A RECIPE FOR WIDESPREAD PERSISTENT DEEP SLAB AVALANCHE CHARACTERISTICS IN WESTERN CANADA

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ABSTRACT: Of the 29 avalanche fatalities during the avalanche season of 2002-03 in western Canada, at least 14 were attributed to persistent deep slab avalanches, including one seven-fatality incident. The next highest number of avalanche fatalities this decade in western Canada was during the avalanche season of 2008-09 with at least 17 of the 25 fatalities attributed to persistent deep slab avalanches. Analysis of the commonalities between these two avalanche seasons showed that rain on a shallow early season snowpack followed by a long period of clear and cold weather set the stage for a deep slab avalanche problem. Similar early season weather occurred during the avalanche seasons of 2001-02 and 2009-10, yet a widespread persistent weak layer did not develop.

This paper presents a retrospective of the past ten avalanche seasons in western Canada. Weather, snowpack, and avalanche occurrence data are used to test the hypothesis that given weather conditions favourable for early season hard crusts with associated facets, persistent deep slab avalanche characteristics depend strongly on early season snowpack depths. It was found that below average early season snowpack depths is one of the major factors contributing to widespread persistent deep slab avalanche characteristics. Furthermore, below average and variable seasonal snowpack depths, weak re-loaded bed surfaces, and favourable snowpack stratification for step-down fractures seemed to contribute to the persistence. By identifying early season patterns leading to the development of widespread persistent deep slab avalanche characteristics, this paper will aid in forecasting such avalanche seasons by providing a recipe using early season ingredients.

1. WESTERN CANADA AVALANCHE WINTER REGIMES

According to Haegeli (2004) the maritime avalanche winter regime in the South Coast Mtns (figure 1) is characterized by a low number of persistent weak layers. Basal facet layers are not uncommon in the interior ranges of the South Coast Mtns, especially in shallow windswept areas. Although, relatively warm temperatures associated with mild air from the Pacific Ocean tends to prevent them from persisting.

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The transitional Columbia Mtn (figure 1) regime typically involves one or two facet-crust combination weaknesses, generally near the base of the snowpack, and several surface hoar layers every season.

In the continental Rocky Mtns (figure 1) basal weak layers and deep slab avalanche characteristics are common. Therefore, this study considers *persistent deep slab avalanche characteristics* to be *widespread throughout western Canada* if a basal weak layer remains active throughout the avalanche season in the South Coast Mtns.

Figure 1: Image of western Canada showing the South Coast, Columbia, and Rocky Mtns. Blowdown Mid and Mt Fidelity weather stations are also shown.

2. AVERAGE EARLY SEASON SNOWPACK DEPTHS

The average early season snowpack depths were compiled using a selection of tree-line and alpine weather stations in the Coast and Columbia Mtns. Data from the closest date between November 30^{th} & December 3^{rd} were used as an approximate of early season snowpack depth. The available values were taken from the 12 am observation on the day with the most data for each year. For the South Coast Mtns, the average snowpack depths were obtained using the British Columbia Ministry of Transportation and Infrastructure's (MoTI) Blowdown Mid (figure 1) and Little Bear automatic weather stations (RWIS), Whistler Mountain's Pig Alley weather plot, and the Solar, Catskinner, and Horstman Hut automatic weather stations on Blackcomb Mountain. For the Columbia Mtns, Parks Canada's Roger's Pass and Mt Fidelity (figure 1) weather plots, the MoTI Kootenay Pass RWIS, and Mike Wiegele Helicopter Skiing's Mt. St. Anne weather plot were used.

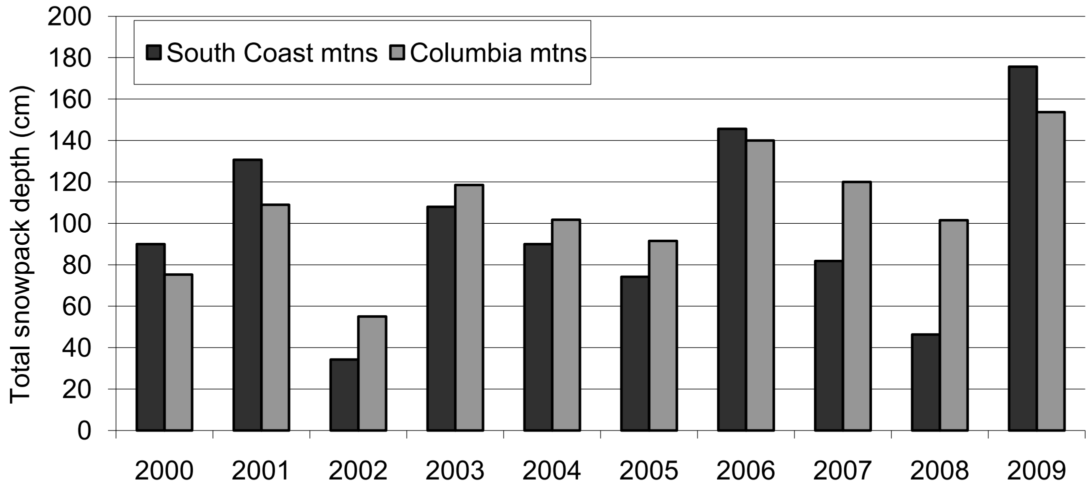

Figure 2: Average early season snowpack depths in the South Coast and Columbia Mtns for the past ten years. The ten-year average for the South Coast Mtns is 98 cm, and 107 cm for the Columbia Mtns.

3. EARLY SEASON ARCTIC OUTBREAKS

Arctic outbreaks occur when dry frigid air that has been deepening north of the Arctic Circle spills south into lower latitudes. The blast of cold air causes temperatures to plummet and the lack of humidity creates clear skies. In western Canada, these cold clear conditions are brought on by ridges of high pressure over the Yukon or northern BC. Arctic outbreaks typically last multiple days and some can persist up to several weeks.

To identify past early season arctic outbreaks, daily minimum and maximum air temperatures as well as snowpack depths were plotted from November 1st to December 31st for each of the past ten years. Blowdown Mid, a treeline automated weather station from the MoTI RWIS network located at 1890 m near Pemberton, British Columbia (figure 1), was deemed an ideal location representative of both the maritime and transitional avalanche winter regimes. Arctic outbreaks were identified by prolonged periods of well below normal temperatures with little to no precipitation. Corresponding surface analyses from the Pacific Storm Prediction Center were verified to confirm the presence of an arctic ridge of high pressure.

Table 1: Early season arctic outbreaks (AO) in western Canada.

Year	Date	Comments
2000	Dec 10-15	Classic AO with light precip during last days.
2001	Dec 20-27	Relatively weak AO although very dry.
2002	Nov 24-30	Not extremely cold but dry throughout.
2003	Nov 20-23	Relatively short AO
2004	Nov 27- Dec 1	Not a true AO, more of a weak cold ridge with small precip amounts
2005	Nov 26- Dec 3	Strong outbreak with short interruption on 29th
2006	Nov 26-Dec 3	Deep AO with very cold temps.
2007	Nov 20-25	Not a true AO, more a cold ridge
2008	Dec 13-21	Perfect example of classic AO
2009	Dec 3-14	Long AO

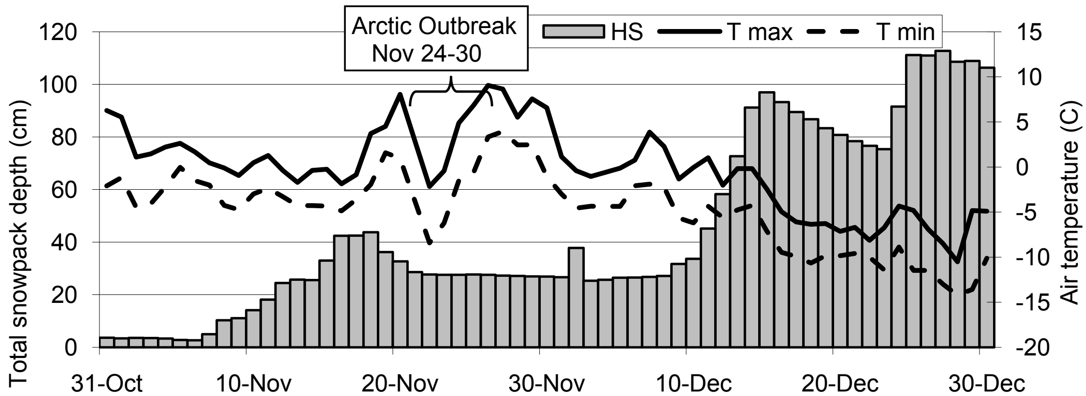

Figure 3: Daily time series of early season 2002-03 total snowpack depth (HS), and minimum (T min) and maximum (T max) air temperature for Blowdown Mid automatic weather station located at 1890 m in the South Coast Mtns near Pemberton.

4. WEATHER, SNOWPACK AND AVALANCHE RETROSPECTIVES

4.1 2000-01

The South Coast Mtns (90 cm) had a slightly below average early season snowpack depth, while the Columbia Mtns (75 cm) were well below average (figure 1). A six-day arctic outbreak occurred mid-December (table 1).

Data from the Canadian Avalanche Association's (CAA) daily avalanche industry information exchange (InfoEx) suggest that a basal facet and depth hoar weak layer formed in the South Coast Mtns. Associated avalanche activity persisted until mid-to-late January, when warm temperatures, rain, and weak temperature gradients resulted in bridging, rounding, and sintering of the basal snowpack.

4.2 2001-02

The South Coast Mtns (131 cm) had a well above average early season snowpack depth, while the Columbia Mtns (109 cm) were about average (figure 1). An eight-day arctic outbreak occurred late-December (table 1).

According to the CAA InfoEx, a significant mid-November rain event followed by a period of below average air temperatures resulted in a facet-crust weak layer that persisted throughout the season across much of western Canada. The pattern of the avalanche activity shows the weak layer to be most persistent in the Rocky Mtns, and limited to the central ranges of the Columbia Mtns. Related avalanche activity was largely absent in the South Coast Mtns (Haegeli, 2004).

4.3 2002-03

Both the South Coast (34 cm) and Columbia Mtns (55 cm) had a well below average early season snowpack depth (figure 1). Multiple rain on snow events occurred before a late-November seven-day arctic outbreak (table 1), which was followed by continued clear, dry, and calm weather in early-December (figure 3).

Data from the CAA InfoEx suggest that the early season rain events followed by clear and cold weather resulted in a combination of several persistent weak layers at the base of the snowpack that was widespread across western Canada. Associated avalanches remained active throughout the avalanche season. Additional persistent weak layers distributed throughout the snowpack created a stratigraphy prone to step-down avalanches (figure 4). Weak reloaded bed surfaces, as well as below average seasonal snowpack depths, also contributed to the persistence. The propensity for remotely triggered avalanches made this deep instability especially dangerous.

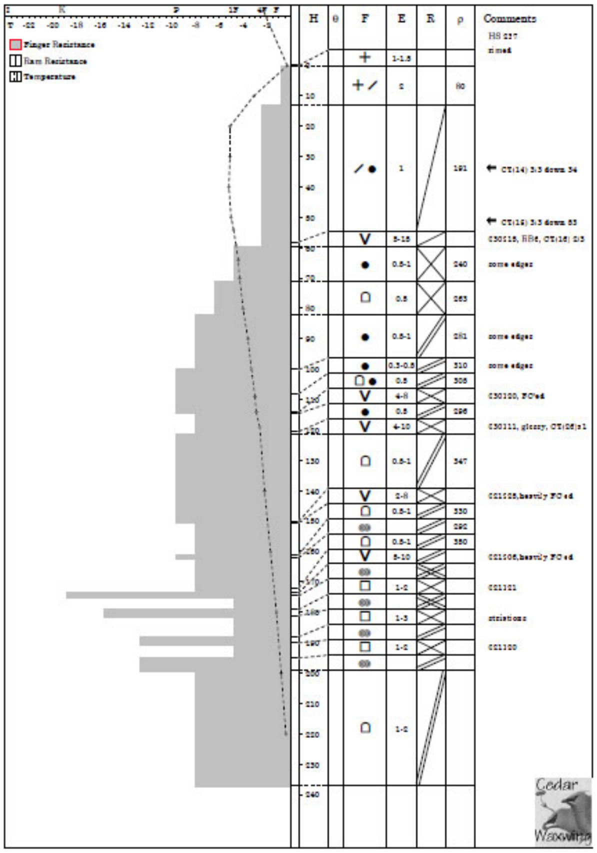

Figure 4: Snow profile from a treeline study plot on Mt Fidelity in the Columbia Mtns observed on 02 March 2003. (Profile: University of Calgary - Applied Snow and Avalanche Research).

4.4 *2003-04*

Both the South Coast (108 cm) and Columbia Mtns (119 cm) had slightly above average early season snowpack depths (figure 1). A relatively short arctic outbreak occurred near the end of November (table 1).

According to the CAA InfoEx, no basal facets formed in the South Coast Mtns. Some areas in the Columbia Mtns reported basal facets at higher elevations, but associated avalanche activity was sporadic throughout the season.

4.5 *2004-05*

Both the South Coast (90 cm) and Columbia Mtns (102 cm) had near average early season snowpack depths (figure 1). A short cold period occurred at the end of November (table 1).

Data from the CAA InfoEx suggest no basal facets formed in the South Coast Mtns. Some areas in the Columbia Mtns reported basal crusts with associated facets and mixed forms at higher elevations, but associated avalanche activity was limited to early season direct action events.

4.6 *2005-06*

Both the South Coast (74 cm) and Columbia Mtns (92 cm) had below average early season snowpack depths (figure 1). An eight-day arctic outbreak occurred during the end of November and into beginning of December (table 1).

According to the CAA InfoEx, no basal facets formed in the South Coast. Basal crusts with associated facets were observed in the Columbia Mtns, but quickly gained strength.

4.7 *2006-07*

Both the South Coast (146 cm) and Columbia Mtns (140 cm) had well above average early season snowpack depths (figure 1). A deep eight-day arctic outbreak occurred at the end of November (table 1).

Data from the CAA InfoEx suggest, both the South Coast and Columbia Mtns had a well-settled and strong early season snowpack with various thick crusts that formed in October and November.

4.8 *2007-08*

The South Coast Mtns (82 cm) had a below average early season snowpack depth, while the Columbia Mtns (120 cm) were above average (figure 1). A short cold period occurred near the end of November (table 1).

According to the CAA InfoEx, basal crusts and mixed forms produced early season avalanches in the South Coast Mtns, but quickly strengthened. However, associated surface hoar at lower elevations in the Columbia Mtns contributed to increased avalanche activity, and stronger temperature gradients allowed associated avalanche activity to persist until late-December.

4.9 2008-09

The South Coast Mtns (46 cm) had a well below average early season snowpack depth, while the Columbia Mtns (102 cm) were about average (figure 1). A mid-December eight-day cold and dry period (figure 5) was the best example of a true arctic outbreak in the past ten years (table 1).

Data from the CAA InfoEx suggest that the snowpack was fundamentally structurally weak throughout western Canada. This was primarily due to a widespread basal facet-crust weak layer with weak reloaded bed-surfaces contributing to the persistence. The characteristics of the associated persistent deep slab avalanche activity were most atypical for the South Coast Mtns, and more typical of a continental avalanche winter regime.

After investigating two separate avalanche fatalities on consecutive days near Whistler, Avalanche Consultant, Chris Stethem concluded that "We are dealing with a continental snowpack more common in the Rockies. This deep seated instability hasn't been seen to this degree in the South Coast region since the late 70s" (Whistler-Blackcomb press release, 2009). Mountain conditions reports (MCR) from experienced South Coast ski guides included statements such as: "Extremely unusual conditions….. Our guiding team has not seen such dangerous conditions in this area before…." (David Lussier, Association of Canadian Mountain Guides MCR, 31 Dec 2008).

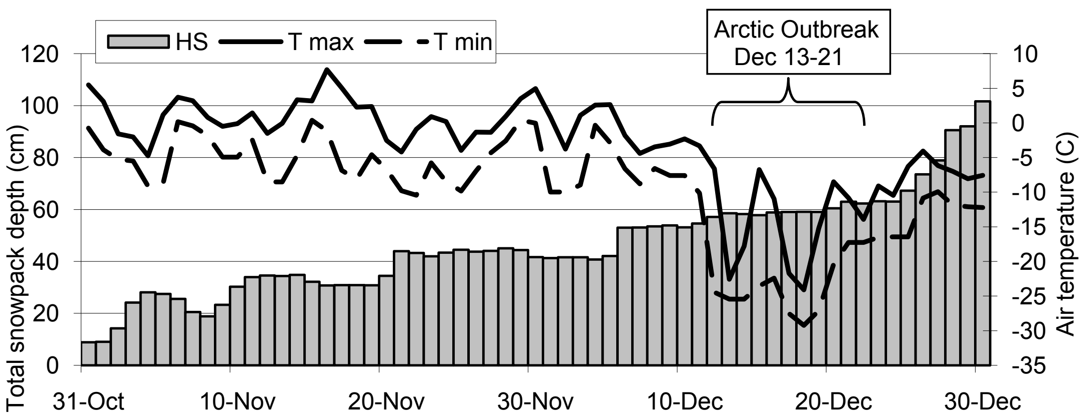

Figure 5 – Daily time series of early season 2008-09 total snowpack depth (HS), and minimum (T min) and maximum (T max) air temperature for Blowdown Mid automatic weather station located at 1890 m in the South Coast Mtns near Pemberton.

4.10 2009-10

Early season snowpack depths in both the South Coast (176 cm) and Columbia Mtns (154 cm) were well above average. A late-November rain-on-snow event was followed by a long twelve-day arctic outbreak in early December (table 1).

According to the CAA InfoEx, the both South Coast and the Columbia Mtns had an early season facet-crust weak layer that resulted in a large mid-December avalanche cycle, but associated avalanche activity didn't persist.

5. DISCUSSION AND CONCLUSIONS

Based on the results presented in this paper, a reasonable recipe for widespread persistent deep slab avalanche characteristics in western Canada starts with below average early season snowpack depths. It is hypothesized that a sufficiently shallow early season snowpack is required to maintain a temperature gradient favouring faceting. However, the early season snowpack must also be sufficiently deep to overcome ground cover and create a uniform bed surface.

Patterns associated with widespread persistent deep slab avalanche characteristics include hard crusts on or near the snow surface, before a prolonged period of clear and cold weather. The duration and magnitude of which must be sufficient for advanced faceting, given the snowpack depth. Surface hoar formation during this period can contribute to the strength and persistence of the subsequent basal weakness.

Below average and variable seasonal snowpack depths, weak re-loaded bed surfaces, and favourable mid- and upper-snowpack stratification for step-down fractures can contribute to the persistence of deep slab avalanche characteristics.

Further studies could analyze more data using statistical methods to determine significance of the contributing factors identified in this paper.

6. REFERENCES

Haegeli, P. (2004). Scale analysis of avalanche activity on persistent snowpack weaknesses with respect to large-scale backcountry avalanche forecasting. PhD Thesis, University of British Columbia. 254pp.