Figure 1. For simplicity the 80th percentile for depth and age are calculated using data from all regions and plotted as vertical and horizontal lines respectively. The vast majority of the data reside in the bottom left quadrant and represent relatively shallow and young avalanches. The focus of this study is the top right quadrant, which is comprised of relatively deep slabs that have persisted for long periods of time before releasing.

3.2. Data quality

Several inherent shortfalls of an operational avalanche data set tend to skew the data.

Environmental factors such as poor visibility and large operational tenures prevent a complete data set (Gruber et al., 2004). Different operations have different goals and observational capabilities which lead to a bias in the data. Mechanized ski operations cover large areas, varied terrain, and deal with an undisturbed snowpack. A major concern is for skier-triggered avalanches while on descent. In contrast, highway operations generally focus on areas directly threatening the road (Haegeli and McClung, 2004). The frequent use of explosives for avalanche control often results in a disturbed snowpack. Finally, the operating season for many of the participating operations is between the months of December and late March or early April. The effect of this is poor early and late season data coverage.

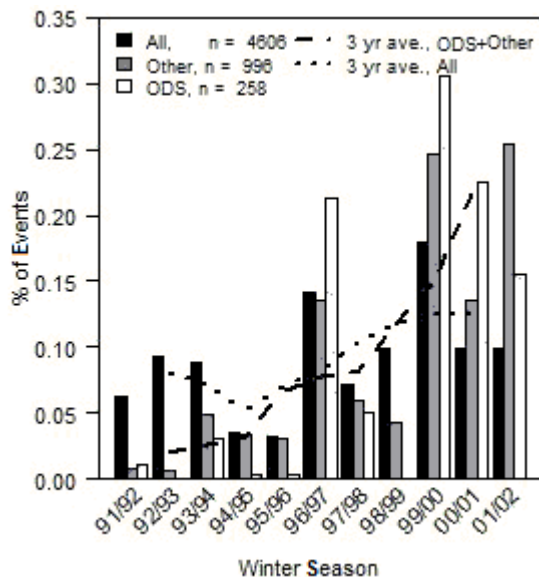


Figure 2: Distribution of avalanche observations by season. Black bars indicate all avalanches. Grey bars indicate Other avalanches and white bars indicate old deep slab (ODS) avalanches. The three year moving-average of all avalanches and ODS plus Other avalanches are plotted.

Seasonal trends in the data restrict seasonal comparisons. The relative frequencies of avalanche observations by season are shown in Figure 2. The 3 year moving-average of all avalanches increases. A steeper increase is seen in the 3 year moving-average of observations containing both a weak layer ID as well as a depth. These trends suggest an increase in quantity and quality of observations. This is likely due to the increased use and familiarity of the InfoEx service as it became established within the Canadian avalanche operations.

Table 2: Avalanche attribute characteristics: first quartile, median, third quartile and the number of recorded occurrences. Old deep slab (ODS) attributes are indicated by a "ods" and the Other attributes are indicated by a "o"

		1 st Quart	Median	3 rd Quart	n
Depth	ods	100	125	150	425
	(cm) o	33	50	73	3228
Age	ods	27	42	58	425
	(days) o	5	8	13	3228
Size	ods	2.0	2.5	3.0	412
	o	1.0	1.5	2.0	2957
Elev	ods	2000	2200	2400	360
	(m) o	1700	1900	2150	2451
Width	ods	70	150	300	331
	(m) o	20	45	100	2091
Length	ods	200	400	700	313
	(m) o	40	100	250	1806
Incl	ods	35	40	45	325
	(°) o	34	35	40	2067

Variations in the way in which avalanche information can be described in paragraph form resulted in the parsing code occasionally extracting incorrect data from the InfoEx reports. This was most often the case when more than one snowpack weakness was active at any given time. Obvious errors were corrected or eliminated. However, errors that were not obvious may be present.

4. RESULTS

The depth and age used to distinguish ODS avalanches from Other avalanches are found in Table 1. We also show the ratio of ODS to Other avalanche occurrences and observations. The North Columbia and South Columbia regions represent the vast majority of the observations and avalanches and it follows that the comparison of ODS and Other slab avalanches using this data set are likely to be more representative of the Columbia Mountains and not of the entire western Canada.

Several avalanche attributes are summarized in Table 2. For this preliminary study we did not perform statistical comparisons.

4.1. Slope angle

As seen in Table 2, ODS avalanches occur on steeper slopes when compared to Other slab

avalanches. However, overlap between the interquartile ranges and the assumption that most slope angle measurements in the data set are estimated not measured may indicate that the median shift is not significant.

4.2. Aspect

A comparison of the aspects for ODS and Other slab avalanches (not shown) reveals that two thirds of all avalanches from each group occurred on North through East aspects. The next most prominent aspect is South for both groups.

4.3. Size

The Canadian size classification system is used to estimate the destructive potential of avalanches (McClung and Schaerer, 2006). The size classes range from 1-5. A class 1 avalanche is common, small and generally harmless to people. Class 5 avalanches are rare and capable of destroying 40 ha of forest. The typical mass increases by a factor of 10 from one size class to the next. The sizes for ODS slab avalanches and Other slab avalanches are shown in Figure 3. A significant median shift can be seen from 1.5 for Other avalanches to 2.5 for ODS avalanches.

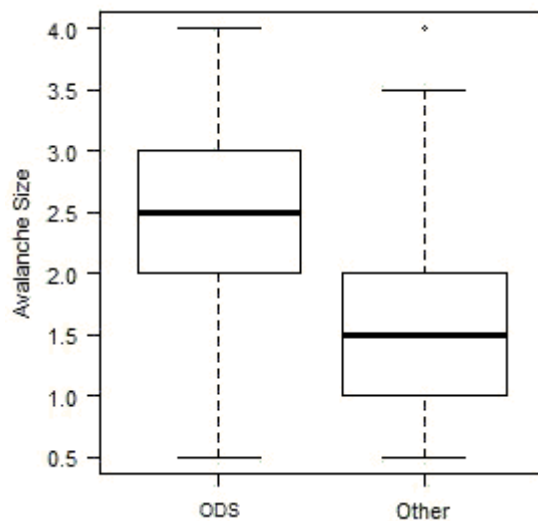


Figure 3: Avalanche size distribution for old deep slab (ODS) avalanches and Other avalanches.

4.4. Triggers

The distribution of triggers for ODS avalanches and Other avalanches is shown in Figure 4. Skier/snowboard triggering is the most common trigger for Other avalanches accounting for over 50% of the occurrences. For the ODS avalanches, natural and explosive triggered avalanches

account for the majority of avalanches and skier triggering accounts for less than 10%.

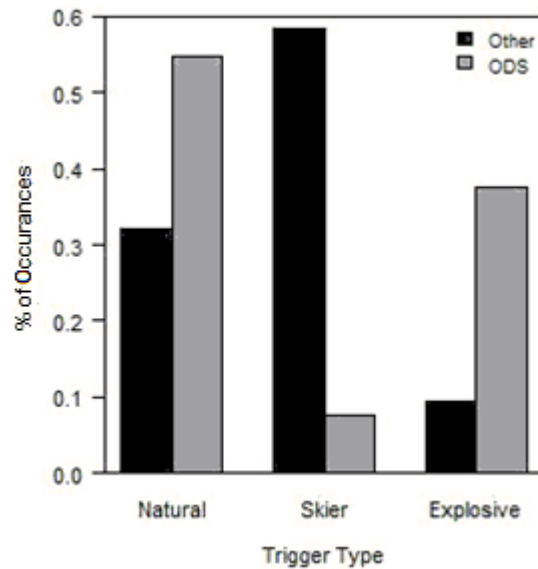


Figure 4: Distribution of avalanche triggers. Other: $n = 3050$, Old deep slab (ODS): $n = 340$.

4.5. Snowpack weakness types

The distribution of the reported snowpack weakness associated with avalanche occurrences is shown in Figure 5. Surface hoar is reported for over 70% of the Other slab avalanches and only about 10% of the ODS avalanches. Weaknesses most significant for ODS avalanches are faceted crystals and crusts representing about 80% of all reported snowpack weaknesses.

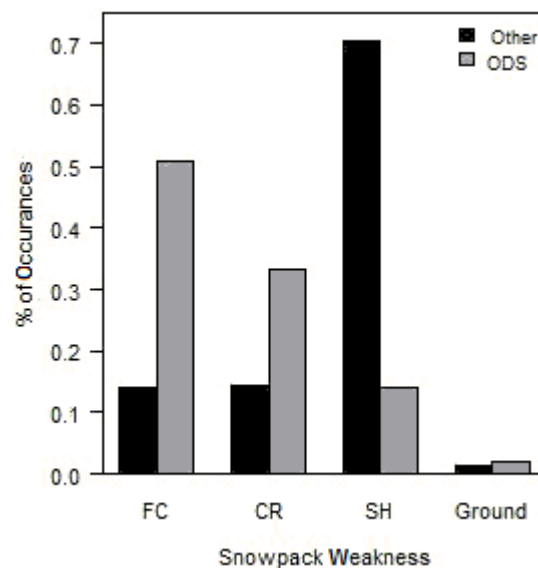


Figure 5: Distribution of Snowpack weaknesses. FC: faceted crystal, CR: crust, SH: surface hoar, Ground: ground. Other: $n = 2302$, Old deep slab (ODS): $n = 444$.

4.6. Temporal Distribution

The distribution of avalanche events by month is seen in Figure 6. ODS avalanches peak in January with a significant rise preceding it in December. Other avalanche events peak in January and February.

Avalanche occurrences by season are shown in Figure 7. The Other avalanches are seen to parallel the trends shown in Figure 2. Significant increases in ODS avalanches relative to Other avalanches are seen during the 1996/97 and 2000/01 winter seasons.

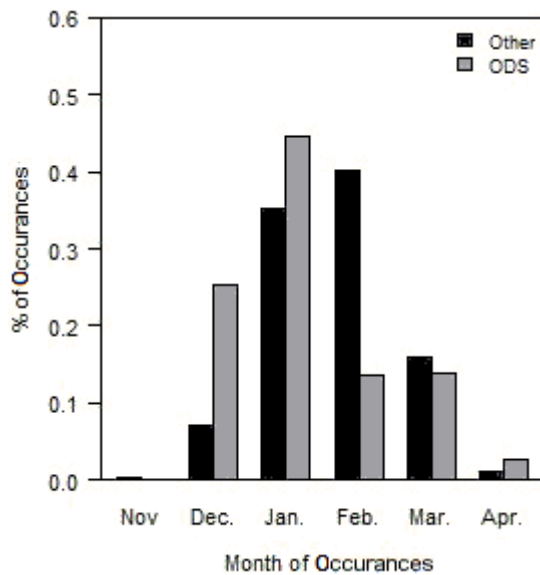


Figure 6: Distribution of avalanche Occurrence by month. Other: $n = 3228$, Old deep slab (ODS): $n = 425$.

5. DISCUSSION

A significant advantage of the ODS definition is the high level of agreement with previous deep slab studies in the selection of avalanche events. It is also a repeatable way of selecting many hard-to-forecast avalanches. Evidence of this can be seen in the spike of ODS avalanche activity during the 1996/97 winter season which coincides with the Jamieson et al. (2001) case study of deep slab avalanches in the Columbia Mountains. The increased ODS avalanche activity during the winter seasons of 1999/00 and 2000/01 relative to Other avalanches have at this time not been correlated to any specific events. Increased association of crust and faceted snowpack weaknesses seen with ODS avalanches is in agreement with Jamieson et al. (2001), Savage (2006) as well as Greene and Johnson (2002). Using 2-D finite element that a hard bed surface such as a crust increases shear stress within a

weak layer directly above. This could explain their increased representation for ODS avalanches.

The agreement with past studies may be due to the location of past studies being similar to the majority of data collected in this InfoEx data set. The Columbia Mountains, much like the Wasatch Mountains investigated by Greene and Johnson (2002) and Lone Mountain investigated by Savage (2006), are geographically located in intermountain or transitional zones (LaChapelle, 1966).

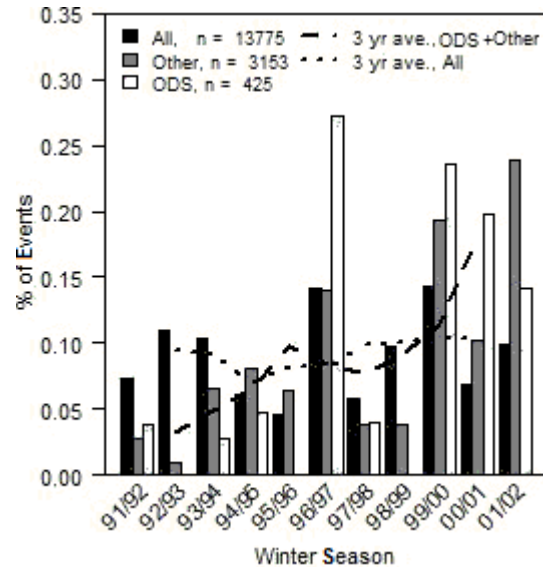


Figure 7: Distribution of avalanche Occurrences by season. Black bars indicate all avalanches. Grey bars indicate Other avalanches and white bars indicate old deep slab (ODS) avalanches. The three year moving-average of all avalanches and ODS plus Other avalanches are plotted.

5.1. Substantial differences

The most significant difference between ODS slabs and Other slabs is the difference in size (Figure 3). A class 2 avalanche is defined as being able to bury, kill or injure a person. Of the Other avalanches, 22% are classified as being larger than class 2 avalanches while 68% of the ODS avalanches are classified as being larger class 2. This increase in size is likely related to the increase of width and length (Table 2).

5.2. Regional differences

Although some characteristics of ODS avalanches such as an increase in size and slab width will be consistent throughout the regions, potentially important differences such as the associated snowpack weakness may not be. LaChapelle (1966) discusses experience in forecasting avalanches in various snow and avalanche

climates and states each region has different snowpack and meteorological characteristics that need to be addressed differently. Haegeli and McClung (2007) support the theory that regional variations in snowpack characteristics exist between regions. These regional differences in forecasting common avalanches may translate to differences in forecasting methods for ODS avalanches. The current data set cannot be used to investigate this hypothesis due to limited data from the Rocky and Coast regions.

5.3. *The forecasting challenge*

Heuristic skills used by forecasters work well in most situations. However, when confronted with rare avalanches such as ODS avalanches they may not work as well. It is known that when the complexity and consequences of decisions are increased, as is the case when forecasting for such rare events, gut feelings can be far less effective (Spiegelhalter, 2010). Decision support tools trained on or developed for such rare events may aid in forecasting for ODS avalanches.

6. SUMMARY AND OUTLOOK

To extract many hard-to-forecast avalanches from a database of avalanches in western Canada we selected slab avalanches that were both deep (70–80th percentile) and old (80th percentile). Our data did not reveal a difference in slope angle or aspect between the deep-old-slab avalanches (ODS) and Other avalanches. However, compared to Other avalanches ODS avalanches were typically of greater size, involved less human triggering, released more often on crusts and weak layers of facets and tended to occur more often in early winter.

Future studies investigating potential predictors for ODS avalanches would be aided by the inclusion of more data to fill gaps in the Coast and Rocky regions. This can be accomplished by analysing the more recent years (2004–2010) of the InfoEx data. With a larger dataset, we hope to analyze the characteristics of human-triggered ODS avalanches. Further, we intend to conduct field measurements of ODS avalanches.

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