Meteorological and Environmental Observations from Three Glide Avalanche Cycles and the Resulting Hazard Management Technique

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ABSTRACT:

Glide avalanches are a significant hazard that threatens people and property in many snowy climates. They are hard to control, poorly understood, and extremely challenging to forecast. This paper presents meteorological and environmental data associated with three glide avalanche cycles. It also discusses hazard reduction techniques from an operational perspective and provides possible explanations why previous attempts to artificially trigger glide avalanches rarely succeed. During Southeast Alaska's winter of 09/10, we witnessed three glide avalanche cycles with over 35 total avalanches. During those cycles we collected data on snowpack, precipitation, temperature, relative humidity, sky coverage and streamflow, as well as slope aspect, elevation, steepness, shape and ground cover. We also recorded visual snow surface observations leading to the transition of some of the glide cracks to avalanches. Although glide avalanche activity is clearly somehow related to atmospheric events, we found no direct correlation between meteorological data and avalanche occurrences. However, we did find a rough correlation between snowpack, terrain and avalanche time distribution in two out of the three cycles. Our lack of reliable forecasting and control tools for glide avalanches implies that limiting the potential destructive size of glide avalanches throughout the entire winter may be the most effective approach to managing the hazard for some operations.

1. INTRODUCTION:

Glide avalanches present a serious challenge to avalanche programs protecting roads, towns and other operations. They can be very destructive as they often mobilize large volumes of snow. They are hard to forecast and difficult to artificially trigger. Glide avalanches result in the entire snowpack sliding on the ground. McClung and Schaerer (1993) loosely characterize glide avalanches as wet slides. However we also know of glide avalanches where the snowpack consisted almost entirely of dry snow. Glide avalanches tend to start in specific start zones within a mountain range and their location is highly dependent on topography (Lackinger, 1987). Active glide avalanche paths can sometimes produce more than one avalanche in a winter.

McClung et al. (1994) concluded that the effects of water on partial separation of the snowpack from the ground interface and infilling of irregularities in the ground has a greater effect on glide velocity than varying snow properties. So, although weather events and snowpack may influence the snowpack/ground interface, there is no direct correlation between weather events and glide avalanche activity, thus making glide avalanche forecasting a challenge (Jones, 2000).

Past research suggests some correlation between glide rate and climatic conditions. der Gand and Zupanièiè (1966) hypothesized that there is critical gliding rate that when exceeded, results in glide avalanche release. However, McClung et al. (1994) and Clarke and McClung (1999) find no clear relationship between glide rate and glide avalanche release. They reported that glide avalanche release may best correlate with periods of increased glide acceleration, rather than increased glide rates. Stimberis and Rubin (2009) observed a glide avalanche within 30 minutes of a dramatic increase in glide rates. Thus, though measurements of glide rates show some promise for predicting glide avalanches, such measurements are currently costly, largely unreliable, and extremely difficult to conduct in multiple paths. There are some new techniques being developed (Hendrikx et al, 2010), but until such tools are shown to reliably measure glide rates in a variety of conditions and until the relationship between glide rates and avalanching has been definitively established, reliably forecasting glide avalanches will remain extremely challenging.

To our knowledge, little research has been conducted on artificial control methods for glide avalanches. They are hard to artificially trigger and as such present a challenge for avalanche control programs (Sharaf, 2008).

In this paper we report on our observation from winter of 2009/2010 where three glide avalanche cycles with over 35

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avalanches occurred in Johnson Stream drainage at the base of Lions head Mountain in the Coastal Range of Southeast Alaska.

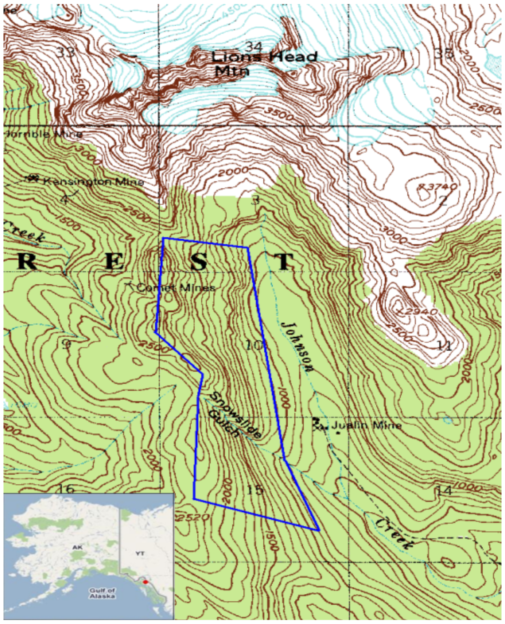

Figure 1: Our study area is located in southeast Alaska, USA. The studied slopes are inside the blue polygon.

2. STUDY AREA AND DATA:

Study area:

Our study area in Johnson Creek Basin is situated 43 miles north of Juneau, Alaska (Figure 1). The majority of the glide avalanches in Johnson Creek were on an easterly facing slope. Start zone elevations range from 300m to 800m above sea level, while slope angles are between 45° and 55°. Although many slopes in the area are steep enough for glide avalanches, and we observed glide crack development on many of them throughout the winter, glide avalanches occurred on only 18 slopes. The ground cover in 16 of the 18 start zones we studied are covered with Sitka Alder shrubs (Alnus viridis subsp. sinuata) up to four m tall (Figure 2). In winter, the Sitka Alders in the study area tend to bend under the snowpack. The remaining two start zones are underlain by rock slabs.

Weather Data:

We collected data from three different weather stations: One from the valley floor (256m above sea level), one at the top of our lower start zones (730m) and one on the ridge top (800m). Weather data included temperature, precipitation (times and amounts), wind speed and direction, snow depth, relative humidity, and barometric pressure. We don't have reliable weather data from around or near the study area from past years. To obtain historical perspective, we compared this winter data in NOAA office in Juneau and Haines airport (about 70 km north and south of the study area) with the data in those locations from the previous 10 years.

Figure 2: A summer photo of one of the slopes we studied. This slope is covered with Sitka Alder shrubs up to four m tall, the same underlying vegetation on 16 of the 18 slopes we observed glide avalanches.

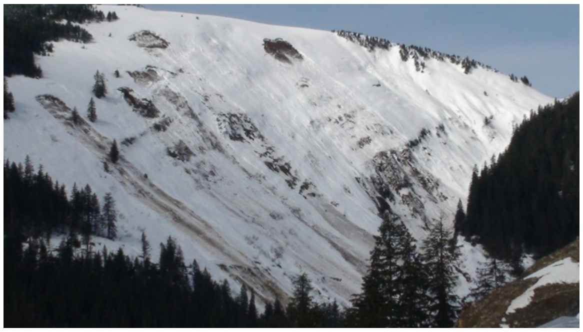

Figure 3: The same slope as in Figure 2 with glide avalanche activity. Photo was taken on 1 April 2010.

Snowpack.

During the winter of 2009 /2010 we regularly collected snowpack observations from the start zones in our study area, including data pits, hasty pits, crown walls and inside glide cracks. Our pit data included all the typical snowpit observations following the techniques described by Greene et al. (2009).

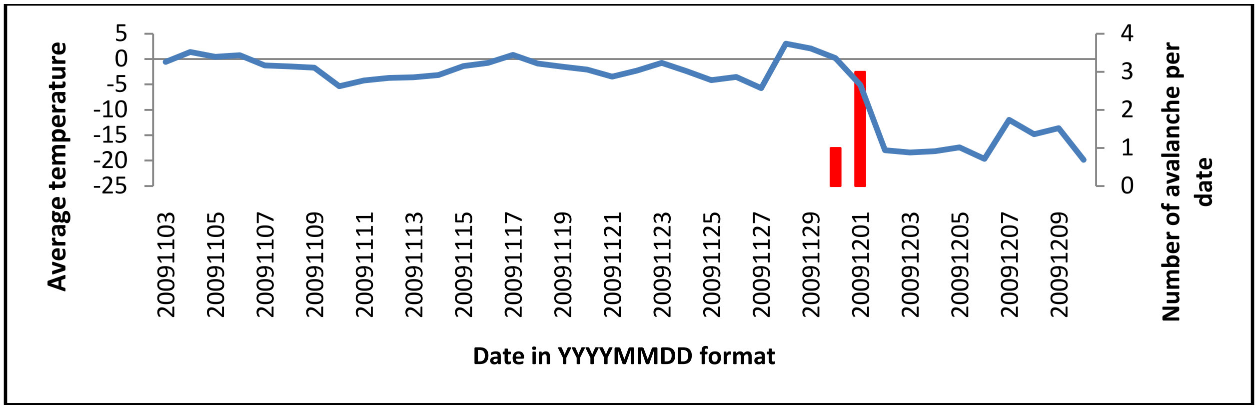

Figure 4: Twenty-four hour average temperatures and avalanche occurrences during November and December 2009. Temperature (in blue) is on the left axis and avalanche occurrences (in red) are on the right axis.

Obvious signs.

We recorded the time and place of obvious visual signs indicating increased creep rates. These signs included glide cracks, gaps in the snow cover, below trees and rock bands, and avalanche observations. In addition, we recorded any unusual or fast changing surface shapes like glide ripples development down slope of glide cracks within a few hours.

Streamflow.

During the winter of 2009 / 2010 we monitored the flow in Johnson creek. Johnson creek flows directly under our study slopes and we hoped to associate changing trends in streamflow with glide avalanche activity.

3. RESULTS AND DISCUSSION:

The November/ December cycle:

Our first glide avalanche cycle took place on 30 November and 1 December 2009. We had two avalanches on the first day and three avalanches on the second day. The largest avalanche of this cycle was an R2/D3 avalanche that took place on 30 November, 2009.

Looking at the weather associated with this cycle, the first half of November 2009 was warmer than average in both NOAA office in Juneau and Haines airport (NOAA database). The warm temperatures likely kept the ground from freezing before the first big snowfall of the season, which occurred on 7 November 2009 setting the stage for a relatively warm ground – snowpack interface. The warm early November was followed by a cooling trend into well below average temperatures during the second half of the month and leading into the avalanche cycle (Figure 4). Average temperatures were below freezing until a few days before the avalanches, when they increased up to about +2° C. At the time of the avalanche cycle, temperatures were below freezing and falling. Unfortunately, we do not have definitive snowfall or rainfall data for the period leading up to this avalanche cycle.

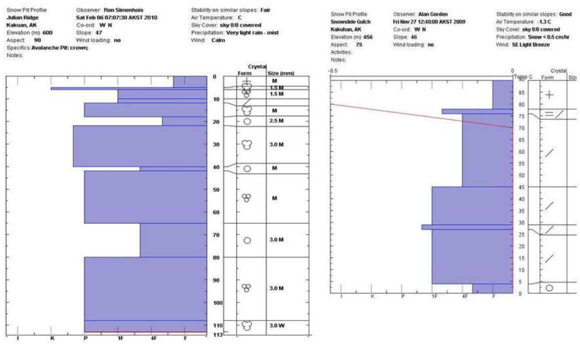

Figure 5: Side-by-side pit charts from the November/December (right) and the January/ February event (left). The snowpack in the study area was consisted almost entirely of decomposed fragments (DF) and during the January/ February cycle almost entirely of melt forms (MF).

The snowpack leading to the late November differed significantly from the snowpack associated with the latter two cycles (Figure 5). Contrary to what is usually expected for glide avalanches, this snowpack consisted of mostly dry snow of decomposed fragments with a warm snow – ground interface where the snow was wet. Since our snow was generally dry, we do not think the basal layer of wet snow was due to either surface melting or rain. Our only explanation for this layer is that the early season snow fell on such warm ground that a small amount of basal melting occurred, resulting in this wet snow layer. Interestingly, we did not observe any glide cracks or other signs of gliding before the first avalanche of the cycle.

Streamflow data from Johnson Creek shows flow increasing by 61% immediately following the last avalanche day. We cannot explain this short spike in the streamflow as we did not observe surface melting or rain during this time period. After that, streamflow declined sharply in the next two days (by 44%) and kept declining for the next two weeks (Figure 6).

January / February cycle:

The second avalanche cycle of the season took place from 28 January through 7 February 2010. We had avalanches on six of those 11 days, with the most avalanches (four) occurring on 6 February. The largest avalanche of this cycle occurred on 29 January, and was classified as an R2/D3.

Above freezing temperatures with eight rain events before 21 January caused the snowpack to go through a melting process. This snow developed water channels to discharge free water and was relatively strong. Prior to this cycle, as in all the glide cracks we investigated throughout the winter, the bottom of the snowpack had no or minimal contact with the ground below. These observations are in line with late spring observations of other avalanche professionals (Glude 2010). Snow depth by late January varied between 0.5 and 2.5 m. Newer dry snow at the top of the snowpack, up to 0.3 m deep existed above elevations of 760 m. Avalanches in areas where the newer dry surface snow layer existed avalanched about five days later than areas without new snow layers. It is unclear whether the later avalanche activity at those locations was related to the new snow or to the higher elevations of those starting zones.

Glide cracks and other signs of increase gliding rate started to appear in early January. However, no new signs of gliding appeared and old signs stopped expanding about a week before the first avalanche, on 28 January. Thus, we did not observe any obvious visual signs that glide avalanching were imminent prior to these avalanches.

In contrast to the first cycle, after the first two avalanches of this cycle streamflow continued to decrease. A day after the second part of the cycle began (5 February) streamflow began to increase, and then it ultimately decreases after the cycle ends. We can see that there is some relationship between streamflow and glide avalanching, but that relationship does not always hold, as evidenced by the first two avalanches of this cycle. Further, when they occur, streamflow changes are typically after the onset of avalanching and therefore are not useful for forecasting purposes.

March / April cycle:

The third glide avalanche cycle of the season was also the most extensive. Taking place from 17 March through 16 April 2010, this cycle consisted of 18 avalanches occurring on 10 of the 31 days in this period (Figure 9). We observed three glide avalanches on two different days, and the largest avalanche of the cycle was an R2/D3 observed on 28 April 2010.

Temperatures for the first half of March were below freezing most of the time with twelve days of snow fall. The first avalanche in March occurred after two days with average temperatures above freezing. The cycle itself really started on 24, March with 12 avalanches in eight days. It started after a day of 0.4 m of snow (34 mm SWE) on 23 March and a day with 17mm of rain on 24 March. Average temperatures throughout the eight days were above freezing with a decreasing trend and three more snow days leading to the second phase of the cycle. Temperatures increased to around freezing at the beginning of the second phase and to about 3.5° C on the last day of the cycle on 16 April.

The snowpack during the cycle was similar to the February snowpack, i.e. melt forms with a dry surface layer at higher elevations. We also observed a similar trend as the previous cycle where areas with dry upper snowpack layers avalanched on average nine days after slopes in areas where the snowpack consisted of entirely melt forms.

Like the previous cycles, we did not see any new signs of gliding in the first half of March. In fact, the first clear sign of increased gliding was the 17 March avalanche. In two cases (on 29 March and 13 April) we saw “glide ripples” developing downslope of glide cracks on concave slopes (Figure 10). In the first case an avalanche occurred within six to 12 hours after the ripples started to form. The second case was less than ¼ of the size of the first case and avalanched three days after we noticed the initial development of the ripples. In both cases, the glides cracks above the “rippled” area developed weeks before the avalanches occurred.

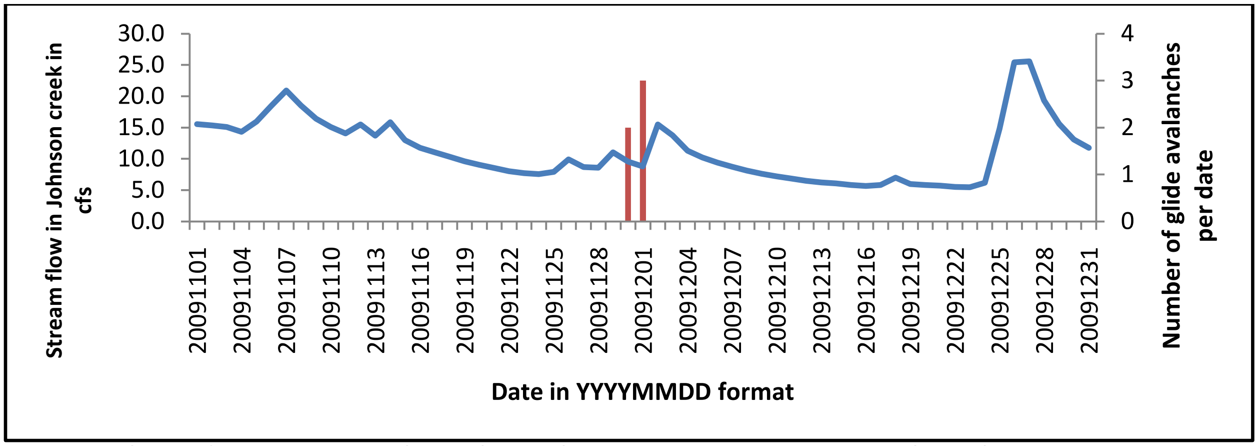

Figure 6: Streamflow in Johnson Creek (in blue) and avalanche occurrences (in red) during November and December 2009. Streamflow is in the left axis and avalanche occurrences are in the right axis.

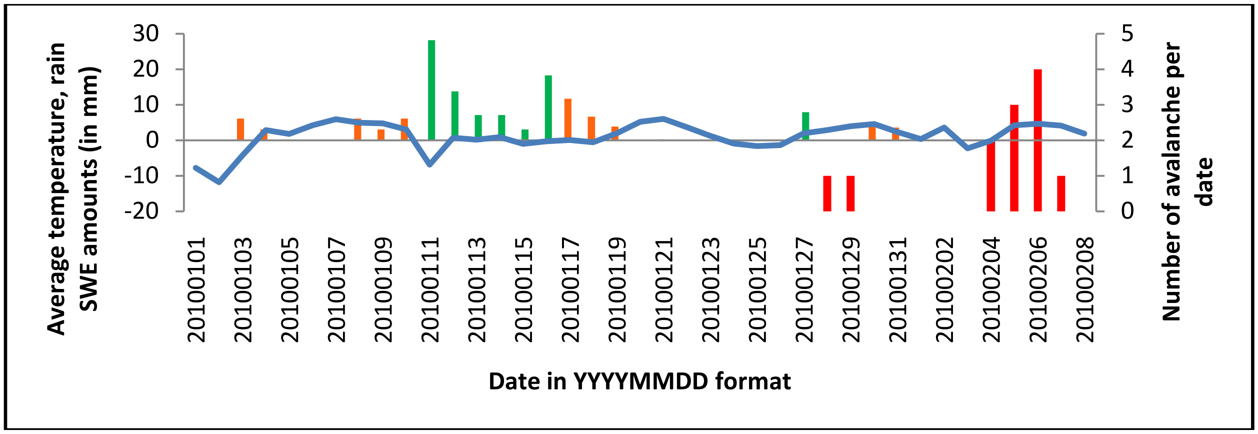

Figure 7: Twenty-four hour average temperatures (in blue), avalanche occurrences (in red), mm of rain (in orange) and mm of SWE (in green) during January and February 2010. Temperature, rain and SWE are in the left axis and avalanche occurrences are in the right axis.

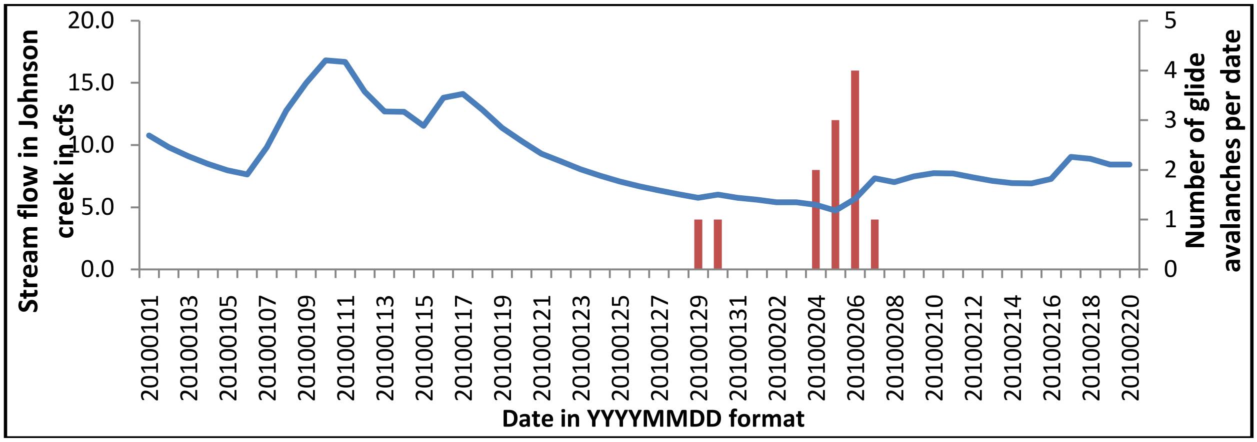

Figure 8: Streamflow in Johnson Creek (in blue) and avalanche occurrences (in red) during January and February 2010. Streamflow is in the left axis and avalanche occurrences are in the right axis.

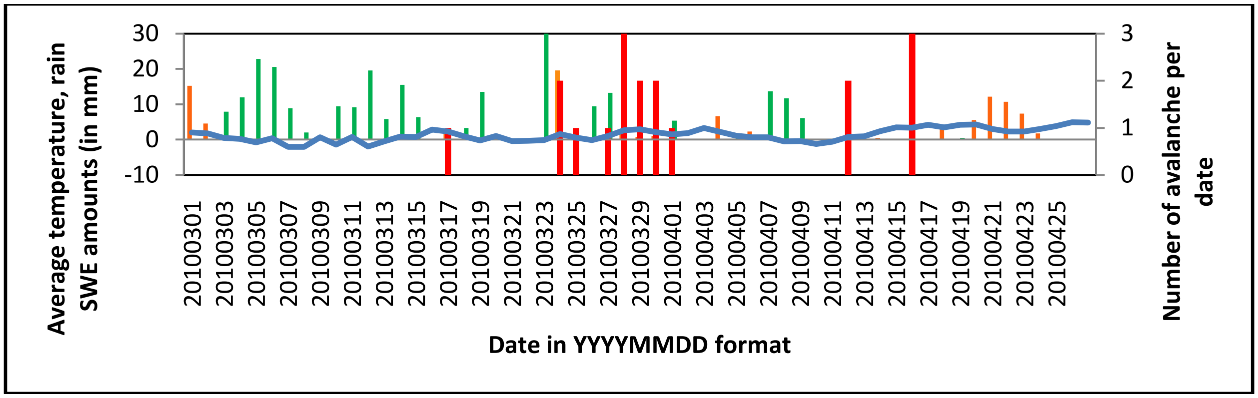

Figure 9: Twenty-four hour average temperatures (in blue), avalanche occurrences (in red), mm of rain, (in orange) and mm of SWE (in green) during March and April 2010. Temperature, rain and SWE are in the left axis and avalanche occurrences are in the right axis.

Figure 10: "glide ripples" under a glide crack at 13:10, 29 March 2010. This piece of snow avalanched at 16:45 on the same day.

Unfortunately, our streamflow data from March and April 2010 is incomplete; the data from 22 March to 8 April is missing due to technical failure. However our existing data shows an increase in streamflow of 244% in four days from the cycle's last avalanche day (16 April). This sharp increase is followed by three days of a sharp decrease (Figure 11). Thus, we again see a rough association between glide avalanches and streamflow, but since the streamflow increases in our case studies follow the avalanche activity, streamflow did not serve as a useful forecasting tool.

4. CONCLUSIONS:

Forecasting:

Our observations demonstrate the difficulty in forecasting glide avalanches. Despite data from three weather stations, regular snowpack observations, regular observations of glide activity (in the form of glide cracks and rippling), and streamflow data, it was not possible to definitively predict the onset of glide avalanche activity. Our experience is consistent with the experience of many other avalanche programs.

In terms of weather observations, our data suggests that any single weather event by itself is insufficient for glide avalanche forecasting. Avalanches were running after four days of sub freezing temperatures in late November – early December and in above freezing temperature in early December and in late March – early April. We also saw no clear relationship between precipitation and glide avalanche activity. We witnessed glide avalanches within a day after rain, snow or warm sunny days, which was more or less what we expected. However we also witnessed unexpected and surprising avalanche releases after prolonged periods of dry weather with sub freezing temperatures and short daylight. Still, there may be a direct correlation between weather events like prolonged periods of heavy rain and glide avalanches (see Stimberis and Rubin (2009) for an example). However, since this study only looks at three cycles in one winter, we don't have enough data for heavy rain-on-snow events in our dataset. Further, we found no direct correlation between glide avalanches and heavy snow fall. In general, precipitation by itself is not a reliable forecasting tool for glide avalanches. Out of 18 avalanche days during the January / February and March / April cycles five days (28%) had rain on the same day, four days (22%) had rain on the previous day and five days (28%) had no rain for five days or more. Out of these 18 days, eight days (44%) had snow on the same or the previous two days and on seven (39%) of the days there was no snow for five days or more. Further, the heaviest glide avalanche day of the season on 7 February (four avalanches) occurred after eight days of no rain and 12 days with no snow.

Snowpack structure varied greatly between mostly dry snow in the first cycle

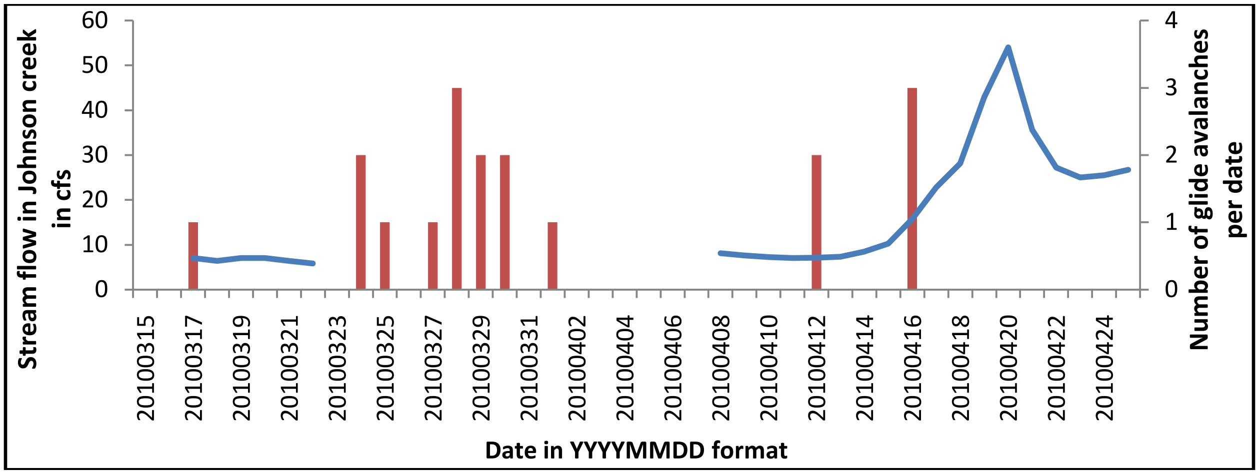

Figure 11: Streamflow in Johnson Creek (in blue) and avalanche occurrences (in red) during March and April 2010. Streamflow is in the left axis and avalanche occurrences are in the right axis.

and wet snow in the latter two cycles. However, in all three cycles we saw no persistent weak layers in the snowpack. Also in all three cycles, the bottom layer of the snowpack was wet. Another consistent observation throughout the winter was that, in all the glide cracks we investigated throughout the winter, the bottom of the snowpack had no or minimal contact with the ground below. These observations are in line with late spring observations of other avalanche professionals (Glude 2010). In both of the later cycles, there were areas with dry snow layer at the top of the snowpack, above the melt forms that comprised the rest of the snowpack. Our limited observations suggest that the new, dry snow layer at the top of the snowpack might have a delaying effect on glide avalanche activity or is an indication that the snowpack is not as close to glide avalanching as an isothermal snowpack. On our study slopes in both January / February and March / April cycles, slopes consisting of only melt forms avalanched an average of eight days earlier than similar slopes with snowpacks consisting of melt form and dry snow layers at the top. Still, we observed snowpacks similar to those that avalanched on other slopes that did not avalanche during all three cycles.

Glide avalanches are usually accompanied by cracks and other clear signs of increasing glide rate. However glide crack formation (or lack of glide crack formation) are not always a good indicator for glide avalanches. In fact, in all our avalanche cycles we observed avalanching *before* new glide cracks other fresh signs of increasing glide rate were observed. Further, in many cases we observed glide crack formation without any avalanche activity. Glide avalanches themselves are usually good indicators that the snowpack is approaching instability. But still in a few cases the snowpack on adjacent slopes remained stable for more than a week even though temperatures were above freezing for a week or more. Lackinger (1987) proposed that glide avalanches might be more likely during certain winters when gliding motion starts early in the season, especially in seasons with early and heavy snowfall. This is what we observed during the 2009/2010 winter in Johnson Creek.

Determining the end of a glide avalanche cycle within a short time frame is important from an operational perspective. For similar reasons that weather is not a good predictor for approaching avalanche activity, we also cannot use it to reliably determine the end of a cycle. Our data show no obvious trends in weather that suggests stabilizing snowpack. In some cases avalanches continued with cooling sub freezing temperatures and stopped even though temperatures were above freezing and in rainy weather. Finally, monitoring streamflow shows limited potential as an end-of-cycle forecasting tool, but more data are needed to determine its value.

We do have some limited observations from the previous four winters (Glude, 2010). Those observations suggest that this past year was an active one from the perspective of glide avalanching. We believe this is because warm temperatures prior to our first snowfall and large early season snowfall led to increased snowpack gliding, thereby setting the stage for an active glide avalanche season. Still, this only provides general guidance, and we found our glide avalanches (and especially dry snow glide avalanches) to be extremely difficult to forecast.

Avalanche control and hazard mitigation:

We typically mitigate avalanche danger through forecasting and active control work.

However, glide avalanches are quite difficult to forecast, and we also are not aware of cases where they have been successfully triggered with control work. Sharaf et al (2008) describe their attempts to reduce the glide avalanche risk in Snettisham, Alaska. They could not trigger glide avalanches by dropping 18 kg explosives, or pouring water into glide cracks, and we were equally unsuccessful in our efforts to trigger glide avalanches. A possible explanation might be our observation of minimal to no contact between the snowpack and the underlying ground. Hence, placing explosives or water into glide cracks may break some bonds in the snowpack, but the bonds that keep the snowpack from sliding remain intact. Although glide avalanches are difficult to control, there are some ways we can minimize the risk they pose. In some cases they can be dealt with using passive defense structures. A more active approach that we took is to try to identify slopes prone to glide avalanches and then minimize the avalanche size potential. Glide avalanches are usually confined to specific slopes (Lackinger 1987), so proactive avalanche control can be limited to the potentially glide avalanche producing slopes. Also, since small avalanches present less danger, maintaining a shallower snowpack can reduce the avalanche danger. Thus, our approach was to actively trigger as many small avalanches as possible throughout the season to keep the snowpack thinner and reduce the potential destructive force of glide avalanches that might occur on those slopes.

Many difficulties exist with forecasting and mitigating glide avalanches. However, we hope that our observations, combined with the observations and work of others (Stimberis and Rubin, 2009; Peitzsch et al, 2010; Hendrikx et al, 2010) can help improve our practical knowledge of glide avalanching and techniques we can use to better deal with them operationally.

5. ACKNOWLEDGMENTS:

Discussions with Brian Davies from Eagle Crest ski patrol, Don Sharaf from American Avalanche Institute and Bill Glude from Alaska Avalanche Specialists contributed greatly to this paper. Also, many thanks to Tom Ainsworth from NOAA's NWS Forecast Office Juneau, AK for helping with historical weather data. Alan Gordon was very instrumental in collecting snowpack data. Clifton Miller provided the streamflow data for this study. We would also like to thank Coeur Alaska for their support and mostly to Ron's wife Jenny for her support and for letting him take the time to work on this paper.

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