# FOLLOWING THE DATA: LESSONS LEARNED FROM A DECADE OF MAPPING AVALANCHES AND EXPLOSIVE USE INTERNATIONAL SNOW SCIENCE WORKSHOP 2026, WHISTLER, CANADA

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ABSTRACT: Taos Ski Valley Ski Patrol has been using GIS mapping software to record explosive use and avalanche activity since 2015. In over a decade, we have deployed more than 17,000 shots of various sizes, triggering more than 4,000 avalanches. This paper reflects on our experience with this method of avalanche documentation, outlines the lessons we learned, and discusses how our operation plans to move forward with GIS technology in the coming years. We hope that sharing our experience will help other practitioners who are collecting similar data.

Recording accurate data requires active participation from the entire ski patrol. Consistency in rating and recording avalanches varies within our crew of almost 50 people, and this variability impacts our data quality. Essential data must be recorded while not overwhelming the patroller inputting observations. It is critical to identify which fields must be mandatory (eg. D-size, primary trigger) and ensure they are entered accurately.

We began a preliminary investigation of the statistical relationship between explosives use and avalanche occurrences, with our 11 years of data. Analyzing the data helps us identify which techniques are working at our operation by removing our historical bias. For example, while only 27.5% of our explosive shots were airblasts (AB), over 50% of our large (D2 or larger) avalanches were triggered by airblasts. Although some of these differences may be due to varying shot sizes or differing conditions, research shows that airblasts are more effective than shots in the snow (Birkeland, 2026). Taos Ski Patrol has utilized airblasts effectively for decades. Incorporating an in-house review has further emphasized this science to our ski patrol. Another benefit of the preliminary examination of our data is it allows us to look critically at the integrity and usefulness of the data we currently collect, which has led us to make changes to our current system and identify areas that still need improvement.

The intention of this paper is to encourage questioning and discover new ways our GIS data can be used to help us improve, not to provide concrete answers.

KEYWORDS: mapping, explosives, avalanches, ski resort, avalanche mitigation, GIS

## 1. LOCATION AND HISTORY

Taos is located in Northern New Mexico in the Sangre de Cristo Mountains. The resort, Taos Ski Valley Inc. (TSVI) was established in 1955 and operates primarily within the Carson National Forest with a Special Use Permit. The Carson NF was established in 1908, but it is important to recognize that TSV Inc. operates on the Taos Pueblo's ancestral land which has been here since time immemorial.

TSVI consists of 1,294 acres with a vertical drop of 3,274 feet and an elevation that ranges from 9,160 feet to 12,481 feet. Taos Ski Valley has complex avalanche terrain and a long history of avalanche mitigation and documentation. There are 339 identified avalanche paths woven across the ski area, many of which run out into beginner terrain. There are seven identified mitigation zones, each containing multiple routes. The areas described in this paper have a north and northeast aspect. This terrain includes Kachina Peak, which has the largest avalanche paths on the mountain, Highline Ridge, which sits at tree line and is leeward, and West Basin, characterized by tight, rocky chutes. Taos ski patrol is composed of approximately 50 professional patrollers. The patrol utilizes a number of tools and techniques to manage and mitigate avalanches within the ski area. The most common mitigation measures applied by patrol are the use of cast primer pentolite hand-charges, two Avacaster avalaunchers and five 3.0 Gazex exploders.

In 2014, Rachel Moscarella (TSVI's Snow Safety Director) and Andy Bond (TSVI Ski Patrol) teamed with Wetherbee Dorshow, the founder and owner of Earth Analytic, to design and populate a GIS system for the ski area. The initial version of this

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https://doi.org/10.15788/1790098632

system, Taos Avalanche Tracker, laid the foundation for what has become the SmartMountain web-based platform. Our GIS avalanche atlas was created to address three key objectives:"*(1) Taos Ski Patrol training and safety, (2) user-friendly data entry using a web based application, (3) and a working real-time database of avalanche occurrences and explosive use."* (Moscarella, et al., 2016) In the 11 years following its implementation, 17,678 explosive deployments and 4,496 avalanches have been recorded (including D1 avalanches).

The introduction of GIS software to track mitigation work and avalanches was not without challenges. Most of the difficulties revolved around a single broad issue: how do we ensure that 50 ski patrollers enter data timely and accurately? We expected to encounter issues in adapting to unfamiliar technology. Small points of friction impacted an individual's commitment to entering quality data. Here is a list of common problems:

- Excessive data fields. Failure to enter a mandatory field produces an incomplete observation that cannot be recorded; frustration builds and observations/data are abandoned.
- Program glitches and slow internet diminish trust and confidence in the program.
- Avalanche size observations are recorded and drawn into GIS. Skill and dexterity with the computer mouse varies greatly within the crew. At times, the assigned D-scale value did not align with the depicted physical size of the avalanche.
- Ski Patrolling is multi-faceted work, particularly during a storm cycle. The many responsibilities in managing a mountain can make computer work a challenge.

The solution to many of these issues was to streamline the data entry system. We minimized the mandatory fields to only those that are critical and ensured that as many fields auto-populate as possible. Reliable internet is challenging in our mountainous terrain, inhibiting our ability to run the SmartMountain platform efficiently. We are now looking into acquiring more desktop computers that can be connected via ethernet for faster internet speed. Observationally, we believe there is a direct correlation between a reduction in friction and a reduction in frustration. Minimizing friction will result in better data.

We know that an individual's perception of D-size varies. This variance became more apparent when we started to query data collected on avalanches. The destructive scale is a critical descriptor that is a foundation of many of our queries. Therefore, consistency in the crew's individual recording is very important. To help our crew build a more accurate view of avalanche D-size, we collectively reviewed Bruce Jameison's tutorial on "Estimating Avalanche Size" (Jameison, 2020). We built upon this exercise by compiling images and descriptions of avalanches that had occurred within the ski area and the surrounding mountains, evaluating them individually and then reviewing our estimates as a group. We believe that collectively evaluating terrain that we are familiar with will lead to a more unified view of the avalanche D-scale.

When we started to examine the data collected, we noticed how many instances of user error existed. These issues are especially problematic during a big storm cycle when we may deploy over one hundred shots each day for several days at a time. The most common user error was that many explosives and avalanches were not entered at all. Starting in 2024, a designated member of the snow safety team began to catch and fix typos more regularly by cross referencing the hard copy of the explosive logs and route sheets with the shots and avalanches entered into GIS. We estimate that we were able to reduce the obvious mistakes and missing numbers to less than 5%. In the seasons prior to 24/25, we suspect that as much as 15-25% of the data may be missing or contain errors.

The 2015/2016 season was the initial rollout of the SmartMountain platform. This season was a live testing and developmental initial use period for the new platform and as a result, the numbers used in the following data section mostly do not include the 2015/2016 season.

## 2. A LOOK AT THE DATA

At Taos, GIS mapping is for internal recording purposes. The outcome of this digital recording is a large data set that is geospatially linked and easily queried. After collecting explosive use and avalanche observations for a decade, we found ourselves asking why. The information we collected is full of subjective judgements and inexact assumptions. Is it worth the time and money invested? How could we make it better and more useful?

We are avalanche practitioners, not statisticians. There is likely more that could be gleaned from our collected data with the help of an expert, and we apologize for any statistical faux pas committed. It's important to remember that in this section, we are making no solid statements of truth but rather asking questions in an experimental manner in an effort to understand our own mitigation program better.

Rather than proving anything concrete, our questions led to more questions, good discussion, and engagement amongst the crew. Each query also highlighted lessons learned, helped us to identify problems with our data set and provided ideas to make improvements in the future.

### *2.1 Overall Numbers from the last ten seasons (2016/17 - 2025/26)*

Since November 2016, we have had 397 separate days in which at least one avalanche was recorded. Our maps include 4,036 avalanche occurrences, 713 of which are listed as D2 or greater in size (Table 1). The busiest five days show 98, 97, 82, 81, and 66 separate avalanches respectively. We have mapped the placement of 16,039 explosives of a variety of types including AE and AB ranging in size (0.5kg-9kg or 1-20lbs pentolite), AL in two sizes (1kg & 2kg pentolite), and AX from five Gazex exploders (Table 2).

Table 1: Predictably, a majority of the avalanches were recorded as less than D2 in size. It is likely that there were far more small slides that went unrecorded than larger slides.

| | # Avalanches | % of Total |
|---|---|---|
| D1 | 2729 | 67.5% |
| D1.5 | 592 | 14.5% |
| D2 | 645 | 16% |
| D2.5 | 40 | 0.01% |
| D3 | 28 | <0.01% |

Table 2: The last ten seasons have been characterized by feast or famine at Taos: three seasons were well below ten year average snowfall (208-266cm) and six seasons were well above (548-607cm). This table shows the ten year averages for snow, explosive use, and avalanche occurrences.

| | | |
|---|---|---|
| Average Season Snowfall | 457 cm (180 in) | |
| Average SWE | 47 cm (18.6 in) | |
| Average Density | 10.30% | |
| Avg Number of Explosives Used | 1603.9 | |
| Avg Number of Avalanches | 403.6 | |
| Avg Number of ≥D2 Avalanches | 71.4 | |
| Avg Explosives per Avalanche | 4 | |
| Avg Explosives per ≥D2 Avalanche | 22.5 | |
| | cm | in |
| Avg Explosives per 1”/1cm SWE | 34 | 86.3 |
| Avg Explosives per 1”/1cm Snow | 3.5 | 8.9 |
| Avg Avalanches per 1”/1cm Snow | 0.9 | 2.2 |
| Avg Avalanches per 1”/1cm SWE | 8.5 | 21.7 |
| Avg ≥D2 Avalanches per 1”/1cm SWE | 1.5 | 3.8 |

Additionally, we were able to identify which areas of the mountain had the most D2 and larger avalanches (West Basin at 213, Kachina Peak at 134, and Highline at 129) and what the most common bed surface recorded was (new snow/old snow interface at 2,110 avalanches, within storm snow at 1,118 avalanches, within old snow at 357 avalanches, and at ground at 333 avalanches).

### 2.2 Airblast Query

We understand that airblasts are more effective than shots in the snow (Bones, et all., 2012). Airblasts take extra time to build and deploy and often it's not possible to place an airblast properly. We looked at the total number of shots labelled AB and total avalanches with the primary trigger listed as AB (Table 3).

Table 3: Since Gazex shots are considered airblasts, we also included those as a separate data point here.

| | |
|---|---|
| Total Number of AB | 4408 |
| AB as % of All Explosives | 27.5% |
| Total Number of AX | 474 |
| AX+AB as % of All Explosives | 30.5% |
| Total Number of Prim. Trigger AB | 1779 |
| AB Trig. as % of All Avalanches | 44% |
| Total Number of Prim. Trigger AX | 31 |
| AX+AB Trig. as % of All Avalanches | 45% |
| Total Number of Prim. Trigger AB ≥D2 | 361 |
| AB Trig. as % of All Avalanches ≥D2 | 50.5% |
| Total Number of Prim. Trigger AX ≥D2 | 11 |
| AX+AB Trig. as % of All Avalanches ≥D2 | 52% |

We found that only 27.5% of all explosives used were airblasts, although 44% of all avalanches were triggered by an airblast and 50.5% of avalanches labelled D2 or greater were caused by an airblast (Figure 1).

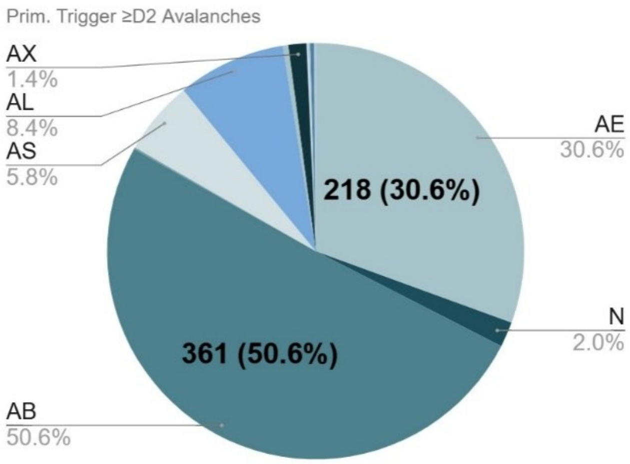


Figure 1: Primary Trigger shown as a percentage of ≥D2 avalanches.

In delving into this airblast data set, we discovered a piece of information that we hadn't collected properly. When recording an avalanche occurrence, patrollers were asked to name the primary trigger as AE, AB, etc. However, there was no explosive size attached to that trigger. The explosives, which are entered separately, do have the weight listed, but correlating avalanche occurrence with the proper explosive entry would be a very time intensive process. There have been some attempts to create a query formula to automatically identify the triggering explosive. We have found that this solution correlates only 42% of our avalanche data.

This missing information complicates our airblast hypothesis because AB shots are more likely to be heavier and larger than AE shots. 33.5% of all AB were greater than 2lb (0.9kg), while only 6% of all AE/AL recorded were greater than 2lb (0.9kg). With the information we have, it is unclear that the apparent increase in efficiency is not due, at least in part, to the size rather than the manner the explosive was used. Therefore, a significant lesson learned from these queries is the importance of asking data questions early; it may become obvious that a piece of the data puzzle is missing.

Additionally, the discussion following these questions led to other theories. We believe a patroller is more likely to put the time into an airblast when the forecast shows a greater likelihood of avalanche occurrence. Furthermore, locations that are conducive to placing airblasts are often along cornices which are frequently more active start zones and on aerial tramlines which have been built in that specific location due to the historical prevalence of avalanches. We are not gathering this data in a controlled laboratory environment and these complications, while interesting, are a good example of the difficulty in using this data.

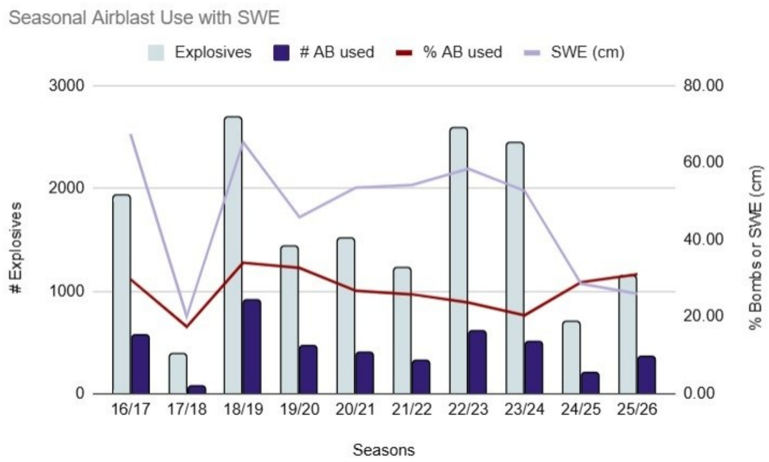


Figure 2: Although our snow and SWE totals were very low in the last two years, we have seen a relative increase in the use of airblasts.

Despite the issues with this data, we have still seen a relative increase (20% in 23/24, 29% in 24/25, 31% in 25/26) in the use of airblasts since we first presented these findings to our crew in 2024 (Figure 2). And, importantly, it has inspired many great conversations and debates. This increase stands out especially when compared to AB use during the 2017-18 season, which had the most comparable snow totals. Though far from conclusive, the recent increase in AB use may be in part due to a deeper connection with the source of the data. We believe it is more powerful to see your own data on a familiar mountain than to read it in a paper. In this way, the information we are gathering in our GIS platform holds potential for education and implementing changes to our mitigation program.

## *2.3 Gazex Query*

The efficiency and use of the five Gazex exploders is another topic that we attempted to evaluate using our GIS entries. The question we asked was whether there have been more, less, or a similar number of D2 and larger avalanches on Kachina Peak (KP) since the installation of the Gazex in 2019. We looked at the four seasons prior to Gazex installation and the four seasons after. (Note that we have included the 15/16 season data for this query). Of course, eight seasons of data is not enough to make conclusions, but this query did lead to interesting follow up observations.

In the four years after the Gazex installation, we saw an 18% increase in ≥D2 avalanches in the chutes not mitigated with the Gazex (Cabin through K2). Meanwhile, in the five zones mitigated with the Gazex, larger avalanches decreased by 78% (Figure 3). This finding suggests that the Gazex is effectively mitigating larger avalanches. To build perspective, we queried the number of ≥D2 avalanches recorded mountain wide, finding a 50% decrease. The only terrain in TSV to see an increase in ≥D2 avalanches was the above tree line slopes on Kachina Peak without RACS installments.

We experienced a 19% increase in snow totals and an 8.5% increase in SWE in the four years after Gazex (compared to the four years before) so low snow is likely not the culprit. With a relatively small data set and many variables we are unable to control for, we cannot definitively confirm that our Gazex system is creating more frequent, smaller slides and decreasing the potential of larger avalanches (Dodge and Gordon, 2024). However, we plan to continue monitoring this area to see if this initial trend continues.

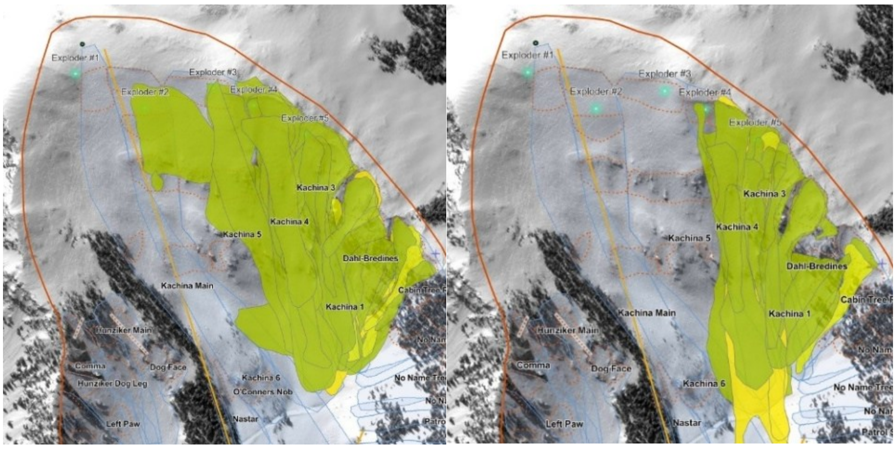

Figure 3: The image on the left shows all D2 and greater avalanches on Kachina Peak in the four years prior to the RACS installation and the image on the right shows the four years after. The Gazex exploders are the teal points along the ridgeline.


Figure 4: A post storm photo of Kachina Peak. Note the impact of all five exploders on the new snow.

This query highlighted how dramatically the overall number of ≥D2 avalanches decreased over the last eleven seasons (Figure 5). These numbers portray that there have been relatively few larger avalanches in the last five seasons and very few in the last three. This is an important trend to note moving forward. Due to the recent lack of large avalanche cycles, patrollers may become more susceptible to the heuristic trap of Familiarity. This data centered reflection of avalanche activity is an aid in combating potential complacency and other human factors.

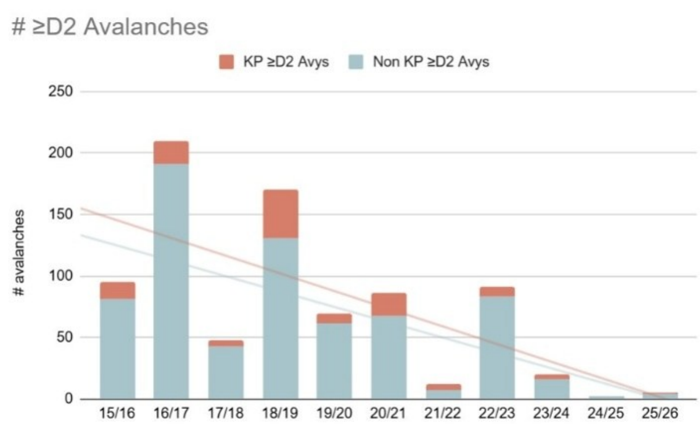


Figure 5: This graph shows the decline in ≥D2 avalanches seen in the last several years.

## 2.4 *Wet Slide Query*

In addition to having geospatial abilities, our GIS data is also linked to weather data from our on-mountain weather stations. This function creates interesting weather-related avalanche queries. One question asked of the data is what types of avalanches have historically occurred within certain 24-hour temperature parameters. In particular, we were interested in wet slides so we pulled all avalanche occurrences for two different types of warm days (defined as having a 24 hour max temperature of 2.2C or 36F at our midmountain weather station, “Poco”):

- Warm days but colder nights (min temp below -0.56C or 31F)
- Warm days and warmer nights (min temp above -0.56C or 31F)

When we first ran this query two seasons ago, we saw what we expected; for warm days and warmer nights, the only types of avalanches we had on record were WL and WS. For warm days with colder nights, we only saw dry snow avalanche types (SS, HS, L). However, after the very warm month of March 2026, we recorded four wet slab avalanches that occurred after nights colder than 31 degrees (-0.56C) at midmountain (Figure 6). This was contrary to the trend previously observed.

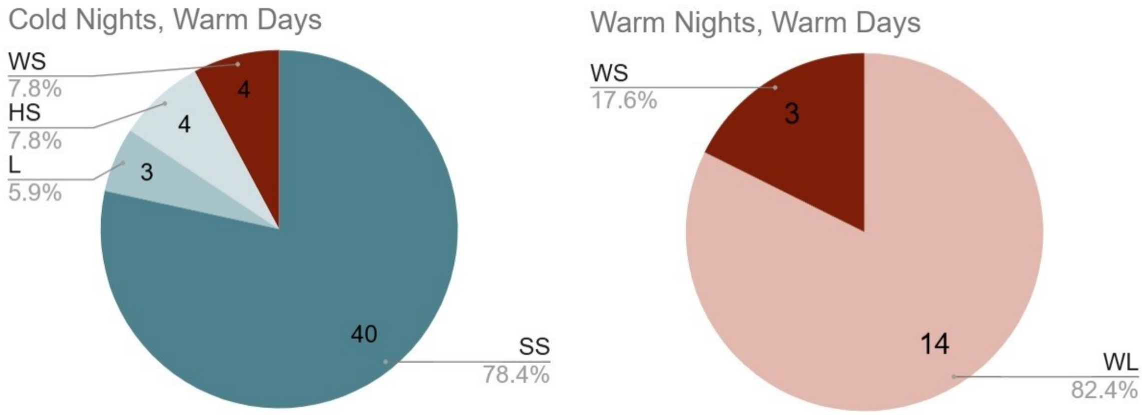


Figure 6: In 10 years of data, we have never seen a dry snow avalanche occur when the 24-hour minimum temperature was above 31 degrees Fahrenheit (-0.56 degrees Celsius). Interestingly, we have seen four wet slab avalanches with minimum temperatures of less than 31F (-0.56C).

It’s important to note that we don’t have a lot of data in these fields. The purpose of asking these questions is to test our data and inspire curiosity in our crew.

We found this query useful because it caused us to question how we are currently correlating our weather data with our avalanche occurrences. In particular, we plan to improve how we query the weather outside the 24-hour period in which the avalanche happened. This will increase our ability to understand how longer-term weather directly affects our avalanche occurrence records.

## 3. FUTURE

Taos Ski Patrol continues to expand our use of GIS documentation to objectively review storms and seasonal work. We can quickly compile data and produce queries/comparisons. For example, we can ask whether AE or AB was more effective or how deep our median crown depth was for a particular storm cycle. Having the ability to root our evaluation of a storm cycle or an entire season in data as opposed to relying solely on the crew's collective reflection helps to alleviate the potential influence of cognitive biases.

When GIS software becomes commonly used, we can more easily share information industry wide. Increasing the collective data set size can help build confidence in correlations and foster a shared sense of community amongst avalanche mitigators.

We see the potential for further development of GIS recording as the technology improves alongside rapid advancements in AI and computer processing. Utilizing AI technology could make the querying process more accessible to more patrollers. Instead of asking propositional and conditional statements or exporting thousands of lines of data to a spread sheet, a practitioner could ask a direct question in more comfortable language and have AI analyze the data accordingly.

## 4. CONCLUSION

In conclusion, the intention of this paper is to encourage questioning and discover new ways our GIS data can be used to help us improve, not to provide concrete conclusions. We fully recognize that our data set is small and certainly contains user errors. We accept this reality because our data is collected from the observations of busy, hardworking ski patrollers who are not only passionate avalanche practitioners but committed emergency medical professionals and dedicated community members. Our GIS system is a great tool to scratch the itch of curiosity we have for the snow and mountains. We may not have novel ideas, but with each query we posited, we stumbled onto more questions. This cyclical process of questioning is what keeps many excited about ski patrolling and snow science. We hope that this paper encourages other avalanche professionals who are recording with a GIS system to take a closer look at their own data and continue the discussion.

## 5. ACKNOWLEDGEMENTS

We are very grateful to Earth Analytic for their pioneering SmartMountain software, continued support, and willingness to entertain our endless requests. We would like to thank Karl Birkeland for the encouragement to put thoughts on paper (though he warned us it might make our lives a little more complicated). Karl's book The Starting Zone was a constant reference throughout this process (Birkeland, 2026). And lastly, a huge thank you to TSVI for all of the support and to TSV Ski Patrol, both past and present, without whom none of this would be possible and life would be a lot less fun.

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