HISTORICAL SNOWPACK REANALYSIS IN OBSERVATIONALLY SPARSE ENVIORNMENTS: A CASE STUDY FROM SLIDE MOUNTAIN, 1986

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ABSTRACT: Mt. Rose Ski Tahoe lacked a formalized avalanche forecasting program until 2008, resulting in a critical observational gap spanning approximately 55 years since resort operations began in 1953. Qualitative records of weather and snowpack are sparse prior to the 2008 season, and data between 2008 and 2018 consists of a mix of scanned paper records and Microsoft Access database, making individual records challenging to query. Institutional knowledge of significant historical avalanche cycles is mostly anecdotal, residing with former patrol personnel no longer affiliated with the operation.

To address this data deficiency, we employed the SNOWPACK numerical snow cover model to perform a meteorological and snowpack reanalysis of a major avalanche cycle that occurred in February 1986. Considered among the most consequential events in the documented history of Slide Mountain, the storm produced approximately 32 inches (81 cm) of snow water equivalent (SWE) at the Mt. Rose SNOTEL station and in excess of 20 feet (6 meters) of total snow accumulation at the top of the ski area. The resulting avalanches caused widespread infrastructure damage, closure of public roadways and the release of multiple artificially and naturally triggered avalanches classified up to D4 in size.

Primary source documentation for this event is limited to photographic records and a single firsthand narrative account from the assistant patrol director at the time. We created a data pipeline to systematically integrate remotely sensed SNOTEL observations with ECMWF reanalysis data. The weather observations were used to reconstruct simulated stratigraphic profiles with SNOWPACK, enabling assessment of the weak layer and loading conditions that facilitated large-scale avalanche release.

This reanalysis framework demonstrates the utility of physics-based snowpack modeling as a tool for reconstructing high-consequence historical events in data-sparse operational environments. Application of this methodology in regions with comparable observational gaps offers a systematic approach to quantifying low frequency high consequence scenarios, assist in accident investigation, inform practitioner safety protocols and enhance infrastructure resilience planning against these high consequence events.

KEYWORDS: SNOWPACK, Snowpack Modeling, Historical Reanalysis, Ski Area Operations.

1. CONTEXT

The 1985-86 winter season followed a typical Sierra Nevada seasonal pattern, with measurable snowpack established by mid-November and an approximately linear increase in both snow height (HS) and snow water equivalent (SWE) from the start of the water year through mid-February (fig. 1). Prior to the storm, all in-bounds terrain at Slide Mountain Ski Area was open to the public and subject to substantial skier disturbance; the snowpack within this managed terrain was generally considered stable.

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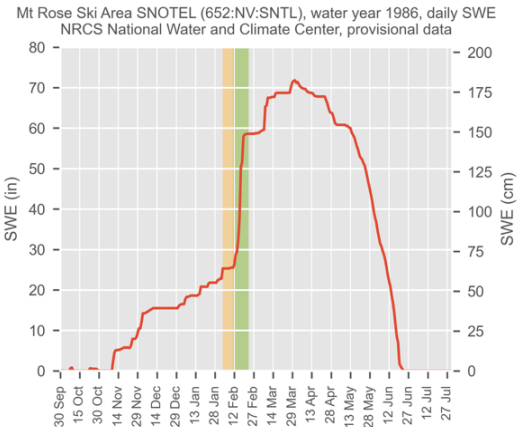


Figure 1: SWE from water year 1986 at the Mt. Rose SNOTEL station #652. The high pressure preceding the event is shown in yellow and the storm period in question shown in green.

During the two weeks preceding the event, Mt Rose SNOTEL data reported above freezing daytime temperatures and anecdotal reports from Hicks (2021) describe the formation of a melt-freeze crust. This crust and associated snowpack metamorphism during the high pressure period would prove to be an important factor in snowpack structure and avalanche release. .

At the time, Mt. Rose Ski Area and Slide Mountain Ski Area operated as independent entities, situated on the northwest and east aspects of Slide Mountain, respectively (Mt. Rose, 2001). The two operations were separated near the summit unload terminals by a boundary rope line known as the Iron Curtain, and by an intervening closed parcel of terrain, The Chutes, to the northeast. The Chutes were not open to public access until the 2004 season and consist of over 30 discrete avalanche paths across approximately 250 acres. Avalanche mitigation responsibility was divided between the two operations within their respective boundaries and along each operation's separate ridge line of The Chutes, primarily to safeguard NV-431 which is impacted by the runouts of this terrain.

2. THE STORM

As of February 9, 1986, forecast models indicated that a large storm system would affect much of the western United States. The system was subsequently characterized as a "Pineapple Express," a large-scale winter storm phenomenon associated with a strong southern branch of the polar jet stream and a slow-moving or quasi-stationary surface frontal boundary along which successive waves of low pressure propagate. At least three distinct low-pressure systems were identified over the Lake Tahoe region during the storm period of February 11-22, 1986.

In the absence of direct instrumented observations, anecdotal accounts indicate that approximately 12 ft (3.7 m) of new snow accumulated at the Slide Mountain base area at 8,260', with roughly 20 ft (6 m) recorded at upper elevations. Wind transported drifts of up to 40 ft (12 m) were reported on upper-mountain terrain near 9,600'. Sustained westerly high winds persisted throughout the event, and snow levels fluctuated between approximately 7,000 and 8,000'.

By February 17, the upper-mountain towers of the Pioneer chairlift, manufactured by the Riblet Tramway Company, were buried to the haul rope (fig. 2), and complete burial occurred by February 18. The Slide Mountain Lodge was similarly buried in its entirety; this burial may have mitigated structural damage that would otherwise have resulted from artificially released avalanche air blasts occurring throughout the storm (Hicks, 2021).



Figure 2: Patrollers sit atop the Pioneer Chair haul rope on February 17, 1986 with complete burial occurring on February 18.

3. RESULTING AVALANCHES

Patrollers at the time noted a series of artificially triggered avalanches whose destructive magnitude has not since been replicated at this location, although similar weather events have been observed in the winter seasons of 1998, 2017 and 2023.

At Slide Mountain Ski Area, a control mission on February 16 produced the **Climax Avalanche** (fig. 3) that destroyed the Overland chairlift mid-station, the Little Red load terminal and structural supports, and a Poma lift near the base area (Hicks, 2021); the Little Red chairlift was subsequently retired as a consequence of this event.

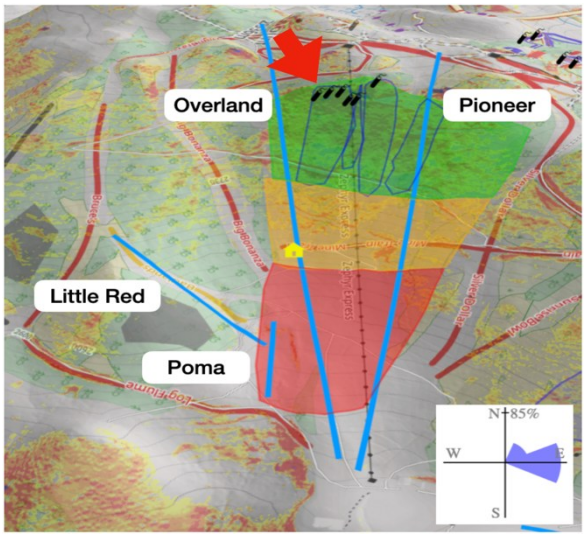


Figure 3: Approximate path of the Climax avalanche with associated infrastructure and usual shot placements. Typical independent slide paths shown with blue polygons and an arrow denotes the initiating shot placement. Typical top and mid-runouts shown in green and yellow, respectively, with the runout of the 1986 event shown in red.

This avalanche is retrospectively classified as D3.5-4, with a slide path of approximately 74 acres, 2,800 ft of horizontal run, toe α=21°, and extended laterally into terrain not typically thought of as avalanche paths. SNOTEL records indicate 6" of SWE accumulation over the preceding 24-hour period (Natural Resources Conservation Service, 2026).

An additional destructive avalanche occurred the following day, February 17 within The Chutes (fig. 4). The **Chutes Avalanche** deposited 6-8 ft of debris across NV-431 and entrained trees up to 8" in diameter at breast height near the toe of the avalanche across the highway. Debris depth was up to three times greater upslope, on the run now designated Tailings, the primary cat-track return to the Chuter chairlift (operational since the 2004 season).

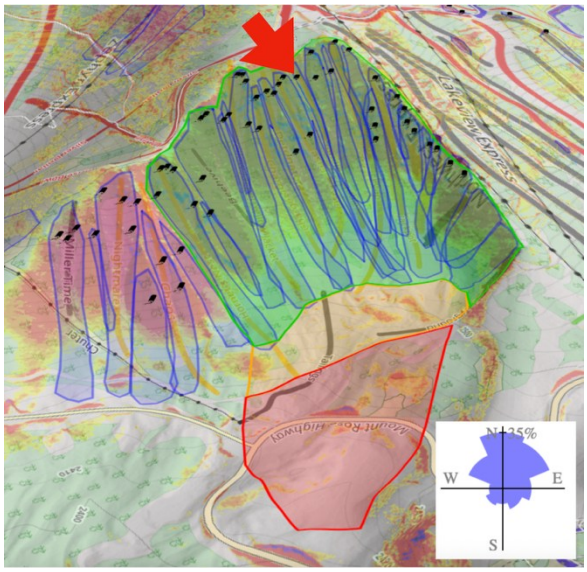


Figure 4: Approximate path of the Chutes Avalanche. Typical independent slide paths shown in blue with an arrow denoting the initiating shot placement. Typical top and mid-runouts shown in green and yellow, respectively, with the runout of the 1986 event shown in red.

This event is retrospectively estimated at D4 in magnitude, with a slide path of approximately 110 acres, 3,700 ft of horizontal run, and α=19.5°; SNOTEL again recorded 6" of SWE in the preceding 24 hours. Whereas current mitigation protocols would typically require as many as 37 hand charges to address these 23 avalanche paths before opening to public access, this avalanche was initiated by a single 2 kg nitroglycerin charge placed at the East Saddle shot point.

Numerous additional large-magnitude avalanches were documented on Slide Mountain and in the surrounding terrain during this period; the final event considered here occurred in Miller Time at the eastern extent of The Chutes, also on February 17. Consistent with other paths within The Chutes, a single hand charge produced the **Miller Time Avalanche,** estimated at D3.5 with a crown height exceeding 8'. The significance of this event lies not in the avalanche itself but in a photograph documenting the resulting crown profile (fig. 5), one of the few surviving visual records from this avalanche cycle, and the impetus for the present reanalysis.



Figure 5: Avalanche crown in the Miller Time start zone approximately 8 ft. in height. Note the near-surface stepdown layer and storm snow stratigraphy.

4. DATA SPARSE REANALYSIS

A patroller maintained a daily journal documenting weather conditions throughout the storm; however these entries are qualitative in nature, exemplified by statements such as "snow started out cold, snowed here then rained most of day and hard most of night." Such records permit only the most general of inferences regarding storm snow stratigraphy.

The Desert Research Institute had installed a remote weather station at the summit of Slide Mountain several months prior to the February 1986 event; however, the instrument had not yet undergone full calibration, rendering the resulting data largely unreliable. The Mt. Rose SNOTEL station, situated within the ski area and operational since 1981 recorded only accumulated precipitation and temperature at uneven, approximately twice-daily intervals; these observations appear to be generally reliable. These two stations represent the only available sources of remotely sensed weather data within useful proximity to Slide Mountain.

The objective of this study is not to establish causation for these avalanche releases, but rather to evaluate whether contemporary computational models can reproduce the snow stratigraphy documented in the Miller Time crown photograph (fig. 5). While several other Lake Tahoe ski areas maintained active forecasting programs in 1986 and retain archived snow profiles, the storm cycle in question produced rain at the lower elevations

characteristic of most such operations, limiting the applicability of these records to conditions at Slide Mountain. In the absence of quantitative field data specific to Slide Mountain, this photograph constitutes the principal empirical basis for stratigraphic assumptions in the present analysis.

5. SNOWPACK MODELING

Using the open-source SNOWPACK model (Bartlet and Lehning 2002), a simulated stratigraphic profile (fig. 6) was generated for Slide Mountain corresponding to February 17, 1986, the date the Miller Time crown photograph was captured. ECMWF reanalysis data were combined with accumulated precipitation and temperature records from the Mt. Rose SNOTEL station to produce this profile via Sastrugi, a graphical modeling interface built on SNOWPACK and developed by a current Mt. Rose forecaster (Lawrence and Antibus, 2026).

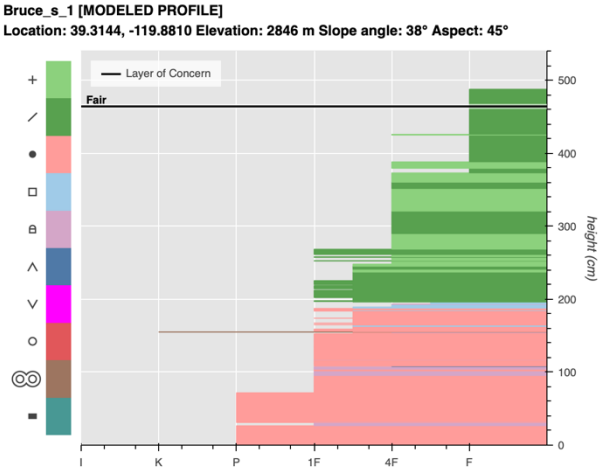


Figure 6: Simulated snow profile of the Miller Time start zone, powered by SNOWPACK and visualized through Sastrugi.

The modeled profile correlates closely with the stratigraphy visible in the Miller Time photograph. Six discrete layers are discernible within the photographed crown, and their relative vertical position corresponds generally with the layering produced by the SNOWPACK simulation (fig. 7).

The model output includes additional stratigraphic detail beyond what is visible in the photograph; however, this additional resolution is of limited interpretive value as the variation is largely confined to grain type rather than hardness.

One notable discrepancy is the model's failure to reproduce the magnitude of the melt-freeze crust widely reported across Slide Mountain, which does appear in the simulated profile, although in a less pronounced capacity than that which was described by the mitigators on-site. Accounts from the team present at Miller Time confirm the presence of a melt-freeze crust at the bed surface, though likely less stout than that observed within open terrain at Slide Mountain Ski Area owing to the more northerly aspect and forested character of the Miller Time start zone. The simulated profile additionally indicates the presence of buried faceted layers; however the validity of this feature remains uncertain as Miller Time, despite being closed to the public, was actively mitigated prior to the storm and the pre-existing snowpack was generally considered stable. Although potentially obvious, it is worth noting that the SNOWPACK model does not take mitigation measures into account. These faceted layers are, in any case, relatively minor within the modeled profile but very well could have contributed to the large avalanches observed within this closed terrain as would be expected after a major loading event.

6. CHALLENGES

ECMWF reanalysis data provided by the Open-Meteo Historical Weather API (Zippenfenig 2023) were selected for this study on the basis of their demonstrated historical accuracy in the Lake Tahoe region. In 1986, ECMWF spatial resolution

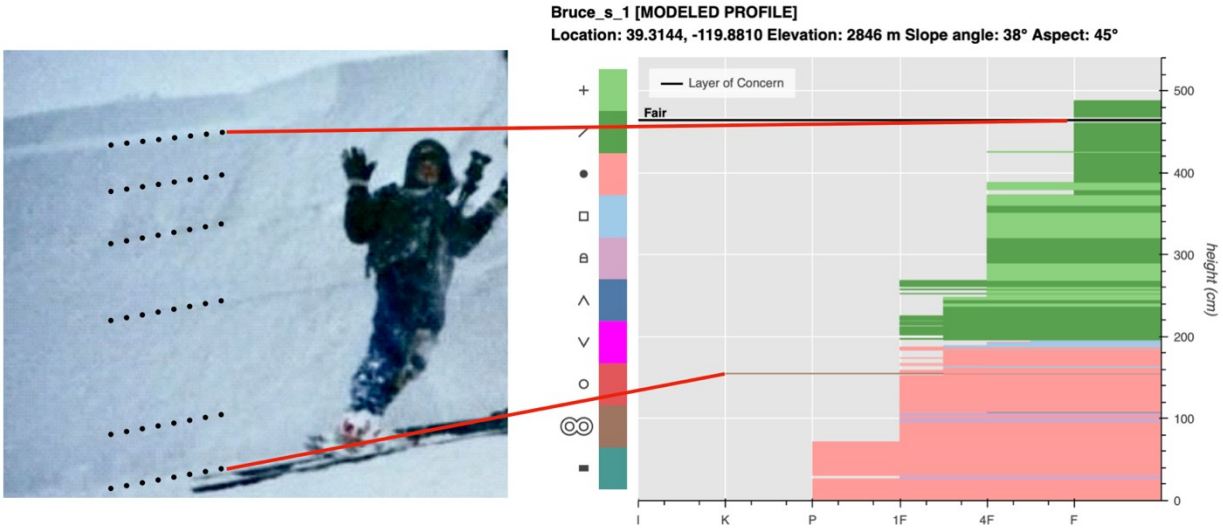


Figure 7: Visualization of the Miller Time crown photograph correlated to the simulated snow profile. Layering marked with dotted lines for visibility. Melt-freeze crust bed surface and layer of concern aligned with simulated profile using red lines.

ranged between 9 km and 31 km depending on the parameter queried. For modeling a single avalanche path, this coarse resolution necessitated supplementary input from remotely sensed SNOTEL data to improve profile accuracy. Further research is warranted to determine the minimum data requirements for accurate historical snow profile reconstruction, given these resolution constraints inherent to both the SNOWPACK and ECMWF reanalysis models.

Anecdotal accounts from the 1986 event indicate approximately 400 cm of new snow accumulation by February 17 at the elevation of the Miller Time start zone, with up to 60% greater accumulation reported in leeward terrain; however, the model output shows only 400 cm of storm snow on this leeward, northeast-facing aspect. Across both historical and contemporary applications of the SNOWPACK model, snow deposition and wind transport appear to be often underestimated by 25–50%, a pattern consistent with the present case study. This discrepancy is likely attributable to a combination of coarse ECMWF resolution and inherent limitations in SNOWPACK's representation of wind-driven transport processes. Research is actively being conducted on how to improve wind effect and transport within the SNOWPACK model and could better capture how these inputs might affect stratigraphy as updates become available (Kruyt, 2025).

The SNOWPACK model identifies the primary layer of concern (Föhn 1987; Jamieson and Johnston 1998) at a depth of only 25 cm below the snow surface (fig. 6); however, the avalanche produced during mitigation released on a melt-freeze crust estimated at approximately 250 cm depth, based on a patroller's pole held overhead while standing beneath the crown (fig. 5). While this discrepancy may indicate a limitation in SNOWPACK's stability algorithm, two considerations merit discussion.

First, SNOWPACK's layer-of-concern determination is calibrated to a skier-induced trigger rather than an explosive charge; the explosive mitigation method employed in this instance may plausibly have stressed the snowpack to a greater depth than a skier trigger would achieve. To add context, SNOWPACK identifies the layer of concern as the layer with the minimum skier stability index evaluated for a 38° reference slope angle, Sk38 (Föhn 1987; Jamieson and Johnston 1998).

Second, it is possible that the model correctly identified a genuine layer of weakness at the 25 cm depth. Examination of fig. 5 suggests that the uppermost layer failed above the patrollers, behind the crown line where the slope angle decreases: a failure that appears to correspond with the 25 cm layer of concern identified by the model, which exhibited comparatively lower stability than the surrounding snowpack. Whether this correspondence reflects genuine model accuracy or coincidence cannot be determined from the available evidence.

Given that only a single crown photograph was available for comparison against this model run, the apparent accuracy of the simulated stratigraphy cannot be ruled out as coincidental. With an effective sample size of one observational data point, broad conclusions regarding SNOWPACK's suitability for historical reanalysis cannot be justified on the basis of this case study alone. Nonetheless, the model appears to have represented the storm snowpack reasonably well in this instance.

7. IMPLICATIONS

Several potential applications could benefit from the continued development of SNOWPACK as a historical reanalysis tool. The most direct application, as demonstrated in this case study, is the derivation of new insight from historical events to inform ski area operational planning for future high-magnitude avalanche cycles and associated mitigation strategies.

Additional value may be realized in accident investigation contexts, particularly where an incident occurs mid-storm and direct snowpack stability assessment is precluded until weather conditions stabilize. Following the 2026 backcountry incident near Lake Tahoe that resulted in nine fatalities, substantial changes in snowpack conditions had occurred by the time investigators were able to access the site. Hour-by-hour reconstruction of snow stratigraphy in such cases could provide meaningful insight into the mechanisms underlying such events and inform post-incident analysis.

Finally, application of SNOWPACK as a historical reanalysis tool may support more detailed characterization of terrain response to varying meteorological inputs in areas lacking focused snowpack assessment. In contexts such as developing regions, new infrastructure projects, or terrain expansion at ski areas or within guided operations, multi-season snowpack modeling could contribute to a more comprehensive understanding of avalanche hazard across a given area.

8. CONCLUSION

This study demonstrates that physics-based snowpack modeling can meaningfully reconstruct historical avalanche conditions in operational settings with minimal instrumented data. By combining ECMWF reanalysis data with SNOTEL observations, the SNOWPACK model reproduced the broad stratigraphic structure documented in the

Miller Time crown photograph, including the relative layering and general presence of the pre-storm cycle melt-freeze crust, despite the near-total absence of site-specific quantitative records from February 1986.

At the same time, the reanalysis surfaced clear limitations. The model underestimated snow deposition and wind-loaded accumulation relative to anecdotal accounts, and it placed the primary layer of concern substantially shallower than the depth at which the explosive-triggered avalanche actually failed. These discrepancies likely stem from a combination of coarse-resolution reanalysis inputs, known limitations in SNOWPACK's representation of wind transport, and the mismatch between skier-calibrated trigger assumptions and explosive loading. Given that this analysis rests on a single photographic data point, these findings should be read as a proof of concept rather than a validated methodology.

Even with these caveats, the results suggest that historical reanalysis offers a viable path toward recovering usable snowpack information from otherwise undocumented events. As ski areas and backcountry operations continue to confront the operational and legal stakes of high-consequence avalanche cycles, tools like SNOWPACK-based reanalysis may help fill critical gaps in institutional memory, support accident investigation, and inform terrain management decisions in places where formal records simply do not exist. Continued refinement of wind-transport modeling and broader application of this framework across additional historical events with independent verification data will be necessary to establish its reliability more rigorously.

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REFERENCES

Bartelt, P. and Lehning, M. (Nov. 2002). A Physical SNOWPACK Model for the Swiss Avalanche Warning: Part I: Numerical Model. In: *Cold Regions Science and Technology* 35.3, pp. 123–145. https://doi.org/10.1016/S0165-232X(02)00074-5.

Birkeland, K. W. and Mock, C. J. (2001). The Major Snow Avalanche Cycle of February 1986 in the Western United States. In: *Natural Hazards* 24, pp. 75–95. https://doi.org/10.1023/A:1011192619039.

Föhn, P. M. B. (1987). The Stability Index and Various Triggering Mechanisms. In: Salm, B. and Gubler, H. (eds.), *Avalanche Formation, Movement and Effects* (Symposium at Davos, 1986). Wallingford, Oxfordshire, UK: International Association of Hydrological Sciences, IAHS Publ. 162, pp. 195–214.

Hicks, B. (2021). *AR Storm February 1986: Report from the Slide Mountain Ski Patrol* [Internal report]. Mt. Rose Ski Tahoe.

Jamieson, J. B. and Johnston, C. D. (Jan. 1998). Refinements to the Stability Index for Skier-Triggered Dry-Slab Avalanches. In: *Annals of Glaciology* 26, pp. 296–302. ISSN: 0260-3055,1727-5644. https://doi.org/10.3189/1998AoG26-1-296-302.

Kruyt, B. (Oct. 26, 2025). *Wind in SNOWPACK*. AvaCollabra. https://avacollabra.org/wind_in_snowpack/. Accessed 2026.