RAPID ASSESSMENT OF A LARGE-MAGNITUDE SNOW AVALANCHE EVENT IN COLORADO

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ABSTRACT: The winter of 2010-2011 set records for snowfall and snowpack depth for many mountain areas in Colorado. Large, destructive avalanches were reported from locations across the state. On April 29, 2011, an impressive slide damaged high voltage power lines along Peru Creek, near Montezuma, CO. The avalanche destroyed a power line tower that had been in place since the 1970s, and deposited massive piles of snow, rocks, and woody debris in the runout zone. The slide created fresh trimlines, widening the existing avalanche path by uprooting, stripping, and breaking trees. The disturbance event left behind many mature downed trees and extensive areas of vegetation damage, providing a unique opportunity to improve our knowledge of local avalanche frequency and magnitude. Initially, we gathered historical records of avalanche incidents and observations, and used repeat photography to track changes in the avalanche path vegetation over time. Next, we used field measurements to survey the vegetation damage, assess relative tree ages, and estimate maximum runout distances. We collected discs and cores from downed trees to detect past avalanche impacts recorded in woody plant tissue. Initial cross section samples from the downed trees avalanche signals included direct impact scars and development of reaction wood in response to tilting. To provide insight on the avalanche dynamics, we used terrain features and local snowpack observations as inputs in a one-dimensional model to estimate the avalanche velocity, height of flowing snow, impact pressures, and mass of the debris. For Colorado, and perhaps elsewhere, we conclude that several vegetation ecology approaches can be used to characterize local avalanche frequency and magnitude.

KEYWORDS:
Large-magnitude avalanche, avalanche path vegetation, tree-ring analyses, disturbance assessment

1. INTRODUCTION

Avalanche path vegetation

Predicting where and when large avalanches will occur remains a significant challenge because avalanche formation is the result of a complex interaction of topography, snowpack, weather events, and human activities. An avalanche path (Martinelli, 1974) refers to an area where a mass of snow moves rapidly down a slope, including the starting zone, where unstable snow releases, the track that is impacted by the moving snow and powder blast, and the runout zone where debris is deposited.

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Avalanche hazard maps are used to plan for construction, transportation, recreation, and other human activities in areas that are endangered by avalanches (CAIC, Atkins, 2001). Slide frequency on a path may vary from several events per year, to as low as one event per three hundred years or more, and frequency is generally higher near the starting zone of a path and lower in the runout zone (Mears, 1992). Documented observations of avalanches are very useful, but there are gaps in the historic record for Colorado, because the known observations are influenced by the various activities of people that have spent time in the mountains during different eras (Atkins 2006).

Avalanche workers use major differences in vegetation regularly in identifying avalanche paths (Mears, 1992; McClung and Schaerer, 2006). Avalanches can damage or kill individual trees and forest stands, and areas of frequent avalanche activity often appear as vertical swaths of open vegetation down steep mountain slopes, characterized by a different type or age of the dominant vegetation, or a lack of vegetation (Martinelli, 1974; Burrows and Burrows, 1976; Johnson, 1987; Patten and Knight, 1994; McClung, 2003; Walsh et al., 2004; Kulakowski et al., 2006; Butler and Sawyer, 2008).

Evidence of past slides can also be recorded in the woody growth layers of trees and shrubs growing in and along the path margins, and in the runout zone (Burrows and Burrows, 1976; Carrara, 1979; Mears, 1992; Jenkins and Hebertson, 2004; Casteller et al., 2007; Butler and Sawyer, 2008; Reardon et al., 2008; Bebi et al., 2009; Luckman et al., 2010). Avalanche dating techniques using dendrochronology can be particularly useful in places where woody vegetation on an avalanche path is likely to experience damage resulting from the impact of snow and debris. Development of reaction wood in response to repeated tilting (visible as darker growth tissue and eccentric rings), recovery from impact scars, and abrupt changes in annual growth can occur in the years following an avalanche (Burrows and Burrows, 1976; Reardon et al., 2008). Cross section discs and increment cores of downed trees on the path and adjacent forested areas also can be useful in assessing relative tree ages and the timing of tree establishment (Casteller et al., 2007).

Vegetation in forested avalanche tracks can be used as an avalanche-frequency indicator, but some of the most destructive avalanches are those that extend well beyond the boundaries of an established path or create a new path (Mears, 1992; Martinelli and Leaf, 1999). Large avalanches can provide a unique opportunity to learn about the timing and extent of past slide activity on a path, because the date of the most recent disturbance event is known, and cross section samples can be collected from downed and broken trees without harming live trees (Burrows and Burrows 1976). Vegetation damage resulting from large-magnitude events can also provide insight on avalanche dynamics and potential maximum runout distances (Mears, 1992; McClung and Schaerer, 2006).

2. BACKGROUND

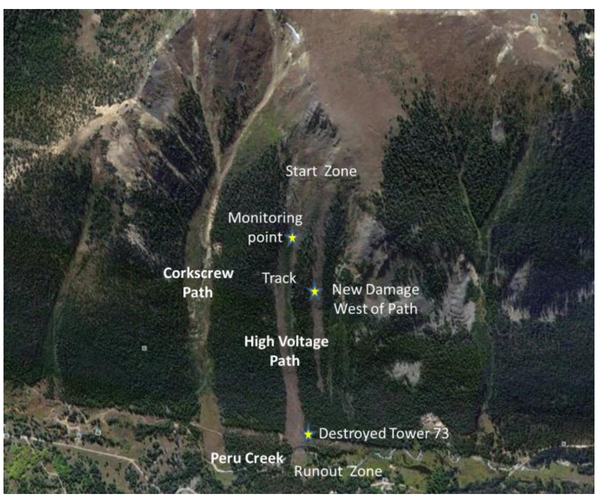
The 2011 “High Voltage” Avalanche

On April 29, 2011, an impressive slide damaged high voltage power lines along Peru Creek, near Montezuma, CO (path location 39°35’57.49”N, 105°50’55.15”W, see Figure 1). The avalanche occurred in an area that we will refer to here as the “High Voltage” path, on a forested north-facing slope of Tip-top peak, west of a larger path known as “Corkscrew.” The High Voltage avalanche destroyed a power line tower that had been in place since the 1970s, along an historic transmission line that was originally constructed in 1906-1909. We do not know of any witnesses to the slide that occurred on the morning of April 29, 2011. At 5:58 A.M., a power outage was reported on the transmission line, and workers found that a large slide had destroyed “Tower 73” and deposited massive piles of snow, trees, rocks, and debris in the runout zone.

The High Voltage slide created fresh trimlines along the forested margins of the path, widening the existing path on both sides by uprooting, stripping, and breaking trees. The avalanche destroyed a large metal power line tower, and left behind stacks of mature downed trees, extensive vegetation damage, and areas of bare soil. Large piles of debris were deposited in the runout zone, including trees, rocks, soil, and dense snow that persisted through the summer.

A new “finger” was also cleared of trees on the forested slope adjacent to the west margin of the main track of High Voltage. This western edge of the avalanche left behind a swath of downed trees approximately 25-30m wide, but it did not extend far enough down the slope to threaten the power line. Although the new forest damage resulted in a much larger path in this area, we could see from images and historic photos that the start zone had run into those trees at some point in the past. Despite the costly outcome of this avalanche, the High Voltage slide provides a unique opportunity to improve our knowledge of local avalanche frequency and magnitude.

Figure 1: Before and after images of the High Voltage path: Before the 2011 event, the lower track and runout had grown in with trees, and the area of new damage to the west of the path was densely forested. The High Voltage path now clearly intersects the power line and Peru Creek in the runout zone, and the track is almost as wide as the adjacent Corkscrew path. Images were collected June 30, 2008 (above), and Sept 23, 2011 (below), Google Earth 2012.



3. METHODS ASSESSMENT:

Avalanche History of Peru Creek

Dozens of notable avalanches have been reported from the surrounding area, but we did not find any records of large avalanches in the High Voltage path in the literature. Several of these local observations were documented with detailed descriptions that correspond to nearby locations scattered throughout the Peru Creek area. Similar to many other mountain areas across Colorado, the local avalanche history in the Peru Creek area is incomplete, and records are strongly influenced by the timing of human activity in the area (Atkins, 2006). For example, many notable avalanches affected the mining towns and camps that occupied several areas in the Peru Creek drainage from the 1860s through the 1930s (Martinelli and Leaf, 1999). By the 1950s, more of the documented avalanche observations were from local roads, and increasingly from neighboring ski areas such as Arapahoe Basin.

Intersecting the runout zone of the High Voltage path, the "Shoshone" power line was built from 1906 to 1909, and the towers were updated in the 1970s along a similar path. The 90,000-volt transmission line was built from the Shoshone hydro-electric station in Glenwood Canyon to Denver, Colorado. A portion of this line traverses the valley floor of Peru Creek near Montezuma in Summit County, and ramps up steeply over the Continental Divide near Argentine Pass before continuing east. This power line intersects the mountains at elevations of up to 4115m, crossing many large avalanche paths along the way.

Pete "Mario" Martinelli and Charles Leaf (1999) carefully documented newspaper articles on avalanche incidents and close calls that were reported from the mining camps of Peru Creek, and from maintenance activities along the Shoshone transmission line. The tower numbers have been updated, and many place names have changed over the years, including several mining camps that were abandoned following damaging snow slides.

One of the earliest examples of avalanche incidents concerning the Shoshone line was reported from February 22, 1912, when a large slide on Ruby Mountain ran through timber and destroyed three steel transmission towers and two cabins. The Ruby Mountain event occurred in an area east of the High Voltage path and west of Argentine Pass, but avalanches were reportedly widespread along the power line that year. As described in a newspaper article in the Georgetown Courier, "The tower where the line branches was built below a body of timber and was thought to be safe from slides" (Martinelli and Leaf, 1999).

The story of a close call for line workers was told in an article in the March 26, 1936 "Berthoud Bulletin," a small town newspaper that was published in Larimer County, CO from 1893-1980. Two power line workers heard an avalanche release while they were on a slope. One managed to escape to the flank, but his partner was caught in the slide and tumbled several hundred feet down slope. The companion noticed the tip of his partner's snowshoe showing above the debris, and he was able to dig his partner out unharmed. The author of the article stated that "This year [1936] slides are reported especially bad. They have started earlier than usual and are more numerous, the result of heavy snows in the high country." A faded picture above the article shows two men standing in a mass of downed timber and with a power line tower in the background. The caption of the photo was "A snow slide destroys everything in its path, even the massive steel transmission towers on the Shoshone Line."

Further west up the Peru Creek drainage, another damaging avalanche interrupted the Shoshone Line at 1:32 A.M., on the morning of February 27, 1939. A large avalanche released off the ridge line that connects Ruby Mountain to Cooper Mountain in the Peru Creek Drainage, on a path known as the "Tariff Slide." As described in an article in the Summit County Journal (March 24, 1939) a large avalanche destroyed tower 724, throwing the 15m-tall tower in the air and depositing it in a crushed mass across Peru Creek. Tons of repair material and equipment were hauled in by a crew of over 20 men, who worked for three consecutive days in severe weather to restore power.

In recent years, backcountry recreationalists have increasingly explored the area during winter, and they have started to report some impressive avalanches. For example, the 2010-2011 avalanche season started in the Peru Creek drainage on November 15, 2010, when an avalanche was reported from the Corkscrew path (a large path just east of High Voltage) that caught a skier and a dog. The Corkscrew path is easily recognized as an area of avalanche hazard, with a complex starting zone and a potential vertical fall approaching 610 meters (see Figure 1).

On April 1, 2011, a group of backcountry skiers travelled a route that traverses the Shoshone power line. As they came under the Corkscrew path they saw a fresh and very large avalanche debris pile. After investigating the debris pile looking for clues or tracks, they concluded that the Corkscrew had run naturally and reported the slide. The slide initiated from below the ridge with a vertical fall close to 366 vertical meters. The fracture line on the Corkscrew was still visible four weeks later, when forecasters visited the area to investigate the High Voltage slide.

Vegetative Indicators

Immediately after the damaging High Voltage event, people started to ask whether the path might be new (see Figure 1). On first glance, the path was somewhat difficult to detect on images available from Google Earth (Google.com/earth/; Composite Satellite Imagery collected from 1999-2008). However, the High Voltage path was much more evident in historic photos. We compared aerial photographs taken in 1938, 1974, and 1994; courtesy of the Dillon Ranger District, US Forest Service. The main track of High Voltage can be distinguished in most of the available photos as a linear, relatively open channel of approximately 50-100m wide. Over the past 20-25 years, the lower track of the path had gradually grown in with dense trees.

The aerial photos also indicated that prior to 1938, the lower track and runout area of the High Voltage path had been almost entirely cleared of trees. The open area extended across the path and up the slope in the direction of the Corkscrew, in a pattern suggestive of fire. We did not find information on the cause of that forest disturbance, but subsequent images showed that the tree cover on the slope continued to increase until at least 2008, and the disturbed area became increasingly difficult to detect. This pattern was not one that we would anticipate in assessing past avalanche frequency using vegetation indicators, but it did provide some insight on the observed variation in relative tree ages. It also provided some support that the oldest (>300 year-old) downed trees had all grown in locations higher on the path, at elevations above the disturbance area.

Despite challenging differences in the scale and extent of available images, qualitative analysis of repeat photography using aerial photographs and other available imagery was valuable in identifying the boundaries of the avalanche path and tracking vegetation recovery following a disturbance event.

Tree-ring Samples

We collected cross-section discs of uprooted and downed trees along the elevation gradient of the High Voltage path (see Figure 2). We targeted trees with visible scars in the outer bark and vegetation breakage suggestive of avalanches. We sampled an initial set of representative trees that grew *in situ* on the High Voltage slope, rather than from logs in the jumble of debris in the runout zone.

Figure 2: Example of a tree disc collected from a downed tree in a fresh trimline on the High Voltage path, showing multiple signals of past avalanche impacts recorded in the growth rings.

Initial cross section samples and cores from the downed trees ranged from 116 to 335 (± 5) years in age, with diameters of up to 60cm. Avalanche signals recorded in the woody plant tissue included direct impact scars and development of reaction wood in response to repeated tilting. Several of the tree disc samples contained multiple clear signals of avalanche disturbance and related growth response as it is recorded in the rings (Pederson et al., 2006; Reardon et al., 2008).

Despite the presence of obvious impact scars, we found considerable variability in the initial tree samples collected from the path. The dates of disturbance signals were not consistent among seven of the highest quality tree samples that we have collected. For example, notable local avalanche years were reported in 1899, 1912, and 1936, while we found impact scars in the tree samples that corresponded to the winter seasons of 1909-1910, 1922-23, 1959-1960, 1964-65, and 1982-1983. The presence of reaction wood in response to tilting was evident in most of the tree samples, and was noticeable during the late 1760s and 1860s in several of the oldest tree samples. The 2011 High Voltage avalanche event occurred during a season of record snowpack, and followed several days of snow accumulation and strong winds resulting in visible snow redistribution in the starting zone. For these reasons, it may be expected that the dates of unique large avalanches such as the event on the High Voltage path will not match the local and regional avalanche records.

We have found evidence of direct impact scars and repeated tilting events that could extend our knowledge of the avalanches that have occurred over more than three centuries. Although the initial samples do not share all of the same signals, the presence of impact scars suggests that, on average, at least one major avalanche event has occurred on this path per 100 years. We are grateful for the opportunity to work with high quality samples from trees that survived on the path for more than 300 years, and we are working to prepare additional tree samples for further analysis.

Avalanche Path Measurements

On April 29, 2011, an avalanche released from the relatively wide (>200m) alpine starting zone at approximately 3600m in elevation, and ran to the valley floor at 3140m, with a vertical fall of about 460 meters and estimated horizontal distance of 1060 meters. The starting zone is the steepest area of the path with a slope angle ranging from 43 to 33 degrees. Slope angles in the track ranged from 22 to 29 degrees, and were 15 degrees or less in the relatively flat area of the runout zone that crosses Peru Creek. The slope angle at the destroyed “Tower 73” is 10 degrees.

In the starting zone of the High Voltage path, we found open alpine tundra vegetation and snow drifts that persisted late into the summer near the ridge. Along the lower edge of the starting zone close to tree line, the open path vegetation contained areas of dense willow shrubs, and many of the trees along the margins of the path were tilted and leaning on each another. At the area of the “stauchwall,” between the starting zone and the main channel of the avalanche track, we found a diverse mix of krumholtz trees, shrubs, and meadow vegetation.

The open linear track area of the High Voltage path is vegetated by a variety of shrubs, grasses, and herbs, while much of the surrounding slope is densely forested. This avalanche “path” pattern characterized by a linear swath of open vegetation on otherwise forested slopes can indicate that slides occur often enough that mature coniferous forest species may not successfully establish (Bebi et al., 2009).

Debris left behind by the 2011 High Voltage event reached well beyond the intersection with Peru Creek, but we also found evidence of an historic trimline and previous vegetation breakage that extended past the toe of the debris. This historic trimline indicates that an avalanche may have run further down on the path at some time in the past. However, this maximum runout event does not necessarily occur from a larger avalanche, depending on the snow type, track conditions, and vegetation conditions at the time of the slide (Mears 1992).

The alpha angle was measured at 25 degrees when measuring from the toe of debris to the starting zone of the High Voltage avalanche. The alpha angle was 23 degrees when measured from the historic trim line, further out in the potential runout zone (for more details on methods see SWAG, Greene et al., 2009).

Snow Height Simulation

To improve our understanding of the dynamics of the High Voltage avalanche, we used rough estimates of slab properties and terrain features on the path as inputs in a one-dimensional model, using the program Aval-1D (Christen et al., 2002).

A monitoring point for the initial model run was selected in the area just below the slab and stauchwall, where the track narrows and the slope is about 28 degrees (39°35’36.59”N, 105°50’49.14”W). The estimated track width above the monitoring point ranges from more than 100m to 50-70m wide in the track, using terrain data from Digital Globe (2011).

Photos taken just after the event showed that the path was visibly wind-loaded at the crown. We were able to use crown photos together with pit profiles from a representative site 5km away, to estimate that the slab in the starting zone was 2.3m deep. This slab depth corresponded to measurements from the nearby Grizzly Peak SNOTEL station. A widespread weak layer was identified within the snowpack, at approximately 50 cm above the ground, and we think that this avalanche ran on the same layer.

Based on the estimates of this initial model run, at the monitoring point, the flowing snow in the avalanche is as high as 4.8m. In the model, snow is moving at up to 31.2m/s, with flow heights of greater than 2m that last for 10 seconds. The slide continues for almost 60 seconds, resulting in a mass of debris of 14,000 metric tons, and an estimated volume of 45,000m^3. The estimated maximum impact pressure is 310Kpa, which is three times the pressure needed to uproot a mature spruce tree (100Kpa, McClung and Schaerer, 2006).

4. DISCUSSION AND CONCLUSIONS

Using the 2011 “High Voltage” event as a case study, we found evidence of both synchrony and asynchrony in local avalanche path histories. Historic records showed that large destructive avalanches in the Peru Creek area were certainly not unprecedented, but we also found evidence of past events on the path that did not coincide with historic records of notable avalanche years in the surrounding area.

This preliminary assessment supports the conclusion that direct observations are the most reliable evidence of the occurrence of snow avalanches on individual paths. However, the historic record is almost incomplete, particularly for paths with long return intervals, and vegetation patterns can be useful indicators of past avalanche frequency and magnitude. A major caveat for using vegetative indicators is that plant species distributions are influenced by many factors other than avalanches. Landscape legacies, past disturbance events, and initial timing of plant establishment can have a strong influence on forest structure and conditions, making observed patterns difficult to interpret (Stohlgren, 2007).

In summary, we found that a variety of approaches used in ecological assessment of vegetation disturbance and recovery can be useful in improving and extending the historical record of avalanche activity on a path. Large avalanche events in particular can provide a unique opportunity to improve our understanding of local path histories. We improved our understanding of the High Voltage avalanche using field measurements of terrain and vegetation, mapping of damage to plants from the moving snow and debris, repeat imagery, and model simulations. Tree ring signals also were useful in extending records of past avalanche frequency and magnitude on the path, particularly through the dating of direct impact scars and repeated tilting events.

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Photo: Scott Toepfer, Forecaster at the Colorado Avalanche Information Center, collects a disc from an uprooted tree in the High Voltage path, August 9, 2011.