ASSESSING POWDER CLOUD IMPACT ON ELECTRICAL TRANSMISSION LINES AT SNOWSLIDE CREEK AVALANCHE PATH IN SOUTHEAST ALASKA

Katreen Wikstrom Jones[1]*, Gabriel J. Wolken[1,2], Michael Janes[3], Chris Wilbur[4], Julia Glaus[5], Perry Bartelt[5], and Marc Christen[5]

[1] Alaska Division of Geological & Geophysical Surveys, Anchorage/Fairbanks, AK, USA
[2] Alaska Climate Adaptation Science Center, University of Alaska, Fairbanks, AK, USA
[3] Alaska Electric Light & Power, Juneau, AK, USA
[4]Wilbur Engineering, Inc., Durango, CO, USA
[5]WSL Institute for Snow and Avalanche Research (SLF), Davos, Switzerland

ABSTRACT: Power transmission lines conduct electricity across avalanche terrain to communities in Alaska. Many of the towers along these lines have been redesigned, and are now strengthened, protected through relocation, or engineered with diverters in response to damage from past avalanche impacts. The challenge that remains in many areas is providing protection to the powerline conductors (powerlines) that are exposed to high impact pressure powder clouds generated from large avalanches. Alaska Electric Light and Power (AEL&P) provides hydro-generated electricity to approximately 17,000 users (meter count) within the City and Borough of Juneau in southeast Alaska. One critically exposed segment of the transmission line is located south of Juneau along Thane Road. The transmission line crosses numerous avalanche paths on Gastineau and Roberts peaks, of which Snowslide Creek is the most prominent, with frequent naturally and artificially generated avalanche activity. Avalanches here have destroyed power transmission towers and conductors many times in the past, and larger events often deposit debris on Thane Road, maintained by Alaska Department of Transportation & Public Facilities (ADOT&PF). A deflecting dam was developed at Snowslide Creek which redirects dense avalanche flow and catches debris in the early part of the season until it fills up. On March 4, 2021, ADOT&PF artificially triggered an avalanche in Snowslide Creek. Most of the dense portion of the avalanche stopped within the deflection dam with only a small portion spilling over; however, the powder cloud snapped the breakaway connections to the towers and the conductor was carried into Gastineau Channel, resulting in a costly repair for AEL&P.

Here we present a back-calculation and reconstruction of this avalanche event using the dynamical avalanche runout model Rapid Mass Movements Simulation (RAMMS) Extended to estimate the powder impact pressures along the transmission line. We collected airborne lidar data at Snowslide Creek pre- and post-avalanche mitigation that was used as input and for validation of the avalanche simulations. We also analyzed video footage from the event and extrapolated information from SNOWPACK model runs at Mount Roberts weather station as well as nearby snow pit information. We reviewed the engineering documents for the transmission line conductors and breakaway connectors and compared these values to our reconstructed powder impact pressures, and we developed ideas for potential system improvements to increase the reliability of this exposed span. Future plans involve exploring instrumentation options for recording impact pressures at Snowslide Creek avalanche path and simulating snowpack scenarios and avalanches representing the changes we anticipate in future climatic conditions in this region.

KEYWORDS: Avalanche modeling, Powder Avalanche, Powder Cloud, Avalanche Engineering, Lidar, Snow Mapping

1. INTRODUCTION

In Alaska, snow avalanches lead to costly repairs of infrastructure. In many instances, particularly in the fjord settings of southern Alaska, there is limited land available for safe construction of roads and utility lines, forcing infrastructure to cross major avalanche paths. In Juneau, southeast Alaska, the Thane Road infrastructure corridor connects the Thane Road residential neighborhood with the rest of the city and supports a transmission line that supplies Juneau with 92% of its power from Alaska Electric Light & Power's (AEL&P) three hydroelectric facilities. The Thane Road corridor stretches along the shoreline of Gastineau Channel and cuts through numerous avalanche paths on Gastineau and Roberts peaks; Snowslide Creek and Cross Bay Creek being the largest and most productive paths

* *Corresponding author address:*
Katreen Wikstrom Jones, Alaska Division of Geological & Geophysical Surveys
Anchorage, AK, 99508
tel: +1 907-268-8051
email: katreen.wikstromjones@alaska.gov

(Figure 1). Going through reports dating back to 1891, Snowslide Creek has a long history of producing large to very large avalanches (> 100,000 m^3) on a return interval of < 10 years (Mears et al,1991). An avalanche debris deflection dam was installed in Snowslide Creek's runout zone in 1974, but it usually fills up with avalanche debris by mid-winter, resulting in minimal deflecting effect on subsequent late-season avalanches. AEL&P has relocated some of their powerline transmission towers outside of major avalanche paths in the Juneau region. However, air blasts from powder cloud avalanches affecting the hanging conductors remain a concern at many paths.

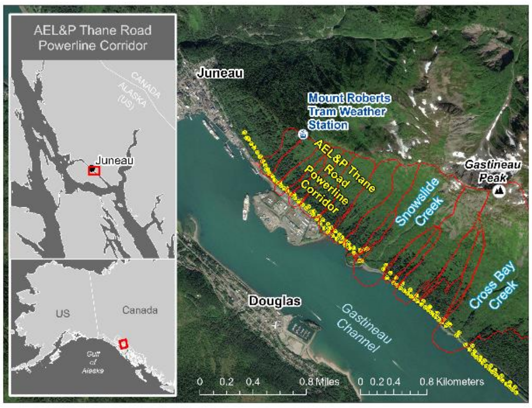

Figure 1: Location map of Snowslide Creek avalanche path and AEL&P Thane Road Powerline Corridor.

Avalanche safety programs under AEL&P and Alaska Department of Transportation & Public Facilities (ADOT&PF) are responsible for avalanche mitigation along the Thane Road corridor. On March 4, 2021, ADOT&PF triggered a large avalanche in Snowslide Creek using explosives from a helicopter. The air blast from the powder cloud caused the powerline to snap two out of three breakaways at AEL&P tower set 14643–14645) and all breakaways at tower set 144333–14435 (Figure 2), and the conductor was carried into Gastineau Channel, resulting in a costly repair for AEL&P. Due to continued avalanche hazard and marginal weather, it took AEL&P six weeks to restore the powerline's full functionality.

Recent scientific progress has been made in understanding and describing the formation and development of powder cloud avalanches and their destructive impact on powerline transmission towers and overhanging conductors. At the Val-

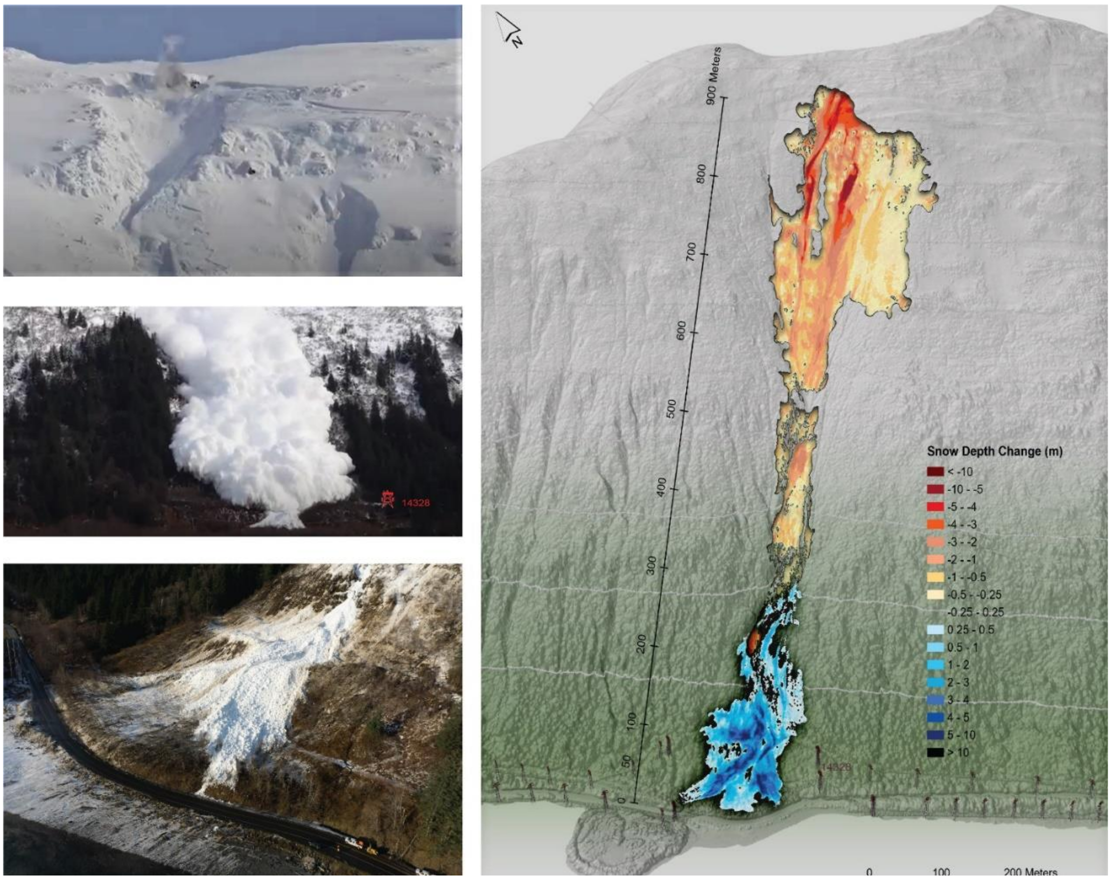

Figure 2: March 4, 2021, Snowslide Creek avalanche (Photo - top left) Avalanche is triggered by heli-bombing, (Middle left) Powder cloud reaches upper powerline, (Bottom left) Deposition of the dense core which stopped short of Thane Road, and remnant powder cloud debris on the beach (Photos: AEL&P); (Map - right) Lidar-derived snow depth change from March 3 to March 4, 2021, showing areas of release/erosion (yellow-red) and deposition (blue) in Snowslide Creek.

lée de la Sionne test site in Switzerland, the general structure of powder cloud avalanches has been documented by measuring impact pressures from load cells, air pressure sensors, particle velocity from optical sensors, and cloud density and particle cluster size from capacitance probes (Sovilla et al., 2015). Caviezel et al. (2021) demonstrated how powder cloud avalanches can both directly produce dynamic loads on transmission towers by striking them, or indirectly by causing stress/deformation waves of the conductor in longitudinal (X) and transverse (Y) directions that propagate back and forth between the towers. These dynamic loads can exceed the wind loads that the conductors are designed for. Transverse loading by the powder cloud has shown to be significantly stronger than longitudinal loads, suggesting a magnification factor based on directional load, which until now is not accounted for in avalanche engineering (Caviezel et al., 2021). High quality data collected in the field has helped the avalanche modeling community to improve the numerical representation of powder cloud avalanches that now compare to real events. For example, in the most recent version of Rapid Mass Movement Simulation (RAMMS) EXTENDED (2.8.25) the user can obtain realistic powder cloud heights, velocities, and impact pressures on obstacles (See Chapter 2.4). Gorynina and Bartelt (2022) reconstructed a powder cloud avalanche in RAMMS::EXTENDED that released on January 28, 1987, at the Ryggfonn avalanche test site in Norway. They applied an inverse calculation approach by using known material properties and tension values of the cables to derive the dynamic forces created by the powder cloud and the resulting stress wave that propagated in the hanging cables.

In this case study of the Snowslide Creek avalanche on March 4, 2021, we combine recent numerical model improvements in RAMMS::EXTENDED with snowpack and avalanche observations collected in the field pre- and post-avalanche mitigation. We reconstruct the mixed flowing/powder cloud avalanche to represent the real avalanche event and compare the model output values to the documented design values of the transmission towers and conductors. We discuss discrepancies between model results and observations collected in the field, and future potential system improvements to exposed powerlines to increase their robustness in the face of avalanche hazard. We conclude with suggestions for instrumenting Snowslide Creek to better assess powder cloud impact pressures in future avalanche events.

2. METHODOLOGY

We collected airborne lidar data at Snowslide Creek pre- and post-avalanche mitigation that was used as input and for validation of avalanche simulations (2.1). We analyzed photos and video footage from the event (2.2), and extrapolated information from SNOWPACK model runs at Mount Roberts weather station as well as nearby snow pit information (2.3). Then, we back-calculated and reconstructed the March 4, 2021, avalanche event in Snowslide Creek using RAMMS::EXTENDED to estimate the powder impact pressures along the transmission line (2.4). Lastly, we reviewed the engineering documents for the transmission line conductors and breakaway connectors and compared those force thresholds with the avalanche modeling results (2.5).

2.1 Pre-and post-avalanche snow depth mapping

Pre- and post-avalanche mitigation airborne lidar surveys were coordinated with ADOT&PF and took place March 3–4, 2021, at Snowslide Creek avalanche path. We used a Riegl VUX1-LR laser scanner integrated with a global navigation satellite system (GNSS) and Northrop Grumman LN-200C inertial measurement unit (IMU) and operated the system from a Bell 206 LongRanger helicopter platform. Lidar data was processed in SDCimport, Inertial Measurement Unit and Global Navigation Satellite System data in Inertial Explorer, and integrated flightline information with the point cloud in Spatial Explorer. A suite of TerraSolid software was used to calibrate the point data. The point cloud was corrected for any vertical offsets using ground control points and then coregistered with our 2019 bare ground dataset. Then, we derived snow depth raster products including snow depth on March 3 and 4 and calculated the snow depth difference between the two dates which allowed for analysis of material loss (release and erosion) and material gain (deposition) in the avalanche runout zone (Figure 2). Lastly, the outline of the release area was digitized using our lidar-derived snow depth difference map and video footage, and with the Zonal Statistics tool in ArcGIS Pro we obtained the average depth within that outline.

2.2 Video footage

Video footage of the artificially triggered avalanche, recorded by ADOT&PF, was analyzed to delineate the separate release areas and their individual time of release. We recorded the powder cloud's time of arrival at specific photo identifiable, topographical features to estimate velocities at each section of the path. Additionally, these arrival times were used to calibrate model parameters that control powder cloud behavior. We used separate video footage to analyze the powder cloud's dissemination into the Gastineau Channel and to estimate the powder cloud heights. Photos were analyzed to estimate the extent and depth of the powder cloud deposit on the Thane Road. Photos of the avalanche debris also revealed avalanche flow characteristics showing the influence of snow entrainment of warm snow (Figure 2).

2.3 Weather station data

Weather data were collected from stations in the area, primarily from the tram station on Mount Roberts (530 m above sea level [a.s.l.], Figure 1) and at road level to review air temperatures and wind loading prior to the event. Snow pit profiles were available from near the tram station and Arthur Peak near the event date. Avalanche Canada provided SNOWPACK model runs of snow depth and snow temperature based on the Mount Roberts tram weather station (Horton, pers. comm.), from which we extrapolated snow temperature at the elevation of the release area (~950 m a.s.l.).

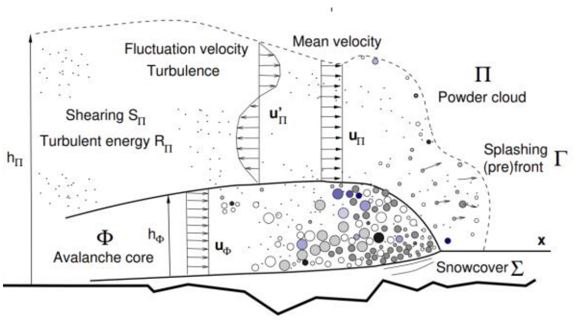

Figure 3: Formation of the turbulent powder cloud Π from the avalanche core Φ. The avalanche travels in slope-parallel direction x at mean core velocity μ_Φ and powder cloud velocity μ_Π (Bartelt and Christen, 2023).

2.4 Modeling in RAMMS::EXTENDED

RAMMS::EXTENDED applies a system of depth-averaged equations to solve for the core and the powder cloud on an XYZ grid (Christen et al., 2010), where: (1) the avalanche is divided into a non-suspended part (core Φ) which is dominated by a laminar shear flow of snow clods, and a suspended part (powder cloud Π) which is dominated by inertial flow of suspended ice particles; and (2) the core and the cloud can inundate different areas and apply different impact pressures on objects in the runout zone. The constant competition between heat energy and random kinetic energy production is what drives flow regime development, rheology, and formation of the powder cloud (Figure 3). In a profile view, the avalanche spans from dense to dilute. The level of turbulence in the powder cloud is a result of energy transfer from the core, internal shearing, and air entrainment (Figure 3). Lower velocities lead to dissipation of turbulence which results in a laminar flow of lower air-blast pressures. Both laminar and turbulent velocities are used to calculate these air-blast pressures at obstacles (Bartelt and Christen, 2023).

3. CASE STUDY: MARCH 4, 2021, SNOWSLIDE CREEK AVALANCHE

3.1 Transmission line at Snowslide Creek

Parallel powerlines cross Snowslide Creek at two locations: ~50 m a.s.l. (conductor is buried) and 10–30 m a.s.l at a 15-degree skew angle to horizontal (Figure 1). The tower sets are of similar design, consisting of three guyed cross-braced wood poles. The lower poles are 25 m tall and the upper poles are 15 m tall. Three conductors span 273 m with ground clearance of 14–25 m and a sag of 5.4 m. At its lowest point, the conductor hangs ~14 m above ground (bare ground) and only ~2 m above vegetation (alders) (Figure 4). That distance is reduced in the wintertime when the ground is covered with snow and avalanche debris. Each conductor is connected to the tower with a custom-designed breakaway link designed to fail at approximately 34 kilonewton (kN) to prevent damage to the poles.

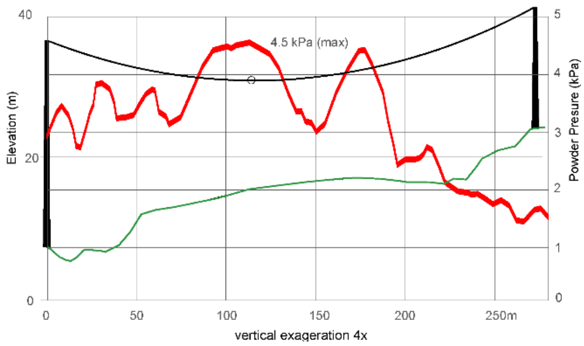

Figure 4: Max powder impact pressure (red line) from reconstructed March 4, 2021, Snowslide Creek avalanche along conductor, starting at AEL&P tower set 14643–14645 at 0 m a.s.l. and spanning 273 m to tower set 144333–14435. Green line is ground.

3.2 Snowpack description

The Juneau area in the southeast region of Alaska is predominantly characterized by a high latitude maritime snowpack (McClung and Schaerer, 2006), though periodically influenced by transitional and even continental large-scale weather patterns (Coleman, 1986). The snow depth gradient from sea level up to ridge tops is typically dramatic, ranging from 0 m to 15 m in snow-drifted areas along ridgelines. Air temperatures at sea level often remain around 0 °C throughout the winter, resulting in precipitation frequently falling as rain at lower elevation, making for a complex snowpack. The Juneau area often gets impacted by strong north-northeast outflow winds at the end of storms, which along the Mount Robert and Mount Gastineau peaks typically result in significant wind-loading and deposition of snow on the lee-ward (southwest) side, supplying large avalanche starting zones. Leading up to March 4, 2021, a series of persistent weak layers, formed around crusts, were present in the snowpack. They were the culprit of a widespread natural avalanche cycle that took place in the area on February 25–26, but during which Snowslide Creek did not release.

3.3 Avalanche event description

Air temperatures were warm on March 4, 2021. The weather station at Mount Roberts tram station recorded -1 °C at 10 am AKST, while at road level, air temperature was already +3.8 °C. The SNOWPACK model run from the tram station showed a snow height of 296 cm and average snowpack temperature of -0.5 °C this day. In the release zone at ~950 m a.s.l., snow height on March 3 measured 4–5 m on average with wind-loaded deposits up to 10 m. Avalanche activity from earlier in the season had deposited debris at various sections of the path from mid-slope and down, with deposit heights up to 10 m in the deflection dam.

Explosives were detonated from a helicopter by ADOT&PF at 10:43 am AKST. The deepest portion of the release area immediately fractured and released, followed by three sequential releases at a ~2 s, 3 s, and 4 s delay. The release area was estimated at ~22,000 m^2 and stepped down into deeper layers resulting in an average depth of 3.3 m (Figure 2). A powder cloud developed immediately, travelling 1310 m (linear distance) between the release area and Thane Road in approximately 33 s, with an average velocity of 40 m/s

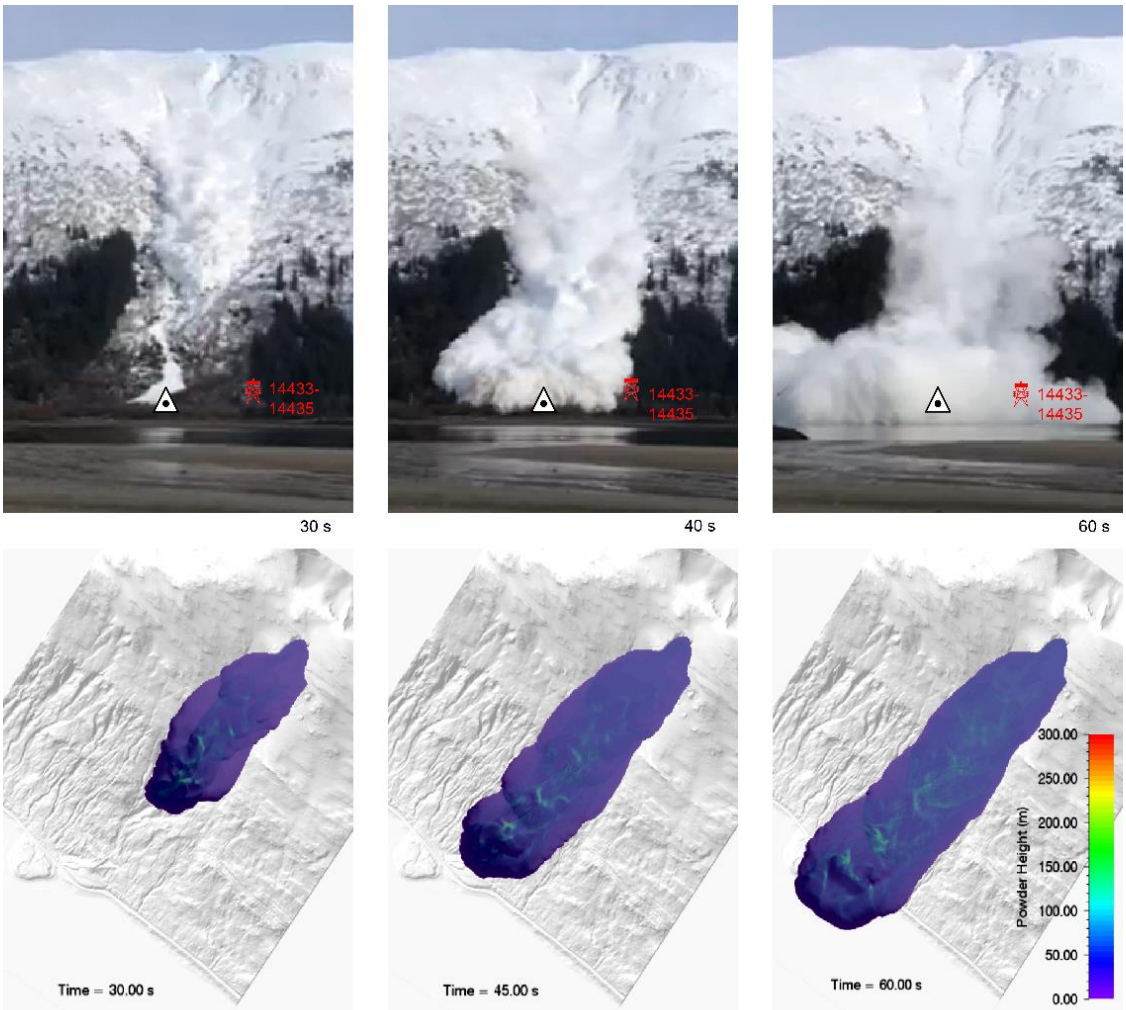

Figure 5: Time series of March 4, 2021, powder cloud avalanche in Snowslide Creek. (Upper tri-panel) Photo captures at 20 s, 40 s, and 60 s after explosives visibly hits the snowpack. Location of AEL&P tower set 14433–14434 is marked in red symbol and center path point is marked by a white triangle (not true to scale). Photos courtesy of AEL&P. (Lower tri-panel) Screen captures of powder height (m) of reconstructed avalanche at 30 s, 45 s, and 60 s, modeled in RAMMS::Extended.

and a maximum velocity of 55 m/s. The powder cloud maintained momentum and reached at least half-way into Gastineau Channel (Figure 5). It also spread laterally into the forest along the avalanche path but quickly dissipated. The powder cloud deposited approximately 0.3–0.5 m of ice dust and vegetation debris on Thane Road.

Erosion depths within the avalanche track averaged 1.75 m and the entrained warm snow at lower elevations contributed to meltwater production and granule formations in the dense deposit. The dense portion of the avalanche was overflowing the deflection dam approximately one minute after the arrival of the powder cloud and stopped short of the road. The deposition spread into flow fingers, typical of wet avalanches (Figure 2).

3.4 *Results of avalanche reconstruction*

In Table 1 we present the parameters of our best model run in RAMMS::EXTENDED. The reconstructed release volume was ~100,000 m^3 resulting in a mass of ~30,000 tons. The eroded mass was ~47,500 tons contributing to ~77,000 tons of flowing mass split into ~72,500 tons in the core and ~4500 tons in the powder cloud. Total avalanche duration was similar between observed and modeled avalanche, though the observed avalanche accelerated faster immediately after the release, resulting in a 5 s time discrepancy (Figure 5). At AEL&P tower set 14433–14435 we obtained a modeled max powder velocity of ~23 m/s and powder cloud impact pressure of ~1.5 kPa. At the avalanche path center point (see white triangle in Figure 5), max powder velocity was ~35 m/s and max powder impact pressure was ~6 kPa (Figure 6). Along a profile drawn between the AEL&P tower sets we see powder impact pressures up to ~4.5 kPa (Figure 4). Once hitting the shoreline, the modeled powder cloud ran into Gastineau Channel and dissipated with a close

Table 1: Parameter values for reconstructed March 4, 2021, Snowslide Creek avalanche (best scenario).

Parameter	Value	Parameter	Value
Release volume (m3)	100509.8	Erosion depth (m)	1.75
Release volume 1 delay (s)	0	Erosion density (kg/m3)	350
Release volume 2 delay (s)	2	No snow steepness (deg)	70
Release volume 3 delay (s)	3	Yield Stress (Pa)	300
Release volume 4 delay (s)	4	Forest code	A
Release depth (m)	3.3	K-value	48
Grid resolution (m)	2	Tree type	Spruce
Core density (kg/m3)	450	Tree diameter (cm)	100
Mu	0.6	Tree height	40
Xi (m/s2)	1000	Generate	5
Cohesion (Pa)	500	Mu wet	0.12
Mu (release polygon)	0.18	Dry wet transition (mm)	100
Xi (release polygon)	6000	Air temperature (°C)	0
Reference altitude	950	Cloud drag	3
Delta D (m/100m)	0.15	Momentum exchange	2
Release temperature	-2	Turbulent air entrainment	2
Delta T (T/100m)	0.3	Turbulence - Beta Powder	1
Release density (kg/m3)	300		

resemblance to the observed powder cloud. The modeled deposition pattern and the depths of the dense core are like the observed pattern and depths, with a maximum depth of 9 m (Figure 7).

4. DISCUSSION

This case study contributes to the validation of our related efforts to produce large-scale snow avalanche hazard indication maps for the State of Alaska. The Snowslide Creek avalanche is a good example of a large avalanche that regularly occurs at a < 10-year reoccurrence interval, and which could pose even more serious threat to the Thane Road corridor in future climatic conditions where, for example, rain-on-snow events and a more complex snowpack structure are anticipated. Here we discuss the model performance (4.1), conductor displacements and dynamic loads caused by the powder air blast (4.2), and implications of this study for AEL&P (4.3).

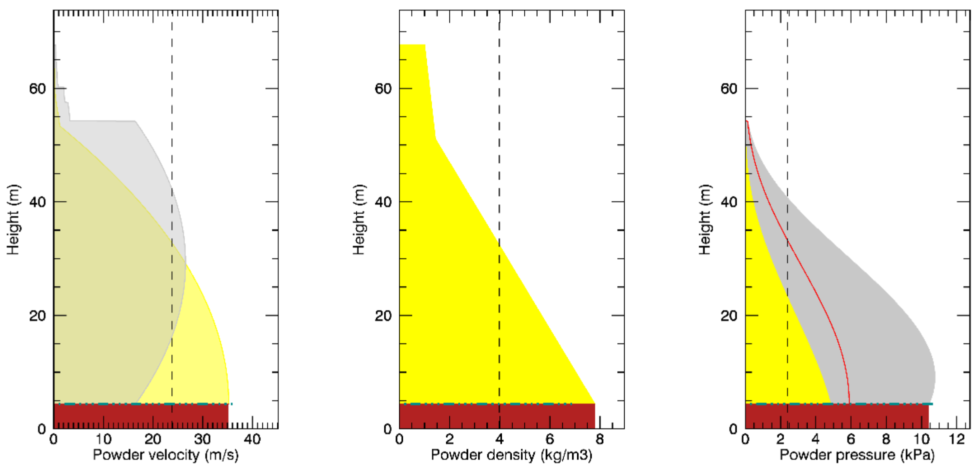

Figure 6: Powder velocity, density, and pressure per avalanche column height measured at center path point, elevation 17 m a.s.l. Red vertical line is the powder pressure (kPa) at this point over time. Yellow area is laminar (normal) pressure. Grey area represents a combination of turbulent and laminar pressure. Red area represents dense flow height of 3.83 m.

4.1 *Model performance*

Our modeled avalanche was approximately 5 seconds slower than the observed avalanche at reaching the points of interest (AEL&P tower set 14433–14435 and center path point). It is possible that we incorrectly timed the separate releases. The observed avalanche accelerated faster immediately after release, and we were not able to replicate that rapid acceleration in our modeled scenarios without negatively affecting other flow variables. We also hypothesize that the use of explosives, which often cause increased fracture speeds due to shockwaves (Hamre et al., 2014), could contribute to the speed of the avalanche itself. The energy from using explosives typically dissipates quickly through attenuation waves in the snowpack, but this has been shown to depend on snowpack stratigraphy (Bones Binger and Miller, 2015) and needs to be further explored.

The expression of the modeled turbulent powder cloud agrees well with the observed one. Modeled average powder cloud heights agree with the observed, but the modeled cloud also includes peaks that are upwards of 150 m tall which may be higher than what was observed (Figure 5).

The observed powder cloud runout extended a large distance over open water into the Gastineau Channel, while the dense core stopped before reaching the shoreline. This shows how the powder cloud and the dense core start to operate as separate entities after the core reaches a certain temperature and distinct flow regimes develop. We were pleased with the similarly distinct separation and runout extent of the modeled powder cloud and the dense core. The overall deposition pattern of the modeled dense core agrees well with the observed pattern, though it was slightly more spread out than the observed deposition, which had more distinct flow fingers and more depth variability (Figures 2 and 7).

Air temperatures were warm on March 4, 2021, likely above freezing for the lower half of the avalanche path. Warm snowpack temperatures have been shown to have significant influence on avalanche flow behavior (e.g., Vera Valero et al., 2015). We believe that entrainment of warm air also may have influenced the powder cloud, likely by dampening its development, i.e., slowing it down and limiting its expansion. To accommodate this observation, RAMMS::EXTENDED was modified to include air temperature in the air entrainment parameter, however, currently only parameterized with an average air temperature.

4.2 *Conductor displacements and dynamic loads caused by the powder air blast*

AEL&P tower set 14433–14435 is located at the edge of the March 4, 2021, Snowslide Creek powder cloud and completely outside of the avalanche core, explaining why modeled powder cloud impact pressures there were low. Toward the center of the avalanche path these values increase and are coincident with the location of maximum conductor sag, i.e., where it hangs closest to the ground. In accordance with recent work (e.g., Caviezel et al., 2021; Gorynina and Bartelt, 2022), we believe that large elastic strains from cable displacements initiated near the center of the 273 m long conductor between tower sets 14433–14435 and 14643–14645 caused enough tensile forces to snap the conductors at the breakaway points.

Video recordings of the March 4, 2021, Snowslide Creek avalanche showed that the powder cloud reached its maximum height and turbulence approximately 2–3 seconds after the front hits the powerline. This observation is corroborated by field experiments of powder avalanche velocity, density, and impact pressure at Vallée de la Sionne in Switzerland, in which peak values of these parameters were achieved a few seconds (2–3 s) after the avalanche front hit the instrumentation, indicating that the most destructive section

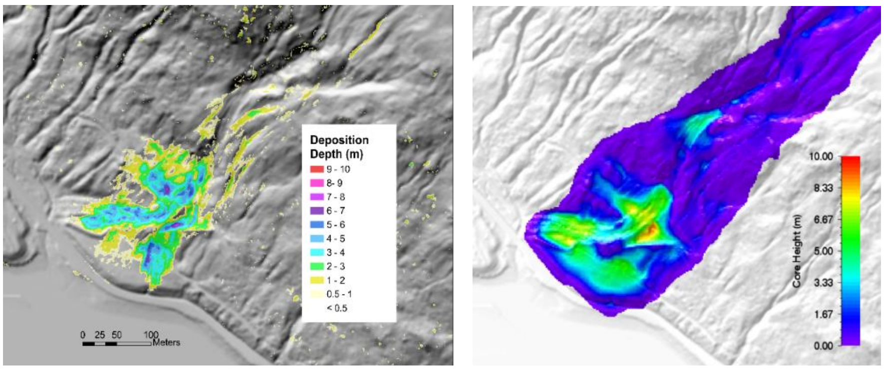

Figure 7: Avalanche core deposition (m) in (left) observed avalanche based on lidar-derived snow depth, and (right) modeled avalanche in RAMMS::Extended.

of a powder cloud avalanche is in the region behind the front (Sovilla et al., 2015).

4.3 Implications for AEL&P

Modeled powder impact pressures acted on the entire span with maximum values of ~4.5 kPa near the maximum sag location (Figure 4). Applying an average uniform pressure of 3.8 kPa or a piecewise pressure ranging from 3.0 to 4.5 to 2.0 kPa is insufficient to exceed the breakaway strengths. As the breakaway failed during the event, this indicates that the dynamic and/or non-uniform nature of the impact loading caused tensions that exceeded the breakaway strengths. The characteristics of the dynamic response are a function of initial tension, span, conductor unit weight and elasticity, and the time and location variations in powder impact pressures. While the modeling provides insight into the pressures and their variations, measurements of tension and/or displacements are needed to improve our understanding of both the loading and the system's dynamic response. AEL&P has identified the following take-away points from the results of reconstructing this event: (1) The break-away connections at the towers performed as designed and prevented damage to the towers. (2) Increasing the tower heights would reduce the risk of outages, but taller towers could not be serviced or repaired with existing equipment. (3) Thane Road provides convenient access for repairs, but the possibility of secondary avalanches can delay repairs, resulting in large expenses for backup diesel power generators. (4) Burying the lower conductors would be costly (estimated at $3.5 million, based on a 1989 estimate of $1.36 million and adjusted for inflation), but it would eliminate the conductor exposure at Snowslide Creek. Another option would be to relocate much of the Thane Road powerline from the hillside to the beach.

5. OUTLOOK

In this on-going study, we have successfully back-calculated a large avalanche that typically releases on a < 10-year reoccurrence interval and thus regularly puts the important Thane Road infrastructure corridor at risk. By reconstructing a real avalanche in RAMMS::EXTENDED, we tuned the model parameters to the snowpack and terrain characteristics of southeast Alaska. Next, we will simulate snowpack scenarios and avalanches representing the changes we anticipate in future climatic conditions in this region and assess the destructive impact on AEL&P infrastructure. To improve future modeling performance, we suggest installing instrumentation at Snowslide Creek, such as snowpack thermistors at different elevations to measure the snow temperature gradient and load cells on the transmission towers/conductors to measure tensions caused by powder impact pressures. More detailed avalanche and snowpack documentation in the field would also improve model input data.

ACKNOWLEDGEMENT

This work was funded by U.S. Geological Survey Climate Adaptation Science Center, Alaska Electric & Power, Alaska Department of Transportation & Public Facilities, and the State of Alaska. We thank Coastal Helicopters for their aviation expertise and contribution to these data products.

REFERENCES

Bartelt, P. and M. Christen: RAMMS Extended Lecture 6 Powder Cloud Dynamics, WSL Institute for Snow and Avalanche Research SLF, May 23, 2023

Bones, J., D. Miller and S. Savage: An experimental dynamic response study of hard slab seasonal snow to explosive avalanche hazard mitigation, in: Proceedings of the International Snow Science Workshop, Anchorage, AK, 16-21 September 2012, 142-148, 2012

Bühler, Y., D. von Rickenbach, A. Stoffel, S. Margreth, L. Stoffel, L., and M. Christen: Automated snow avalanche release area delineation – validation of existing algorithms and proposition of a new object-based approach for large-scale hazard indication mapping, Nat. Hazards Earth Syst. Sci., 18, 3235–3251, https://doi.org/10.5194/nhess-18-3235-2018, 2018.

Caviezel, A., S. Margreth, K. Ivanova, B. Sovilla, and P. Bartelt: Powder snow impact of tall structures, 8th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, Athens, Greece, 27—30 June, 2021

Christen, M., J. Kowalski, and P. Bartelt. RAMMS: numerical simulation of dense snow avalanches in three-dimensional terrain. Cold Reg. Sci. Technol., 63(1–2), 1–14, DOI: 10.1016/j.coldregions.2010.04.005, 2010

Coleman, B. R., The winter climate of Juneau: A mean of contrasting regimes, Natl. Weather Dig., 11, 29-34, 1986

Gorynina, O., and P. Bartelt: Powder snow avalanche impact on hanging cables, Int. J. Impact Eng., 173(71):104422 DOI:10.1016/j.ijimpeng.2022.104422, 2022

Hamre, D., R. Simenhois, and K. W. Birkeland: Fracture speeds of triggered avalanches, in: Proceedings of the International Snow Science Workshop, Banff, AB, 29 September - 3 October 2014, 174-178, 2014

Lehning, M., I. Völksch, D. Gustafsson, T. A. Nguyen, M. Stähli, and M. Zappa: ALPINE3D: a detailed model of mountain surface processes and its application to snow hydrology, Hydrological Processes, 20, 2111–2128, https://doi.org/https://doi.org/10.1002/hyp.6204, 2006

McClung, D. M. and P. A. Schaerer: The Avalanche Handbook. 3rd ed, The Mountaineers, 347 pp., 2006

Sovilla, B., J. N. McElwaine and M. Y. Louge: The structure of powder snow avalanches. Comptes Rendus Physique. 16. 97-104. 10.1016/j.crhy.2014.11.005., 2015

Vera Valero, C., K. Wikstrom Jones, Y. Buhler, and P. Bartelt: Release temperature, snow-cover entrainment and the thermal flow regime of snow avalanches. J. Glaciol., 61(255):173 – 184, DOI: 10.3189/2015JoG14J117, 2015